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<th>IMOS Node</th>
<th>Southern Australian Integrated Marine Observing System</th>
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Date: 26/05/2014
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1 Executive Summary

The Southern Australian Integrated Marine Observing System (SAIMOS) ten year science and observational plan, has been designed to provide data streams across five major research themes (Fig. 1) that underpin key physical and biological processes important to the regions unique marine ecosystem. These data streams will help determine:

a) Spatial and temporal variation in physical oceanographic conditions off Southern Australia, including shelf and slope currents, cycles of upwelling/downwelling, and the influence of major boundary currents and climate variability.

b) The way this variation influences connectivity, cross shelf exchange and nutrient enrichment in the four main oceanographic sub-regions off Southern Australia: south eastern shelves (Cape Otway to Cape Gantheaume); eastern Great Australian Bight (Cape Gantheaume to Cape Bauer); central-western Great Australian Bight (Cape Bauer to Cape Pasley); and the Gulfs (Gulf St Vincent, Spencer Gulf, and Investigator Strait).

c) The influence of variations in physical oceanographic conditions, nutrient enrichment, and connectivity between oceanographic sub-regions on ecosystem dynamics, food web structure, and key biological patterns and processes from microbes and plankton to apex predators.

Fig. 1 Research themes for SAIMOS
The research themes are summarised in Fig. 1. The physical observational program will allow for the determination of the dynamics and nature of the upwelling/downwelling cycle in the region, including the role of the Flinders Current, canyons, wind-forcing and El Nino–Southern Oscillation (ENSO) events. Upwelling events are likely to underpin the planktonic ecosystem of the region that now supports South Australian and Victorian fisheries and aquaculture industries worth almost $500M (GVP) annually.

We will maintain the assessment of nutrient concentrations and the abundance and community composition of microbial and planktonic communities. This information will be collated to improve our understanding of the role of physical (meteorological and oceanographic) forcing and control. These are the drivers of nutrient enrichment and cycling that underpin productivity of the microbial and planktonic ecosystem, which cascade through the food web and ultimately support higher trophic levels. This integrated approach is unique at both the national and international levels. We will continue to use tagged apex predators to collect physical and biological data (e.g. temperature, salinity, irradiance, fluorescence with depth) across the region to provide direct observations from biologically important regions and at places and times inaccessible to other platforms. These biologging data streams will complement the mooring and glider data streams. Passive acoustic moorings will provide indices of residence by great whales in the eastern Great Australian Bight (GAB) and off the Bonney Coast (Cape Otway to Cape Jaffa) in the south eastern shelves region. Through AATAMS, curtains and arrays of acoustic receivers will be used at various locations to monitor the relative abundance, movements and migratory patterns of pelagic predators and assess how these are influenced by variations in the physical, chemical and biological parameters measured by other components of the SAIMOS facility.

Going forward, in addition to maintaining the core observations detailed above, we plan to: i) establish new moorings off the Bonney Coast and in the Gulfs that will add continuous time-series and vertical information to support current data streams supplied by the (existing) Acoustic Observatories and CODAR HF RADAR; ii) deploy new biologging instrumentation with additional sensor capabilities on a diversity of apex predator species for additional observations from across the four oceanographic sub-regions and in a range of habitats; iii) extend the coverage of the SAIMOS area of interest via cross-shelf curtains and arrays of acoustic receivers to improve the monitoring of apex predators movements; and iv) deploy a new set of temperature loggers across the Otway shelf off the Bonney Coast.

Data streams will be developed for the central-western GAB, Gulfs, and south eastern shelves via data collection using Ships of Opportunity (SOOP). Current biological data streams will be extended to include monitoring of microbial and zooplankton abundance and community composition, primary and secondary productivity and carbon cycling. We plan to enhance observations of biological response to change at high trophic levels through monitoring apex predator populations. This will provide a whole of ecosystem response to understand how changes in physical forcing affect the primary, secondary and tertiary productivity that underpin apex predator populations.
SAIMOS support for the IMOS Strategic Priorities

Provisioning a national backbone for observing boundary currents and enhanced observations of the southern ocean:

Support here will be achieved through the shelf and slope moorings, Kangaroo Island National Reference Station (NRS), and survey work (including data collected by SOOP) in the eastern and central-western GAB, Gulfs, and south eastern shelves. Tagged apex predators, gliders, and SOOP will provide data for the shelf slope and sub-tropical front.

Ongoing development of regional nodes:

The enhanced SAIMOS Node Plan now includes 11 different institutions. We are in discussions with DSTO and the University of Adelaide to grow the Node through development of capability in gliders, HF RADAR and other observing platforms.

Engagement with Deakin University will continue at a modest level through temperature logger, CTD and ADCP moorings off the Bonney Coast. The University of Adelaide, Flinders University, Curtin University and the SA Department for the Environment, Water and Natural Resources (DEWNR) are also providing acoustic receivers/loggers to extend the acoustic coverage within the SAIMOS region.

Exploring the potential for whole-of-system approaches:

Data assimilating hydrodynamic models are under development for SAIMOS and will be used to evaluate the importance of data streams in predictive skill: this will allow costs to be driven down by the re-location or deletion of moorings etc. It is also envisaged that the data streams will allow for the development of operational now-cast/forecast models of ocean circulation. Such models will for example, enable the trajectories of harmful algal blooms, toxins, pollutants etc. to be forecast and be of immense value to fisheries and aquaculture industries.

In addition, a major aim of the node over the next 10 years will be to develop a coupled hydrodynamic/biogeochemical model for the region. These models will help understand the ecosystems of the region and may highlight biophysical controls of the distribution of key commercial species such as sardines and tuna. To reach this ambitious goal, the biogeochemical sampling of nutrients and phytoplankton will be extended. New sampling will include monitoring of microbial and zooplankton abundance and community composition, primary and secondary productivity and carbon cycling. This information will be analysed in relation to the physical processes. Cross-shelf data streams collected by tagged apex predators will be used to estimate the spatial and temporal distribution of upwelling and primary production off southern Australia. In combination with the improved understanding of apex predator movements through acoustic monitoring, these will be used to provide a biological response to physical shelf circulation models. Analyses of primary and secondary productivity in relation to the distribution and movements of apex predators will increase our understanding of the drivers underpinning spatial and temporal
variations in apex predator distributions across the nodes’ area of interest, providing a whole-of-system approach.

Temperature logger moorings on the shelf off the Bonney Coast will be used to measure the depth and cross-shelf extent of upwelled water below the surface layer and identify the start and end of the stratified summer hydrology and winter homogeneity. The data also graphically illustrates the intensity and dynamics of individual upwelling seasons and the variability between them.

**Driving down the cost per observation:**

Additional sensors (biological and AATAMS acoustic receivers) will be deployed on existing moorings and current water samples will be used for the production of multiple biological, nutrient and isotope data streams. Glider retrievals will be made during SAIMOS cruises. Biologging with apex predators (collecting CTD, fluorescence and irradiance data streams) provides a means to sample the marine environment at unsurpassed resolution and spatial scales. It also adds observational power at places and times not possible using existing platforms at a fraction of the cost. As much of the SAIMOS region is adjacent to sparsely populated coast distant from major ports and infrastructure, biologging provides an essential platform to provide data streams from the remote regions. Through data analyses and regional hydrodynamic/biogeochemical modelling, the observational strategies will be modified so as to be sustainable in the long-term. This will ensure that key drivers of the marine environment are observed while those of a secondary nature are ceased. Where possible, the use of cheaper proxies will be examined.

As noted above the development of hydrodynamic data assimilating (and biochemical) models will allow the importance of the various data streams to be quantified.

**Impact and delivery through improved model output:**

The SAIMOS data streams have already been used to validate the Southern Australian Regional Ocean Model. This in turn has been used to drive a high resolution hydrodynamic/biogeochemical model of Spencer Gulf to assist in studies of carrying capacity for finfish aquaculture and in the sustainable harvest of prawns. In the former case, the SAIMOS collected nutrients were invaluable in setting the open boundary condition for the biogeochemical model. Both studies have been well received by SA government and industry.

The SAIMOS data streams are also to be used in the $20M GAB Research Program ([www.misa.net.au/GAB](http://www.misa.net.au/GAB)) to help validate the hydrodynamic models that are under development by SARDI and CSIRO. These models will be used to provide a baseline view of the circulation in the GAB including ecosystem dynamics and paths of potential oil spill events.

**Ensuring data are used:**

The hydrodynamic and biogeochemical modelling outlined above will ensure the uptake of the SAIMOS data streams into the future. Currently, data are also to be used for bio-fuel microalgae prospecting, acidification studies, hydrocarbon exploration and extraction, and desalination site
appraisal – see Section 4 for detail. In addition, numerous presentations have been made to the research, government and industry communities on SAIMOS. The data are being used by those active in SAIMOS, and uptake by the broader community is continuing – see Section 3.1.1. A focus over the next plan will be increased uptake and utility of SAIMOS data streams for Government and industry.

All data obtained from SAIMOS acoustic receivers are uploaded to the AATAMS online and freely accessible database (https://aatams.emii.org.au/aatams). Scientists from other nodes have used data obtained from SAIMOS enhancing the value of their studies.

Partnering for sustained observing:

SAIMOS now involves 8 different institutions with SARDI and Flinders University having provided cash and in-kind support of near $3M. Joint glider missions have also been run by SARDI and DSTO. Discussions are underway with the University of Adelaide with regard to assisting with the HF RADAR facility. Several PhD students have (or are) completing their degrees using the SAIMOS data and have brought partnerships with SARDI, Flinders, ANU, UNSW, UTas and CSIRO – see Section 3.1.2 for details.

Socio-economic context

The SAIMOS Node region encompasses coastal and shelf/slope waters off southern Australia between Cape Pasley (WA) and Cape Otway (Victoria) (Fig. 2). The region contains diverse ecosystems including the Lower Lakes and Murray Mouth, SA’s unique gulfs, numerous off-shore islands and most of the GAB. Southern Australia’s coastal, estuarine and marine waters have significant environmental, economic, social, and cultural value. Southern Australia’s coastline spans approximately 8,000 km (including islands) and varies from cliffs, rocky shores, and sandy beaches in the South-East and West Coast, to mud flats and mangrove habitats in the upper Gulf St Vincent and Spencer Gulf. Over 100 estuaries, which are significant breeding and nursery habitats for a broad range of species, are also found across the region.

The region’s waters are internationally acknowledged for their unique diversity (Shepherd and Edgar 2013). They support more than 6,000 invertebrate species, 1,200 algal species, 350 fish species, 16 breeding seabird species, 33 mammal species and 12 seagrass species (Edyvane 1999a, b). In addition, the level of endemism found in Southern Australian waters is high, accounting for 75% of red algae, 85% of fish and 95% of seagrass species. In comparison, the Great Barrier Reef shares more than 80% of its fish, coral reefs and other marine organisms with other countries in the tropics (Phillips 2001). The southern shelves also host the largest temperate “carbonate factory” in the world. Shelf bedforms are largely biogenic in origin, containing fragments of bryozoan, molluscs, foraminifera and coralline algae calcium carbonate skeletons (James and Bone 2011). This additional endemism gives the oceans of the southern shelves national and international significance.
South Australia’s marine environment is critically important to the State’s blue economy and culture, and is a unique and highly valued natural asset. A healthy marine environment underpins fishing, aquaculture, ecotourism and mining, all of which are important to the regional communities, and make an important contribution to the State’s economy.

Finally, the shelf waters of the eastern GAB, where most of SAIMOS activities have been conducted, support significant commercial fisheries, and the most diverse marine ecosystems with the greatest density of apex predators in Australia. The development of relevant management, conservation and sustainability strategies requires in-depth understanding of the physical forcing in this sub-region and the way this impacts on the biological patterns and processes that underpin the overall productivity of the ecosystem.

![Map of SAIMOS region identifying 4 oceanographic sub-regions](image)

**Fig. 2** – Map of SAIMOS region identifying 4 oceanographic sub-regions

**National Priorities**

The sustained observations of physical and biogeochemical systems undertaken by SAIMOS align with a number of national initiatives and priorities. These include:

- National Framework for Australian Climate Change Science through a) measurements of ocean temperature, salinity and acidity in the Southern Ocean (through tagged apex predators, moorings and gliders); b) provision of data for the National Climate Change Adaptation Research Facility and DoA Climate Change Research Programs; and c) ACCESS model verification.
- National: CSIRO/BoM/RAN Bluelink ocean forecasting.
- National Marine Bioregional Planning (through the identification of plankton species and areas of ecological importance to apex predators, and demonstration of oceanographic connectivity between the four key oceanographic sub-regions in Southern Australian waters).
- Higher education training in marine observing systems through PhD projects and the use of SAIMOS data during undergraduate lectures and practicals.

2 Scientific Background, by Major Research Theme

Contrasting ecological processes predominate in southern Australian waters. These are driven by spatial and temporal variations in meteorological and oceanographic processes, which govern the supply of nutrients and irradiance that underpin the productivity of these ecosystems. Quantifying differences in ecology and food web structure will provide insights into ecosystem function, and facilitate the development of data streams for monitoring ecological indicators. Monitoring is vital to assess the potential impacts of anthropogenic and climate-driven environmental variation on the ecosystems of southern Australia, which will assist in promoting the sustainable management of its marine resources.

Waters of the SAIMOS Node region include four oceanographic sub-regions: south eastern shelves (Cape Otway to Cape Gantheaume, including the Bonney Coast); eastern GAB (Cape Gantheaume to Cape Bauer); central-western GAB (Cape Bauer to Cape Pasley); and the Gulfs (Gulf St Vincent, Spencer Gulf, and Investigator Strait) (Fig. 2). While each sub-region is influenced by different bathymetric and oceanographic conditions, connectivity between them can have an important influence on nutrient enrichment, productivity and ecosystem dynamics. Uniquely, the SAIMOS Node region lies along the world’s longest zonal, non-polar continental margin. The region is exposed to wind forcing by meridional pressure belts across the Southern Ocean as well as by boundary currents from the west and east that can be modulated by ENSO events in the equatorial Pacific (Fig. 3).
Fig 3. Major Boundary Currents and water mass paths (Richardson 2014). Tasman Sub Antarctic Mode Water (TSAMW) formed off SW Tasmania, depth ~500 m (Barker 2004). Deeper Tasman Intermediate Water (TIW) formed west of Tasmania, depth ~1000 m, Antarctic Intermediate water (AAIW), South Indian Central Water (SICW), Indian central Water (ICW) and a new water mass, S.A. Basin Central Water (SABCW) (Richardson 2014), depth ~ 200 – 300 m. Formed at STF – moved to Tasmania (Shodlock and Tomczak 1997).

The major boundary currents are illustrated in Fig. 3. The deep slope Flinders Current (FC) carries water masses formed off the west coast of Tasmania to Western Australia where it forms part of the Leeuwin Undercurrent. Off Kangaroo Island and the Bonney Coast, summertime upwelling occurs. Indeed, the oceanography and ecosystems of the region are somewhat similar to eastern boundary currents, where upwelling sustains planktonic systems that support such pelagic species as krill, sardines and squid. These in turn provide the fundamental food source for higher predators including tuna, sharks, seals, seabirds and whales. The region may also be an important high latitude foraging ground for some sea turtles. Indeed, in some ways the offshore extent of SAIMOS might be defined by the foraging habits of some of the region’s key apex predators that concentrate their foraging activities along shelf, slope and oceanic waters south to the sub-tropical front (~ 50° S), although some highly migratory species extend their foraging into polar, sub-Antarctic and tropical regions (Fig. 4).

As noted above, the southern shelves also host the largest temperate “carbonate factory” in the world. Shelf bedforms are largely biogenic in origin, containing fragments of bryozoan, molluscs, foraminifera and coralline algae calcium carbonate skeletons (James and Bone 2011).

In the following, a review is made of the important physical and biological oceanography of the region and key science questions posed along with the data streams necessary for their resolution. The latter are listed in the Tables presented. We begin with the current “climate” and seasonal nature of the physical oceanography and then consider shelf and coastal processes with a focus on cross-shelf exchange (including upwelling). Climate variability is then considered along with the drivers and tipping points that may be associated with decadal change, followed by an examination of the extent of ecosystem responses to these physical drivers.
2.1 Major boundary currents and inter-basin flows

2.1.1 The Flinders Current (FC) system including the Tasman Outflow and Leeuwin Current

Several studies (Middleton and Bye 2007, Richardson 2014) have shown that the wind stress curl in the Southern Ocean (during both summer and winter), drives an equatorward Sverdrup transport that is deflected to the west along the southern shelves. The resultant Flinders Current (FC) transports water masses formed off the west coast of Tasmania as far west as Albany where it forms part of the Leeuwin Undercurrent (LUC, Fig. 3a). Evidence for this is convincing but the details need further description. Uniquely, the FC is perhaps the only “small sister” of the East Australian Current (EAC) and other great western boundary currents of the world (Middleton and Bye 2007). In the far-east, the FC appears to be enhanced by the Tasman Outflow, a remnant of the East Australian Current (Ridgway and Hill 2009; Fig. 3a). As will be noted below, the FC appears to be implicated in cross-shelf exchange and is important to the ecosystems of the region. For example, as with the EAC and LUC, the bottom boundary layer of the FC is upwelling favourable so that onshore exchange of nutrients may be enhanced. In common with these other boundary currents, it also flows with the shelf slope on the right, so that upwelling through canyons can also occur.

2.1.2 Seasonal Shelf Currents

During winter, the LC enters the GAB as a shelf current and extends as far as the Eyre Peninsula (Godfrey et al. 1986, Middleton and Cirano 2002). To the south east, the mean winter winds drive this shelf boundary current into Bass Strait and along the west coast of Tasmania (where it is known as the Zeehan Current). The local wind forced currents are also to the east with bottom boundary layers that are downwelling favourable. The downwelling is also enhanced by dense water outflows from the coastal regions.
During summer, the coastal winds often reverse to the northwest and the influence of the eastward LC is smaller. The episodic south-easterly winds can drive shelf flows to the northwest and west in the GAB. The bottom boundary layers of these shelf flows are upwelling favourable and enhance the wind forced Ekman upwelling (see Section 2.2 below).

Evidence also exists for an eastward flowing South Australian Current that is located over the shelf break of the GAB and Eyre Peninsula (Middleton and Platov 2003, Middleton et al. 2014). During winter this current is associated with the LC and wind forced currents. Modelling suggests that during summer its origin is associated with the wind-driven, poleward topographic transport over the shelf of the GAB (Middleton and Platov 2003, Herzfeld and Tomczak 1997, 1999). This transport converges with the (deep ocean) equatorward Sverdrup transport at the shelf edge and acts to raise sea level. The resultant pressure gradient drives an eastward transport at the shelf edge.

Most importantly, the convergence of the Sverdrup transports also acts to downwell water at the shelf edge to depths of ~250 m. While these numerical studies are somewhat idealised, strong evidence for the summer downwelling in the GAB is presented in Middleton et al. (2014) through examination of CTD data. Moreover, the summer downwelling appears to likely control the distribution of neritic carbonate sediments in the eastern and central-western GAB. For the former region, summer upwelling occurs and the neritic animals are well fed by nutrients, with their distribution extending to depths of ~250 m. In the central GAB, the downwelling negates the wind forced Ekman upwelling and the nutrient supply is poorer: the neritic sediments only extend to depths of ~120 m. Further evaluation of such physical control of the benthos is indicated.

2.1.3 The Antarctic Circumpolar Wave

The boundary currents may also be subject to the Antarctic Circumpolar Wave (ACW) with temperature changes along Australia’s southern shelves of up to 1 °C. This wave is thought to propagate around the Antarctic with a period of four years, and may be tied to the ENSO cycle (Middleton and Bye 2007). The ACW is postulated to result from an interaction of the oceanic and atmospheric boundary layers, has a four year period and amplitude of 0.5 °C off South Australia (White and Peterson 1996, Baldwin and Thompson 2009). The impact of this wave on shelf and slope circulation off southern Australia is not known.

2.1.4 Eddy processes in boundary currents

Evidence for quasi-stationary, 70 km-scale eddies along the southern shelves is given in the altimeter analyses of Ridgway and Condie (2004). For the winter period, a sequence of high pressure eddies is found off the topographic promontories associated with the Eyre Peninsula, Kangaroo Island and south-eastern South Australia. Between these high pressure eddies, low pressure eddies are found. Cirano and Middleton (2004) found similar high pressure (low pressure) eddies in their numerical model of the winter circulation and attributed their generation to vortex stretching (squashing).

During summer, eddies are also found along with a notable upwelled surface plume off south-eastern South Australia (e.g. Fig. 5). For both winter and summer, such high pressure (low pressure) eddies will enhance (retard) the FC.
Both the eddies and FC are weaker than those found off the east and west coast of Australia with amplitudes of ~10 cm/s. Nonetheless, they may be important to localised upwelling through interaction with canyons and other topographic irregularities.

2.1.5 Science questions

The following high-level science questions will guide the SAIMOS Node observing strategy in this area:

a) Limited observations and modelling studies indicate that the FC does exist and is likely much stronger in the west. Is this the case and how well connected is it to the Tasman Outflow, and Leeuwin Undercurrent? This might be answered by additional CTD sampling and moorings off the southern tip of Tasmania and in the GAB. Sea gliders could be used to map the CTD structure down to 1000 m.

b) Evidence exists for summer downwelling in the central GAB. Can this be confirmed using repeated CTD sampling, glider data and associated model development?

c) Does the ACW exist? Long time series of temperature observations at the KI National reference station are needed.

d) What is the importance of mesoscale eddies in the central and eastern GAB? Data assimilating hydrodynamic models are needed.

Fig. 5 The summer time (February 2008) SST for the SAIMOS region. Arrows denote estimated surface velocities (courtesy David Griffin, CSIRO).

2.1.6 Notable gaps and future priorities

Future priorities:
Evidence to determine the causes drivers and extent of the FC.

Evidence to determine the nature and drivers of the summer downwelling in the central GAB.
2.2  Continental Shelf and Coastal Processes

2.2.1  Cross-shelf exchange: summer upwelling

The shelf waters of southern Australia host a large summertime upwelling system spanning a distance of ~800 km with upwelling hotspots centred in the Bonney Coast and eastern GAB regions (Kaempf et al. 2004). Both historical and SAIMOS data (Fig. 6) indicate that upwelling in the eastern GAB originates to the south and south-east of Kangaroo Island, is largely sub-surface, and directed along the 100 m isobath to the north and north-west (Fig. 7). In addition, the results of the numerical simulations (Fig. 8) indicate that the low-frequency weather-band flow (associated with upwelling) is essentially directed along isobaths. These results intrinsically provided the rationale behind the choice of deploying the SAIMOS key reference station in the upwelling plume and on the 100 m isobath (Fig. 9).

![Figure 6: Bottom temperature and salinity obtained from the first SAIMOS field survey during February 2008. The large black arrow indicated de Coudic Canyon.](image-url)
**Fig. 7** Temperature depth profiles from shelf waters off SA (for February 2010) indicating cold (blue) upwelled water that is largely sub-surface underlying warmer (red) surface water. Data from CTD tags deployed on Australian sea lions.

**Fig. 8** Bottom temperature and currents (cm/s) for February 1998 as predicted by the SA Regional Ocean Model (Middleton and Bye 2007). Contour levels range from 11 to 18 °C.
An additional feature of the upwelling events is that along-isobath currents are generally too weak and/or infrequent to transport upwelled water from the shelf slope (200 m) off Kangaroo Island in the eastern GAB to the surface off the Eyre Peninsula. That is, the upwelled water appears to reside in a sub-surface “Kangaroo Island cold pool” (McClatchie et al. 2006), until a subsequent upwelling event can drive it to the surface region off the Eyre Peninsula (van Ruth et al. 2010a). Levings and Gill (2010) and Morrice (2014) have found a similar situation off the Bonney Coast, where a cold pool is established during upwelling, but off western Victoria it is generally masked by warm surface waters, only occasionally appearing at the surface inshore along the western Victorian coast.

### 2.2.1.1 Mechanisms for upwelling: winds

Between November and April each year, south-easterly winds lead to an offshore Ekman transport that can then induce upwelling across the shelf over a wide longitudinal range (Kampf et al. 2004,
McClatchie et al. 2006, Middleton and Bye 2007, Nieblas et al. 2009, Levings and Gill 2010). During this time, upwelling-related daily primary productivity in 'hotspots' in the eastern GAB is comparable to levels seen in the Benguela and Humboldt boundary current systems (van Ruth et al. 2010a). Within this broader system, a prominent surface cool-water upwelling plume extending from Cape Nelson, Victoria toward Kangaroo Island, South Australia, often referred to as the Bonney Upwelling, is the most predictable and intense upwelling off southern Australia (Butler et al. 2002, Nieblas et al. 2009). The development of stratified conditions in the eastern GAB, with a warm surface mixed layer overlying a cold, upwelled, Kangaroo Island pool has been described by McClatchie et al. (2006) and Kaempf (2010). van Ruth et al. (2010a) have shown that a significant volume of the Kangaroo Island pool is present within the euphotic zone, above the critical depth, promoting sub-surface areas of high productivity. In winter, winds favour downwelling and shelf waters are well mixed (Middleton and Bye 2007). From May to October, prevailing winds reverse and downwelling occurs (see below).

Examination of the SAIMOS data has shown (Middleton pers. comm.) that upwelling does not always occur when the winds are upwelling favourable. Other studies (Middleton and Platov 2003, Middleton and Leth 2004) have shown that significant reductions in wind forced Ekman upwelling can occur where the offshore Ekman transport is provided by a divergence in the alongshore currents. The role of this mechanism needs to be examined in the context of both the Kangaroo Island upwelling and that off the Bonney Coast.

2.2.1.2 Mechanisms for upwelling: Boundary Currents

As noted above (2.1.1), the FC is analogous to western boundary currents, and can through bottom boundary layer transport, cause deep upwelling from depths of around 600m depth and possibly allow nutrient rich cold water to entrain onto the shelf. This appears more likely to occur in the western GAB where the FC appears to be stronger in magnitude.

2.2.1.3 Mechanisms for upwelling: Canyons

In conjunction with the west-ward FC, submarine canyons may also be important to upwelling in the region. Many studies have demonstrated that shelf break submarine canyons can support a deep localised upwelling in situations when the ambient slope currents run opposite to the direction of Coastal Trapped Waves (CTW) propagation (Kaempf 2006, 2007). Previous mooring observations indicate that such conditions associated with north-westward flow are established during the summer months south of Kangaroo Island (Hahn 1986). Alternatively, an examination of 2 years of the 600 m depth SAIMOS ADCP shows that the deep currents are almost always to the southeast and downwelling favourable (Richardson et al. 2014). Moreover, the bottom CTD data obtained from SAIMOS in February 2008 (Fig. 10) does not show strong evidence that cold fresh water is upwelled through de Couedic Canyon.

Further research on canyon upwelling should be deferred until the strength and spatial extent of the FC is established.
2.2.2 Cross-shelf exchange: winter downwelling and mechanisms

In winter the winds become downwelling favourable. In association with coastal cooling (and negative buoyancy), water generally becomes well mixed over the shelf and is driven down to depths of 200-300 m (Middleton and Bye 2007). However, it is also known that the cold, salty, dense water formed in Spencer Gulf during winter can cascade out onto the shelf. Analyses of SAIMOS data, together with numerical models of the region, show that the density current consists of a sequence of low pressure (salty) and high pressure (fresh) eddies (diameters 20 km) that propagate out onto the shelf. The eddies in turn are formed within the Gulf through a process of geostrophic adjustment and then baroclinic instability (Teixeira 2010). This dense water outflow was confirmed using SAIMOS data collected in the winter of 2008 (Fig. 10). As a consequence, the du Couedic Canyon also appears to represent a focal point for the outflow of the dense water. The wintertime flushing of detritus and carbon from Spencer Gulf may be significant to the overall carbon budget for the region. During summer, exchange with the Gulf is minimal so that a strong seasonal signal in carbon fluxes is expected.

Based on a single cruise of CTD data, Petrusevics et al. (2009) have also shown that substantive dense water transports can originate in the coastal waters of the mid-GAB and exit to depths in the eastern GAB. The spatial and temporal extent of dense water formation is otherwise unknown, but represents a major mechanism of cross-shelf exchange. In addition, where does the water come from to replace the downwelled water and does the downwelling enhance the associated eastward shelf currents?

2.2.3 Shelf currents

The seasonal shelf currents discussed above are modulated by intense wind-driven Coastal Trapped Waves (CTWs) that enter the GAB from Cape Leeuwin and by those locally generated by intense storms. These waves have typical velocities of 25 cm s⁻¹ with annual extreme values of up to 50-90 cm s⁻¹. On the shelf, water is advected back and forth along isobaths with periods of 5-20 days,
although such waves can be important to cross-shelf exchange. In turn, the waves generated along the southern shelves drive CTWs within Bass Strait and on the NSW shelf (Middleton and Black 1994). The CTWs can also be important to setting the degree of upwelling (Middleton and Leth 2004) through the set-up (or otherwise) of alongshore divergence of the shelf velocity field. Such divergence can “feed” the offshore surface Ekman transport and shut-down upwelling over the slope. The role of CTWs in setting the degree of upwelling off southern Australia remains to be determined.

2.2.4 Surface waves and internal waves

In addition, the open southern Australian coast faces the highest energy surface waves in the world (Short 1988). Deep water waves of the Southern Ocean normally exceed 5 m (Chelton et al. 1981) but are attenuated across the wide continental shelf in the GAB (Provis and Steedman 1985). Such waves may increase bottom friction and modify the along-shore flow and mixing. Such waves are known to affect the benthos. Coastline orientation and near-shore calcarenite reefs and headlands can further decrease wave energy near the coast (Short et al. 1986). Consequently, diverse landforms typical of high and low wave-energy environments can occur along the southern Australian coast. It is critical to develop a better understanding of the role of high energy Southern Ocean waves and how they change as they approach the coast, the variation in wave energy seasonally and in the long term, and how waves modify and interact with the coast as they enter shallower waters such as Spencer Gulf and Gulf St Vincent.

Internal waves may also be important in vertical mixing as found on the northwest shelf slope. Preliminary SAIMOS temperature logger data from the shelf slope also indicates such waves to exist and the observational data streams need to be re-continued.

Collectively, instabilities arising from either the differential motion of water (i.e. current shear, internal waves) or the different molecular diffusion coefficients of heat and salt (i.e. double-diffusion) generate turbulent mixing. Observations and quantification of both these forms of turbulent generating processes on vertical diffusion and diapycnal mixing rates in the SAIMOS region is limited (Doubell et al. 2014a), despite their importance for budgets of heat, salt and momentum in the ocean and the exchange of nutrients and carbon between the surface and deep waters. Future identification and quantification of turbulent mixing processes requires additional observational data-streams.

2.2.5 Science questions

The following high-level science questions will guide the SAIMOS Node observing strategy in this area:

a) There are several mechanisms for upwelling that include (i) Ekman wind forcing and modification due to alongshore divergence and CTWs, (ii) upwelling by the bottom boundary layer of the FC, (iii) canyons, and (iv) ENSO variability. The latter (iv) will be discussed in the next section. The mechanisms (ii) and (iii) will need data and studies that better define the magnitude and spatial extents of the FC. Studies of mechanisms (i) will need the current data
streams (CTD, ADCP) to be continued and replicated for the Bonney Coast and complemented by hydrodynamic modelling that allows the data streams to be extrapolated in space and time. Long (>10 year) time series are needed so that regression analyses can be made. We have in mind here that proxies for variables such as alongshore velocity and bottom temperatures may exist (e.g. coastal sea level and SST). In this case, expensive moorings might be sensibly replaced using sea level and SST data to provide useful estimates of upwelling.

b) What is the spatial and temporal extent of cross-shelf exchange associated with winter downwelling? Such downwelling may represent a major component of cross-shelf exchange. In addition, where does the water come from to replace the downwelled water and does the downwelling enhance the associated eastward shelf currents?

c) Are internal waves important? Internal waves may also be important in vertical mixing as found on the northwest shelf slope. Preliminary SAIMOS temperature logger data from the shelf slope also indicates such waves to exist and the observational data streams need to be re-continued.

d) What is the role of the intense surface waves in (i) modifying the ocean circulation and mixing, and (ii) determining the distribution of the benthos? A waverider buoy is needed in the mid-GAB as well as Gulf St Vincent to monitor changes in wave climatologies. These wave data could be used to validate coupled wave-hydrodynamic models. What is the wave climate in the Gulf St Vincent and how does it affect patterns of sediment transport, coastal erosion and pollutant dispersion along the Adelaide Metropolitan Coast?

e) What is the role of turbulent mixing processes on vertical diffusion and rates of diapycnal mixing? Ocean microstructure measurements are needed in the estuarine and shelf waters to quantify vertical budgets of heat, salt, nutrients and momentum. Observations of vertical diffusivities of heat, salt and nutrients can be used to validate wave-hydrodynamic models and biogeochemical fluxes which underpin new production in the four SAIMOS oceanographic sub-regions.

2.2.6 Notable gaps and future priorities

Notable gaps:
Temperature loggers: Temperature loggers deployed on dedicated moorings would be an inexpensive method for monitoring upwelling dynamics along Bonney Coast. These shelf areas are not amenable to gliders because of the large number of lobster pots that are present; bio-logging has not been conducted in these areas and pinnipeds which sample to the seafloor (i.e. Australian sea lions) do not occur there. Existing or proposed acoustic logger moorings have temperature loggers only near the seafloor.

Arrays deployed at strategic locations on the shelf in these subregions (and possibly the eastern GAB) would accurately record the dynamics and intensity of upwelling events. Loggers would be deployed at depth intervals which would document stratification at a resolution of ~20 m or less, offering
insights into the spatial and temporal variability of thermoclines, and their relationship to variability in upwelling intensity over multiple seasons.

Temperature loggers would provide useful long-term data for the study of temporal and spatial variability in cycles of upwelling and downwelling, including stratification and connectivity between upwelling areas. The loggers would also provide continuous long-term data useful for the study of such taxa as krill, rock lobster, giant crabs, a range of finfish species and their predators including other fish (e.g. teleosts, bluefin tuna), seabirds, and marine mammals such as seals, dolphins and whales.

**Turbulence microstructure:** High-resolution observations of turbulent microstructure (e.g. Wolk et al. 2002, Doubell et al. 2009, 2014b) undertaken on SAIMOS cruises would provide for quantification of turbulent mixing processes and their spatial variability across the SAIMOS sub-regions and temporal variability between stratified (summer) and non-stratified (winter) conditions and up and downwelling periods. The data would provide useful information of vertical fluxes, as well as ecologically relevant information on small-scale processes which affect the productivity and dynamics of phytoplankton, plankton and larvae (Doubell et al. 2014b).

**Future priorities:**

Determine the spatial and temporal nature of the FC to evaluate the importance of boundary and canyon induced upwelling. Implement CTD and ADCP moorings for the Bonney Coast so as to provide information to determine the role of Ekman upwelling and alongshore current convergence. Use the data to determine cheaper proxies for the estimation of upwelling in the long term.

Additional CTD sampling and further strategic use of SOOP to evaluate the spatial and temporal extent of downwelling, mixed layer depths and critical depths. Develop simple proxies (e.g. a single mooring) that could be used to estimate these parameters for the long term.

The continued production of wave data streams from the WERA radar in SA by ACORN. This will provide intermittent information that would be sufficient for model validation purposes.

### 2.3 Climate variability and weather extremes

#### 2.3.1 Inter-annual climate variability

#### 2.3.1.1 El Niño –Southern Oscillation (ENSO)

As noted, the ocean currents of the SAIMOS region appear to be influenced by ENSO/El Nino events in the Pacific, whereby a relaxation of equatorial winds drives an eastward flow of deep warm water. The thermocline in the western Pacific is thus raised and this signal propagates around the shelf slope of Papua New Guinea, the west coast of Australia and as far as Victoria (Li and Clark 2004, Middleton et al. 2007). Evidence suggests (Middleton et al. 2007) that the thermocline is raised by 170 m or so leading to enhanced upwelling off the Bonney Coast and Kangaroo Island. In addition, evidence suggests that such El Nino events also reduce the wintertime Leeuwin Current and
eastward shelf currents along Australia’s southern shelves and be important to the transport of marine biota such as Australian salmon and southern rock lobster larvae (Middleton and Bye 2007). During La Nina events, the opposite likely occurs and downwelling and eastward currents may be enhanced. These ENSO driven events are clearly important although further observations are required to determine the form of the ENSO slope waves and the interaction with wind driven upwelling and shelf currents.

2.3.1.2 Changes in basin scale winds stress curl

The Southern Annular Mode (SAM) is a large scale alteration of atmospheric mass between the mid and high latitudes (Baldwin and Thompson 2009) and is characterized by pressure anomalies of one sign centred in the Antarctic (~ 65°S) and anomalies of the opposite sign centred over about 40°S. The impact of these features on shelf and slope circulation off southern Australia is not well known. Information from the Bureau of Meteorology (http://www.bom.gov.au/climate/enso/history/ln-2010-12/SAM-what.shtml) indicates that:

“The Southern Annular Mode (SAM) describes the north–south movement of the westerly wind belt that circles Antarctica, dominating the middle to higher latitudes of the southern hemisphere. The changing position of the westerly wind belt influences the strength and position of cold fronts and mid-latitude storm systems. In a positive SAM event, the belt of strong westerly winds contracts towards Antarctica, leading to weaker than normal westerly winds and higher pressures over southern Australia, thus restricting the penetration of cold fronts inland. Conversely, a negative SAM event reflects an expansion of the belt of strong westerly winds towards the equator. This shift in the westerly winds results in more (or stronger) storms and low pressure systems over southern Australia. During autumn and winter, a positive SAM value can mean cold fronts and storms are farther south. However, in spring and summer, a strong positive SAM can mean that southern Australia is influenced by the northern half of high pressure systems, and hence there are more easterly winds bringing moist air from the Tasman Sea.”

Changes in the position of atmospheric high and low pressure systems driven by the SAM affect the influence and strength of westerly/easterly winds in the Southern Ocean. Changes of winds in the Southern Ocean (and, indeed, the Pacific and Indian Oceans) may be important to changes in wind stress curl and thus Sverdrup transport and strength of boundary currents that impact the SAIMOS Node region. For example, the EAC has strengthened over the last 60 years and this may have led to an increase in the Tasman Outflow and the possibly FC (Ridgeway and Dunn 2007, Hill et al. 2008). Changes to the wind stress curl in the Southern Ocean will also directly impact on the strength of the FC.

As noted, the summer slope downwelling in the GAB is driven by the convergence of the deep ocean equatorward Sverdrup transport with the poleward topographic Sverdrup transport generated in the wide shelves of the GAB. Long-term changes in the wind stress curl will have a corresponding effect on the downwelling.

2.3.1.3 Weather extremes
The southern Australian shelves are subject to the cold, extreme weather that originates in the Southern Ocean. Wave heights can exceed 8 m 1.3% of the time and 5 m 17% of the time. Heat losses by the ocean can exceed 100 W/m$^2$, while during summer the opposite occurs (Rogers et al. 2013). Wind speeds can exceed 80 km/hr during winter. During summer, the shelves are exposed to the hot dry winds associated with desert conditions. During heat waves, surface ocean temperature off Kangaroo Island can be up to 23 °C or 5 °C above the long-term average. The strong differential between ocean surface and land temperature can lead to sea breezes of up to 10 m/s (36 km/hr) in the mid GAB. The coastal oceans are also subject to evaporation all year round of up to 1 m/yr, with no significant sources of fresh-water river discharge.

The coastal oceans (and ecosystems) have adapted to these extremes in seasonal meteorology through the development of a correspondingly extreme seasonal, variation in the oceanic flows and cross shelf exchange. Over the next 10 years, we expect that the individual oceanographic processes will become better documented and understood. However, SAIMOS may need to adapt some of its sampling strategies to examine the effects of extreme events.

### 2.3.2 Science questions

The following high-level science questions will guide the SAIMOS Node observing strategy in this area:

a) What is the impact of ENSO events on upwelling, downwelling and alongshore shelf currents? What other factors drive upwelling variability in the region (e.g. variability in the SAM)? Data sets needed are the continuation of the SAIMOS and WAIMOS observing systems along with additional deep water (to 300 m) CTD/seaglider transects. These data (and shelf and slope moorings) will be collected for both the Kangaroo Island and Bonney Coast regions to be compared to hydrodynamic model output so as to determine the above.

b) How do long-term changes in wind stress curl affect the boundary currents important to the region? The data needed here will include the SAIMOS moorings along with those off the southern tip of Tasmania and Perth. The required meteorological data/modelling is collected/available elsewhere. The effects of changes in the wind stress curl will be determined using the data collected and assimilating models that the node will build in the next decade.

c) What is the role of weather extremes in the shelf currents, cross-shelf exchange? Over the next 10 years, we expect that the individual oceanographic processes will become better documented and understood. However, SAIMOS may need to adapt some of its sampling strategies to examine the effects of extreme events.

### 2.3.3 Notable gaps and future priorities

**Notable gaps:**
Mooring data from the Bonney Coast (see previous section).

**Future priorities:**
See science questions
2.4 Multi-decadal ocean change

2.4.1 Southern Australian Ocean circulation

2.4.1.1 Wind stress curl and ENSO

As noted above, multi-decadal change in circulation can arise from long-term changes to wind stress curl in the South Pacific and Southern Ocean that act to drive the EAC and FC, respectively. In the context of the latter, changes in the wind-stress curl can also affect the degree of downwelling found in the central GAB. Intensification of the Indonesian through-flow can also enhance the Leeuwin Current and the shelf circulation in the GAB during winter.

The frequency of El Nino events appears to have increased over the last century and if continued could see greater upwelling off the southern shelves.

2.4.1.2 The southern Australian hydrological cycle (salinity and temperature)

Southern Australia encompasses two inverse estuaries: Spencer Gulf and Gulf St Vincent, where salinity depends on freshwater loss by evaporation and seawater inflow from the continental shelf (Nunes-Vaz 2012). In winter, the winds induce downwelling favourable conditions and a cold, dense high salinity outflow occurs from Spencer Gulf that is driven by surface cooling of high salinity waters at the head of Spencer Gulf (Middleton and Bye 2007). These high salinity waters are released from the Gulf by a series of bottom flowing gravity currents, to be replaced at the surface by less saline water from the continental shelf. Under the semi-arid climate of the sub-region, we however observe a well-defined salinity gradient along Spencer Gulf throughout the year. Recent research has shown that ocean salinity patterns express an identifiable fingerprint of an intensifying water cycle, suggesting intensification of the global water cycle in the future (Durack and Wijffels 2010, Durack et al. 2012). This is especially relevant in areas such as southern Australia where saline waters are predicted to become even saltier. This raises questions about the future of the gulfs and how this will impact biological productivity.

Enhanced upwelling through El Nino events may also act to bring fresher, colder water on to the shelves in the eastern GAB and off the Bonney Coast. This water is currently blocked from entering the Gulfs during summer though a density minimum at the mouth of the Gulfs. However, climate change may increase salinities and temperatures within the Gulfs. The implications for blockage at the Gulfs’ mouth are unknown.

More generally, decadal changes in the surface temperatures, salinity and density of the coastal oceans can lead to changes in coastal currents. Changes in surface density can act to raise or lower sea level through the production of relatively dense or light water: cold (warm) water sits lower (higher) in the water column and associated sea level gradients will drive geostrophic currents. This is the mechanism that drives the Leeuwin Current. The waters of the Indonesian through-flow are warmer and lighter than those to the south and the meridional sea level gradient drives an onshore flow that results in the pole ward Leeuwin Current.
2.4.2 The Southern Australian carbon cycle (inventory, air sea fluxes, physical controls)

As noted above, cross-shelf exchange on the southern shelves is highly seasonal with summer upwelling in the eastern GAB and Bonney Coast. During winter, downwelling is found along the entire southern shelves and in the Gulfs, and acts to flush the coastal waters of detritus and carbon. Generally, this water is replaced by inflows of the Leeuwin Current. Estimates of carbon fluxes for this system might be made but would need reliable estimates of the degree and extent of upwelling and the carbon composition. During summer, the principal source of carbon will be related to upwelled water – see Section 2.5.

2.4.3 Science questions

In the above, an outline of possible causes of decadal change in the circulation has been given. These are quite speculative. Indeed beyond the routine monitoring outlined above, there are real problems in identifying definitive causes and effects and region specific questions for decadal periods which might be answered.

The first problem is that the southern shelves are characterised by extremes in the seasonal variation in cross-shelf exchange and hydrographic properties. These extremes act to mask any long-term changes that might be present. The second problem is that climate induced decadal changes in the meteorology are at best only quantified for basin scales due to the relatively coarse resolution (~5 °C) of GCM’s used for climate prediction. A third problem is that the best available Ocean GCM for the Australian coastal region (BluelinkReAnalysis, Oke et al. 2008) can only at best give a qualitative description of shelf temperatures and salinities. For example, daily bottom temperature extracted for the Bonney Coast shows a 1 °C per decade increase over the period 1992-2008. The increased temperatures are not associated with climate change, rather ascribed to problems in the applied atmospheric heat fluxes near the coast and the relatively coarse vertical grid of 10 m (David Griffin pers. comm.). Data assimilating models such as BluelinkReanalysis can take advantage of the very long data sets that IMOS will develop. However, as with atmospheric models, there is likely to be a plateau in improvements in predictive (hind-cast) skill. The use of these models need intelligent application to further refine what observations will best increase skill.

Central to these tasks is the collection of very long-term data sets (> 20 yrs) through IMOS.

2.5 Ecosystem Responses

2.5.1 Ocean chemistry – nutrients

The waters of southern Australia, and the eastern GAB in particular, were traditionally perceived as having limited biological activity due to low nutrient availability (Motoda et al. 1978, Young et al. 2001). However, evidence of the occurrence of coastal upwelling in summer-autumn characterised by low surface water temperatures and elevated concentrations of chlorophyll a (Kaempf et al. 2004, McClatchie et al. 2006), suggest that during this period, surface waters may be enriched with
nutrients and promote high levels of primary productivity. Further studies have indicated that concentrations of macro-nutrients in the eastern GAB were at all times, in both upwelled and no-upwelled water, above those that may be considered limiting to phytoplankton growth (NO$_x$ > 0.4 µmol L$^{-1}$, P > 0.1 µmol L$^{-1}$, Si > 1 µmol L$^{-1}$, van Ruth et al. 2010a, b), and there was no indication of macro-nutrient limitation of primary productivity in the eastern GAB. These were spot measurements taken once per season, and therefore may not represent the extent of potential variation in nutrient concentrations in the region (van Ruth et al. 2010a, b). More recent observations have shown the significance of the upwelled water mass for generating double-diffusive instabilities, which drive enhanced vertical nutrient fluxes during summer, and have highlighted their significance for supporting the enhanced productivity of the upwelled water mass (Doubell et al. 2014a).

Nutrient concentrations in Spencer Gulf (SG) are highly variable in space and time. van Ruth and Doubell (2013) report peak macro-nutrient concentrations (particularly NO$_x$ and SiO$_2$) in SG that were comparable to those measured in the upwellings of the eastern GAB (see van Ruth 2010a, b). Despite this, SG waters were generally characterised by low concentrations of macro-nutrients. NO$_x$ concentrations were < 3 µM, with clear peaks observed in south western SG during winter and spring, and very low concentrations (typically below detection limits) in summer and autumn. NO$_x$ concentrations in northern and south eastern SG remained low throughout the year (< 0.5 µM). NH$_3$ concentrations across SG were relatively stable throughout the year (< 0.3 µM). Maximum concentrations occurred during autumn and winter, particularly in northern SG where concentrations exceeded 1 µM. PO$_4$ concentrations were typically very low, with most samples below the detectable limit (0.01 µM). Intermittent high concentrations of PO$_4$ (> 1.0 µM) were observed but showed no clear spatial or temporal patterns. Si levels were typically low (~0.5 - 1 µM) in southern SG, and were always greatest in northern SG, where concentrations peaked during autumn/winter (~2 - 5 µM). A similar pattern was previously reported for south western SG (van Ruth et al. 2009a). Potential limitation of phytoplankton growth was indicated for all macro-nutrients, with the exception of Si in northern SG. Of most interest was the fact that PO$_4$ was almost always found at concentrations likely to limit phytoplankton growth, an unusual occurrence for marine waters. Nitrogen inputs into SG appear to be large enough to promote the draw-down of phosphorus to limiting concentrations (Doubell et al. 2013, van Ruth and Doubell 2013). The largest nitrogen input into SG comes from inflows of shelf waters in the south west in autumn, with fluctuations through the rest of the year driven predominately by changes in anthropogenic inputs (waste-water treatment plants, heavy industry, aquaculture).

Changes in nutrient dynamics (speciation, supply ratios), driven by variations in meteorological and oceanographic conditions, can influence phytoplankton size structure and community composition, impacting on the pelagic food web dynamics. Such changes also impact the calcareous benthic biota and thus seafloor sediment composition. Ongoing monitoring of variations in nutrient dynamics in southern Australian waters is a fundamental requirement for understanding the structure and function of the pelagic ecosystem in the region.
2.5.2 Ocean chemistry – carbon and acidification

The absorption and sequestration of atmospheric CO\textsubscript{2} lowers the pH of the ocean which could have profound effects on marine ecosystems and food web dynamics. Southern Ocean acidification is expected to cause major problems for calcifying plankton species (e.g. cocolithophores, pteropods, larvae of some commercially important species) by lowering the concentration of carbonate ions to levels where both species of calcium carbonate (aragonite and calcite) begin to dissolve (known as aragonite/calcite undersaturation) (McNeil and Matear 2008). Evidence from western North America has emerged showing the upwelling of aragonite undersaturated water onto large portions of the continental shelf. Feely et al. (2008) concluded that upwelling processes are enhancing the entrainment of aragonite undersaturated waters onto the continental shelf. Aragonite dissolution is already taking place in the bottom sediment (James et al. 2005). Given the projected rapid occurrence of aragonite undersaturation in the Southern Ocean (McNeil and Matear 2008), the origin of water upwelled in the SAIMOS node region, there may be severely detrimental effects for planktonic community composition and food web dynamics, and issues for commercially important shellfish industries in the area (e.g. oysters). To foster our understanding of the impacts of ocean acidification on the ecosystems and industries supported by waters of the SAIMOS Node region, the monitoring of dissolved inorganic carbon (DIC), total alkalinity (TA) and salinity must continue at the Kangaroo Island National Reference Station, and eventually expand to include stations further west and east. Monitoring with the pCO\textsubscript{2} mooring should also be a priority. Furthermore, effects of dissolution on calcareous sediment particles must be monitored.

2.5.3 Plankton

Variations in primary and secondary productivity in southern Australian waters are implicitly related to variations in meteorology and oceanography in the region, which drive the supply of nutrients and irradiance to the autotrophic phytoplankton that underpin the entire food web. Rates of primary productivity in the eastern GAB are highest during the summer upwelling season, although there is considerable spatial variation (van Ruth et al. 2010a, b). The overall productivity of a summer/autumn upwelling season appears to be highly dependent on within-season variations in wind strength and direction, which dictate the number, intensity, and duration of upwelling events. Rates of primary productivity in areas of the eastern GAB that were influenced by the upwelled water mass were comparable to levels reported for the highly productive upwelling systems of the Benguela Current off southern Africa, and the Humboldt Current off the coast of Chile (van Ruth et al. 2010a, b). Euphotic depths in the eastern GAB during summer/autumn are shown to be always 20-40 m deeper than mixed layer depths, indicating that large volumes of the upwelled water mass were present below the surface mixed layer, yet still within the euphotic zone, and above the critical depth (van Ruth et al 2010a, b). This suggests that high primary productivity in the GAB can occur without the surfacing of the upwelled water mass. The contribution of the surface mixed and bottom layers of the euphotic zone to total primary productivity in the eastern GAB can vary considerably between years. At times, the surface mixed layer accounted for <40 % of total productivity despite the fact that it made up >50 % of the euphotic zone (van Ruth et al. 2010a). Indeed, deep chlorophyll maxima persist throughout the eastern GAB during the upwelling season, occurring in the upwelled water mass below the surface mixed layer (McClatchie et al. 2006, van Dongen-Vogels et al. 2011, 2012, van Ruth et al. 2010a, b). Highest phytoplankton abundances in the
region were also associated with the upwelled water mass, with the >5 μm phytoplankton community of the eastern GAB dominated by diatoms and dinoflagellates, with small flagellates present but much less abundant (van Ruth 2009). Peak meso-zooplankton abundances and biomass in the eastern GAB have been shown to occur in highly productive upwelled waters, in areas with greatest phytoplankton abundances, with the community dominated by copepods (van Ruth 2009, van Ruth and Ward 2009). Similarly, the spatial and temporal abundance of macro-zooplankton and small pelagic fish at a site off western Victoria were closely associated with the proportion of upwelled water on the shelf, and alongshore wind stress (Morrice 2014). It is likely the neritic fauna and thus sediments off the Bonney Coast are also closely linked to meteorological and ocean processes affecting primary production and sediment formation (James and Bone 2011).

In the first comprehensive study of lower trophic ecosystem function in SG, van Ruth and Doubell (2013) report on an ecosystem that appears to be regulated by “bottom up” factors, with potential primary productivity restricted by phosphorus limitation. This results in relatively low rates of primary productivity that prevent the accumulation of high concentrations of phytoplankton biomass. As a consequence, secondary productivity is also relatively low. While phosphorus limitation likely restricts overall productivity in SG, variations in nitrogen concentrations drive variations in phytoplankton biomass and abundance and primary productivity (van Ruth and Doubell 2013). van Ruth and Doubell (2013) conclude that:

“The annual cycle of productivity in SG appears to begin with a period of relatively high (for the region) primary and secondary productivity through summer/autumn. Decreasing secondary productivity in late autumn, when primary production remains relatively high, promotes the autumn/early winter peaks in biomass. Increasing phytoplankton growth rates through winter most likely reflect the influx of nutrients from shelf waters and aquaculture, but rates of primary productivity are low due to the short daylengths and reduced irradiance characteristic of winter months. Decreasing phytoplankton growth rates through spring into summer may signal the bottoming out of productivity as available nutrients disappear, and the beginning of the new cycle.”

The patterns in plankton dynamics reported by van Ruth and Doubell (2013) are in agreement with patterns identified in previous studies in SG (van Ruth et al 2009a, van Ruth et al. 2014) and south eastern Gulf St Vincent (van Ruth 2010, 2012).

It should be noted that the information presented above represents measurements collected over limited temporal and spatial scales in the SAIMOS node region and therefore may not represent the extent of potential variation in plankton productivity and community dynamics in southern Australian waters. There are still significant limitations in our conceptual understanding of ecosystem function and food web dynamics. Data are needed on the size structure and productivity of the microbial and planktonic communities of the SAIMOS node region, together with more data on patterns of regional connectivity, and intra- and inter-annual variability, to enable discrimination between long-term trends and rapid shifts in food web dynamics. This information is also needed to explain patterns in the distribution, abundance and migration patterns of apex predators, and their vulnerability to anthropogenic impacts.
2.5.4 Mid trophic levels (micro-nekton)

There have been relatively few studies of micro-nekton (including small pelagic fish) in the SAIMOS Node region. There is a paucity of information about the physical and biological processes that may underpin fluctuations in abundance/composition of micro-nekton assemblages, or linkages between the productivity of planktonic ecosystems and micro-nekton abundance. Recent reviews of the key species have highlighted the general lack of knowledge, with little to no research regarding their ecological role and spatial and temporal variability in the central GAB region (e.g. Rogers et al. 2013) or on the south eastern shelves. The importance of micro-nekton to the distribution and abundance of top predators has been reported for the eastern and western GAB inshore and shelf region (Page et al. 2006, Ward et al. 2006a, Goldsworthy et al. 2011), but little is known about their distribution in mesopelagic waters (200-1000 m depth) and their connectivity with epipelagic production.

Regarding small pelagic fish, Rogers et al. (2013) report:

“The assemblage of small pelagic fishes that occurs in the GAB is relatively diverse compared to other ecosystems (Bakun 1996); at least ten species belonging to six families regarded as common in the region (Rogers et al. 2006, Rogers and Ward 2007a, Rogers et al. 2008). Clupeids including Australia sardine, round herring (Etrumeus teres), sandy sprat, and blue sprat are all relatively abundant in some areas (Rogers et al. 2006). Other species that are also relatively common include: Australian anchovy, jack mackerel and yellowtail scad (Trachurus declivis and T. novaezelandiae), blue mackerel (Scomber australasicus), redbait (Emmelichthys nitidus) and the saury (Scomberesox saurus).

Some biological information is available for most species (with the exceptions of E. nitidus and S. saurus); mainly from the eastern GAB and the adjacent South Australian gulfs (see Rogers et al. 2006, 2008 for reviews). The Australian sardine, which supports Australia’s largest commercial fishery by weight (i.e. the South Australian Sardine Fishery), has been studied intensively and its life history and population size/dynamics are relatively well understood (Ward et al. 2001a, Ward et al. 2001b, Ward and Staunton-Smith 2002, Ward et al. 2006a, Rogers and Ward 2007b, Strong and Ward 2009, Ward et al. 2011). Blue mackerel, which is a quota species in the Commonwealth Small Pelagic Fishery, was also the subject of a four year dedicated biological/fisheries research program that established a reasonable understanding of its biology and provided some information on its patterns of distribution and abundance (Rogers and Ward 2007b, Rogers et al. 2009b, Ward et al. 2009). Some basic biological data are available for jack mackerel (Stevens et al. 1984). Two student projects provided valuable information on fisheries biology and ecology of sprats (Rogers et al. 2003, Rogers and Ward 2007a) and Australian anchovy (Dimmlich et al. 2004, Dimmlich and Ward 2006, Dimmlich et al. 2009). Virtually nothing is known about the biology or ecology of saury and redbait in the GAB.

Sprats and Australian anchovy are mainly found in South Australia’s gulfs and coastal embayments in the eastern GAB (Rogers et al. 2003, Dimmlich et al. 2004, Dimmlich and Ward 2006, Rogers and Ward 2007a, Dimmlich et al. 2009). Shelf waters of the eastern GAB support significant populations of Australian sardines, blue mackerel, jack mackerel and saury, but patterns of relative abundance appear to vary substantially among years (Ward and Rogers 2007).”

The limited information that is available on the spatial and temporal variation in abundance and composition of small pelagic fish assemblages in the eastern GAB has been obtained from
ichthyoplankton studies (Bruce and Short 1990, Ward et al. 2001b, Dimmlich et al. 2004, Rogers et al. 2006, Dimmlich et al. 2009). There have been few limited studies of the physical and biological processes that may underpin variations in abundance and composition (Bruce and Short 1990, Ward et al. 2001b, Ward and Staunton-Smith 2002, Dimmlich et al. 2004, Ward et al. 2006a). Minimal information has been obtained on the small pelagic fishes in shelf waters of the central-western GAB, although this area has been identified as a potentially significant spawning ground for blue mackerel (Ward and Rogers 2007), with no information for the south eastern shelves. Virtually no data have been collected on pelagic fishes beyond the continental shelf in any part of the GAB or the south eastern shelves.

2.5.5 Top predators

Southern Australia has been identified as supporting the greatest density and biomass of apex predators to be found in Australian coastal waters. This includes many populations of iconic species and apex predators of national and international conservation significance (Goldsworthy et al. 2011, Gill et al. 2011, Goldsworthy et al. 2013, Rogers et al. 2013). Their distribution encompasses the southern gulfs, neritic and continental shelf slope ecosystems that form the northern-most boundary of the Southern Ocean. These discrete systems support large densities of marine mammals, seabirds, sharks and large pelagic fishes. However, their relative abundance, population structure, foraging dynamics, residency, and migratory patterns in southern Australia are poorly understood compared to other productive global marine ecosystems (e.g. Block et al. 2011, Hindell et al. 2011).

Marked shifts in relative distribution, foraging locations, diet, reproductive success and population dynamics of apex predators are predicted to occur in response to prey availability. Such changes are ultimately driven by oceanographic changes such as processes related to boundary currents, upwelling events, and ENSO, as well as connectivity between oceanographic sub-regions, and thermocline breakdown associated with the progression of winter downwelling (Page et al. 2006, Baylis et al. 2008, Bruce and Bradford 2013). Such linkages between predator diversity, distribution and abundance and the underlying bio-oceanographic and climatic drivers remain unresolved for most of the key species, but are central to understanding the why the region is important to apex predators and how changes may impact their population distribution and abundances. This information gap is currently restricting our ability to better understand ecosystem structure and function, which ultimately support many of our key marine industries and communities.

The oceanographic processes that underpin primary-secondary-prey productivity and predators distribution and movements can be elucidated through the integration of IMOS datastreams, which will accelerate our ability to characterise what constitutes marine productivity ‘hotspots’ and ‘areas of ecological significance’ (Hindell et al. 2011). Such improved understanding of the key drivers underpinning abundance and movements of predators will allow better prediction of changes due to anthropogenic activities or climatic events (Lowther et al. 2013).

Given the national and international conservation significance of many apex predators and iconic species, there is urgent need to improve our understanding of their abundance, movements, growth, residency, critical habitat and the role and importance of SAIMOS waters of the Great
Australian Bight to these species. In particular, there is a need to understand the underpinning bio-oceanographic and climate drivers, which may be influenced by the increase in anthropogenic activities in the Gulfs, shelf and near-slope ecosystems. For example; the little studied Otway shelf off the Bonney Coast is relatively wide and upwelling is only occasionally visible along the shore in SSTs. The cool upwelled water is usually present across the shelf throughout summer and autumn below the warm mixed surface layer and shows a high degree of connectivity with the hydrography of the Bonney, and Lincoln Shelves (Levings and Gill, 2010). The extent to which the subduction occurs shoreward is contingent on the magnitude of wind forced transport of surface waters and compensatory pumping of Antarctic intermediate water/sub-Antarctic mode water. Although these nutrient laden waters are masked by warmer oligotrophic surface layers, the clarity of the top layers allow deep penetration of sunlight, stimulating primary production and subsequent food chain links that ultimately support blue and other great whales (Gill et al. 2011, Morrice 2014).

2.5.6 Benthos

The biogeochemistry of coastal systems plays a key role in elemental cycling (e.g. nitrogen and carbon), with local and global consequences for elemental budgets (Nixon and Pilson 1983). The high productivity of continental shelves in general, and the upwelling system of southern Australia (van Ruth et al. 2010a, b), provide for active sites of fixed nitrogen removal from the ocean through microbially mediated denitrification in sediments (Fennel et al. 2006). The role of sediment processes on biogeochemical cycling in southern Australia remains poorly quantified but recent work suggests that it is profound (James et al., 2005; Rivers et al, 2005). However, limited observations (Lauer et al. 2007a, b) and model results (Doubell et al. 2013) in the anti-estuarine system of Spencer Gulf suggest denitrification processes are the largest sink for nitrogen, removing approximately 84% of nitrogen annually entering the Gulf, and strongly influence the yearly cycle of the Gulf’s chemical and biological systems.

Oceanographic processes contribute to benthic community composition by providing larval (Underwood and Fairweather, 1989) and nutrient transport (Ward et al. 2006, van Ruth et al. 2010a, b) and hydrodynamic forces to the benthos (seafloor animals and plants) (Ferrier and Carpenter, 2009), as well as affecting sediment transport, which in turn affects the distribution of fauna (Snelgrove and Butman 1994). As noted above (section 2.1.2), there is strong evidence that the shelf distributions of neritic carbonate sediments is determined by the cross-shelf supply (or otherwise) of nutrients.

Systematic surveys of benthic infauna and epibenthos in Southern Australian waters have been rare until the last decade when surveys of the GAB shelf and adjacent areas (Ward et al. 2006, Sorokin et al. 2007, Currie et al. 2008, 2009, Currie and Sorokin 2009), Spencer Gulf (Currie et al. 2011), Gulf St Vincent (Tanner 2005, Rowling 2009) and du Couedic and Bonney canyons (Currie and Sorokin 2014) have shown that the benthos is highly diverse with many previously unknown species. However, spot surveys of benthic infauna and epibenthos have also shown substantial changes over time in both Gulfs (e.g. Tanner 2005, Loo 2007, Rowling 2009). Details of deeper-water continental slope in the GAB are virtually unknown. A preliminary survey of the epibenthos and infauna of the GAB slope (Currie and Sorokin 2011) provided an insight (84 epifaunal species and 57 infaunal species) but has yet to be followed up with a comprehensive survey.
Circulation patterns of bottom water in the GAB are poorly understood with minimum information available on the transport of sediments, or the movement of benthic larvae and nutrients (Ward et al. 2006). Recent isotope geochemical study points the way to future research (Richardson et al, 2009). Many of the marine species that inhabit the temperate waters of southern Australia are characterised by short larval periods and localised dispersal. For these reasons, it has been proposed that there is a high tendency for local and regional rarity and endemism in temperate waters. Currie et al. (2008) found little evidence to support this on the GAB shelf suggesting that the shelf epifauna are components of the wider Flindersian biogeographical province. Currie et al. (2009) suggest that the moderate diversity of infauna in the GAB could be due to low input of terrigenous sediments and nutrients compared to the comparatively high diversity of epifauna whose food supply is supplemented by enhanced pelagic productivity in the eastern GAB due to seasonal upwelling.

In Spencer Gulf there are large differences in benthic community composition between the northerly and southerly regions of the Gulf. Currie et al. (2011) suggest that this difference is likely to result from various oceanographic factors including temperature gradients, turbidity and the north-south salinity gradient (Nunes and Lennon 1986). In addition, benthic abundances and biomasses are much higher on the western side of the Gulf, compared with the eastern side (Currie et al. 2011). The clockwise pattern of water circulation in the Gulf may be influencing this, but further supportive oceanographic data are needed to clarify the effects of oceanographic factors on the distribution of benthos (Currie et al. 2011).

A high biomass of benthos at the top of du Couedic Canyon south of Kangaroo Island, (Currie and Sorokin, 2014), also poses questions for oceanographic processes and pelagic productivity. It is suggested that either seasonal upwelling that promotes hotspots of productivity (Ward et al. 2006, van Ruth et al. 2010a, b) or a nutrient-laden dense tongue of hypersaline water formed in the Austral winter that flows from the Spencer Gulf (see Section 2.2.2.) could be responsible for the biomass, which is significantly lower in the Bonney Canyon (Currie and Sorokin 2014).

As mentioned above, variations in climate and upwelling cycles influence larval recruitment and population dynamics (Underwood and Fairweather 1989, Menge et al. 2009). Shelf circulation along southern Australia occurs in synchrony with the timing of the Austral seasons, and the scale and duration of the associated weather events. The scale of the events are node wide and overlie global ocean current circulations, hence we see pulses of larval recruitment in the Southern Rock Lobster fishery at the same scale across South Australia, western Victoria and Tasmania (Linnane et al. 2010) and giant crabs which live as nomads in a thermal niche, exhibiting similar depth distributions at widely separated locations at this scale (Levings and Gill 2010).

The extent of subduction of Antarctic Intermediate Water/Sub-Antarctic Mode Water to nearshore areas shallower than 60 m has the potential to impact on the moult frequency and increment of southern rock lobsters. These important commercial species are poikilotherms with no internal temperature regulation, whose metabolisms for growth rely on the temperature of their external environment. Over 90% of the lobster harvest is derived from nearshore areas <60 m and the discrimination of natural factors that influence greater or lesser abundance of harvestable size classes is advantageous for the management of this species.
2.5.7 Science questions

Science questions that will guide SAIMOS examinations of ecosystem responses have been designed with the following aims in mind:

- To quantify elemental fluxes of nitrogen and carbon in the four key oceanographic sub-regions of SAIMOS.
- To assess variation in primary and secondary productivity and food web structure.
- To provide information on the distribution and abundance of microbial (i.e., viruses and bacteria, nano- and pico-phytoplankton), planktonic (i.e., phytoplankton, micro-, meso- and macro-zooplankton), benthic (infauna and epibenthos) and micro-nekton (krill, small pelagic, meso-pelagic fish) communities.
- To monitor the distribution, movements, abundance, and critical habitats of key apex predators.
- To examine the influence of variation in cycling of upwelled and downwelled water on mixed layer depths and critical depths, associated food web dynamics and biogenic sediment production.
- To examine the influence of upwelling cycles on larval recruitment and population dynamics.
- To assess the level of connectivity between the four key oceanographic sub-regions in SAIMOS’ area of interest, and uncover the bio-oceanographic processes that determine the extent of such connectivity.
- To determine long-term changes of apex predators movements and relative distribution in relation to climatic and bio-physical oceanographic changes.
- To establish the relationship between nutrient availability, planktonic and benthic trophic resource partitioning, chemical and physical oceanography, and regional calcareous sediment patterns.

The following high-level science questions will guide the SAIMOS Node observing strategy in this area:

Productivity

a) How do variations in oceanographic processes, nutrient dynamics (speciation, supply ratios), and connectivity between oceanographic sub-regions influence ecosystem productivity, carbonate sediment production, and shifts in food web structure between the microbial and classic upwelling food webs?

b) What is the extent of spatial and temporal variation in primary and secondary productivity in southern Australian waters, how is this influenced by variation in oceanographic processes and connectivity between oceanographic sub-regions, and what are resultant seafloor sediment facies?

c) What is the lag between an upwelling event and increased primary and secondary productivity?
d) What role does upwelling driven primary and secondary productivity play in explaining the spatial dynamics and temporal windows that constitute ‘hot spots’ (Areas of Ecological Significance) for apex predators and high carbonate sediment?

e) What combination of physical and biological oceanographic factors and conditions define the ‘marine deserts’ that comprise the migration and movement pathways of predators between ‘hot spots’?

**Distribution and abundance**

a) How do variations in oceanographic processes, nutrient dynamics (speciation, supply ratios), and connectivity between oceanographic sub-regions influence the distribution, abundance, and size structure of microbial (i.e., viruses and bacteria, nano- and pico-phytoplankton), and planktonic (i.e., phytoplankton, micro-, meso-, and macro-zooplankton) communities and thus calcareous sediment distribution and apex predators?

b) What roles do short- and long-term variations in upwelling cycles play in the success of larval dispersion, recruitment, growth and population dynamics of key species in the SAIMOS Node region?

c) What are the key physical and biological oceanographic features that underpin the distribution, key foraging locations, movements and migratory patterns of apex predators? How are predator distributions and abundance impacted by dynamic changes in physical and biological oceanography at seasonal, annual and longer-term time scales?

d) What have been the changes in past carbonate sediment patterns driven by oceanographic change and thus what are the likely implications of climate change and extreme climate events on the status, distribution and abundance of microbial, planktonic and apex predator populations?

e) What are the present relationships between climate change and ocean acidification as reflected in biogenic and sediment mineral specific dissolution?

**2.5.8 Notable gaps and future priorities**

**Notable gaps:**

**Rates of sediment nutrient fluxes:** The role of sediment processes in biogeochemical cycling in southern Australia remains poorly quantified, but is very important. Sediment denitrification processes can be an important sink for nitrogen, and strongly influence the cycles of chemical and biological systems. Further investigation and quantification of biogeochemical fluxes and variability in the oceanographic sub-regions of southern Australia are necessary to understand their influence on ecosystem structure and function and the development of more accurate biogeochemical models for the SAIMOS node.

**Rates of primary and secondary productivity:** To date, IMOS data streams have focussed on spatial and temporal variations in plankton biomass (which has been termed net community productivity).
Relying on this information alone can lead to incorrect conclusions being drawn regarding variations in ecosystem productivity. A full understanding of variations in lower trophic ecosystem productivity and food web dynamics cannot be achieved without considering changes in the physiological rates that drive the accumulation and decay of plankton biomass. Routine measurement of rates of primary and secondary productivity, via fluorometry, stable/radioactive isotope, and biochemical studies, is necessary to address this knowledge gap.

**Connectivity between the four key oceanographic SAIMOS sub-regions:** There is a paucity of data regarding ecosystem dynamics in the south eastern shelves and central-western GAB. Information is needed on spatial and temporal variations in nutrient concentrations, microbial and plankton biomass, abundance and community composition, primary and secondary productivity, and apex predators. The extent of connectivity across the SAIMOS node area cannot be determined without understanding variations in the dynamics of individual sub-regions. Foraging apex predators traverse great distances across the node area, and the identification and monitoring of important habitat and migratory paths of these animals could help explain connectivity between sub-regions and overall ecosystem dynamics in the SAIMOS area of interest.

**Future priorities:**

Measurements of rates of sediment denitrification and such other important sediment fluxes as carbon, alkalinity and dissolved oxygen.

Measurements of rates of primary and secondary productivity via fluorometry, stable/radioactive isotope, and biochemical studies.

Sampling on the south eastern shelves and in the central-western GAB to assess spatial and temporal variation in nutrient concentrations, microbial and plankton biomass, abundance and community composition.

Identification of important habitat and migratory paths of apex predators, environmental conditions characterising these habitats/paths, and predator-prey interactions affecting spatial and temporal fluctuations in their distribution and residency. SAIMOS would look to set receivers, in agreement with the ATAAAMS facility, in locations designed to answer the science questions of the node, specifically around connectivity of the SAIMOS sub-regions, and the identification and characterisation of important habitat, residency and migratory paths of apex predators.
3 How will the data provided by IMOS be taken up and used?

Table 14: How IMOS Facilities deliver to the Nodes. $P = \text{primary relationship and } s = \text{secondary relationship}$

<table>
<thead>
<tr>
<th>Bluewater &amp; Climate</th>
<th>WA</th>
<th>QLD</th>
<th>NSW</th>
<th>SA</th>
<th>TAS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Argo</td>
<td>$P$</td>
<td>$s$</td>
<td>$s$</td>
<td>$s$</td>
<td>$s$</td>
</tr>
<tr>
<td>SOOP</td>
<td>$P$</td>
<td>$P$</td>
<td>$P$</td>
<td>$s$</td>
<td>$s$</td>
</tr>
<tr>
<td>Deepwater moorings</td>
<td>$P$</td>
<td>$s$</td>
<td>$s$</td>
<td>$s$</td>
<td>$s$</td>
</tr>
<tr>
<td>Ocean gliders</td>
<td>$s$</td>
<td>$P$</td>
<td>$P$</td>
<td>$P$</td>
<td>$P$</td>
</tr>
<tr>
<td>AUV</td>
<td>$P$</td>
<td>$P$</td>
<td>$P$</td>
<td>$P$</td>
<td>$P$</td>
</tr>
<tr>
<td>Shelf Moorings</td>
<td>$P$</td>
<td>$P$</td>
<td>$P$</td>
<td>$P$</td>
<td>$P$</td>
</tr>
<tr>
<td>Ocean Radar</td>
<td>$P$</td>
<td>$P$</td>
<td>$P$</td>
<td>$P$</td>
<td>$P$</td>
</tr>
<tr>
<td>Animal Tagging</td>
<td>$P$</td>
<td>$P$</td>
<td>$P$</td>
<td>$P$</td>
<td>$P$</td>
</tr>
<tr>
<td>Sensor networks</td>
<td>$P$</td>
<td></td>
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</tr>
<tr>
<td>SRS</td>
<td>$P$</td>
<td>$P$</td>
<td>$P$</td>
<td>$P$</td>
<td>$P$</td>
</tr>
<tr>
<td>eMII/AODN</td>
<td>$P$</td>
<td>$P$</td>
<td>$P$</td>
<td>$P$</td>
<td>$P$</td>
</tr>
</tbody>
</table>

3.1 Ensuring the data are used

The SAIMOS Node has been pro-active in promoting the use of the data streams to decision makers, as well as the research community and industry. In the following we list several major projects that are making use of the SAIMOS data streams followed by student projects and training in field work and data analysis.

3.1.1 Major Projects

- The Great Australian Bight Research Program. This $20M, four year program seeks to provide baseline information on the physical, biological and geological properties of the GAB, as well as the benthos, microbes, plankton, micro-nekton and iconic species (www.misa.net.au/GAB). Extensive use will be made of the SAIMOS and other
observations particularly through the assessment of food web dynamics, the development and validation of hydrodynamic models of the region, and modelling of apex predator distributions and habitat. The GAB Research Program is a collaboration between BP, CSIRO, SARDI, the University of Adelaide, and Flinders University.

- FRDC, The South-East Climate Adaptation Program. (DEPI, IMAS, CSIRO, SARDI). This multidisciplinary 3-year project has provided adaptation strategies to climate change for the SE region of Australia (Hobday et al. 2012).


- FRDC, Prawn and Crab harvest optimisation: a biophysical management tool, $269K, (SARDI).


- Seafood CRC - Project 2013/746: Optimizing the size and quality of sardines through real-time harvest monitoring, $170K, (SARDI).

- Nectar: Marine Virtual Laboratory (MARVL), $1.3M.

- Transects for Environmental Monitoring and Decision Making. This program is being developed and involves setting up long-term monitoring of the terrestrial and marine environment for the purposes of monitoring climate and climate change. Monitoring and north-south transects of the Gulfs within S.A. are also proposed and a potential link to IMOS noted (DoE, SARDI, NRM, DWLBC and SA Universities).

- Predicting impacts of global climate change on coastal waters, using southern Australian aquaculture as an example: risk assessment, business susceptibility and ecological assays. This (proposed) 3 year project will use a portion of water samples collected by SAIMOS to determine the temporal and spatial variability of acidification (University of Adelaide, SARDI, SA Water).

- SA Water will use the mooring data collected off the Eyre Peninsula to determine the suitability of the region as a host for a desalination plant.

- From individuals to populations: multiscale approaches to ensure long-term persistence of whaler sharks (ARC Linkage project between Flinders University and the University of Adelaide)


### 3.1.2 Student Projects

**PhD**

- Carlos Teixeira, The Ocean Circulation of Spencer Gulf: a numerical study, SARDI/UNSW, August 2006 - December 2010, Accepted, Supervisors: J. Middleton, M. Roughan

- Virginie van Dongen-Vogels, Impact of physical forcings (upwelling/downwelling) and nutrients availability on the space-time dynamics of picophytoplankton communities, Flinders University, January 2008 - July 2011, Accepted, Supervisors: L. Seuront, S. Leterme

- James Paterson, Coastal upwelling and its effects on marine microbial processes, Flinders University, February 2008 - November 2012, Accepted, Supervisors: L. Seuront, J. Mitchell


- Margie Morrice, Fine-scale foraging habitat and behavioural responses of pygmy blue whales, Deakin University, 2013, Accepted, Supervisors: A. Bellgrove, G. Quinn and T. Jarvis.

- Laura Richardson, Water Mass Connectivity and Mixing along the Souther Margin of Australia: hydrographic and stable isotope analysis; SARDI/ANU, March 2009 - February 2014, Submitted, Supervisors: J. Middleton, B. Opdyke


- Michael Drew, Assessment of the vulnerability of whaler sharks (genus *Carcharhinus*) to South Australian commercial fisheries, August 20011 – March 2015, Flinders University, Supervisors: C. Huveneers, P Rogers

**Honours**

- Nathavong Navong, Impact of upwelling events on the phytoplankton communities off the South Australian continental shelf, Flinders University, February - October 2010, Supervisors: S. Leterme, C. James

**Student Training in field work (all students are Flinders students unless otherwise indicated):**

40
3.1.3 Others

- Commonwealth and State managed fisheries and aquaculture will use the data streams of the status, trends and health of apex predator populations to assist in ongoing assessments and the ecological sustainable development (e.g. SA Sardine Fishery, Small Pelagic Fishery – FRDC $1.1M). Commonwealth and State marine parks may use these data as a performance indicator of marine parks, and more broadly of ecosystem health.

- The AATAMS community and network encompass over 110 scientists from about 35 institutions. The receivers’ part of the South Australian network will be able to detect any fish tagged by these 110 scientists, who will utilise the detections obtained to infer large-scale movements and changes in residence times or migratory patterns.

3.1.4 Partnering for sustained observing.

Partner Institutions include:

Flinders University, University of Adelaide, Curtin University, Macquarie University, the Institute of Marine and Antarctic Studies (University of Tasmania), Sydney Institute of Marine Sciences, Deakin University, CSIRO, AFMA and the SA Government organisations, Dept. Further Education Employment, Science and Training, Dept. for Environment, Water and Natural Resources, Primary Industries and Regions South Australia (PIRSA), and the South Australian Research and Development Institute (SARDI). SAIMOS Advisory Board members are also drawn from DSTO, the Bureau of Meteorology and the National Tidal Facility.

Co-investments made:

The partnership is led by SARDI and Flinders University who will, by June 2015, have contributed $2.96M in-kind and cash to SAIMOS (see the Table below).

Marine Innovation Southern Australia (MISA) also provides salaries for Node members who provide in-kind to SAIMOS and to carry out research on the SAIMOS data. These have included Middleton, Luick, James, Leterme, Seuront, Huveneers, Goldsworthy, van Ruth, Malthouse, and Byrnes.

Additional in-kind contributions have been made by Huveneers and Goldsworthy (Flinders/SARDI) to the AATAMS facility. $10,000/year will be provided by Flinders University to service and download additional receivers deployed along the South Australian coastline.
An in kind contribution of ~$60K has been made by A. Levings and P. Gill in the deployment of temperature logger arrays off western Victoria between 2001-08.

**Table of SAIMOS Investments for the 8 year period, July 2007 to June 2015.**

The following lists an approximate breakdown of investments (excluding in-kind support for tagged apex predators) in $K. Total $9,116K.

<table>
<thead>
<tr>
<th>Type</th>
<th>Commonwealth NCRIS(EIF/NCRIS2)</th>
<th>SA Govt, inc. SARDI</th>
<th>Flinders Uni.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cash (inc. vessel time)</td>
<td>5,950</td>
<td>946</td>
<td>65</td>
</tr>
<tr>
<td>In kind</td>
<td>1,670^</td>
<td>1,094*</td>
<td>852</td>
</tr>
<tr>
<td>Total</td>
<td>7,620</td>
<td>2,040</td>
<td>917</td>
</tr>
</tbody>
</table>

*Only includes salaries.

^ excludes in kind IMOS support for gliders and RADAR

The total investment in SAIMOS is $10.58 M.

**Industry Engagement:**

We have continued engagement with the marine industry through presentations and meetings with representatives in Adelaide, Port Lincoln, Kingscote and surrounding regional areas. The purpose of these meetings is to explain what SAIMOS is, provide industry with a sense of “ownership”, seek their help in the future development of SAIMOS, and encourage and promote the update of SAIMOS data streams in their decision making. To illustrate the benefits of SAIMOS, we have also presented on our modelling and measurement capability through various projects, including the FRDC Finfish Aquaculture Carrying Capacity project which made extensive use of the SAIMOS data streams. We have presented to the industry associations for oysters, finfish aquaculture and sardines.
4 Regional, national and global impacts of IMOS observations

4.1 Short term: 5 to 10 years

In the next 5 to 10 years, the SAIMOS data streams will enable many of the key science questions detailed in the Node Plan to be addressed and answered. In particular, data over the next decade will enable the climate of, and relationships between, the physical environment and ecosystems to be determined. Impacts over this time frame include:

- The existence of the SAIMOS data streams has already led to additional investment of $1.9M by government and the FRDC in the Carrying Capacity, Prawn and Spencer Gulf Research Initiative projects (see section 3.1.1 above) and the Seafood CRC Sardine project.

- In conjunction with hydrodynamic and biogeochemical model development, the SAIMOS data will be of great use in providing improved tools to better inform the management of SA’s and western Victoria’s marine environment and fisheries. Coupled, calibrated and validated hydrodynamic and biogeochemical models provide valuable predictive management tools for regulators and industry. This work has begun with the FRDC Carrying Capacity, Prawn and Seafood CRC Sardine projects noted above.

- The development of biogeochemical and hydrodynamic models that assimilate the SAIMOS data streams. These models will help answer the science questions, “interpolate” the data streams and identify proxies for key variables to drive observational costs down.

- Based on the above, the development of operational hydrodynamic model for now-casts and forecasts. These models will be invaluable in alerting marine industries to likely vectors of pathogens, harmful algal blooms, etc.

- At a national level, the SAIMOS observations will link to those off W.A. and Tasmania to provide the first quantitative measure of connectivity through our “shared” Tasman Outflow, Flinders and Leeuwin Currents and ENSO forcing.

- The increase of acoustic receiver data from SAIMOS within the AATAMS database enabling the Australian scientific community to answer large-scale questions about the movements and relative distribution of apex predators. AATAMS is also a major international collaborator and the key Australian contributor of the International Ocean Tracking Network (OTN). The OTN leads the deployment of acoustic receivers at key locations throughout the globe and allows the integrations of the movements of organisms outside Australia.

- The Great Australian Bight Research Program will provide baseline information on the physical, biological and geological properties of the GAB, as well as the benthos, microbes, plankton, micro-nekton and iconic species (www.misa.net.au/GAB). Extensive use will be made of the SAIMOS and other observations particularly through the assessment of variations in the size structure of microbial and planktonic communities and food web dynamics, and the development and validation of hydrodynamic models of the region.

- Biologging and acoustic monitoring of apex predator populations will provide critical data on the habitat needs, and oceanographic and ecological factors that underpin the high trophic
levels, and their foraging ecology and critical foraging areas including those utilised by multiple species (Areas of Ecological Significance). At a regional and national level such information will be critical to managing human utilisation of marine resources to ensure sustainability, and in the management of marine parks. At an international level, miniaturisation of instrumentation that incorporate new sensors is rapidly evolving as well as new technology (e.g., Vemco’s VMT) providing new opportunity to collect additional data streams, investigate interactions between species and individuals, and utilise a broader range of species that can gather observations from other sub-regions and regions.

- The increased acoustic coverage provided by the receivers from the South Australian network will fill in a coverage gap identified by AATAMS and the user community. The compatibility of the receivers deployed with the equipment used nationally and internationally (e.g. Ocean Tracking Network) will provide sustained observing for tagged predators regionally, nationally, and internationally. Interstate migrations have already been recorded by acoustic receivers, whereas international interest in acoustic telemetry has grown exponentially with the OTN and the increased number of tagged organisms around the world.

- The passive acoustic observatory will provide indices of several great whale species which migrate nationally along the southern, western and eastern Australian coasts (i.e. pygmy and Antarctic blue, dwarf minke, Antarctic minke, fin, sei and humpback whales) and internationally, into the southern ocean (i.e. Antarctic minke, fin, sei, humpback and pygmy and Antarctic blue whales). The SAIMOS observations will be a key piece in understanding movements and local habitat utilisation by these whales.

4.2 Long term: 20 years and beyond

Over decades, the data streams will enable the determination of long-term trends in climate and ecosystem dynamics, and aid in the identification of ecosystem responses to changes in climate. The strengths of the major boundary currents may vary in response to basin-scale changes in winds and wind stress curl and affect connectivity between oceanographic sub-regions. Warmer waters may be driven further south, although upwelling may be enhanced. Regime shifts in microbial and planktonic abundance and community composition may occur with unknown consequences for populations and distributions of pelagic fish and apex predators.

It is expected that such impacts will be determined by analyses of the data streams being collected at the national level by both the coastal and bluewater nodes.
5 Governance, structure and funding

5.1 The Node

5.1.1 Funding:
Each of SARDI and Flinders University contribute $2.5K each year to support SAIMOS Node activities including glider deployments/retrievals.

5.1.2 Membership:
The node membership is open to all and is achieved by registration of email address with SARDI.

5.1.3 Governance:
Draft Node plans are submitted to the membership for discussion and input to ensure the plans reflect the wishes of the broader research community. A SAIMOS Advisory Committee exists to provide the Node Leader with advice from the broader, environmental, industry and management community.

5.1.4 Stakeholder engagement and co-investments
Detailed under section 3.1.3 and 3.1.4.
6 References


Linnane A, Gardner C, Hobday D, Punt A et al. (2010a) Evidence of large-scale spatial declines in recruitment patterns of southern rock lobster Jasus edwardsii across south-eastern Australia. Fisheries Research 105, 163–171


