Keys to affordable regional marine forecast systems

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Introduction

Only the wealthiest countries in the world can propose governmental services with decent financial support to provide marine forecasting on an operational level. If a laboratory of oceanography or meteorology in a developing country needs to provide marine forecast to support its country's economy or prevent pollution, *what alternative can be found*? This is precisely the kind of questions that the Institute of Research for Development (IRD) is designed to answer.

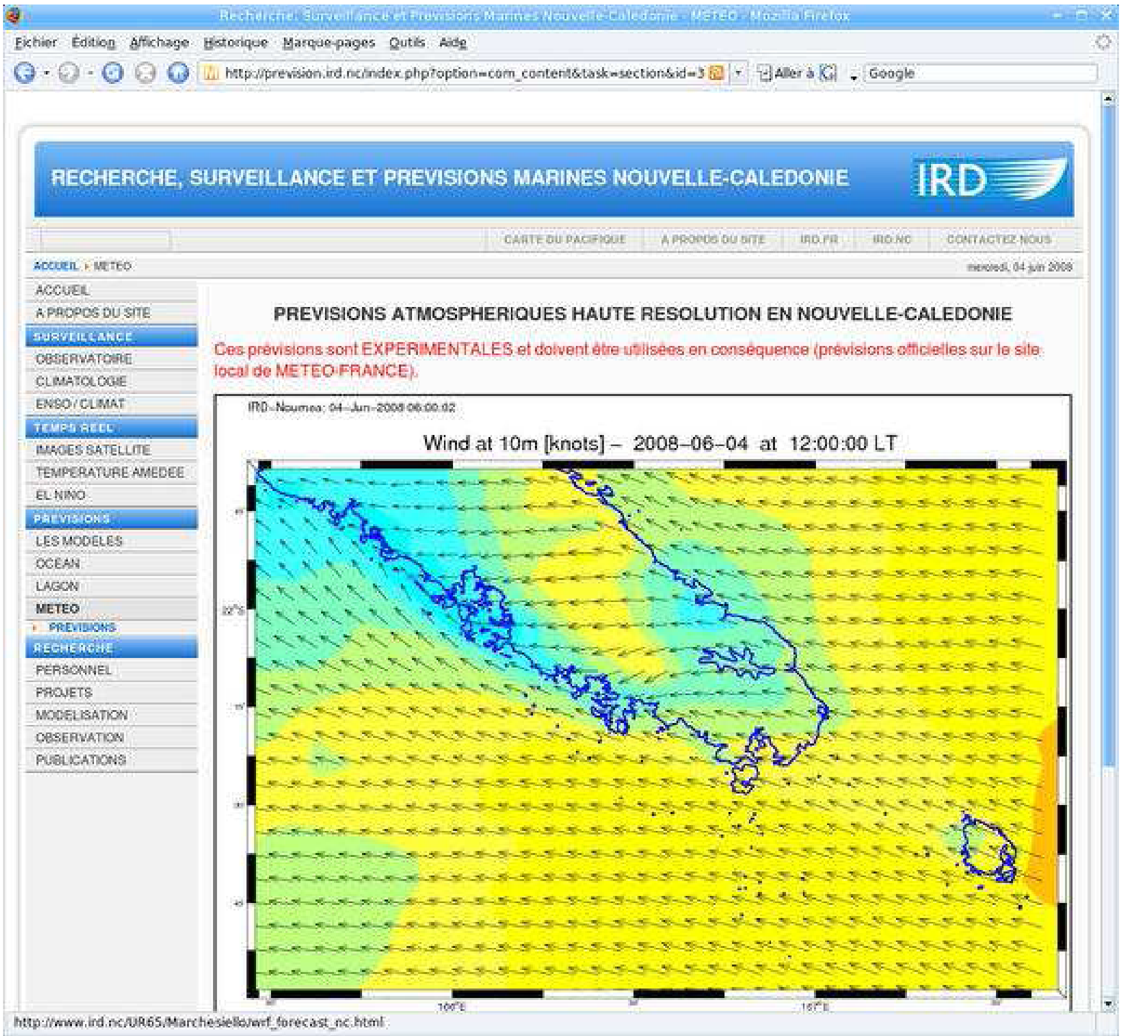

Figure 1

The oceanographic research group at the Nouméa-IRD center proposes a functional but experimental nowcast/forecast integrated system of marine meteorology, deep sea and lagoon oceanography which is updated everyday through the web site: http://prevision.ird.nc

Our understanding is that a regional marine forecast system needs at its core some state-of-the-art regional oceanic and atmospheric models which can be applied in a downscaling mode to refine the results of existing global systems, rather than generating entirely new solutions. The challenge is to find *freely available* models and global operational data sets, then build interfaces extracting these data, interpolate it to the regional grids, integrate the models in both nowcast and forecast modes, analyze the results and present them to potential users through a distributed media (the World Wide Web). A key condition for our system to work is that maintenance be minimal, which can only be achieved if the system is entirely *automated* through scheduled commands and scripts.

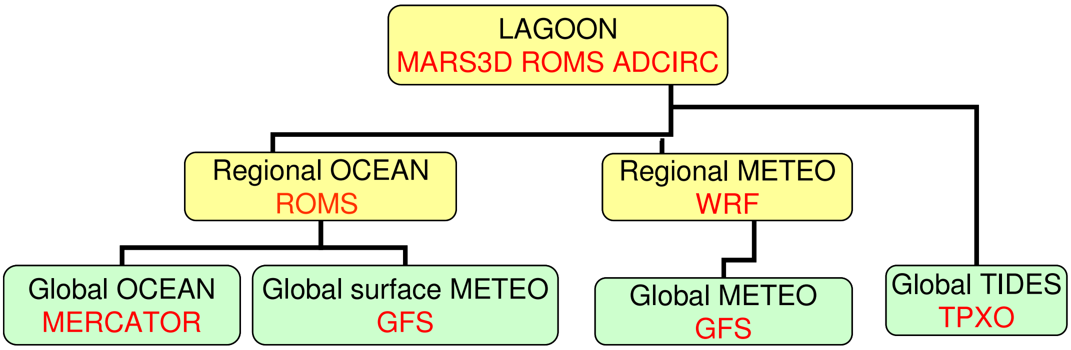

Figure 2

Diagram presenting the different parts of the IRD integrated operational system. Extraction and transfer from global (green) to regional (yellow) stages are done using the OPeNDAP extraction protocol; each step is completely automated through the Linux CRON service. It takes about 2 hours every night for the entire system to run on 4 processors.

With support from the PREVIMER project, as well as IRD (Institut de Recherche pour le Développement), ANR (Agence Nationale de la Recherche) and ZoNéCo (New Caledonia government research program), an experimental but fully automated system was created for marine survey and forecast of the New-Caledonia region (http://prevision.ird.nc ; Figure 1). New Caledonia is well suited for the experiment because it gathers most of the constraints encountered in developing countries, i.e. slow internet connection, remoteness from data centers, expensive or unavailable hardware and software. Meanwhile, good research conditions at the IRD-Nouméa center and a comfortable financial support has provided the means to explore different paths and reach the experiment's goal. In a second phase, the experimental system should be exported towards developing countries. This step is underway as parts of the system are already active in Peru, Mexico, Senegal and South Africa.

The marine forecast system of New-Caledonia is rather complex as it comprises 3 parts: the oceanic, the lagoon and the atmospheric models (Figure 2). In the following we present those different parts, emphasizing key points that are relevant to a portable and affordable operational system.

Hardware

Recent modeling developments have greatly benefited from the rapid progress of Personal Computers, including hardware, operating systems, libraries and compilers. Those in turn are largely profiting from the free software era in which we now evolve. As a result, multiple processor machines are so efficient that single-core, single-processor machines are not found on the market anymore. Therefore, oceanic and atmospheric modeling is unconceivable without code parallelization, which can simultaneously use multiple cores of one processor, or/and multiple processors of one PC, or/and multiple PCs of a cluster. Under these circumstances and because our models are efficiently parallelized, we have found support during the last 3 years to progressively build an experimental PC cluster in Noumea for scientific computing (Figure 3); our objective is to demonstrate that a cheap and efficient local-size machine (40 processor units) can be built in developing countries. In this experiment, we have learned that all necessary computer software (operating system, cluster administration system, communication libraries, compilers, job manager system) is freely available and functional, provided that a few options are properly set. The performances of local-size PC clusters can be excellent, although it shows a few bottle necks such as dual-core parallelization (there is efficiency loss using message passing protocols on a dual-core processor compared to a bi-processor, but the loss has been found acceptable) and more importantly the PCs connection system. A high communication bandwidth capability appears indispensable when the number of grid points exchanging information becomes large compared to the total grid points (with slow connection, the volume of data transfer becomes too large compared to actual computing). Therefore, our choice went to the InfiniBand connection (10Gbps of bandwidth) which allows using the full cluster capacity even on computational grids that are relatively small. Based on the lessons learned and selected choices, a similar PC cluster is now being implemented in Lima (Peru) as a second phase of the experiment.

Figure 3

Nouméa PC cluster, made of 10 bi-dual-core Opteron processor 246 and 285, with motherboard Tyan S2885 and Infiniband connection for communication between the PCs. The Cluster was assembled at the IRD-Nouméa center.

The oceanic system

This section only concerns the oceanic system at the regional scale (Figure 2). The lagoon of New Caledonia, which is an isolated body of water with limited connections to the ocean, is treated in the section below "Coupling".

Model and configurations

The Regional Ocean Modeling System (ROMS) is a new generation ocean circulation model (Shchepetkin and McWilliams, 2005). It has been specially designed for the accurate simulation of regional oceanic systems with coastal margins. IRD jointly with INRIA (Institut National de Recherche en Informatique et en Automatique) are maintaining a separate branch of the model (ROMS_AGRIF) which features multi-level 2-way nesting capability (Penven et al., 2006), and a modified code structure to straightforwardly handle realistic modeling and its application modules. The conjunction of a stable, accurate and efficient model with robust open boundary conditions (Marchesiello et al., 2001) allows us to follow a systematic approach to obtain a "standard" regional configuration (Marchesiello et al., 2003). To that end, a series of MATLAB routines and several essential datasets were gathered in an integrated toolbox called ROMSTOOLS (Penven et al., 2007; the toolbox and the model can be freely downloaded at: http://www.brest.ird.fr/Roms_tools/). ROMSTOOLS requires only a minimum list of elements (location and size of parent and nested domains, resolutions …) to obtain a model simulation for almost any region. The standard pre-processing tools include interpolation procedures, generic land masking and topography smoothing. Refinements are then added as needed, i.e. nested domains, more accurate wind forcing, initial, boundary and topographic data, as well as various biogeochemical data for relevant applications. In various complex configurations, ROMSTOOLS and ROMS_AGRIF have been applied successfully on a variety of regional studies of the world ocean (Blaas et al., 2007; Blanke et al., 2002; Capet et al., 2004; Karakas et al., 2006; Gruber et al., 2006; Marchesiello et al., 2003, 2007; Messie et al., 2006; Peliz et al., 2007ab; Penven et al., 2000, 2006; among others). Note that ROMSTOOLS should evolve in the future towards free programming languages replacing MATLAB (OCTAVE for example) in order to better comply with our portability-affordability constraint.

The configuration of the New Caledonia region which is currently used for daily forecasts is built on a 1/6° resolution grid encompassing the whole southwest Pacific. A nested domain for grid refinement (5 km) over the New Caledonia Exclusive Economic Zone has been implemented and tested (Figure 4 and section below "A low-cost observatory for survey and validation"), and should be operational in a future system upgrade.

Forecast_tools

The impact of climate change on the coastal oceans and operational oceanography are two of the highlights of modern oceanography. ROMSTOOLS allows running both inter-annual and real-time simulations. In the latter case, we rely on operational global ocean circulation models for the initial and lateral boundary conditions and operational global atmospheric models (introduced through bulk formulations) for surface forcing. Alternatively, we can use a regional atmospheric model to provide small-scale surface forcing data (cf. section below "The atmospheric system" and Figure 2).

In order to limit the volume of data transferred over the Internet, we use the Open-source Project for a Network Data Access Protocol (OPeNDAP) and extract only the necessary subgrid. This method reduces by a great amount the bandwidth needed for data download. This point is critical for laboratories which do not have access to a high performance Internet connection. Another critical point of the same type is the availability of data. It should be acknowledged that U.S. data bases are far more interesting in this respect than European ones, although the efforts made by Mercator (partly under IRD's demand) to provide its quarter-degree resolution forecast product through an OPeNDAP server is encouraging.

If large scale ocean dynamics are slow in comparison with those of the regional system (this might be incorrect near rapidly changing large scale systems such as western boundary currents), the lateral boundary conditions can be interpolated from a coarse-resolution operational model. The issue of the global model resolution becomes more sensitive when considering the initialization problem. In a regional domain with low intrinsic variability where the circulation is directly forced by surface fluxes (for example in the nearshore zone of coastal upwelling regions; or in the deep sea regions away from fronts and eddies), initialization is of lower importance (a restart file created at a given forecast cycle can be used for the next cycle). In this case, ocean circulation predictability is relying on that of the forcing fields. Those are generated using extracted data from the half-degree, 6-hourly Global Forecast System (GFS), freely available via OPeNDAP by the U.S. National Center for Environmental Prediction (NCEP/NOAA). Higher resolution winds from our regional atmospheric model can also be used, as in the lagoon component of the system (See sections below "The atmospheric system" and "Coupling").

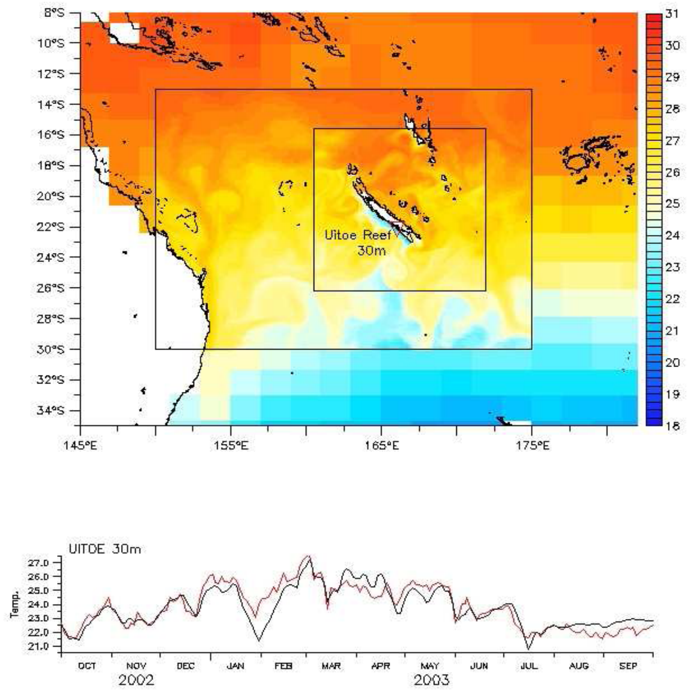

Figure 4

ROMS embedded in Mercator Ocean. Over New Caledonia EEZ, a fine grid at 5km resolution is nested in the parent ROMS domain at 1/6°. Top: model SST for January 30, 2003 . Bottom: comparison of model temperature at 30 m with Uitoé station.

The problem becomes more complicated if oceanic intrinsic variability is dominant. In this case, mesoscale eddies, with dynamics evolving at a time-scale of the order of the month, are generated on a regular basis and have low predictability. The model may well provide a very statistically reliable image of the mesoscale dynamics (Marchesiello et al., 2003), but eddies at any given time are usually not correlated with real events. An initialization method is therefore needed to adjust the statistically reliable oceanic variable to the real time. To that end, a now widely used method is data assimilation. For our nested version of ROMS, a three-dimensional variational system called ROMS_DAS (Li et al., 2008) was developed at the Jet Propulsion Laboratory during a collaborative project involving UCLA (some of the authors, now at IRD, participated in this project). The project called AOSNII consisted in evaluating an adaptive ocean sampling design (Chao et al., 2003), where observations and model solutions regularly interact in order to optimize the survey sampling. Despite the good performances shown, ROMS_DAS has not yet been incorporated in the New Caledonia operational experiment. Instead, we have opted for an alternative method, which makes use of Mercator's new quarter-degree resolution forecast product. The global product in this case assimilates for us real-time mesoscale eddies from satellite altimetry and in-situ data. Then, *Newtonian nudging* is used to adjust Mercator data to ROMS dynamics. The nudging is performed during the nowcast step, and a few iterative cycles can be done to guarantee convergence of the resulting nowcast field (for example when first starting up the operational system).

The strategy for a nowcast/forecast cycle is as follows. A first week of simulation (from t_0-7 to t_0, t_0 being the present time) in hindcast mode is run using interpolated data from Mercator for lateral boundary conditions and GFS for surface forcing. A ROMS restart file (from a previous forecast) is used for initialization at time t_0-7, while nudging assimilates the Mercator global ocean data (with a nudging time-scale of 15 days). This provides a nowcast at t_0, which is the initial condition of the forecast run for the following week. A Shell script (make_roms_forecast.sh) manages the whole procedure: download and pre-processing, hindcast and forecast simulations, post-processing and transfer of graphics to the web page, data storage and preparation of the next nowcast/forecast cycle. To improve the system, the build-in 2-way nesting procedure can be used for local refinement. In this case, the results may be improved in the future by assimilation of small-scale data, as in the AOSNII experiment (Chao et al., 2003).

A low-cost observatory for survey and validation

The oceanographers of the IRD–Nouméa center have developed since 1958 a coastal station network in the southwest tropical Pacific Ocean. Part of this network has been managed in collaboration with the ZoNéCo program since 1992. Originally based on bucket samples, most of the stations are now equipped with automatic ONSET instruments (StowAway TidbiT from HoBo, accuracy +/- 0.2°C) providing temperature time seri es in the upper 10m depth (the station at Uitoe also gives subsurface temperature and surface salinity data from Seabird SBE16 sensors). The station at the Amédée lighthouse has a real-time connection and we have recently added an automatic process to provide our web site with daily real-time temperature. The in-situ data is completed by real-time satellite images (also automatically deposited on our web site) as well as oceanographic cruises and merchant ship data. These observations can be used for real-time survey, oceanic climate studies, or model validation.

Some validation of the operational system has been performed by Vega (2007) as part of the PREVIMER project. Here, we reproduce a short model-data comparison intended to illustrate the potential usage of our coastal network to assess the benefit of the regional system in resolving sub-mesoscale processes. Of particular interest is the southwest part of New Caledonia barrier reef (station Uitoe), characterised by regular coastal upwelling events. These are produced by trade winds flowing northward along the coast. The Mercator product is unable to capture the upwelling process which requires resolution of 1-10km. Figure 4 presents a snapshot of model SST as well as a 2-year time-series at Uitoé station for both model and station data; the following table (Table 1) also presents some statistics of intra-seasonal variability at various depths:

Onset	Depth	Time serie	Location	ROMS rms	Obs. rms	Bias (°C)	R	Number of Obs
Uitoe 1	10 m	Sep99-Mar-06	21.8°S, 166.1°E	0.65	0.55	-0.72	0.69	633
Uitoe 2	35 m	Jul01-Mar-06	21.8°S, 166.1°E	0.30	0.22	0.26	0.47	816
Uitoe 3	62 m	Jul01-Mar-06	21.8°S, 166.1°E	0.18	0.29	0.25	0.46	669

Table 1

Statistics of intra-seasonal temperature variability at Uitoe station located on the New Caledonia barrier reef. Statistical parameters are: root mean square (rms), bias and correlation (R)

The match between modelled and observed temperatures (in temporal and spatial structure) demonstrate the skills of the regional model in reproducing correctly all the upwelling events. It confirms that coastal upwelling is a predictable process as long as the wind forcing is accurate and the background oceanic conditions are realistic.

The atmospheric system

Similarly to ROMS, the Weather Research & Forecasting (WRF) model (figure 2) is a next-generation regional atmospheric model developed mainly at the National Center of Atmospheric Research (NCAR). WRF is destined to replace the widely used community model MM5 with its advanced numerical methods and parameterizations designed for mesoscale numerical prediction and research. The model comes with WPS (WRF Pre-Processing System) which is a FORTRAN equivalent of ROMSTOOLS able to robustly pre-process global operational model data. In addition, we have developed in a collaborative work between IRD and INRIA a shell-script (make_wrf_forecast.sh) providing an interface between the user and WPS. This simple, yet robust, interface manages data downloads and files system, defines pathways and environment variables, generates all various *namelist* files for WPS executables (geogrid.exe, ungrib.exe, metgrid.exe), run the WPS executables, generates namelist files for WRF and run WRF. Finally, another Shell script file calls for matlab routines to analyze and plot the results, then transfer the graphics to the operational web page.

WRF configuration for the New Caledonia region uses 3-level, 2-way nested domains spanning the area of New-Caledonia Exclusive Economic Zone (20km resolution) with refinement of the horizontal resolution over the Southern Province (6km), and Nouméa area (2km resolution). Terrestrial data are provided by the US Geological Survey, apart from the 50m topography of New Caledonia, which is provided by New Caledonia's Geographical Information System service (SGVL). The simulation starts one day before present using initial and boundary data interpolated from the half-degree, 6-hourly Global Data Assimilation System (GDAS). Next, a 4 day forecast is conducted using boundary data from the half-degree, 3-hourly Global Forecast System (GFS). Note that the time lag (forward in New Caledonia) with the U.S. time is to be taken into account.

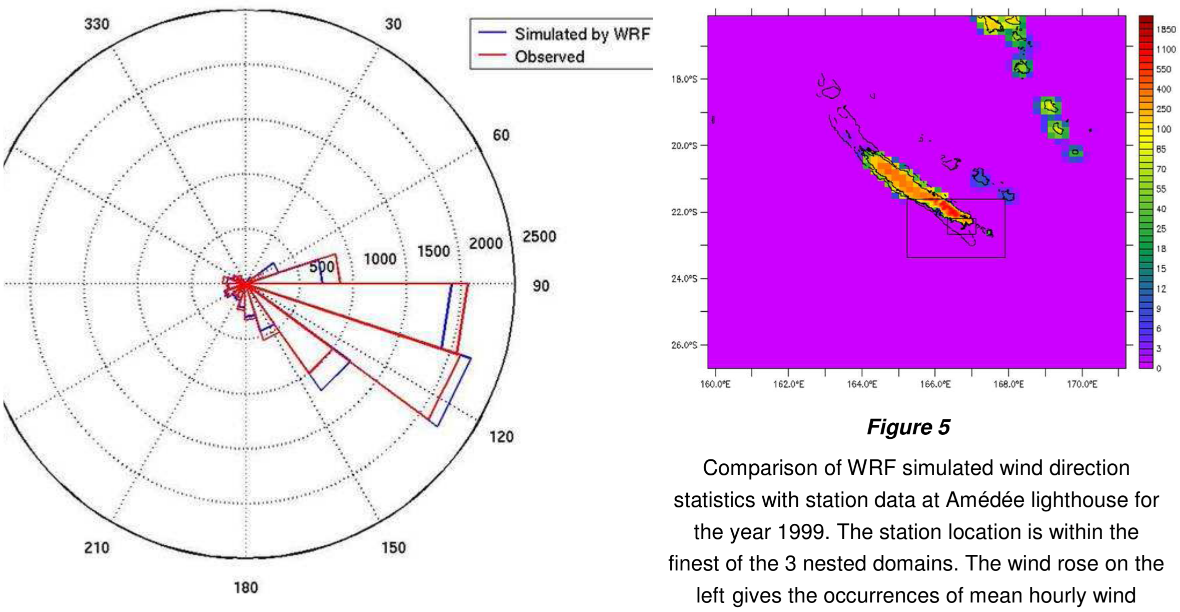

Figure 5

Comparison of WRF simulated wind direction statistics with station data at Amédée lighthouse for the year 1999. The station location is within the finest of the 3 nested domains. The wind rose on the left gives the occurrences of mean hourly wind direction in 18 quadrants of directions.

The validation experiment performed on yearly simulations using the same 3-level nested downscaling system has shown very good results. Figure 5 illustrates the excellent statistical comparisons which partly result from the configuration setup. The model domain is small enough that most of the synoptic variability is generated by the global model while the regional model is used optimally for its capability to produce fine scales from local topographic control and local scale thermal winds.

Coupling

While gaining control of both oceanic and atmospheric models, the idea of coupling them has naturally emerged in the scope of our research and operational projects. Rather than using generic couplers (OASIS for example), which can be difficult to implement and therefore goes against our principle of portability, a specific coupler has been devised for ROMS-WRF (Lemarié et al., 2008). The application of the coupling method to our nowcast/forecast system is in principle straightforward and will be implemented in the future.

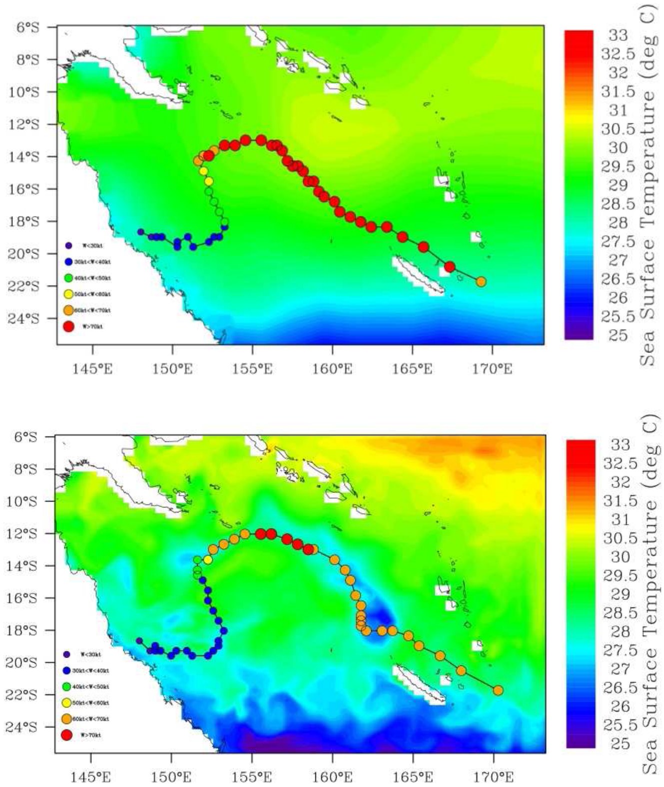

Figure 6

WRF Forced simulation (top) and ROMS-WRF coupled simulation (bottom) of Cyclone Erica moving over New Caledonia in March 2003 (Lemarié et al., 2008). Cold waters are produced on the cyclone track due to strong surface mixing induced by the hurricane-force winds; the cold water induces a negative feedback on the tropical cyclone which is weaker and more realistic as a results (orange rather than red color). Note that the real cyclone path is similar to the simulated one except that it crosses New Caledonia about 200km further south.

Actual 2-way coupling algorithms for realistic high-resolution regional applications are not numerous; examples can be found in Bao et al. (2000). The approach used for climate applications with low coupling frequency are not appropriate for generally fast modes regional applications, and may generate large inaccuracies in the numerical solutions. On the other hand, high frequency coupling (at the ocean time step) may also have its drawbacks as estimated turbulent fluxes can be uncertain on time scales lower than 10 minutes. The choice is either to implement more detailed physical processes relevant to high temporal frequency coupling, such as spray contributions to heat fluxes and the wave boundary layer (Bao et al., 2000), and/or to improve asynchronous methods. In the latter case, it may be useful to impose various coupling properties, in particular the convergence of oceanic and atmospheric fluxes at the interface as well as flux conservation between the two systems. In our coupling algorithm, an iterative method based on domain decomposition (Global-in-time non-overlapping Schwarz methods) was implemented to obtain convergence between fluxes. A FORTRAN package manages the calls to oceanic and atmospheric models and their coupling. It has been applied successfully to the coupled simulation of real tropical cyclones showing the role of oceanic feedback in limiting the potential growth of tropical cyclones (Figure 6; Lemarié et al., 2008).

The lagoon

Lagoons are very specific bodies of sea water, often largely isolated from oceanic waters by a barrier reef, with only a limited number of passes to make the connection. The Lagoon of New Caledonia is the largest closed Lagoon in the world with large biological diversity and degrees of endemism. As such it is a valuable entity to be understood, surveyed and protected. The Lagoon is shallow and its circulation is dominated by barotropic tides and direct wind influences. Therefore, its modeling requires accurate tidal and wind forcing. For tides, freely available data sets such as those from the global model of ocean tides TPXO (version 6 or 7), assimilating satellite altimetry, have proved to be very valuable in many regions, including New Caledonia. Accurate wind forcing at the lagoon scale can only be produced by regional numerical models of which WRF is a good example.

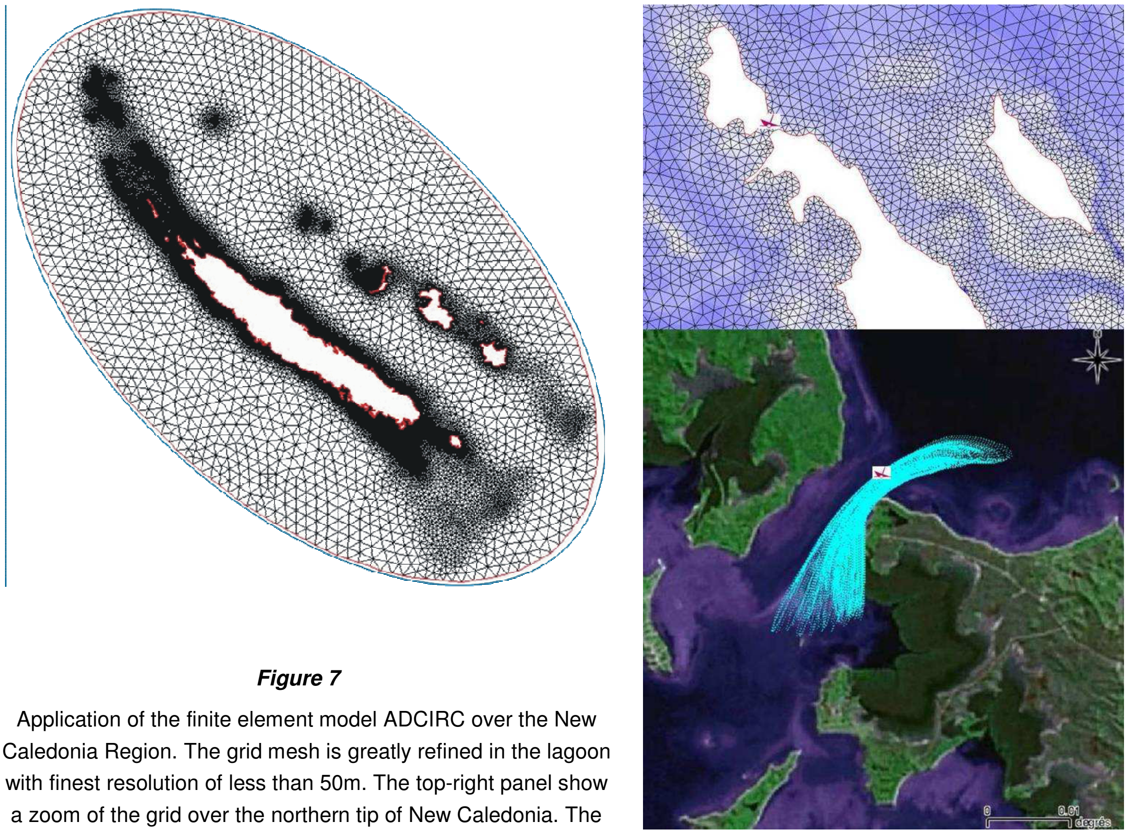

Figure 7

Application of the finite element model ADCIRC over the New Caledonia Region. The grid mesh is greatly refined in the lagoon with finest resolution of less than 50m. The top-right panel show a zoom of the grid over the northern tip of New Caledonia. The lower panel shows a simulation of oil spill during 48 hours after a virtual wreck at Boat Pass.

Three different oceanic models have been used for the New Caledonia lagoon (Figure 2): ROMS, MARS3D and ADCIRC. MARS3D, developed by IFREMER, is historically the first code applied to the lagoon. Its local IRD version benefits from a long experience, where validation against in-situ data (collected during observation programs) permitted fine parameter tuning. MARS3D is in essence similar to ROMS but with less emphasis on numerical aspects as it is traditionally used in shorter term, engineering-type applications. For an operational version of the lagoon model, we used a modified version of ROMS forecast toolbox which provides tidal forcing (from TPXO or local data), surface forcing (from WRF), as well as sub-tidal oceanic forcing (from ROMS oceanic application). This MARS3D operational version is only implemented to the southwest part of the lagoon where most human activities are concentrated.

With the announced spreading of human activity over the whole highland, a new priority is given for modeling and forecasting the whole lagoon. It appears that finite-difference models become limited to that end and we have turned to community finite element models such as the ADvanced CIRCulation model (ADCIRC) (figure 7). If those have not yet proven totally reliable to handle three-dimensional oceanic dynamics (large efforts are currently devoted to that), their successful application to shallow water dynamics have long been recognized. The unstructured grid mesh is a classical feature of these models and is particularly interesting to locally refine the resolution with considerable flexibility. Using TPXO6 tidal data and local high resolution topographic data, we have been able to reproduce tidal elevation and currents with an accuracy and resolution that have never been achieved before (less than 50m locally). The system is further refined by employing our WRF simulations for small-scale surface forcing.

Technology transfer in Peru with local specifications

Several IRD teams in South America have already benefited from the developments of the above described system. In particular in Peru, several steps towards the implementation of a regional marine forecast system have been recently completed. First, a PC cluster platform based on the Nouméa prototype has been funded by IRD's computing support department (DSI: Direction des Resources Informatique) and implemented at IMARPE (Instituto del Mar del Peru: the Peruvian

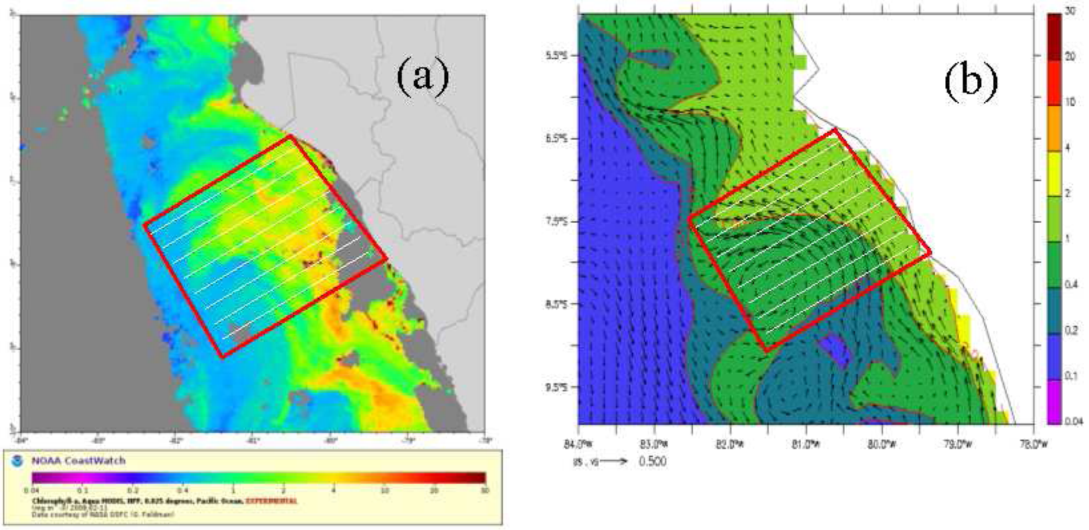

Figure 8

Surface chlorophyll-a (mg Chl/m3) off Peru. (a) Satellite observations in February 2008 (courtesy of F. Chavez, MBARI). (b) ROMS-PISCES (1/6°) chlorophyll and currents during a similar upwelling event. The model is initialized and forced by the Global 1/4° monovariate Mercator product. The white lines show the "filamentos" cruise track. The cruise data and operational modeling system will be used jointly during the MESUP project to further refine the biogeochemical module parameters and improve prediction capabilities.

marine research institute). Those improved computing capabilities are needed to carry on-going modeling projects, which include the PCCC project (Peru-Chile Climate Change, funded by the French ANR) and research activities dedicated to biogeochemical modeling (using the module PISCES which is implemented in ROMS). Those modeling efforts are made in re-analysis (hindcast) rather than real-time and forecast mode, but they rely on the same forcing strategy, in particular the Mercator products for initialization and lateral forcing at the open-boundaries of the regional oceanic model configuration. Recently, in conjunction with an observational field operation off Chimbote (9°S) dedicated to the study of a cold upwelling filament structure ('Filamentos' cruise), a modeling project was proposed and funded by Mercator to simulate the filament and its associated biological response (project MESUP) (Figure 8).

Other projects at IMARPE are focused on the equatorial Kelvin wave impact on the regional circulation off Peru. They make use of equatorial wave models (that are suitable for developing countries since they permit generating their own large scale products without the requirement of a complex ocean general circulation model) and Mercator outputs that can be used to derive an estimation of the equatorial Kelvin wave contribution (see Dewitte et al. 2007 as well as Illig et al. 2007). Finally, a near real-time application of the modeling tools will be experienced at the occasion of a regional cruise, which is planned for October 2008 off the coast of Central Peru (in the frame of the VOCALS international program). Clearly, the Peruvian IMARPE-IRD projects tend to confirm that the development of 'handy' modeling platforms, in parallel with affordable large scale assimilation products, are the warrant for a sustainable evolution of the collaborations with developing countries.

Assessment of system usefulness and conclusion

The assessment of system usefulness is a key ingredient in motivating our interest in operational coastal and regional oceanography. Since our prototype system for New Caledonia has been known for 2 years. we are now able to synthesize local information and user feedback. Potential users in New Caledonia are variably interested in the different component of the system (ocean, atmosphere, and lagoon). The high resolution wind forecast on its own appears to satisfy the largest demands, especially as no other high resolution product is available (Météo-France does not have any refinement strategy in the region and relies on a good observational network and global forecast from Toulouse). The wind forecast has first been used by our scientist colleagues, when field experiment conditions in the lagoon are strongly affected by small-scale winds; it has then been known also by professionals proposing sailing or diving services, or by private persons practicing leisure activities in the lagoon (including us), and a demand seems to emerge from wind power companies which relies importantly on local wind prediction. The interest of oceanic survey and forecast outside the lagoon appears only obvious for local small fishing companies looking for pelagic fish whose presence is highly dependent on oceanic environmental conditions (tuna in particular). This part of the system has also been of use to oceanographic cruises on occasions. The potential usefulness of lagoon forecast is expected to be major, provided that additional information is given. For example, the New Caledonia Anti-Pollution Comity (which assembles petrol and mining companies together with governmental agencies to optimize emergency actions against pollution) would be more interested in our product if a drift model for oil spill or chemical pollution is coupled to the lagoon circulation model.

More generally, there are a number of application modules that can improve the usefulness of operational systems: *oil drift* modules integrating wind and current effects; *biogeochemical* and *sediment* transport modules for assessing the risks of biochemical pollution; biological modules to predict larval connectivity for optimal monitoring of marine reserves (see for example the IBM model implemented during the PREVIMER project by Lett et al., 2008); other types of biological modules to predict fish population density as a function of environmental variables and fishing pressure (see on-going implementation of the SEAPODYM tuna model for New Caledonia); modules assessing the risks of *extreme events* (cyclones) or even *emerging infectious diseases* (malaria and dengue are a major health concern in tropical countries; an IRD diagnostic module exists that has been tested for dengue risks assessment in New Caledonia, using WRF predictions).

Finally, the relevance of an operational marine system is dependent on the type of environmental events. Our present system for example is not covering oceanic processes relevant to high-frequency surface conditions such as swell and tsunamis. Swell prediction should eventually be incorporated into the system, as swell can greatly affect the flushing of the lagoon; tsunami prediction relies greatly on international networks of observation and alert, as well as local expensive moored stations. In conclusion, if progress can be made to meet some hypothetic usefulness standards, the present first approach towards building affordable marine forecast systems has reach its main objectives and leaves us with an encouraging prospect.

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