National Marine Science Plan - Marine Sovereignty, Security and Safety Theme

Abstract

Marine sovereignty, national security and safety require accurate information about the oceanic, atmospheric and hazard domains in order to support prediction, prevention, mitigation and compliance activities from global to nearshore spatial scales and on timescales from weeks to hours. From a sovereignty perspective, Australia's continental shelf is almost completely defined. There are, however, significant gaps in high-resolution coastal bathymetry and topography data which underpin many scientific and operational applications, such as inundation forecasting, coastal development and mitigating risks of marine and geo-related hazards. Existing but limited blue water, ocean wave, tsunami and cyclone forecasting capacities require long-term commitment to help further develop the national operational oceanographic and marine hazard forecasting capability, with enhanced coastal and littoral zone components. These operational forecasting and reanalysis systems will predict deepwater, seabed, offshore coastal and shoreline conditions and be able to provide a clear indication of the reliability of the forecast and ability to meet growing user requirements. As science advances our understanding of Australia's marine environment, so too grows the user pool who rely on the science applications and their ability to meet user needs of the growing populations in our coastal margins. These aspirations will all need to be supported by a wide range of observations, collected both remotely and *in situ*, to feed into forecasting and compliance systems.

Background[1]

Given the diversity of scientific challenges and associated applications faced by addressing national security and marine safety, the spectrum of research providers includes many public and some private sector institutions. Leading federal and state government R&D providers and agencies include BoM, CSIRO, GA, AIMS, RAN, DSTO and SARDI.

Our university sector has a strong international reputation. UNSW Water Research Laboratory and the University of Queensland coastal group both have 50+ year track records of internationally leading research in this area, with the University of Western Australia also having a strong track record (Gourlay, 1996). Led by UNSW, a consortium of these universities hosted the peak International Conference on Coastal Engineering (ICCE) in Sydney in 1980 and

[1] Definition: for the purpose of this paper we will regard the ocean as a spatial and temporal continuum from the deepwater to the estuaries and on time scales from hours to weeks. Some specific science challenges require a more detailed definition like "coastal" which can be defined as covering domains from the upper continental shelf into the head of estuaries, that is, the part of the ocean that is significantly affected by tides. A sub-region to "coastal" is the very nearshore or littoral zone, which can be approximately described as that part of the ocean where the effects of surface waves are felt at the sea bed (with the potential to cause significant sediment resuspension).

2000. In early July 2014, the privilege of holding ICCE was again awarded to Australia and is to be held in Sydney in 2020. The University of Tasmania and Swinburne University have developed international reputations in the area of oceanography and maritime engineering in the last decade, held the major international wave-modelling meeting WISE-2007. Weaknesses continue to exsits in certain areas due to **lack of, e.g., critical mass, observations, infrastructure and funding.**

Funding is mainly provided by the Australian government (CSIRO, BoM, GA, AIMS, RAN, state and local governments), the Australian Research Council (Universities) and maritime industries and international grants (e.g., US Office of Naval Research).

There are three major jurisdictions involved in dealing with issues in the coastal ocean domain:

1. The Australian Federal Government has primary responsibility for managing Australia's Economic Exclusion Zone in waters beyond 3 nautical miles.
2. State Governments have primary responsibility for economic and environmental management of coastal activities out to 3 nautical miles.
3. Local government has primary responsibility for the management of the infrastructure that serves coastal communities. In Australia, these are predominantly represented by the National Sea Change Taskforce (http://www.seachangetaskforce.org.au/).

Furthermore, the Australian Meteorological and Oceanographic Society (AMOS, http://www.amos.org.au/), the Australian Coastal Society (ACS, www.australiancoastalsociety.org), the National Committee on Coastal and Ocean Engineering (NCCOE) (http://www.engineersaustralia.org.au/coastal-ocean-engineering) and PIANC Australia (http://pianc.org.au/) are groupings who represent the interests of scientists and engineers in the coastal domain.

Australia's marine zone is often managed through a combination of federal and state marine protected areas (http://www.environment.gov.au/topics/marine/marine-reserves).

Legal continental shelf

From a sovereignty perspective, **Australia's continental shelf is almost completely defined**. In 2012, Australia proclaimed the vast majority of the limits of its continental shelf. The only outstanding areas are the Australian Antarctic Territory (AAT) and two small areas (by Australian standards) of continental shelf each representing about 40,000sqkm of seabed (Joey Rise at the north-western corner of the Exmouth Plateau and Williams Ridge, a sub feature of the Kerguelen Plateau).

Coastline and territorial sea baseline

Australia's effort is presently focused on the review of the territorial sea baseline. This program involves detailed mapping of the coastline of Australia, including its external territories, every Island, rock, reef, cay and low tide elevation must be mapped and assessed (Geoscience Australia). Finalising this program will probably take another three to four years. At the end of this mapping program the expectation is that Australia will make a proclamation permanently describing the limits of all its maritime zones. As much as a scientific/technical program, it is a program to improve the administration of the marine space. Geoscience Australia delivers this program through collaborative arrangements with State land management agencies and the Australian Hydrographic Service. For Australia, this program is approximately half complete. It will be **one of the most comprehensive mapping programs undertaken of the Australian Coastline** – the effective mapping scale is approximately 1:1000. The mapping is undertaken using high-resolution aerial photography supplemented with hydrographic data.

National ocean forecasting system

In 2003, the Commonwealth Scientific Research Organisation (CSIRO), the Bureau of Meteorology, and the Royal Australian Navy (RAN), developed a partnership and established the BLUElink Project. The goal was to develop an operational ocean forecasting system and related tools to meet Australia's defence and community needs. Over the past decade, **the BLUElink partnership has developed and delivered a world-class ocean forecasting system**. Australia's state-of-the-art ocean forecasting capability, which is run operationally by the Bureau of Meteorology with the support of CSIRO, currently provides a robust service to meet recreational and industry users of deep-ocean forecasts (temperature, salinity, currents), as well as Navy's specific operational requirements to ensure efficiency and safety of Defence activities. BLUElink is the only global-to-regional scale ocean forecasting system in the southern hemisphere and among a handful of systems which cover these scales like the UK MetOffice, US Navy, Mercator (France). The performance of the operational ocean forecasts delivered by the BLUElink modelling and analysis systems is state-of-the-international-art.

Marine hazard forecasting

Waves are forecasted by the Australian Bureau of Meteorology, using the American national wave forecast model WAVEWATCH-III. A new version of WAVEWATCH-III was released in March 2014 which includes observations-based physics developed by Swinburne University.

Relevance

Australia's large Exclusive Economic Zone (EEZ) corresponds mostly to continental shelf waters, which has consequences for defining sovereignty, security (defence and border/resources protection), prosperity and sustainability through informed management. This includes offshore severe weather systems that threaten offshore users and eventually coastal communities. Offshore industries significantly contributing to GDP (oil & gas, coastal engineering, fisheries, shipping, tourism, recreational boating) commercially operate in this domain and will benefit from enhanced marine environmental intelligence. Emergency service agencies use hazard forecast in dealing with impacts of marine hazards (eg. storm surge, dangerous seas) and especially inundation events. Submarine landslides have the potential to create damaging, localised tsunamis. Lifesaving associations and professionals and recreational beach goers use the information for avoiding hazardous situations.

Recreational users and public transport carriers operate primarily in this domain, providing focus on security and safety. The EEZ also contains major marine ecosystems such as GBR and others as described in the Integrated Marine and Coastal Regionalisation of Australia (IMCRA) - http://www.environment.gov.au/resource/guide-integrated-marine-and-coastal-regionalisation-australia-version-40-june-2006-imcra. Federal and state marine park managers have a need for enhanced baseline and trend information for all these bioregions.

Accurate predictions of wind seas and swells are also of use to the marine industries and Navy for better facilitation of at-sea loading activities (eg. FLNG, oil rigs) and other operational issues, for optimal and safe navigation.

There is a clear need for long-term sustaining of observational systems by operational agencies to be able to properly understand, monitor, safely and economically utilise and manage Australia's extensive marine environment. Australia's unique ecosystems are vulnerable to extremes, with ocean extreme temperatures for example having had to date a significant impact on the marine environment (see Theme 5 dealing with Climate Change). Such impacts are potentially significant for a number of industries. These include Australia's aquaculture and fisheries industry, worth about $2.23B, and tourism industry both of which rely on a healthy, productive marine environments.

Climate variability and change of wave extremes are relevant to a range of stakeholders including coastal managers, port operators, the oil and gas industry and the renewable energy industry. Variability of waves (power and direction) influences coastal erosion and, when coupled with sea level rise, coastal impacts must increase. The emerging sector of the ocean renewables and the oil and gas industries, have planning horizons of decades, and so there is a need to understand effects of variability and change of extremes for platform/device designs.

The specific needs associated with near shore wave and current measurements and predictions fall into three board categories:

1. climatological (what is the general nature of wave and current patterns and how do these vary in time?);
2. operational (what impact will present or forecast waves and currents have on specific activities?);
3. design (what is the statistical character and probability of extreme winds, waves and currents and how might these impact coastal ocean infrastructure and adjacent settlements?).

Table 1 contains a list of applications of near shore wave and current models in Australian coastal waters with examples. Note that active wave breaking remains poorly characterised by numerical modelling and reference is made to physical studies in the table below where this is the primary consideration. This table gives a more comprehensive summary of “natural hazards” than previously adopted.

Table 1. Present applications of near shore wave and circulation modelling, the specific aspects under consideration and some example applications (adopted from Peirson *et al*. (2012) with modifications).

Application	*Specific Consideration*	*Example*
Infrastructure design and coastal inundation	wave loadings	McCowan and Lawry (2011)
	current loadings	Tian *et al.* (2011)
	elevated water levels	Harper *et al.* (2011)
	wave energy	Hemer and Griffin (2011)
Contaminant dispersion	oil spills	Zigic *et al.* (2011)
	sewage discharges	Cathers and Peirson (1991)
	desalination plumes	Miller *et al.* (2007)
	dredging operations	Bettington and Miles (2009)
	ballast discharges	Murphy *et al*. (2009)
Marine and port operations	navigation	Youdale and Priestley (2005)
	safety	Banner and Morison (2010)
	military operations	*Oceanography* (2014)
Recreational and tourist safety	vessels	Babanin (2011)
	rock fishing	Shand *et al.* (2009)
	surfing	Lane *et al*. (2010)
	swimming	McCaroll *et al.* (2012)
Extractive industries	sediment transport	Orpin *et al*. (2009)
Research activities	biotic behaviour	Baird *et al*. (2006)
	forensics	Cox and Wang (1995)

Through the BLUElink project, BoM and CSIRO are servicing the Navy's requirements for ocean-temperature structure to support their sonar activities. Similarly, work by university researchers on mixing (e.g. Robertson, 2006) and underwater acoustics (e.g. Manasseh *et al.*, 2006) potentially benefits sonar operations of both the RAAF and RAN, as well as fisheries because mixing impacts nutrient replenishment and primary productivity and thus affects the fishing fleet and food security.

Search-and-rescue and spill responses are largely managed through Federal agencies (e.g. AMSA and NOPSEMA). In addition to the defence applications, the BLUElink forecast information supports maritime and commercial operations, like the search for MH370 in the Indian Ocean, oil and gas operations and emergencies like the Montara oil spill in 2011. Engagements by various national R&D providers (universities, CSIRO, BoM) with the oil and gas industry have assisted their operational activities, e.g. though provision of forecasts of current to the operators during their the exploratory offshore drilling.

In the eReefs project, two systems are being developed, one by the BoM in the form of a coastal operational forecast system and one by CSIRO to support catchment and scenario modelling management (marine impact of land-based management), in order to provide input to optimal marine spatial planning and adaptive ecosystem-based approaches to the decision making conducted by end users. Whilsui eReefs provides an example of water quality applications for the Great Barrier Reef, it is also a possible template for expanding the service more widely.

Other applications beyond forecasting and scenario modelling include offshore engineering design, fishery management (e.g. connectivity of ecosystems) and environmental management, including aquaculture. For these activities, coastal ocean reanalyses can be regarded as the most effective aid to the planning. Overall, requirements for coastal-ocean predictions tend to be localised and intermittent, with no current effort to take a more nationally coordinated and funded approach which would ultimately deliver a more cost-efficient information to the public and private sector.

BLUElink has started down the path to littoral-zone prediction in order to support the Navy's amphibious and anti-mine operations. However, while the near-shore science and engineering is a rapidly developing international field, there is still much to be learned. Beyond the Navy, there are other obvious applications in coastal property management and beach safety. Australia's residents cluster at the coast, and much of Australia's most valued real estate and recreational amenity is at the coast. This is an obvious area for future scientific and business development, and an opportunity for the future forecasting service.

Science needs

<u>Bathymetric mapping</u>

Beyond Australia's territorial waters, **measurements of AAT, Joey Rise and Williams Ridge need to be completed**. Finalising these areas will require a field program that must include sampling of the basement rocks and comprehensive multibeam mapping. With respect of the AAT, Australia's submission does not contain material on ongoing sedimentary processes of the continental slope and rise. The collection of multibeam data, shallow seismic and sub-bottom profiler data on the AAT slope and rise should be supported as a national interest activity, since it both contributes to any possible future examination of Australia's continental shelf and demonstrates Australia's ongoing commitment to the Antarctic.

The **Great Barrier Reef is the least well mapped**, and suffers the greatest information deficit of any part of the Australian Jurisdiction. It should be a matter of priority to seek bathymetric cover of the reef, whether this is LADS or satellite derived bathymetry followed by the production of appropriate hydrographic products that support Australia's capacity to operate in all areas of the reef. Poor tidal modelling of the GBR also has an impact on the operational envelope of vessels that need to enter these areas.

Inundation modelling to understand and forecast the impacts of storm surges and tsunamis on coastal communities requires high-resolution bathymetric and coastal topography data around the Australian mainland and offshore territories.

In Australia, research in the area of submarine landslides and tsunami is an incipient science. Except for the bathymetric surveys reported in Boyd et al. (2010) and the ongoing studies (Hubble, Airey, Webster and colleagues) arising from the 2008 Southern Surveyor voyage and the 2007 voyage to the central NSW margin, relatively little detailed work of this type has been undertaken in the Australian context and virtually no geotechnical modelling, analysis or sediment testing have been performed on appropriate samples. In particular, given the small number of dated slides, it is not possible to reliably estimate the frequency of sliding from the upper slope. Therefore, making a correlation between observed tsunami events and offshore landslides is not possible at this stage.

- Though all the densely populated Australian cities are located on the Eastern margin, Keene et al. (2008) review of the available literature (published papers and government reports) identified "significant large gaps in the basic knowledge of" and available data for this significant region. In particular, the lack of perceived petroleum prospectivity (with the obvious exception of the adjoining Bass Basin oil fields) has resulted in a relative dearth of seismic reflection surveys and relatively limited coverage of multibeam swath mapping – particularly of the lower slope and adjacent abyssal plain. Further studies and marine surveys to enhance the geological and tectonic framework of overall SE Australian margin are necessary
- Detailed studies of submarine landslides in the margins are needed. A major limitation to assessing the tsunami potential is lack of age control and subsequent frequency of occurrences of landslide events
- Key to understanding the tsunami potential, is to determine landslide movement velocity, which requires long term monitoring of seabed movement.

Littoral zone

The existing *Integrated Marine Observing System - IMOS* and *Terrestrial Environment Research Network - TERN* observing networks are providing invaluable and unprecedented data-streams of real significance and application to the wider coastal zone – *IMOS* principally seaward of the 50 m depth contour, and *TERN's* primary focus is inland of the open coastline at estuaries and coastal catchments. The **critical missing gap between these two existing observational programs is rigorous and sustained observations of the littoral zone specifically encompassing the land-ocean boundary**. Nominally spanning water depths of 20 – 0 m along open coastlines and extending landward to include frontal dunes, this critical region where the land meets the ocean currently falls outside any nationally-coordinated monitoring effort.

At the present time rigorous observations and resulting data-streams of shoreline conditions, variability and trends around the Australian continent are sparse, ad-hoc, uncoordinated and largely depends upon the motivation of individuals (and often volunteers). As a result, the coverage and sustainability of these observations (e.g. shoreline erosion, shoreline retreat, coastal inundation and flooding, coastal hazard lines, coastal infrastructure at risk) is unsecured, incomplete and inadequate to support marine science at a national scale. Research institutions and governments will increasingly rely upon the expanded availability of sustained coastline data-streams to support coastal research, management and policy development (Establishment of a National Coastline Observatory Facility, DRAFT, 2014).

Coastal zone and continental shelf

A principal aim with respect to the coastal zone and continental shelf is to improve numerical model predictive capability substantially over the coming decades at the required spatial and temporal scales to resolve and forecast the dynamic properties, primarily due to improved capabilities in computational power, improved physics and model integration and coupling. Although Australia is very active in the development of improved techniques to determine waves and coastal circulation, it has **very limited facilities from which concerted field research campaigns can be deployed**. Those that may be available (e.g. the bypassing jetties near the Queensland-NSW borders) have significant limitations from a research point of view.

Australia will continue to incur unwarranted expenditure on coastal and offshore infrastructure that must be designed to be overly conservative in the absence of reliable long-term data. The importance of long-term data collection programmes has assumed increased significance in the context of climate change. Not only are changes in the coastal behaviour anticipated due to changes in atmospheric and oceanic circulation (including potential changes to the magnitude of storm surges and wave heights), but ongoing monitoring is fundamental to determining whether and when expensive coastal settlement and infrastructure adaptation becomes necessary. Existing (<40 year) data collection programmes must continue if factual information with regard to changes in coastal storm behaviour is to be determined (NCCOE, 1993). The current situation where long-term wave observations are being collected by several State Government and large State-owned corporations independently is not ideal. Data processing and archiving is inconsistent between the data custodians, which may limit the application of the data for determining long-term historical variability and change on a National scale. Centralisation of the operation of these on-going observations may significantly broaden their present utility.

These ongoing wave data collection programmes provide a critical dataset for ongoing validation of Australia's national operational wave model carried out at the Bureau of Meteorology (Durrant et al., 2011). Satellite remote sensing data now encompass a few decades and a comprehensive and inter-calibrated database of such data can provide another resource for evaluations of climate trends (Young et al., 2011).

Future coastal planning activities, undertaken at all tiers of Government, are dependent on sea-level rise projections, but also understanding of potential changes in storm wave activity. To establish confidence in wave climate projection models (e.g., Hemer et al., 2012a,b), they must demonstrate skill in simulating observed historical variability of wave climate under historical climate model forcing. Long-term wave observation records are sparse and require ongoing support.

Further, for both operations and design, defining event extremes is not sufficient – scour and economic loss dictate that event duration and form are both critically important characteristics (Carley and Cox, 2003). The conjunctive probability of both currents and waves is an important aspect of coastal infrastructure design that is presently very poorly understood (e.g. Shand *et al*., 2012).

Australia's fundamental research with regard to determining dangerous sea states is amongst the best in the world (e.g. Banner and Morison, 2010; Babanin, 2011) with corresponding implications for improved vessel safety and applications in the near shore region (e.g. Shand et al., 2011).

Improved techniques for more economical and reliable land-based monitoring of near shore waves and circulation have been a focus of recent IMOS HF Radar activities (Jaffrés *et al*., 2010). Recent assessment is that considerable development remains to be undertaken (Coghlan, I. and Flocard, F., 2014, *MARine Virtual Laboratory (MARVL) SWAN Wave Model - Stage 2: Test Cases Report*. UNSW Water Research Laboratory Research Report 257. Sept. 2014 ISBN TBA).

Renewable forms of energy will assume increasing importance over coming decades. Although mapping of mean wave energy impacting the Australian coastline has been undertaken (e.g. Hemer et al., 2010a,b ; Hughes and Heap, 2010; Pattiaratchi and Bosserrele, 2010), design of wave energy facilities will have to include extreme events. The availability of suitable platforms for the field testing of wave energy devices may be a key consideration in the development of future data gathering facilities along the Australian coast.

Although the deeper ocean currents along Australia's coast have been characterised in some areas, characterisation of currents in the near shore region will assume greater significance as energy extraction from ocean currents is going to be considered as a potential contributor to Australia's renewable energy mix. If the energy extraction is significant, coastal circulation and environmental issues need to be taken into consideration.

Both waves and currents have a strong influence on the flux of constituents through the air-sea interface. There is a present research shift towards computing these based on the surface sea state (e.g. Suzuki and Toba, 2011), and increasing attention on the potential feedbacks of the wave dependent component of these fluxes on the coupled climate system (Babanin, 2011, Hemer et al., 2012c, Cavaleri et al., 2012). Australia is well-placed to play a strategic role in such developments but they will require appropriate observational facilities. The IMOS supported Southern Ocean Time-Series mooring (Schulz et al., 2012) provides a new platform to support research aimed at increasing the knowledge of this unique open ocean environment critically-important to the regional and global climate, whilst providing rare observations in the globally important Southern ocean. Similarly, ship-based wave observations (e.g. wave radar proposed for the new National Facility INVESTIGATOR) will provide data to support complementary new observations of the sea surface.

Large-scale numerical modelling of near-shore waves and circulation and their impacts on coastal water quality, sediment transport and biogeochemical systems have become commonplace. Assessment of biological impact is generally undertaken in terms of water quality characteristics. However, there is significant scope to better understand bio-geochemical systems in terms of a broader physical context (e.g. Baird *et al.*, 2006).

Ocean forecasting and reanalyses

1) Global system (BLUElink):
   For at least the next 3-4 years the operational ocean forecasting system run at the BoM will have a spatial resolution of 1/10° (http://www.bom.gov.au/oceanography/forecasts/index.shtml). With increasing supercomputing resources other global systems will continue to push for higher horizontal and vertical resolutions to meet growing user needs and also provide boundary conditions for high-resolution coastal forecasting applications. For example, the US Navy schedule included global 1/25° grid operationalin 2016. Funding and resource limitations put Australia at risk of losing the connection to this leading edge science and its independence from other systems. **The latter potentially poses a national security risk.**

2) Continental shelf and coastal systems (BLUElink and other systems run in research mode at, e.g., UWA, SARDI, UNSW):
   The big **technical and scientific challenge for coastal ocean modelling is in data assimilation**. Off-the-shelf and in-house (e.g. BLUElink/BODAS) data assimilation schemes are freely available, but the observations often do not support the required model resolution. Sea-surface temperature is usually the best spatial data set, but may not have sufficient data density (remotely sensed) or structure in the coastal region. Altimetry is sparse in space and time as a descriptor of coastal dynamics. Ocean colour is being explored as an indicator of surface advection. High-frequency coastal radar is the potentially good data source, but there are only a few installations around the Australian coast. The Australian research community as yet still has little experience in coastal data assimilation.

   On the 20-year timeframe, intensity of human activity in the coastal domain will increase greatly. This is a critical area for development and in-turn security and safety, particularly in Australia. Enhanced climatologies and future projections of waves are needed: recent IPCC reports assign low confidence to regional projections of waves and storm surges. For waves, this is because to date **studies on past wave climate change and future projections on the global scale are only emerging as part of an international coordinated program** between relevant international agencies (the Coordinated Ocean Wave Climate Intercomparison Project, COWCLIP), which is led by Australia with funding from the Australian Climate Change Science Programme (ACCSP) and endorsed at the international level by JCOMM and WCRP.   Continued efforts are needed to obtain maximum benefit from this project.

3) Littoral zone (Universities and CSIRO):
   Key advances required in littoral zone/coastline research as identified in the White Paper about Establishment of a National Coastline Observatory Facility, DRAFT, 2014:
   - the ability to quantify contemporary and future coastline variability, erosion hazard and change;
   - make available 'standard' community data-streams for coastal sites encompassing regional differences around Australia's open coastlines;
   - underpin 'real-time' model - data assimilation and coastline hazard forecasting (storm erosion);
   - baseline coastal data-streams for testing and improving the next generation of longer-range coastal change forecasting tools (climate change);
   - coordinated network of coastline laboratories nationally, co-located (where possible) to established National Reference Stations, to support the next advances in fundamental and applied process-based marine science research.

4) On all scales of interest here **ocean mixing is one of the most prominent problems in physical oceanography today**. Mixing maintains the stratification, drives the global overturning circulation [*Munk and Wunsch*, 1998], distributes nutrients and larvae for biological productivity and fisheries [*Wilson,* 2011], redistributes heat and salt, and influences climate dynamics. Both measuring and simulating mixing are difficult, due to its localized and sporadic nature and the many contributing processes, which span scales from centimetres to hundreds of kilometres. Improvement of mixing parameterizations for models is an important, overdue, and much needed step forward. Coupling of small-scale and large-scale oceanic processes, in the light of rapid increase of computing capabilities, becomes possible.

Perspective

Coastline and territorial sea baseline

GA expects that it will be possible to deliver the whole **web-based regulatory framework** of the Australian marine jurisdiction within two years. Within five years GA would hope to have completed all of the proclamations to permanently describe Australia's maritime limits. 0-5 years: continue to collect fine-scale hydrographic/bathymetry data and disseminate via web-based services.

Littoral zone/coastline

The following core baseline coastline data and data-streams are required (Establishment of a National Coastline Observatory Facility, DRAFT, 2014):

- continious imaging of the nearshore, surfzone, shoreline and subaerial beach;
- periodic beach profile surveys;
- co-located to existing wind, waves and water-level measurements;
- shelf-to-shore bathymetry;

- beach and nearshore sediment characteristics;
- evaluation of paleo-coastline evolution;
- water quality;
- baseline ecology;
- beach usage and hazards;
- video monitoring of waves, beach volumes and shorelines;
- wave and storm tide monitoring networks;
- ad hoc current measurements for specific projects;
- water quality monitoring of coastal waters.

Continental shelf and coastal domain

Australia links well to international efforts in terms of research, modelling and forecasting winds and waves with Europe and North America; and storm and hurricane/cyclone forecasting with the American research but less so with Asia. Understanding and state of the art modelling of winds, waves, ocean circulation, tropical cyclones, storm surges are presently going through the most intensive period of advancement. Challenges and key science gaps to be addressed in the coastal domain:

- Improving the forecasting capability in the coastal domain and on the continental shelf. UNSW Canberra, SARDI, Swinburne University are working with CAWCR/BOM on implementation of tides and improved vertical mixing parameterization in ROMS and ACCESS.
- Comprehensive use of all available observations in bio-physical-sediment coastal circulation models in forecast and reanalysis mode.
- Work on acoustic propagation to improve sonar operations for the RAN and RAAF in the Australian waters. This requires more glider operations and moorings off the coast to provide temperature and salinity information on which to base the acoustic propagation studies.
- Better understanding and modelling of ocean-atmosphere coupling at continental shelf scales, leading to enhanced forecasts.
- Hazard impacts: better understanding and ability to monitor, analyse and model/forecast impacts of severe weather and ocean extremes on Australian communities, infrastructure and ecosystems, utilising and tailoring overseas experiences and expertise wherever possible.
- Better understanding and modelling of waves in coastal regions. Underpinning the coastal modelling efforts, there is the need for sustained funding into atmospheric modelling to ensure improvements in the representation of extreme weather events that provide the forcing for extreme waves. With respect to the waves, there is the need for: coupled wave-current, wave-surge modelling approaches; coupled wave-bottom, sediment suspension and bottom erosion models; relevant in situ observations; remote sensing (coastal and ship radars, satellites).
- Research in the area of submarine landslides leading to tsunamis.

The overarching challenges in coastal/shelf-scale monitoring and modelling can be summarised as follows:

- 0-5 years:
  - Improve modelling and understanding of processes and interactions of physical and biogeochemical parameters on the continental shelf scales, in order to reduce uncertainties and deliver forecasts to meet user needs in safely and economically utilising and managing the continental shelf environment. Continue to leverage existing international efforts such as GODAE OceanView, CLIVAR and IMBER.
- 5-10 years:
  - Sustained marine observing systems.
  - Develop and implement hazard impacts prediction services, building on knowledge.
  - Develop and implement fully coupled atmosphere/ocean/waves/bottom/coast modelling, high resolution, with assimilation of, e.g., in-situ data, coastal radar systems and satellite observations.
  - Development and implementation of coastal ocean (and potentially global and littoral zone) **interpretative tools to facilitate user uptake**.
- 20 years: operationally sustain marine observing and forecasting/reanalyses systems.

Deep-water domain

Regarding maritime meteorology and oceanography the BoM has strong international collaboration and makes leading contributions through World Meteorological Organisation (WMO), Intergovernmental Oceanographic Commission (IOC) and conventions/obligations like Safety Of Life At Sea (SOLAS). The Hydrographer of the Royal Australian Navy (RAN), supported by states and territories, has strong international collaboration and has a recognised national responsibility through the International Hydrographic Organisation (IHO) for hydrographic measurements and bathymetric mapping (but note lack of comprehensive high-resolution bathymetry).

WCRP has identified a number of scientific 'Grand Challenges' (http://www.wcrp-climate.org/index.php/grand-challenges) as priority areas of research that focus on modelling, analysis and observations. Two of these Grand Challenge topics ('Climate Extremes' and 'Regional Sea Level Rise') have adopted extremes in sea levels and waves and shoreline response as important areas for future research providing the opportunity for enhanced engagement at the international level.

The international R&D context for forecasting on various spatial scales is provided by GODAE OceanView (www.godae-oceanview.org) which coordinates international collaboration in operational oceanography. Australian scientists are actively involved in this international effort. BLUElink R&D efforts are fully aligned with the five key research areas of GODAE OceanView (0-5 year time horizon):

- development of global and regional ocean forecast systems, including data assimilation;
- automated inter-comparison and validation of these systems;
- observational system evaluation and taking advantage of the full suite of observations in the data assimilating forecast systems (rather than the traditional variables);
- marine ecosystem assessment and prediction; and
- short-to-medium range coupled prediction. There is already experimentation in some international meteorological and oceanographic agencies with coupled atmosphere-ocean modelling for short-term numerical weather and ocean prediction. When coupled forecasting becomes a reality, coastal and global ocean circulation becomes integral to routine weather forecasts. The estimated time scales for full operational implementation of such coupled systems at leading centres is about 5 to 10 years. Australia will have to decide now if it wants to become a leader or follower in this research area. If it is the former, significant new investment in computational infrastructure and human resources is required.

Despite this broad alignment with international efforts there are **significant existing gaps in the global component of the BLUElink system:**

- lack of a sea ice module. Although fragmented efforts exist in Australia in this R&D domain (e.g. ACCESS, ACE-CRC, Gateway) a focused efforts does not exist. At the moment, Australia is the only signatory of the Antarctic Treaty with global ocean forecasting capability which does not produce high latitude sea-ice forecasts.
- lack of explicit tides, improved surface forcing/surface fields and waves/current interactions;
- no capability to assimilate new observations including HF-radar, sea-ice, salinity, and biological/biogeochemical observations;
- no biogeochemistry module. Most other systems are now working towards coupled physical-biogeochemical state estimation (both global and regional) and, eventually, coupled ocean-wave-ice-atmosphere-biogeochemistry predictions;
- lack of routinely produced error estimates at all relevant scales for biogeochemical variables of interest if included (lower trophic level, including nutrients and carbon) through, e.g., multi-model ensembles;
- limited reanalyses, improved error covariances and bias correction schemes, increased high-resolution regional predictions and ensemble forecasting.

Although there are aspiration by some agencies to increasingly fill some of the gaps as part of their plans, e.g. routinely produced error estimates and reanalyses by the Bureau operational ocean services, limited funding prevents a rapid implementation and delays availability of this information to users.

Realisation

Littoral zone and coastal domain

Without long term data sets, coastal design and planning of coastal operations must adopt conservative approaches when assimilating the limited information available.

Data sets and information tools required and impediments to be encountered:

- Facilities from which concerted littoral zone and coastal field research campaigns can be deployed. Those that may be available (e.g. the bypassing jetties near the Queensland-NSW borders) have significant limitations from a research point of view.
- Continue the existing (<40 year) data collection programmes if factual information with regard to changes in coastal storm behaviour is to be determined.
- Centralise data processing and archiving between the data custodians. The current situation where long-term wave observations are being collected by several State Government and large State-owned corporations independently is not ideal. Centralisation of operation of these on-going observations may significantly broaden their present utility.
- Extreme events data have to include information on waves and currents, event duration and form which, combined, are an important aspect of coastal operations and infrastructure design that is presently poorly understood.

Continental shelf and coastal domain

Establishment of a Centre of Excellence on marine extreme events and environments is recommended. A CoE would investigate the nature of dynamic marine extreme events in the coastal and deep-water domain, methodology for their prediction. This effort could be linked to the proposed "National Coastline Observatory Facility" (see White Paper "Marine Nation 2025 – Establishment of a National Coastline Observatory Facility").

Data sets and information tools required and impediments to be encountered:

- Fine-scale hydrographic data and charts: reduce uncertainties in coastal scale forecasts required by users, where bottom boundary conditions are important: support GA in efforts to achieve complete and high-resolution mapping of coastal and territorial seabed baseline.
- Observations: many observations are required to be maintained long-term, rather than short-term as per programs like IMOS, in order to improve our understanding and ability to monitor and manage changes/variability on a broad range of time scales:
    - HF-radar: dense (nation-wide) network of coastal radars to observe currents and waves (research, forecasting services, and border security applications). Maintain ACORN. Also consider introducing sustained coastal radar network with coverage out into shelf waters. However, also see comments under "science needs" about known issues with HF radar systems.
    - Waves: wave monitoring in Australia is undertaken by state authorities and the data coverage is patchy. For example, the NSW coast is well sampled, yet the

southern Australian coastline and Tasmania (which experience considerable waves and swells from the Southern Ocean) are poorly sampled. Additionally, many of the existing wave records only have wave height and period and not wave direction. In some regions of Australia such as the northwest shelf, wave buoys may be operated by the oil and gas industry, but the data is not readily available to the research community.

  - Currents: in-situ surface drifter observations (routine and event based) to evaluate and constrain/force drift models used in air-sea rescue and marine pollution modelling.
  - Water quality monitoring stations: need sustained monitoring sites in key locations all around the country (i.e. longer than existing IMOS relatively short–term time-series and with greater national coverage).
  - All of the above extensions to the national observing network require substantial new investment by the public and private sector.
- Forecasting: higher-resolution shelf-scale models resolving physical sand biogeochemical environment at coastal scales also require greater computing resources to operate, especially in real-time for operational services. Models like SWAN, WAVEWATCH-III, ROMS and morphological models have to be adapted, extensively tested and validated for the Australian coastal domain.

Deep-water domain

The BLUElink project is a part of the Australian investment in the national network of ocean forecasting research and development. Observation tools and systems are estimated to be of the order of $175 million over four years (2011-2014)[2]. That investment has yielded world class ocean forecasting tools that are deployed operationally, helping to reduce costs and provide tactical advantages to Australia. This does not include investment by agencies such as the Bureau of Meteorology in maintaining the operational ocean forecasting services and ongoing marine observation networks. In addition, Australia's capability relies upon and leverages international investments, overall orders of magnitude larger, in global satellite and in situ observational programs. There is currently no funding allocated to the BLUElink project that finished in June 2014. Starting in July 2015, however, funding for the maintenance of the existing BLUElink systems at the present level of capability has been secured through a service agreement between the Bureau and Navy for the operational systems to support Navy specific needs. This agreement, however, does not support comprehensive R&D efforts which are required to maintain the internationally competitive status of BLUElink models and analysis systems. Without further funding for BLUElink R&D, Australia will not capitalise on investment to-date and may lose its position among leading nations in the global-to-regional operational oceanography and forecasting.

[2] Total Australian R&D investment benefitting ocean forecasting over four years (see pie chart in attachment A): ~$175m.

Additional comments

Apart from the scientific challenges there are a wide range of additional factors which will influence the progress of ocean and marine hazard forecasting. Some of these are beyond the control of Australia and form part of international efforts. Among these challenges and factors are:

- the **sustainability and expansion of the physical and biogeochemical components of the Global Ocean Observing System (GOOS) continues to be an issue globally for many countries supporting GOOS**;
- the advent of "intelligent" new sensors and new remote sensing technologies both from space and in-situ;
- the future growth of the public profile and visibility of ocean forecasting and analysis (public awareness creates interest, which creates user pull, which must be aligned with science capabilities and developments);
- the associated **need for and evolution of enhanced service delivery**, including those between R&D providers, intermediate and end users of oceanographic information (this particularly relates to offshore petroleum industry where advances in underwater observations, remote handling and construction technology now allow for safe operations in deeper waters under a wider range of oceanographic and meteorological conditions);
- the need for continued and increasing **close research collaboration and cooperation with other major international research domains** like the weather and climate communities and international programs like CLIVAR, THORPEX and IMBER, in research areas of mutual interest and benefit, in order to leverage and hence further capitalise on the Australian R&D investment; for example, developing "seamless" prediction (spatially and temporally) towards Earth System Modelling, environmental prediction and forecasting (http://www.icsu.org/future-earth).
- capacity of institutional and national computing infrastructure;
- ongoing support for the maintenance of operational and R&D related marine observations.

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References

Babanin, A.V., 2011: Breaking and Dissipation of Ocean Surface Waves. Cambridge University Press, 480p**.**

Baird, M. E., P. G. Timko, I. M. Suthers and J. H. Middleton (2006) Coupled physical-biological modelling study of the East Australian Current with idealised wind forcing. Part I: Biological model intercomparison. *J. Mar. Sys*. 59: 249-270.

Banner, M.L. and Morison, R.P. (2010) Refined source terms in wind wave models with explicit wave breaking prediction. Part I: Model framework and validation against field data. *Ocean Modelling* **33,** 177–189.

Bettington, S.H. and Miles, K.E.. (2009) Modelling of Dredge Plumes. 19th Australasian Coastal and Ocean Engineering Conference., Wellington, N.Z., 16 to 18 September 2009. Paper 40.

Boyd, R., J. Keene, T. Hubble, J. Gardner, K. Glenn, K. Rumming, N. Exon and the crews of Southern Surveyor 10/2006 and 12/2008 (2010). Southeast Australia: A Cenozoic continental margin dominated by mass transport. Submarine mass movements and their consequences, advances in natural and technological hazards research. D. C. Mosher, R. C. Shipp, L. Moscardelli et al., Springer. **28:** 491-502

Carley, JT and Cox, RJ (2003), "A Methodology for Utilising Time-Dependent Beach Erosion Models for Design Events, *Proc. Australasian Coasts and Ports Conf.*, Auckland, Engineers

Australia. Paper 28. ISBN 0-473-09832-6.

Cathers, B. and Peirson, W.L. (1991) Sydney Deepwater Outfalls Environmental Monitoring Program. Commissioning Phase. Numerical Modelling. Australian Water And Coastal Studies Report 91/01, September.

Cavaleri, L., B. Fox-Kemper and M.Hemer (2012) Wind-waves in the coupled climate system. Bulletin of the American Meteorological Society. In Press.

Cox, D.R. (2003) Oceanographic Modelling of Ocean Outfall Options: Canterbury Region, South Island, New Zealand., *Proc. Australasian Coasts and Ports Conf.*, Auckland, Engineers Australia. Paper 27. ISBN 0-473-09832-6.

Cox, D.R. and Wang, Y-C (1995) Sydney Coastal Waters Ocean Monitoring Program: Pollutant Source Identification Model. Australian Water And Coastal Studies Report 95/22, June.

Day, K. A. (Ed) (2010) Proceedings of the Australian Wind Waves Research Science Symposium, 19-20 May. Gold Coast, Queensland, Australia. CAWCR technical report; No. 29. ISBN: 978-1-921605-94-9

Gourlay, M. R. (1996), *History of Coastal Engineering in Australia*, in N. C. Kraus, ed., 'History and Heritage of Coastal Engineering', ASCE, New York.

Harper, B. A., Mason, L. B., Hanslow, D. J. and Rainbird, J. (2011) Estimating Extreme Water Levels in Torres Strait 20th Australasian Coastal and Ocean Engineering conference., Perth, W.A., 28 to 30 September 2011. ISBN: 9780858258860.

Hemer, M.A. and D.A. Griffin (2011) The wave energy resource along Australia's southern margin. Journal of Renewable and Sustainable Energy, 2(4), 043108, doi:10.1063/1.3464753.

Hemer, M.A., K.L. McInnes and R. Ranasinghe (2012a) Exploring uncertainty in regional east Australian wave climate projections. International Journal of Climatology. *In Press.*

Hemer, M.A., J. Katzfey and C. Trenham (2012b) Global dynamical projections of surface ocean wave climate for a future high greenhouse gas emission scenario. Ocean Modelling. *Submitted.*

Hemer, M.A., X.L. Wang, R. Weisse, and V.R. Swail (2012c) Community advancing wind-waves climate science: The COWCLIP project. Bulletin of the American Meteorological Society, 93(6), 791-796. doi: 10.1175/BAMS-D-11-00184.1.

Hughes, M.G. and Heap, A.D. (2010) National-scale wave energy resource assessment for Australia. *pp.* 78-81 in Day (2010).

Jaffrés, J.B.D., Heron, M.L., Banner, M.L., Middleditch, A., Steinberg, C.R. and Durrant, T.H. (2010) Evaluation of ADCP wave, WAVEWATCH III and HF radar data on the GBR. *pp.* 114-117 in Day (2010).

Keene J.B., Baker C., Tran M., and Potter A., 2008: Sedimentology and Geomorphology of the East Marine Region of Australia. Geoscience Australia Record 2008/10.

Lane, C., Gal, Y., Browne, M., Short, A., Strauss, D.R., Tomlinson, R.B., Jackson, K., Tan, C. and Blumenstein, M. (2010) A New System for Break Zone Location and the Measurement of Breaking Wave Heights and Periods. *Proc. of IEEE International Geoscience and Remote Sensing Symposium*, Hawaii.

Manasseh, R., Babanin, A.V., Forbes, C., Rickards, K., Bobevski, I. and Ooi, A. (2006) Passive acoustic determination of wave-breaking events and their severity across the spectrum. *J. Atmos. Oceanic Tech.,* 23(4), 599–618.

McCarroll, J.; Brander, R.; Macmahan, J.H.; Turner, I.L.; Reniers, A.J.H.M.; Brown, J.A. (2012) RIPSAFE - Rip current swimmer and flater experiments. In *International Rip Current Symposium*, SLSC.

McCowan, A.D. and Lawry, E. (2011) Comparison of Physical and Numerical Model Test Results for Martha Cove Breakwaters. 20th Australasian Coastal and Ocean Engineering conference., Perth, W.A., 28 to 30 September 2011. ISBN: 9780858258860.

Miller, B.M., Hawker, K. and Tate, P.M. (2007) Coastal Oceanographic Processes and Numerical Modelling for the Proposed Kurnell Desalination Plant. *Water Research Laboratory Technical Report 2007/02.* September.

Munk, W. and Wunsch, C. (1998), The moon and mixing: Abyssal recipes II, *Deep-Sea Res.,* 45, 1977-2010.

Murphy KR, Boehme JR, Noble M, Smith G & Ruiz GM (2009). Deducing ballast water sources in ships arriving in New Zealand from southeastern Australia. *Marine Ecology Progress Series,* 390: 39–53.

NCCOE (1993) *At what price data?* Institution of Engineers Australia. National Committee on Coastal and Ocean Engineering. ISBN 0858255960.

Oceanography (Special Issue on Navy Operational Models) (2014) 27 (3), 160p.

Orpin, A., Bostock, H., Nodder, S., Barnes, P. and Lamarche, G. (2009) Resource evaluation, exploration and current prospecting interests of west coast ironsands, North Island, New Zealand. 19th Australasian Coastal and Ocean Engineering Conference., Wellington, N.Z., 16 to 18 September 2009. Paper 15.

Pattiaratchi, C. and Bosserrele, C. (2010) Observations and modelling of waves along the southwest WA coast. *pp.* 50-53 in Day (2010).

Peirson, W.L., Hemer, M., Banner, M.L. and Pattiarachi, C. (2012) Wave and near-shore modelling: status and observation requirements in Australia. *Australian Coastal and Oceans Modelling and Observations (ACOMO) Workshop*, October 3-4, 2012.

Robertson, R. (2006) Modeling internal tides over fieberling guyot: resolution, parameterization, performance. *Ocean Dynamics,* doi 10.1007/s10236-006-0062.

Shand, T.D., Peirson, W.L., Banner, M.L. and Cox, R.J. (2009) Predicting Hazardous Conditions for Rock Fishing – A physical model study. *Water Research Laboratory Research Report 234*. ISBN 0-85824-078-05. March.

Shand, T.D., Mole, M.A., Carley, J.T., Peirson W.L. and Cox, R.J. (2011) Coastal Storm Data Analysis: Provision of Extreme Wave Data for Adaptation Planning. *Water Research Laboratory Research Report 242*. ISBN 0 85824 085 8. February.

Shand, T.D., Wasko, C D, Westra, S., Smith, G.P., Carley, J.T. and Peirson, W.L. (2012) Joint Probability Assessment of NSW Extreme Waves and Water Levels. *Water Research Laboratory Technical Report 2011/29. March.*

Suzuki, Y. and Toba, Y. (2011) Future global mapping of air–sea CO2 flux by using wind and wind–wave distribution of CMIP3 multi-model ensemble. Eds. S. Komori, W. McGillis and R. Kurose. Kyoto University Press ISBN 978-4-87698-560-9 , 452-463 (11 pages).

Tian, Y., Cassidy, M.J. and Youssef, B.S. (2011) Consideration for on-bottom stability of unburied pipelines using a dynamic fluid-structure-soil simulation FE program, *International Journal of Offshore and Polar Engineering*, **21**(4): 308-315.

Wang, Y C and Tate, P M (1998) Review of Yuen Long and Kam Tin Sewerage and Sewage Treatment Requirements Users' Manual. Australian Water And Coastal Studies Report A98/01, January.

Wilson, C (2011) Chlorophyll anomalies along the critical latitude at 30oN in the NE Pacific, *Geophys. Res. Lett*, 38, L15603, doi:10.1029/2011GL048210.

Youdale, J. and Priestley, S. (2005) Dredging of Rangitoto Channel, Auckland, New Zealand. 17th Australasian Coastal and Ocean Engineering Conf, Adelaide, W.A., 20 to 23 September 2005. ISBN: 0-646-45130-8.

Young, I.R., Zieger, S. and Babanin, A.V. (2011) Global trends in wind speed and wave height. *Science*, 332, 451-455.

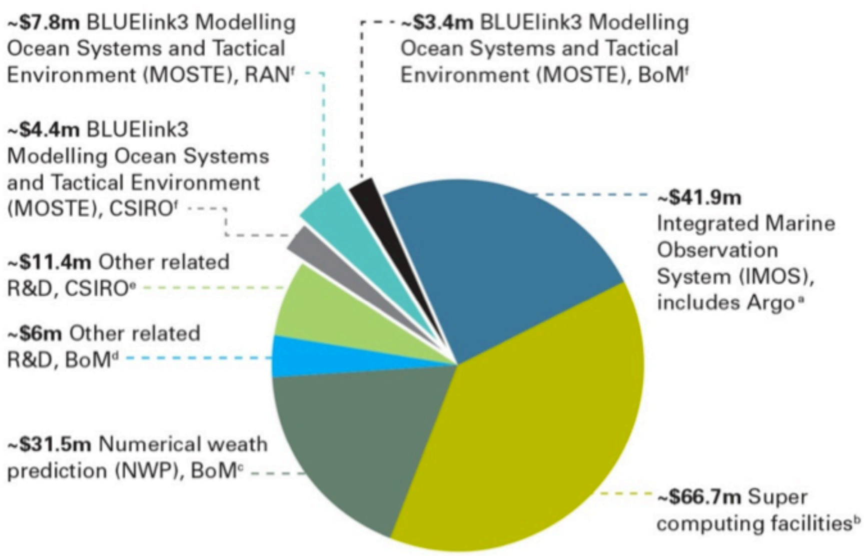
Zigic, S., King, B., and Langtry, S. (2011) Quantifying the net environmental benefit of using dispersant on oil spills in western port bay, Victoria. 20th Australasian Coastal and Ocean Engineering Conf., Perth, W.A., 28 to 30 September 2011. ISBN: 9780858258860

Attachments

ATTACHMENT A

The BLUElink R&D collaboration has been underpinned by indirect investments from the Australian and overseas governments and research bodies of the order of $175 million over four years. Estimates of the R&D investments that benefit ocean forecasting are shown below. In addition, BLUElink capability relies upon international investments in global satellite programs. These figures do not include further support provided for operational delivery of services and maintenance of operational/ongoing marine observational programs by agencies such as the Australian Bureau of Meteorology (e.g. $7M/yr or $28M over four years operating costs and $15M in assets).

Australian R&D Investment in Ocean Forecasting - BLUElink: 2011-2014



a Source: IMOS Annual Reports 2011–2013, IMOS Project Plan 2014 ~80 per cent last year, IMOS–BoM calculated as four-sevenths of the seven-year budget.

b Source: NCI annual Report 2011–2012 (figures for 2011 and 2012), and assuming funding continues for 2013 and 2014 at the same level. Includes capital investment and operating costs. While the facility is considered 60 per cent for climate and marine research, the total cost is included here, because a facility of this magnitude is essential for ocean forecasting to operate at the standard BLUElink provides.

c Based on estimated 31.5 full-time staff per annum. Source: Peter May.

d Based on OOAP BoM staff allocations. Source: Eric Schulz.

e Source: CSIRO Dynamic Ocean Theme Finance Reports (2011–2013) and Dynamic Ocean Theme 2013/2014 Investment Planned budget.

f Source: MOSTE, BLUElink 3 Contract Schedule B.