Executive Summary - Australian National Shelf Reanalysis

The concept of an Australian National Shelf Reanalysis (ANSR) project was first discussed at the February 2014 Annual Planning Meeting of the Integrated Marine Observing System (IMOS). This led to development of a scoping document in June 2014 (see Attachment 1). This scoping document laid out the Need and Opportunity for ANSR as follows:

> *Australia is a marine nation, and our continental shelf is providing massive social, economic, and environmental benefits which will continue to accrue to future generations if well managed - though oil & gas extraction, renewable energy, fishing, marine tourism, ecosystem services, climate services etc. Adequate understanding of this environment is fundamental to its sustainability - we could not imagine managing terrestrial environments without the weather and climate services that industry, community and government now take for granted on a daily basis. Australia needs to strive for a comparable effort in operational oceanography at the regional scale, a key component of which is ocean reanalysis. Reanalysis provides accurate descriptions of past states and time series showing trends and changes. Australia is currently in the fortunate position of having an unprecedented level of shelf ocean observations from the Integrated Marine Observing System (IMOS), as well as access to state-of-the-art numerical modelling and computing facilities developed over the past decade through the Bluelink project. The time for an Australian national shelf scale reanalysis is now.*

A Technical Task Team (TTT) was formed and initial concepts were developed and presented at the Australian Coastal and Oceans Modelling and Observations (ACOMO) workshop held at the Australian Academy of Science in October 2014. Based on strongly positive feedback from the science community, plans to undertake the technical scoping were progressed and culminated in a three day workshop at the Bureau of Meteorology in Melbourne on 10-12 March 2015. This report summarises the outputs of that workshop, which drew on all of the discussions held and input provided by the science community since February 2014. Our thanks go to all who have contributed to date.

A key objective of the TTT scoping was to estimate the level of effort required to undertake an Australian National Shelf Reanalysis, and this is outlined in the report. ANSR is currently an unfunded project, and 'sizing the task' is a fundamental first step. We must know the potential cost in order to compare it to potential benefit and determine whether or not there really is a compelling case for investment. Significantly, the inaugural Australian Forum for Operational Oceanography (FOO) will be held in Fremantle on 21-23 July 2015, providing an ideal stage on which to present ANSR to a 150-person invited audience drawn from R&D providers, government agencies, service providers and marine industries.

Key recommendations are as follows:

The success of ANSR is heavily reliant on a well-tuned national reanalysis system that represents the key dynamics that stakeholders have identified. To this end the national grid and observational database are the foundations for the ANSR system. The national grid and observational database spans all coastal Australian states and Territories and will need to cater to a diverse range of needs. There is unlikely to be one stakeholder who wishes to fund the entire project, on the other hand, this project cannot be undertaken with a focus on only one user group or geographical location. Therefore the success of ANSR is reliant on all stakeholders retaining the greater vision of a national shelf scale reanalysis, that will benefit many regions and stakeholders. Therefore a key recommendation of the ANSR scoping group is to retain the “big picture” goals of ANSR and the project must be sold as a whole, rather than an amalgamation of independent regional projects and associated model grids. However, the inclusion of regional experts within this project to ensure ANSR adequately captures key regional dynamics is absolutely critical to the success and uptake of ANSR products within the broader marine science community and will build on existing strengths in the regional modelling community.

Finally, the USA is moving towards an ‘open sandbox’ approach where data and model configurations along with data assimilation (DA) schemes are made freely available, such that individuals can access code and output for transparent evaluation, we suggest this is a successful model for us to follow.

ANSR Products:

Five key products were identified as being the major outputs from ANSR. Details of these products are given in section 2, with a detailed work package breakdown presented in section 3.

- Product 1: Versioned ANSR Observation database stored on NCI
- Product 2: High-resolution observation based Shelf Climatology derived from product 1.
- Product 3: Non-Assimilating Control Run of the National Model with evaluation metrics reported.
- Product 4: Completed ~20 year reanalysis including comprehensive community validation and published documented
- Product 5: Demonstration regionally focussed very high resolution (~1km) products developed by regional experts

This report is structured as follows:

Section 1: Background and Motivating factors

Section 2: The ANSR system – key components

Section 3: Work packages and Products

Section 4: Preliminary Phasing and Estimate of Effort

Section 5: Risks and Limitations

Appendices then contain supporting documentation.

<u>Next steps are as follows:</u>

A compelling business case needs to be prepared and commitment from ANSR co-investors should be explored. To assist in this process, we suggest that some demonstration products be developed so that the system can be communicated to non-expert decisions makers. This is not a trivial task and will require time and effort to generate the appropriate visualisations that can be used in a prospectus and presentations. We therefore recommend an initial business development project be instigated.

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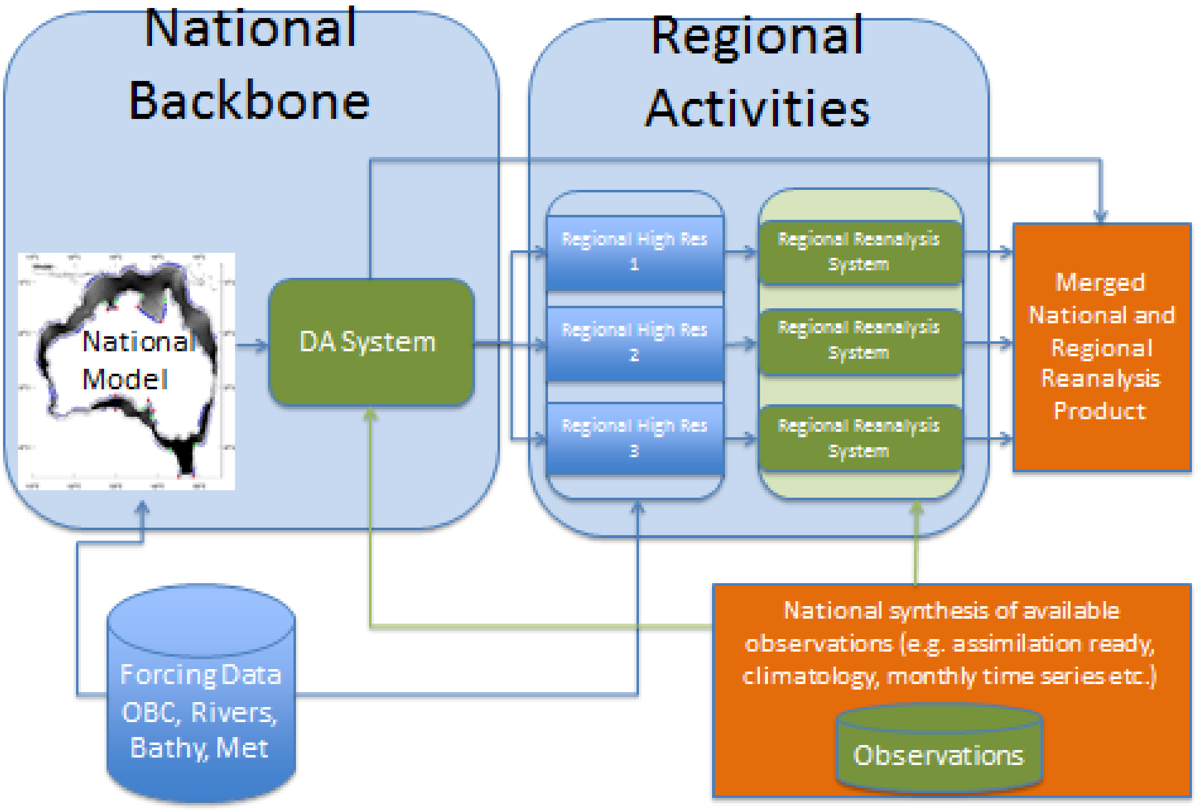

Figure 1: Schematic diagram showing the conceptual frame work for ANSR. This is built upon option 2, presented below. The national model and DA system form the national backbone, while regional activities are integrated through the evaluation of the national products, but there is also the potential for running regional high-resolution models. The products and outputs from ANSR are listed in the orange boxes.

Introduction:

This document details the development and approach to implement the first Australian National Shelf Reanalysis (ANSR). An ocean reanalysis is the historical reconstruction of the ocean state generated by assimilating observations spanning an extended period into a single consistent model run. This yields the "best estimate" of the ocean state given the sparse nature of observations and the presence of model and observation error. Australia has built substantial capability in ocean observing most recently through the IMOS program, which has been the catalyst for encouraging collaboration within the observing community. In contrast, coastal and shelf scale modelling is undertaken amongst regionally isolated groups around the country, with little collaboration. Therefore the ingredients for a national scale shelf reanalysis exist and the time is right to build on the momentum gained in the coastal ocean community in recent years. Australia is well placed to start a high resolution shelf modelling project with a unified approach.

There have been a number of shelf-scale reanalysis projects internationally that range in scale from regional enclosed seas (e.g. the Mediterranean Sea), through to the continental shelves along the east and west coast of the USA. Such studies have included both the hydrodynamics and also biogeochemistry. The key difference between international cases and ANSR is the scale (length of our coastline and potential size of the domain), sparsity of in-situ observing system and the co-ordinated interaction among key participants on a national scale within Australia. This gives it the potential to be a world-leading scientific endeavour with high socio-economic relevance.

The terms of reference set by the interim steering committee are:

1. Scope out the optimal approach to developing an Australian National Shelf Reanalysis (ANSR) V.0, based on national capability and experience and taking international developments into account (e.g. via GODAE OceanView);
2. Determine a realistic timeline for delivering an ANSR, with details of products to be generated along the way;
3. Identify the capabilities required, and therefore the key teams to involve, and provide 'ballpark' estimates of the effort required (e.g. in FTE, by months);
4. Identify key risks and management options;
5. Explicitly consider ICT needs (compute, storage and serving) and assess suitability of existing infrastructure options.

Much of the content of this document is a summary from a workshop held at BoM in Melbourne from the 10-12 of March 2015. A workshop participant list and list of ANSR collaborators can be found in Appendix B. This document is arranged as follows: Section 1 presents the background and motivating factors, Section 2 outlines the key components of ANSR, Section 3 details the phasing, milestones and deliverables, Section 4 gives an indication of approximate costs for the ANSR components and work packages and Section 5 outlines a risks and limitations of the system.

Section 1: Background and Motivating factors:

During discussions prior to and during the 2014 IMOS National Planning meeting, it was suggested that an Australian National Shelf Reanalysis (ANSR) would provide a synthesis of the 'step change' in new observations on the shelf obtained primarily through IMOS and make use of and grow Australia's burgeoning shelf scale modelling capability. It was identified that the first step towards ANSR was the collation of all available observations into a database, and then subsequent incorporation into a National Shelf Atlas. The second component was then a multiyear (e.g. 20 year) reanalysis spanning the Satellite Altimeter period (commencing in 1993) and incorporating as many of the diverse observation data sets as possible.

The underpinning goals of this project are to:

1. Develop national capability for performing shelf-scale ocean reanalyses; and
2. Strengthen collaborations between and skills within the Australian coastal/shelf-scale oceanography community.

1.1 The Need for a National Shelf Reanalysis

Through the Bluelink project, industry group, defence, R&D organisations and the general public have been exposed to the benefits of operational oceanography. Many users and stakeholders are using the Bluelink products (BRAN and Ocean Maps) on a regular basis for a variety of purposes that range from tactical decision making in commercial and defence applications through to long-term connectivity patterns in the Australian region. However, in many instances, Bluelink products are being used in regions (notably shelf) and applications they were never designed for (e.g. particle tracking on a narrow shelf etc.).

Additionally, through the investment in IMOS infrastructure, there is an unprecedented level of observations now available in Australia's shelf and coastal seas. When this observing program is combined with the present effort in coastal modelling, we are well positioned to develop and serve coastal oceanography products that fill user needs that cannot be served by the Bluelink products. ANSR will provide an intermediate to high resolution on the shelf with a minimum approximate resolution of 4km, and will provide a bridge between high resolution coastal models and global models (10km). Though we acknowledge this will evolve as more efficient models are developed and compute power increases.

When observational and/or modelling products are used in isolation, it becomes clear that observations are relatively sparse in space and time (even with IMOS investment), and in many cases models are subject to errors associated with geophysical chaotic behaviour and other sources of error. Therefore neither product yields a complete or error free picture of the ocean state. By merging the two data streams through a reanalysis, it is possible to reconstruct the "best estimate" of the ocean state in 3D, spanning a long period of time.

Such a product will fulfil the user needs that have been canvassed and reported in Appendix A. The specific requirements from a user community are the 3D time evolving structure of the coastal ocean that include dynamics such as tides, river inputs, upwelling, 3D baroclinic circulation and the interaction with deep water processes and boundary currents. While many stakeholders have requested a nowcast/forecast system, a reanalysis product does not fill the niche, however it is a key step towards a nowcast/forecast system and does meet many requirements that have been identified.

To this end, we suggest that the reanalysis system is applied to observations that are available at varying periods behind real time. We suggest that a reanalysis using all available observations (including observations from delayed mode systems) be run approximately once per year, in step with the updating of BRAN. However, to support other end user needs a more timely, but potentially less accurate, product can be run regularly at, for example, 1 week or 1 month behind real time, taking into account all available observations that may not necessarily be used in a nowcast/forecast system. We anticipate that the system will be designed such that it is compatible with BoM operational forecast systems.

1.2 Experience to Date

One of the main lessons learnt from previous efforts such as Bluelink and eReefs is the need to fully cost the assessment of products and model output. It is not feasible to rely on the community to undertake rigorous evaluation without specific funding and objectives. The Bluelink project was a good mix of ambitious but focused goals, with good research outputs in addition to the operational forecasts. Having the research organisations (CSIRO and BoM), operational agency (BoM) and the user/client (RAN) involved together from the beginning was key to success.

From the outset, consensus was that ANSR was and should be an ambitious and exciting project. As one indicator, our international guests were prepared to travel long distances to attend the workshop and contribute. It was agreed that while the scope of ANSR is a shelf reanalysis, the reanalysis and forecasting capability are tightly linked, and we should not decouple the two efforts. In fact system technical design is indeed a product. This includes the numerical model, the data assimilation system and the observational data base. ANSR should be designed with the operational end point in mind. We define this operational end-point as being products (as defined below) that are routinely updated according to a set schedule and made publicly available.

It should also be noted that we are not starting this project from scratch, there exists considerable coastal modelling expertise within a number of regional and national organisations. The proposed system below takes advantages of this expertise as follows:

a) ANSR (national model) levers off the considerable efforts that have gone into the regional models,
b) takes advantage of local expertise and understanding of regional dynamics and
c) hopefully will deliver resources to the regional groups and keep them engaged with the “big picture” through either improving processes in the national grid, undertaking process studies and through evaluation of the national products.

In addition considerable experience has been gained in data assimilation and ocean prediction through the Bluelink Project and these efforts will form the back bone of this new effort.

Section 2: The ANSR system – key components:

2.1 System design

Three possible system designs were presented to the workshop participants as below. Consensus was reached that Design 2 was the current baseline to strive for:

1. A simple system consisting of a single national model coupled to an appropriate data assimilation (DA) system.
2. A system consisting of a national model and DA system with nested high-resolution models and DA system where high-density observations are available. See Figure 1 (above) for a graphic representation of this system.
3. Multiple national grids (allowing for multi-model comparisons), with high-resolution regional models and DA system where high-density observations are available.

At the core of the ANSR project is the national model and associated DA system. The national system must produce high quality solutions that capture dynamics not represented by the global (10km resolution) Bluelink System, and to this end the national model is considered to be a core component of the ANSR system. Without a national model that is fit for purpose, subsequent activities and uptake in regional modelling effort will revert to other products that may come on-line in the near future e.g. HYCOM 4km etc. However it is doubtful that an internationally led global product would be tuned appropriately for the complex Australasian region. In addition, an Australian product would make use of all available locally collected observations (e.g. IMOS), thereby making the local product (ANSR) superior.

2.2 Observations

All IMOS and AODN observations are openly accessible and backed by standards-based metadata, controlled vocabulary, and quality assurance and control procedures. This presents a huge opportunity for ANSR. The MARVL (MARine Virtual Laboratory)-3 project aims to assemble shelf scale observations of a limited number of variables (i.e. Temperature and salinity) so as to be 'model ready', and in a form that may be used in the ANSR project. It is noted that assembling the observations and creating tools to access them is a worthwhile exercise. Presently MARVL-3 is only considering observations to the 500m isobath and it is noted that ANSR will require observations further offshore than this (see below). An updated climatology of Australia's shelf seas will be a useful tool for evaluating regional modelling efforts such as ANSR. ANSR requires observations in the rawest form, but the act of drawing them together and the creation of code/ routines to access disparate observations will be very useful.

Key points about observations required for ANSR are as follows:

- Observations are presently distributed across multiple sources with multiple curators (internationally), however in Australia the AODN and IMOS websites host the majority of the Australian ocean data collection.
- MARVL-3 as an example is presently creating a shelf atlas of temperature. In addition to MARVL-3, ANSR requires extraction and archiving of variables such as salinity, zonal and meridional velocity, free surface height, and biogeochemical properties (BGC).
- A local data collection that is extracted from all sources should be archived and versioned on the high performance computing infrastructure where ANSR is run (e.g. NCI, see below).
- Version controlled – Data products should be version controlled for consistency.
    - The first ANSR products will be observational products.
- Multiple reanalysis runs will be run (over short timescales initially) using a range of observations.

- The skill of the system as a whole can be evaluated using short forecasts and all available observations before they are assimilated.
- Multiple alternative runs where a range of observations are withheld for validation.

Product 1. ANSR Observations Database:

- Design to be informed by WOD, BOA, or other relevant databases;
- Data QC'ed, filtered (where needed), ready for ingestion into the system
- Documented method and atlas metrics;
- Uncertainties given to each observation, (e.g. errors arising through instrumentation limitations/resolution and empirical relationships, but not representation error) noting that this may be difficult to achieve;
- Observations include in-situ, Satellite Remote Sensing (GHRSST, Altimetry) and radar data.

Milestone: Data base constructed

Deliverable: Database is made accessible on public infrastructure

Output: Australian Shelf Database, documented in a journal such as Journal of Ocean Atmosphere Technology (JOAT), published via IMOS

Benefits: Easy to use for analysis and evaluation, overseas groups more likely to ingest into their ocean reanalyses

Product 2: ANSR Observational Shelf Climatology

- Highly resolved along the shelf – vertically gridded
- A statistical fit to the observations, modelling them as a sum of the mean, inter-annual, annual (cyclic) and intra-seasonal ('noise') components of the signal.
- Multiple parameters where necessary

Milestone: ANSR Shelf Climatology Completed.

Deliverable: Climatology is made publicly accessible.

Output: Fine resolution shelf climatology in the form of an atlas, documented in JOAT, published via IMOS.

Benefits: This provides the benchmark product for ANSR. It could be considered a high-resolution shelf version of CARS, for which there is substantial public demand. One should not underestimate the significant effort required for the data accumulation and analysis part of the project. It is a great opportunity to amalgamate datasets, which may not yet have been made publically available or incorporated into other data products for the Australian coastal region.

2.3 National model

Grid:

It was agreed that we need to develop a tailored grid around the nation (e.g. cyclic polar curvilinear grid) – an example of an early prototype grid is the CSIRO Ribbon Model. However, the Ribbon Model is not suitable for ANSR as the offshore boundaries are not tuned to capture key dynamical features as discussed below. An alternative to the ribbon model is the example of OzROMS which has a curvilinear-orthogonal grid. The benefits of the cyclic polar curvilinear grid include having the grid parallel to wave guide and the coast, and it cuts out many costly land cells across the Australian continent which are present in the curvilinear-orthogonal grid. This in turn reduces storage requirements and compute times in empty cells. MARVL has a good grid generator that exports to various model configurations including MOM and ROMS, thus it is possible to generate the grid in MARVL.

Offshore boundary placement:

The offshore boundary needs to extend a reasonable distance offshore, and we need to develop rational criteria for each region around the country, i.e. some further research is required. These criteria include calculating the Rossby radii from Bluelink, calculating a climatology of eddy energy (e.g. TKE) in order to make an informed decision. Some considerations: The open boundary should be where the topography flattens out, noting that the bathymetry will require care when smoothing. Care must be taken such that the boundaries are not under-specified so that the global model is being redone in the model. Conversely if the boundaries are over specified the interior solution on the shelf could be in conflict with the blue water. Reasonable distance off the shelf (~ 3 Rossby radii off-shelf – to flat topography (4000m) (or beyond the energetic region of the boundary current mesoscale?) e.g. east of the EAC recirculation i.e. ~500km offshore, depending on shelf width. .

Northern Boundary:

It was acknowledged that Torres Strait and Indonesian Throughflow (ITF) circulation are important for the circulation in Northern Australia, and this should be considered in the placement of the northern boundary, since neither is well resolved in OFAM.

Resolution 4km:

It was acknowledged that downscaling ratios (from 10km Bluelink products) will determine the grid resolution; hence 3-4km is appropriate for the national model.

Land boundary:

Salt wedges resulting from estuarine outflow will be poorly represented in a 4km model thus the salinity (freshwater) inflow will be poorly represented, which creates false buoyancy. A regional model could account for this through the generation of 'pseudo estuaries'.

Output:

High frequency output ('Backbone') saved at 10-20 mins (to resolve tides). 1 hr is the upper limit needed to resolve inertial oscillations (e.g. off the Great Australian Bight). Compromise based on data storage and end user needs. Consider what needs to be output to include BGC running later or particle trajectory modelling.

Vertical depth layers:

Surface layer should be well resolved 0.5-1 m in the surface. (This will allow trajectory modelling for stake holders.) 40 vertical layers. Sigma or Z co-ordinates depending on the model used.

Land boundary:

Model to the high tide mark (4-8m tidal ranges) so turn on wetting and drying – help with tidal surge. Use islands in the north.

Rivers:

Use pseudo estuaries that represent the length and cross sectional area correctly (a channel estuary) so that they get the volume flow rate and freshwater salinity correct.

Simulation Period:

Start with a short time period e.g. from 2010 onwards, post- ACCESS encompassing a data-rich time period (e.g. EAC transport array) for initial testing. Longer run should cover the BRAN period (post altimetry). We note that stakeholders might have input on this. We need data density to inform the model.

Bathymetry:

A new Geoscience Australia product is being developed, however it may be a few years off. Until then, GEBCO_2014 (global 30 arc-second grid) is the best and can be smoothed or corrected locally where needed. http://www.gebco.net/data_and_products/gridded_bathymetry_data/

Atmospheric forcing:

Use highest resolution forcing product available over domain. BRAN: uses ERA-40 and ERA-Interim however it is a fairly coarse resolution product. CFSR (NCEP); 1979-present; is based on a coupled reanalysis. CFSR is the default option for the project. However, a key feedback from ANSR to the BoM will be a comparison and evaluation of the model solutions derived from using ACCESS-R and other international products.

Open boundary conditions (OBCs)

BRAN may be updated every year in Feb in the future. We need to consider this in choosing our nesting options, including the significant benefits of feeding back into our community by using BRAN.

River Forcing

Much discussion was had regarding freshwater inflow (river input) and the need to get this right. However we are looking to BoM to help. It is thought that there is a comprehensive database of gauge heights and ratings curves that can be used for all major Australian rivers. It is important that this point is clarified during the early stages of ANSR.

Product 3: Non-Assimilating Control Run of the National Model spanning a 20 year period.

- Approximately 4km resolution spanning the entire Australian Shelf.
- Appropriately evaluated against pre-determined criteria that ensures it represents key features identified by end users and stake-holders.

Milestone: 20 year control run of the National model.

Deliverable: Model configuration, associated forcing and output is uploaded and made publicly available.

Output: Documented evaluation of the control run where key dynamics and features are evaluated against predetermined criteria.

Benefits: This model and associated output can be used by the community in a variety of ways. Most importantly, this run will be dynamically balanced and as such can be used for biogeochemical simulations if needed. Additionally, it will be used for the Ensemble Optimal Interpolation DA system.

2.4 Data Assimilation System

Presentations were given by Pavel Sakov, Paul Sandery, Gary Brassington (BoM) and Colette Kerry (UNSW) regarding the pros and cons of different data assimilation schemes methods (EnOI, EnKF, and 3Dvar/ 4DVar). It was recommended that ANSR start with a simple scheme while testing more complex and computationally expensive schemes.

It was agreed that ANSR should strive to assimilate multiple datasets including tides, Sea Level Anomaly with tide, on the shelf, diurnal cycle, night-time SST. It was acknowledged that assimilating velocities (HF radar and moored observations) may be challenging, but preliminary results show the benefit. Two grand challenges identified here as stretch components of ANSR will be to 1. test and evaluate the benefits of HF radar and coastal altimetry products and 2. To develop their integration into more advance data assimilation schemes.

Product 4: 20 Year Reanalysis System and Output

- Significant intellectual effort will go into the System design which forms a product in and of itself.
- Model Output at ~4km resolution.
- Will assimilate all available observations that are deemed appropriate for assimilation.
- This will yield the “best estimate” of the state for Australia’s coastal and Shelf seas.

Milestone: 20 year ANSR Completed.

Deliverable: ANSR is made available publicly via a web interface and archived on NCI.

Output: ANSR products and evaluation metrics will be reported in a peer reviewed publication authored by ANSR participants.

Benefits: This will be the first shelf and coast specific reanalysis of the Australian region. These products will be specifically targeted at delivering the requirements specified by the end-users identified in Appendix A.

2.5 Regional Integration

The inclusion of high-resolution (~1km) regional models as a key component of ANSR has been proposed to account for: (1) topographic complexities not captured at the 4km resolution, (2) improved physics (e.g. internal tides, cyclones, non-hydrostatic behaviour, internal waves, estuaries (land ocean connection), and (3) to assess the feedback from sub-mesoscale dynamics on broad scale circulation. In addition, the higher resolution solutions will improve stakeholder relevance with potential for increased investment from parties interested in highly localised characterisation. The downside risk is that in reaching for regional relevance we lose some of the power of a national reanalysis project. Care needs to be taken in striking an appropriate balance.

It is proposed that the criteria for development and or inclusion of regional downscaled (1km or better) models within ANSR be a clear demonstration of:

1. User needs – downstream applications;
2. Modelling teams that are active now and are ready to be tightly integrated;
3. Diversity – e.g. non hydrostatic core, wetting drying, strong tides;
4. Test beds for processes or studies that are too difficult or expensive to run within the national model;
5. Contribution to improving the back bone (better physics, better sub grid scale parameterisations);
6. Better representation of the observations (can guide observing system design).

There was significant discussion around the need for inclusion of regional partners and a strategy for their inclusion, in addition to meeting stakeholder needs. High-resolution regional grids are a good way to accomplish these objectives where there is a clear benefit in either the evaluation of the coarser national grid, or for methods testing in smaller, cheaper grids. However, there may need to be some rationalisation in that not all regional grids may be affordable under ANSR. An alternative is to consider the national grid as core to ANSR and the regional models as non-core components of ANSR. Regardless of whether regional grids are included as a core component of ANSR or not, engagement with the regional community through the evaluation process, whereby regional models are used to evaluate the national model is essential. A proposed alternative is to allow for sections (segments) of the national grid to be modularised and then used as test-beds to improve processes, parameterisations or used as fast "sub-models" for DA methods testing.

Product 5: High resolution Nesting

- Very high resolution nests that have resolutions better the 1km.
- Focussed in areas such as shelf seas (or estuaries) where there are high density observations.
- Targeted towards representing dynamics that are not well captured by the national grid.
- Can be used where specific needs of a stakeholder require a high resolution grid.

Milestone: Pilot high resolution grids are functioning and value adding to the national product.

Deliverable: All output from high-resolution nests are made available publicly and potentially integrated into the ANSR product.

Output: Fine resolution reanalysis and/or free run solutions are served via the ANSR web infrastructure and reported in a peer reviewed publication.

Benefits: These high-resolution nests add value to the national grid and provide information about dynamics that are not well represented by the coarser national grid.

2.6 System Evaluation

We identified that significant effort is being placed on system evaluation within the Framework of the European COST Action 1402 "Evaluation of Ocean Syntheses". This includes 4 dedicated working groups (see presentation by Pierre De Mey). Consensus was reached that system evaluation should be considered a-priori to be included in the delivery timeline, and it was noted that this is not a small portion of the project as reanalyses are about quality. It was recommended that reanalysis products must be accompanied by performance assessments with a detailed evaluation to confirm that the products met end user needs.

To assist in community (Australian and Global) participation and evaluation, one suggestion is that the system is set up in such a manner that it can be "containerised" and ported to different users. The key driver behind this was to facilitate the development of and improvement of different components in an offline manner. This could include physics improvements, alternative DA algorithms, inclusion of BGC models, etc. However, to achieve this, an appropriate public license must be applied.

In terms of the scope during Phase 1 of ANSR, the system should be limited to hydrodynamics, but with the provision to integrate BGC at a later date. In fact BGC can be done at the regional nest level initially as a pilot project. To this end, an early activity in Phase 1 will be the development of an evaluation plan that does not just include state variables, but also key metrics such as transport, or region specific metrics etc. These evaluation tasks will be done with groups that are familiar with the regional dynamics but in close collaboration with the lead model and DA developers.

Evaluation by regional groups

- Run own tests for each of free run, V0, V1 (see Appendix B for important dynamics, Table 4)

National – Direct comparisons with other data and products

- Comparison with other RA products: BRAN, global ORA (GLORYS, Reading)
- Comparison with climatologies such as CARS, WOA etc., global BGC products, data-based syntheses
- Comparison with withheld observations in early short runs
- SST if not directly assimilated? (Foundation SST or Skin SST)
- Tides from tidal solutions (FES etc.)
- Dedicated validation cruises?
- Run similar diagnostics for BRAN to identify changes & check added value on shelf & shelf break
- Other diagnostics?

- The above list can be prioritised depending on the user pull.

National – Assimilation (mostly)

- Built-in assimilation diagnostics: e.g. DFS, spread reduction, others
- Innovation statistics (CLIVAR/GODAE Class 4) for validation in short-term prediction mode, and to recalibrate observational errors
- Rank histograms if using Ensemble method – to evaluate spread of ensemble (too small/large/cold/warm/etc.)
- Robustness: Ensemble stats or variational-based sensitivity studies.
  - Runs with different parameters (multi-physics ensembles)
  - Adjoint sensitivity
  - Cross-Validation (withholding data)? CV also useful as criticism of multivariate inter/extrapolation properties.
  - GCV possible with Hessian (e.g. from 2nd order adjoint: available for ROMS) or Desroziers randomisation method
- Other diagnostics?

National / regional – Analysis & consistency tools

- Volume transports at straits in the North, Bass strait
- T-S relationships on shelf/off-shelf
- Estimation of Rossby radii
- Rate of dense water cascading off shelf
- Rate of occurrence of particular processes
- Need options for statistical validation of short spatial scales. Spectra (e.g. wavelet-based) of RA product and remote-sensed image-based products such as OC?
- Short anisotropic scales: Lyapunov exponents? Compare with what? Any drifting thing we cannot use in DA? (e.g. undrogued drifters, larvae concentration, others?)
- Need options to validate high frequencies on the shelf (mostly barotropic dynamics) – can perhaps withdraw tide gauges in some locations?
- If we have model Ensembles, match observation dataset with regions of high Ensemble variance to see if we are missing some of them (along the lines of the ArM approach – more a criticism of the obs network and a guide for improvement than a validation proper)
- Other diagnostics?

2.7 Infrastructure needs

It in envisioned that the ANSR project will approach NCI to form a "project space" on their infrastructure that is accessible to all active ANSR participants. This project space will facilitate the development and routine running of ANSR models, hosting of model output, and storage of observations used for assimilation. Products will then be transitioned to outwards facing HPC server for serving to the general public.

As a first guess, the Model independent requirements on NCI (e.g. Raijin) are: 1 MSU per annum for 5 yrs in years 1 and 2 for the EnOI system. 3-5 M Su p.a. in years 3, 4, and 5

50 TB of storage.

Section 3 Work packages and Products

1. Build the cyber infrastructure (including sandbox)
2. Observations
   Product 1: Versioned ANSR Observation database stored on NCI
   Product 2: High resolution Shelf Climatology
3. Assemble Forcing and Bathy Products (river run off/ atmospheric products)
4. Evaluation
   a. Develop plan for evaluation (include sources of error)
   b. Evaluate (nationally and regionally) at each step / product /
   c. Impact assessment of forcing products (especially atmospheric and river)
5. 20 yr free run at 2.5-4km resolution (back bone)
   a. Grid generation
   b. Model Configuration (forcing / parameterisations)
   c. Run the model
   Product 3: Non-Assimilating Control Run of the National Model with evaluation metrics reported.
6. Back Bone Reanalysis 2 yr tests of DA - V0aV0bV0c with EnOI / EnKF /4 DVar
   a. Development of DA system and DA diagnostics for V0 (Day 2 am discussions)
   b. DA testing methodology / schemes/ observation impact ongoing radar / velocity / start in a partial (sub) grid
7. Back Bone 20 yr Reanalysis V0 (EnOI) — not for release
8. Back Bone 20 yr Reanalysis V1 (improved DA)
   Product 4: Completed ~20 year reanalysis including comprehensive community validation and published documented
9. Regional High Res model/ science questions (feeds into 4 / 5 / 6 /7 /8), depends on 5
   Product 5: Demonstration regionally focussed very high resolution (~1km) products developed by regional experts
10. ANSR Outputs: Value adding to products from workpackages above e.g transport files for BGC, fluxes, connectivity tools etc.
11. Scoping of Phase 2 and Scoping research to operational transition

Section 4 Preliminary Phasing and Estimate of Effort

Note tasks are identified above in Section 3, work packages. Estimates are provided in full time equivalent (FTE), per annum.

Table 1: Workpage break down and estimate of effort for each task.

Work Package	(Sub) Task	YR 1	YR 2	YR 3	YR 4	YR 5	Total per Task
1 Cyber-inf		2	2	2	1	1	8
2 Observations		2	2	1	1	1	7
3 Assemble forcing and bathy		0.5	0.1	0.1	0.1	0.1	0.9
4 Evalualtion	a	0.5	0.2	0.2	0.2	0.2	1.3
	b	2	2	2	2	2	10
	c	0.2	0.6	0.6	0.2	0.2	1.8
5 Freerun of Model	a	0.3					0.3
	b	2	1				3
	c						
6 DA testing on	a	1.5	2	1	0.5	0.2	5.2
7 ANSR V0 (Backbone only)			0.4	0.4			0.8
8 ANSR V1 Improved (Backbone only)				0.4	0.4		0.8
9 Incorporation of Regional activities		1.5	1.5	1.5	1.5	1.5	7.5
10 Products and Outputs			0.2	0.2	0.2	0.2	0.8
11 Scoping of Phase 2					0.2	0.6	0.8
Total per year		12.5	12	9.4	7.3	7	

Section 5 Risks and Limitations

Licencing: Any product that we develop comes out with a creative commons attribution licence, so anyone can use it, but must acknowledge use.

There is a risk that groups may undertake studies that conflict or compete with ANSR if they are not integrated well.

Dynamical Limitations

ANSR will not be able to resolve certain dynamics which will result in a failure to capture certain events and processes. For example strongly forced high energy (short lived) events such as tropical cyclones or non-hydrostatic processes such as formation of salty plumes near the coast (NW shelf) and their cascade along the bottom. However, ANSR will provide the backbone with which to undertake improved studies of these events and dynamics.

Choice of Model:

We have not explicitly chosen a model platform through this process. However we suggest that open source, nationally and internationally accepted with a broad user base (within Australia) is adopted. To engage with the regional groups ROMS is a logical choice. However ROMS is not the only candidate. The choice of model will determine the success of ANSR in achieving the goals (as outlined on page 6).

Regional Engagement:

One of the underpinning goals of ANSR is engagement and buy in from the regional community. There is a risk that groups may undertake studies that conflict or compete with ANSR if they are not integrated well.

Service Delivery / Access to Data:

Consideration must be given to what kind of service people could expect? How do they get access to the data? How is the project supported into the future? What is the project management strategy. This will be determined as the Business case evolves.

Quality of Forcing Products:

Limitations presently exist with the quality of the forcing products, in particular atmospheric forcing (at sufficient resolution) and access to River gauge data. In areas that are intermittently subjected to large river discharge, the ability of the forcing data to capture these events will directly affect the quality and accuracy of the reanalysis.

Choice of Data Assimilation Tools:

There is a compromise between computation Intensity versus efficiency and potential degraded accuracy that depends on the system being used. Australia presently has limited capability in DA, however we are looking to grow this skill set.

Products:

We have limited the scope of ANSR in the first instance to the physical variables of currents (u, v), temperature, salinity and sea surface elevation; we are not including waves, sediment transport or biogeochemistry in V1.

Section 6 Summary of ANSR Products

Table 2 showing the key ANSR products and the suggested temporal and spatial resolution.

	Timespan	Temporal Resolution	Spatial Resolution
Product 1. ANSR Observations Database:	1993- Present		Time dependent as a function of the observing system
Product 2: ANSR Observational Shelf Climatology	This product will give a similar resolution to the CARS product	-	-
Product 3: Non-Assimilating Control Run of the National Model spanning a 20 year period.	1993- Present	Hourly data	3-4km
Product 4: 20 Year Reanalysis System and Output	1993- Present	Hourly data	3-4km
Product 5: High resolution Nesting	Various depending on application	Hourly data	250m upwards
ANSR V2 Include Waves, BGC, Multiple model ensembles, Forecasting mode	Various depending on application	Hourly data	250m upwards

Appendix A: Stakeholder Needs Survey Results

Table 3: Table to identify end users, products (**R**eanalysis, **N**owcast, **F**orecast) and end needs and required dynamics.

Stakeholder	Group	R	N	F	End Needs	Required Dynamics
Industry	Aquaculture	X			• Site selection • facility design • projected stocking rates. • Historical understanding of mean water circulation for planning • Alternative management scenarios • Hind-casting to provide information on extreme and possibly harmful events. • Hind-casting and scenario studies of nutrient levels due to anthropogenic sources inc. aquaculture • Estimate the impacts of other human impacts on aquaculture lease sites including pollution/ballast spills, and deposition during dredging and loading of mining and agricultural products.	Baroclinic and barotropic circulation, upwelling, mixing, tides, runoff, storm surges, wave-driven circulation. Regional scale 3D dynamics that can be downscaled to local dynamics
			X	X	• Facility management • Towing of pens • Stocking rate projections. • Early warning systems: Cold water/riverine-freshwater plume/ algal bloom	As above, Water quality, HAB model

					• Reduction in vessel fuel costs of towed tuna cages through "surfing" now-cast/forecast ocean currents, waves and atmospheric winds • Rapid and accurate Information on the likely trajectory of harmful algal blooms/toxins/pathogens • Information on likely source of contaminants, toxins, pathogens during an emergency response. • Now-casts/forecasts on ocean "weather" (e.g., for better planning aquaculture pen maintenance, fish transfer) • Information to inform best emergency response options (where to move tuna pens/oyster baskets *etc*)	
	Fisheries and Ecosystem Operations and Management	X			• Understanding life-cycles of target species, and natural causes of inter-annual catch variability. • Connectivity • Spatial and temporal patterns for management of commercial and threatened species • Impact of nutrient/pollutant loading on marine ecosystems • Oil well spill trajectories following possible production and impact on ecosystems	Upwelling, wind and current driven Tides/internal tides where internal tide induced mixing is significant. Regional scale 3D dynamics that can be downscaled to local dynamics

			X	X	• Fleet management, by-catch reduction, safety, maximize catch for least cost • Possible now-casts/forecasts (out to a week) of likely location of Sardine & SBT schools – complimentary to CSIRO & SARDI work. • Now-casts/forecasts on ocean "weather" (e.g., for rec and commercial diving, stock estimation) • Reduction in vessel fuel costs through "surfing" now-cast/forecast ocean currents, waves and atmospheric winds • Rapid and accurate Information on the likely trajectory origin of mass fish mortalities • Oil well spill trajectories following possible production and impact on ecosystems • Now-casts/forecasts on ocean "weather" (e.g., for rec and commercial diving, stock estimation)	Mesoscale and sub-mesoscale eddies Upwelling, wind and current driven Tides/internal tides where internal tide induced mixing is significant. Surface Currents
		X	X	X	Harmful Algal Blooms	Biogeochemistry, Physical circulation
	Port operations	X	X	X	• Under-keel clearance • forces on mooring lines • collision avoidance • on-time arrivals	Tides, wind driven currents, storm surge, waves, meso and sub-meso scale circulation

	Tourism	X	X	X	• Identification of marketable 'product', e.g. timing of whale migrations, clear water for diving, other natural spectacles. • Recreational fishing: regional to localized scale dynamics, i.e targeting temperature fronts for black marlin • Early warning systems: Near-shore conditions for divers, fishers, surfers, swimmers: coastal conditions for whale/dolphin watching; algal alerts	Biogeochemistry, Optics, Temperature (Upwelling), Waves
	Coastal Engineers	X	X	X	• Coastal erosion • cooling water intake • wave, tidal, and ocean current renewable energy. • Increasing resolution toward the coast: wave, currents, sediment transport. Risks/threats to infrastructure and community including coastal inundation and storm surge. • Dredging • Port and harbor developments	Tides (barotropic), storm surge, wave setup Waves Internal tides where they cause significant currents on the shelf/slope Wave and wind driven currents, and potentially the large-scale circulation intruding onto the shelf if it affects sediment transport. Circulation that includes extreme events.
	Oil & Gas	X			• Rig etc design • risk assessments • Environmental impact statements • spill management plans. • Modelling oil spill dispersal/fate of in estuaries and coastal environments	Full 3D circulation and density field

			X	X	• Towing of large structures • timing of drilling and/or production (e.g. when to connect or disconnect a pipe string) • spill response	Full 3D circulation and density field
	Transport			X	• Reduced fuel consumption, on-time arrival	
Defence	Navy	X	X	X	• Information superiority (for both avoiding and detecting enemies) • safety (e.g. subs hitting seafloor or surface because of current or water density anomalies) • cost reduction (transit time, well-advised searching), for submarines, surface fleet, amphibious operations, helicopters.	Meso and sub-meso scale circulation, Tidal currents (barotropic) Internal tides for submarine operations Sea water Density, waves
SAR		X	X	X	• Surface current for trajectory modeling • surface temperature for survival time estimation	Surface currents, waves
AMSA		X	X	X	• Surface current for pollution prosecution (backtracking sightings to offender)	Surface currents, waves
Environmental Management Organisations	Local NRM Boards and Councils	X		X	• Early warning systems: Beach amenity/rec water quality from ocean drivers • Management of beaches and estuaries: mean state and extremes	3-D near-shore and shelf dynamics

	State / Federal EPA	X	X	X	• Ghost nets • Pollution • Dispersion and fate of pollutants from point sources and catchments	3-D near-shore and shelf dynamics
	Regional / State Management (e.g. GBRMPA, WA DPaW)	X	X	X	• Dispersion and fate of nutrients and pollutants as threats to coast and shelf ecosystems • Links to distribution of benthic species (habitat mapping) inter/intra zone and park scale: Fine-scale (sub-km) characterization of water mass characteristics. • Early Warning Systems: algal blooms/human health/recreational water quality/coastal erosion • Sediment transport in and around the shoreline; Alongshore and offshore transport/budgets • Assessing impacts of environmental disturbances (historical and forecasting) on marine ecosystems	3-D shelf and near-shore and shelf dynamics including extreme events, coastal water quality.
	Federal Department of Environment					
Research Institutions	University	X	X	X	• "Best" estimate of the physical oceanographic setting for process studies • nesting of biogeochemical models	Full 3D ocean state, with tides, rivers and (sub)-meso scale features.
	Publicly Funded Research	X	X	X	• Open Boundary conditions for high res models	Full 3D ocean state, with tides, rivers and (sub)-meso scale features.

	Agencies (PRFA's)				• cross-shelf exchanges • Connectivity • Regional Characterization for eco-systems etc.	
National Facilities	MNF - Investigator		X	X	• Supporting Chief Scientists who need to seek and sample particular ocean features	
	IMOS	X	X	X	• Array design, path-to-end user	
Recreation	Beach-goers		X	X	• Water temperature	
	Racing sailors, ocean kayakers	X	X	X	• Trip time minimization, trip planning	

Appendix B Regional integration

Table 4: The identification of key dynamics, and capabilities within regional groups and models to contribute to the evaluation, value adding and assessment of the ANSR national system. The table has been left blank, but is included to provide guidance for further discussion.

	Dynamics	eReefs 1km	eReefs 4km	SEAROMS	Stockton Bight	Coffs	NW Shelf High Res	NW Shelf	Perth	SA Gulfs
Studies to improve the national backbone using regional models	Freshwater Input									
	Large Tides									
	Wave Coupling									
	Cyclone Impacts									
	Surface Boundary Conditions									
	Sub-gridscale parameterization									
	Boundary Current and Shelf Interactions									
Value add to the national backbone by regional models through increased resolution	Internal tides									
	reef processes									
	Canyon Flows									
	Sub-meso Scale Dynamics									
	Cyclone Impacts									
Skills and expertise that can contribute to the backbone	4dVar									
	BGC									
	EnKF/EnOI									

Workshop Attendees

Table 5: Workshop attendees.

Name	Organisation
Moninya Roughan	UNSW
Colette Kerry	UNSW
Emlyn Jones	CSIRO
Ryan Lowe	UWA
Mike Herzfeld	CSIRO
David Griffin	CSIRO
Gary Brassington	BoM
Paul Sandry	BoM
Tim Moltmann	IMOS - ANSR SC
Roger Proctor	IMOS
John Wilkin	Rutgers (USA)
Pierre De Mey	Legos (France)
Carlos Rocha	UNSW
Jessica Benthuysen	AIMS
Sarath Wijeratne	UWA
Andreas Schiller	CSIRO
Pavel Sakov	BoM
Greg Stuart	BoM