Chapter 17

BLUELINK: LARGE-TO-COASTAL SCALE OPERATIONAL OCEANOGRAPHY IN THE SOUTHERN HEMISPHERE

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Abstract: In 2003, the Australian Government, through the Bureau of Meteorology (BoM), Royal Australian Navy and CSIRO, initiated BLUElink - *Ocean Forecasting Australia*, a project to deliver operational short-range ocean forecasts for the Asian-Australian region by 2006. Global advances in technologies necessary to observe and simulate the oceans have provided scientists at CSIRO and the Bureau of Meteorology with the tools to deliver near real-time information on ocean behaviour. Central to BLUElink is the development of a global and nested ocean prediction system. The BLUElink initiative centres on ocean prediction and analysis, and forecasting of day-to-day variations in ocean currents and temperatures around Australia. Ocean forecasts will be updated to include the latest changes in the ocean state and weather systems, particularly extreme conditions such as from tropical cyclones. The aim of the project is to generate ocean charts for marine users similar to weather forecast charts available to the rest of the community. The BLUElink system will provide information on coastal and open-ocean currents, surface and subsurface ocean properties, products that impact and are linked to maritime and commercial operations, defence applications, safety-at-sea, marine environmental sustainability, and regional and global climate. CSIRO is currently developing a high-resolution, coupled atmosphere-ocean model predicting out to 3 days which has been specifically designed for coastal and shelf applications. Standard products of the coastal forecasting system will be surface winds and sea-surface height, and 3-dimensional fields of ocean temperature, salinity and currents.

Keywords: Operational ocean forecasting, South-East Asian-Australian region, Indonesian througflow, nested modeling, ocean reanalysis.

1. Introduction

Ocean forecasting has become achievable because of rapid developments in computing power, remote observations and autonomous ocean instruments. Technical developments and intensive research have given the global marine community a broad understanding of the behavior and circulation of the oceans and seas. Although there is still a long way to go, scientists today have a good understanding of the “inner-workings” of the ocean. The state of the ocean can now be monitored and predicted. In line with international trends, operational oceanography in Australia is evolving in support of the community and its marine industries, as well as defense, environmental protection, and improved climate prediction.

BLUElink is a three-year project to develop the ocean model, analysis and assimilation systems required to provide timely information on, and forecasts of, the oceans around Australia. It will build on Australia’s weather and climate forecasting systems, extending its capability to the marine environment, through an initial investment of $US 10M. BLUElink forecasts will provide information on coastal and open-ocean currents and eddies, and surface and sub-surface ocean properties; information that is useful for maritime and commercial operations, defense applications, safety-at-sea, sustainability of the marine environment, and regional and global climate. BLUElink is Australia’s contribution to the international Global Ocean Data Assimilation Experiment (GODAE), an international experiment in ocean prediction. With new computer technologies and a greater understanding of the ocean and “how it works”, scientists can start to run models that emulate the ocean environment and predict its evolution.

The Australian Bureau of Meteorology already provides operational weather services for marine users. This service focuses on the state of the sea surface and forecasts of wind conditions, storm surge heights, and sea-surface temperatures. BLUElink will provide the core of an extended oceanographic service at the Bureau of Meteorology in which the ocean model and assimilation prediction system will maintain up-to-date analyses of the state of the ocean. High-resolution analyses will be generated each day and twice-a-week forecasts will be generated out to 28 days incorporating the latest changes in the marine weather and wind systems. These extensions will complement the Bureau’s existing weather and climate services and provide an integrated suite of products for the public and private sectors. The service will provide essential infrastructure for industry and the ocean community.

2. Data and product management

The international marine community shares a common desire to synthesize and assimilate global, real-time data of winds, ocean temperature, salinity and sea level. These data are collected by nations participating in the Global Ocean Observing System (GOOS) and stream in hourly to shared data networks. European and US satellite missions and the new wave of ocean-borne measuring instruments, such as the *Argo* profiling floats, are the centerpieces of the ocean observing system. BLUElink has instituted a sophisticated arrangement for reception, management and quality control of these data. The Bureau of Meteorology has installed the Meteorological Archive and Retrieval System (MARS) developed by ECMWF and this will be used to manage the entire ocean and product data streams for the operational ocean systems. State-of-the-art information technology will be deployed to ensure data are provided swiftly to models and to ensure products are available to participants and the wider community as soon as possible, e.g. via Live Access Servers. A preliminary web page with some background information about the project is available at http://www.marine.csiro.au/bluelink/.

3. Analysis and modelling systems

Just as zones of high and low pressure drive atmospheric changes and our weather, similar forces are at work in the ocean. The ocean responds directly to exchanges of energy with the atmosphere, through wind and surface heating. However, the ocean also delays its reactions to these forces, to later generate its own “weather” (ocean eddies) and fronts, as well as longer-term climate variations such as El Niño. The topography of the sea floor and the presence of the bordering land also have profound effects on the ocean, in a way that is unique to the ocean and its coastal subsystems. The BLUElink ocean models aim to capture key regional ocean currents, such as the East Australian and Leeuwin Currents, the Indonesian Throughflow and the Antarctic Circumpolar Current (Fig. 1). All of these currents are subject to strong short-term variability, which is superimposed to variability on seasonal and climate change timescales (for further details see Tomczak and Godfrey, 1994). Furthermore, basin-scale wave dynamics in the Pacific, Indian and Southern Oceans on seasonal and longer timescales has a direct impact on regional ocean variability around Australia (Wijffels and Meyers, 2004). All of these features need to be properly simulated in an ocean model which has a regional focus on the oceans around Australia.

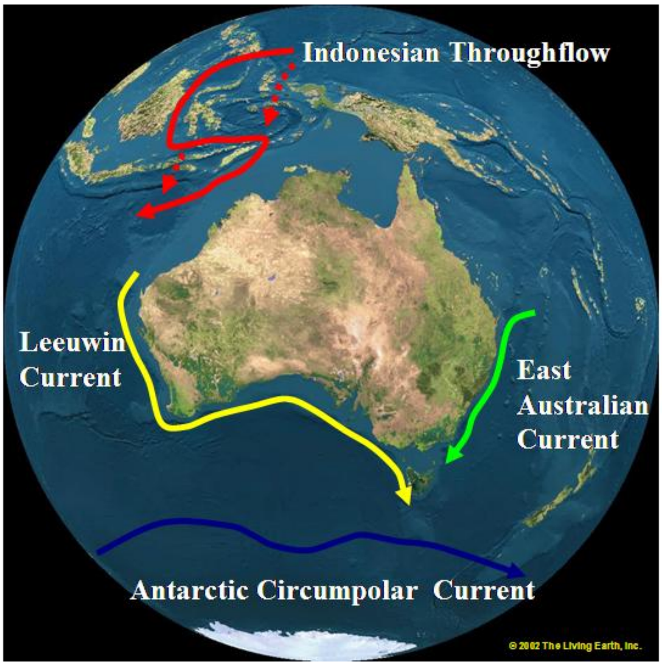


Figure 1. Schematic of major currents in the Asian-Australian region. The background image is © Copyright 1996 The Living Earth, Inc./Earth Imaging by permission of the publisher.

3.1 Analysis system

Modern weather prediction relies on access to accurate observations of the atmosphere. BLUElink will depend upon access to a range of surface and sub-surface observations of the ocean. To be useful, the data must be communicated and managed in a way that maximizes its contribution to the forecasts. The information required includes surface winds and temperature, sea level, ocean currents, and sub-surface temperature and salinity. Primary data types and sources are:

- Historical information obtained since about 1900, but mostly from recent decades (T, S);
- *Argo* profiling floats (T, S);
- Expendable bathythermographs (XBTs) deployed from “Ships of Opportunity” (T);
- Surface weather and ocean observations from voluntary observing ships (T, S, **u**);
- Surface drifting instruments (**u**);
- Coastal sea level from tide gauges (η);

- Open ocean sea level from the *Envisat* (ESA), *Jason* (NASA-CNES) and *GFO* (U.S. Navy) satellite altimetry (η);
- Sea surface temperatures from polar orbiting platforms and geostationary platforms, using both infrared and microwave instruments (SST);
- Surface wind estimates from satellite-borne instruments and numerical weather models (τ);

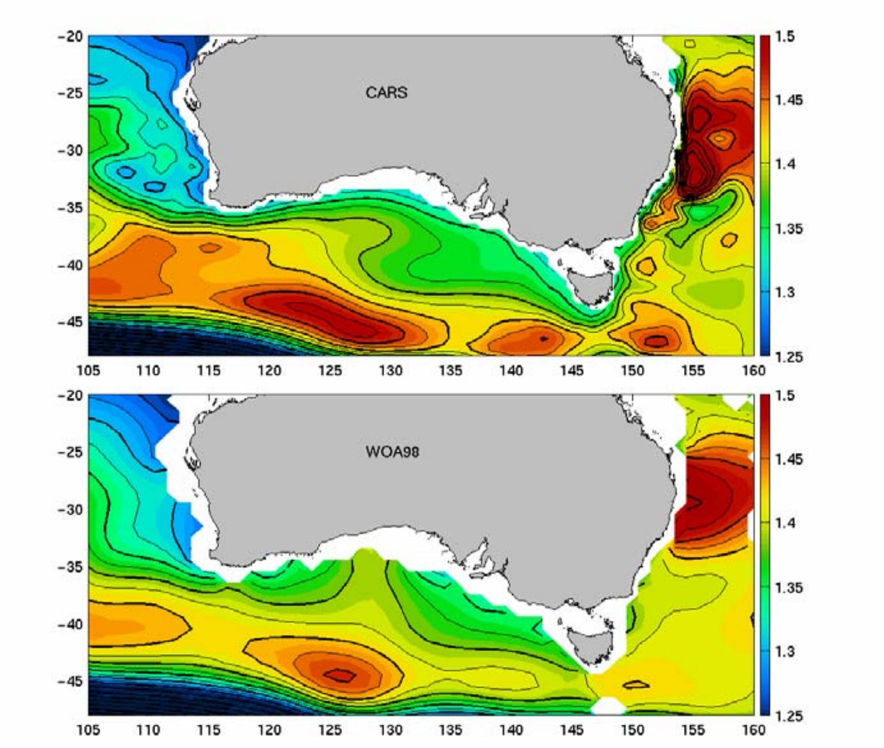


Figure 2. Dynamic height 400/2000 dbar. Top: CSIRO Atlas of Regional Seas (CARS) (Ridgway et. al., 2002); bottom: World Ocean Atlas (Levitus and Boyer, 1994).

CSIRO has already developed and maintains the CSIRO Atlas of Regional Seas – a regional (10ºN-60ºS: 90ºE-180ºE) high resolution, quality controlled, three-dimensional ocean climatology of temperature and salinity fields. The Atlas has been enhanced with additional historical temperature and salinity information for the Indonesian and New Zealand regions. Fig. 2 shows improvements in the fine-scale structures of CARS compared to the World Ocean Atlas (WOA). In CARS, a continuing coastal current is visible (Leeuwin and South Australian Current), which is missing in the WOA. The atlas uses a methodology which explicitly allows for the influence of bathymetry and island barriers which resolves both the large-scale structure as well as narrow boundary features.

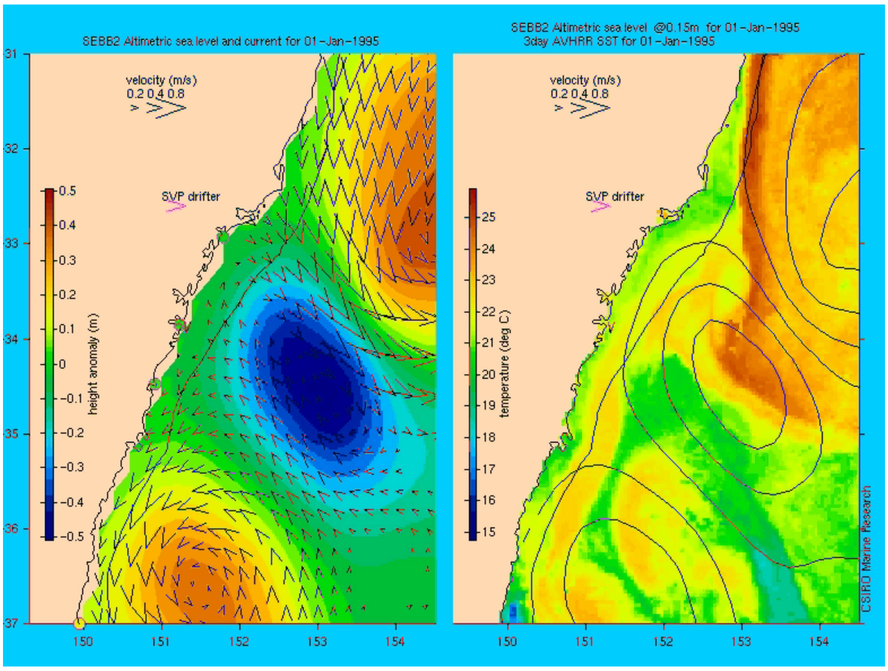


Figure 3. Example of satellite-based data analysis (ERS-2, Topex Poseidon and NOAA AVHRR). Date: 1 January 1995. Left panel: altimetric sea-level height (background) and vectors of geostrophic currents. Right panel: sea-surface temperature (background) with contours of sea level overlayed (contour interval 0.15 m). Shown are a cold-core eddy at the centre of each panel with two adjacent warm-core eddies to the north and south. Courtesy David Griffin, CSIRO Marine Research.

Near-real-time satellite altimeter data from platforms such as the *Jason-1* and *Envisat* satellites and coastal tide-gauge sea-level estimates are used to map sea-level (Fig. 3). These maps will be used in conjunction with a statistical projection method, the Regional Atlas, and available ocean *in situ* data (e.g. *Argo* profiling floats, XBTs, research and navy vessels) to infer three-dimensional estimates of the ocean's state. An enhanced, high-resolution real-time sea-surface temperature (SST) analysis will also be developed, with around 2–5 km spatial resolution in the Australian region. The analysis will take advantage of geostationary satellite data to partially resolve the diurnal cycle and of microwave SST data to eliminate gaps arising from cloud cover. BLUElink will contribute Level 2 data from the Australian region to the GODAE High Resolution SST Pilot Project (GHRSST) and develop dedicated data sites to support the validation of SST products. Surface currents will be estimated from images of remotely-sensed sea-surface temperatures, using a method that tracks the movements of small-scale features. A high-quality enhanced regional wind speed and direction product will also be developed.

3.2 Modelling and assimilation system

3.2.1 Global model and data assimilation system

BLUElink has developed a global ocean model based on the GFDL MOM4 code (Griffies et al., 2004), called the Ocean Forecasting Australia Model (OFAM), with a resolution telescoping from 2º in the North Atlantic and North Pacific to (1/10)º in the Asian-Australian region. The Asian-Australian region is defined as extending from longitudes 90º E to 180º E, and from latitude 16º N to 75º S which is very similar in extent to the part of the earth shown in Fig. 1. OFAM has 47 vertical levels with 35 levels in the top 1000 m and a thickness of the uppermost levels of 10 m. The model uses the third-order “quicker” scheme for tracer advection (Leonard, 1979), a hybrid mixed-layer model based on Chen et al. (1994), viscosity mixing based on Smagorinsky (1993) and isopycnal mixing with the Gent-McWilliams parameterisation of eddy-induced stirring (Gent and McWilliams, 1990). Due to the model’s variable grid size anisotropic options have been chosen for the latter two parameterisations.

OFAM will form the backbone of the operational ocean forecasting system run by the Bureau of Meteorology. A multivariate Optimum Interpolation scheme (BODAS) is used to assimilate ocean observations in near-real time into the model to improve the initial conditions of the forecasts. A schematic diagram of this forecast system is presented in Fig. 5. BODAS is a stand-alone system that is intended to be adaptable to other ocean models. BODAS calculates a global analyses of surface height η, temperature T, salinity S and the horizontal components of current (u, v) by combining a forecast from OFAM with observations of sea-level anomaly (SLA) from along-track altimetry and temperature and salinity from various sources including Argo profiles, CTD surveys and moored arrays. BODAS performs this calculation through a series of steps that are summarized as follows:

1. Calculate analysis of η, T and S
2. Convectively adjust T and S
3. Spatially filter increments of η, T and S
4. Calculate geostrophic increments for u and v
   (or use statistical approach).

The analyses for η, T and S are produced using ensemble-based multivariate optimal interpolation (EMOI), which is based on simulated ensembles produced by the model's spin-up run. Modules from MOM4.0 are used to convectively adjust gravitationally unstable temperature and salinity profiles. The spatial filter is applied to eliminate near-grid-scale features in the analysis increments. These modifications to the EMOI- based analyses are made before the geostrophic adjustments are computed for u and v in an attempt to construct dynamically balanced analyses. Further details about BODAS can be found in Oke (2004, unpublished manuscript).

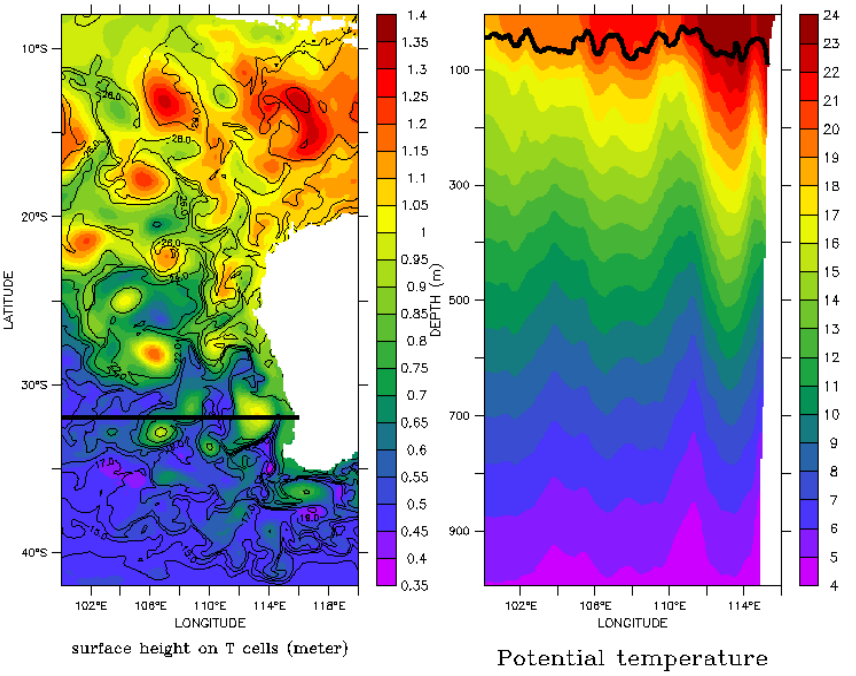


Figure 4. Example of daily-averaged eddy structures in OFAM forced by ERA-40 winds. Left Panel: sea-surface height (colour) and sea-surface temperature (contours) along Leeuwin Current. Right panel: Potential temperature and mixed-layer depth along a section indicated by the horizontal line in the left panel.

The model will be run daily in analysis mode. Twice a week forecasts will be issued with a 7-day short-range forecast and 28-day long-range forecast, respectively.

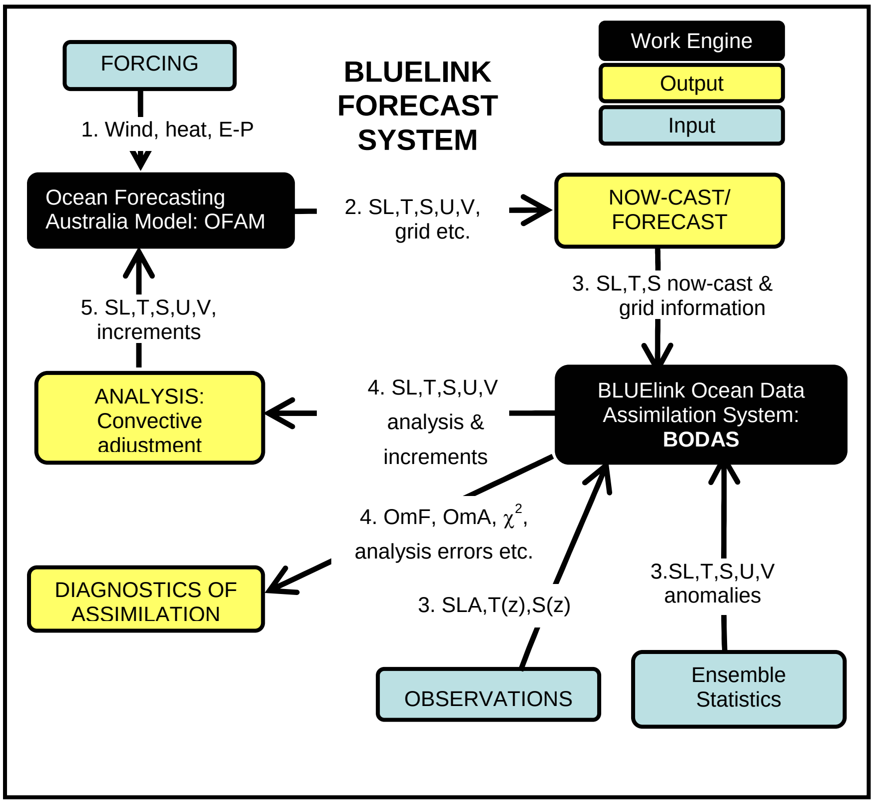


Figure 5. Schematic of BLUElink Ocean Data Assimilation System (BODAS). The three main components are the ocean model and the data assimilation component ("work engines"), the observational input data (surface forcing, satellite and in situ observations), and the analysed output fields which are combined with the model to provide now- and forecasts. The numbers denote the sequence of steps performed during an assimilation cycle. Courtesy Peter Oke, CSIRO Marine Research.

3.2.2 Relocatable ocean atmosphere model

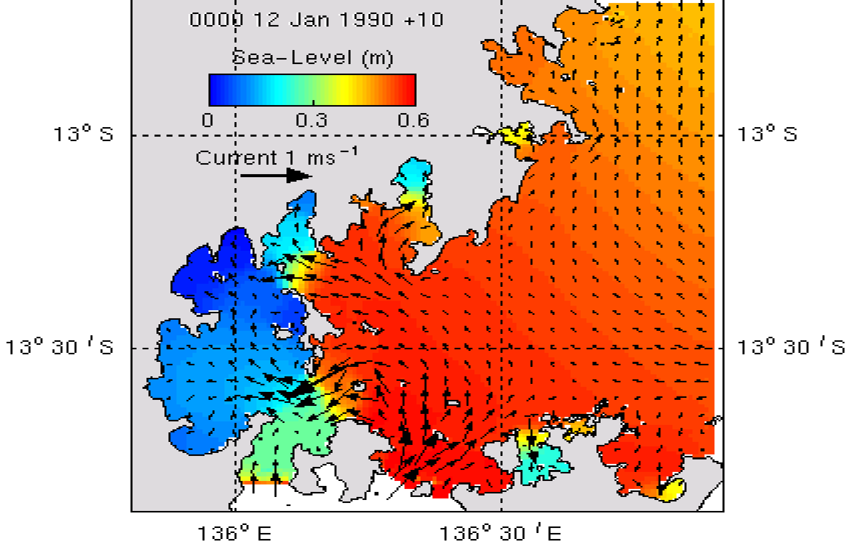
A relocatable, high-resolution, coupled oceanic-atmospheric model called the Relocatable Ocean-Atmosphere Model (ROAM) is under development. The ocean component of ROAM is based on a primitive equations model developed by Walker and Waring (1998) and the atmospheric component has been adopted from the Colorado State University (Regional Atmospheric Modelling System; Pielcke et al., 1992). ROAM will be embedded within the global OFAM model, bringing the resolution down to 2 km for domains of the order of 100 km x 100 km.

ROAM will enable high-resolution forecasts of the water column, of the atmosphere and of conditions at the ocean-atmosphere interface out to 7-10 days (Fig. 6). In this way, scientists can account for the effect of large-scale winds and currents on the Australian region. With ROAM, an operator at a computer terminal will be able to specify a particular geographic region. This might be Bass Strait or the Timor Sea, for example. ROAM will then automatically interrogate the latest output from BLUElink's global ocean and the Bureau's global atmospheric models, and "nest" more detailed atmosphere and ocean models inside it. It will then produce a forecast of the meteorological and ocean conditions for the next several days. ROAM will predict wind, rain and temperature in the atmosphere, and currents, temperature and salinity in the ocean. The model is being developed for the Navy to calculate the behavior of radar and sonar in particular operational locations for their next few days of activity. As implemented in BLUElink, ROAM will typically cover the continental shelf. ROAM will facilitate the implementation of higher resolution nested circulation models for coastal embayments and estuaries.

4. Conclusions

By 2006, the BLUElink project will be the first operationally implemented ocean forecasting system in the Southern Hemisphere covering large-to-coastal scales. BLUElink participates in the international GODAE project and results will be made available to the scientific community and to commercial users of ocean forecasts. Potential benefits from BLUElink will include:

- Optimum ship routing to achieve fuel savings and shipping schedules.
- Enhanced environmental information for onboard naval tactical response systems, improved sonar performance.
- Predictions of changes in ocean conditions with design and cost implications for floating (oil exploration, oceanic and coastal fish farms, marinas) and permanent structures (jetties, breakwaters, pipelines, cables).
- Enhanced coastal and wildlife protection through modelling the dispersion of accidental oil and pollutant spills.
- Improved capabilities for maritime rescue and safety authorities in support of offshore maritime operations and recreational activities.
- Sustainable fisheries and fisheries management, through better understanding of how changes in the currents and the temperature and salinity of the water influence the fisheries resource.



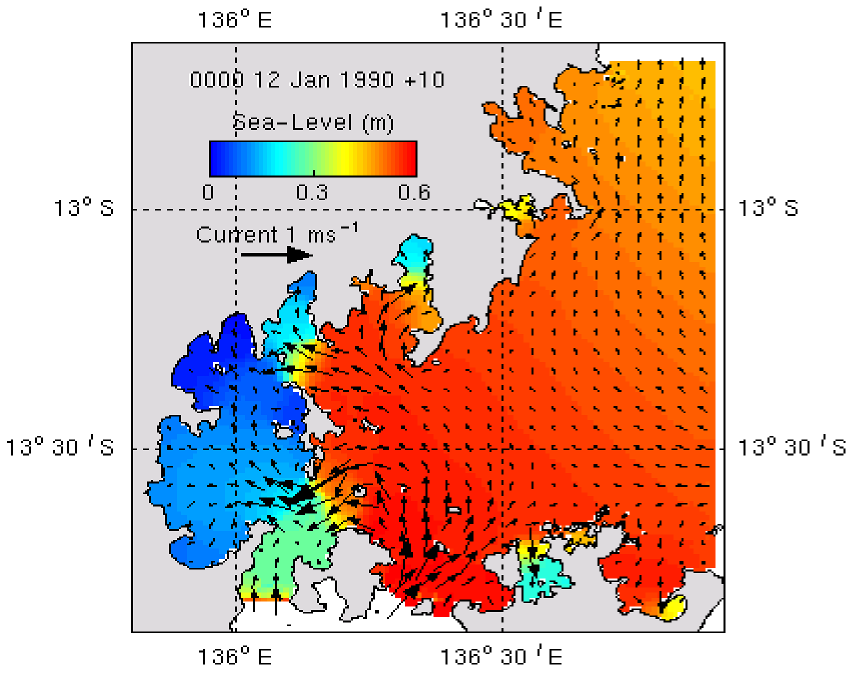


Figure 6. Example of high-resolution ROAM ocean simulation showing sea level and currents in the Gulf of Carpentaria. Courtesy Mike Herzfeld and Scott Condie, CSIRO Marine Research.

At the time of writing, this chapter the work focussed on the first global reanalysis run over the last decade which also serves as a first test of the combined global model, data assimilation system and observations (see section 3.1 for observations assimilated in the model). In hindcast/ reanalysis mode the model is forced by 6-hourly ERA-40 data from the ECMWF (plus weak restoring towards observation-based estimates of sea-surface temperature and sea-surface salinity), whereas in forecast mode atmospheric forecasts from the Bureau of Meteorology's NWP system will be used as surface forcing for OFAM. This first experiment will also provide preliminary but important information about the statistical behaviour of the system (the box labelled "Diagnostics of Assimilation" in Fig. 5).

The next step will be the operational implementation of the forecasting system at the Australian Bureau of Meteorology. Observations received in near-real time from satellites (altimetry and SST) and in situ platforms such as Argo floats will be analysed and ingested daily and into the forecasting system. Short-range forecasts will be issued twice a week.

Future developments beyond the timescale of the current project will focus on an improved data assimilation system (e.g. Ensemble Kalman Filter) and on the implementation of a sea-ice model.

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