Coastal and Shelf Oceanography in Australia

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Abstract

Recent national-scale activities have ideally positioned the Australian coastal oceanography community to monitor, understand, and predict the circulation and properties of Australia's marine environment. The implementation of Australian Integrated Marine Observing System is delivering unprecedented levels of observations of the oceans around Australia. In concert with this development, ocean models have reached a level of maturity that they can be used to inform researchers and decision-makers about the past, current, and future state of the ocean. This positions the Australian community to sustainably manage, protect, and exploit our vast marine environment.

Background

Australia is a marine nation, with a coastline of over 25000 km and over 20 million people living within 10 km of the coast (Frusher et al. 2012). Australia's coastal ocean hosts a diverse range of activities, including industry (e.g., oil and gas, fisheries, shipping), public (e.g., sailing, yacht racing, fishing), and government (e.g., defence, search and rescue, environmental monitoring and management) activities.

Recent national-scale activities have introduced a step-change in the capabilities and understanding of Australia's coastal oceans. This includes activities under the Australian Integrated Marine Observing System (IMOS; www.imos.org.au) – established in 2007 under the National Collaborative Research Infrastructure Strategy (NCRIS); and multi-institutional projects like the Bluelink (www.csiro.au/Outcomes/Oceans/Oceans-and-climate/BLUElink.aspx), the Marine Virtual Laboratory (MARVL; www.marvl.org.au), and eReefs (www.eReefs.org.au). Together, these initiatives have provided Australian researchers and industry groups with unprecedented information about Australia's coastal ocean and shelf seas.

Shelf scale observations

With the establishment of Australia's IMOS communities around the country formed into regional "nodes". These nodes represent a critical mass of people from university, government, and research organisations. Expertise in coastal and shelf oceanography are primarily found at the Australian Institute of Marine Science (AIMS), the Bureau of Meteorology (BoM), the Commonwealth Scientific and Industrial Research Organisation (CSIRO), the University of New South Wales, (UNSW) the University of Tasmania (UTAS), the University of Western Australia (UWA), and the South Australian Research and Development Institute (SARDI). Under the auspices of IMOS, over 30 shelf moorings have been deployed as part of the IMOS program (Figure 1), augmented by a fleet of coastal glider deployments, in situ biogeochemical sampling and an array of HF radar installations. These new observations form the backbone of the IMOS network. IMOS is seen internationally as an exemplar in coastal ocean observing, particularly for its central co-ordination and open data access policies.

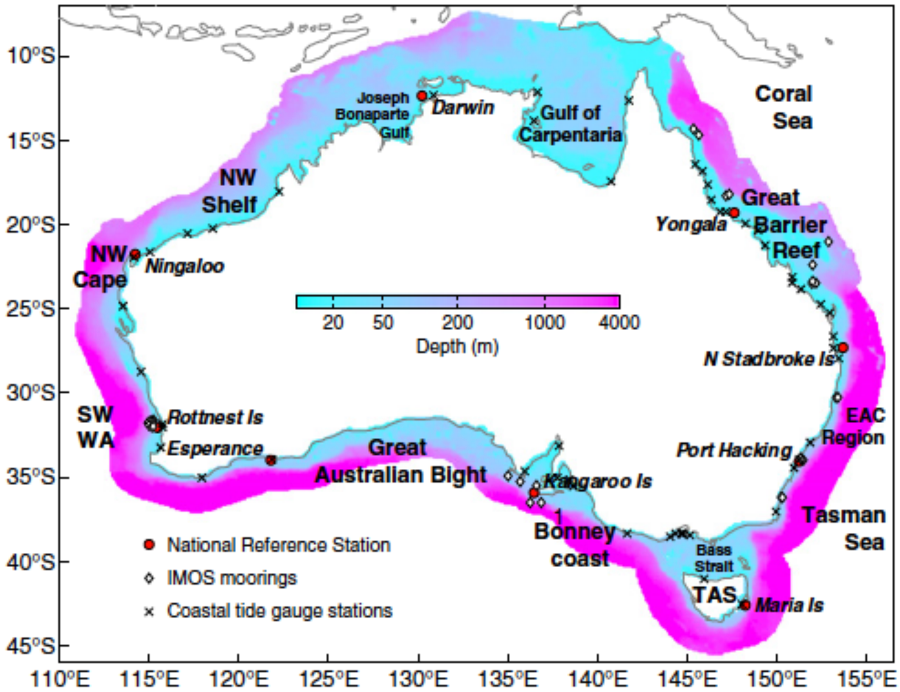

Figure 1: Map of the Shelf topography (colour) and mooring locations (red dots and diamonds) and tide gauge stations (crosses) around Australia (adapted from Oke and Sakov 2012).

Regional Modelling

Individual coastal ocean modelling efforts include the development of OzROMS (@UWA), SAROMS (@SARDI), SEA-ROMS (@UNSW; e.g. McDonald et al. 2013), ROAM (@CSIRO; Oke et al. 2013), plus a suite of models of the Great Barrier Reef under eReefs (@CSIRO, BoM and AIMS; Schiller et al. 2014). Of these systems, most are primarily for research purposes (OzROMS, SAROMS, SEAROMS), but ROAM and eReefs are for both research and operational forecasting.

ROAM represents the state-of-the-art in relocatable ocean modelling – with only one other comparable system (RELO; Wei et al. 2013) in the international community.

MARVL, is a world-leading development designed to enhance collaboration between Australian researchers by automating the inter-operability between models and modelling systems. This project, led by UTAS, and including researchers from 7 other Australian organisations, is consistent with a national trend for Australian researchers to increase collaboration, share resources, and develop community tools. This cooperation – largely made possible by the success of IMOS, has significantly enhanced our ability to inform decision-makers about the state of the ocean, allowing the Australian community to sustainably manage, protect, and exploit our vast marine environment.

Relevance

There are many end-users of coastal oceanographic research in Australia – including the Royal Australian Navy (Schiller et al. 2009), the oil and gas industry, AMSA (Davidson et al. 2009), the fisheries industry (e.g., Frusher et al. 2012), and environmental management (e.g., under eReefs). Many of the key end-users have invested in coastal ocean research through the deployment of instrumentation (e.g., under IMOS), through investment in modelling and forecasting capabilities (e.g., under Bluelink), or through sustained funding of applied research (e.g., Fisheris Research development Corporation; FRDC). Examples or engaged and contributing stakeholders include the Royal Australian Navy (RAN) partnership in Bluelink (between RAN, CSIRO, and BoM); fisheries investments through FRDC and state agencies, such as SARDI and NSW Department of Primary Industry (DPI) - Fisheries, plus industry groups including BP (investing in GAB project undertaken by CSIRO and SARDI), BHP (investing in eReefs, undertaken by CSIRO, BoM, and AIMS).

Science needs

Observational and modelling capabilities of Australia's coastal oceans has reached a critical mass – providing researchers with the opportunity to understand, monitor, and predict Australia's marine environment like never before. Despite this, many science gaps and challenges remain.

Provision of an accurate and complete picture of the three-dimensional time-varying ocean circulation, resolving scales of around 1 km is seemingly within reach. However, development of the necessary systems that can bring together the observations and models to deliver this goal is challenging. This will require a national effort that brings together the expertise of the ocean modelling community and the observational community to succeed. A strategy to achieve this is being developed – in the form of the Australian National Shelf Reanalysis (the ANSR). The ANSR strategy involved a staged national development. The first step (1-2 years) is the validation of existing regional models and the consolidation of the wealth of observations delivered through IMOS. The second step is the sharing of knowledge and expertise to aid the development of a national modelling system (3-5 years), capable of realistically reproducing all of the key oceanographic processes, from coastal upwelling, to cross-shelf exchange, to headland and island wakes. The third step is the development of an ocean data assimilation system suitable for the initialisation of high-resolution national shelf-scale model (3-5 years) to aid the performance of a suit of high-resolution ocean reanalyses (4-6 years) to deliver a realistic and complete picture of the three-dimensional time-varying ocean circulation around Australia. Such a product/dataset would be invaluable to Australian researchers, industry groups, and stakeholders to promote sustainable management, protection, and exploitation of Australia's marine environment. The final step in this development is the implementation of the high-resolution, national data assimilating system into an operational environment (5-8 years) to deliver daily forecasts of the ocean circulation for 7-21 days ahead of time.

The benefits of a capability like ANSR are far reaching. The benefits to Australian researchers are clear. The availability of a high-resolution ocean reanalysis will allow many research questions to be answered – quantifying cross-shelf exchange, understanding of fundamental dynamical processes, quantification of tele-connections, and biophysical coupling, to name a few. The benefits to marine managers will be significant – allowing different scenarios to be considered in a virtual world – allowing decision-makers to make informed decisions about sensible industry activities, promoting safety at sea (e.g., search and rescue), improving efficiencies (e.g., ship routing), minimising the impacts of environmental disasters (e.g., oil and gas approvals; oil spill response), and promoting sustainable environmental management (e.g., fisheries).

Although IMOS has delivered an unprecedented level of observations of Australia's coastal oceans, the array is far fro complete. There are many gaps in the IMOS coverage (e.g., Oke and Sakov 2012) – leaving large gaps that are relatively un-monitored. Completion of the Australian ocean observing system, following the lead of other countries (e.g., USA) would further enhance our ability to monitor, understand and manage our vast ocean resource. Moreover, sustained monitoring is of critical importance – particularly in a changing environment, where the impact of climate variability and change on the coastal ocean remains unclear.

Perspective

Science Priorities

Circulation and exchange between coastal and oceanic waters along the Australian Coast is influenced by many factors including topography, local and remotely forced winds, river inflows, tides and circulation in the adjacent ocean. Changing patterns of local and global weather will alter rainfall distribution and evaporation patterns, which in turn will modify the volumes and frequency of river flows discharged into the coastal zone. On a broad scale, global winds are changing the strength of the large-scale ocean currents, and ocean warming is modifying the stratification and mixing processes of the surface ocean. The impact of climate variability and change on the coastal ocean environment is unclear. At continental shelf scales, key areas of uncertainty of the oceanographic response to climate change include sub-mesoscale processes and ocean-shelf exchange. Ocean warming in the shelf context, bio-physical interactions and the response of coastal marine ecosystems all remain uncertain.

Sub-mesoscale processes and ocean-shelf exchange

In many parts of the Australia coast, sub-mesoscale processes play an important role in the shelf circulation, but also in modulating the exchange of water between the shelf and the ocean. Increasingly, emphasis is being placed on the importance of sub-mesoscale features (fronts, filaments, eddies, and other coherent flow structures). Until recently they have been difficult to observe, and virtually impossible to predict. With increasing observational density – for example, high-resolution High-Frequency (HF) radar arrays and repeat glider missions, combined with ever improving remote sensing algorithms and increasing model resolutions – the goal of understanding, parameterising, and explicitly resolving these processes has become attainable. This will remain a priority in the next 3-10 years as we grapple with understanding the dynamics and evolution of these highly Lagrangian and rapidly evolving systems. This is one area in which ANSR – see above – can shed significant light.

Ocean Warming in the shelf context

While efforts have been made to understand the broadscale patterns of sporadic upwelling on both the east and west coasts (e.g., Rossi et al. 2013; 2014), little is known about future changes to upwelling and stratification. It is hypothesised that with ocean warming, an increase in stratification will lead to a suppression of upwelling processes, and hence a suspected decrease in coastal productivity. These assumptions have been made from coarse-resolution climate models that don't properly represent the continental shelf circulation and its key processes. Attempts to address this issues by "downscaling" coarser climate predictions through the application of higher resolution regional and coastal models still presents research challenges (e.g., Chamberlain et al. 2013), as a significant amount of physical and biological response on the continental shelf is due to episodic oceanic and atmospheric events that occur at a frequency not resolved by coarser models. Specific questions relate to:

- the modification of the strengths of our dominant boundary currents (strengthening EAC; weakening Leeuwin) and understanding the impacts on associated upwelling and productivity of shelf waters;
- understanding the response to altered local and regional wind fields and impacts on mixing of coastal and shelf waters and modification of wind-driven coastal currents and upwelling; and
- impacts of the observed increase in frequency, intensity and transport of WBC eddies (Cetina Heredia 2014).

Bio-physical interactions

With increasing human impacts on the coastal ocean, understanding bio-physical interactions has become critical. Our greater understanding of our shelf seas has also improved our comprehension of the vital role that circulation and physical processes plays in driving biophysical coupling. Tight coupling has been observed between some physical process and phytoplankton response (e.g., Armbrecht 2014), However in oligotrophic environments such as western boundary currents the cumulative biological impact of changes to physical processes (e.g., the impact of sub-mesoscale eddies on enrichment and productivity) is not yet known. Tropicalisation of coastal ecosystems has been observed, particularly in western boundary current regions that are undergoing the fastest rate of warming of anywhere on the planet (Verges et al. 2014) and climate forecasting has yet to resolve many of these processes at an adequate scale.

Historically, biogeochemical modelling of estuarine and shelf systems has been undertaken in separate studies, without considering dynamical feedbacks between the two different scales. This approximation is often reasonable because open ocean forcings on estuarine and coastal waters can be relatively constant, and the scale of terrestrial inputs into the shelf ocean have been considered small at the shelf scale. For example, terrestrial inputs of nitrogen into the NSW shelf are small compared to oceanographic processes such as shelf upwelling (Baird et al., 2006).

For recently emerging problems, however, estuarine-shelf feedbacks require better representation. Firstly, the warming and acidifying ocean has a changing impact on the coastal ocean, reef, and estuarine environments. Thus, the impacts of ocean acidification on a reef matrix of the Great Barrier Reef cannot be considered by a reef scale model alone (Mongin and Baird, 2014; similar for Nigaloo Xu et al, 2013; Falter et al., 2013). Secondly, the scale of terrestrial forcings on coastal environments has recently expanded greatly due to the massive coastal developments, and their associated sediment movement (Margvelashvili et al, 2008). Further climate change has the potential to drive large changes in terrestrial inputs through changes in rainfall.

Thus, neither a shelf model without land impacts, nor an estuarine model without shelf circulation, can be used to adequately capture the likely impacts of the mining boom on the Great Barrier Reef. To meet this change we require models that either span the estuarine to global scale, or we require sensible and accurate coupling (e.g., nesting) across these scales.

Realisiation

Observational Priorities

No single platform can provide all the necessary observations to resolve all the processes in the coastal ocean. However, the combination of land based HF radar arrays (resolving surface velocity fields between 1-6km resolution) and autonomous glider deployments (measuring hydrography and biogeochemical parameters) provides much needed observations in the vertical, horizontal, and in time.

- Additional HF Radar stations in significant locations in relaqtion to boundary current dynamics – e.g., Stockton Bight EAC Separation point.; and
- More glider deployments. Increased spatial and temporal converage – e.g., where the Tasman Sea is warming - on the shelf from Sydney – Eden; southwest Western Australia.

Modelling Priorities

Due to limited resources (both human and financial), unfortunately Australia is lagging behind world-class efforts to assimilate and forecast the coastal and shelf seas. This is being addressed to some extent by individual projects (e.g., e-reefs, SEA-ROMS, Bluelink). However we have not yet developed nation-wide forecasting and assimilation capability in the coastal and shelf ocean. This was largely the motivation for the development of the ANSR strategy (described above).

Improved techniques for downscaling temporally and spatially coarsely resolved climate prediction to include accurate representations of higher frequency and locally/regionally significant events and processes (e.g., local wind fields, tropical cyclones,) that drive persistent coast and shelf dynamics and ecosystem response.

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