TAMING AUSTRALIA'S LAST FRONTIER

BY ANDREAS SCHILLER, GARY MEYERS, AND NEVILLE R. SMITH

With more than 6 million km^2 of ocean comprising the third-largest Exclusive Economic Zone (EEZ) of undersea resources in the world, the marine environment around Australia is justifiably termed that nation's "last frontier." The increasing economical exploitation of its resources and the sustainability of its ecosystems demand an accurate knowledge of the circulation and structure of its oceans. Accomplishing this requires observations on a regular basis—in the same way meteorologists follow weather—and a significant investment to support it. Every day, marine managers and researchers worldwide draw on ever-increasing information networks fed by global observing systems, ocean general circulation models, data assimilation, and short-term ocean forecasts. This nexus of ocean observations and ocean modeling is key to the recent revolution in the realm of oceanic and ocean–atmosphere research.

The implementation of a multidisciplinary Integrated Marine Observing System (IMOS) and, simultaneously, the first operational global and regional ocean forecasting system in the Southern Hemisphere (BLUElink) is a big first step forward to increasing our knowledge of the oceans around Australia. Together, IMOS and BLUElink inform decisions about protecting marine biodiversity, risk management for sea operations and offshore industries, recreational pursuits, hazard prediction, and national security.

In 2006, the Australian government launched IMOS (www.imos.org.au), a US$40 million national initiative (with a nearly equal amount invested by universities and other national research agencies) designed to monitor the oceans around Australia and provide value-added products as well as free, open, and timely access to data. IMOS records and analyzes changes in the marine environment, from the major boundary and ocean currents to the 30,000-km-long Australian coast.

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Based on the need for regular high-quality analyses and forecasts for the oceans surrounding Australia, the government also launched project BLUElink. The initiative took advantage of both the increasing number of global ocean observations in the last decade and the IMOS project to deliver in 2007 the first operational global ocean forecasting system with a focus on the Asian–Australian region (www.bom.gov.au/bluelink).

INCREASING OCEAN KNOWLEDGE. Our current knowledge about the major large-scale circulation features around Australia is largely based on recent progress associated with IMOS in our ability to observe the oceans. Key features of the regional ocean circulation are the Indonesian Throughflow, the Leeuwin Current, the Leeuwin Current extension (also labeled the South Australian Current), and the East Australian Current (Fig. 1).

North of Australia, a system of currents in the ocean's upper 300 m called the Indonesian Throughflow drains water from the Pacific into the Indian Ocean through the Indonesian archipelago—a process that influences Australian rainfall. Downstream of the Indonesian Throughflow, interannual and decadal variations of the Leeuwin Current off the west coast of Australia are to a large extent a response to the large-scale variation of the Indo-Pacific Ocean. For example, the Leeuwin Current responds to remote factors such as ENSO (El Niño–Southern Oscillation), with a documented impact on Australia's most valuable fishery—the Western Rock Lobster.

The southeast coast of South Australia experiences large seasonal coastal upwelling during the austral summer months (December–April). Paradoxically, winds that upwell favorably near the coast drive currents that converge over the shelf break, leading to downwelling of 100 m or more, and an eastward current that flows in the opposite direction to both the nearshore currents and Flinders current (a northern boundary current) farther offshore.

Australian scientists recently have identified an overlooked ocean pathway—or "supergyre"—linking the three Southern Hemisphere ocean basins, which will help them explain more accurately how the ocean governs global climate. The new research confirms a current flowing out of the Tasman Sea, past Tasmania, and turning toward the Indian Ocean, ultimately reaching the South Atlantic. The "supergyre" is a previously undetected component of the world climate system's engine room—the thermohaline circulation, or "global conveyor belt."

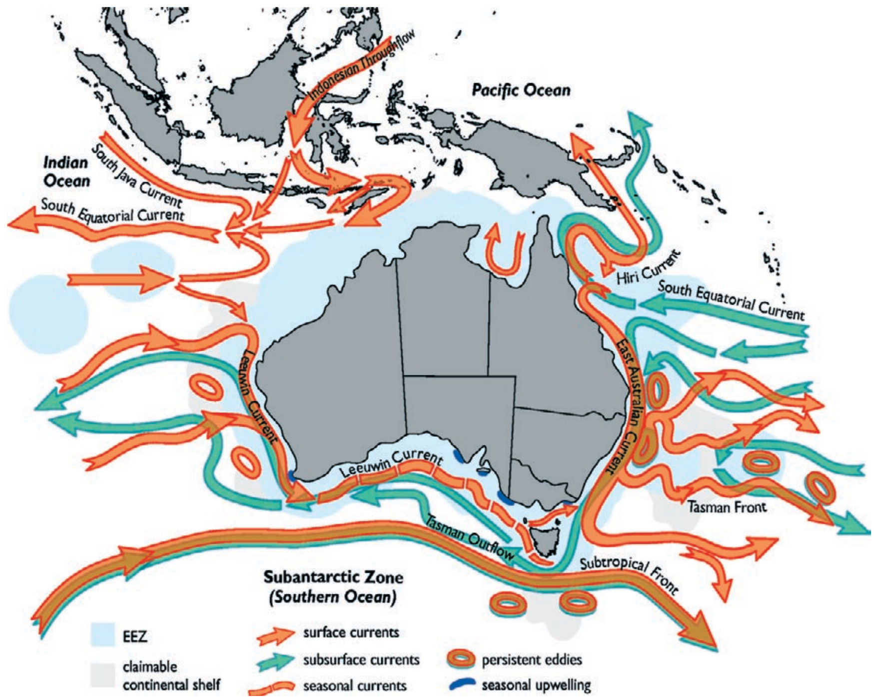

Fig. 1. The main ocean currents in the Australian region.

In addition to the oceanographic features, ocean–atmosphere interaction plays a significant role in modulating the regional weather and climate system. Tropical cyclones (TCs), for example, tend to form near Australia's northern coastline, which is close to the equator and within the region of primary TC development. Consequently, TCs pose a serious threat to Western and Northern Australian communities and industry. Often the most significant impacts from TCs are flooding, destructive winds, and storm surges, which can lead to loss of life (www.bom.gov.au/weather/cyclone/about/about-tropical-cyclones.shtml). Monitoring, understanding, and predicting ocean–atmosphere interactions such as TCs are integral parts of IMOS and BLUElink.

LINKING IMOS TO BLUELINK. As previously alluded to, IMOS is a distributed set of equipment, data, and information services covering the oceans around Australia. IMOS activities are split into bluewater (i.e., open ocean) and coastal components (Fig. 2). The former supports research into climate change and its impacts, while the latter focuses on regional aspects of the physical and biogeochemical environment and how it is changing. Among others, IMOS includes national facilities for Argo floats, ocean gliders, moorings, coastal radar networks, and ocean remote sensing. The infrastructure also contributes to Australia's role in international programs of ocean observing.

A range of IMOS-related oceanic observations is required by the BLUElink forecasting system to enable accurate estimation of the present and future physical state of the ocean. Continually measured ocean observations that are fed into the BLUElink system are sea level anomalies (SLA) from *Envisat* and *Jason-1* radar altimeters, sea surface temperature (SST) from the thermal imagery satellite AMSR-E, and in-situ observations of temperature and salinity from free-drifting Argo profiling floats and TAO moorings in the tropical Pacific. Immensely powerful computer networks synthesize and process these vast volumes of data to ensure the best possible representation of the ocean state as a basis for the forecasting system.

BLUElink, generalized as a functioning system, is an Australian national ocean modeling effort that focuses on phenomena of smaller scale and shorter duration than typical climate models. At the heart of the system is a global ocean model with a variable-

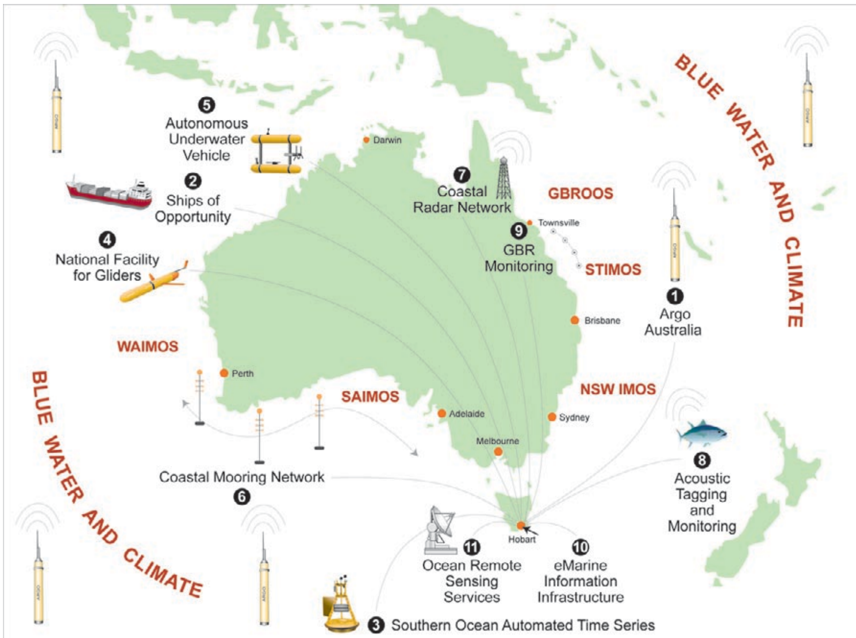

Fig. 2. Components of the Australian Integrated Marine Observing System (IMOS). Labels with numbers indicate various instrument platforms and infrastructure components. There are five science nodes (in red), one "Blue Water and Climate" node, and four regional nodes. These nodes are responsible for the process of identifying the scientific objectives of various components of IMOS.

resolution grid telescoping from 200 km in the Atlantic to 10 km around Australia. With a grid spacing of 10 km in the Australian region, this model is able to simulate prominent oceanographic features—such as the East Australian and Leeuwin Currents and associated eddy structures—far more realistically than coarser-resolution models.

The model is also data-assimilating to determine accurate initial conditions for forecasts. Observations are assimilated by Multivariate Ensemble Optimal Interpolation, a method that uses past runs of the model to learn how to use observations to intelligently correct many model variables, at many locations and depths. It is run like a weather-forecasting model—frequently compared with data and adjusted to minimize the errors.

The model is run in two modes: forecasting, out to a week ahead of time, and hindcasting (reanalyzing), from 1992 to the present. The two naturally serve different but related purposes. Both produce three-dimensional estimates of the ocean's physical state—its temperature, salinity, and velocity, from the surface to the sea floor, at 10-m vertical resolution for the top 200 m.

The major operational component of BLUElink is a global Ocean Model, Analysis, and Prediction System (OceanMAPS), which forms the backbone of the ocean forecasting system operated by the Bureau of Meteorology. Forecasts are issued operationally twice a week (Fig. 3). OceanMAPS results are communicated to user communities under the Bureau of Meteorology's Oceanographic Services program (www.bom.gov.au/oceanography/forecasts).

APPLICATIONS. With about 90% of the Australian population living within 50 km of the coast, there has been a significant financial investment in coastal infrastructure associated with economically critical mining, shipping, and oil and gas extraction. Oceanic conditions also influence wild fisheries and most aquaculture endeavors, and observations are leading researchers into new areas of study.

The data provided by IMOS and BLUElink on ocean conditions are important inputs for an ecosystem-based approach to fisheries management. Physical conditions in the ocean determine patterns of productivity, connections between regions, and the suitability of local conditions for various species. Together these patterns are used to predict the distribution and dynamics of fish species targeted by commercial and recreational fisheries. Predictions of catch rates for these species are an essential basis for understanding the economic, biological, and social impacts of fishing, and underpin informed management of these impacts for sustainability goals.

BLUElink's hindcast data provide a rich historical dataset against which past biological data can be evaluated. For instance, past tuna catches can be compared to ocean conditions to develop predictive models of habitat associations for these important commercial species. Conversely, biological models such as these can be used with forecasting data to predict future biological conditions in regions of interest. These types of predictions are used to manage tuna fisheries on Australia's east coast. Output from BLUElink is also being used to inform ecosystem models of Australia's EEZ; an example is the ecosystem model for southeast Australia, Atlantis SE, that looks at impacts of fishing on marine ecosystems starting in the early 1900s. The integration of physical and biological models has long been a goal in marine science. This goal is increasingly within reach, and scientists at CSIRO are in the early stages of exploring this integration and its usefulness for management of our ocean resources.

The IMOS Regional Nodes use sustained, integrated datasets for physical, chemical, and biological oceanography to investigate interactions between coastal ecosystems and changes in the major boundary currents. Australian universities contribute key facilities and provide science leadership to many of these regional nodes. Conversely, due to these strong links, the tertiary education sector is also a major beneficiary of IMOS. In addition to many university researchers playing leading roles in the design and implementation of IMOS observing platforms, there is a rapidly increasing number of students who pursue unprecedented research opportunities provided by IMOS data in multidisciplinary research applications. Even more exciting for many young researchers is their ability to simultaneously draw on IMOS observations and BLUElink model products, thereby enabling them to address complex multidisciplinary research applications using observations and simulations.

There are many research applications on short time scales, such as the impact of ocean frontal structures on fish larvae communities, determining responses of marine plankton communities to climate variability, and benthic habitat mapping using Autonomous Underwater Vehicles (AUVs). On longer time scales, flooding of Coral Sea waters onto the Great Barrier Reef associated with variations of the East Australia Current (EAC) is thought to be a factor in coral bleaching. Additionally, IMOS has shown that strengthening of the EAC during the twentieth century has shifted ecosystem boundaries southward. By using a combination of observations and simulations, scientists are trying to answer how well the EAC is simulated in climate change models and what models predict will happen in the twenty-first century.

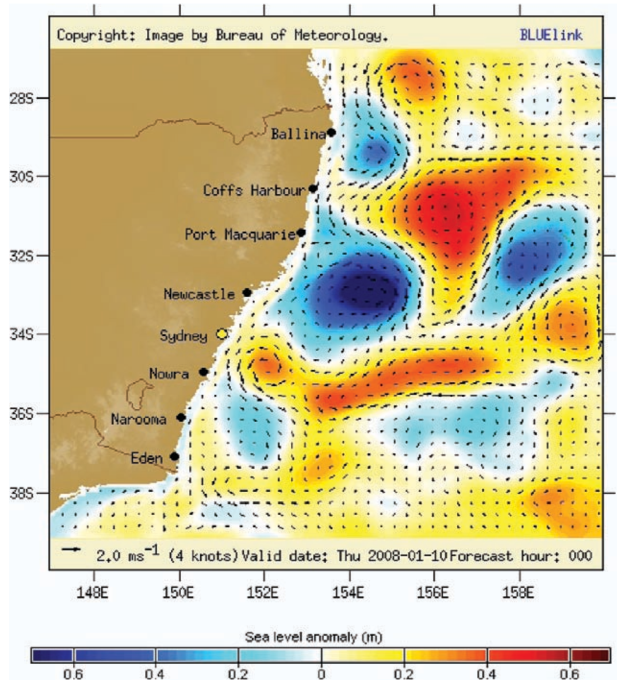

Fig. 3. Operational ocean forecast (sea level anomaly and surface currents) for the ocean near Sydney (www.bom.gov.au/oceanography/forecasts), from the Bureau of Meteorology's Web site.

FUTURE. It is envisaged that by 2012, IMOS will have implemented a comprehensive array of ocean observing platforms, using the latest advances in technology—including satellites and autonomous instruments in the ocean—to observe the physical and biological properties of the coastal and open oceans around Australia. Already, autonomous floats and gliders sample mesoscale ocean variability (resolution better than 100 km) and contribute to the sustained observing system for the region. Remotely sensed SLA, SST, and sea ice are complemented by satellite-based and in situ biogeochemical observing systems, and all data are made available to users in near-real time. Such advances will facilitate and enable research on, and answers to, many of the critical marine issues facing Australia, including climate change impacts and sustainability of its ecosystems.

Supported by tremendous increases in supercomputing power over the last decade, by 2012 the BLUElink project will have delivered an updated ocean forecasting system that provides even more accurate and detailed forecasts of the oceans around Australia with horizontal resolutions near Australia's coasts of about 1 km. The comprehensive forecasting system will include prediction of nearshore waves and an operational coupled ocean–atmosphere tropical cyclone prediction system, providing an enhanced early warning system to cyclone-prone regions in the northern and western parts of Australia. Combined physical and biogeochemical forecasting systems running in operational mode will resolve and predict plankton concentrations in individual ocean eddies.

The combination of IMOS and BLUElink is a "step change" in Australia's ability to enhance the knowledge of its oceans, to deliver economic benefits to its climate-sensitive industries, and to safeguard the environment. It is just what Australia needs to tame its ocean frontier.

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TECHNOLOGY

Lasers Look into Tropical Forest Changes

Researchers are taking to the air with lasers on the Big Island of Hawaii to examine changes in the tropical forest. The new technology being used by the U.S. Forest Service and Carnegie Institution is helping to examine changes from non-native plants and other environmental factors that affect carbon sequestration. The researchers published their findings in the January issue of *Ecosystems*.

The Carnegie Airborne Observatory used lasers that can measure elevation to within 6 inches. Combined with GPS and advanced imaging spectrometers that identify plant species from the air, the observatory collected data from an airplane that flew over the Mauna Kea Volcano and the Hawaii Tropical Forest. Flint Hughes, a Forest Service ecologist and one of the study's authors, compared their field measurements of tree diameter, canopy height, and wood density estimates with the data from the airborne observatory.

"These findings showed airborne data correlated with data derived from study plots on the ground," says Hughes. "They also demonstrated what might be the most important environmental factors affecting forest biomass and carbon sequestration." The researchers discovered that getting results from the aircraft was more efficient, given the difficulty of retrieving data in dense vegetation. Their findings also revealed how invasive plants, many of which grow much faster than the native species, could affect biomass levels in the context of carbon sequestration and climate change mitigation.

The study found that invading alien tree species can rapidly lower the carbon storage capacity of the rain forest. While continued growth of the forest's dominant trees can offset some of this loss, even the shape of the land needs to be factored in to biomass levels, with poorly drained terrain capable of maintaining just 75% of the biomass of well-drained forest terrain.

The researchers hope that this method of observation can aid in assessing the changes in other tropical forests. (Source: U.S. Forest Service)