

IMOS is an initiative of the Australian Government being conducted as part of the National Collaborative Research Infrastructure Strategy

Bluewater and Climate Node

Science and Implementation Plan

Node Leader: Mr. Ken Ridgway

CSIRO Marine and Atmospheric Research

Castray Esplanade, Hobart, Tasmania, Australia

Ph: +61 3 62325226

Fax: +61 3 62325053

ken.ridgway@csiro.au

1. Introduction

The Bluewater and Climate Node (BCN) encompasses ocean observations from the open ocean, in support of both short time-scales associated with ocean prediction and the longer term scales of climate research. The predominant focus is with the physical and dynamical state of the ocean (sea level, temperature, salinity, currents) however, there is also a growing recognition of the importance of acquiring biogeochemical observations on a regular basis.

The target research communities cover climate change and its impacts, particularly in the marine environment, seasonal-to-interannual climate variability and prediction, Antarctic and Southern Ocean research across all time scales, ocean/marine variability and prediction. There are a range of research activities that indirectly draw on ocean observation infrastructure, including weather prediction, studies of the water and carbon cycles, and cryospheric research.

Australia has research interests in the tropical and western Pacific, the Indian Ocean, and the Southern Ocean. These interests extend to regional features such the east Australian Current, the Leeuwin Current, the Coral and Tasman Sea regions, and the Indo-Pacific Throughflow.

Open-ocean and related climate research has long been closely connected to, and integrated with, international research programs. There are many substantial international links, leveraging additional observational effort in our region. The TOGA, WOCE, JGOFS and CLIVAR programs have been important vehicles for coordinating this involvement. Pilot projects such as GODAE and Argo have been important for providing a research setting for developing robust, sustainable infrastructure. The Global Ocean and Global Climate Observing Systems (GOOS and GCOS, respectively), largely depend on significant research investments such as IMOS.

The implementation plan presented here should be seen in this broader national and international context. It demonstrates how the Bluewater and Climate Node activities provide additional leverage of existing and planned international observing activities, particularly from the major satellite agencies such as NASA, NASDA and ESA.

This document provides the scientific background to the Node and describes how these elements fit together to form a national integrated system.

2. Socio-economic Context

Australia is an island continent, with a coastal and marine territory that borders three great oceans: the Pacific Ocean in the east, in the west the Indian Ocean, and the Southern Ocean providing a southern boundary. To the north it is bounded by the shallow waters of the Timor Sea, Arafura Sea and Torres Strait which flanks Indonesia, East Timor and Papua New Guinea.

Australia has one of the largest marine areas in the world, extending over about 16 million square kilometres. This is more than double the continent's land area and includes some 4.4% of the global ocean area. Australia's ocean domain includes all five of the world's ocean temperature zones - tropical, subtropical, temperate, subpolar and polar. The domain encompasses diverse marine and estuarine habitats ranging from small estuaries to the extended continental shelf, and from the tropics to the Antarctic and to the island ecosystems of Australia's external territories. Coastal habitats of beaches, dunes, rocky

shores, seagrass beds, algae-covered reefs, coral reefs and mangrove swamps commonly occur. These habitats contain a wealth of fauna and flora, most of which are unique to Australia. Examples include marine invertebrates that show the world's highest degree of biodiversity, tropical and temperate seagrasses which are the worlds largest in area and species diversity, and the richest diversity of mangrove species.

For thousands of years, indigenous peoples have been custodians and users of Australia's marine environments, and their cultural associations remain strong. From an indigenous perspective, the sea is not additional to but part of their traditional territory. Since European settlement, human activity has become even more focused on the coastal rim of the continent. Much of the culture and lifestyle of Australians and visitors is centred on the coastal and marine environment, and approximately 80% of the population now live in cities and towns on the coastal fringe. The coastal zone is used for activities such as settlement, industry, agriculture and mariculture. The ocean environment supports a number of activities, including petroleum mining and commercial fishing.

Under the United Nations Convention on the Law of the Sea (UNCLOS), Australia has one of the largest marine jurisdictional zones in the world (Figure 1). This zone comprises about 12 million km², excluding Antarctica, and is about 50% larger than the Australian landmass. The UNCLOS allows nations to claim territorial seas (which extend 12 nm from the coastal baseline), a 200 nm exclusive economic zone (EEZ) and a legal continental shelf. In some places, Australia's continental margin extends further out than the 200 nm limit. A recent decision by the UN confirmed Australia jurisdiction over an additional 2.5 million km² of continental shelf that extends beyond 200 nautical miles from its territorial sea baseline.



Figure 1 – Australia's Exclusive Economic Zone (EEZ).

Australia thus has sovereign rights to explore and exploit, conserve and manage, the living and non-living natural resources within this extended EEZ. There are a further range of international agreements to which Australia is party and which influence marine management. Australia has further international obligations in Antarctica and fisheries in the Southern Ocean are subject to the requirements of the Convention on the Conservation of Antarctic Marine Living Resources (CCAMLR).

Australia's marine area includes about 12,000 islands and some of these islands have an important role in extending Australia's EEZ, and hence our marine responsibilities. For example, Heard Island, the McDonald Islands and Macquarie Island in the Southern Ocean; Christmas Island, the Cocos (Keeling) Islands, Ashmore Island and Cartier Islet in the Indian Ocean; the Coral Sea Islands and Torres Strait Islands; and Lord Howe and Norfolk Islands in the South Pacific Ocean. Finally, Australia shares maritime borders with five other nations - Indonesia, Papua New Guinea, Solomon Islands, New Zealand and France (New Caledonia)

A range of industries associated with Australia's marine environment contribute significant benefits to our economy and society. These marine activities include four general categories; marine resource base industries (commercial fishing, aquaculture, oil/gas exploration, extraction and processing), marine systems industries (boat and ship infrastructure, marine environment management and research), marine operations and shipping (transport), and marine-related equipment and service providers (boat and ship building, tourism, cultural and recreational activities, recreational fishing). The combined value of to the Australian economy was estimated to be \$30 billion annually in 1997 and is likely to be much greater today. The largest contributor to the economy is marine tourism, estimated to be 50% of the total, with oil and gas at 27% the other major component. Smaller contributions arise from shipping, transport and ship building (13%) and commercial fishing and aquaculture (5%). To place just one sector into a global perspective, Australia is the 5th largest user of shipping in the world on a tonnes per km basis. Each year about 12,000 ships arrive from overseas and almost 380 million tonnes of freight are carried in Australian waters.

Australia has 13 regional marine domains, an ecosystem-based classification which extends from the Antarctic to the sub-Antarctic, temperate and tropical. Australia's ocean territories feature major coral reef complexes off the north-east (Barrier Reef) and north-west (Ningaloo Reef), with Australia having the largest area of coral reefs of any nation. Australia has the world's two largest marine parks -the Great Barrier Reef Marine Park and the Great Australian Bight Marine Park.

3. Scientific Background

Largescale Environment

The waters around Australia form a complex intersection of the Pacific and Indian Oceans. There are two major 'gateways' between these ocean regions; the Indonesian Throughflow (ITF), an ocean pathway through the deep channels connecting the western Pacific and the northeast Indian Ocean (Godfrey and Golding, 1980), and the Tasman Outflow (TO) which provides a trajectory around Tasmania for the residue of East Australian Current (EAC) to penetrate into the Indian Ocean (Ridgway and Dunn, 2007). The ITF includes flow in the upper 300-m, the maximum sill depth of the main Indonesian passages, while

the TO flow occurs mainly at intermediate depths in the range 500-1200-m (Figure 2).

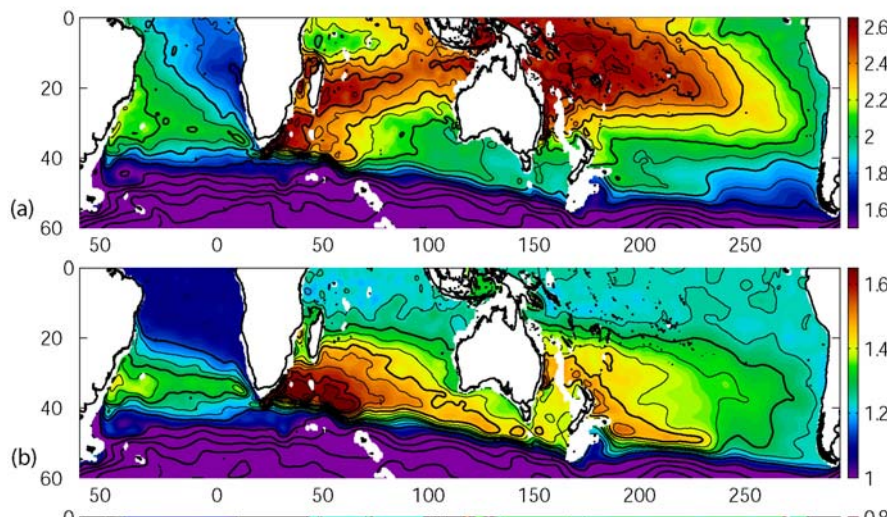


Figure 2 - The interbasin gyre system for the Pacific and Indian Oceans as shown by the flow at the (a) surface (the main connection is the Indonesian Throughflow) and (b) 900-m level (Tasman Outflow).

The main large-scale influences on this ocean region arise from the two major subtropical gyre systems - the South Pacific in the east and the Indian Ocean in the west. These 'gyres' are the pathways followed by the flow in each ocean basin. They span the ocean basins and flow in an anticlockwise direction (Tomczak and Godfrey, 1994).

A complex regional ocean circulation pattern has been determined from the available large-scale observational datasets (Figure 3). The region is dominated by several major ocean currents;

The East Australian Current (EAC) flows southward adjacent to the east coast from Brisbane to Tasmania transporting warm, high-salinity water (Ridgway and Dunn, 2003). This is one of the world's major western boundary currents. Along its path large eddies (300-km in diameter) are generated and separate off into the Tasman Sea (Nilsson and Cresswell, 1981).

The Leeuwin Current (LC) originates off the North West Shelf and flows down the Western Australian coast in winter, bringing warm, relatively fresh water (Cresswell and Golding, 1980). The current turns around the south coast and penetrates eastward as far as western Tasmania (Ridgway and Condie, 2004). As well as influencing the regional climate along its path, the LC transports many tropical organisms into southern Australia (Maxwell and Cresswell, 1981).

The Indonesian Throughflow (ITF) flows between the Pacific and Indian Oceans through the Indonesian archipelago. This flow has a major influence on both the climate of the Indian Ocean and the global oceans (Godfrey et al, 1995).

The Antarctic circumpolar current (ACC) flows eastward around the entire globe and passes through the Southern Ocean between Antarctica and the Australian mainland. It has a major influence on Earth's climate (Rintoul, 2000).

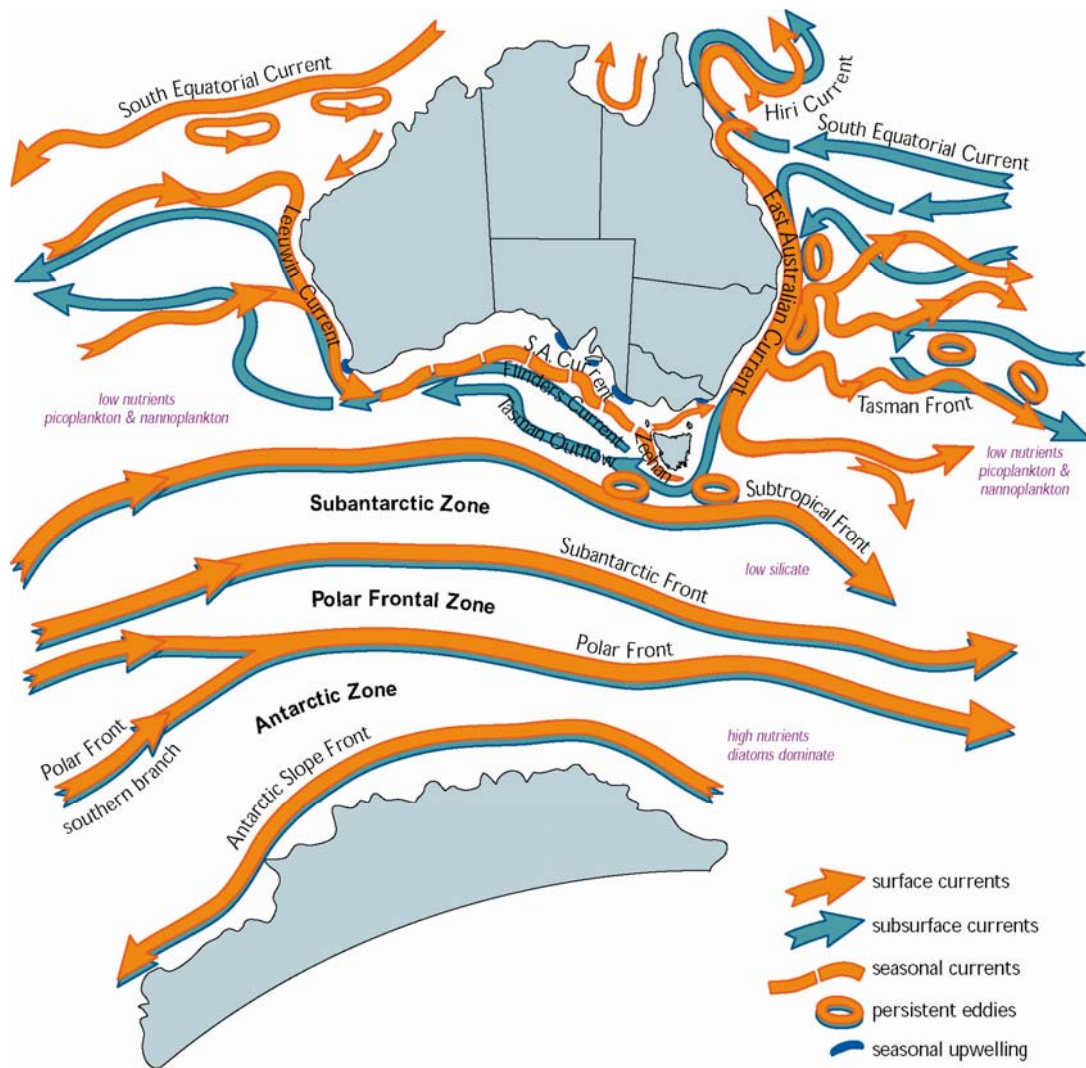


Figure 3 – The circulation in the oceans around Australia. The surface currents are shown in orange and subsurface currents in green.

The pattern in Figure 3 describes the mean state of the ocean circulation, however, the ocean is actually a very dynamic environment and changes on timescales from hours to centuries. Over periods of days to weeks the variability is dominated by mesoscale eddies. In Figure 4 the large, spatially coherent regions of mesoscale sea surface height variability are shown. In particular, there are very energetic regions of mesoscale eddies associated with the EAC, the ACC and to a lesser extent the LC.

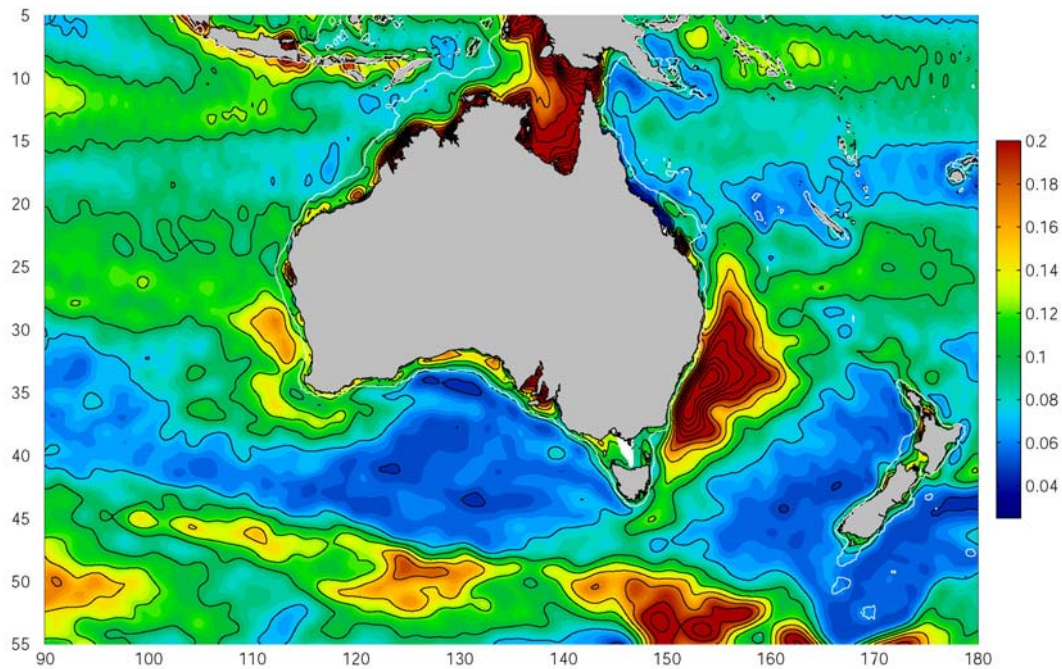


Figure 4 – The RMS variability of the sea surface height as determined from satellite altimetry data from 1992-2006.

Climate in the Australia maritime region varies due to the combined effects of seasonal variations, natural decadal-scale variability and other signals including the El Niño/Southern Oscillation (ENSO), the Indian Ocean Dipole (IOD), the Southern Annular Mode (SAM) and global warming.

For example, it has been long observed that remotely driven low-frequency (interannual) Pacific wind energy penetrates into the throughflow region and southward along the Western Australian coast (Pariwono et al. 1986; Wijffels and Meyers 2003) and modulates both sea level and thermocline depth nearly in phase with the El Niño–Southern Oscillation (ENSO). This remote energy is believed to arise from the transmission of equatorial Rossby waves generated by zonal wind anomalies in the central equatorial Pacific into coastally trapped waves where the New Guinea coast intersects the equator. These coastal-trapped waves then propagate around the western tip of New Guinea and poleward along the Arafura/Western Australian continental margin.

Recent studies document a spin-up and southward shift of the Southern Hemisphere subtropical ocean circulation (Cai et al., 2005; Cai, 2006; Roemmich et al, 2007). The oceanic changes are forced by an intensification of the wind stress curl arising from a poleward shift in the circumpolar westerly winds (Gillett and Thompson, 2003). These changes arise from a strengthening of the Southern Annular Mode (SAM) due to ozone depletion. Observations indicate that regional responses to these gyre changes include a southward extension of the EAC and intensification of its flow past Tasmania (Ridgway, 2007) and a large scale warming of the thermocline in the mid-latitude region of the Indian Ocean (Alory et al, 2007). These changes have major climatic and biological influences. Climate models predict a strengthening of this trend due to increasing atmospheric CO₂ concentration (Cai et al., 2005).

Regional Science Overview

The Coral Sea current system

The inflow to the Coral Sea is provided by the westward flow of the South Equatorial Current (SEC) which enters the region, in the depth range 200-800-m, between the Solomon Islands and New Caledonia (Wyrski, 1962). This represents the northern arm of the anti-clockwise flow of the South Pacific Subtropical Gyre circulation which is the main pattern of flow in the mid-latitude region. As it approaches the east Australian coast the SEC is separated into a series of narrow jets by the complex island and reef systems in the SW Pacific (Webb, 2000). At the coast the westward flow is split into northward and southward components (Church 1987). The position of this bifurcation varies in time (it moves to at least 14°S during summer) and also moves southward with increasing depth (from 15°S at the surface to 19°S at 500-m depth). This means that over the first 3-400-km the northern boundary current is an undercurrent which then extends to the surface at ~ 15°S (Church and Boland, 1983; Ridgway and Dunn, 2003).

Beyond the northern end of the GBR (15°S) the coastal Hiri Current is steered in a clockwise trajectory around the shelf-edge connecting northern Queensland the southern coast of PNG. Some of this flow recirculates back to the Queensland coast, while the remainder turns northwards around the southeastern tip of Papua New Guinea to feed the New Guinea Coastal Undercurrent which flows through Vitiaz Strait (Quo and Lindstrom, 2002).

The East Australian Current system

The circulation of the EAC system is made complicated by the complex topography in the region. The bathymetry is dominated by several ridges radiating northward from the New Zealand continental land mass. The further presence of a complicated pattern of island groups, reef systems, and seamounts all influence the circulation at both large and small scales. In particular, the geometry of the region serves to contain the boundary current system within the region producing extensive recirculation, mixing and hence very uniform ocean properties in the southern Coral Sea and northern Tasman Sea (Ridgway and Dunn, 2003).

The southern branch of the bifurcation provides the source waters of the East Australian Current (EAC). This is a major western boundary current, equivalent to the Gulf Stream and the Kuroshio, and it dominates the regional circulation. Over the first 500-km this is a relatively shallow surface flow but just south of the GBR it intensifies and deepens and reaches its maximum strength between 25-30°S. Within this region at the surface the current averages ~ 1-ms⁻¹, and transports up to 30 x 10⁶m³s⁻¹. Peak values may be more than twice this size.

The upper layers of the EAC separate from the coast before reaching Sydney, a substantial portion recirculates within the abyssal basin adjacent to the coast with the remainder meandering eastward across the Tasman Sea (Godfrey et al, 1980). A semi-permanent eddy is established over the Norfolk Basin which is one of sequence of such features all tied to bathymetric structure (Ridgway and Dunn, 2003). The deep layers of the EAC continue southward along the Australian coast as far as Tasmania (Ridgway and Godfrey, 1994).

At the boundary the EAC is highly variable and is associated with a highly energetic eddy field (Figure 4). The eddies are 200-300 km in diameter and 2-3 eddies are generated annually and have lifetimes often exceeding a year (Nilsson and Cresswell, 1981; Bowen

et al, 2004). They follow complicated southward trajectories but are generally constrained within the deep basin. The EAC flow varies seasonally - it is strongest in summer, and the separation location also migrates up and down the coast with season (Ridgway and Godfrey, 1997). These features also vary over shorter periods and exhibit major differences from year to year.

The separation of the current is important for various fish populations. For example the gemfish run and spawning are believed to be linked to it. In fact the location and timing of gemfish aggregations are determined by the oscillations of the EAC. Other species such as tuna appear to favour the frontal region - either on the subtropical or subantarctic side (Hobday and Hartman, 2006). The eddies themselves are important for nutrient cycling, and biological productivity. For example the phytoplankton productivity in eddies differs from that of the surrounding waters. Higher up the food chain there is strong evidence of biological contrast across eddies (Tranter et al, 1980; Tranter et al, 1982).

The main biological influence of the eddies is to increase the vertical mixing within the upper ocean in the western Tasman Sea, in effect extending the effective mixed layer depth and thus suppressing the winter phytoplankton and zooplankton populations due to the light limited conditions. These conditions result in spring and autumn blooms of chlorophyll-a. In addition upwelling associated with eddies supplies more nutrients to the surface layer once the bloom has begun delaying the exhaustion of nutrients and prolonging the duration of the blooms (Tilburg et al, 2004).

The EAC and its eddies frequently move onto the continental shelf and close inshore and influence the local circulation patterns. At prominent coastal features the EAC moves away from the coast, driving upwelling which draws nutrient-rich water from a depth of 200-m or more. However, while the EAC may drive nutrient-rich water onto the shelf, upwelling-favourable winds (northerly) bring the water to the surface (Rochford, 1984; Cresswell, 1994, 1996; Church and Craig, 1998).

The Leeuwin Current system

The Western Australian boundary is the geographical analogue of the eastern boundary current regions of the Atlantic and Pacific Oceans. In all these ocean regions equatorward (upwelling favorable) winds are observed. However, unlike these other regions, Australia's west coast has no broad equatorward flow within 1000-km of the coast and no sustained coastal upwelling. Instead, there is a narrow, shelf-edge poleward current, the Leeuwin Current (LC), flowing from at least North West Cape (22°S) to Cape Leeuwin (34.5°S), against the wind stress which then turns to the east and continues along the southern Australian coast (Cresswell and Golding, 1980). The driving force for this current is the strong alongshore density gradient. The large steric height gradient off WA appears to be due to the Indonesian Throughflow transporting warm water from the Pacific to the Indian Ocean (Godfrey et al., 1995). This pressure gradient generates an eastward geostrophic flow that is large enough to overcome any coastal wind-forced upwelling; the eastern flow downwells, deepening the surface mixed-layer near the shelf-edge, and sets up a poleward flow there which is balanced by bottom friction (Godfrey and Ridgway, 1985). As a result temperatures near the coast and on the upper slope are much warmer than on other eastern boundaries.

The LC is fed by relatively fresh, nutrient poor, tropical water associated with the SEC from the north of Western Australia (Indonesian Throughflow Water) and also with salty subtropical water from west of Western Australia (South Indian Central Water, Rochford, 1969). Although the LC flows throughout the year it shows a clear seasonal variation - it

is strongest in autumn-winter (Cresswell and Golding, 1980). This variation is due to both a strengthening of the pressure gradient and a weakening of the winds at this time (Smith et al, 1991). The seasonal changes in the advection of warm, low salinity water produces a distinct seasonal cycle in the water properties along the western Australian coast.

Below the poleward flow of the LC at depths of 300-400 m an undercurrent flows equatorward throughout the year which advects saline, high-oxygen, low-nutrient water, associated with the South Indian Central Water (Thompson, 1984).

The Leeuwin Current is able to carry passive organisms many hundreds of kilometres. For example, it is likely to be responsible for the distribution of dinoflagellates from southwest Australia to Tasmania (Maxwell and Cresswell, 1981). It is probable though not established that species such as Southern Bluefin Tuna, Australian Salmon and herring utilize the current to transport eggs, larvae and juveniles along its path.

Near the shore in summer, in the shallow water on the shelf, the equatorward wind stress is a maximum and drives a corresponding system of northward currents along the WA coast against the alongshore pressure gradient. In the south, the Capes Current, a cool, saline current flows northward between Cape Leeuwin and Perth (and possibly as far north as 29°S). This current derives from a region of localized upwelling further to the southeast (Pearce and Pattiaratchi, 1999). Apart from the upwelling being a source of nutrient rich water, this current is likely to play an important role in the local fisheries. For example migrating Australian Salmon would benefit from its flow as they head northward to the WA coast to spawn (Pearce and Pattiaratchi, 1999). Further to the north, the Ningaloo Current flows northward on the inner shelf from September to April. This flow is likely to facilitate the dispersal of coral larvae following the autumnal mass reef spawning. Its interaction with the Leeuwin Current sets up a system of recirculation of water in the region which retains planktonic biomass within the Ningaloo ecosystem (Taylor and Pearce, 1999).

The southern Australian current system

The 2000-km extent of the zonally oriented southern shelf of Australia forms a natural northern boundary. The open boundaries at the eastern and western endpoints allow a free exchange of properties between the major basins. The southern shelf has a maximum width of 200-km in the central Great Australian Bight which narrows to about 20-km at each endpoint. The South Australian Basin, a major abyssal plain (depth 5500-m) is located offshore, adjacent to the shelf region. The zonally oriented coastline allows wind systems to propagate eastward, and readily promotes meridional exchange between continental and oceanic air masses (Middleton and Bye, 2007).

A broad meandering, equatorward flow is located south of Australia. At the slope boundary this transport is deflected to the west to form the Flinders Current, an upwelling favourable westward boundary current (Middleton and Cirano, 2002). This provides the connection between the flow of the EAC and the broad anticyclonic gyre circulation of the Indian Ocean (Ridgway and Dunn, 2007). The source of this transport is a zonal jet to the south of Tasmania, the Tasman Outflow, which itself originates from the EAC extension turning around the southern tip of Tasmania after completing its polewards path along the eastern Australian shelf-edge (Rintoul and Sokolov, 2000). Once past Tasmania, a portion of the Tasman Outflow separates northward and provides the initial source of the FC. The FC is strengthened along its path toward the west by further contributions from the meandering northward transport steadily accumulate. West of the GAB the FC reaches its maximum level as a reconstituted zonal jet and proceeds due westward into the main

Indian Ocean Gyre. Beyond the Western Australian coast it proceeds with a meandering trajectory in a generally northwestward direction while a portion turns northward around Cape Leeuwin and provides source waters for the Leeuwin Undercurrent (Ridgway and Dunn, 2007).

The currents along the shelf-edge of the southern coast are driven by seasonally reversing winds. During winter water is transported into the coast causing the sealevel to rise and in summer the sealevel falls when there is an offshore transport (Cirano and Middleton, 2003; Ridgway and Condie, 2004). In winter this means that there is an eastward flow at the shelf-edge, in fact when combined with the enhanced wintertime Leeuwin Current off WA, there is a continuous warm current on the continental slope that flows from Northwest Cape, turns to the southeast around Cape Leeuwin, continues across the GAB and finally flows southward down the west coast of Tasmania (Ridgway and Condie, 2004). This flow provides the mechanism for several tropical marine species occur either along the path or off the west coast of Tasmania - implying that they have completed the journey from the north (Ridgway and Condie, 2004).

In summer, with the winds reversed, the coastal drop in sea level drives a meandering westward flow located some 150-200-km from the northern boundary. This represents a surface expression of the Flinders Current, a year-around upwelling favourable boundary current flowing from east to west along Australia's southern shelves (Middleton and Platov, 2003).

Southern Ocean

The dominant feature of the Southern Ocean circulation is the Antarctic Circumpolar Current (ACC). The ACC is the largest current in the world ocean, carrying about $150 \times 10^6 \text{ m}^3 \text{ s}^{-1}$ from west to east around Antarctica (Rintoul, 2000). The flow of the ACC occurs along a number of narrow jets or fronts; water mass properties change abruptly across each of the fronts, while in the zones between the fronts the water properties are relatively uniform (Orsi et al, 1995). From north to south, the fronts and zones of the Southern Ocean are: the Subtropical Front, the Subantarctic Zone, the Subantarctic Front, the Polar Frontal Zone, the Polar Front, and the Antarctic Zone. The ACC fronts extend throughout the water column and are clearly evident in maps of sea surface height (Sokolov and Rintoul, 2003, 2007). In contrast, the Subtropical Front is restricted to the upper 400 m and has only a weak dynamic signature (Ridgway and Dunn, 2007).

The temperature of the surface mixed layer tends to warm by about 3°C in summer across the width of the Australian sector of the Southern Ocean. Salinity changes with season are small. Mixed layer depths vary strongly with season in the Subantarctic zone in the north (100 m in summer, >500 m in winter), to a moderate extent in the Polar Frontal Zone (100 m in summer, 200 m in winter), and to a small extent further south (80 m in summer, 120 m in winter). The location of the fronts varies by about 1-2 degrees of latitude, on a variety of time-scales.

There is some evidence of interannual variability in sea surface temperature, although the records are short. For example, the Antarctic Circumpolar Wave is a pattern of anomalies in surface temperature, sea ice extent and winds, which propagates from west to east around Antarctica (White and Peterson, 1996). There is limited evidence that the circumpolar wave has an impact on marine ecosystems, but the lack of biological data makes it difficult to be conclusive.

The fronts of the ACC are important biogeographic boundaries and define the limits of distinct biological communities (Sokolov and Rintoul, 2007). For example, throughout

the year the Antarctic Zone is rich in major nutrients such as silicate, nitrate, and phosphate, allowing diatoms to dominate the phytoplankton community. In contrast, Subantarctic Zone waters are low in silicate year-round and are dominated by coccolithophorids. Primary production throughout the Southern Ocean is probably limited at least in part by lack of trace nutrients such as iron.

Antarctic region

The Antarctic Slope Front (ASF) is associated with a current that flows from east to west over the continental slope of Antarctica. It is the dominant circulation feature in the EEZ of Australia's Antarctic territory. Further offshore, the southernmost part of the ACC, the so-called "southern ACC front" and "southern boundary of the ACC" carry water from west to east. The ASF separates cold, fresh water on the continental shelf of Antarctica from the warmer, saltier Antarctic Surface Water found further offshore (Bindoff et al, 2000). The ASF is covered by sea ice in winter, but is largely ice-free in summer in the Australian sector of the Southern Ocean. The region is high in nutrients and relatively high in primary productivity relative to offshore regions of the Southern Ocean. The high productivity is focused near the ice edge in spring and summer and over parts of the continental shelf.

Research Challenges

Australia is responsible for a very large sector of the global ocean and hence has a central obligation to establish a systematic observing system capable of addressing the most important research challenges. Gaining an understanding of these scientific questions is also of crucial importance to Australia for a combination of environmental, social, and economic reasons. Research questions include;

- Ocean State Estimation- There are many applications including defence, shipping, coastal engineering, search and rescue, which would benefit from the provision of accurate estimates of the Ocean State including some term prediction skill at timescales of up to 7 days. Such a system requires both an ocean model with realistic physics and a comprehensive observation network which provides essential observational constraints on the model. The goal is to enable the regional features of the boundary current systems and eddy fields to be characterized at high-resolution.
- Seasonal to Interannual Climate Variability- Due to our reliance on commodity exports and our large agricultural sector, Australia has a climate sensitive economy. There is a strong need to support research into improved prediction on seasonal and longer timescales, and to improve understanding of such climate variability and its links to the marine and terrestrial environment.
- Climate Change - Climate change is one of the most prominent national issues at present and there is a strong imperative to support research that informs national policy development, including mitigation and adaptation strategies. Climate change impacts both land-based and marine economies. The ocean plays a major role in shaping climate change and open ocean observations play a key role in enhancing understanding and reducing uncertainty in future climate scenarios.
- Antarctica and the Southern Ocean – This region plays a critical role in the global environmental system. Processes of interaction between the atmosphere, oceans, ice,

and biota affect the entire global system through feedbacks, biogeochemical cycles, circulation patterns, transport of energy and pollutants, and changes in ice mass balance.

- Marine resource management - policy requires that we maintain healthy and properly functioning ecosystems, and that this is best achieved by managing the marine ecosystem in an integrated way (Australia's Oceans Policy 2000). The response of ocean physics, chemistry and biology in response to climate variability and change is needed as part of this integrated ecosystem based management. Examples where this information is urgently required is ecosystem based fisheries management (EBFM) and in the planning for bluewater Marine Protected Areas (MPAs).
- Stewardship of marine biodiversity- Under the Environmental Protection and Biodiversity Conservation (EPBC) 1999 Act, Australia has a responsibility to not only protect marine biodiversity but to have inventories of what is there and its ecological role.
- Risk management/Harm Abatement for at sea operations and offshore industries:
 - Transport and Fisheries
 - Recreational and leisure pursuits, e.g. sailing
 - Safety of life at sea
 - Hazard prediction and mitigation
 - National security
- Global climate variability may have serious repercussions for Australia's coasts and oceans in the future. The two aspects that could affect Australia's coastal and marine environments are rises in sea surface temperature and sea level change. Climate variability may in the future result in extreme events in different parts of the country and drought in other places. Floods associated with the increasing trend in extreme rainfall events could result in increased sedimentation and nutrient levels in estuaries and coastal ecosystems and harsher erosion events, threatening coastline stability and coastal infrastructure. Any increase in the frequency of cyclones or storms in tropical areas could also result in increased resuspension of sediments.

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4. Existing Capability

Before the establishment of the IMOS Bluewater network several components of an ocean observing system within the waters around Australia were already in place. These include contributions from Australian programs, international institutions and collaborative projects. Deployments are both ongoing and more limited period activities

HD and FRX repeat XBT network

Repeat temperature sections through regional flow systems to monitor variability of regional circulation and temperature structure

- Established in early 1980's
- Part of network supported operationally at BoM
- Part of network supported by research funds on a yearly basis (Tasman Sea, Southern Ocean)
- Invaluable – getting on 10-20 years of data for some lines
- Only current means of monitoring regional current transport and heat flux variability
- Proven technical capability and strong relationships with shipping industry at BoM and CSIRO
- QC system well bedded down, dissemination via GTSP and CLIVAR DAC
- Part of international system coordinated by JCOMM-OPS

Gaps – imperfect tool for WBC monitoring - no salinity data; XBT's are shallow (700m); no velocity data; no corresponding biogeochemical or ecosystem information; not real time on all lines

Argo Australia

- Array of profiling floats that measure temperature and salinity down to 2000m every 10 days in real time
- Essential and dominant *in situ* data stream for ocean and climate research and prediction/reanalyses
- becoming more important given the current serious decline in satellite altimetric data.
- Small pilot funded by CSIRO in 1999 has grown to a 100 float array at this time
- Core operations funded by AGO and CSIRO (annual research funding) with contributions from ACE CRC, BoM and RAN (recent and ad hoc)
- Proven technical capability – good success record
- Robust and well designed data system
- Well integrated into international Argo program and active in Argo leadership

Gaps – current funding provides unsatisfactory coverage around Australia. To ensure 50% of design coverage in the Australian region requires deployment of 60 floats/year which will sustain an array of 210-230 floats. CSIRO/AGO funding year by year and tenuous – no prospect adoption as “operational” by BoM over the next 5 years and thus must remain in research sector; does not measure BGC parameters but oxygen is possible now.

Pulse Ecosystem Mooring:

- Site instrumented with various moored sensors for BGC/lower trophic parameters
- Allows study of fast ecosystem responses to physical variability
- In important region for air-sea interaction (deep mixed layers), global carbon uptake.
- First instrumented seven years ago in pilot engineering mode and there has been a build up of mooring expertise and sensor knowledge
- Serviced by Hobart based ships e.g. Aurora Australia, Southern Surveyor
- Attracted substantial international investment and interest – one of a very few Southern Hemisphere time-series sites
- Funded by ACE CRC – plan to 08/09.
- Internationally linked to the JGOFs program

Gaps: not real time, no surface meteorology/flux measurements, ACE funding runs out in 08/09; no consistent data treatment or dissemination to broader community

Ship of Opportunity network: Surface flux, biogeochemical, carbon and plankton measurements

- Sparse set of lines measuring different parameters
- Summer Antarctic line – French resupply vessel L' Astrolabe measuring T(z); surface T/S/Fluorescence and pCO₂- ACE CRC funding plus heavy international involvement, particularly from France.
- Summer Southern Ocean – Aurora Australis – phytoplankton and zooplankton species information, surface T/S; solid capacity in plankton monitoring at Australian Antarctic Division for more than 10 years. Contribution to an international network

Gaps: coverage not national - no BGC/ecosystem off east or west coast; no lower trophic information on most lines; no consistent data treatment or dissemination to broader community; marine meteorological information poor and insufficient for air/sea flux estimates

Coastal Automatic Weather Stations

- Extensive national network of automatic weather stations on the coastal fringe sampling the coastal maritime environment.
- A robust and reliable observing system used for validating wind estimates and delivering consistent, quality controlled marine meteorological data.
- Smaller number situated in harbours, on islands or reefs reporting on coastal sea weather.

Gaps: Though sparse, the system is adequate for IMOS purposes.

Coastal wave measurements

- Network of 26 wave-rider buoys in Australian coastal seas.
- Bureau runs two sites, others belong to state bodies who provide data.
- Real-time observations are processed and data disseminated by the Bureau.
- Main source of data for research on ocean waves.

Gaps: The system is sparse and not really adequate for research but is not the focus of this Node.

Coastal hydrological stations

- Three hydrological stations have been maintained for more than 60 years at Maria Island, Rottneest Island and Port Hacking.
- Temperature, salinity and several other variables are sampled at 1-2 month intervals.
- The first 2 stations are maintained by CMAR and the data quality is generally good.

Gaps: coverage is not national, no real-time capacity and the sampling frequency is often irregular.

Deep-Ocean Tsunami Buoy Network

- Four to six deep ocean-deep tsunami detection buoys are planned to be deployed in FY07/08

- Two buoys will be deployed south of Java, one-two in the Coral Sea, one-two SW of New Zealand
- The buoys will be serviced once per year by either research or commercial vessels.
- All data will be available for research purposes.

Gaps: Network is supported through the Australian Tsunami Warning System initiative.

Sea level network

- A baseline network of around 16 gauges is maintained around Australia, and a further 11 are maintained in the Southwestern Pacific as part of the South Pacific Sea Level Climate Monitoring network (National Tidal Centre).
- Sea level, water temperatures and a suite of meteorological properties are sampled and transmitted in real-time. Data collected for 18-20 years.
- Supplementary geodetic measurements (including permanent GPS surveys) are also collected.
- Fully integrated into international GLOSS network.
- Array supports research on tides, ocean prediction and climate change.
- Additional stations maintained by range of institutions, provide generally lower quality data. Fremantle & Sydney records extend for > 100-years.

Gaps: Support for climate change research could be enhanced.

Research Vessel Voyages

- A range of oceanic and meteorological properties are collected on voyages of Southern Surveyor, Aurora Australis, Cape Ferguson, and Solander.
- Spatial and temporal coverage is variable
- driven by the particular aims of individual research projects.

Deep Ocean Time Series Sections

- Only means of tracking changes in the deep ocean (below the reach of Argo) and the powerful bottom boundary currents ventilating the huge volume of the deep Pacific and Indian Basins.
- Sparse set of lines
- Repeat cycle of station occupation 5-7 years.
- Occupy key sections in ocean surrounding Australia - Southern Ocean (south of Perth, and Tasmania, eastern Indian Ocean and western Pacific)
- These sections simultaneously measure full suite of ocean parameters: temperature, salinity, oxygen, nutrients, carbon.
- Sections are a component of the International Repeat Hydrography and Carbon Program.

Gaps: National lack of ability to measure CFC's, or tritium/helium.

Summary of Current Capacity:

Strengths

- Substantial national capacity exists in many areas and proven ability to run systems for sustained periods with tried technology e.g. plankton monitoring, XBT networks, SOOP underway BGC/Carbon, Argo array
- Internationally valued activities and many elements are well connected/integrated with international programs, leveraging substantial resources into our region
- Several activities have strong links and uptake by the modelling and reanalysis community who produce gridded products which are of greater use to a larger part of the research sector.

Weaknesses:

- poor integration between disciplines – few examples where physical/BGC/ecosystem measurements overlap
- present fragmentation of research means that funding is not used optimally
- many elements do not have standardized and timely publicly available data streams
- national coverage is mixed for certain elements e.g. no surface BGC in west or north of Sydney
- funding is haphazard and tenuous for several elements
- lack of surface air/sea flux *in situ* information
- inadequate real-time monitoring of strong currents

5. Required Capacity and Observations

Through NCRIS we will build an integrated observation network of physics, chemistry and biology around largely proven capacity, consolidate the existing activity, coordinate the disparate programs, enhance national coverage and widen parameters measured to cover greater disciplines (e.g. ecosystem, air/sea fluxes), standardize, increase the timeliness of the data streams and make them publicly available, and through collaboration with the modeling/synthesis community provide gridded products for use by the Australian Marine Research Community. We will also fill three large gaps – lack of *in situ* measurements of air/sea fluxes, begin to provide a pathway to monitor regions of strong currents, and regular large-scale observations of the base of the marine ecosystem.

Allocated IMOS Resources

IMOS resources allocated to the Bluewater and Climate Node include three main data facilities, Argo Australia, Multidisciplinary Network and the Southern Ocean Time Series (SOTS). While each of these facilities have been in operation in some form prior to receiving NCRIS funding, their inclusion within IMOS will greatly expand their capability.

Consolidate and Enhance Australia's contribution to Argo

This investment will monitor in real-time, the broad-scale ocean structure (temperature, salinity and deep currents) around Australia by building and maintaining an array of autonomous profiling floats as part of the international Argo program (www.argo.net). Research in the fields of climate science, physical oceanography, ocean forecasting, coastal ocean dynamics and ecosystem and fisheries influenced by physical variability will benefit from regular, high-quality, timely observations of the ocean state.

To ensure a minimum coverage of 1 float every 3° x 3° bin around Australia (90° - 180°E; Antarctica - equator), an overall deployment of 120 floats/year is required. The IMOS deployments will provide the largest component of the Argo Australian contribution of

some 60 floats/year - providing about half of the design density. The remainder derives from several international partners. The Argo Australian array will consist of about 220-240 operating floats.

Measurements from Ships of Opportunity:

This component will implement a set of integrated observing systems in Australian regional seas that link physical, chemical and biological oceanography. The target regions are the boundary current systems off Eastern and Western Australia, the Southern Ocean, the shelf seas across northern Australia, and the Great Barrier Reef.

The work will build on an existing framework of XBT and biogeochemical (BGC) observations to improve coverage and to supplement these with the first concurrent species-level data on lower trophic levels (phytoplankton and zooplankton) for the Australian Region. These will be complemented by equipping subsets of Australian Volunteer Observing Ships with sensors capable of providing high quality sea surface temperature measurements in real-time for calibration of satellite SST observations; measurements in the tropics to calibrate satellite ocean colour and "climate quality" meteorological measurement systems on Australian research vessels, capable of providing high quality air-sea flux measurements on a near real-time basis.

- Enhance and broaden current disparate underway measurement programs using commercial and research ships of opportunity (SOOP)
- Establish plankton and basic BGC/carbon measurements on SOOP lines providing national coverage for the first time
- Establish air-sea flux measurements on SOOP
- Merge and standardize new lines with existing activities into a seamless data stream for IMOS

Southern Hemisphere Deep Ocean Times Series Station

In this component we will establish the first comprehensive Southern Hemisphere Deep Ocean Times Series Station in the Australian Sub Antarctic Zone. We will acquire and deploy moored instruments for time-series observations of physical, biological and chemical properties in the Sub-Antarctic Zone southwest of Tasmania. Time-series observations are crucial to resolving ecosystem processes that effect carbon cycling, ocean productivity, and marine responses to climate variability and change, ocean acidification, fishing and other stresses. This Southern Ocean time-series will be one of only 29 high temporal resolution sites identified globally by the Global Ocean Observing System time series working group, and 1 of 3 proposed for the Southern Ocean (www.oceansites.org). Australia currently leads in the implementation in the Southern Ocean and this investment will extend that achievement. The aims of this facility are:

- Enhance measurements from an existing biogeochemical mooring.
- Establish a surface flux mooring nearby to determine the magnitude and variability of air-sea heat, freshwater and carbon exchange for the Southern Ocean and waters around Australia.

- Assess the role of rapid mixed-layer dynamics in the Southern Ocean on plankton production and carbon transports.

Additional Resources Required

The Bluewater Node is focused on open-ocean and climate research, however, understanding the interaction of the open ocean and coastal boundary is of central importance to many of the research goals. We are therefore very much dependent on the data streams provided by several of the data facilities associated with the regional nodes. These include the coastal radar (CODAR) and the coastal moorings. In particular, the reference stations resolve all temporal scales and will establish a long-term temporal context for results from other observation systems. The records at Maria Island, Rottneest Island and Port Hacking (> 50-years) are existing examples.

Similarly, the ocean glider deployments are not strictly within the BLUEwater Node but they have a crucial role to play in our efforts to resolve the major boundary current systems. Experience gained with the initial program of glider deployments should provide a pathway to monitor regions of strong currents. Future deployments may involve combined mooring/glider arrays to fully capture the highly energetic, highly variable boundary current flows.

Two further observation platforms have been identified as being of high priority.

A Mooring/Glider Timeseries in the South Java Upwelling Zone

- Fill an important gap in the International Indian Ocean Tropical Moored Array which is of particular importance to Australian climate variability
- Establish a mooring initially, followed by a glider pilot in station-keeping mode to deliver realtime upper ocean information

Gulf of Carpentaria Mooring

- enhance tropical cyclone and air/sea interaction research by establishing a mooring in the Gulf of Carpentaria

International Links

The individual observation platforms presented here provide valuable data in their own right and as a contribution to a national network such as IMOS. Possibly the greatest the 'value adding' occurs when these data streams are incorporated into a range of international programs

- The elements contributing physical/dynamical observations will be integrated with other international contributions coordinated through the CLIVAR research program
- Many research contributions are also coordinated through GOOS and GCOS and the contribution to climate change research is explicitly recognized by the UN Framework Convention on Climate Change – Australia needs active engagement.
- There is the need to reinforce and strengthen Australian links to international satellite and *in situ* data streams to enhance leverage for the benefit of Australian research.
- Links to other research programs of the World Climate Research Program and World Weather Research Program, e.g. SOLAS, CliC, THORPEX, International Polar Year initiatives, Coupled Modelling, IPCC.

- Links to research under the IGBP, e.g GLOBEC, IMBER

6. Implementation Plan

Argo Australia

The goal is to build up the Argo Australia array to 220-240 operating floats which will provide 50% of the design coverage in waters around Australia. Experience suggests that with careful preparation and handling, we can achieve an average float life-time of 3.5-4 years, a failure rate < 10%, delivering a very high quality real-time and climate-quality data set for IMOS.

The Argo team is made up of a Scientist in Charge of Operations, an engineer, an Argo technician, and data QC analysts. A rolling deployment plan will use all available opportunities including both Australian and foreign research vessels, icebreakers, RAN ships, coast-guard ships, commercial container ships etc. Approximate deployment locations must be known before the floats are shipped from the US manufacturer, since there is a lead-time of 4-5 months between time of order and delivery.

Multidisciplinary Underway Network

The project aims to link complex physical, biogeochemical and biological observing systems in Australian regional seas and the Southern Ocean. Given logistical and funding constraints it is not practical to instrument every ship for a complete set of observations. The lines described below have been selected to maximize the return on the investment, to build on established underway observing systems and infrastructure by adding new capability in plankton and BGC observations, by adding real-time data delivery for XBT work, and to provide coverage over critical ocean regions. The work will provide an opportunity to investigate how the network might be enhanced in future.

High-density XBT Sections - To monitor the major boundary currents around Australia we will operate 5 major (HRX) high-resolution expendable bathythermograph (XBT) lines. HRX lines are those whose sampling require boundary to boundary profiling, with closely spaced sampling to resolve the spatial structure of mesoscale eddies, fronts and boundary currents. The lines are typically repeated 4 -6 times per year and the measurements are made by a technician on board the ship. The routes have been chosen to effectively sample the flow of a particular major boundary current system within the constraints of available commercial or supply vessel traffic. All of the transects will be upgraded to full real-time transmission of the data.

Biogeochemical Program - The biogeochemical observing program uses the RV Southern Surveyor and the l'Astrolabe in the Southern Ocean on the IX28 line. These are the only biogeochemical observing systems in Australian offshore waters. They sample the critical regions of the Southern Ocean and Australian waters, which have a major impact on CO₂ uptake by the ocean and are regions where biogeochemical cycling is predicted to be particularly sensitive to changing climate. Biogeochemical and air-sea flux (see below) observations will also be added to the research ship, Southern Surveyor. While RV Southern Surveyor does not always travel along repeat tracks it has the best spatial coverage of any ship in Australia and each year covers tropical to sub-polar waters.

The Astrolabe, or IX28 line, is one of the most significant repeat sampling lines for the ocean and samples all major Southern Ocean water masses. Observations of carbon, nutrients, pigments, phytoplankton species and bio-optical properties of organic matter made on Astrolabe cover the spring through late summer period when the region is most active biologically. The work will benefit by the addition of CPR sampling outlined below, through closer integration with the XBT measurements made on the ship, and will provide a regional perspective to the PULSE time series mooring in the sub-Antarctic.

AusCPR - To monitor plankton we will use the proven technology of the Continuous Plankton Recorder (CPR). This is the only platform that can assess plankton species and be towed behind ships of opportunity (SOOPs) unaccompanied by research staff; currently there is no alternative technology available. International experience has shown that species-level information is vital to answering questions associated with mesoscale productivity, biodiversity, and climate impacts on marine ecosystems. Two seasonal routes will be operated on existing XBT lines in the Southern Ocean (IX28), and the Coral Sea (PX30).

Sensors on Tropical Research Vessels – Fixed sensor sets will be installed on the 2 AIMS research vessels (*RV Cape Ferguson* and *RV Solander*). The instruments will obtain underway observations of temperature, salinity, chlorophyll, fluorescence, light absorption, and irradiance. Data will be collected in both the Great Barrier Reef waters, the western Coral Sea, and Arafura Sea within repeated transects and individual voyage tracks. The actual location of data collected will depend on the operational schedules of both vessels.

Sea Surface Temperature Sensors – This component includes the installation, calibration, maintenance, quality control and data management of SST sensors on Australian Volunteer Observing Fleet (AVOF) vessels (as part of the Australian Weather Service, AWS) and several passenger ferries. The vessels routes include the Southern Ocean, coastal Australia, Bass Strait and the Tasman Sea. On the AVOF vessels, hull-mounted temperature sensors will supply high-quality bulk SST data fed into current AWS data management systems and broadcast via satellite back to Australia every one to three hours. The SST data shall be quality assured, placed on the GTS and fed into the BoM's near real-time satellite SST data validation system. The SST data shall also be made immediately available and archived for use by the research community. Radiometers operated by AIMS and CMAR on ferries will supply high-quality skin SST data in near real-time and this data will be available and archived for use by the research community.

Research Vessel Real-time Air-Sea Fluxes - To equip the Marine National Facility (MNF) (*RV Southern Surveyor*) and the *RSV Aurora Australas* with "climate quality" meteorological measurement systems, capable of providing high quality air-sea flux measurements and delivered to researchers on a near real-time basis. Obtaining the full set of air-sea fluxes essential for climate studies requires observations of: wind, air and sea temperature, humidity, pressure, precipitation, long- and short-wave radiation. The existing ship meteorological sensor sets are incomplete for this task and lack the necessary quality that can only be assured by regular calibrations. The meteorological measurement system will be realised by limited enhancements consisting of a combination of new instruments and comprehensive calibration programs to the pre-existing ship meteorology system. The Southern Surveyor will be equipped with four new radiometers, plus two refurbished radiometers (2 long-wave and 2 short-wave in operation, and one set in maintenance and calibration, 6 month exchange), a optical rain gauge (ORG) and anemometer, and an additional set of wind, temperature, and humidity sensors to allow

maintenance cycling. The Aurora Australas will be fitted with two long-wave radiometers and one ORG (serviced during winter port time). A comprehensive program of annual calibrations for all meteorological sensors will be implemented. Data streams will be fed into the existing ship data management system, and broadcast via satellite back to Australia daily. Meteorological data shall be quality assured, placed on the GTS, and processed to generate air-sea bulk fluxes which will be made immediately available and archived for use by the research community.

Southern Ocean Time Series

The IMOS Southern Ocean Time Series incorporates 5 platforms.

1. Southern Ocean Flux station (SOFS) Meteorological mooring
 - Engineering test version built 2008, deployed 2009
 - Full mooring deployed 2009/10.
2. Pulse biogeochemical mooring
 - Engineering test version deployed Dec 2007 to April 2008.
 - Instrumented mooring deployed Oct 2008
3. Tethered profiling float
 - Acquired in 2008
 - Mission and tether development late 2008.
4. Glider transects to/from site (Glider supplied through ANFOG)
 - Deployed following successful deployment of 1 and 2.
5. Deep ocean sediment trap moorings (ACE CRC in-kind contribution)
 - First deployment successfully recovered 2007
 - Next deployment following successful deployment of 1 and 2.

The investment includes the acquisition of hardware and engineering support for mooring and float design of mooring platforms 1 to 3, including instrument preparation and deployment, data quality control and delivery. The separate platforms are designed to work in combination, to enhance the overall data stream and provide some redundancy. For example, the most comprehensive set of biogeochemical instruments are deployed on platform 2, but further BGC measurements will be obtained on the other platforms. Similarly, while platform 1 will collect most of the physical variables, 2 and 5 will have current meters and 3 and 4 will collect CTD profiles.

Role in national IMOS

The aim of the IMOS observation framework is to provide long-term measurements that benefit the nation as a whole. It is therefore critical that all systems are well integrated and that the networks exploit as far as possible established infrastructure. The bluewater and regional components share a common purpose and have a high level of interdependence.

The comprehensive Bluewater and Climate system with national coverage is essential for the regional nodes, as much of the Australian shelf and coastal environment is strongly forced by conditions offshore. The data streams from this node and their associated products will be used as a context and boundary conditions for study of the regional processes. Much of this information stream will be via data-model syntheses such as BLUElink and ACCESS. One specific data stream is plankton, regional and coastal nodes

are generally not planning to gather detailed information on plankton, so the large-scale plankton data will prove valuable for them.

Several of the data facilities associated with the regional nodes will be of great benefit to open-ocean and climate research in the Bluewater Node. These include the coastal radar (CODAR) and the coastal moorings. In particular, the reference stations resolve all temporal scales and will anchor results from other observation systems. The long-term records at Maria Island, Rottneest Island and Port Hacking are existing examples. The glider deployments have a crucial role to play in resolving the major boundary current systems.

The importance of the eMII data assembly and serving node is high for this node, and there are strong dependencies and synergies with the satellite data node for complimentary surface information to the in situ data supplied by this node.

6. Impact on Research

The output from these facilities will provide data of national significance, contribute to international networks of physical and biogeochemical observations for the global ocean, and provide the first regular broad-scale lower trophic level data for the Australian region. While the data streams are valuable in their own right, for example process studies using output from the SOTS mooring, much of the impact of the observations collected in this node will be via a range of reanalysis products. As seen in atmospheric sciences over many years, reanalysis products tend to produce a greater uptake in the scientific community than 'raw' data streams, and result in a step up in scientific productivity and understanding resulting from data sets. The data from the IMOS Bluewater Node has a clear synthesis pathway through two major funded projects in ocean reanalysis: the BlueLink Project and ACCESS.

The BlueLink project will assimilate data from IMOS into a global model but with 10km resolution in the Australasian region from 1992 to the present. This product will be suitable for detailed ocean circulation/dynamical studies, forcing coastal models, ecosystem studies and many other applications. While its short temporal duration limits its utility for climate studies it will form the basis for the spatial downscaling of results from output from climate models. The ACCESS reanalysis will produce a global 50 year data set including IMOS and historical data, which will be of great utility in ocean, marine and climate studies. The synergy, then, between IMOS and these reanalysis efforts is a great strength.

There is a large community of users at universities and other research organisations waiting for lower trophic level information to integrate into ecosystem models. These data will provide the springboard for ARC and other research grants.

Overall the outcomes from the Bluewater and Climate Node may be described in terms of short, medium and long-term impacts.

Short term outcomes

These outcomes generally depend on the real-time capability of the IMOS data facilities.

- Deliver data from Argo and XBT lines in real time to be assimilated daily in the BLUElink OCEANMAPS short term prediction system. These data underpin the prediction system (along with satellite altimetry and mooring temperature data) and

are crucial for constraining the model trajectory in order to improve the realism of the results.

- Contribute to similar ocean prediction schemes under the umbrella of GODAE.
- Provide additional climate quality meteorological data in the region leading to improved local and global air-sea flux products
- Increase the supply of high-quality in situ observations resulting in improved real-time SST products
- Provide offshore boundary condition for coastal studies, coastal models and coastal ocean state estimate systems.

Medium Term Outcomes

These outcomes will be delivered after the collection of 3-5 years of data.

- Provide gridded ocean information for researchers in all areas of marine science, so that the effect of varying environmental conditions on other processes can be assessed quantitatively (In the Australian research community, this is being illustrated by the uptake of the BlueLink data products by ecosystem scientists).
- Demonstrate improved ocean state estimation, by providing more extensive coverage of the ocean salinity field, in tropical regions and in the Southern Ocean (early results already strongly suggest this is the case).
- Seasonal climate forecasting; improve the predictability of seasonal forecasts (ECMWF studies have shown increased skill in predicting ENSO when including Argo data).
- Determine the heat and freshwater budgets of the oceans around Australia and gain an understanding of the role of ocean circulation in climate maintenance and fluctuations.
- Obtain improved empirical algorithms required for the determination of global air-sea flux products
- Use ground truth SST data to improve satellite algorithms
- Determine the magnitude and variability of air-sea heat, freshwater and carbon exchange for the Southern Ocean and waters around Australia.
- Assess the role of rapid mixed-layer dynamics in the Southern Ocean on plankton production and carbon transports.
- Resolve the seasonal cycles of surface water and lower atmospheric properties (heat, momentum, fresh-water, and greenhouse gases), surface to deep ocean transfers of particulate matter (sediment trap chemical and biological measurements) , and biological production within the mixed layer ($p\text{CO}_2$, O_2 , fluorescence, transmission, nutrient concentrations, etc.).
- Develop models of the these processes and calibrate against the above observations

- Evaluate the uptake of CO₂ by our regional seas, its variability on seasonal through interannual scales and the impact of climate variability and change on the uptake capacity.
- Establish the rates of change of ocean pH and deliver baseline data to assess the vulnerability of pelagic species and plankton community composition to acidification.
- Enable the development and testing of biogeochemical models, determine the drivers of air-sea CO₂ exchange and carbon and nutrient cycling in our regional seas,
- Obtain the first time series of lower trophic level distributions in Australian waters – describe the species present, their distribution, abundance and seasonal cycles.
- Ecosystem Health and harmful algal blooms. Provide the only large-scale species-level information on the spatial extent, timing, and environmental variables that trigger harmful algal blooms in Australian waters.
- Molecular Biology. Molecular work on planktonic larvae (e.g. urchins and oysters) will help understand the dispersal of species to better conserve and manage marine biodiversity.
- Provide initialisation and validation to aid development of Biogeochemical/Ecosystem Models Local and regional-scale carbon, phytoplankton and zooplankton (NPZ) models and other ecosystem models.
- Remote sensing. Species-level phytoplankton data will aid validation of remote-sensing products.
- Biogeochemical and Biological Oceanography. Identify and understand mesoscale features that drive production, nutrient and carbon cycling, and biodiversity in Australian and regional offshore waters.
- Marine Pest Introductions. Establish data to document the spread marine pest species.
- Marine conservation. Data on lower trophic levels will be used as inputs of productivity and biodiversity into allocation of Marine Protected Areas in Australia.
- Climate Change Impacts: Provide baseline data to assess sensitivity of the physical-biogeochemical-biological system to climate change.
- Evaluate controls on phytoplankton production and responses of the system to perturbations (like iron inputs from dust storms)
- Fisheries Oceanography. Data on fish eggs and larvae will help identify species spawning grounds and timing of many species, and provide a critical baseline for how these may change in the future. Information on the biomass of lower trophic levels will be extremely relevant for many commercially-exploited shelf and oceanic fish species such as tuna.

Long Term Outcomes

Data records of greater than 10-15 years duration are required to begin to assess decadal scale signals while climate change effects will only be observed with more than 20-years.

- Climate Change Impacts: determine changes in the physical-biogeochemical-biological system resulting from climate change.
- Document the southern 'choke-point' across the Antarctic Circumpolar Current, the Indonesian Throughflow, the Leeuwin Current and the East Australian Current from seasonal, interannual, decadal to long-term timescales from the XBT lines. (Many studies have already documented the flow of the ITF, ACC and EAC at decadal timescales).
- Describe the time-varying nature of ENSO propagation from the Pacific to Indian Oceans, and the Indian Ocean Dipole, on the Australian region
- Provide longterm reference sections for model validation.
- Assess the sensitivity of the biogeochemical cycling and CO₂ uptake to climate change (warming, circulation change, altered buffering capacity, production),

