The SimOcean initiative

Developing ocean modelling capacity in southern Africa
to support both reseach and operational activities

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1 Motivation

Following a recent workshop on the implementation of an operational oceanography system for southern Africa, held in Cape Town in July 2009, the inception of several national initiatives and international bilateral agreements, the urgent need for a southern African ocean modelling strategy has emerged.

In 2008 the Department of Science & Technology (DST) adopted a 10 year innovation plan: the Global Change Grand Challenge, which aims to implement measures to deal with global climate change. One of their key areas of research and development is to improve understanding of our changing planet. Through this initiative DST aims to include interventions to support the implementation of the research results and the identification of areas for accelerated technological development and innovation. Resulting initiatives such as the African Centre for Climate and Earth System Science (ACCESS), and regional project tenders such as the Benguela Current Commission (BCC) and the Agulhas-Somali Current Large Marine Ecosystem project (ASCLME) have furthermore identified the need to develop regional capacity in ocean modelling.

Considering the dynamic nature of the ocean surrounding southern Africa, its marine resources and proximity to one of the most energetic current systems in the world, the Agulhas Current, the need for operational oceanographic monitoring is well defined. The Agulhas Current exhibits intense mesoscale activity, including eddy shedding events at the Agulhas Retroflection, the interaction of eddies from the Mozambique Channel with the Agulhas Current core, and large meanders of the Agulhas Return Current (Lutjeharms, 2006). The unpredictability and intensity of the currents represent a direct threat to the industrial, commercial and leisure activities, for example, accidental pollutants, such as oil spills, which may advect onshore to the detriment of the coastal environment. In the years following the catastrophic Prestige wreck in Galicia, 10% to 15% of the ships at sea still do not conform with international safety regulations and represent a risk for further accidental pollutions. Furthermore, the Benguela Current system, which hosts one of the worlds most productive fisheries, is known to be sensitive to climate change and climate variability associated with, for example, the El Niño Southern Oscillation (ENSO). Understanding these dynamics and their role in ecosystem functioning, is an important part of resource management

Numerical modelling is an essential component of integrated ocean monitoring efforts, and is one of the most important tools helping oceanographers, marine biologists and coastal managers to cope with the complexity of space and time scales that drive variability in the regional and coastal environments. The development of meaningful early warning and forecast systems requires that the physical processes of the system are thoroughly understood. In this regard, numerical modelling techniques can be an invaluable tool and, for this reason, we propose the development of an ocean modelling working group for southern Africa (preliminarily called **SimOcean**).

Currently, the ocean modelling activity in southern Africa is sub-critical. Building capacity and local expertise in numerical ocean modelling and operational forecasting forms a key component of SimOcean. International bilateral agreements between South Africa and institutes in Norway, France, and Japan are in place, or are being negotiated and provide important links with the international community and potential for local training and development. Furthermore, successful international programmes such as the Global Ocean Observing System (GOOS), and the Global Ocean Data Assimilation Experiment (GODAE) provide frameworks for the international coordination of an efficient global ocean measurement network for better ocean observations and ocean forecasts. SimOcean would benefit greatly by aligning its activities with such initiatives.

While the full scope of the SimOcean will be to augment and develop numerical modelling capacity in southern Africa in general, both in research and operational capacities, the initial goal will be to set up an operational system that delivers regular and consistent nowcasts and forecasts of the state of the ocean, which is of key interest for the following purposes:

(i) Marine safety: to improve the predictability of extreme events, such as cut off lows and mesoscale convective systems; to monitor and predict the pathways and spreading of various tracers including toxic contaminants such as oil spills; to support search and rescue of people and goods lost at sea.

(ii) Marine and coastal environment: to provide rapid environmental assessment in order to monitor and mitigate against the effects of, for example, harmful algal bloom (HAB) and low oxygen water (LOW) events as well as large-scale, climate related changes on the oceans surrounding southern Africa.

(iii) Marine resources: to provide support information for the offshore oil and gas industries, fisheries management and ecosystem characterisation; to condition bio-geochemical modelling of ocean primary productivity.

Falling within the framework of the African Centre of Excellence as represented by the African Centre for Climate and Earth System Science (ACCESS), the SimOcean initiative is an effort to establish a southern African ocean modelling working group whose aim is to develop ocean modelling capacity to support operational activities and ocean research efforts. It is intended to be multi-institutional and it's operational activities will be closely coordinated with those of the Marine Remote Sensing Unit (MRSU) as well as in situ observational activities led by several organizations. As such, the group's activities are collaborative, cross-cutting and multi-disciplinary in their developmental, implementation and research efforts. In this document we describe a strategy plan for the initiation of SimOcean, which will commence with the development of an operational system.

2 Objectives

The concept of an ocean modelling working group arises from the need to generate a core of ocean modellers who, in addition to developing an operational ocean modelling and forecasting system for southern Africa, engage in ocean research activities, thereby providing a focal point where new students may learn about ocean modelling and research. In order to predict the effect of potential changes in the oceans and to interpret forecasts in a meaningful manner, it is essential that we have a thorough understanding of processes that drive the current state of the ocean. Research capacity will therefore develop in parallel and be of equal priority in the long term.

In order to ensure the sustainability of a dynamic ocean modelling working group for southern Africa, the primary driver of the SimOcean initiative is capacity building and is essential in the development and sustainability of an operational modelling system. Currently, the ocean modelling capacity in southern Africa is sub-critical. A logical first step would therefore be to establish a critical mass of ocean modellers with the skills to move forward with the implementation of an operational oceanography modelling system. This could be done by advertising positions to appropriately experienced international ocean modellers (e.g. with knowledge of ocean modelling and/or data assimilation). Inviting international scientists to collaborate in modelling activities would also be of tremendous benefit to the local community, as would attending international workshops and summer schools or visiting international laboratories. Advertising our successes by attending workshops and conferences, in both operational and research capacities, as well as publishing our findings in peer-reviewed journals, will promote South Africa as a center of excellence in modelling and ocean science. This will attract researchers who will help to strengthen our core of ocean modellers. In order to build local modelling capacity, which is fundamental to the

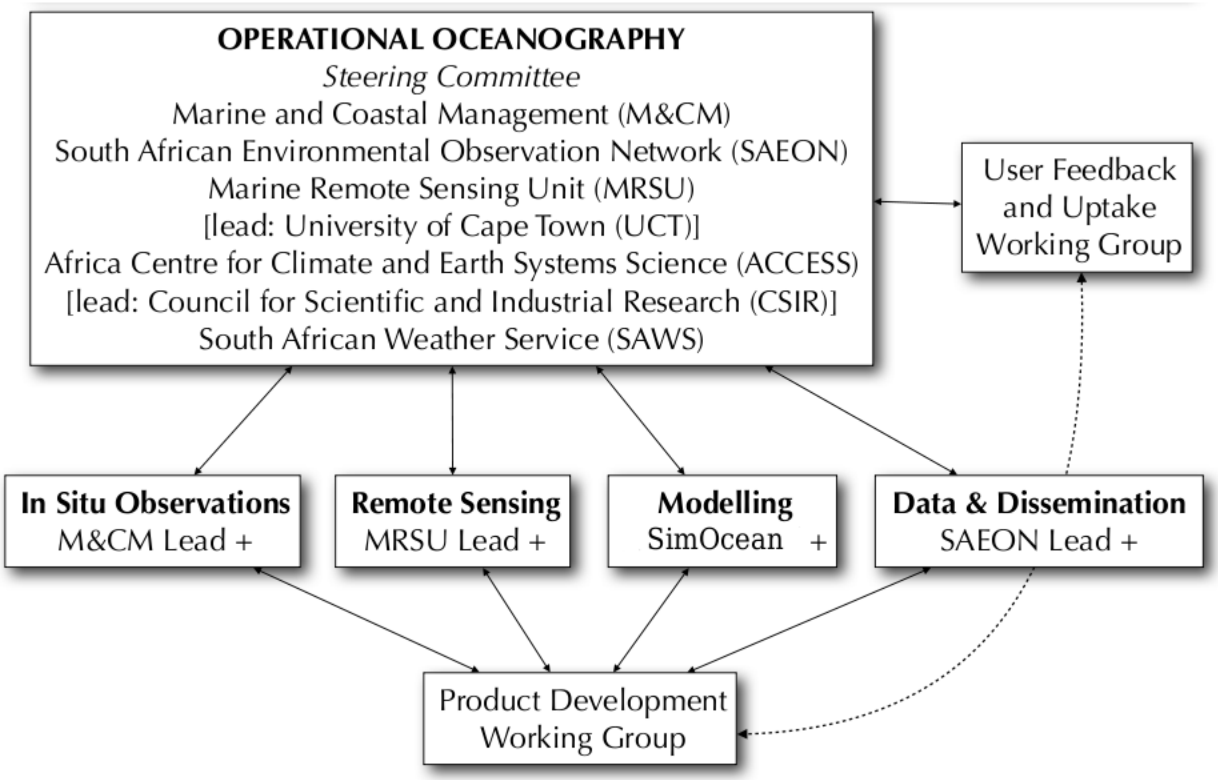


Figure 1: Schematic of the South African Operational Oceanography programme, the contributing institutes, and their respective roles.

sustainability of a southern African working group, workshops on Earth-system science and modelling would be run for high-school, under- and post-graduate audiences. Formal partnerships and collaborative agreements with international institutions would also help to build local modelling capacity.

In this section we give a thorough description of the implementation plan and specific objectives of the operational modelling initiative, which will be the first task of SimOcean. We also describe ways in which these operational modelling objectives have the potential to contribute to research activities, which form an equally important part of the SimOcean initiative. The development of both the research and operational components of SimOcean will require expertise that will facilitate capacity-building in ocean modelling techniques in southern Africa.

2.1 Operational modelling

Overview

The first task of SimOcean will be to develop the modelling component of the operational oceanography programme for South Africa as mapped out in the OceanSAfrica meeting in July 2009 (see the schematic: Figure 1). The OceanSAfrica vision:

> *Through a combination of modelling and observations we will deliver regular and systematic information on the state of the ocean that is of known quality and accuracy on open ocean to shelf-scales.*

In the context of operational oceanography in South African (OceanSAfrica), the objective of SimOcean is to develop an ocean forecasting system that provides regular estimates of the ocean state and its evolution into the future which are better than climatology and more accurate than persistence forecasts. In order to achieve this vision, the modelling group will work closely with the three other tiers of the proposed operational oceanography working group (i.e. remote sensing, in-situ data and dissemination). A key factor in the success and longevity of an ocean modelling working group and operational activities in southern Africa is to make the most of all available resources including national and international connections. A collaborative effort should therefore be employed, not only between institutions such as MCM (Marine and Coastal Management), SAWS (South African Weather Service), SAEON (South African Environmental Observation Network), CSIR (Council for Scientific and Industrial Research), UCT (University of Cape Town), and the CHPC (Centre for High Performance Computing), but also between the various research fields of, amongst many, oceanography, meteorology, marine biology, geology and biogeochemistry. Furthermore, a strong collaboration with observational activities within these spheres, such as in-situ monitoring and remote sensing, play a key role in strengthening the forecasting capabilities and their reliability. A good observational network is not only necessary to validate the forecasting system, additionally these observations may be assimilated into the ocean model in order to obtain a more accurate estimate of the state of the ocean, which is essential for improving the skill of the forecast.

Communication with users should be maintained throughout the planning, implementation, pre-operational and operational phases. Their feedback on the usefulness of the disseminated products is essential for validating the system and ensuring the sustainability of the system. Potential users include offshore industries (shipping, fisheries, oil and gas), the navy, marine biologists, ecosystem modellers, marine resource managers, marine leisure activities (sailing, surfing, diving etc.). A reliable and robust now- and forecast system will also provide the benchmark from which to develop the means to produce medium-range (monthly and seasonal) and long-range predictions (climate variability), which will be useful for managers in mitigating against the effects of potential climate change scenarios.

Potential for local and international affiliations

The operational activities of SimOcean will complement, or be complemented by current and planned research and operational programmes of several local and international organizations. As such, the group's activities are collaborative in their developmental, implementation and research efforts. For example, the short- and medium range ensemble atmospheric forecasts generated by SAWS could be used to force ocean forecasts in the operational SimOcean initiative. Research tenders recently advertised by the BCC also fall in line with the SimOcean vision and call for the use of ocean modelling, both within the context of research activities as well as more operational projects within the BCLME (Benguela Current Large Marine Ecosystem) that focus on the implementation of an early warning system for events such as Benguela Nios, harmful algal blooms, low oxygen water and hypoxia, that are known to have critical impacts on ecosystem functioning. Similarly, the SimOcean initiative could play a key role in the objective of the ASCLME to ensure long-term sustainability of the living resources by providing modelling support to their goal of developing an ecosystem approach to management. Furthermore, the operational component of SimOcean will provide real-time information on the state of the ocean to the South African Navy in support of their recently established Rapid Environmental Assessment (REA) program that aims to collect and analyse data operationally for the benefit of maritime operators. In other international operational oceanography programmes, the navy is classified as a supporting user and plays a major role in the development and maintenance of the operational system. As such their input from an early stage of the development process is essential.

An international collaboration between the Marine Research Institute (MA-RE) at UCT and the Nansen Environmental and Remote Sensing Center (NERSC) based in Bergen, Norway, has been formalised in the form of the establishment of the Nansen-Tutu Centre for Marine Environmental Research hosted at UCT. Its mandate is to support and improve marine research and knowledge-based ecosystem assessment, prediction and management around southern Africa. The operational oceanography, modelling and data assimilation expertise available at NERSC through this collaboration will be of particular importance for capacity building in southern Africa. Furthermore, NERSC is strongly involved in the MyOcean project, which is a pan-European programme with the objective of providing a capability for ocean monitoring and forecasting. Given that the goal of SimOcean is to set up a similar system in southern Africa, a strong collaboration with the MyOcean project would be beneficial. Finally, the SimOcean initiative has been designed such that its objectives are aligned with the scope of the following international operational oceanography programmes: the Global Ocean Observing System (GOOS and, in particular, GOOS-Africa) and Global Ocean Data Assimilation Experiment (GODAE). Aligning our activities with these programmes could encourage a co-ordinated approach to operational efforts.

Implementation plan

The implementation plan of the modelling component of the operational oceanography initiative is separated into two phases (refer to schematic: Figure 2):

Phase I Implementation

Phase II Operational, system development and research

The project is arranged into work packages that are designed to facilitate the implementation and development of the ocean modelling and forecasting system (see Appendix). Each work package falls within the scope of a Post-doc or a PhD project, and in Phase II there is scope to develop work packages for MSc or Honours projects. The two phases are summarised below, and the proposed timeline for the two phases and respective work packages is given in Figure 4.

Phase I will focus on implementing, validating and disseminating data from an ocean forecast system. The aim is to provide unassimilated $5-7$ day forecasts that are available for a wide variety of users by the end of Phase I. In setting up a regional ocean modelling system for southern Africa we will adopt a downscaling strategy, introducing a series of nested grids downscaling from the global model to a regional high resolution model, which will then provide boundary conditions for a very high resolution limited areas model. However, the present computing hardware capacity in southern Africa is not enough to run a global model operationally. Therefore the boundary conditions for the regional model will obtained by collaborating closely with international institutes that produce global operational products.

In WP-1 the global operational ocean forecast models used by MyOcean and the HYCOM Consortium will be thoroughly evaluated and their viability for use as the lateral boundary conditions of the regional system will be assessed. Using the output from global operational systems to force the boundaries of southern African regional domains will forge and maintain useful international collaborations. The regional and limited area models will be implemented using the Regional Ocean Modelling System (ROMS; Shchepetkin and McWilliams, 2005).

The objective of WP-2 will be to nest regional southern Africa model (SAM), with a horizontal resolution of $^1/_{12}{}^\circ$ (~ 9 km) within the global grid (see black line in Figure 3). The model grid will be based on the SAfE configuration (Southern Africa Experiment;Penven et al., 2006), and its geographical boundaries will mimic those of the regional

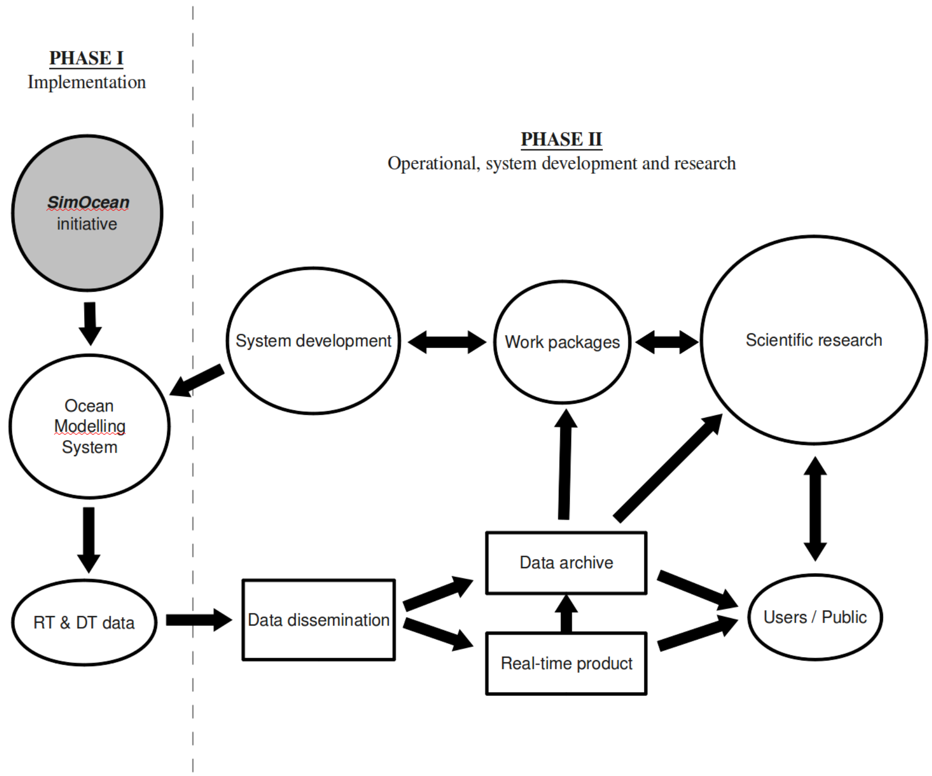


Figure 2: Schematic of the ocean modelling system, its products and inputs.

Agulhas model based on the NEMO code (Madec, 2006), developed by the DRAKKAR collaboration (e.g. Biastoch et al., 2008). A long-term hindcast simulation will be run in order to verify that ROMS is capable of reproducing all of the salient oceanographic features surrounding southern Africa. This validated hindcast simulation will provide valuable data for various studies, especially those with the aim of understanding oceanic variability around southern Africa.

In WP-3, a pilot study will introduce an additional nest within the SAM that spans the Benguela upwelling region (Figure 3, dashed white line) and resolves salient features there at a resolution of $1/36°$ ($\sim$ 3 km). Although the pilot study will focus on the west coast, its implementation will be generic and therefore applicable to any other region of interest. A validation procedure will be designed for hindcast, nowcast as well as forecast products in order to ensure that data of a known quality is supplied to users. In order to develop a robust validation system, it is essential that cooperative activities with the remote sensing and in situ observation pillars of the OceanSAfrica programme, as well as interaction with potential users, commence as soon as possible.

An important aspect of developing operational modelling activities, is the routine and consistent dissemination of the forecast products. The objectives of WP-4 are to develop the reliable dissemination of $5-7$ day forecast products (via a website) that have been subject to a systematic and rigorous validation procedure in order to fulfill the vision that the data provided are of *known quality.* This will ensure visibility of the initiative, and hopefully attract users, developers and students to the project. Good communication with users, and incorporation of their feedback, is an essential component of developing useful ocean monitoring and forecast products. This will be addressed through outreach programmes such as user forums and workshops.Work Packages 5 to 7 are focussed on high resolution forecasts in coastal embayments and nearshore environments.

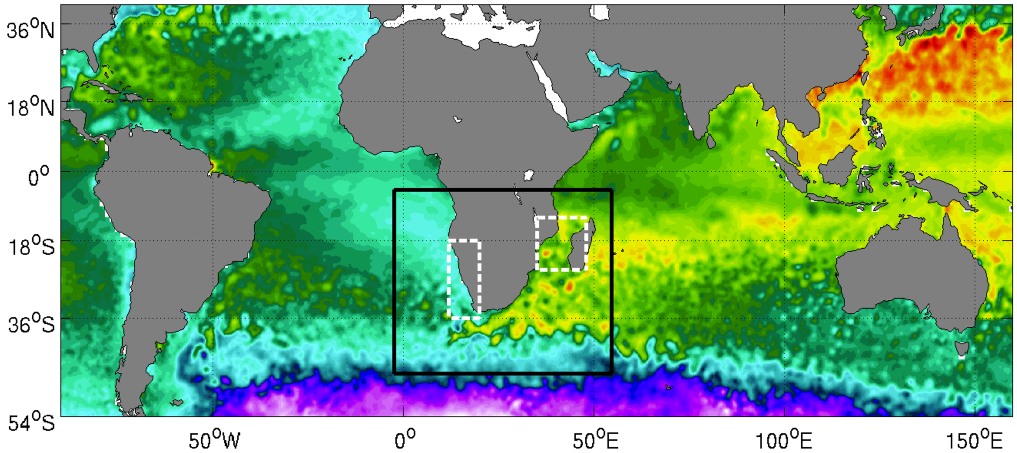


Figure 3: An example of the downscaling strategy, using the Global Mercator $1/4°$ forecast product as the parent domain. The black rectangle represents the regional domain and the white dashed rectangles are examples of domains of potential limited area models.

In Work Package 5 it is intended to implement high resolution forecast models on a coastal embayment scale, based on existing well-validated DELFT3D model set-ups at two pilot sites. The focus in Phase I is on developing appropriate assimilation infrastructure for forcing data streams (largely provided by the existing operation WAVENET and IPOSS systems) and appropriate forecast cycles and dissemination of model forecasts. In Phase II it is anticipated that the requisite open boundary conditions and high resolution atmospheric model results will be available within which to nest these high resolution models. This will remove existing limitations on model accuracy. It is anticipated that progress will be made through both Phase I and II in validating the ROMS systems at these higher resolution coastal embayments scales.

In Work Package 6 the focus is on implementing wave forecast models that will support forecasts in coastal embayment and higher spatial resolutions, i.e. the localised scales important to most users. Presently only certain wave parameters on a relatively coarse grid and for limited parameters are available from the NCEP operational model. The intention is to implement a large-scale regional operational WAVEWATCH model that provides the required wave parameters at appropriate resolutions to support wave forecasting in coastal and nearshore systems (see the WAVENET system).

Implementation of a biogeochemical modelling system at a coastal embayment scale is planned in Work Package 7. Potential implementation sites are St Helena Bay, Saldanha Bay and Algoa Bay. Initial model implementations will be developed during Phase I, however given the reliance of biogeochemical models on accurate hydrodynamic simulations at appropriate scales, it is likely that the dissemination of biogeochemical model will only occur during Phase II.

In **Phase II**, the ocean forecast system, and its products, will be improved and expanded upon. The $5-7$ day forecasts will continue to be made available, and in parallel, emphasis during Phase II is placed on system development and research. Enhancements of the forecast system include the implementation of data assimilation techniques, coupling of the ocean current models to atmospheric and ocean wave models, inclusion of additional high resolution nested models of, for example, the Mozambique Channel and the South African East Coast. These additional research and development tasks will be structured into work packages and undertaken as MSc, PhD or Post-doc projects and upon completion, implemented in the operational system. In this manner local capacity in ocean modelling as well as operational implementation is developed, and concurrently the ocean forecast system is

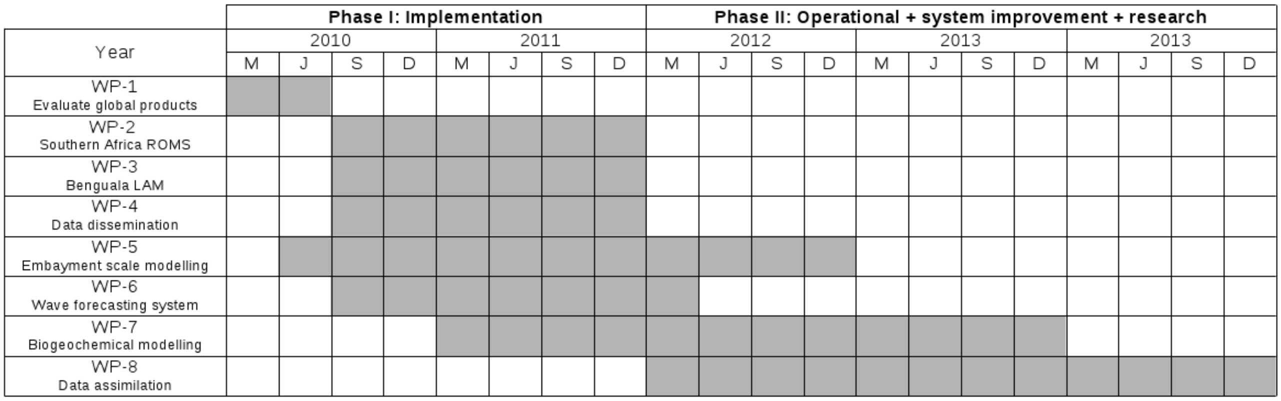


Figure 4: Timeline for the SimOcean project phases and work packages.

continuously improved and kept up to date with cutting edge developments. In addition to enhancing the system an extensive data archive will be developed, including reanalysis data and the generation of long time series data from the model output. Following the successful implementation and enhancement of the ocean forecast system, to become fully operational and sustainable, it will need to be hosted by an operational institute such as MCM, SAWS, or the Navy. Redundancy of the computer system is a major component of an operational ocean forecasting system and is done by duplicating the system, running it in parallel and archiving the data on an backup high performance computer.

Technical and people requirements

Implementing Phases I and II has considerable technical requirements, in which the Centre for High Performance Computing (CHPC) will play a major role. In order for the ocean modelling system to become fully operational requires: (i) dedicated prioritized computing time on the CHPC supercomputing facilities to provide operational nowcasts and forecasts on a weekly basis; (ii) dedicated web-server for hosting nowcasts and forecasts; (iii) large amounts of bandwidth for downloading forcing data, and uploading data products; (iv) data storage capacity for the model output archive (at least 10Tb for the model initialization phase) and (v) a mirrored system in order to ensure redundancy (should the primary system fail). The archiving of continuous data generation will require additional storage capacity.

The full scope of the ocean modelling working group will require a significant number of people, both in research as well as in the more technical arena. This will encourage local capacity building and international exchanges of expertise. As the first task of the ocean modelling working group, the number of people required to set up the operational oceanography modelling system will increase as the initiative develops. The development of the operational component of SimOcean is described in a number of specific work packages, as described in the next section, each of which identifies the number of people required.

2.2 Research activities

Although a strong emphasis in this strategy document is placed on the implementation of an operational ocean modelling system for southern Africa, intrinsic to the developmental process is the scope for research activities. For example, the archived data from the operational system as well as hindcast simulations could prove instrumental in contributing toward building an extensive oceanographic data-base that could support several research projects including the characterisation and study of climate variability (change) in southern Africa. Alternatively, specific problems or features identified in the ocean forecast system can be addressed in separate model simulations that require a more idealized and process-based model experiments. The expertise that will develop from, and be attracted by, the operational modelling initiative will naturally increase local modelling capacity. This, together with several model-based research positions and tenders, will promote South Africa as a center of excellence in ocean modelling.

Research activities within SimOcean should be collaborative and inclusive in their approach in order to most efficiently make use of all resources. For instance, the ocean and atmosphere are coupled systems and therefore modellers of either of these systems would benefit significantly from close interaction with the other. Furthermore, the output from ocean models can be used to feed, for example, biogeochemical, sediment, ecosystem and wave models. While the work packages described in the appendix focus on the implementation of the operational system, a parallel set of work packages could be developed for the research component of SimOcean. These packages could describe projects that are distinct (in terms of objectives, funding and deliverables) but that require, or would benefit from, input from other packages.

3 Concluding summary

This document has stressed the urgent need to generate a core of ocean modelling expertise (preliminarily referred to as the SimOcean initiative) and has outlined a potential way forward for developing modelling capacity in ocean science in southern Africa. SimOcean will launch it's activities by forming the modelling pillar of the implementation of an operational oceanography system for southern Africa. However, the development of its research component will be of equal importance. The primary goal of SimOcean is to generate capacity in southern Africa and to facilitate its role as a center of excellence in modelling and ocean sciences. To meet this goal, it is essential that SimOcean take a collaborative and inclusive approach in order to make best use of all available expertise and resources.

Appendix: Work package descriptions

To fulfill the objectives outlined in Phases I and II, the project is divided into work packages aimed toward establishing an operational ocean forecast system for southern Africa (Figure 2). The details are provided below.

Phase I Implementation activities

- WP-1 Assessing global ocean forecast products for the southern African region
- WP-2 Implement regional southern Africa model
- WP-3 Implement pilot limited areas model of the Benguela Current region
- WP-4 Data dissemination and product development
- WP-5 Pilot coastal embayment scale and higher resolution operational forecasts
- WP-6 Regional and localised wave forecasting system
- WP-7 Biogeochemical modelling at coastal embayment and near shore scales

Phase II Operational, system development and research activities

- WP-8 Data assimilation

Other potential work packages:

- Limited areas models of other southern African regions
- Ocean-atmosphere coupling
- Reanalyses, establishing long time series

Work package number	1	**Start date or starting event**	Project kick-off
Number of participants	2 (Post-doc)	**Work package duration**	6 months
Work package title	Assessing global ocean forecast products for the southern African region		
Activity type	Implementation		

Objectives

The objective is to assess global forecast products such as those produced by MyOcean and the HYCOM Consortium for use as lateral boundary conditions for the regional southern African model. This includes:

1. Validating the global model output against available satellite remote sensing and in-situ observations.
2. Assessing the cyber infra-structure and determining the amount of data transfer required.

Description of work

Task 1.1. The archived model output from the operational forecast products produced by MyOcean and the HYCOM Consortium will be validated against available satellite remote sensing and in-situ observations for the greater Agulhas and Benguela Current regions. In particular the extent to which each model captures salient features of the oceans around southern Africa will be investigated and compared. These include the Angola-Benguela Frontal Zone (ABFZ), the Lüderitz upwelling cell-Orange river cone area (LUCORC), the Benguela upwelling system as well as the Agulhas Current, its retroflection and associated mesoscale features, such as Mozambique Channel eddies and Natal Pulses. The success of each at capturing event-scale and extreme fluctuations of salient oceanographic features will be assessed, such as the timing and intensity of Benguela Niño events, and interannual fluctuations of the Agulhas retroflection.

Task 1.2. The reliability and timeous availability of the lateral boundary conditions from the forecast products will be investigated. Large amounts of data will have to be transferred from MyOcean or the HYCOM Consortium to the CHPC on a weekly to twice-weekly basis. This will put significant strain on the cyber infra-structure, and South Africa in general is limited by low band-width.

Methods for reliable and timeous transfer of the required data need to be tested. The various options for doing this include accessing the data via OPeNDAP enabled clients (e.g. Ferret, NCO, Matlab, etc.) through which data can be quickly and efficiently loaded into your application. Alternatively data may be streamed directly from the servers to the CHPC via OPeNDAP without downloading individual data files. A more data streaming intensive method is using either HTTP Access or FTP Access Direct to access individual data files archived on the the servers.

Input

MERCATOR is the $1/4°$ $(6-26$ km) global forecast product based on the OPA ORCALIMO25 ocean circulation model and made available through the MyOcean project (`www.myocean.eu.org`). It is run weekly and produces a 14 day forecast as well as a 14 day assimilated hindcast. The surface forcing is the 6-hourly ECMWF (European Center for Medium Range Weather Forecasting) output. A bulk formulation uses cloud coverage, surface humidity, air temperature at 2 m and wind at 10 m obtained from ECMWF to calculate fluxes. Archived data for this operational system is available from October 2005.

From October 2005 to October 2008, the only data assimilated into the product were alongtrack sea level anomalies obtained from GFO, Envisat and Jason-1. This was done by optimal interpolation. SST and temperature and salinity in-situ profiles were included to the assimilation system in April 2008, using the Kalman-Seek method.

MERCATOR Ocean disseminates their weekly forecasts on standard grids in NetCDF format and is available on two servers: the Thredds (Thematic Realtime Environmental Distributed Data Services) / OPeNDAP server contains realtime data that is less than one year old and an archive server contains data older than this. Products such as Ferret, Matlab and NCO can be used to stream the forecast data directly from the Thredds / OPeNDAP server, alternatively data can be visualized and downloaded from a LAS. The archived data can be obtained on CD-ROM, direct downloading via the internet or by server storage (which requires a user account).

The HYCOM consortium runs a $1/12°$ Global HYCOM Nowcast / Forecast System including data assimilation which is run daily at the NAVO HPC and generates a 5 day hindcast and a 5 day forecast (`www.hycom.org`). Surface forcing is from Navy Operational Global Atmospheric Prediction System (NOGAPS) and includes wind stress, wind speed, heat flux (using bulk formula), precipitation.

The Navy Coupled Ocean Data Assimilation (NCODA) system (Cummings, 2005) is used for data assimilation. NCODA uses the model forecast as a first guess in a multi-variate Optimal Interpolation (MVOI) scheme and assimilates available satellite altimeter observations (alongtrack obtained via the NAVOCEANO Altimeter Data Fusion Center) satellite and in-situ Sea Surface Temperature (SST) as well as available in-situ vertical temperature and salinity profiles from XBTs, ARGO floats and moored buoys. MODAS synthetics are used for downward projection of surface information (Fox et al., 2002).

The data are made available typically within two days of the model run via servers located at the Center For Ocean-Atmospheric Prediction Studies (COAPS), Florida State University. The HYCOM format archive files are converted to CF 1.0 compliant NetCDF files using standard HYCOM post-processing package. These files contain diagnostic output at standard Levitus depth levels for several variables including: currents, temperature and salinity.

The data is accessible via OPeNDAP enabled clients (e.g., Ferret, NCO, Matlab, etc.) through which data can by quickly and efficiently loaded into your application. Data is streamed directly from the servers to the client via OPeNDAP without downloading individual data files. Alternatively HTTP Access or FTP Access Direct access to individual data files is also available using any web browser or FTP client. Live Access Server (LAS, *experimental phase*) LAS can be used for quick online visualization and downloads of data in several formats.

Deliverable / Output

D1.1. Report on HYCOM and MERCATOR model intercomparison for the greater Agulhas and Benguela regions, advising on the most suitable model to use for boundary conditions.

D1.2. Report on the required cyber infra-structure and the most suitable method for transferring the lateral boundary data to the CHPC.

Work package number	2	Start date or starting event	3^{rd} quarter, year 1
Number of participants	1 (Post-doc)	**Work package duration**	$1^1/_2$ years
Work package title	Implement a regional model of southern Africa		
Activity type	Implementation		

Objectives

The objective of this work package is to set up a regional model of the greater Agulhas and Benguela Current system at $^1/_{12}°$ (9 km) horizontal resolution. This model will provide the first downscaling from the global model, and it will also provide the lateral boundary conditions to the limited areas model (WP-3). The Regional Ocean Modelling System (ROMS) will be implemented and a long term interannual simulation experiment up to present will be run for the initial validation and implementation of the system.

Description of work

Task 2.1. The implementation of a regional model of southern Africa serves as the first downscaling toward the high resolution limited area models and will form an integral part of the operational forecasting system. As a first step ROMS will be implemented as the regional model at a horizontal grid resolution of $^1/_{12}°$, but there is scope to include other models, such as HYCOM. The regional model will be based on the SAfE (Southern African Experiment) configuration (Penven et al., 2006), which was designed to capture the salient oceanographic features around southern Africa, and the geographical extent will mimic that of the regional model of the Agulhas developed under the DRAKKAR project (e.g. Biastoch et al., 2009), which encompasses the region spanning 20°W−70°E and 47° − 7°S. This will allow for potential inter-model comparisons and collaboration.

Task 2.2. For the model spin up, an interannual hindcast simulation experiment, up to present, will be run. Depending on the extent of the historical data archive of the chosen boundary conditions (see WP−1), the hindcast period ideally should begin as far back in time as possible. Allowing for the generation of a consistent long term data base will allow for extensive model validation at mesoscale, seasonal, interannual and decadal time-scales. Such a data archive will also form an important part of fascilitating the research component of the group.

Task 2.3. Model validation is very important aspect of running ocean model simulations. The model output will be compared to available in-situ and remote sensing data in order to determine the accuracy of the model simulation. To do so objectively, statistical metrics of the model fields compared to independent observations will be calculated, the use of summary figures are also a useful tool for evaluating model output (e.g. Taylor, 2001).

Input

Ocean General Circulation Models Generally, primitive equation ocean models utilise geopotential (z- or height) coordinates as the basis for simulating ocean currents. In some applications, however, it may be advantageous to apply suitable transformations to the vertical coordinate of the ocean model grid. Alternatives include terrain-following (σ) and density (isopycnal, ρ) coordinate systems, such as those utilised in ROMS and HYCOM. In South Africa, both ROMS and HYCOM have been used successfully in the research arena, and although presently the focus here will be to implement ROMS, there is scope to include different models in the operational system at a later stage.

The motivation for using ROMS initially is based on the fact that ROMS has been designed for high resolution process studies of the shelf regions. It has very good numerics and has been shown to accurately simulate the Agulhas Current over long time periods (e.g. Rouault et al., 2009). ROMS has good nesting capabilities, including a two-way nesting scheme (Debreu and Blayo, 2008). which has been shown yield beneficial results in simulating the Benguela, which is often affected by very intense Agulhas Rings, that become trapped in the domain when using the standrad 1-way nesting approach (pers. comm. Dr Jennifer Veitch). A major advantage of ROMS is that it is easily adapted to custom boundary conditions and alternative wind forcing products. This is an important aspect to consider especially since the lateral boundary conditions will come from another model, with a different vertical grid configuration. Furthermore, the use of alternative wind forcing products will facilitate collaboration with the South African Weather Service and the CSIR Natural Resources and Environment (CSIR NRE) Atmospheric Modelling group, who run regional atmospheric models.

Forcing A choice of datasets summarised below will be required in an operational system for the spin-up and they would also be very useful for research purposes that focus on climate issues.

- *NCEP / NCAR Reanalysis 1*

  6−hourly, 1° atmospheric reanalysis data is freely available from `http://www.esrl.noaa.gov/psd/data/gridded/data.ncep.reanalysis.html` in NetCDF format, spanning 1948−present. This project uses an analysis and forecast system to perform data assimilation using all available data from 1948.

- *ERA40*

  ERA40 is a reanalysis product of atmospheric variables spanning September 1957 to August 2002 and makes use of all available in-situ and satellite measurements (see `http://www.ecmwf.int/research/era/do/get/era-40`). The horizontal resolution is ∼ 125 km and the temporal resolution is 6 hours. The data is available for research purposes on the ECMWF MARS database at the cost of a minimal handling charge (`http://www.ecmwf.int/products/data/software/mars.html`).

- *ECMWF (European Center for Medium Range Weather Forecasts)*

  ECMWF produces 6 hourly, global analyses and 10−day forecasts on a 1/4° grid that are daily updated.

- *GFS (Global Forecast System)*

  The GFS model is used by NCEP for their operational forecasting mission for global prediction. Output is supplied at a horizontal resolution of 1/2°, equally-spaced in longitude / latitude and a temporal resolution of 6 hours. The forecast interval spans 3 hours to 180 hours (7.5 days). More information of the model can be found at `http://wwwt.emc.ncep.noaa.gov/gmb/moorthi/gam.html`. The output (or a particular subset of interest) can be freely obtained via OPeNDAP from the NOAA NOMADS database (`http://nomads.ncep.noaa.gov/`).

Deliverable / Output

D2.1. Report on the set up and implementation of a regional ocean model of southern Africa.

D2.2. Data report of long term interannual spin up simulation.

D2.3. Model validation report: assessment of the representation of the dynamics, and variability at mesoscale to seasonal, interannual and decadal time scales.

Work package number	3	Start date or starting event	3^{rd} quarter, year 1
Number of participants	1 (Post-doc)	**Work package duration**	$1^1/_2$ years
Work package title	Limited areas model of the Benguela Current region - pilot operational experiment		
Activity type	Implementation		

Objectives

The objective of this pilot project is to set up a high resolution limited areas model (LAM) of the Benguela Current region, run an interannual hindcast simulation experiment up to present, validate the models fields, and prepare the model for running in operational forecast mode. This model will receive its lateral boundary conditions from the regional model of southern Africa (WP-2), and therefore the participants of WP-2 and WP-3 will work closely together in setting up and implementing the system.

Description of work

Task 3.1. A pilot limited areas model (LAM) of the Benguela Current region, with a horizontal grid resolution of $^1/_{36}°$ will be nested within the regional model of southern Africa (WP-2). This model, also based on ROMS, will provide the next downscaling from the regional model, and will have a horizontal resolution $^1/_3$ of the regional model. It is proposed that the limited areas model should encompass the Agulhas Bank, and the St. Helena Bay area within the Benguela upwelling region.

The Benguela is a key area for fisheries and is therefore regularly monitored. It is also a region that is subject to the seasonal occurance of harmful algal blooms, providing a good testing ground for a pilot operational experiment.

The aim is make the nesting approach and grid generation for the LAM as generic as possible so that it is easily ported to another region of interest within the regional model.

Task 3.2. For the model spin up, an interannual hindcast simulation experiment, up to present, will be run. The interannual run will be for the same period as the regional model (WP-2), which will provide the boundary conditions.

Task 3.3. The interannual model run will be validated against available satellite remote sensing and in-situ measurements. Statistical metrics of the model fields, as well as summary figures (e.g. Taylor, 2001) compared to independent observations will be calculated.

Input

Benguela Limited Areas Model The limited areas model of Benguela, will be based on the ROMS configuration implemented in Veitch et al. (2009), and nested in the regional model of southern Africa (WP-2). It will use the same forcing fields as the parent model.

Two-way nesting approach A major advantage of the two-way nesting approach (Debreu and Blayo, 2008) is that the feedback of the child grid to the parent grid enables more accurate outflow of features from the child to parent than in a 1-way nested approach. This is particularly beneficial when modelling the Benguela system due to the throughfare of large ($\sim 200 - 300$ km diameter) Agulhas Rings in the Cape Basin region. These may become trapped in the domain when using the standrad 1-way nesting approach (pers. comm. Dr Jennifer Veitch).

Deliverable / Output

D3.1. Report on the set up and implementation of the limited areas model.

D3.2. Data report of long term interannual spin up simulation.

D3.3. Model validation report: assessment of the representation of the dynamics, and variability at mesoscale to seasonal, interannual and decadal time scales.

Work package number	4	Start date or starting event	3^{rd} quarter, year 1
Number of participants	1 (Technician)	**Work package duration**	1½ years
Work package title	Data dissemination and product development		
Activity type	Implementation		

Objectives

The objective of this work package is to develop reliable and regular dissemination of data products via the internet, which includes:

1. Disseminating the $5-7$ day forecast products of the regional and limited area models.
2. Automating the system from the data streaming of the boundary and forcing conditions to the dissemination of the forecast product.
3. Archiving selected hindcast data, the nowcast and forecast products.
4. Develop online data extraction and interactive data plotting tools for users.

Description of work

Task 4.1. Develop a dedicated website to disseminate the real time nowcast and forecast data from both the regional and limited area models. The website should be integrated with the remote sensing and in-situ data products made available from the Marine Remote Sensing Unit (MRSU), and the in-situ tear of the operational oceanography programme.

The data products from the modelling and forecasting system include nowcasts and $5-7$ day forcasts of sea surface height, the 3-dimensional temperatures, salinities, and current fields.

A vital component for the development of the operational system is the interaction with potential users, and for this purpose the website will include an online blog, where registered users may comment on the data products will be included.

Task 4.2. Automate the data streaming of the boundary and forcing conditions, the running of the model on a weekly basis, the dissemination of the nowcast and forecast producs via the website, and the archiving of the hindcast data as well as the nowcast and forecast products.

Task 4.3. Develop online data access services, where users may select a time period and geographical subset of the model data to download for research purposes (non-commercial applications).

Input

Data access service enables users to access scientific data, such as those produced by ocean models, via the internet. This may be achieved using open source software such as OPeNDAP (`http://opendap.org/download/`

hyrax.html), and the THREDDS Data Service (www.unidata.ucar.edu/projects/THREDDS/), which have been adopted in GODAE.

OPeNDAP is an open source software that provides a data access protocol (DAP) to access data over the internet, enabling subsetting (and other) capabilities for the data at the server. The THREDDS server is the framework / portal that contains the data and the OPeNDAP service. The OPeNDAP protocol supports data request constraints, such as temporal and spatial subsetting, specific variable field returns and multiple fields per request, multiple data format return types, and metadata information in XML and DAS formats.

The THREDDS data server supports data services, such as DAP, NetCDF subset, direct access (via HTTP), and cataloging, as well as many data formats, including amongst many NetCDF3-4, HDF5, and GRIB-1 / 2. It can also read data from other DAP servers, and can serve virtual data sets and data aggregation.

OPeNDAP can be accessed using web-browsers and is compatible with many graphical, command-line and custom clients, including Ferret, GrADS, Matlab, IDL, Python, NCO and FORTRAN.

Data format is an important aspect to consider in making data available to users. The data format should be machine independent, i.e. portable, it should be efficient, appendable and easy to use. NetCDF (network Common Data Form; www.unidata.ucar.edu/software/netcdf/) is a set of software libraries that satisfies these criteria, and is commonly used to create, access, and share array-oriented scientific data. NetCDF is also easily integrated into the OPeNDAP and THREDDS service. When writing NetCDF files for users, it is strongly recommended that these comply with the NetCDF Climate and Forecast (CF) Metadata Convention (http://cf-pcmdi.llnl.gov/).

Deliverable / Output

D4.1. Website which disseminates the nowcast and forecast data products from the regional and limited area models as well as the remote sensing and in-situ real time data products from the Marine Remote Sensing Unit and the in-situ tear of the OceanSAfrica operational oceanography programme.

D4.2. Report and user guide on how the system has been automated, and what products, where, and in which format the data has been archived.

D4.3. Report and user guide on the online data access service.

Work package number	5	**Start date or starting event**	3^{rd} quarter, year 1
Number of participants	3 (1 Scientist, 3 MSc)	**Work package duration**	2-3 years
Work package title	Pilot coastal embayment scale and higher resolution operational forecasts		
Activity type	Implementation (some development)		

Objectives

The objective is to implement forecast models at coastal embayment and higher spatial resolutions, ultimately nested within the limited area models planned for implementation under the SimOcean initiative.

High resolution coastal modelling systems will be implemented at two pilot sites, namely Saldanha Bay and Table Bay, that will be integrated into both the CSIR BAYNET[1] system and the CoastSAfrica dissemination system.

Motivation

There is a need to provide operational information to users and researchers in the marine environment that is sufficiently accurate and at scales of relevance to users in these marine activity hubs. This work package intends to provide early progress in achieving these goals by implementing, on a coastal embayment scale, forecast versions of existing well-validated models.

Description of work

Background The DELFT3D-FLOW modelling suite has been well validated in a number of southern African coastal embayments at these spatial and temporal scales using local atmospheric forcing fields and local wave and current measurements. It is proposed that the existing DELFT3D model implementations in number of selected coastal embayments, be fully operationalised so as to provide some early progress in the SimOcean project at these scales while more substantive regional and limited area model developments efforts are underway.

In terms of operational forecasts, these models have recognised limitations associated with general the lack of large-scale open boundary conditions and high resolution atmospheric forcing fields.

Under this project it is the intention to address these limitations by:

- Utilising the larger-scale open boundary forcing (and possibly high resolution atmospheric modelling) from the other components of the SimOcean initiative as inputs to improving coastal embayment implementations of the DELFT3D-FLOW software suite. Existing planned activities in the SimOcean initiative are likely to provide appropriate open boundary conditions to the coastal embayment models, however plans to provide the other required input to these models, namely higher resolution atmospheric forcing, *are noticeably absent from the present SimOcean workplan.*

[1]BAYNET is a coastal embayment information and management system under development within the CSIR. While the BAYNET system is more wide-ranging in its goals, the focus here is on the rapid development of the operational aspects of the BAYNET system that comprises a natural extension of the existing WAVENET system.

- Better integrate these coastal embayment forecasts with the enabling data streams available from the existing WAVENET and IPOSS decision support systems.

The initial focus will be on getting operational forecast outcomes in the two designated coastal embayments. In years to follow the network of coastal embayment forecast models will be expanded, using the learning from the pilot studies. At the same time an effort will be made to implement and validate ROMS to the same extent that the DELFT3D-FLOW modelling suite is validated at these smaller scales, providing greater flexibility in the forecast systems being proposed.

Work Package 5.1: Operational forecast model implementation in Saldanha Bay;

Work Package 5.2: Operational forecast model implementation in Table Bay;

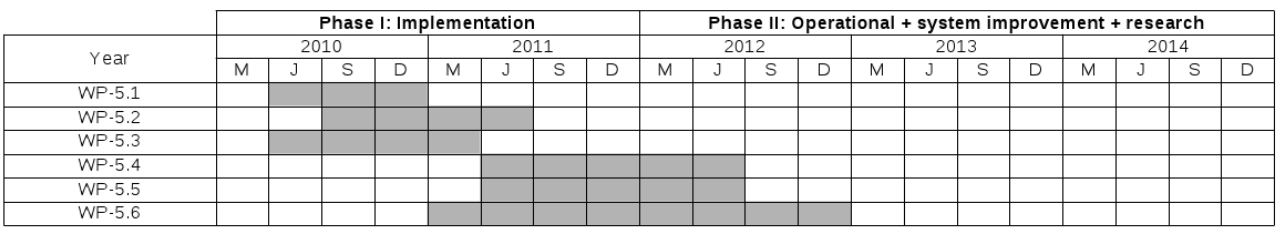
Work Package 5.3: Development of ROMS/Delft3d-FLOW coupling system;

Work Package 5.4: Nesting of Saldanha Bay operational forecast model in ROMS LAM model;

Work Package 5.5: Nesting of Table Bay operational forecast model in ROMS LAM model;

Work Package 5.6: Implementation and validation of ROMS at a coastal embayment and higher resolution scale.

Time Schedule



Work Package 5.1: Operational forecast model implementation in Saldanha Bay Here the existing DELFT3D-FLOW model in Saldanha Bay will be operationalised using local data sets. The model will be calibrated and verified using existing data stream from Saldanha Bay. The focus will be on ensuring reliable forecast (accurate and always available) and developing outputs/products that will be useful to users in the area.

Work Package 5.2: Operational forecast model implementation in Table Bay Here the existing DELFT3D-FLOW model in Table Bay will be operationalised using local data sets. The model will be calibrated and verified using existing data stream from Table Bay. The focus will be on ensuring reliable forecasts (accurate and always available) and developing outputs/products that will be useful to users in the area. In Table Bay a particular issue to be resolved is the need to include high resolution wind forcing.

Work Package 5.3: Development of ROMS/Delft3d-FLOW coupling system This is a minor work package to ensure that the DELFT3D-FLOW model can be nested in larger-scale models as and when such model outputs become available. This will require specific boundary condition software development.

Work Package 5.4: Nesting of Saldanha Bay operational forecast model in ROMS LAM model The existing coastal embayment model implementation in Saldanha Bay will be linked to / nested within larger scale operational models such as ROMS and higher resolution atmospheric forcing implemented if available.

Work Package 5.5: Nesting of Table Bay operational forecast model in ROMS LAM model The existing coastal embayment model implementation in Saldanha Bay will be linked to / nested within larger scale operational models such as ROMS and higher resolution atmospheric forcing implemented, if available.

Work Package 5.6: Implementation and validation of ROMS at a coastal embayment and higher resolution scale The intention here is to develop and validate ROMS capabilities in process modelling as the higher temporal and spatial scales of relevance in coastal embayments and nearshore environments. This is envisaged as a collaborative effort between CSIR and UCT that will be focussed on developing capacity to use ROMS to model at these smaller scales and to validate such models. Included will be the development wave and sediment modelling capabilities in ROMS.

Work packages 5.1 and 5.2 are so designed to benefit from progress in other SimOcean work packages but not necessarily dependant on such progress in the initial stages of the project, the focus being on the rapid development of operational forecast systems in coastal embayments and the dissemination of the resultant outputs.

Deliverables/Outputs

Deliverables include

D5.1. An operational forecast modelling system for two pilot sites;

D5.2. A capability to nest these models within larger-scale limited area models such as ROMS;

D5.3. Validated ROMS modelling capabilities at coastal embayment and higher resolutions.

Work package number	6	**Start date or starting event**	April 2010
Number of participants	3 (1 Scientist, 1 MSc / PhD)	**Work package duration**	2-3 years
Work package title	Regional and localised wave forecast system		
Activity type	Implementation (some development)		

Objectives

The objective is to implement wave forecast models that will support forecasts in coastal embayment and at higher spatial resolutions, i.e. the localised scales important to most users.

Presently only certain wave parameters on a relatively coarse grid and for limited parameters are available from the NCEP operational model. The intention is to implement a large-scale regional operational WAVEWATCH model that provides the required wave parameters at appropriate resolutions to support wave forecasting in coastal and nearshore systems (see the WAVENET system).

Motivation

Presently the CSIR operates a network of wave buoys (WAVENET) around the South African coast on behalf of the National Ports Authority (NPA). The data from this network of buoys are an important component of a wave forecasting effort. Available from these buoys are the real-time wave measurements and in some cases existing wave forecast information. In some sheltered areas such as Table Bay the offshore wave forecast parameters are substantially different to those experienced closer inshore. The wave data provided in Table Bay are, however, not obtained directly from measurements, but are based on a numerical wave transformation model using measurements as input. In some special areas e.g. Mossel Bay, the Port and other maritime users in the Mossel Bay, through the Wavenet website, are provided with the actual wave conditions and a forecast on a real-time basis based on existing NOAA National Centre for Environmental Prediction (NCEP) outputs.

Presently only certain wave parameters at a relatively coarse grid are available from the NCEP operational model. To improve the situation it is proposed to run a regional operational WAVEWATCH model that provides:

- more detailed output can be obtained (i.e. the directional wave energy spectrum would be a significant improvement on the current NCEP outputs used);
- forecast data at grid-point positions closer to relevant locations around the coast, providing greater flexibility and accuracy in setting-up and providing more accurate localised forecasts;
- a large-scale wave modelling facility (regional implementation of the WAVEATCH III model on similar scales to that envisaged initially for the ROMS modelling activities) that would provide an enabling research and forecasting resource to others over a larger area than just South Africa.

Description of work

The following Work Packages are proposed.

Work Package 6.1: Implementation of WAVEWATCH II at a regional scale Here the WAVEWATCH III wave model will be implemented at a regional scale. It is assumed that appropriate large-scale wind field with appropriate temporal resolution will be available for use in the regional model.

This regional model will be implemented in a forecast mode that provides the requisite fields for higher resolution wave forecast in the coastal systems.

Work Package 6.2: Assimilation of the data streams from the regional model into exiting WAVENET forecast models The improved quality and resolution WAVEWATCH III outputs will be used to force the existing higher resolution models used in the virtual bouy systems in WAVENET.

Time Schedule

	Phase I: Implementation								Phase II: Operational + system improvement + research											
Year	2010				2011				2012				2013				2014			
	M	J	S	D	M	J	S	D	M	J	S	D	M	J	S	D	M	J	S	D
WP-6.1																				
WP-6.2																				

Deliverables/Outputs

Deliverables include

D6.1. An operational regional wave forecast modelling system providing higher resolution and more detailed model outputs

D6.2. Validated ROMS modelling capabilities at coastal embayment and higher resolutions.\

Work package number	7	**Start date or starting event**	April 2010
Number of participants	3 (1 Scientist, 1-2 MSc / PhD)	**Work package duration**	2-3 years
Work package title	Biogeochemical modelling at coastal embayment and nearshore scales		
Activity type	Development and Implementation		

Objectives

The objective is to implement a biogeochemical modelling system at a coastal embayment scale. Potential implementation sites are St Helena Bay, Saldanha Bay. And Algoa Bay For reasons detailed below Saldanha Bay has been chosen as the pilot biogeochemical modelling site. The modelling and dissemination of model results will occur at scales deemed useful to users in the Saldanha Bay – Langebaan Lagoon system.

Motivation

The CSIR intends to implement a pilot biogeochemical modelling system in Saldanha Bay. The reasons for selecting Saldanha Bay for such a pilot study is that:

- the physical and biogeochemicalprocesses within the bay are relatively well understood;
- the CSIR has made significant progress in implementing hydrodynamic and biogeochemical models in Saldanha Bay and therefore can focus more on specific scientific questions and user requirements in terms of operational outputs;
- a significant database of measurements exists for Saldanha Bay to support such a study;
- the bay is a multi-user environment where there is a need to maintain ecosystem integrity, assess and manage potential impacts of future developments and where operational oceanographic outputs will be useful to the many users of the bay.

Description of work

The following Work Packages are proposed.

Work Package 7.1: Implementation of a pilot operational biogeochemical modelling system in Saldnaha Bay. Here the Delft3D-WAQ system will be implemented in Saldanha Bay and verified using existing measured data (and any data that may be obtained from future research programmes. The modelling system will be implemented and run so that operational outputs can be provided at spatial and temporal scales useful to the users of the bay.

Work Package 7.2: Implementation and validation of the biogeochemical process modelling capabilities of ROMS (or other appropriate models) at a coastal embayment and higher resolution scale. The intention here is to develop and validate ROMS (or other modelling systems) biogeochemical modelling capabilities in process modelling as the higher temporal and spatial scales of relevance in coastal embayments and nearshore environments. This is envisaged as a collaborative effort between CSIR and UCT that will be focussed on developing capacity to use ROMS (or other modelling systems) to model at these smaller scales and to validate such models.

Progress with Package 7.2. will depend on whether such activityies are deemed a priority and whether the capacity exists in the broader oceanographic community to undertake such activities.

Time Schedule

	Phase I: Implementation								**Phase II: Operational + system improvement + research**											
Year	2010				2011				2012				2013				2014			
	M	J	S	D	M	J	S	D	M	J	S	D	M	J	S	D	M	J	S	D
WP-7.1																				
WP-7.2																				

Deliverables/Outputs

Deliverables include

D7.1. An pilot operational biogeochemical modelling system in Saldanha Bay that will both provide a platform for assessing future developments in the bay and provide relevant operational output to users in the bay

D7.2. Validated ROMS biogeochemical modelling capabilities at coastal embayment and higher resolutions.

Work package number	8	Start date or starting event	1^{st} quarter, year 3
Number of participants	1 (Post-doc / PhD)	**Work package duration**	3 years
Work package title	Data assimilation		
Activity type	Implementation and system improvement / enhancement		

Objectives

The objective of this work package is to implement a data assimilation scheme in the Regional Ocean Modelling System (ROMS) simulation of the regional ocean of southern Africa. Data assimilation is a vital component of ocean forecast systems because numerical models are likely to have errors due to deficiencies in the model physics, grid resolution, lateral boundary conditions, or atmospheric forcing.

Description of work

Task 8.1. Set up a simple idealised channel model to test the hybrid data assimilation method (EnKF-OI; Counillon et al., 2009) compared to the the Ensemble Kalman Filter (EnKF; Evensen, 2006) and the Ensemble Optimal Interpolation (EnOI; Oke et al., 2002; Evensen, 2003) in ROMS.

Task 8.2. Implement the most suitable sequential data assimilation scheme in the regional model of the Agulhas Current. In hindcast model test the assimilation of alongtrack sea level anomaly data from satellite altimeter measurements, sea surface temperatures from OSTIA (Operational Sea Surface Temperature and Sea Ice Analysis), temperature and salinity profiles from XBTs and ARGO floats (available from Coriolis; `www.coriolis.eu.org`). Compare the assimilated and unassimilated model fields and validate against independent observations.

Task 8.3. Use the ocean modelling and data assimilation system to perform Ocean Simulation Evaluations (OSEs) and Ocean System Simulation Experiments (OSSEs).

Input

Ocean data assimilation is a mathematically rigorous process by which ocean observations are combined with ocean models to provide the best possible estimate of the state of the ocean from relatively sparse and incomplete data.

System Name	Country	Data Assimilation Method	Reference
BODAS	Australia	Ensemble Optimal Interpolation	Oke et al., 2008
ECCO-JPL	USA	Kalman filter and smoother	Fukumori, 2002
FOAM	UK	Analysis Correction	Martin et al., 2007
Mercator	France	Static SEEK filter	Brasseur et al., 2005
MOVE / MRI.COM	JAPAN	Multivariate 3DVAR	Fujii and Kamachi, 2003
NCODA	USA	Multivariate Optimal Interpolation	Cummings, 2005
NEMOVAR	European Union	Multivariate Incremental 3DVAR	Weaver et al., 2005
TOPAZ	Norway	Ensemble Kalman filter	Evensen, 2006

Table 1: Data assimilation methods used by GODAE systems

A range of methods exist for assimilating observations into ocean models (Table 1), from relatively simple schemes, such as Analysis Correction and Optimal Interpolation, to more sophisticated schemes such as variational and ensemble techniques.

The choice of data assimilation scheme is historically limited to the available technological capacity (i.e. computing power) and the grid resolution of the ocean model. The computational cost of advanced data assimilation methods, such as the Ensemble Kalman Filter and Smoother (EnKF / EnKS; Evensen, 2006) and 4D-variational methods (Bennett, 2002) are significant, approximately 100 times that of the numerical model. Whereas simpler data assimilation schemes, such as the Ensemble Optimal Interpolation (EnOI; Oke et al., 2002; Evensen, 2003), which uses a static ensemble of model states rather than a dynamic ensemble (as in the EnKF), are computationally (relatively) inexpensive. Therefore, in practise, one has to either favor high model resolution combined with an inferior data assimilation method, or a more advanced data assimilation method at the expense of the model resolution. However, for the Agulhas Current region it is important to have sufficient model resolution in order to obtain a realistic representations of the ocean dynamics and its mesoscale variability.

Recently, a hybrid data assimilation method (EnKF-OI; Counillon et al., 2009), which combines the computationally inexpensive EnOI scheme with the computationally expensive EnKF scheme, was tested in a high resolution model of the Gulf of Mexico with favourable results. It was shown that a 10-member EnKF-OI reduces the forecast error over a 10-member EnOI, while a 10-member ensemble was insufficient for the EnKF scheme. Hence the benefits of applying such a hybrid scheme are large compared to the relatively small increase in computational cost.

Ocean observations play an essential role in improving the description of the ocean state, and since ocean forecasting is essentially an initial value problem, a more accurate description of the ocean state at the nowcast stage will improve the forecast skill. There are a variety of operational ocean data available for assimilation into ocean models. Some of the groups providing data considered essential for assimilation into ocean models are described briefly below.

The alongtrack sea level anomaly data from satellite altimeter measurements is available in (near-) real time from SSALTO / DUACS distributed by Aviso, with support from the Centre National d'Etudes Spatiales (CNES; `www.aviso.oceanobs.com`). The delivery of the the data is delayed from a few hours to 3 days after the measurement was taken. The data are available via FTP, and for data less than 1 month old a data use agreement has to be signed with CNES indicating that the data is being used for scientific applications.

The OSTIA (Operational Sea Surface Temperature and Sea Ice Analysis; `http://ghrsst-pp.metoffice.com/pages/latest_analysis/ostia.html`) sea surface temperatures (SSTs) use satellite data provided by the GHRSST (Global High Resolution SST) project, together with in-situ observations to determine the sea surface temperature. The analysis is performed using a variant of optimal interpolation (OI) described by Martin et al., 2007. The analysis is produced daily at a resolution of $1/20°$ (approximately 5 km). OSTIA data is provided in GHRSST netCDF format every day. The Marine Remote Sensing Unit (MRSU; `www.afro-sea.org.za/`) has signed an agreement with MyOcean, and is downloading the data in real time on a daily basis.

The objective of Coriolis data center (`www.coriolis.eu.org`) is to develop a continuous, automatic, and permanent ocean observation network. They provide quality-controlled in-situ data in real time and delayed modes. Managed data sets are mainly temperature and salinity profiles and time series from profiling floats, XBT's, thermo-salinographs, drifting and moored buoys. Data transmitted by floats are processed, checked for quality and distributed to the GTS and Internet with minimum delay of 24 hours.

Observing system design is essential in the development of an ocean observing system catered for research as well as operational activities. An ocean modelling and data assimilation system may be able to provide useful information in this regard. Furthermore, since ocean forecasting is essentially an initial value problem, a more accurate description of the ocean state at the nowcast stage is essential for ensuring good forecast skill.

Ocean Simulation Evaluation (OSEs) and Ocean System Simulation Experiments (OSSEs) address questions regarding the type of variables that should be monitored, how these observations will be used, and where these observations should be made. For example, the importance of near shore current observations from a CODAR network may be tested by generating synthetic observations and assimilating these into the model and assessing the benefit to the simulation and the forecast product. Similarly, the effect of having a point measurement from a mooring may be tested. Such experiments may aid in motivating and maintaining observational networks, and models and data assimilation tools should routinely be used to contribute to the discussions about observing system design.

A maintained observing system is not only important for ocean forecasting, it plays an integral role in furthering the understanding of the physical processes that drive ocean and climate system. Furthermore, by assimilating these data into the ocean modelling system used to generate the forecasts, it will be possible to create reanalysis data products, which provide a historical description of the state of the ocean that can be used to characterise and study climate variability (change).

Deliverable / Output

D8.1. Report on the intercomparison of sequential data assimilation methods in an idealised simulation using ROMS.

D8.2. Report on the comparison and validation, against independent observations, of the unassimilated and assimilated hindcast simulation experiments for the regional model of southern Africa.

D8.3. Report on the use of the ocean modelling and data assimilation system in Ocean Simulation Evaluation (OSEs) and Ocean System Simulation Experiments (OSSEs) for the southern African region.

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