Australia's changing oceans: Building knowledge for actionable outcomes

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Abstract

Australia's oceans are vital to the nation's economy, environment and way of life. Australia's island geography, surrounded by the Indian, Pacific and Southern Oceans, exposes it to significant ocean-driven global, regional, and local environmental influences, driving the country's climate. Extreme weather events, superimposed upon continued climate-driven changes of our oceans, present risks to Australia's industries, national safety, society and environment. As a marine nation, Australia depends on the oceans for trade, industry, and recreation, making it essential to safeguard people, economy, infrastructure, and communities from ocean-related hazards. Rising atmospheric CO_2 levels are altering ocean temperature, salinity, carbon, currents and waves, leading to sea-level rise, intensified marine heatwaves, shifting species distributions, extreme weather and sea level inundation, and unprecedented social challenges for coastal communities and ecosystems. These ocean changes exacerbate threats to climate-sensitive agricultural and aquacultural industries, coastal infrastructure, marine and terrestrial ecosystems, marine protected areas (MPAs) and traditional cultural practices. In an era of rapid ocean change, addressing these multifaceted, interconnected challenges requires research and regulatory systems that are proactive, clear and centres environmental sustainability as its driving objective. A greater understanding of the current and future state of Australia's oceans will ensure greater understanding of Australia's vast marine estate and support robust decision-making, risk management and adaptation strategies via the development of actionable, evidence-based science.

Relevance

As articulated in Australia's sustainable ocean plan (1), Australia's island geography – surrounded by the Indian, Pacific, and Southern Oceans – along with its globally iconic coral reefs, and diverse, sensitive coastal environments are central to Australia's way of life and profoundly influence its climate, marine ecosystems, industries and society. Australia's weather, seasonal cycle, decadal, and longer-term climate are all influenced by the surrounding oceans and coastal seas (Figure 1 and 2). As a result, Australia's economy, environment and societal well-being are inextricably linked to the health and state of its surrounding oceans, with over 85 % of its population residing near the coast. The knowledge and understanding of the ocean environmental condition (physical, biogeochemical and biological), both current and projected, and variability of Australia's vast ocean estate, underpin crucial industries, for instance, the marine industry generated $118.5 billion in output in 2020-21 and supported 462,000 FTE jobs (2). Australian economic prosperity from existing and future industries, as well as societal ocean interactions, are increasingly threatened by climate variability and change and ensuing impacts (3). In recent years, observed impacts include extended drought and intense rainfall, rapid and extreme ocean warming, acidification, deoxygenation, sea-level rise, changing intensity and frequency of marine storms, coastal erosion, and shelf and coastal carbon and nutrients supply.

Australia's vast oceanic region, influenced by major climate modes such as the El Niño-Southern Oscillation (ENSO), the Indian Ocean Dipole (IOD) and the Southern Annular Mode (SAM), requires deep understanding of ocean-driven climate variability for improved regional to local ocean forecasting, predictions, and projections across the temporal continuum from weekly, monthly, seasonal, interannual, decadal to centennial timescales (Figure 2). In the 10-years since the adoption of the 2015-2025 marine science plan, Australian researchers have led significant advances in our understanding of the ocean-drivers of the climate modes, ocean carbon sequestration, biogeochemical cycle and, teleconnections of the climate modes and impacts on our regional seas and coastal environments (Figure 1, 2 and 3). Learnings from this research underpin the Sustainable Ocean Plan (1), National Climate Risk Assessment (3), and other national and international climate assessment reports (4-11), which are in-turn used to develop the national adaptation strategy (12). Our research has also enabled us to identify the key challenges and uncertainties that continue to impact our ability to provide robust and reliable ocean circulation, heat and carbon forecasts and predictions, providing the scientific bases for future research foci (1,13-15).

To lead to positive outcomes, scientific knowledge must be 'actionable', that is, based on scientifically robust knowledge (e.g., peer-reviewed, reasonable confidence) and application-relevant (e.g., aligned to decision-making frameworks) (16, 17). Active collaborations between researchers, and industry and government decision makers, including industry-funded ocean climate research, are crucial indicators of the utilisation of research findings, ensuring production and dissemination of relevant scientific information, its accessibility and uptake to meet stakeholders needs. The development of tailored data products, indicators that respond to societal needs and the support for policy, and management-relevant national reporting are key steps in ensuring research translates into tangible benefits.

Australia's vulnerability to oceanic-driven global, regional, and local influences underscores the critical relevance of focused ocean research (Figure 2). The ubiquitous influence of the oceans upon Australia results in a wide array of stakeholders that directly and indirectly benefit from enhanced Australian ocean science. Ocean stakeholders, including Indigenous Australians, coastal communities, coast and port asset owners, managers and insurers, tourist and recreational businesses are direct beneficiaries of improved understanding of the impacts and most plausible future trajectories of ocean warming, sea-level rise, change in storm surges, tides, wave conditions, and coastal erosion. These will inform better planning, infrastructure development, and early-warning systems, enhancing community safety and resilience, through the development of actionable science (3). Other stakeholders, including Australian marine parks (AMP), fishing and aquaculture industries, offshore energy (oil and gas, and renewable), and shipping industries will benefit from targeted research. In particular, research on the impacts of changing ocean conditions on marine operations, infrastructure design, fish stocks, species distribution shifts, and the prevalence of marine heatwaves and algal blooms, will enable more sustainable management practices and potentially identify new opportunities (18-20). Australia's extensive marine ecosystems like the Great Barrier Reef and Ningaloo Reef systems, the Great Southern Reef, and other coastal and off-shore marine protected areas (MPA), will benefit from ocean research that supports their conservation and resilience. Accessible and area specific ocean information will support AMP and Indigenous Australian's Sea Country management and help preserve marine cultural heritage. Terrestrial stakeholders, including infrastructure, agriculture, health and energy industrial sectors, communities and environments will benefit from improvements to climate prediction through increased understanding of ocean variability and change.

The delivery of these benefits can be tracked through various indicators. Environmental benefits can be assessed via long-term monitoring of key ocean environmental and ecosystem indicators, such as ocean temperature, sea-level, currents, carbon, ocean acidification and nutrients, biodiversity, and habitat health as synthesised by the State of the Climate report (9), State of the Environment report (8), and AMP management plans. Biodiversity credits, and other related schemes, are a measure of conservation and restoration success or reduced impact of threats. Economic benefits can be tracked through the performance of terrestrial and marine industries, considering factors like sustainable resource management, climate adaptation policies and strategies, optimising marine operations and safety using ocean and weather forecasts, climate information, and providing baseline information to emerging and growing industries, such as marine renewable energy and insurance. Regional-scale economic valuations have already demonstrated substantial returns on investment in ocean observing systems (21). Societal benefits, coastal resilience and community preparedness for ocean-driven and ocean-related hazards, can be assessed through surveys, MPA risk assessments, engagement in marine tourism and with Traditional Custodians, and evaluations of the effectiveness of early-warning systems. Robust ocean and ecosystem indicators for coastal and marine habitats will provide environmental inputs for consideration in the development of MPA zoning and management policies, sustainable tourism and recreational activities, and support of Indigenous Australians culture.

Indigenous Australians have deep and enduring connections to Sea Country, holding invaluable knowledge accumulated over millennia of marine ecosystems, species behaviour, and environmental changes (1). To genuinely integrate Indigenous knowledge, research needs to move towards Indigenous-led co-design and co-production of science, where Indigenous knowledge holders are leaders in formulating research questions, methodologies, data collection, the interpretation and implementation of findings from as early as the proposal stage (22). This requires building partnerships based on mutual respect, trust, and the recognition of Indigenous data sovereignty and intellectual property rights (22). It also requires a long-term strategy to facilitate the access to decision making roles for Indigenous Australians. Providing resources and capacity building for Indigenous communities to engage in research and monitoring activities and ensuring that research outputs are accessible and relevant to their needs and cultural contexts, are also crucial (1). Inter-weaving Indigenous knowledge systems with western science practice can provide a more holistic and nuanced understanding of ocean environments and lead to more effective and culturally appropriate solutions for sustainable ocean management and climate change adaptation.

Current state of Science Research and Development

Ocean research in Australia encompasses a wide array of topics and spans the vast geographical extent of surrounding ocean basins, regional seas, and shelf seas adjacent to our shores (Figure 1, 2 and 3). Research focuses on ocean variability as a moderator of climate variability and change through heat and carbon exchange with the atmosphere, and the consequent impacts of these changes. Central to this mission is understanding of the 4-dimensional (latitude, longitude, depth and time) ocean circulation including major current systems; the heat, salt, carbon nutrients and other property distribution; major ocean-driven climate modes that impact Australia's climate such as ENSO, IOD, and SAM; the exchange of ocean properties and the connectivity between the open-ocean and continental shelf; the oceans interactions with the cryosphere, and extreme weather and marine events, their predictability and effects on the environment. This large research portfolio and expansive geographical focus reflects the nation's vast ocean estate and its susceptibility to ocean-driven global climate change.

Australian-led Pacific Ocean research has investigated the response of the basin circulation to climate change, including ENSO, and teleconnections and impacts on the Coral and Tasman Seas. The east coast of Australia is the western boundary of the South Pacific gyre, as such it is the impact point of Pacific Ocean variability and change. The boundary currents – the southward flowing East Australian Current and northward flowing Hiri Current and North Queensland Current in the Gulf of Papua – rapidly distribute ocean property variability and change from the equator to the high latitudes. This research has quantified the strength, variability, and instabilities of the East Australian Current and Hiri and North Queensland Currents transports. The influence of these boundary currents and inflow from the South Equatorial Current on the Coral, Tasman, and Solomon Seas has been investigated, including the associated eddies. Coastal ocean and the boundary currents variability is strongly connected to ENSO phases; thus, a primary research focus has been on understanding the ocean-atmosphere interconnections and ocean circulation modulations during ENSO.

Tropical Pacific and Indian Oceans variability has profound impacts on Australia's climate and seasonal rainfall. As the only low-latitude connection between the Pacific and Indian Oceans, the Indonesian Throughflow (ITF), remains an active area of research as it substantially influences both the Australian and regional climate. New insights into how the ITF redistributes heat and ocean properties between the Pacific and Indian Oceans have been documented, providing improved knowledge of the two-way ocean-based teleconnection pathway for tropical climate signals and impact on marine heat waves along both the eastern and western coastal regions. This research has provided improved insights critical for Australia's agricultural security and public safety (flood and fire events).

The focus of Australian research in the Indian Ocean encompasses the rapid warming and changes in ocean circulation, and tropical and extra-tropical ocean-atmosphere interactions. Studies have investigated the meridional overturning circulation and the influence of the IOD on Australian rainfall patterns. Research on ocean-atmosphere coupling and interaction has considered the impact of the Indian Ocean Madden-Julian Oscillation (MJO) on weather patterns, particularly those impacting sea surface temperatures, tropical cyclones, marine heatwave frequency and coral health of west Australian reefs. Furthermore, Indian Ocean research has examined boundary currents variability, such as the Leeuwin Current and the Southern Australia Current System. The variability in ocean heat content and exchanges in the Indian Ocean was also of interest, highlighting its crucial role as a clearinghouse for anthropogenic heat. Widespread coastal erosion along the south-western coast of Australia have driven research interest in the combined influence of climatological variability of the swell generated in the Indian Ocean sector of the Southern Ocean and sea-level, and associated beach and coastal response.

Antarctic and Southern Ocean research has focused on the region's fundamental role in global climate heat and carbon sequestration and redistribution, as well as its impact on sea level rise through changes in ice sheets and ice shelves and the potential for continued or enhanced carbon sequestration. A major output has been the improved understanding of the complex Antarctic ocean-atmosphere-cryosphere system, encompassing the ice sheet, ice shelves, and sea ice, and its crucial influence on global climate systems. This also includes research into shifting weather patterns, and extreme events. New understanding of the dynamical interaction between the Southern Ocean and Antarctic Ice Shelves, mediated by sea ice, has shown that these interactions control the rate of mass loss from the Antarctic Ice Sheet and determine future sea-level rise. In addition, improved understanding of the oceanographic processes of the Southern Ocean, including the Antarctic Circumpolar Current (ACC) and the abyssal ocean overturning circulation, has highlighted its role in global circulation, heat and carbon uptake, and its potential to continue to moderate the impact of climate change. The Southern Ocean wind climate has been another area of active research due to its unique wind-wave generation environment and global influence. We are also understanding variability in these themes that are linked to the SAM, a key climate mode for the region.

Significant shelf and coastal ocean research, crucial given Australia's large coastal population and significant coastal-based industry and infrastructure, has been undertaken. This includes studies on boundary currents, cross-shelf exchange, coastal sea level variability, sea-level and sea-state extremes and coastal erosion, dynamics of ocean extremes, and upwelling events. A primary focus has been to quantify and characterise the ocean processes and air-sea interaction driving extreme ocean temperature given the vulnerability of coastal and offshore marine ecosystems to extended marine heatwave events, including in the subsurface. Other key areas include the study of the ocean's role in global biogeochemical cycles and carbon-climate feedback. These studies are becoming increasingly important with consideration of ocean-based carbon solutions as a way to enhance the oceans' capture and storage of carbon from the atmosphere, thereby helping to reduce global carbon levels. Research has also focussed on the prediction of marine extremes, such as dangerous sea states and storm surges for both operations and design specification for structural loads, coastal hazard assessments, renewable energy projects, and related coastal and maritime engineering needs. Additionally, research also examined coastally trapped waves and their impact on currents.

Research undertaken in Australia employs a diverse range of data and methods. These are comprehensively discussed in the companion “enabler” white papers. Significant support for in-situ and modelling infrastructures is provided by the National Collaborative Research Infrastructure Strategy (NCRIS) to the Marine National Facility (MNF), National Computational Infrastructure (NCI), Integrated Marine Observing System (IMOS), Australian Community Climate and Earth System Simulator- National Research Infrastructure (ACCESS-NRI) and the Australian and New Zealand International Scientific Drilling Consortium (ANZIC). Additionally, short-term research activities also support the collection of in situ observations and model developments and simulations. The ocean research infrastructure programs are highly leveraged with in-kind investment by the research institutions. As research infrastructure, they fund acquisition of ocean observations and model development, and code optimisation to support researchers and end-users. However, they do not support researchers in the use of the ocean observations and application of model code to produce scientific information or improved ocean knowledge required by policy makers, and industry end-users.

Numerous institutions in Australia undertake ocean research, including a variety of publicly funded research agencies (PRA), universities, and collaborative research centres. Combined, these institutions provide a broad range of skills and expertise to enable research that addresses ocean climate change impacts across various regions, from the equator to Antarctica, the open ocean to the coast, and broad expertise, including observing system development, biogeochemical cycling, ocean dynamics at multiple scales, ocean-atmosphere exchanges, and satellite oceanography. The funding that supports ocean research at these institutions is complicated, with reliance on short-term 3-7 years funding programs. Many of these programs, across the University and PRA sector have either recently ended or will end in the coming 2-3 years, with no clarity of future funding programs. As such, the lack of long-term funding certainty severely impacts our ability to retain or expand a skilled capability within Australia.

The ability of the institutions to work collaboratively, particularly between PRA's and Universities, has diminished significantly over the last 5 years due to changes in funding rules at the Australian Research Council (ARC) and within the PRAs. The Australian Academy of Science Decadal Plan for Earth System Science 2024-33 (24) notes that programs such as the National Environmental Science Program and ARC Centres of Excellence which exist in the ARC Linkage program have moved significantly to end-user driven research. This investment in climate services and products has occurred without commensurate investment in the new foundational ocean science capability required to underpin these new end-user-driven services and products. An impact of the changing focus of funding agencies has been reduced research and capability coordination amongst the PRAs and universities. This disjoint hinders Australia's effectiveness to tackle key questions and challenges confronting ocean science and diminishes our ability to participate and lead international ocean science activities central to Australia's economic and social interests.

Knowledge and Disciplinary Requirements for Advancing Australian Ocean Science

In early 2025, Australia introduced legislation mandating climate related financial disclosures, applicable for large businesses and financial institutions. This mandate together with Australia's membership of the High level Panel for a Sustainable Ocean Economy (1) and the activities of the Australian Climate Services (https://www.acs.gov.au/) will increase the demand for science-based ocean information to facilitate rapid and scientifically sound decision making. Central to this, is an in-depth understanding of the Indian, Pacific, and Southern Oceans and their interplay with Australia's shelf and coastal waters (Figure 3). To provide this information, key knowledge gaps and challenges need to be addressed. Overcoming these challenges requires transdisciplinary research and integration across spatial and temporal scales.

Enhanced knowledge of the Pacific and Indian Oceans and their tropical connection is required for improved understanding of factors controlling the tropical and extra-tropical variability and its climatic influence, which are crucial. Upper ocean variability of the Indian and Pacific Oceans impacts rainfall and temperature patterns over the Australian continent. Warmer than average sea surface temperatures can provide more energy and moisture to the atmospheric systems with significant impact to Australia, for example feeding disruptive tropical cyclones.

In the tropical Indian and Pacific Oceans, including the ITF, key science gaps include understanding of the physical drivers of tropical climate phenomena, such as ENSO and IOD, on various time scales, their interactions and teleconnections, future change under ongoing climate change, and impact/feedback to the atmosphere and coastal systems. Yet ocean-atmosphere feedback mechanisms, particularly through the coupled boundary layer and teleconnections to coastal and shelf regions are poorly understood and modelled. Net surface heat fluxes are uncertain over much of the tropical ocean, schemes to calculate fluxes in models need urgent attention and predicted/modelled trends sometimes contradict the observed heat content increase. Obtaining observations and accurate model predictions in high flux boundaries remains a significant challenge and is a key requirement for improved seasonal and interannual ENSO and IOD climate predictions.

In the Southern Ocean there are also critical gaps in knowledge regarding the interactions between the ocean, atmosphere, surface waves, tides, sea ice, and the Antarctic ice shelves, which are crucial for understanding the rate of Antarctic ice loss and future sea-level rise. This region is subject to several potential interacting tipping points with major and irreversible consequences that require focused research. Knowledge of the stability of the overturning circulation, a key factor controlling global climate and heat and carbon exchanges with the atmosphere, and connecting Indian and Pacific Oceans, is lacking. Furthermore, there is a paucity of studies analysing the differences in the trajectories of polar cryosphere and ocean systems between low and very low greenhouse gas emission scenarios. Understanding the characteristics of key ocean and sea ice habitats is important for predicting the future states of Southern Ocean ecosystems, but there is a need to better characterise indirect responses to physical change using models and observations.

Significant knowledge gaps persist in understanding our regional oceans' heat, carbon, and nutrient storage and redistribution. Ocean carbon storage and redistribution are important as they have strong implications for moderation of the impact of climate change and atmospheric carbon dioxide concentrations. Ocean-atmosphere heat exchange and feedback to atmospheric weather systems is particularly important with the predicted increase in intensity and occurrence of extreme weather events (3). Cycling of heat, carbon and nutrients between the open ocean and shelf and coastal regions have direct impacts on the sustainability of the marine ecosystems (1). Understanding of the drivers and variability of the boundary currents, as key connectors of the open-ocean to the coastal seas is required. Capturing the variability across multiple time-scales of the boundary currents is essential to understand their role in transporting heat, freshwater, nutrients, and carbon, and in driving climate variability.

Over $226b worth of building and infrastructure assets in Australia are estimated to be at risk to a 1.1 m rise in sea-level (23). Early warning systems - both at operational and planning time-scales - that integrate the combined impacts of sea-level rise, low-frequency sea-level variability (on interannual - ENSO - cycles), seasonal sea level variability, tides and sea-level extremes (the combined influence of storm-surge and wind-waves) are still in development. Such systems have the potential to offer coastal managers and planners' options to reduce uncertainty, increase management efficiencies and protect their investments in years to come from adverse conditions. Infrastructure such as offshore energy (oil and gas, and wind energy) platforms, and aquaculture facilities, and the operations that occur thereon, are similarly exposed to climate related risks related to present and changing hazards (e.g., metocean - wind and wave - conditions, sea surface temperature, and ocean circulation).

With Australia's population concentrated along the coast, the influence of regional seas is keenly felt via numerous economic sectors, and recreational and cultural values. Key knowledge gaps and science challenges hinder a comprehensive understanding of Australia's coastal and ocean environments. Significant uncertainty remains regarding the impact of climate variability and change on the coastal ocean environment as well as the ability to translate large-scale ocean changes to potential local impacts. Australia’s coastal and shelf waters are directly connected to the open-ocean and readily exchange properties across the continental shelf and slope boundary. The drivers and mechanisms of open-ocean and shelf exchange and sub-mesoscale ocean processes in coastal circulation are not fully understood. Furthermore, many of the finescale processes are not represented adequately in regional ocean circulation models. The influence of ocean-basin drivers on the boundary current variability, also linking to eddies and marine heatwaves, need to be better characterised. Boundary current dynamics affect the continental shelves and coastal regions along the most densely populated coastlines. Subsurface and deep ocean variability, for instance through eddies and undercurrents, is also a knowledge gap due to the sparsity of observations and access to high-resolution coastal modelling systems. Further research is needed on the drivers of coastal ocean warming and stratification changes on the shelf and the impact of changes in boundary currents. Improved understanding of these ocean dynamical and biogeochemical processes will advance the prediction of marine heatwaves, upwelling, and other extreme events on sub-seasonal to seasonal timescales, which is particularly important for effective marine resource management (Figure 3).

There is a need to better quantify the role of the open-ocean and Australia's coastal oceans in global biogeochemical cycles and carbon-climate feedback. These gaps present significant challenges to understanding the bio-physical interactions and the response of coastal marine ecosystems to physical ocean changes. Understanding extreme events and the long-term consequences of ocean acidification and its interactive effects with other drivers of change remains a key research gap. Understanding of how carbonate structures (e.g., coral reefs) will respond to a rapidly acidifying ocean, especially the rate of erosion and dissolution, remains a significant research gap. In terms of biogeochemical cycles, there are many gaps, including nutrient limitation patterns and the relationship between primary production and the planktonic food web structure. Additionally, biogeochemical impacts of boundary currents are poorly understood, and are a critical gap given the changes occurring in these current systems.

Addressing these complex issues requires a collaborative, transdisciplinary and connected research structure, fostering collaboration across all agencies and institutions. Integrated interdisciplinary studies and model development are essential to find integrated solutions to ocean change. Furthermore, integration of knowledge requires effective engagement from physical science, natural sciences, social sciences, local communities, and Indigenous knowledge holders. Addressing these critical issues necessitates sustained investment in observations, coupled and ocean-only modelling, ecosystem models, process-based understanding, and prediction capabilities, supported by essential research infrastructure. Enhanced national coordination and strategies are vital for overcoming the fragmentation of research efforts. Fostering international collaborations and partnerships, particularly with Indian Ocean rim countries and Pacific Island States, is crucial for regional capacity development and data sharing. Ultimately, a more integrated and collaborative approach will advance our understanding of these critical ocean regions and enable us to respond effectively to the challenges we face (Figure 4).

Infrastructure and capability need

Societal demand for science-based ocean management and policy advice from marine and coastal management, industries and communities is increasing, and relies upon long-term, coordinated research outcomes provided by foundational research (2-5). Understanding these demands, and the data, research and insights required to meet them, is key to developing actionable ocean science. The effectiveness of current ocean research to meet stakeholder and end-user needs is a critical question. Research priorities are also influenced by the pressing need to understand and respond to climate change impacts. Co-design of research activities with key users and stakeholders is crucial to meet prioritised societal requirements. Strong national and international engagement, collaboration, and long-term funding commitments are vital to maximise the value of Australian investment and ensure national and international activities address issues relevant to Australia and the wider Indo-Pacific and Southern Ocean regions. Given our geographical position, ocean-climate understanding is the entry fee to credibility in our region.

Sustained funding and a coordinated national approach will advance ocean research. The influence of the broader Indian, Pacific and Southern Oceans on Australia's marine estate, coasts and terrestrial climate necessitates a broader regional responsibility, requiring investment in improved ocean understanding beyond those recognised as direct stakeholder interest. Specifically, the Decadal Plan for Earth System Science 2024-33 emphasises the need to develop a strategy and methodology to prioritise process-based studies for ocean systems and ensuring strong collaboration with observational and modelling efforts. Operationally sustaining ocean monitoring, and forecasting, reanalysis and projection modelling systems to both meet operational needs for safety at sea and increase the resilience of marine and coastal systems to ongoing change over the long term is a key requirement. Continued and expanded contributions to international collaborative programs are vital for Australia's maritime interests.

Australia engages in multiple forums within the Indo-Pacific region, including the Pacific Island Forum and the Secretariat of the Pacific Regional Environment Programme, and the Indian Ocean Rim Association (IORA; 1). Australia maintains a presence in delivery of climate services across the Pacific, including through programs like COSPPac and Van-Kirap. Given Australia's strong involvement in numerous international science forums and its expertise in ocean observation and modelling, it is reasonable to suggest that Australia should continue to contribute to the broader international understanding of the tropical ocean through data sharing, model development, and active leadership and participation in the significant international scientific programs occurring in the Indian and Pacific Ocean (1). Thus, we need to grow our participation in these international programs, all of which are also connected to our own national ocean sustainability challenges.

Australia must continue to play a significant role in Southern Ocean and Antarctic Science (1,14). As noted in the Australian Academy of Science submission to the inquiry into the importance of Antarctica to Australia's national interests, Australia's leadership and capacity in Antarctic and Southern Ocean research demands a comprehensive scientific agenda capable of addressing both national and global research priorities (6). The Australian Antarctic Science Decadal Strategy 2025-2035 finds that maintaining and strengthening collaboration among national and international partners, including alignment and coordination of research effort, will be critical to achieving the outcomes identified in the decadal strategy, which builds on Australia's long and proud history of Antarctic exploration and scientific research and collaboration (14).

Currently, fragmentation of Australian ocean science research and limited integration across science, policy, and industry interfaces hinders the ability to address these national challenges. A shortage of funding sources that support collaborative work between university and publicly funded research agency scientists impedes progress at a national level and meaningful participation in international research and planning endeavours. Maintaining a world-class Australian ocean science capability that plays strongly in the international collaborative processes is crucial to leveraging our resources and investments for detecting, monitoring, and predicting ocean climate variability and change.

There is also a gap between research outcomes and connection to policy and next- and end-users. Engagement, following co-design principles, amongst science, policy-making and funding priorities is crucial for enabling broader community involvement and consideration in management. The connection between the large climate adaptation research community and the ocean communities needs to be strengthened. This includes increasing investment in translating science to all levels of government, policy and industry decision makers which will support the design and implementation of effective management solutions.

Progress/Impact Measurement

The changing ocean and its variability are drivers of many extreme climate events (3). Thus, the endeavour of improving ocean knowledge and understanding is a crucial investment in Australia's national security, economic prosperity, and environmental stewardship and leadership.

Australian ocean research has enabled the detection and attribution of climate change and provides a robust science base from which mitigation and adaptation policies can be built that best meet the needs of Australia and the region. This information is delivered through domestic and international data and service platforms, along with international, national and state government and industry reporting mechanisms (3-5,7-11,23, 25,26). The knowledge provided is the foundation that underpins marine management decisions, climate services and end-user needs, as well as national and international research, into climate impacts of drought, flood, bushfire, sea level inundation, and other extreme climate events.

To manage and mitigate climate change impacts on our terrestrial and marine environments, understand weather patterns and make climate and weather predictions, it is important to understand the key dynamical processes that set the ocean circulation and ocean-atmosphere interactions. Ocean research outcomes have contributed to improved knowledge of ocean processes, ocean circulation and ocean modelling, and have led to the provision of the climate information required for assessment of climate risk and development of mitigation and adaptation policies. Without accurate knowledge and services, Australia risks substantial maladaptive investment from both the private and public purse.

Australia is the leading nation in the Southern Hemisphere for ocean research. Australia makes a significant international contribution to the understanding of physical and biogeochemical changes in the ocean, along with research focused on ocean-based solutions for climate change. The

Australian scientific community contributes to high-profile international documents such as the high-level Panel for a Sustainable Ocean Economy, and the Intergovernmental Panel on Climate Change (IPCC) Assessment Reports (1,7-10). Australian scientists are prolific publishers in leading academic journals and actively participate in leadership roles within influential international committees and working groups of organisations such as the International Council for Science (ICSU), the World Meteorological Organisation (WMO), and the United Nations Educational, Scientific and Cultural Organisation (UNESCO). Global research initiatives and processes provide Australia with access to many times our contribution of data, information, knowledge and expertise – all of which contributes to and informs our own understanding of Australia's climate and how it may change under continued global warming. In addition, Australian scientists will continue to work with Governments and Industry on co-designing knowledge generation that suits management needs, including translating research findings and data into actionable outputs that directly feed into decision-making processes.

Dependencies and Priorities

Ocean knowledge depends on nationally sustained ocean observations and modelling systems, and collaborative and supported diverse research communities with strong connections. These systems also need to link effectively with next users, end users and stakeholders (Figure 4). Australia must maintain a strong and proactive international profile with partnerships with international oceanographic research institutions, and governmental and non-governmental agencies. This engagement enables us to leverage our ocean investment with significant contributions from the global north and subsequent investment in key ocean challenges that directly benefit Australia and the wider Indo-Pacific region (1).

There is a strong need for regionally specific, and process-based studies that connect the large-scale ocean change and variability to the coastal and shelf seas for effective decision-making and adaptation strategies. Therefore, understanding, monitoring, and predicting oceanic and ocean-driven climatic changes are fundamental for safeguarding Australia's national interests. Increased and sustained personnel, and resource capability and capacity investment in understanding the ocean controls and feedback on Australia coastal and shelf regions is required to protect our unique marine biodiversity, ensure the sustainability of marine industries, enhance the resilience of coastal communities, infrastructure, and maritime safety and security.

Improved understanding of the ocean regions that directly influence Australia also depends heavily on international investment at all levels. The potential loss of international investment would have significant consequences, including gaps in critical data streams. An investment priority for the next 10 years should therefore include securing our own capabilities, exploring opportunities to fill potential international gaps, and developing strategies to safeguard access to critical ocean data and models. These efforts would help maintain Australia's leadership in ocean research and strengthen our contributions to global initiatives, even in an increasingly uncertain international funding landscape.

Priorities and milestone for the next 5 years (2025-2030)

- **Establish a transdisciplinary Australia Oceans coordinated program** across PRAs, Universities and other institutions, with a focus on Australia's oceans estate across the open-ocean and coast boundary. The program will focus on Indo-Pacific teleconnections, ocean-ecosystem processes and interactions that translate basin and regional ocean change and variability to our coastal and shelf domains. It will develop research priorities directed to providing ocean understanding to underpin existing and future climate services and marine eco-system needs. The transdisciplinary program will unite the different ocean disciplines towards common goals, breaking the discipline-specific approaches that are commonly used, and include integration of the ocean research community, policy-makers, and industry stakeholders enabling engagement to identify shared challenges and accelerate the application of scientific insights. The program will align with the "enabler" priorities - data, modelling and infrastructure. Including use of
    - observational programs and multi-scale process-based studies.
    - modular ocean and coupled modelling, data assimilation and eco-system model infrastructure that span regional/global, physics/BGC/biology.
    - connected data systems.

- **Develop and implement requirements to monitor and mitigate risks associated with potential ocean-based carbon solutions to climate change**, recognising the oceans' role in climate mitigation and adaptation. Risks associated with these solutions—environmental, social, and economic—must be thoroughly identified, evaluated, and addressed through transparent, science-based assessment. Establishing these safeguards is essential to ensure the responsible scaling and long-term sustainability of ocean-based climate interventions.

- E**nsure sustained Southern Ocean and Antarctic research**.
    - Maintain long-term observational and modelling programs for the polar region.
    - Strengthen Australia's leadership role in international Antarctic science.
    - Translate research into strategies that safeguard Australia's environment economy, and security.

Building on these, the outcomes and extensions in 10-year (2030-2040) goals would be:

- A strengthened ocean literacy and wide-public support for ocean research, including public acknowledgement that Australia's climate variability is largely driven by our island geography, emphasising that unexploited knowledge obtained from ocean research investment is essential for improving Australian economic and society prosperity.

- Actionable, evidence-based ocean science that provides knowledge and information essential for Australia's environment economy and society.

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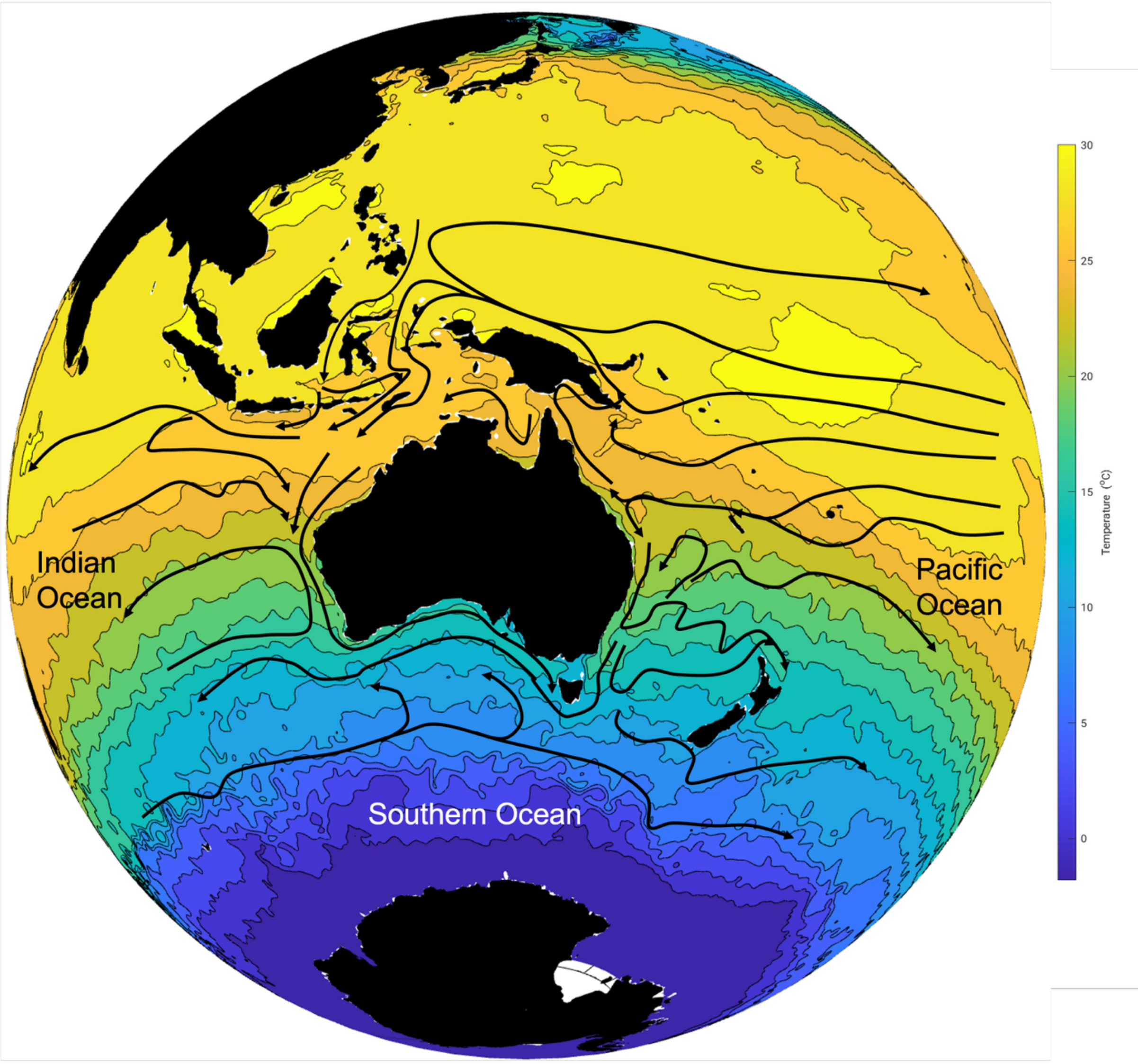

Figure 1. Australia is an inland nation at the centre of three major ocean basins that are connected through our regional seas and northern, western, southern and eastern boundary currents. Mean sea surface temperature (color) from NOAA OISST and schematic of prominent ocean currents (black lines) that encircle Australia.

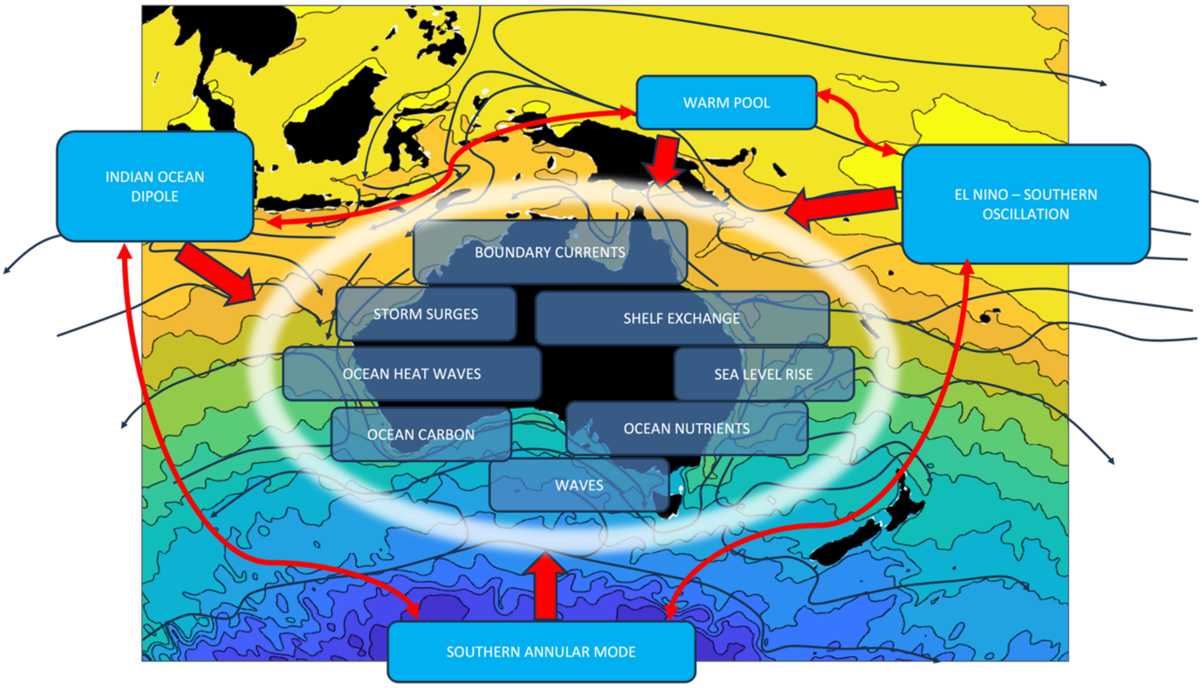

Figure 2. The tropical, mid- and high-latitude oceans around Australia provide an ocean teleconnection of the three global climate modes (light blue boxes and red double arrow lines) that directly impact Australia ocean environment (red arrows). The climate signals drive the ocean state of our coastal marine environment (boxes inside white halo).

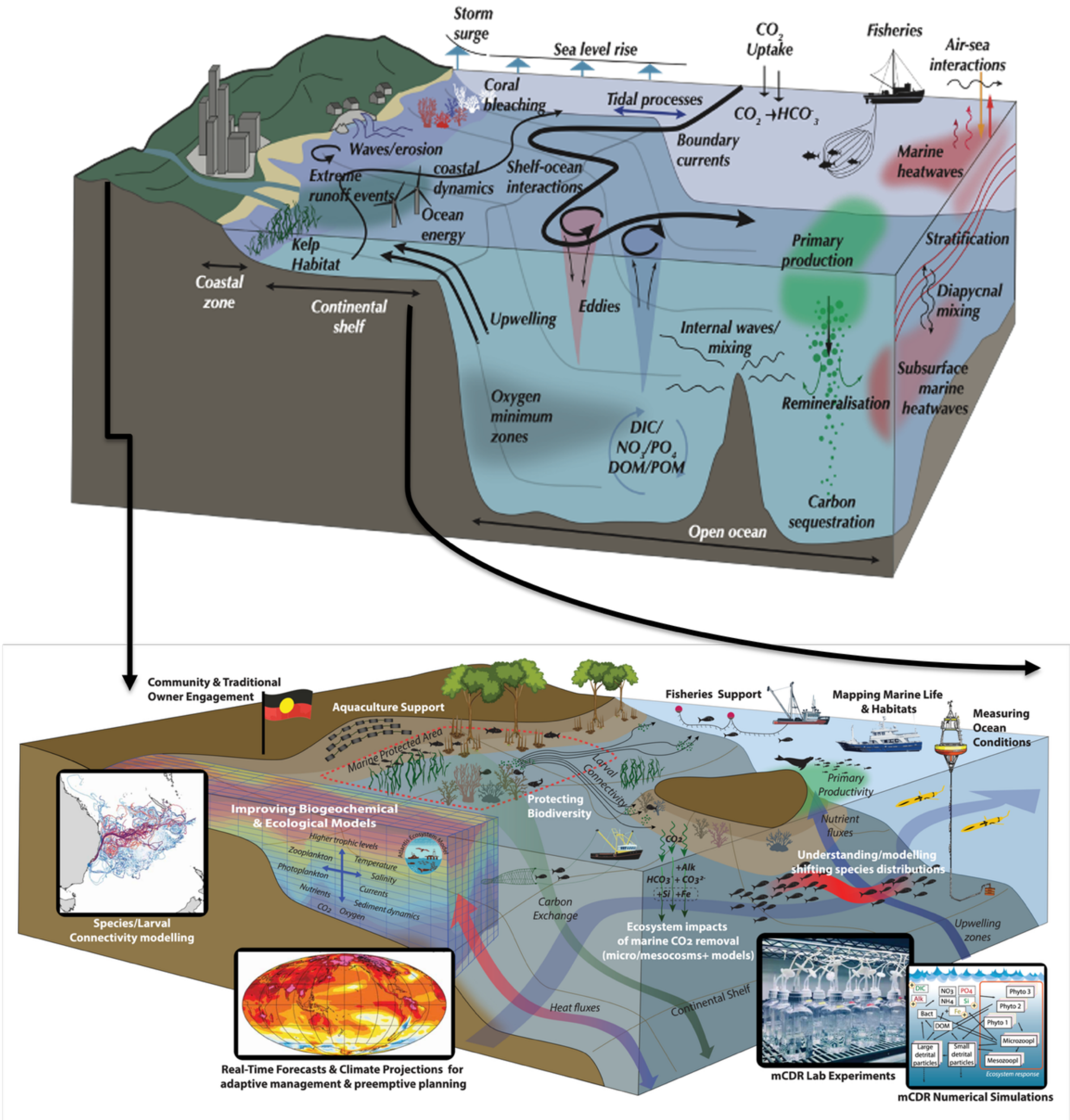

Figure 3. Connection between the physical, biogeochemical and biological systems and exchanges between the open-ocean and shelf. These exchanges are driven by large and small-scale ocean and ecosystem processes that are inherently interdependent. Schematic from the proposed ARC Centre of Excellence for Our Future Oceans

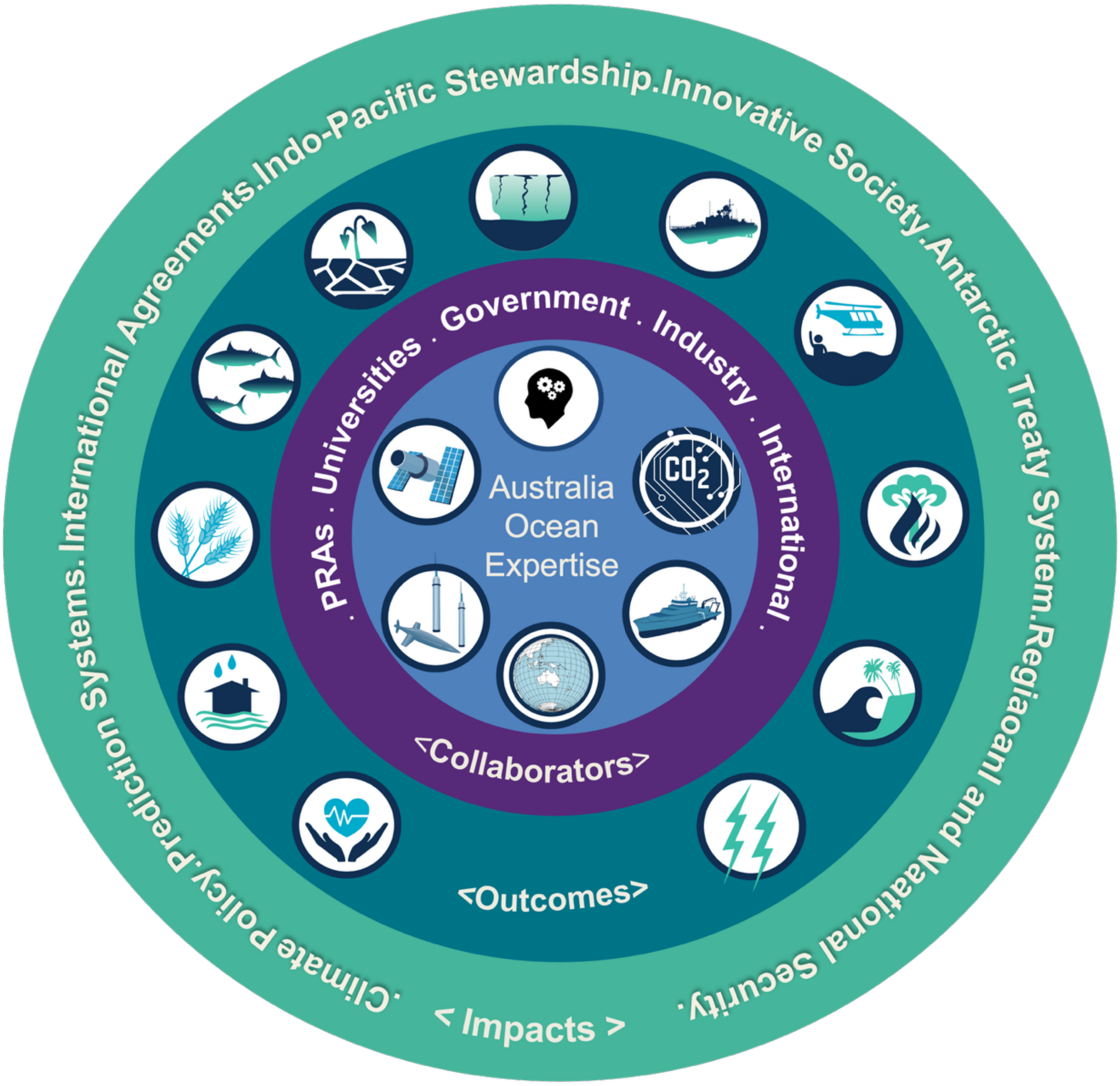

Figure 4. Combined Australian ocean infrastructure and research communities meeting the needs for actionable outcomes and impacts to meet Australia's key challenges.