Workshop Report:

The Australian Coastal and Oceans Modelling and Observations Workshop (ACOMO 2014)

7-8th October 2014, Shine Dome, Australian Academy of Sciences, Canberra

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1. Executive Summary

The second Australian Coastal and Oceans Modelling and Observations Workshop (ACOMO 2014) was held on the 7th and 8th October 2014, at the Shine Dome, Australian Academy of Sciences, Canberra. The meeting brought together over 80 participants from several organisations, including international organisations and private industry and was attended by Australia’s Chief Scientist Professor Ian Chubb who closed the first day’s session.

The aim of this meeting was to bring the national observations and modelling communities together and give an update on the activities and developments accomplished over the last two years.

To follow up the intention for ACOMO to progressively move up from hydrodynamics to ecosystem models, the ACOMO 2014 workshop devoted a whole session on biogeochemistry and introduced a talk on ecosystem modelling. Another important topic included in this workshop was the shelf reanalysis session, which included a talk and discussion about the plan to undertake a whole of Australia shelf reanalysis project. Interest on this project was first brought up at the IMOS National Planning meeting in Hobart this year and ACOMO 2014 provided the right forum to put forward the idea and consult a wider community to further the planning process.

The other two sessions included in the workshop were: developments in coastal modelling and observations; and modelling toolkits. The coastal modelling session included various talks that covered the shelf all the way to harbours and gulfs. The modelling toolkit session included important information on the Marine Virtual laboratory (MARVL) and the Climate and Weather Science Laboratory.

In terms of concrete steps going forward, it was suggested to note:

- The unanimous support amongst ACOMO attendees for moving to the next stage of scoping a national Shelf Reanalysis project, taking into account key points discussed and agreed at the workshop.
- That in most IMOS Nodes there is now co-evolution of the regional observing systems with regional modelling efforts, and there has been a growth in coastal/regional modelling capability within Australia since ACOMO 2012.
- A number of talks covered modelling and observing in harbours and gulfs. The level of IMOS engagement in these activities is quite heterogeneous and it would be sensible for IMOS to have a clearer strategy in terms of future decision making.
- That in having greater emphasis on BGC (and ecosystems) over time, we need to ensure we are engaging observational and experimental biologists as well as modellers.
- That it is important to build stronger links with ecosystem scientists for ACOMO 2016, and seek opportunities to strengthen those links in the intervening period. Work by the Southern Ocean Observing System (SOOS) to develop ecosystem essential ocean variables (eEOVs) may provide one such opportunity.
- An important opportunity through which to progress a number of the issues raised at ACOMO 2014 would be the National Marine Science Committee process to develop a national marine science plan. Attendees were encouraged to ensure that where possible they are making this connection with the white papers currently under development.

A number of other specific issues, activities and recommendations raised during the workshop are summarised below.
2. Summary of actions and recommendations

A number of proposed actions and a small number of specific recommendations emerged through the course of the workshop, and these are summarised below.

Shelf reanalysis requirements:

**ACTIONS:**

- IMOS and AODN to look into developing workflows that ensure we can deliver ‘model ready’ data on an ongoing basis. A necessary step for the Australian National Shelf Reanalysis project is to get IMOS and other shelf data ‘model ready’. Funding secured from NeCTAR and ANDS for a ‘MARVL- 3’ project could assist with this activity.
- The ANSR Technical Task Team (TTT) will need to discuss with relevant people in the Bureau of Meteorology (e.g. Peter Steinle) the importance of high resolution atmospheric forcing and the need for consistency between atmospheric data resolution and that of the shelf (ocean) reanalysis.
- A complete TTT needs to be formed and a workshop organized to discuss the scientific/technical issues to come up with a proposal (including options and staging) for consideration by the SC. Potential candidates for joining the TTT to be identified from the workshop and expressions of interest will be open until Wednesday 15 October. Co-chairs of the TTT to recommend the proposed membership by Wednesday 22 October for approval by the SC, and advise if any resources are required to run the scientific/technical workshop.

**RECOMMENDATIONS:**

- The ANSR project will need to have an operational end in mind from the beginning. The steps, timing and partner engagement required to achieve this will need to be worked through.
- ROMS must be in the mix of models used for the ANSR project given the growth in capability at the national level, opportunities available for international collaboration, and the decision by the Bureau of Meteorology to use ROMS as its coastal modelling platform.

Biogeochemistry:

**ACTIONS:**

- IMOS to consider options for collecting nutrients at higher temporal resolution as funding permits. This is a high priority for the BGC modelling community.

**RECOMMENDATION:**

- It was noted that in having greater emphasis on BGC (and ecosystems) over time, we need to ensure we are engaging observational and experimental biologists as well as modellers.

Developments in coastal modelling and observation:

**RECOMMENDATIONS:**
• Noting that there has been growth of the ROMS user group in Australia, it is important to maintain a national model development capability. This is necessary to allow for innovation and to enable solving of problems specific to Australian marine and coastal systems, and furthering the understanding of how to adequately parameterise complex coastal dynamics. **Mechanisms for ensuring model developments in Australia feed into international communities such as ROMS will need to be considered.**

• Expectations in using altimetry for coastal modelling should remain modest at this stage. A national product using altimetry near the coast is under development by the CSIRO/IMOS *OceanCurrent* group, but it still needs further work.

• The level of IMOS engagement in modelling and observing in harbours and gulfs is quite heterogeneous, it would be sensible for IMOS to have a clearer strategy in terms of future decision making in this area.

**ACTIONS:**

• **IMOS to discuss access to surface wave data with the Bureau of Meteorology and other national and international partners, as it arose as an issue during the workshop and gaining access is important for the shelf and coastal research communities (including MARVL and ANSR amongst other projects).**

**Modelling toolkits:**

**RECOMMENDATION:**

• IMOS, NCI and AODN will need to think carefully about how to build successful virtual laboratory activities into sustainably funded information and modelling infrastructures, as to date, it is unclear whether NeCTAR would be willing or able to continue investing in them over the longer term.
3. Introduction

IMOS Director, Tim Moltmann opened the workshop and provided a brief summary on IMOS and how ACOMO fitted within IMOS objectives and its role in the marine science strategy in Australia.

He explained how ACOMO is expected to evolve in time (Fig. 1) and reflected that from 2 years ago ACOMO had progressed from being physical oceanography based and now had a stronger contribution in biogeochemistry modelling and observations. He also gave an update on the progress of the action items raised at ACOMO 2012 (Table 1), with most action items progressing.

**Table 1. Action items from ACOMO 2012**

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<tr>
<th>1.1. Nearshore observations and Modelling:</th>
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<td><strong>ACTION</strong>: Convene an IMOS Session at Coasts and Ports 2013 to raise awareness of the role of collaborative activities in the coastal zone</td>
<td>An IMOS special session was included in the Coast and Ports 2013 meeting in Sydney</td>
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<td><strong>ACTION</strong>: Complete a list of priority datasets/products that the community would like to see made more broadly available</td>
<td>Progressed though activities such as MARVL.</td>
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<th>1.2. Regional and coastal observations and modelling</th>
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<td><strong>ACTION</strong>: Develop a proposal for the formation of a coastal modelling user group/community of practice</td>
<td>Not done per se, but has progressed through activities such as MARVL, Bureau coastal modelling, and the Forum for Operational Oceanography</td>
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<th>1.3. National/bluewater observations and Modelling</th>
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<td><strong>RECOMMENDATION</strong>: A coastally focussed CARS climatology supported by IMOS data should be explored in the future. An assessment of data requirements for a useful climatology would be needed</td>
<td>MARVL-3 is taking the first step in this direction with the intended creation of a shelf seas data collection (of physical parameters)</td>
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<td><strong>RECOMMENDATION</strong>: Biogeochemical modellers are invited to meet with the IMOS Bio-optical working group to identify data requirements for data assimilation in biogeochemical models, and identify opportunities strengthen the connection between observations and modelling</td>
<td>The bio-optical working group engaged strongly with the CSIRO Environmental Modelling Group. Mark Baird and Emlyn Jones presented an update on including bio-optical modelling and data assimilation at ACOMO 2014.</td>
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<tr>
<td><strong>RECOMMENDATION</strong>: Pursue approaches to interoperability of coastal model output through MARVL/US-IOOS</td>
<td>Further discussion with US-IOOS revealed that their ‘testbed’ is really a mechanism from bringing models into operational readiness. Collaboration being pursued with PacIOOS (including Powell keynote at ACOMO 2014).</td>
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The workshop was structured into four major themes:

1) Shelf reanalysis requirements, which aimed to include information on boundary and initial conditions e.g. met forcing, open ocean boundary, bathymetry, catchment loads, data assimilation schemes for reanalysis, models suitable for reanalysis, observations for inclusion in reanalysis, data impact studies. Additionally, this session aimed to discuss the planning to undertake a whole of Australia shelf reanalysis project.
2) Biogeochemistry, which aimed to include information on boundary and initial conditions e.g. meteorological forcing, open ocean boundary forcing, bathymetry, catchment loads, data assimilation schemes, improvements in processes e.g. optics, mixing, validation and application of outputs for management.

3) Developments in coastal modelling and observations, which aimed to include information on sea level and storm surge modelling, wave modelling, two-way ocean/atmosphere coupling and use of coastal altimetry among others.

4) Modelling toolkits, this aimed to include information on data availability via AODN, MARVL, visualization tools, parameter libraries and uncertainty estimates.

Two international speakers were invited to speak at the workshop; Dr Brian Powell from the University of Hawaii and Dr Kate Hedstrom from the University of Alaska Fairbanks. Australia’s Chief Scientist Professor Ian Chubb delivered a talk at the end of day 1 and talked with a few young scientists during the Poster session.

The workshop was attended by representatives of some of the NCRIS e-research capabilities, New Zealand’s National Institute of Water and Atmospheric Research, Australian Maritime Safety Authority, Department of Defence, consulting industry, universities and other government agencies.

![Figure 1. A potential future trajectory of ACOMO workshops.](image-url)
4. Day 1 Keynote

The first keynote talk for the workshop was delivered by Dr Brian Powell who has been collaborating with scientists in Australia and who specialises in understanding our ability to predict ocean conditions. He is a member of the core ROMS 4D-Var development team, and is the modelling project head for the Pacific Integrated Ocean Observing System (PacIOOS).

The talk focused on how his work brings together basic research and operational oceanography, with models (ROMS) ran operationally from the University of Hawaii. The models are combined with observations in real time and are dominated by remote sensing Sea Surface Temperature and Sea Surface Height, radar, moorings, sea gliders and some ARGO. They combined models with observations by making a state estimate using the physics of the model to manipulate the model itself and tell us how best to match the observations. They define their metric Delta J (which is the transport) to inform how each observation affects the outcome of Delta J. To do this analysis the boundary conditions, the initial conditions and the atmospheric forcing are adjusted. Forcing will affect 20% and the rest is the initial conditions. It is important to know how the ocean affects our observations, i.e. how the observations co-vary with one another and with the state of the ocean and allowing us to know what is happening in the ocean over time and in other areas. This type of analysis will be undertaken in the EAC in Australia in collaboration with Australian researchers. This analysis allows the examination of how observations inform models but also helps identify if any observational platforms are starting to fail. It can also inform where to have observations.

5. Shelf reanalysis requirements

The session was chaired by Andreas Schiller and talks included data assimilation of historical data whereby models are used to resolve processes, observations that constrain the models and data assimilation tools to synthesise observations and models.

An example of data assimilation was given for the Philippines Sea where observations from tide gauges, moorings, remote sensing (SST and SSH), ARGO, gliders and CTD profiles were assimilated into a ROMS model. The importance of models to resolve tides in reanalysis and assimilations was highlighted, bearing in mind that errors could be inflated if tides are incorrectly included in the models. Another example of ROMS was presented to estimate shelf-ocean exchanges for alongshore and across shore transport in the Australian coastal ocean (OzROMS) where observations were used for validation only. The main features of the boundary currents in Australia and all dominant physical processes were reproduced with this model, with plans to adopt the model to predict extreme water levels around Australia.

Use of the Sparse Hydrodynamic Ocean Code (SHOC) for eastern shelf of Tasmania was also included in the session with the model forced by realistic forcing over the 1993-2013 period and was compared against observations.

Overall, the session showed there was close agreement between the models and the observations, with the exception of salinity in the Eastern Tasmania study where modelled and observed data did not agree.

The poster session included additional studies in this theme.
A talk on the strategy to plan an Australian National Shelf Reanalysis (ANSR) project was presented to the community in order to seek their input and discuss issues with this proposed project. A vision of the proposed ANSR, the motivation, current capabilities, opportunities and options were addressed during the talk. The strategy as discussed includes 20-year synthesis of all available ocean observations at 1 km resolution ocean dynamics around Australia. This is seen to have flow on research benefits as well as benefits for industry such as, among others, environmental management, planning, developments, establishing environmental baselines. Current capabilities mentioned included IMOS shelf-scale observations, Bluelink, and national (OzROMS, SHOC) and regional (SAROMS, SEA-ROMS, NWS ROMS) scale modelling. Steps that need to be worked through to undertake the project were outlined.

Discussion about this project followed the presentation and was continued on day 2 during the wrap up session. Unanimous support amongst ACOMO attendees for moving to the next stage of scoping a national Shelf Reanalysis project was given by the community although a number of issues were raised with key points discussed and agreed to listed below:

- There are several things that need to be worked out at both the scientific/technical level and at the partner engagement level. Responsibilities need to be clearly specified and divided between different groups, for example:
  - A Technical Task Team (TTT) to be co-chaired by Peter Oke (CSIRO) and Moninya Roughan (SIMS/UNSW) will be responsible of progressing the scientific/technical issues.
  - An interim Steering Committee (SC) formed by Tim Moltmann (IMOS/UTAS), Susan Wijffels (CSIRO) and Peter May (BOM/CAWCR) will take responsibility for working through the partner engagement issues.
  - Both the TTT and SC will need to interact, with the SC providing the appropriate guidance to ensure that the TTT effort, which is currently being contributed ‘in-kind’, is focused on the scientific/technical issues only.
- It was agreed that the project will, from the beginning, need to have an operational end in mind, i.e. that it should not be seen as a purely academic exercise. It is recognised that the steps, timing and partner engagement required to achieve this will need to be worked through.
- The pros and cons of multi-model approaches were discussed at the workshop, but deeper consideration of the options needs to be undertaken by the TTT. It was agreed that ROMS must be in the mix given the growth in capability at the national level, opportunities available for international collaboration, and the decision by the Bureau of Meteorology to use ROMS as its coastal modelling platform.
- Getting IMOS and other shelf data ‘model ready’ is a necessary step for this project. Funding secured from NeCTAR and ANDS for a ‘MARVL- 3’ project could assist with this activity. As part of this process IMOS should look to develop workflows that ensure we can deliver ‘model ready’ data on an ongoing basis.
- The importance of high resolution atmospheric forcing was discussed, highlighting the need for consistency between atmospheric data resolution and that of the shelf (ocean) reanalysis. A high priority next step for the TTT will be to discuss this issue with relevant people in the Bureau of Meteorology (e.g. Peter Steinle).
• A complete TTT needs to be formed and a workshop organized to discuss the scientific/technical issues to come up with a proposal (including options and staging) for consideration by the SC.
  o A number of potential candidates for joining the TTT were identified during the workshop and expressions of interest were open until Wednesday 15 October.
  o The co-chairs of the TTT will recommend the proposed membership by Wednesday 22 October for approval by the SC, and advise if any resources are require to run the scientific/technical workshop.
• It was recognised that there could be potential tension between being highly consultative and inclusive about development of the Shelf Reanalysis project, and being highly focused and driven to get something done which capitalises on the tangible opportunities (e.g. the step change in availability of shelf observations now available via IMOS). The manner in which the Shelf Reanalysis project was openly discussed at ACOMO sends a clear signal of collaborative intent. However there are also clear signals within the National Innovation System that Australian Governments are expecting more socio-economic payoff from publicly funded research. There does need to be a sense of urgency around this project, but this should not be misinterpreted as exclusivity.

The technical issues highlighted during discussions were:
• The importance to include waters in the north of Australia to get the reanalysis right as it is a key area.
• Spatial resolution needs to be discussed and agreed on, but it will be dependent on the modelling approach adopted.
• Meteorology can be a limiting factor when setting boundary and initial conditions, with atmospheric heating and evaporation in the surface near the coast not very accurate, as was the case in South Australia where the comparison between observed temperature and that estimated by BlueLink was not good due to meteorological bias. Regional models will be key to providing a way to rectify these biases.
• Need to define from the start the questions that this reanalysis project will answer
• A wave model and high resolution atmospheric model were also flagged as important to follow from the ocean model but this will need to be developed over time.
• Significant work will need to be undertaken in the north to get things right and river input and catchment inputs will need to be considered, particularly for that region.
• The sparsity of in-situ data prior to the inception of IMOS was highlighted as a potential limiting factor. It was suggested that perhaps due to this, the data density is not good enough for a 20 year reanalysis and a more recent shorter period should be considered.

6. Biogeochemistry
Biogeochemical (BGC) modelling was identified in ACOMO 2012 as the potential focus for the subsequent workshop and progress in this domain allowed for the inclusion of a whole BGC session in ACOMO 2014. It was noted that in having greater emphasis on BGC (and ecosystems) over time, engagement with observational and experimental biologists as well as modellers will be necessary.
A total of 9 talks were delivered with other BGC work presented as posters. Talks in this session included research that ranged from the open ocean to estuaries and harbours. They mostly included hydrodynamic models coupled with BGC models with case studies undertaken in the North West Shelf of Australia, GBR and various Australian estuaries. Some of the models presented in the talks included ACCESS, ROMS, CSIRO Environmental Modelling System (EMS) suite and eReefs, among others. A framework called Framework for Aquatic Biogeochemical models, which allows to couple BGC models with hydrodynamic models was the topic of one of the talks where several different modules were tailored to Australian estuaries and where many BGC and hydrodynamic models were experimented with.

Emphasis was made on the importance of observations of nutrients close to the coast to help improve accuracy of the model in that region. IMOS moorings and remote sensing facilities were some of the observations used to validate/calibrate models with one case (eReefs) of data assimilation of the IMOS Ocean colour data.

Some of the recent developments and progress in BGC modelling include:

- The use of carbon isotopes to investigate the carbon pathways within estuaries and to estimate the uncertainties in BGC models.
- The development of a general framework to set up isotope dynamics on top of any biogeochemical model was described, where isotope sub-models can be run independently from the underlying biogeochemical model allowing for scenario/parameter studies.
- Modelling of reflectance to compare with observed satellite reflectance with the ability to make this comparison at individual bandwidths (eReefs). Reflectance has lower error than MODIS OC3 chlorophyll–a, and/or regional algorithms, therefore by simulating what we observed the error is reduced when comparing with observations, making data assimilation a possibility.
- Used of data assimilation techniques in eReefs linking models with observations and helping in identifying the errors propagating in the models.
- Use of allometric relationships to try to link phytoplankton radius with zooplankton growth and swimming velocities and check for parameter perturbations.
- Use of a vertical-1D model that includes only nitrate and phytoplankton to try to understand the influence of the vertical processes and deep chlorophyll maximum near the coast and help assess if 3D models are working.
- Use of models to estimate primary production and how it is influenced by tidal mixing and cyclones.
- Use of models and modelling scenarios to understand coastal environments and help policy and management.
- Use of the Framework for Aquatic Biogeochemical models to model estuarine health with the aquatic model linked to the terrestrial/riparian zone. The models were used to assess issues such as hypoxia, impact of river diversion on habitat, among others.

The issues highlighted in BGC modelling were:

- Sparse observations particularly in the vertical distribution of the different variables, with estimates relying on remote sensing with very few vertical observations.
- Problems in boundary conditions and parameterization in hydrodynamic models propagating in to the BGC models, similarly the propagation of uncertainties in atmospheric forcing.
- Parameterization in BGC models is very complex adding another layer of uncertainty to the BGC models besides the uncertainties propagated by hydrodynamic models and atmospheric forcing.
- Nutrient observations at higher temporal resolution are a high priority for the BGC modelling community. **IMOS to consider options for strengthening in this area as funding permits.**

7. **Day 2 Keynote**

The keynote talk on the second day of the workshop was delivered by Dr Kate Hedstrom from the University of Alaska in Fairbanks. She has been involved in the development of ROMS from the beginning.

Observations and model comparisons were done using drifters, radar and gliders. She gave examples of different projects undertaken around the Alaskan Sea. She described what observations are being taken using radar and gliders and the different models they used which included simple models, 2D models with only wind forcing, models covering the full Northeast Pacific using ROMS to run multi-decadal variability. For the Bering Sea a ROMS model is validated with observations but several parameters needed to be tuned as there were differences between model and observations. Number of levels, light penetration and heating and freshwater input were some of the parameters tuned to improve vertical stratification. Albedo effects and sensitivity to shortwave radiation were tuned to improve ice coverage. She gave examples of biological coupling applying models to simulate larval fish dispersal, in this example there were differences between observations and models. In one of the projects to be undertaken a comparison will be made of drifters with modelled particles to examine their dispersal patterns. Other examples are models to estimate ice and fast ice climatology, ice thickness, ice formation and concentration.

8. **Developments in coastal modelling and observation**

Talks during this session covered several different topics and a variety of models including; ROMS, RiCOM, SHOC/EMS, TUFLOW, FVCOM, SWAN, WW3, Shorfor, MOM and HYCOM. A growth in the uptake of ROMS modelling compared to the previous workshop (ACOMO 2012) was noted. The diversity of models and applications in Australia and New Zealand was the highlight. The research presented in the session was highly heterogeneous and included:

- Modelling in ports and harbours to assist port operations (Darwin) and assess issues related to dredging activities.
- Modelling and forecasting the movement of the coastline, i.e. sand dynamics in the beaches and the effect of sea level rise (SLR), and storm energy eroding beaches.
- Development of modelling tools that can be used to work out where and when coastal inundation is likely to be a problem.
- Development, improvements and issues of wave models.
- The value of using altimetry to constrain coastal models and issues related to this data set.
• The use of multi-modal consensus forecasting during the search for missing airliner MH370. Having access to as many credible models as possible assists in understanding model uncertainty during search and rescue operations.

Examples of ROMS models use in South Australia (SARDI) and Eastern Australia (UNSW) were given. Observations from IMOS moorings were used to validate the models and in the case of Eastern Australia observations from gliders and XBT from Ships of Opportunity were also used. In the case of SA, the models were used to estimate carrying capacity in the gulfs, to estimate circulation and connectivity in the Great Australian Bight, among others. ROMS models have been used to couple with sediment transport models.

There have been recent developments in improving process parameterisations in regional and coastal hydrodynamic models. Including new boundary conditions yielding far better internal model solutions when nesting in global models, new river discharge parameterizations (dynamic salinity input) have yielded improved salinities in regional models and dynamic 2-way nesting allowing the exchange of information between very high resolution (50-100m res) with coarser regional models.

Sediment transport models have been developed to model dredge spoil dumping sites and to understand how it affects the local ecology, and how suspended sediments affect light attenuation in the water column. Information on waves and currents and their interactions were highlighted as some of the most important processes that affect sediment dynamics.

In the wave modelling domain, wave models presented and assessed included SWAN and WAVEWATCH III. Developments in this field included great improvement in the process representation of input and dissipation terms in Operational 3rd generation wave models. An example on the use of MARVL to get the data to run both WAVEWATCH III and SWAN was included in one of the talks. An important consideration for wave models in the near coast was to account for sea-breezes in the wind forcing of the model. Observations used to validate wave models included data from radar and wave rider buoys.

The IMOS NRS site in Darwin was noted as a very useful data source for the region where the data is used in real time to run models and help port operations. The models used are mostly 2D models that can be run locally and in a quick manner. Real time information from this NRS is being used and seen by stakeholders in their smartphones and it has been helping water quality monitoring. These data are used for boundary conditions so the models can be run in near real time.

The potential to use altimetry data for coastal modelling was discussed, with cleaner signal from the new altimetry satellite (SARAL) improving the prospect of using this data near the coast. However, altimetry data may not be dense enough to constrain models, but could be useful for model assessment.

Other tools that are being developed to work out where and when coastal inundation is likely to be a problem and innovative techniques used to model and forecast the movement of the coastline were also shown in this session, with both developments of high importance for local governments.

Some of the issues highlighted in this session were:
The need for high spatial and temporal resolution of the wind fields.

The need for better spatial coverage for wave observations, since wave data in Australia is very sparse.

There is a need for a national strategy to store and archive wave data.

Nesting high resolution models into coarser models presents issues such as bias in ocean heating and evaporation from coarser models near the coast when compared to observations.

There is a need for more mixing observations, micro structure (or ADCP/Glider) observations of internal mixing rates to validate the parameterizations.

Coarse atmospheric models are problematic to force high resolution wave and hydrodynamic models near coasts.

Efforts in a few key areas of ROMS model improvement need to be continued, ie. Horizontal and vertical mixing parameterizations.

Other highlights and take home messages from the discussion include:

- In most IMOS Nodes (QIMOS, NSW-IMOS, SAIMOS), there is now co-evolution of the regional observing systems with regional modelling efforts. This was a striking and very positive difference between ACOMO 12 and 14.
- While there has been a growth in ROMS users in Australia, it is important to maintain a national model development capability. This is necessary to allow for innovation and to enable solving of problems specific to Australian marine and coastal systems. Mechanisms for ensuring model developments in Australia feed into international communities such as ROMS will need to be considered.
- Expectations in using altimetry for coastal modelling should remain modest at this stage. The international community is working on better range in the presence of land, and better corrections on the shelf. A national product using altimetry near the coast is under development by the CSIRO/IMOS OceanCurrent group, but it still needs further work.

9. Modelling toolkits

This session included the first ecosystems modelling talk for ACOMO with the intention to increase the participation of the ecosystem modelling community in future ACOMO workshops.

This talk gave an overview of the challenges and approaches in understanding and predicting changes in Southern Ocean (SO) ecosystems. The approach they will be taking for assessment of status and trends in ecosystems is to use R Tools to facilitate the access to environmental data and generation of summaries of those data that will feed into the habitat assessments. These will be contributing to the development of ecosystem Essential Ocean Variables (EOV) and help the observing design for the SO. The work is closely linked to the work of ecosystem processes modelling and to finally link in to end-to-end ecosystem models, such as Atlantis. The parameters and underlying information have been documented in the Southern Ocean Knowledge and Information wiki (SOKI), which aims to provide a source of standardised and validated (peer-reviewed) reference material on Southern Ocean ecosystems and on the research tools used in the region. The
hydrodynamical forcing for this model comes from a polar version of ROMS (coupled to a layer of Atlantis).

Information on how to facilitate modelling activities and what is required to run the models was included in the other talks of this session.

Two virtual laboratories were discussed in this session; Australia’s Marine Virtual Laboratory (MARVL) and the Climate and Weather Laboratory (CWSLAB). These virtual laboratories are intended to facilitate and simplify the steps needed to run models in a region of interest in both ocean and atmosphere.

The models in MARVL are MOM4, SHOC, ROMS, SWAN, WaveWatch-III, datasets options include ACCESS-a, NCEP, OFAM, BRAN3 and uses the IMOS observational database. A few issues were mentioned for this virtual laboratory and more development needs to happen, but overall it has good potential and MARVL funding has been extended to June 2015.

The CWSLAB provides a modelling environment that was suitable for the Bureau of Meteorology to continue their work, improve ease of use, reproducibility, support and sharing of code, data and experiments. Some of the analysis services from this laboratory are direct access to model data in NCI /g/data lustre filesystems, interactive environment: a user can explore data using ncview, Matlab, Python, Ferret, R, etc., and access the CMIP5 database (currently requires user & passwd), among others.

Talks on the Marine Virtual laboratory (MARVL) and the Climate and Weather Science Laboratory demonstrated the potential of these tools to add considerable value at the observations to modelling interface. It is unclear whether the program which has funded these activities (i.e. NeCTAR) would be willing or able to continue investing in them over the timeframe on which we need to sustain IMOS, and the NCI. We will need to think carefully about how to build successful virtual laboratory activities into sustainably funded information and modelling infrastructures.

Other modelling tools and data tools presented in this session include:

- Strudel: interactive environment to process, analyse and visualise data produced by a range of imaging modalities.
- Earth System Grid Federation (ESGF): established to manage and provide access to the vast amount of modelling outputs generated in the CMIP5 and related projects.
- GeoNetwork: improves access to and integrated use of spatial data and information and allows to easily share geographically referenced thematic information between different organizations.
- IOOS Data Management and Communications (DMAC): The Asset inventory is a comprehensive, automated inventory of observational assets. The services in this Catalogue publish metadata records of various formats that describe the source of the data published via the services.
10. **Wrap up**

A summary of the outcomes of ACOMO 2014 was done by Tim Moltmann. Among the high level issues highlighted were:

- **The need for IMOS and AODN to provide model ready data that can be built up routinely, particularly in view of a potential ANSR project.**
- **It was very pleasing to see the far greater presence of BGC observations and modelling at ACOMO 14, and the progress made over the last couple of years.**
- **The need of nutrient observations at higher temporal resolution than the ones currently available.** With the development of new sensor technology IMOS should think about how to integrate this into its program.
- **BGC modellers confirmed that developments to assimilate light (PAR) are being adequately supported by the IMOS Satellite Remote Sensing Facility.**
- **It was noted that in having greater emphasis on BGC (and ecosystems) over time, we need to ensure we are engaging observational and experimental biologists as well as modellers.**
- **In most IMOS Nodes (QIMOS, NSW-IMOS, SAIMOS), there is now co-evolution of the regional observing systems with regional modelling efforts.** This was a striking and very positive difference between ACOMO 12 and 14. WAIMS stands out as something of an exception at the moment, perhaps in part because it is such a large region. Whilst there is a lot of modelling activity being undertaken, it is not currently coming together in a way that is providing IMOS with useful advice about design of an effective and efficient observing system for the WA shelf. This is particularly important at the moment as the Node goes through a consolidation of effort following cessation of WA Government co-investment which supported expansion into the Pilbara and Kimberley over the last 3-4 years. The WAIMOS Node needs to consider this issue.
- **A number of talks covered modelling and observing in harbours and gulfs.** The level of IMOS engagement in these activities is quite heterogeneous. In Darwin Harbour the IMOS NRS and second co-invested mooring in Beagle Gulf are clearly very relevant to the modelling developments. In SA, the successful shelf scale collaboration between IMOS and the SAROM regional modelling activity is being leveraged into the SA Gulfs with the aim of creating a new, co-invested partnership. In Sydney Harbour a major project is spinning up with little contribution from IMOS, other than some assistance with information infrastructure and delivery of ship of opportunity measurements. This isn’t necessarily a problem, but it would be sensible for IMOS to have a clearer strategy in terms of future decision making.
- **Access to wave observations came up as an issue and IMOS will discuss access to surface wave data with the Bureau of Meteorology and other national and international partners, as it arose as an issue during the workshop and gaining access is important for the shelf and coastal research communities (including MARVL and ANSR amongst other projects).**
- **Talks on the Marine Virtual laboratory (MARVL) and the Climate and Weather Science Laboratory demonstrated the potential of these tools to add considerable value at the observations to modelling interface.** It is unclear whether the program which has funded these activities (i.e. NeCTAR) would be willing or able to continue investing in them over the timeframe on which we need to sustain IMOS. We will need to think carefully about how to build successful virtual laboratory activities into sustainably funded information and modelling infrastructures.
• In addition to the greater emphasis on BGC at ACOMO 2014, it was pleasing to have a presentation on Ecosystem modelling and assessment in the Southern Ocean. We should aspire to have much stronger engagement from ecosystem scientists at ACOMO 2016, and will need to look for opportunities to build stronger links in the intervening period. Work by the Southern Ocean Observing System (SOOS) to develop ecosystem essential ocean variables (eEOVs) may provide one such opportunity.

• The National Marine Science Committee process to develop a national marine science plan was noted as an important opportunity through which to progress a number of the issues raised at ACOMO 2014. Attendees were encouraged to ensure that where possible they are making this connection with the white papers currently under development.

The last and most important outcome of this workshop is the decision to pronounce the name of the workshop AC’omo (‘AYCO-MO’), to the disappointment of the chair and one of the SC members.
### Appendix I: AGENDA

**Australian Coastal Ocean Modelling and Observations Workshop (ACOMO) 2014**  
The Shine Dome, Australian Academy of Sciences, Canberra  7-8\(^{th}\) October 2014

**Tuesday 7\(^{th}\) October 2014**

<table>
<thead>
<tr>
<th>Time</th>
<th>Event</th>
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<tbody>
<tr>
<td>8.00-8.30</td>
<td>Arrival, registration and coffee</td>
</tr>
<tr>
<td>8.30-8.35</td>
<td>Ana Lara Lopez</td>
</tr>
<tr>
<td>8.35-8.45</td>
<td>Tim Moltmann</td>
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<tr>
<td>8.45-9.20</td>
<td>Brian Powell (Keynote speaker)</td>
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**Shelf reanalysis requirements**

<table>
<thead>
<tr>
<th>Time</th>
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<tbody>
<tr>
<td>9.40-10.00</td>
<td>Colette Kerry and Brian Powell</td>
</tr>
<tr>
<td>10.00-10.20</td>
<td>E.M.S. Wijeratne, Charitha Pattiarachi, Roger Proctor</td>
</tr>
<tr>
<td>10.20-10.40</td>
<td>Morning Tea</td>
</tr>
<tr>
<td>10.40-11.10</td>
<td>Moninya Roughan, Peter Oke, Ryan Lowe, John Middleton, Gary Brassington, Susan Wijfells, Peter May, Tim Moltmann</td>
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<tr>
<td>11.10-11.40</td>
<td>DISCUSSION of Shelf reanalysis requirements</td>
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**Biogeochemistry**

<table>
<thead>
<tr>
<th>Time</th>
<th>Event</th>
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<tr>
<td>11.40-12.00</td>
<td>Pete Strutton, Katie Jones, Helen McDonald, Nicole Jones, Cynthia Bluteau, Christine Pequignet, Ryan Lowe, Greg Ivey</td>
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<tr>
<td>12.00-12.20</td>
<td>Jim Greenwood and Peter Craig</td>
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<tr>
<td>Time</td>
<td>Activity</td>
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<tr>
<td>12.20-1.05</td>
<td>Lunch</td>
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<td>1.05-1.25</td>
<td>John Zeldis</td>
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<tr>
<td>1.25-1.45</td>
<td>Jenny Skerratt, Mark Baird, Mathieu Mongin, Farhan Rizwi, Karen Wild-Allen</td>
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<td>1.45-2.05</td>
<td>Matthew R. Hipsey, Louise C. Bruce, Sri Adiyanti, Bradley Eyre, Perran L.M. Cook, Justin D. Brookes</td>
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<td>2.05-2.25</td>
<td>Sri Adiyanti, Matthew R. Hipsey, Isaac Santos, Damien Maher, Bradley Eyre</td>
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<td>2.25-2.45</td>
<td>Afternoon Tea</td>
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<td>2.45-3.05</td>
<td>Klaus D. Joenk</td>
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<td>3.05-3.25</td>
<td>Mark Baird, Karen Wild-Allen, Mathieu Mongin, Jenny Skerratt, Farhan Rizwi, Barbara Robson, Emlyn Jones, Thomas Schroeder</td>
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<td>3.25-3.45</td>
<td>Emlyn Jones, Mike Herzfeld, Mathieu Mongin, Mark Baird, Peter Oke</td>
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<td>3.45-4.15</td>
<td>DISCUSSION of Biochemistry</td>
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<td>4.15-4.30</td>
<td>Australia’s Chief Scientist – Professor Ian Chubb</td>
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<tr>
<td>4.30-6.00</td>
<td>Poster session</td>
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<td>7.00-late</td>
<td>Dinner</td>
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### Wednesday 8\textsuperscript{th} October 2014

#### Developments in coastal modelling and observation

<table>
<thead>
<tr>
<th>Time</th>
<th>Session</th>
<th>Speaker(s)</th>
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<tr>
<td>8.00-8.30</td>
<td>Coffee</td>
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<tr>
<td>8.30-9.00</td>
<td>Kate Hedstrom (Keynote speaker)</td>
<td>Exploring Alaska’s Seas</td>
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<tr>
<td>9.00-9.20</td>
<td>John Middleton, John Luick, Charles James, Mark Doubell, Hugo de Oliveira</td>
<td>Coastal Modelling at the South Australian Research and Development Institute</td>
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<tr>
<td>9.20-9.40</td>
<td>Mike Herzfeld and Philip Gillibrand</td>
<td>Model optimization through development: the eReefs example.</td>
</tr>
<tr>
<td>9.40-10.00</td>
<td>David K. Williams, Craig Steinberg, Paul Rigby, Richard Brinkman, Simon Spagnol, Ruth Patterson</td>
<td>Observations and modelling in support of port activities for Darwin Harbour, Northern Territory, Australia</td>
</tr>
<tr>
<td>10.00-10.20</td>
<td>Xiao Hua Wang and Moninya Roughan</td>
<td>Estuarine and sediment transport modelling for the World Harbour Project</td>
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<td>10.20-10.40</td>
<td>Morning Tea</td>
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<tr>
<td>10.40-11.00</td>
<td>Robin Robertson</td>
<td>Parameterization of Vertical Tidal Mixing in ROMS</td>
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<tr>
<td>11.00-11.20</td>
<td>Alexander V. Babanin, Ian R. Young, W. Erick Rogers, Stefan Zieger</td>
<td>Third Generation Wave Models Based on Observational Physics</td>
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<tr>
<td>11.20-11.40</td>
<td>Charles James, Mark Doubell, John Luick, John Middleton</td>
<td>SWAN model study: Effects of wind forcing temporal resolution on waves in Spencer Gulf</td>
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<td>11.40-12.00</td>
<td>Scott A. Stephens, Richard M. Gorman, Rob G. Bell</td>
<td>Coastal inundation modelling in New Zealand</td>
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<td>12.00-12.20</td>
<td>Ian L. Turner, Mark A. Davidson, Kristen D. Splinter, Tom Beuzen</td>
<td>Forecasting sandy coastline response to varying/changing coastal wave climates-data needs, challenges and solutions</td>
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<tr>
<td>12.20-12.45</td>
<td>Lunch</td>
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<td>12.45-13.05</td>
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<tr>
<td>13.05-13.25</td>
<td>Ian Coghlan, Bill Peirson, Russel Morison, Michael Banner</td>
<td>Measured and Modelled Wave Climates of South-Eastern Australia</td>
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<tr>
<td>13.25-13.45</td>
<td>David Griffin and Madeleine Cahill</td>
<td>Coastal Altimetry 101</td>
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<tr>
<td>13.45-14.05</td>
<td>Nurul Hazrina Idris, Xiaoli Deng, and Angela M. Maharaj</td>
<td>A comparison of SARAL/Altika coastal altimetry and in situ observations across Australasia</td>
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<td>14.05-14.25</td>
<td>Ben Brushett, Sasha Zigic, Ryan Alexander, David Wright, Murray Burling</td>
<td>Operational Drift Forecast Modelling in support of AMSA MH370 Search</td>
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<tr>
<td>14.25-14.50</td>
<td>DISCUSSION of Developments in coastal modelling and observation</td>
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<td>14.50-15.15</td>
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#### Modelling toolkits
<table>
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<tr>
<th>Time</th>
<th>Session Title</th>
<th>Speakers</th>
<th>Location</th>
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<tbody>
<tr>
<td>3.15-3.35</td>
<td>Australia’s marine virtual laboratory</td>
<td>Roger Proctor, Peter Oke, Uwe Rosebrock, Brandan Davey, Xiaoming Fu, Peter Blain, Benedicte Pasquer, Gary Carroll, Simon Pigot</td>
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<tr>
<td>3.35-3.55</td>
<td>Challenges and innovations in Southern Ocean ecosystem modelling and assessment: the future</td>
<td>Jess Melbourne-Thomas, Andrew Constable, Stuart Corney, Michael Sumner, Elizabeth Fulton</td>
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<tr>
<td>3.55-4.15</td>
<td>Data Management Update for the U.S Integrated Ocean Observing System (IOOS)</td>
<td>Eoin Howlett, Kelly Knee, Derrick Snowden</td>
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<tr>
<td>4.15-4.35</td>
<td>Community research services and meteorological forcing data at the ANU/NCI facility</td>
<td>Tim Pugh, Tom Beer, Robin Bowen, Martin Dix, Ben Evans, Tim Erwin, Michael Naughton, Scott Wales</td>
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<tr>
<td>4.35-4.50</td>
<td>DISCUSSION of Modelling Toolkits</td>
<td>Tim Moltmann</td>
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<tr>
<td>4.50-5.30</td>
<td>Wrap up and meeting close</td>
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**Posters:**

1. **Assessment of CMIP5 Biogeochemical Models for the New Zealand Exclusive Economic Zone (NZ EEZ): Present Day Analysis as a Framework for Future Predictions and Downscaling**
   Graham Rickard, Mark Hadfield

2. **A high resolution re-analysis for the East Australian Current**
   Colette Kerry, Moninya Roughan, Brian Powell

3. **Predicting extreme water levels around Australia**
   Charitha Pattiaratchi, E.M.S. Wijeratne, Ivan Haigh, Matt Eliot

4. **Spatial patterns of warming off Western Australia during the 2011 Ningaloo Niño: quantifying impacts of remote and local forcing**
   Jessica Benthuysen, Ming Feng, Liejun Zhong

5. **Coral Reef parameterization in numerical models**
   Hemerson Tonin, Richard Brinkman

6. **Current predictions for the Rottnest channel swim**
   Agi Gedeon, E.M.S. Wijeratne, Charitha Pattiaratchi, Roger Proctor

7. **Simulating the dynamics of continental shelf waves generated by tropical cyclones in Western Australia**
   Elizabeth Joseph, Charitha Pattiaratchi, E.M.S. Wijeratne
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<tr>
<th></th>
<th>Title</th>
<th>Authors</th>
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<tbody>
<tr>
<td>8</td>
<td>The Influence of the Leeuwin Current on the West Australian Wave Climate</td>
<td>Moritz Wandres, Charitha Pattiaratchi, E.M.S. Wijeratne</td>
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<tr>
<td>9</td>
<td>Tropical cyclone stirring on the inner continental shelf off north-west Australia observed through Ocean gliders</td>
<td>Charitha Pattiaratchi</td>
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<tr>
<td>10</td>
<td>Challenges, Benefits and Opportunities in Australia’s Northern Tropical Seas.</td>
<td>Paul Rigby, Craig R. Steinberg, David K. Williams, Gary Brinkman, Richard Brinkman, Hemerson Tonin and David Hughes</td>
</tr>
<tr>
<td>11</td>
<td>Integrated Marine Observing System / Australian Ocean Data Network: Improving users access to data</td>
<td>Roger Proctor, Peter Blain, Sebastien Mancini</td>
</tr>
<tr>
<td>12</td>
<td>Wave measurements from the Australian Coastal Ocean Radar Network</td>
<td>Lucy R Wyatt</td>
</tr>
<tr>
<td>13</td>
<td>Recent Applications of the Regional Ocean Modeling System (ROMS) at Open Ocean, Coastal, and Embayment Scales Around New Zealand</td>
<td>Mark Hadfield, Graham Rickard</td>
</tr>
<tr>
<td>14</td>
<td>Surface currents on the Rottnest continental shelf, Western Australia</td>
<td>Jennifer Penton, Charitha Pattiaratchi, Hrvoje Mihanovich</td>
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<tr>
<td>15</td>
<td>Sea breezes force near-inertial waves on Rottnest Shelf, Western Australia</td>
<td>Florence Verspecht, Hrvoje Mihanovich, Charitha Pattiaratchi</td>
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<tr>
<td>16</td>
<td>The seasonal cycle of Chlorophyll along the Two Rocks Transect</td>
<td>Miaoju Chen, Charitha Pattiaratchi, Anas Ghadouani</td>
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<tr>
<td>17</td>
<td>The Holloway Current along North-West Australia</td>
<td>Charitha Pattiaratchi, Mohammad Hadi Bahmanpour, E.M.S. Wijeratne, Craig Steinberg, Nick D’Adamo</td>
</tr>
<tr>
<td>18</td>
<td>Particle (‘Debris’) Tracking at possible crash sites of MH370</td>
<td>Charitha Pattiaratchi, E.M.S. Wijeratne</td>
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<tr>
<td>19</td>
<td>Peddies: what, where why ?</td>
<td>Charitha Pattiaratchi and Hrvoje Mihanovich</td>
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<tr>
<td>20</td>
<td>The eReefs relocatable biogeochemical model (RECOM) and its parameter libraries</td>
<td>Barbara J. Robson, Farhan Rizwi, Leonie Geoffroy, Jerome Brebion, Mark Baird, Jenny Skerrat, Mathieu Mongin, Karen Wild-Allen, Emlyn Jones, Nugzar Margvelashvili and Michael Herzfeld</td>
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<td>21.</td>
<td>A higher resolution model of shelf circulation and marine connectivity of the north-west shelf</td>
<td>Frank Colberg, Dirk Slawinski, Ming Feng</td>
</tr>
<tr>
<td>22.</td>
<td>La Niña causes extreme freshening of the Leeuwin Current</td>
<td>Ming Feng, Jessica Benthuysen, Dirk Slawinski</td>
</tr>
<tr>
<td>23.</td>
<td>Past, present and future transport patterns along the east Australian coast and its impact on larval dispersal</td>
<td>Paulina Cetina-Heredia, Moninya Roughan, Erik van Sebille, Melinda Coleman, Ming Feng</td>
</tr>
<tr>
<td>24.</td>
<td>MARine Virtual Laboratory (MARVL) high-resolution ROMS test: the East Australian Current at 30 S in Solitary Island Marine Park (SIMP)</td>
<td>Amandine Shaeffer and Moninya Roughan</td>
</tr>
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IMOS is a national collaborative research infrastructure, supported by Australian Government. It is led by University of Tasmania in partnership with the Australian marine & climate science community.

This workshop is also supported by:
Quantifying the role of observations in a numerical model  

Dr Brian Powell

ROMS state-estimation has been successfully used around the world, and it will soon find significant success in Australia with its recent adoption within commonwealth agencies. In state-estimation, we aim to combine ocean observations with a numerical model in a dynamically consistent way that --- in a least-squares sense --- provides a better estimate that either alone. ROMS accomplishes this problem using a time-dependent variational scheme (4D-Var) that uses the model dynamics to build the covariances required to perturb the initial conditions, atmospheric forcing, and boundary conditions. In solving this problem, we are also able to compute the dynamical covariance between the observations and the model that provide an estimate of the observability of the ocean. The impact of each observation can then be assessed to compare the relative importance of different observations to our estimate of the ocean state. As part of PacIOOS, we evaluate the observations on a daily basis to understand which observations are providing the most information for our numerical models.

In this talk, I will present the methodology and results for understanding the observations that provide the greatest informational content to the model for Hawaii. We have assimilated three years worth of satellite and in situ data into a circulation model of the Hawaiian islands. Despite their relatively small size, the Hawaiian islands have a significant impact upon the atmospheric and oceanic circulations of the northern, sub-tropical Pacific. High volcanic mountains extending from the seafloor block the NE trade winds and Northern Equatorial Current, forcing them to squeeze between the islands and creating a wake that extends 3,000 km across the Pacific. Using the results of the assimilation experiment, I will present a look at how each observation contributes to our estimates of the circulation around the islands and quantifying which portion of the dynamics is sampled by the observation.

Bio---

Dr. Powell is an Associate Professor of Oceanography at the University of Hawaii with research specializing in understanding our ability to predict ocean conditions on the "weather" timescale of 7-30 days. He is a member of the core ROMS 4D-Var development team, and is the modeling project head for the Pacific Integrated Ocean Observing System (PacIOOS). This US national effort attempts to monitor and predict the coastal ocean for all US territories. PacIOOS is responsible for all US territories in the Pacific: Hawaii, Guam, Mariana Islands, Palau, Marshall Islands, and the Federated States of Micronesia. Operational nested ocean, atmosphere, and wave models for these regions are
used to both hindcast and predict local conditions. For ocean circulation, state-estimates using the previous three days of observations are integrated each day to produce seven day forecasts. In Hawaii, these models are nested from 4km to 40m resolution in the nearshore environment that includes predictions of surface waves and ground runoff. Dr. Powell received his Ph.D. in Aerospace Engineering with an emphasis on Physical Oceanography from the University of Colorado at Boulder in 2005. In 2009, Dr. Powell was chosen as an Office of Naval Research Young Investigator, an award for those identified as the top young scientists in the United States.
SHELF REANALYSIS

A numerical ocean model for the continental shelf off Eastern Tasmania

_Eric C. J. Oliver and Neil J. Holbrook_
Institute for Marine and Antarctic Studies, University of Tasmania, Hobart TAS, Australia
Australian Research Council Centre of Excellence for Climate System Science

The southwest Tasman Sea is a global warming ocean hotspot, with multi-decadal scale increases in upper ocean temperatures in this region having substantial impacts on the distribution and range of various marine species. However, translating our knowledge about these larger-scale offshore warming changes to the continental shelf is challenging. Existing observations of historical marine variability and climate on the continental shelf off eastern Tasmania are highly valuable, albeit spatially and temporally inhomogeneous, particularly for studies of regional marine ecology. While the large-scale ocean reanalysis, Bluelink ReANalysis (BRAN), is an excellent resource for studies of the open ocean circulation and ocean state around Australia, the underlying model was not designed for coastal and nearshore studies across the continental shelf – and hence BRAN tends to be unreliable in this domain.

To address these limitations and build mechanistic understanding of the drivers and responses in the coastal and nearshore domain, we have developed a regional model, using the Sparse Hydrodynamic Ocean Code (SHOC), for the continental shelf off eastern Tasmania. There are three open boundaries: two across the shelf, one south of Bruny Island and another at the northeast tip of Tasmania, and one running parallel to the shelf break in deep water. At these open boundaries we force the model with estimates of the ocean state from BRAN and at the surface we force with surface fluxes from the NCEP Climate Forecast System Reanalysis (CFSR) to perform a hindcast over the period from 1993-2012. We present comparisons between the model hindcast and in-situ data (Maria Island time series, Spring Bay tide gauge, etc). We also present the results from a number of sensitivity tests exploring (i) the coupling between the tidal and non-tidal components, (ii) the role of river runoff from the Derwent and Huon rivers, and (iii) the influence of extending the northern edge of the domain to include the Furneaux Group of islands (including an open boundary along Banks Strait - part of Bass Strait).
In prediction of the atmospherically-forced eddying ocean circulation, data assimilation procedures are used to combine observations with a numerical model to produce a circulation estimate that is superior to either alone, subject to prior hypotheses about background, model, and observation errors. In regions of strong internal tides, the baroclinic tides constitute a significant, non-deterministic, component of the observations. In a circulation model without tidal dynamics, the internal tide signal becomes an error term, limiting the value of observations around the thermocline in constraining state estimates.

Focusing on the Philippine Sea, a region of energetic internal tides and dynamic mesoscale circulation, we assess how the internal tides affect estimates of sub-tidal dynamics through the assimilation of a variety of surface and subsurface observations. We use 4-dimensional variational data assimilation (4D-Var), an advanced assimilation technique that uses the model dynamics to determine an optimum state estimate. The results show that surface and subsurface mesoscale state estimation and predictability is significantly improved with the inclusion of tidal dynamics in the circulation model. This study highlights the importance of correctly representing the internal tides when estimating and predicting the subtidal circulation, and has significance for prediction in marginal seas and ocean basins around the globe.
Estimates of alongshore and cross-shelf transports around Australia

E.M.S. Wijeratne\textsuperscript{1}, Charitha Pattiaratchi\textsuperscript{1}, Roger Proctor\textsuperscript{2}
\textsuperscript{1}School of Civil, Environmental and Mining Engineering & UWA Oceans Institute, The University of Western Australia
Email: sarath.wijeratne@uwa.edu.au
\textsuperscript{2}eMarine Information Infrastructure, Integrated Marine Observing System, University of Tasmania

Abstract

Alongshore and cross-shelf transport along the Australian continental shelf based on 3 year model simulations using the high-resolution Oz-ROMS simulations. The Oz-ROMS model has been configured to include the entire Australian continental shelf and slope together with the adjacent deep ocean using Regional Ocean Modelling System. Hindcast simulations were undertaken using three-hourly atmospheric forcing (wind, atmospheric pressure, heat and fresh water inputs) using ECMWF ERA interim data. The model open boundary traces (salinity and temperature) and transport (barotropic and 3D velocity components) were specified using the global Hybrid Coordinate Ocean Model (HyCOM) outputs. The model open boundary forcing included tides derived from the TPX07.2 global tidal model and monthly mean sea levels using satellite altimeter data derived from the AVISO database.

The performance of the Oz-ROMS circulation model is assessed by comparing model results with various oceanographic observations covering different part of Australian shelf and coast. We have also evaluated the model prediction capability of various temporal and spatial scale physical processes (e.g. sporadic upwelling, internal tides, inertial oscillation, dense water formation and cascading, shelf/trapped waves generation and propagation etc.) in Australian coastal and shelf seas. The model has reproduced almost all of the known major processes and circulation structures on Australian shelf and coastal seas. The model is able to reproduce the spatial and temporal scales of the Leeuwin Current System and East Australian Current (EAC) including associated eddy fields and other meso-scale processes. Predicted seasonal Leeuwin current transport and seasonal variability compare well with the measured data. We found that the distribution of atmospheric pressure (in addition to other forcing agents) significantly influences the strength of Leeuwin current in winter. We also found that Holloway current system in northwest shelf is a significant contributor to Leeuwin current system. Model results clearly indicated Leeuwin current is much stronger in La-Nina years (e.g. 2011). The observed high temperature water in 2011 in NW shelf region particularly in Shark Bay and Ningaloo region whose distribution is also reproduced by the model. The cross-shelf transport estimated based Oz-ROMS showed that the NW and NE shelves mainly act as net influx, SW corner and SE-NSW shelf act as net outward flux, net influx at all the major upwelling regions and small cross-shelf exchange along southern Australian shelf.
A National Shelf Re-Analysis Project for Australia

Moninya Roughan, Peter Oke, Ryan Lowe, John Middleton, Gary Brassington, Susan Wijfells, Peter May, Tim Moltmann

Australia is a marine nation, and our continental shelf is providing recognised social, economic, and environmental benefits that will continue to accrue to future generations if well managed - through oil & gas extraction, fishing, marine tourism, ecosystem services, climate services etc. Adequate understanding of the shelf-scale marine environment is fundamental to its sustainable exploitation. 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 currently 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. ANSR is the answer!

We will present a number of options that could be suitable for a national shelf scale reanalysis. We will use the time to workshop some of the ideas around choice of model, baseline physics for inclusion to capture essential processes, a national approach to validation and verification and how to get maximum community engagement and uptake. We outline the key steps needed to build ANSR nationally.
This presentation will summarise the results thus far of a coupled physical-biogeochemical study on Australia’s northwest shelf (NWS). The goal of the project is to understand the dynamics of ocean transport and mixing processes and their role in regulating primary productivity. This goal is being approached via a combination of observations and modelling. The observations include data from IMOS moorings, satellites and a field campaign in 2012. Moored observations of internal bores on the continental slope have revealed near-seabed intensified currents, and large turbulent overturns and dissipation with consequences for nutrient delivery. Biogeochemical observations have thus far been used to focus on summer productivity, when short-lived blooms occur that together are comparable to the larger and longer winter bloom. Case studies have been performed of tropical cyclones, to estimate their impact on regional productivity. A coupled physical-biogeochemical model is being developed to further investigate transport and mixing on the NWS. Model output has been created for summer 2011/2012 and a case study performed on Cyclone Lua (March 2012). Together these observations and modeling will enhance our understanding of processes regulating productivity on the NWS.
The vertical distribution of phytoplankton in the ocean has a major influence on primary production and transfer of energy to higher trophic levels. This vertical structure is invisible from space, meaning that estimates of ocean primary production based on remote sensing must rely on sparse vertical profiles and models. However, variations in vertical mixing, submarine light, gravitational settling, and nutrient supply on the continental shelf make accurate prediction of the vertical phytoplankton distribution difficult. To demonstrate and seek to understand some of this variability we have applied a one-dimensional model of phytoplankton and nitrate for coastal-water conditions. We use the model to highlight some of the basic processes that determine the coastal ecosystem.
Linking eutrophication and ocean acidification to land use: 18 years of ocean observation in the Hauraki Gulf

John Zeldis

The ecosystem services of the Hauraki Gulf include wild and farmed fisheries, natural amenity and recreation, and assimilation and regulation of natural and human impacts. The Gulf’s coastal areas – especially the Firth of Thames – are its most productive, where phytoplankton and zooplankton are most concentrated, snapper spawn most intensively, and most marine farms are located.

The high productivity is sustained by nutrient loading, which in the Firth is driven mainly by riverine input, with about 60-70% of its load entering from the intensively farmed Hauraki Plains. High productivity is then sustained by efficient nutrient recycling in situ.

NIWA has sustained an ocean observation programme which has monitored conditions in the Gulf and Firth for 18 years, using time-series and process studies supported by mooring and ship-based surveys. This programme is beginning to reveal important ecosystem stressors associated with the productive nature of the Firth. They include:

- Eutrophication – Oxygen in the deeper waters of the Firth is depleted in autumn of most years. This occurs as organic matter produced during the previous spring-summer is decomposed in situ, consuming oxygen. In some autumn periods these sags in oxygen have approached deleterious levels (about 60% oxygen saturation).
- Ocean acidification – At the same time the oxygen decreases, the pH of the Firth waters becomes more acidic (pH about 7.9) relative to adjacent open-ocean values (pH about 8.1). This acidification is more intense than that attributable to atmosphere-driven acidification, and is caused by carbon dioxide released during the decomposition of organic material. Acidification can impede the growth of shellfish and has been shown to affect behaviour of larval fish.

Thus, we have found that while the enriched water quality of the Firth promotes benefits through high productivity, it also introduces potential stressors (low oxygen interacting with low pH) derived from the highly intensified land-use in its catchments. It will be crucial to assess these impacts and forecast their trajectories under future land-use scenarios, using biogeochemical observations linked to modelling.
The use of biogeochemical models for predicting scenarios for coastal waters is increasing. Their use is due to the need of managers and policy makers to understand the impact of coastal development on a broad scale. Catchment loads into coastal waters are seen as one of the only inputs that managers have some control over in an urban coastal system. Policy makers, observational scientists and modellers have a number of choices when deciding on scenarios. The time cost of some scenarios is higher than others; i.e. climate change scenarios where both hydrodynamic and biogeochemical models are altered versus catchment loads where fewer inputs and parameters are altered. Biogeochemical models that include catchment loads are only useful in understanding biological processes, nutrient loading and consequently future management strategies, if they have been initially assessed to observations. It is extremely important to define catchment loads and flows accurately from the start of this process as well as comparing against biogeochemical observations. It is best if these observations are easily accessed and highly resolved rather than discrete samples. We will show examples from our highly resolved 3 dimensional model of different catchment scenarios in south east Queensland and Tasmania.
Modelling the effect of environmental change on estuarine health: challenges for model development and observing systems

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Estuaries support multiple ecosystem services vital to Australian society yet remain subject to continued deterioration despite our substantial management efforts. A particular concern within Australia is understanding how changes to hydrological regimes, due to both water diversions or climate variability, are contributing to increased stress and consequent decline in estuarine health. Such stresses include eutrophication pressures, coastal acid sulfate soils, hypoxia and anoxia, and loss of habitat and fish nurseries. Whilst models of estuaries are widespread, developing reliable models able to connect hydrological change to water quality and ecosystem health remains challenging. It is the aim of this presentation to document examples of modelling inland estuarine systems taken from across the nation, where coupled 3D finite volume biogeochemical models have been applied to assess the above management challenges. For many of the areas outlined above it is critical to model the interaction of estuaries with the terrestrial margin, however this is a capability currently lacking in our model systems. Further, the need for more rigorous process and system-scale validation of model predictions is outlined and opportunities for improved uncertainty assessment through model integration with isotope and sensor network data is discussed. Given the general trend for local management agencies to reduce the cost and scale of monitoring programs, it is argued that there is a need for more efficient approach to data collection and improved integration of models with observation systems for Australian estuaries.
A framework for Estimating Uncertainty of a Carbon Isotope-enabled Model for Validating Carbon Flux Pathways in an Estuary

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Estuaries link terrestrial systems with the coastal waters, receiving and processing large inputs of organic matter and nutrients. Despite a relatively small footprint, estuaries play a major role in global carbon cycling as locations where atmospheric, terrestrial, and marine carbon cycles interact (Cai, 2011). Modelling the ‘metabolism’ of an estuary is not an easy task due to the large spatiotemporal variability in water quality of the contributing environments and biogeochemical processes within the estuary, which would not be captured with routine monitoring programs. The accuracy of such model depends heavily on the accuracy of model structure, input variables, and model parameters.

In this study we report a framework that has been developed for application to estuaries that (a) aims to reduce model equifinality through application of a coupling hydrodynamic and “isotope-enabled” biogeochemical models, and (b) introduce an approach to undertake an uncertainty assessment on the biogeochemical parameters by using a 1-D isotope-enabled mixing model within a Markov chain Monte Carlo (MCMC) algorithm. The 1-D mixing model was developed using the fractional freshwater method (Reignier and P’Kane, 2004) that uses salt as an index of mixing of the water masses.

We use the framework to capture the carbon budget of the sub-tropical Caboolture Estuary in Queensland. A comprehensive water quality dataset collected by the Southeast Queensland Ecosystem Health Monitoring Program (SEQ-EHMP) and Centre for Coastal Biogeochemistry (CCB) of Southern Cross University were utilised. In this example, the simple 1-D isotope-enabled mixing model is utilised to reproduce the horizontal behaviour of dissolved inorganic and organic carbon, and 13C fractions of each, for which calibration data were measured over five snap-shots from Dec 2011 to May 2012. The posteriors resulted from MCM runs were ported into a 3-D hydrodynamic isotope-enabled carbon model to detail the carbon budget that captures the wide range of hydrology regimes experienced by the estuary from mid-January 2011 (post the 100-yr ARI event) to June 2012. The uncertainty assessment of the model output is presented.

References:

Building stable isotope fractions into a coupled hydrodynamic/biogeochemical model

Klaus D. Joehnk
CSIRO, Land and Water

Stable isotope analyses have been widely used in aquatic ecosystems in an effort to identify food web linkages and to assess the flow of energy from different sources through the various trophic levels. Stable isotope measurements have been combined with sophisticated process biogeochemical models in other domains (e.g., forest ecology) and this combination has shown its value in interpretation of ecological data. However, in modelling of aquatic systems, specifically using complex biogeochemical-hydrodynamic coupled ocean models, this approach is yet rare.

Here we present a stable isotope model built into an existing suite of hydrodynamic and biogeochemical models for aquatic systems (SHOC/EMS) taking into account internal processes like denitrification, nitrogen fixation, and sediment exchanges leading to isotope fractionation. Using C and N stable isotope signatures in such a modelling system provides an improved basis for interpreting isotopic data and lead to better estimates of flux rates in biogeochemical models, it allows to identify sources and sinks of carbon and nutrients in aquatic ecosystems, and helps to improve the analyses of energy flows through foodwebs.
eReefs biogeochemical model assessment – ocean colour and in situ observations.
Mark Baird, Karen Wild-Allen, Mathieu Mongin, Jenny Skerratt, Farhan Rizwi, Barbara Robson, Emlyn Jones, Thomas Schroeder etc.

The eReefs model captures at the scale of the Great Barrier Reef a range of biogeochemical processes including water column plankton dynamics, benthic productivity, coral calcification, carbon chemistry and oxygen dynamics. The model is able to provide near-real-time biogeochemical products and simulate future climate and catchment scenarios. Here we use ocean colour and in situ observations to assess the ability of the model to capture seasonal climatologies and event driven processes in a 2010-present hindcast. In particular, a spectrally-resolved optical model has been developed that produces quantities such as surface reflectance and phytoplankton absorption to allow direct comparison of model outputs with observations, without the need for a complex observational model. Finally, model-simulated true colour is introduced as a powerful model analysis and assessment tool. True colour provides an intuitive measure of multiple water quality indicators such as sediment plumes, bottom irradiance and phytoplankton blooms.
eReefs data assimilation – from the hydrodynamics to the biogeochemistry.
Emlyn Jones, Mike Herzfeld, Mathieu Mongin, Mark Baird and Peter Oke ... others

The goal of data assimilation (DA) is to reduce model error using the available observations. The application of DA algorithms in hydrodynamic models is maturing thanks to projects like Bluelink and eReefs Phase 1. In the eReefs project, the coastal hydrodynamic model RMS errors have been reduced by up 60% in the GBR Region by assimilating SST and in-situ temperatures. The next step is to apply DA to the biogeochemical (BGC) model. The core difference between DA in the hydrodynamics and the BGC, relates to where the dominant sources of error lie, the available observations and also the purpose of use for the model. In this presentation we will outline the method used in the hydrodynamics, and the key challenges of extending the DA work to the biogeochemistry. Preliminary results show that the assimilation of light (PAR), and remotely sensed Chl-a can constrain a subset of the key BGC parameters and unobserved state variables. By assimilating PAR, we show the importance modeling the observations, rather than trying to observe what the model predicts.
KEYNOTE 2

Exploring Alaska's Seas
Kate Hedstrom, Seth Danielson, Enrique Curchitser and Tom Weingartner

People at the Institute of Marine Science have spent decades piecing together an understanding of the physical and biological properties of the oceans surrounding Alaska. Some recent observational studies will be presented including logistics of remote sites. Due to the complexity of these systems and the expense of working in coastal Alaska, there is growing interest in using numerical models to complement the in situ observations. An overview of some model domains from the simple to the complex will be shown, along with some lessons learned along the way.
DEVELOPMENTS IN COASTAL MODELLING AND OBSERVATION

Coastal Modelling at the South Australian Research and Development Institute


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Abstract:

A summary of past present and future modelling at SARDI is given. Over the last 6 years, SARDI Oceanography has developed very good capability in using the ROMS suite of ocean models and add-on routines. Beginning in 2006, Carlos Teixeira developed the 5 km grid, prototype, Southern Australian Ocean Model (SAROM). SAROM extends from the mid-bight to the Victorian border. This work formed part of Carlos’ PhD thesis (accepted 2010) and he was able to show that Spencer Gulf has “weather” that is manifest by baroclinic instabilities during winter that in turn lead to high and low pressure systems or “Speddies”. SAROM has since been refined to a 2.5 km grid and found to compare favourably with data collected by SAIMOS. At the time of writing, it is being embedded in the global model OFAM so as to capture monthly to annual mean currents. A comparison of model output with SAIMOS data will be presented. An additional research project (de Oliveira) is to extend SAROM to the west coast of Tasmania so as to build a data assimilating model using the Kalman Filter technique. SAROM is also being modified so as to encompass the Great Australian Bight through the GAB Research Program. This model will be used to examine paths of connectivity and biophysical drivers of ecosystem function.

SAROM has also been used to close open boundaries of a fine 600 m resolution model of Spencer Gulf Model (SGM). The Gulf model has been coupled to other (validated) models including:

a) a larval transport model to optimize prawn harvest (LTRANS)
b) a wave model (SWAN)
c) a biogeochemical model (Fennel) to examine carrying capacity of finfish aquaculture in the Gulf.

Highlights of results obtained will be presented along with current and future plans.
Model optimization through development: the eReefs example.

Mike Herzfeld, Philip Gillibrand

Abstract: Applications of coastal hydrodynamic models often consider phenomena which are poorly represented in generic modelling packages, and ‘out-of-the-box’ application of these models often perform sub-optimally. If processes representation and numerical schemes in hydrodynamic models are tailored to local features, modeling skill can improve. This has been our experience from the application of models to numerous regions throughout Australia. We demonstrate this for our latest case study; eReefs, which aims to provide an information system for the Great Barrier Reef (GBR), spanning scales and disciplines. Specifically, for the hydrodynamic application, the areas subjected to development were:

- Improved open boundary conditions (OBCs) to reconcile the conflict between wind driven low frequency sea level changes in the lagoon, which requires a passive OBC, and large tidal oscillations which require an active OBC. The Dirichlet OBC method was enhanced to allow dual relaxation time-scales that are sequentially applied to each sea level component, resulting in high skill for tidal and low frequency sea level when compared to observation.
- The GBR has 22 river inputs, some of which are capable of delivering > 15000 m$^3$s$^{-1}$ and impacting much of the lagoon. The literature shows that freshwater input into regional models is not a trivial exercise, with models often generating a spectrum of unrealistic responses. We extend the Dirichlet OBC to account for in-estuary processes, which reduces the numerical plume response to the freshwater input and requires no $a$ priori parameterization.
- Two-way nesting is a means to seamlessly transition to high resolution, and we implement this through development of an automated relocatable model (RECOM), based on BlueLINK’s ROAM. Some current two-way approaches are overly complicated (e.g. AGRIF), and we show how, with minor modification, the existing infrastructure in models can be used to accommodate two-way nesting.
Observations and modelling in support of port activities for Darwin Harbour, Northern Territory, Australia

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Abstract

Marine observing systems deliver the information needed to support the development and operational management of ports and harbours. Most ports and harbours are multi-use regions supporting industry and recreational activities, and observing systems play an important role in both port operations, and in generating understanding of processes that impact the sustainable use and development of these areas (e.g. sediment transport, water quality). Observing systems that deliver data in near real time enhance the operational efficiency of ports by supporting the implementation of dynamic navigational and vessel traffic management systems. The observing systems can also provide boundary conditions for numerical models of hydrodynamics, sediment transport and water quality that are used to actively manage the harbour.

Darwin Harbour is a large macro tidal estuary in the Northern Territory of Australia. The harbour area covers 640 km² and has extensive mangroves, tidal flats and shoals. The city of Darwin, the rapidly expanding capital of the Northern Territory, spans the northern and eastern shores of the harbour, which been an important port since the 19th century and the last decade has seen a major acceleration in development of marine infrastructure. It is now becoming an important centre for the servicing of vessels supporting the oil and gas industry and the export of minerals. With the development has been the increase in the need for capital and maintenance dredging and the identification of spoil grounds. Design of major infrastructure has been done through the use of models and it is important to note that wave climate has been modelled and only scant observations have been made. With the establishment of the Integrated Marine Observation System (IMOS) National Reference Station (NRS) network information for the harbour, information on currents, tides, waves, wind and some water quality variables (chl-a and turbidity) are now available in near real time.

An unstructured mesh model that was previously developed for evaluating marine infrastructure has been refined and is now using the IMOS data to input time series boundary conditions. The model is being used to evaluate the impacts of the rapid industrialisation and urbanisation of the eastern side of the harbour. This presentation will present the IMOS data being collected and used as boundary conditions and how the model has been improved and how it is being used as a design tool for infrastructure developments that interact with the harbour.
The world is becoming increasingly urbanized, and many of the world’s major cities are located on estuaries and coasts. This poses significant challenges to the health, use and management of urban marine and estuarine environments. The World Harbor Project (WHP) is a Sydney Institute of Marine Science (SIMS) initiative aimed to facilitate, link and enhance programs of research and management across major urban harbours of the world, in order to help build resilience globally for these iconic urban waterways and the cities that surround them. The Sino-Australian Research Centre for Coastal Management (SARCCM) is both a part of this initiative and an independent research centre at UNSW and is taking the lead to facilitate Chinese partnerships in the WHP. This talk concerns topics from both observation and modelling of estuarine dynamics and sediment erosion, transport and siltation in the ports, estuaries and other coastal environments. We will present several case studies of the estuarine and sediment dynamics in the estuaries such as Shanghai Port, China, Darwin Harbour and Sydney Harbour, Australia, where urbanization and human activities have placed these ecosystems under intense multiple stressors.
Parameterization of Vertical Tidal Mixing in ROMS

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To improve forecasting in coastal waters, high-resolution coastal simulations are being implemented with the Regional Ocean Modelling System (ROMS). Vertical mixing is of key interest in these simulations due to their influences on cross-shelf transports, dense water flows, nutrient replenishment, formation of tidal fronts, and other processes. Much of the vertical mixing is attributed to internal waves and tides. Tides have been estimated to contribute about 1 TW of energy to mixing in the ocean with the mixing energy originating from interactions of the baroclinic tides with topography generating baroclinic tides. Estimates of tidal mixing in the model are only as good as the performance of the mixing parameterization. ROMS has a wide variety of mixing parameterizations. In this study, the performances of ten different vertical mixing schemes were evaluated against observational data in order to determine which one(s) performs best.

In order to evaluate vertical tidal mixing in the current version ROMS, the combined tides for four constituents, $M_2$, $S_2$, $K_1$, and $O_1$, were modeled over Fieberling Guyot using different vertical mixing parameterizations. Although estimates for the major axes of the tidal ellipses were similar between all vertical mixing schemes, the temperature and diffusivity fields varied widely between parameterizations. Most of the parameterizations generated spectra consistent with the Garrett-Munk observational spectra for baroclinic tides. In the velocity fields, the greatest differences between the different parameterizations occurred at high frequencies. There was a strong correlation between schemes with high diffusivities and less energy in the velocities at high frequencies. Several parameterizations could be eliminated based on comparison of the vertical diffusivity estimates with observations, resulting in a few top performers. Of these best performers, Nakanishi-Niino stood out, as it was the only parameterization that responded to the spring-neap tidal cycle. Additionally, a new mixing parameterization was developed to handle mixing in the mid-water column, which is not addressed well by the present boundary layer based mixing parameterizations.
Third Generation Wave Models Based on Observational Physics

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Major update of the physics of the third generation models will be presented. 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.
Two moorings fitted with wave measuring ADCPs were deployed in Spencer Gulf during 2010-2011. One mooring was placed near the mouth of the gulf and exposed to long period ocean swell and the other one was placed near the top of the gulf in shallower, sheltered water where the waves tend to be dominated by winds. It has been suggested that while the mooring observations at the mouth of the gulf are well simulated using WW3 swell forcing on the southern boundaries, the wave characteristics at the upper gulf site may be more influenced by rapidly fluctuating coastal winds that are not resolved in daily averaged atmospheric data. Directional spectra, peak wave heights and periods will be compared with the results of model runs using the WW3 swell forcing and either daily or 3-hourly wind forcing to investigate the sensitivity of the model results to the temporal resolution of the wind forcing.
Coastal inundation modelling in New Zealand
Scott A. Stephens, Richard M. Gorman, Rob G. Bell

Like much of the world, New Zealand’s major cities have developed around coastal access ways and ports, with 75% of the population living within 10 km of the coast and 4% highly-exposed living below 3 m above mean high water in 2006. Thus there is high exposure to coastal hazards in the form of storm-tides, coastal erosion, damaging waves and tsunami, with losses escalating each year through storm-related coastal inundation. Rising sea-levels are increasing the frequency of exposure to storm-tides and will continue to do so. The New Zealand coastal policy statement requires coastal hazards and climate change be assessed for “at least 100 years”, thus New Zealand’s territorial and local authorities face the challenge of planning now to manage both present-day and future inundation risk, creating high demand for robust coastal hazard information. Tide is the dominant source of sea-level variability and NIWA’s web-based red-alert tide calendar has proved invaluable for emergency managers, with a majority of the most severe inundation events occurring during perigean spring-tides (aka “king tides”).

We outline the approaches being taken to model and map inundation in New Zealand, demonstrating novel techniques to combine short-duration datasets (in joint-probability space) and modelling through several case studies. New Zealand has sparse data records and the recently completed Waves And Storm-surge Prediction (WASP) hindcast is proving invaluable, but requires careful comparison with gauges. Joint-probability techniques are being used to maximise the usefulness of short sea-level records for determining extreme storm-tide elevations, and joint probability analyses of storm-tides and waves allow the likelihood of resulting total sea-level elevation to be robustly estimated. An interactive Coastal Calculator holds modelling output, allows interactive and “future-proofed” data extraction, and is proving popular with end users. NIWA’s RiskScape tool is facilitating coastal risk profiling, combining hazard exposure with demographic and built-environment data. Currently a national coastal risk profile is being developed to provide a national overview of the risk coastal margins face in New Zealand as sea-level rise increases.
Coastal managers, scientists and engineers have long sought a robust and practical solution for the prediction of shoreline changes along sandy coastlines, over time-scales spanning several years to decades. The existing models, which at the present time come closest to satisfying these requirements, generally include a considerable level of empiricism and may be termed top-down or data-driven models. A fully process-based description of shoreline adjustment to varying and changing wave forcing is currently beyond our present physical understanding of all the complex processes involved.

Recently there have been several advances both in Australia and internationally, in the field of long-term (multiple years) but relatively high-resolution (days to weeks) shoreline prediction based on more behaviour-orientated approaches. ShoreFor (Shoreline Forecasting) is one such model, that has been formulated to primarily encapsulate shoreline displacement forced by wave-driven cross-shore sediment transport. Hysteresis effects have shown to be important and are central in the model, whereby present shoreline change is influenced by past as well as present hydrodynamic and morphological conditions. Time-stepping in the evolution of the shoreline is typically every hour, with the potential magnitude of shoreline change increasing with incident wave power and the degree of morphodynamic disequilibrium.

A particular challenge to the further development of this type of shoreline modelling approach is the requirement for extensive observational data, currently needed for site-specific model calibration. The reality is that suitable, historical shoreline datasets are rare world-wide.

The objectives of the proposed ACOMO2014 presentation is to outline the need for and approaches to longer-term shoreline modelling, and then present a recent and detailed analysis of the type and extent of historical shoreline monitoring data that is required for successful model calibration. The example application of the ShoreFor model to a range of diverse sites in Australia, the USA and Europe will be used to illustrate. To circumvent the challenge that historical shoreline monitoring datasets are generally absent, a new area of investigation will be presented that uses an alternative parametric approach to the calibration of model free parameters, based on more readily available wave records and site-specific sedimentological information. Current and future modelling data needs will be clarified and discussed, within the context of the present and future IMOS program.
In recent years, a series of performance assessments of several wave models administered by various government and academic institutions within Australia has been completed by the Water Research Laboratory. This presentation compares the performance of the HI-WAM wave model (developed by the Australian Bureau of Meteorology (BoM), SWAN and WW3 wave models for the state of NSW (developed by the NSW Office of Environment and Heritage) as well as SWAN and WW3 wave models in the Marine Virtual Laboratory (MARVL) with measured data.

BoM predicted coastal and offshore wave conditions using HI-WAM for the period 1997 to 2008. This model was a high resolution version of the ocean wave prediction model WAM (WAve Model). HI-WAM was the most detailed (and computationally intensive) wave model of the Australian coastline developed by BoM. Subsequent collaboration completed the first national assessment of the performance of the HI-WAM wave model by benchmarking the output of HI-WAM against long term recorded wave measurements from 18 locations around Australia (Coghlan, 2010).

Earlier studies of offshore wave buoys in the NSW coastal wave monitoring network had observed that wave heights measured at Batemans Bay were systematically lower than elsewhere on the East Australian coast. Although the performance of the buoy had been questioned, the wave climate in the vicinity of Batemans Bay was analysed based on the output from HI-WAM (Coghlan et al., 2010). Agreement between modelling and observations confirmed that the mean wave climate in the vicinity of Batemans Bay is less energetic than along the rest of the NSW coast.

UNSW Australia is presently developing and testing the SWAN and WW3 wave models within the Marine Virtual Laboratory (MARVL). MARVL is being established by the University of Tasmania (UTas) as part of the National eResearch Collaboration Tools and Resources (NeCTAR) Project. Progress to date is summarised in Davey et al. (2013) and Coghlan et al., 2014. The MARVL wave models will be compared against output from existing NSW OEH wave models (Cardno, 2011) at two locations. At Narrabeen Beach the performance of each wave model will be assessed against measurements from three wave buoys in deep, intermediate and shallow water depths. At Coffs Harbour, the performance of the wave models will be compared with measurements from a deep water directional wave buoy and combined measurements from two high frequency (HF) radar stations.

References
'Coastal Altimetry' is code for 'squeezing even more out of altimetry than was ever thought possible'. Why try? Well, if you want to do a 20-year shelf-scale ocean re-analysis, coastal altimetry is one of the very few data sets that might be useful for assimilation or validation. What does it offer? Sea-level measurements along the ground-tracks of the various altimeters that have flown since 1992. The pros: 1) the 22-year extent of the data set, 2) global coverage, 3) locally synoptic data – i.e. a long line of sea level measurements, so you get gradient information as well as height. The cons: 1) infrequent – observations are snapshots, 10 days apart at any one point for NASA-CNES missions or 30 days apart for ESA missions, 2) noisy – this is where all the work is presently focussed, and what will be the subject of the presentation. Raw altimetry data is very noisy and subject to numerous sources of interference. For 20 years now, we have used time-averages of the data at <0.2Hz frequency (>40km along-track) and ‘standard’ procedures for discarding ‘bad’ estimates - which included all data over the continental shelf. The ‘coastal altimetry’ proposition is that cleverer processing of the raw data will yield cleaner averages at higher frequency, e.g. 1-0.5Hz (6-3km along-track) – which are useful seaward of ~5km offshore.
A comparison of SARAL/Altika coastal altimetry and in situ observations across Australasia

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The lack of high resolution and quality observations for coastal zones has created a significant gap not only in our ability to monitor and understand coastal inundation, erosion and sea level changes but also to provide robust constraints and validation for climate model simulations and regional sea level projections. This is particularly an issue for small nations, such as the South Pacific islands, where costly in situ instruments (e.g., moorings, radar arrays, etc) will likely never be deployed at a sufficient scale. Coastal satellite altimetry is therefore an invaluable resource for regions like Australasia. Furthermore, Australia’s recent investment into coastal monitoring provides a useful resource to validate altimetry data against for the region.

Launched in February 2013, the SARAL/Altika (altimetry in the Ka band) mission promises to provide an unprecedented level of ocean sea surface height (SSH) data as close as 10km from the coast. We examine selective Altika passes over the Maritime Continent (e.g., Langkawi Island, Malaysia), South Pacific islands (e.g., Christmas Island, Kiribati) and the Australian eastern seaboard (Fort Denison, Sydney and Coffs Harbour) and validate against local tide gauge stations. Preliminary results with the limited number of passes currently available suggest that several tide gauge stations in the South Pacific (Tuvalu and Fiji) do not correlate well with the altimeter. In contrast, the Maritime Continent and Australian Eastern Seaboard tide gauges show a good correlation and low RMS error against the altimeter.

Other in situ data, such as moorings and HF radar, available through the IMOS portal for the eastern coastal waters of Australia are also examined against altimeter derived surface velocities. Additionally SARAL and Jason 2 cross-over points are used to examine the altimeter waveforms to investigate the impact of land and rainfall as well as the options for waveform retracking to optimize the altimetry data near the coast.
Following the determination that the likely splash point for the missing Malaysian Airlines Flight MH370 was in the Indian Ocean, RPS APASA supported AMSA in their operational search area planning with daily drift forecasting. A variety of objects were simulated 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 BLUElink, HYCOM (from NCEP), the US Navy HYCOM model and the Bureau of Meteorology ACCESS-R products fed via the RPS ASA Environmental Data Server (EDS).

Each day, or sometimes several times per day, three separate forecasts were prepared and then combined to produce maps of spatial consensus based on the number of model hits on a 10 km grid, as well as the number of trajectory particles or hit density in those areas. These results were part of the information kit used by AMSA to formulate the search areas each day. Comparison to a significant set of SLDMB data during the event allowed comparison of the performance of the various forecasts over different time-scales, highlighting the value in the consensus approach. Predictions were also compared to, and matched very well with, those made by the US Coast Guard through their SAROPS system.
MODELING TOOLKITS

Australia's 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 include determining the time and space scales and processes of the required simulation; obtaining data for the initial set up and for input during the simulation time; obtaining observation data for validation or data assimilation; implementing scripts to run the simulation(s); and running utilities or custom-built software to extract results. 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 new development in modelling frameworks for researchers in Australia. MARVL uses the TRIKE framework, a java-based control system developed by CSIRO that allows a non-specialist user to configure and run a model, to automate many of the modelling 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, and is being considered as an educational aid in teaching.

In MARVL we have developed a web-based open source application which provides a number of model choices and provides search and recovery of relevant observations, allowing researchers to:

1. efficiently configure a range of different community ocean and wave models for any region, for any historical time period, with model specifications of their choice, through a user-friendly web application,
2. access data sets to force a model and nest a model into,
3. discover and assemble ocean observations from the Australian Ocean Data Network (AODN, http://portal.aodn.org.au/webportal/) in a format that is suitable for model evaluation or data assimilation, and
4. Run the assembled configuration in a cloud computing environment, or download the assembled configuration and packaged data to run on any other system of the user's choice.

MARVL has been applied in a number of case studies around Australia ranging in scale from locally confined estuaries to the Tasman Sea between Australia and New Zealand. The underlying infrastructure will be described and examples of its use will be given.
Quantification and attribution of ecosystem change in the Southern Ocean is complex, costly, and often confusing. This is despite significant, recent advances in our understanding of ecosystem dynamics, of species’ responses to environmental drivers, and of the spatial and temporal variability of Antarctic marine and sea ice ecosystems. But the Southern Ocean is huge, and the pot of money available to study it – either directly or remotely – is getting smaller. The really big unknowns for the ecosystems research community and for managers are: How do we reliably detect change on large scales? Are we likely to encounter big surprises in terms of future changes in Southern Ocean ecosystems? And how do we design robust management strategies for marine living resources in the face of climate change? We present a summary of the ecosystem modelling and assessment toolkit that has been developed at the ACE CRC, AAD and CSIRO and describe our strategy for expanding and applying this toolkit over the next five years. The outcomes of this work will be an assessment of past, current and future ecosystem states in the Indian Sector of the Southern Ocean, and the design of a cost-effective observing system to detect and attribute ecosystem change.
Data Management Update for the U.S Integrated Ocean Observing System (IOOS)

Eoin Howlett (RPS ASA), Kelly Knee (RPS ASA), Derrick Snowden (NOAA IOOS)

The U.S Integrated Ocean Observing System (IOOS) consists of 11 Regional Associations (RA’s) that manage a wide range of ocean observing assets and data feeds, including in-situ buoys, drifters, gliders, radar, satellite data, and numerical models. The Data Management and Communications (DMAC) subsystem of IOOS provides the procedures, protocols and technology solutions to allow integration of these disparate data feeds from the regional providers. The DMAC subsystem includes management of HF Radar data, drifters, gliders, in-situ buoys, satellite data, and a variety of model data. As IOOS has matured over the last decade, this paper provides a discussion on the evolution of DMAC within IOOS, the status of the current system, and the way forward as the RA’s transition to operational ocean observing.
The Centre for Australian Weather and Climate Research (CAWCR), a partnership between CSIRO and the Bureau of Meteorology, with our infrastructure and science partners at the ANU National Computational Infrastructure (NCI) facility and the Centre of Excellence in Climate System Science are establishing essential services in support of a fully coupled earth system model to study climate and weather phenomenon, impacts, and prediction using the Australian Community Climate and Earth System Simulator (ACCESS).

These research services, supporting workflows and data services within the Climate and Weather Science virtual Laboratory (CWSLab) at NCI provide scientists with access to the ACCESS simulation environment for coupled and uncoupled modelling experiments, climate model analysis workflows, Earth System Grid Federation services, and a vast collection of scientific data at the NCI RDSI node. This data storage node consist of the Bureau’s weather and climate modelling data and the international reanalysis and climate data collections such as the CMIP5 experiments. NCI data services will enable local HPC access and remote data access to the vast collections of meteorological data for ocean and marine applications and analysis using community open source software and tools, protocols and services.
For the first time biogeochemical (BGC) models are included in the Coupled Model Intercomparison Project (CMIP) process. From the CMIP5 5th round (CMIP5) archive 16 BGC models have been assessed in terms of their representation of monthly means of surface Chlorophyll-a, temperature, nitrate, phosphate and silicate for the NZ EEZ for the present day (taken as 1976-2005 for the models). The assessment is based on a model ranking of area-averaged measures of root-mean-square error and bias compared to annual cycles from the observational data sets for a set of representative sub-regions around the NZ EEZ. These sub-regions cover the nutrient limited oligotrophic waters in sub-tropical waters to the north of the EEZ, to the iron limited sub-antarctic waters to the south. In between lie the productive regions associated with the Chatham Rise and the Tasman Sea. This set of regimes provides a challenge to the range of physics and biogeochemistry represented by the 16 BGC models.

The analysis shows that a best-fit ensemble for the present day can be obtained from the model ranking. This ranking can then be used in consideration of likely future changes to the biogeochemical fields under the representative concentration pathways (rcp) 4.5 and 8.5. The ranking can also help in assessing fields like integrated primary production and dissolved iron concentration, for example, that are presently difficult to constrain and validate.

This assessment and ranking process can also be applied to the Southern Ocean waters and the Ross Sea to the south of NZ. While the observational data sets become more constrained further south, and the cryospheric processes modify the biogeochemical and physical regimes, nevertheless it is possible to ask similar ranking questions of the models as a further test of their ability to resolve processes in such waters.

In terms of future planning, the most complex step is to take the relatively spatially coarse BGC model solutions and produce downscaled solutions at the coastal and embayment scales of importance to productive capacity. While this is more routinely down for the atmosphere, it remains a challenge for the ocean, and even more so for the ocean with biogeochemistry. It is hoped, however, that on-going analysis of the CMIP5 models will point the way toward generation of consistent model formulations and boundary conditions that can then produce the high-resolution present day and future scenario solutions of interest.
A high resolution re-analysis for the East Australian Current

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The East Australian Current is a dynamically challenging region to measure, model and predict. In a first step toward improving our circulation models and our dynamical understanding of the circulation, we are developing a high resolution re-analysis 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. The time period from April 2012 - September 2013 is chosen to coincide with the maximum number of concomitant IMOS data streams. These include velocity and hydrographic observations from the EAC transport array, Coffs Harbour HF radar, shelf and sea gliders, and the SE Qld and NSW mooring arrays. We exploit the ROMS (Regional Ocean Modeling System) 4D-Var assimilation tools to combine all of the available satellite, IMOS, and ARGO data streams with the model fields providing a reanalysis of the ocean state at 6km resolution over this period. This reanalysis will provide our best estimate of the EAC/shelf exchange along the eastern coast to assist with a number of local studies. In addition, we will be able to determine the dynamical variability of the EAC, its transport, and how the IMOS data help to constrain our understanding.
Predicting extreme water levels around Australia
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Abstract

Accurate estimates of extreme water levels are critical for coastal planning and emergency planning and response. The potential impacts of extreme water level events on our coasts are increasing as populations grow and sea levels rise. To better prepare for the future, coastal engineers and managers require estimates of exceedance probabilities for extreme water levels. Coastal regions experience sea level changes which vary at timescales of hours, days, weeks, months, annually governed by the astronomical tides, meteorological conditions, seismic events, local bathymetry etc. Meteorological conditions contribute to extreme events through the generation of (1) storm surges both locally and remotely through continental shelf waves; (2) through wave set-up by generation of surface gravity waves; and, (3) meteorological-tsunamis generated during thunderstorm activity. In a recent study, we estimated the present day probabilities of extreme water levels uniformly around the entire coastline of Australia. Tides and storm surges generated by extra-tropical storms were included by creating a 61-year (1949-2009) hindcast of water levels using a high resolution depth averaged hydrodynamic model driven with meteorological data from a global reanalysis. Tropical cyclone-induced surges were included through numerical modelling of a database of synthetic tropical cyclones equivalent to 10,000 years of cyclone activity around Australia. Predicted 61 year water level hindcast data were analysed using extreme value theory to construct return period curves for both the water level hindcast and the synthetic tropical cyclone modelling. These return period curves were then combined by taking the highest return water level at each return period. We have now started to extend this study by the use of OzROMS model grid and ROMS to include the effects of continental shelf waves and tropical to extra-tropical transitions. Model studies for predicting meteo-tsunamis will also be presented.
Spatial patterns of warming off Western Australia during the 2011 Ningaloo Niño: quantifying impacts of remote and local forcing

Jessica Benthuysen (AIMS/UTas), Ming Feng (CSIRO), Liejun Zhong (CSIRO)

In austral summer 2011, an unprecedented Ningaloo Niño event occurred with sea surface temperature anomalies reaching 5°C off the west coast of Australia, with significant impacts on marine ecosystems. In this study, a high resolution (~2 km) hydrodynamic model (Regional Ocean Modelling System) is used to analyse the variations in the near-surface temperature from 2009 through mid-2011. The model is evaluated against Integrated Marine Observing System (IMOS) mooring data at the Two Rocks transect, demonstrating that the model achieves the timing of the local Leeuwin Current intensification and the temperature peak.

Model results indicate that the peak temperatures in the broad mid-West coast of Australia during the marine heat wave are predominantly due to poleward advection of warmer, tropical water (= 2/3 contribution). However, positive air-sea heat flux into the ocean also contributes (= 1/3 contribution) to the rise in temperature. The anomalous advection of warm water is caused by changes in the poleward flowing Leeuwin Current due to both local and remote wind forcing.

In early 2011, the Leeuwin Current intensified owing to remote forcing associated with the 2010-2011 La Niña. In addition, the southerly winds off the west coast of Australia weakened, allowing the Leeuwin Current to further intensify in speed at the peak of the event. Concurrently, the inshore, equatorward Capes Current was suppressed and reversed direction. The poleward flow over the shelf contributed to near-shore warming, in contrast to cooling by equatorward advection from the Capes Current in previous years. In addition to capturing the warming event, model results indicate notable freshwater anomalies along the coast, a topic for further investigation. Long-term thermal structure monitoring need to be continued, and it is desirable to have air-flux measurements off the coast.
The hydrodynamic models developed and applied as part of the eReefs project have horizontal grid resolutions approximately 4 km and 1km. At these resolutions, many of the features of the reef matrix and bathymetry associated with the coral reef, together with their influence on the momentum balances and the broader scale circulation, are unresolved by the model grids. The choice of the spatial resolution of the grid in the area where you seek the numerical solution of a phenomenon is typically guided by the assumption that higher resolutions provide better approximations; however, this choice is often limited by practical issues such as computational efficiency, data availability, etc (Brand, 1984). The topographic complexity and vast range of relevant length scales on the Great Barrier Reef, and the interactions of processes at different scales necessitated an investigation into appropriate schemes for inclusion of sub-grid features.

This parameterization study was designed to identify and assess existing methods and evaluate an alternate method for parameterization of coral reefs in the context of 3D numerical models. We performed numerical experiments with three horizontal resolutions for the numerical grid. The numerical simulation with highest resolution was used as reference, while simulations using grids with lower spatial resolution were used with existing and newly developed methods for coral reefs parameterization. The new approach is based on reef porosity (permeability) and it is applied on the vertical axis.

Both quantitative analyses (kinetic energy) and qualitative analysis (vertical velocity and vorticity) show that the standard seabed roughness acting together with the vertical parameterization of coral reefs through porous plate is able to achieve the proposed objectives: to maintain and percolate comparable kinetic energy equivalent to the reference model while maintaining a vertical and spatial structure of water circulation. In summary, an approach based on a porous plate seems to be an appropriate parameterization method for coral reef to be used in numerical modelling.
Current predictions for the Rottnest channel swim
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Abstract

Rottnest Channel Swim is a 19.7km open water swim from Cottesloe Beach to Rottnest Island, held in February of each year and is one of the largest open water swim competitions in the world with 2300 participants in 2014. As the swim is held during the summer months the resulting prevailing winds usually result in a south to north flow along the continental shelf with stronger currents occurring close to Rottnest Island as the flow has to go around the Island. This also the time when the swimmers are coming to the end of the race and are generally tired. Previous participants have said: “some years we’ve been swept to the north so that as you get close to Rottnest you spend as much time swimming south as you are west at exactly the time you are feeling the worst”. The uncertainty in the current direction has skippers setting GPS coordinates km by km on a straight line, a southerly course and a northerly route as contingencies to gain benefit from the current on the day. Some strategic swimmers have shown interest in the IMOS HF Radar from the WERA system in previous so this year WAIMOS members at UWA used real-time predictions of surface currents with careful testing and observations over several months in order to release ocean current predictions before the Rottnest Swim.
Simulating the dynamics of continental shelf waves generated by tropical cyclones in Western Australia

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Abstract

The energy input by cyclonic winds and the resulting water circulation patterns generate continental shelf waves which propagate over large distances. Generation and propagation characteristics of these continental shelf waves generated through tropical cyclones (TC) in Western Australia are investigated using the Regional Ocean Modelling System (ROMS). An idealised model of the North West Shelf with approximately 4 km spatial resolution and 30 vertical sigma layers was forced by idealised tropical cyclones that varied in speed, direction (parallel, perpendicular or at 45° to the coastline) and intensity. Realistic tropical cyclone simulations using an Oz-ROMS were performed for Tropical Cyclones Bianca and Carlos (2011) and compared to measured tide gauge data along the West Australian coastline.

Results from the idealised numerical model indicate that a cyclone’s path, speed and intensity influence the continental shelf wave generation and propagation. Cyclones travelling parallel to the coast near the continental shelf break generated forced waves with the maximum amplitude. An increase in forward speed by up to 10 ms\(^{-1}\) produced a corresponding increase in continental shelf wave height. Higher wave heights were also correlated with greater cyclone intensity.

Tropical cyclones travelling parallel to the coast for a one-quarter of the model domain generated continental shelf waves with similar properties to those associated with both perpendicular and 45° cyclones that made landfall. Cyclones following these paths generated continental shelf waves that had a lower wave height. An increase in cyclone forward speed decreased the wave height. The propagation speed of these waves scale to the Coriolis parameter and the continental shelf width. These characteristics resembled a continental shelf wave travelling as a free wave.

Propagation characteristics of continental shelf waves generated by TC Bianca and TC Carlos using the OzROMS model domain indicated the cyclone path and continental shelf bathymetry influenced continental shelf wave height and propagation speed. Continental shelf waves were generated for both TC Bianca and TC Carlos around Port Hedland which subsequently travelled southwards. The estimated average travel speed from lag correlation analysis was 5.8 ms\(^{-1}\). The propagation speeds for these two waves decreased between Exmouth and Carnarvon where the continental shelf width decreases rapidly. The path of TC Bianca was generally parallel to the Western Australian coastline and travelled southwards to Fremantle (by which time the TC became a low pressure system), resulted in an increase in the wave height through resonance. This wave continued further east to Thevenard (South Australia). The curved coastline of the southwest Capes Region resulted in wave scattering. TC Carlos, however, continued offshore from Exmouth resulting in a continental shelf wave with insufficient energy to propagate around the Capes Region. Results from this study demonstrate the influence of cyclone properties on the generation of continental shelf waves along the West Australian coastline.
Abstract

The hydrodynamic processes along south-west Australian (SWWA) shelf region are of great importance for future coastal planning and management, energy extraction as well as for navigational purposes. The WA shelf current regime is dominated by the Leeuwin Current (LC), a strong and narrow poleward flowing surface current. A meso-scale eddy field is a feature of the LC system. The WA coastline is exposed to both, large swells, mostly originating from storms in the Southern Ocean, as well as locally generated wind waves. Ocean currents and associated meso-scale eddies are known to alter wave conditions significantly; however, there are no studies that quantify the influence of the large-scale current systems on the shelf and coastal wave regime. The influence of the LC on surface gravity waves on the WA shelf was examined using the three dimensional, free surface, terrain-following hydrodynamic model ROMS (Regional Ocean Modelling System) coupled to the third generation wave model SWAN (Simulating WAves Nearshore). The models were coupled using the model coupling toolbox (MCT). The coupled model was then compared to a SWAN wave model of the same domain. A significant influence of the LC, and other surface currents on the WA shelf wave climate can be seen when comparing the two models. Changes in wave height, period and direction of the incoming waves in areas where current velocities were strongest could be observed.
Tropical cyclone stirring on the inner continental shelf off north-west Australia observed through Ocean gliders

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Abstract

Acquisition of surface and sub-surface oceanographic data under extreme weather conditions present many challenges but the use of ocean gliders provide a platform from which water column impacts may be documented. Tropical Cyclone Rusty, a severe category 4 cyclone, made landfall on Western Australia’s Pilbara coast on 27 February 2013 and its impact on the inner continental shelf (depth ~ 40m) water column was recorded by two Slocum gliders. The path of TC Rusty bisected the paths of the two gliders. One of the gliders were located in a region where the mean onshore winds were over 90 km/hr which resulted in a rapid increase in the depth mean currents to > 0.8 m/s, a doubling of the background tidal currents. The water column was well mixed in density throughout the period of observation. High sediment resuspension was observed during and after the passage of the cyclone extending throughout the water column. The measured concentrations (backscatter at 700 nm) exceeded the range of the WETlabs eco-puck sensor for a period of 6 days and returned to pre-cyclone conditions after 8 days. The re-suspension event had a strong influence on the light climate by reducing the depth of light penetration from > 40m before the cyclone to < 10 m during the cyclone. The glider data also indicated that TC Rusty stirring resulted in an increase in the chlorophyll concentrations which formed a massive offshore plume which extended over a region in excess of 600 km².
Real-Time Marine Observing Systems: Challenges, Benefits and Opportunities in Australia’s Northern Tropical Seas

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Abstract

The wellbeing and prosperity of Australia is strongly linked to the ocean, with most of the population living in highly urbanised centres along a narrow coastal strip. Infrastructure development and population growth along the coast has already, and will continue to place growing pressure on the marine environment and its natural resources, requiring a knowledge-based approach to the management of risks to these assets. Decision making around sea level rise, storms and extreme events, shipping and maritime operations, fisheries and aquaculture, and marine park zoning must be informed by an understanding of coastal ocean processes, their drivers, and ecosystem responses. This requires both coastal and open ocean observations.

Since 2007, these observations have been provided by the Integrated Marine Observing System (IMOS). 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, covering physical, chemical and biological variables. The near real time data delivered by IMOS comprises 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 ocean observing systems in the coastal and the remote outer continental shelf, operated by the Queensland and Northern Australian moorings & National Reference Station sub-facilities of IMOS. These examples demonstrate the benefits of having a national collaborative approach to marine observing with a clear focus on open access to data. Increasingly the data uptake by modelling has matured through eReefs modelling of the Great Barrier Reef and other higher resolution efforts such as in Darwin Harbour. 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.
The Australian Integrated Marine Observing System (IMOS, www.imos.org.au) is a research infrastructure project to establish an enduring marine observing system for Australian oceanic waters and shelf seas. Marine data and information are the main products and data management is therefore a central element to the project’s success. Gaining access to large quantities of observational data can become tiresome if the search and download process results in many individual files or inappropriate formats. Working with scientists through Use Cases has guided IMOS infrastructure development to improve the efficiency of data access (http://imos.aodn.org.au/imos123/). These developments include implementing controlled vocabularies and web services for data delivery and greater international connectivity. The new data access protocols are also benefitting the wider Australian marine community served by the Australian Ocean Data Network. The Use Case descriptions illustrate how infrastructure decisions are made, and how these improve the use of data by physical and biological oceanographers.
The Australian Coastal Ocean Radar Network (ACORN) is a Facility of the Australian Integrated Marine Observing System (IMOS) and comprises 12 HF radar stations operated in pairs at 6 sites located around the west, south and east Australian coast. Four of these sites are WERA1 phased-array radar systems and two are Seasonde2 direction finding systems. The primary application for these radars is to study the dynamics of the major current systems, the Leeuwin along the west coast, the South Australia Current along the south coast and the East Australian Current (EAC) along the east coast. In the latter case also of interest is the interaction of the EAC with the southern Great Barrier Reef and its lagoons. This paper focusses on the wave measurements that can also be obtained from the WERA systems. Wave measurements can also be made with the SeaSonde radars but these are not currently available. The measurements are obtained through an inversion algorithm which takes as input the power (Doppler) spectrum of the radar backscatter signals from both radars in the pair and provides as output the directional wavenumber (or frequency) spectrum together with parameters derived from the spectrum such as significant waveheight, mean and peak period and direction. These measurements are provided at all locations in the radar system field of view that meet specified signal-to-noise criteria. The potential use of these radar systems for wave measurement is of interest to organisations responsible for monitoring coastal processes such as beach erosion and sediment transport, obtaining design statistics and operational support for coastal engineering and construction projects, monitoring severe weather conditions which could lead to storm surge and coastal flooding and for research leading to wave model development and validation.

There have been a number of previous studies of wave measurements from WERA4,5, and other radar systems6,7, using the same methodology which have produced good results. However the application to the Australian data is proving to be more problematic due to often high radio interference, 50Hz mains signals, antenna array issues leading to high sidelobes and the radar configurations themselves in term of both siting, data transmission limitations and operating frequency. Nonetheless wave measurements have been obtained from the ACORN systems and these will be discussed. Where comparisons with in situ data have been possible the accuracy of the radar wave data will be assessed.

5 Wyatt, L.R., Green J.J. and Middleditch A., 2011. HF radar data quality requirements for wave measurement, Coastal Engineering, 58, 327-336.
The continued exploitation of oceanic, coastal, and embayment waters around New Zealand (NZ) has generated much interest in the production of integrated predictions of likely impacts in such waters. The complex processes associated with dispersal and transport of biota, oil, sediment, and other tracers notwithstanding, the generation of accurate and timely hydrodynamic fields at the scales (spatial and temporal) of interest remain challenging enough. Further, the topographic spatial complexity of much of the NZ coastal zone poses a numerical challenge to a model like ROMS built around a Cartesian spatial decomposition.

Here we describe some recent ROMS applications in the NZ waters based on a series of nested solutions to enable the downscaling from the open ocean scales into the shelf break and the coastal shelf, and finally into coastal embayments and sounds. Although our nested solutions do not yet incorporate data assimilation, the largest scale boundary conditions are typically from assimilated products (e.g. HYCOM), while surface forcing fields (such as wind) used to drive the inner ROMS models are derived from analyses generated by a NIWA operational atmospheric model suite. With the addition of tides, these inner ROMS models integrate together the forcing fields of relevance in a time stamped fashion. In particular, recent developments with sediment and sediment dispersal and transport will highlight the continued progression of ROMS for such applications.

While we continue to explore other models perhaps better suited to coastal topography in terms of spatial discretisation (e.g. Delft3D, Gerris, RiCOM, SELFIE etc), the efficiency with which ROMS can be run on a parallel architecture means it remains a competitive choice for integrating simulation periods of many months and longer. Furthermore, the nesting capability of ROMS continues to develop (in particular see the detail and discussion at: https://www.myroms.org/wiki/index.php/Nested_Grids ), thereby retaining the relative numerical efficiency of ROMS while at the same time recognising the importance of the horizontal spatial grid structure in the coastal zone. The relative parallel efficiency also means we are able to maintain relatively high vertical resolution, allowing resolution of the competing boundaries in the coastal zone. How far the present ROMS physics (particularly the hydrostatic assumption) can be pushed at coastal scales remains to be seen; nevertheless we show examples of high resolution ROMS simulations that continue to capture many of the observed features (within the limits of course of relatively limited coastal observing systems).

In our non-assimilating framework, then, ROMS represents an effective tool to generate integrated hydrodynamic solutions firstly at the whole of NZ scale, and then latterly at the coastal down to embayment via nesting (presently one way, but working toward two way). The challenge remains to upscale the observing network in order to be able to effectively exploit the 4D-VAR assimilation scheme in ROMS, and so complement our already existing operational suite for the atmospheric, storm surge, and wind-wave components.
Surface currents on the Rottnest continental shelf, Western Australia

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Abstract

The use of High-Frequency radar for measuring surface currents on continental shelves has been well established through development for over 30 years. The West Australian Integrated Marine Observing System (WAIMOS) has access to surface current data from a WERA phased array system with shore stations located at Leighton Beach and Guilderton. The HF Radar systems are operated by the Australian Coastal Ocean radar Network (ACORN). The data include hourly values of surface currents on a regular grid with spacing of 4 km. The surface currents measured by the HF Radar, over 18 months, are correlated with the winds measured at the Rottnest Island meteorological station. The wind field in the region has a seasonal variability is southerly winds during the summer months and storms during winter. During the summer there two main systems which dominate the wind pattern: (1) sea breeze system with easterly winds during the morning and strong southerly winds in the afternoon; and (2) summer storms where the southerly winds are enhanced during the afternoon due to the sea breeze and may persist for 2-3 days. Winter storms are related to the passage of a frontal systems with the region is subject to strong winds from the north-west, which change direction to the west then south-west over 12–16 hours, gradually weakening over two to three days. At the vector scale, the vector correlations between the wind and surface currents during the summer months indicated a high correlation (> 0.7) along the shelf regions during the summer months which decreased during the winter. The offshore areas, where the Leeuwin Current was dominant indicated low correlations with winds. At the event scale (of order 2-3 days), where the winds were stronger there was relatively high correlation between the surface currents and winds.
Sea breezes force near-inertial waves on Rottnest Shelf, Western Australia

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Abstract

At locations close to the latitudes 30° south and north, the inertial frequency is approximately diurnal and forcing at these ‘critical latitudes’ at the diurnal period (by tides or wind stress) result in a resonant response in the currents. Multi-platform (moorings, HF Radar and remote sensing) data sets, along the Rottnest continental shelf reveal strong anti-cyclonic circular motions that often exceed the mean Leeuwin Current by speeds greater than 0.3 m s⁻¹. The region is low in tidal energy, therefore the resonant response of the currents was due to the diurnal sea breeze system. The data indicated that diurnal energy was observed to depths up to 350 m (much larger than then the Ekman depth of around 70 m). The mixed layer depth determined the offshore extent to which isotherm oscillations were observed in the mooring data. Four factors were proposed as key determinants of the depth of the mixed layer and consequently also influence other interacting factors such as phase locking with the wind, efficiency of the wind and downward energy transfer: (1) the strength of the Leeuwin and Capes Currents; (2) the strength of the Leeuwin Undercurrent; (3) the position of mesoscale and sub-mesoscale eddy dynamics; and, (4) the strength, frequency and direction of wind forcing. In the absence of significant tidal mixing at this location, sea breeze forcing of near-inertial waves and isotherm oscillations is an important candidate for vertical mixing and dissipation across the pycnocline.
The seasonal cycle of Chlorophyll along the Two Rocks Transect
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Abstract

Temperature and salinity (and associated density) data together with fluorescence, backscatter and underwater light climate collected using autonomous shallow water Slocum ocean gliders along the Rottnest Continental Shelf are presented. The data sets span a period of 5 years (2009 to 2014) and provide information on the changes in fluorescence (as chlorophyll) at seasonal and inter-annual time scales. The region experiences a Mediterranean climate with hot summers and cold winters and the oceanography is dominated by the Leeuwin Current during the winter and the Capes Current during the summer. Cross-shelf transport is dominated by dense shelf water cascades. The shelf and slope waters in the study region is oligotrophic and thus the primary productivity and chlorophyll concentrations are relatively low in summer due to the well mixed water column due strong sea breezes. The phytoplankton blooms (higher fluorescence) occur in late autumn and winter. For all transects, the fluorescence levels in the surface 30 m were higher along the inner continental shelf when compared to offshore waters (Leeuwin Current) with a deep chlorophyll maximum being a common feature offshore. There were also significant inter-annual variability in the fluorescence concentrations.
The Holloway Current along North-West Australia

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Abstract

The Holloway Current is a surface current postulated to flow towards the south-west, parallel to the coastline, along the north-west shelf and provides a conduit to transport warmer, lower salinity water from northern Australia into the Leeuwin Current. During the summer months, strong south-westerly winds (Australian monsoon), pile up water in the Arafura Sea and Gulf of Carpentaria and as the wind relaxes, the water flows south-westward. Seasonal heating may also have an influence on the mean sea level which would enhance the alongshore pressure gradient, the driving force of the current. Evidence for the presence of the current, to date, has been from numerical models and current meter data from the north-west shelf, including the North Rankin location. These studies indicated that the current was well established during the autumn months when the winds relaxed. In February 2012, as a result of co-investment in IMOS by the WA State Government, two mooring transects were established off the Kimberley and Pilbara with 4 and 3 stations across the continental shelf, respectively. Analysis of 24 months of the data (February 2012 - February 2014) indicate that the south-westerly flow is a consistent feature of the current field on the continental shelf inshore of the 200m isobath transporting ~2 Sv of water towards the south-west. These estimates correspond with similar values predicted using OzROMS model in the region.
Abstract

Malaysia Airlines flight MH370, with 239 passengers on board, was scheduled to fly from the Malaysian capital, Kuala Lumpur, to Beijing in China on Saturday March 8 2014. It disappeared from civilian radar screens about an hour into the scheduled six-hour flight. Initially the search region was in the south China sea but on March 24, it was revealed that satellite data from Inmarsat indicated that the plane flew along the southern search corridor and the flight "ended in the southern Indian Ocean". Initially the search area was in the Southern Ocean sector of the Indian Ocean (86-90o E 44-46o S). Further analysis of the Inmarsat data indicated that the flight may crashed ~1000km to the north of the southern ocean site (94-98o E 27-34o S). Subsequently, the search site was moved further north to the vicinity of the Wallaby Plateau (103-104o E 20-21o S). There was a huge demand by the media on how oceanography could help with the search and the modelling group at The University of Western Australia performed particle tracking, forward and backward in time to examine the surface currents in the region and the dispersal pattern of any possible debris. We used the flow fields from the HYCOM global ocean model as input to a particle tracking model which was able to simulate both forward and backward in time. The results of simulations (undertaken in near-real time during the search period) are indicated that the oceanographic conditions varied considerably between the different locations and at the location in the Wallaby plateau the circulation was dominated by a large sub-mesoscale eddy for several weeks.
Peddies: what, where why?
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Abstract

Eddies are a common feature in the oceans with diameters ranging from millimeters, to hundreds of kilometers. The smallest scale eddies, due to turbulence, may last for a few seconds, whilst the larger features may persist for several months. Those eddies which are between 50 and 500 km in diameter, and persist for periods of days to months are commonly referred to in oceanography as mesoscale eddies and are a common feature of the Leeuwin Current System. In these eddies, the Coriolis force is dominant and therefore the Rossby number, $Ro << 1$. Smaller scale eddies with less than ~40km diameter are defined as sub-mesoscale eddies, with $Ro$ of order 1, and persists for periods of 2-3 days and are now believed to be important features for nutrient cycling in the upper ocean. IMOS provides a range of marine data streams using different platforms and in this paper we use multi-platform (moorings, HF Radar, ocean gliders; ship borne measurements and satellite remote sensing) to examine the generation, structure and occurrence of Peddies. Along the Rottnest continental shelf, data from the WERA HF Radar system, indicate the presence of these eddy structures in which the water depths influence the vertical scale and are defined here as peddies (‘petite’ eddies). In this paper examples of selected peddies including those which were sampled with a ship and an ocean glider. In many cases satellite imagery have shown these features to have eddy centres and/or perimeters which had different water properties (temperature, chlorophyll) to those of the adjacent ocean. Shipborne ADCP and CTD transects across one of the peddies indicated max current speeds up to 0.5 ms$^{-1}$ with colder water upwelling at the centre of the peddie from the bottom to the surface where water depths are 100-150 m. The peddies are usually associated with high chlorophyll at the surface and sub-surface. It is shown that, along the south-west Australian shelf, majority of the peddies occur on the interface between the southward flowing Leeuwin and northward flowing Capes currents due to the horizontal shear between the two current systems and this region forms the ‘peddie alley’.
The eReefs relocatable biogeochemical model (RECOM) and its parameter libraries
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The eReefs relocatable coastal ocean model (RECOM) is a modelling tool designed to substantially reduce the costs and labour involved in setting up a full-featured biogeochemical and hydrodynamic modelling suite for application to a new estuary or local of coral reef or coastal ocean. RECOM includes the CSIRO and eReefs biogeochemical, sediment dynamics and hydrodynamic model EMS with SHOC, a graphical interface to facilitate grid generation, bathymetry and parameter libraries for areas within the Great Barrier Reef, and the capability for one-way or two-way nesting within the regional scale eReefs models in either hindcast or near-real-time mode and inheritance of inflow boundary conditions from the larger-scale model. A pilot version exists and is currently undergoing testing and further development. RECOM has been designed with data assimilation in mind, so the development of parameter libraries for the model includes identification of key parameters for calibration and preparation of evidence-based prior distributions for these parameters.
A higher resolution model of shelf circulation and marine connectivity of the north-west shelf

Frank Colberg, Dirk Slawinski, Ming Feng

The Pilbara/Ningaloo region is the source region of the Leeuwin Current, being dominated by the southward flowing Holloway Current and Leeuwin Current during the austral autumn and winter; and by the Australian monsoonal wind-driven currents during the austral summer. Tidal currents, tropical cyclones, and Madden-Julian Oscillation are also important factors in driving horizontal and vertical mixing processes on the shelf and in the nearshore environment. The understanding of local hydrodynamic retention and connectivity between reef ecosystems in terms of supply of larvae and recruits, driven by ocean currents, are important in managing marine protected areas. In this study, we use a high resolution ocean ROMS model to simulate the shelf circulation in the northwest shelf Australia during 2003-2010. We validate the model performance using satellite sea surface temperature and altimeter data, IMOS mooring data on the shelf, and coastal sea level data. Based on the model results, particle tracking method is used to understand regional connectivity off the coast.
La Niña causes extreme freshening of the Leeuwin Current
Ming Feng, Jessica Benthuysen, Dirk Slawinski

Indonesian Australian Basin in the south-east Indian Ocean experiences strong interannual variability in upper ocean freshwater content. Heavy precipitations in the Indonesian seas during La Nina tend to fresh the Indonesian Throughflow and the outflow region in the south-east Indian Ocean. In 2010-2011, one of the strongest la Nina events that occurred in the Pacific, which has caused significant freshening of the Indonesian Throughflow waters, as well as a record strength of the Leeuwin Current during austral summer, instigating an unprecedented marine heat wave event off the West coast of Australia – the 2011 Ningaloo Nino. In this study, we will use the Argo float data in the south-east Indian Ocean, shelf moorings data, and glider transect to describe expansion of the salinity anomalies of the Indonesian Throughflow waters in the south-east Indian Ocean, especially along the pathway from the Indonesian-Australian basin to the Leeuwin Current. A data-assimilating numerical ocean circulation model is used to quantify the variation of the Leeuwin Current during the event and the impacts on the salinity budget in the region.
Observational and modelling studies have shown recent changes in circulation due to shifts in atmospheric circulation and climate. Understanding how such changes will affect larval dispersal is crucial for an adequate management of marine resources. Along the eastern Australian coast the circulation is driven by the East Australian Current (EAC), a western boundary current that flows along the coastline and separates from the continent at approximately 31°S; south of the separation latitude, a pole-ward residual flow and a meso-scale eddy field dominate the circulation. To elucidate potential changes in dispersal along the eastern Australian coast we used a lagrangian approach to quantify the rate of southward transport by the EAC and transport across its separation latitude from 1980-2010. We found that the southward transport along the coast outside and inside eddies has a significant positive (increasing) trend. Projections of circulation induced by a future climate scenario also show an increase of the EAC transport and the meso-scale eddy field. In order to evidence how present and future circulation induce larval transport patterns we simulated the dispersal of generic larvae along the east Australian coast with velocity outputs from an eddy resolving hydrodynamic model (OFAM) forced with i) contemporary and ii) a projected climate scenario. The results show that meso-scale eddies play an important role in the latitudinal distribution of larvae, and future circulation inducing a southward shift of the latitude at which most of the larvae arrives, and a decrease in abundance of larvae supplied to coastal habitats.
MARine Virtual Laboratory (MARVL) high-resolution ROMS test: the East Australian Current at 30°S in Solitary Island Marine Park (SIMP).

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ROMS-MARVL was implemented off Coffs Harbour SIMP, a region of complex topography in a Western Boundary Current dominated environment. The high-resolution configuration (1 km) was nested from BRAN3 and forced at the surface with ACCESS-a wind stress, net freshwater and heat flux, covering the period April-July 2012. Results were then assessed using a number of data streams including IMOS HF coastal radar, oceanographic moorings, glider transects and remotely sensed data.

Compared to the parent model BRAN, the East Australian Current vertical structure and inshore front are better represented. The high-resolution model is also able to generate shelf current reversals, in agreement with HF radar measurements, and eddy activity, in particular small scale cyclonic vortices on the inshore edge of the EAC. These frontal structures sometimes turn into well defined cold core eddies with sharp temperature gradients that are expected to have great implications in terms of vertical uplift of nutrients and productivity. These results are very promising for the investigation of cross-shelf processes, upwelling and connectivity in the SIMP area using high-resolution modelling.