Wealth From Oceans project:

Linking models to sensor networks (LMSN) – an operational modelling platform for INFORMD (2009-2011)

Final Summary Report

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CMAR Hobart 2011

Summary

This document summarises major achievements of a three year "Linking models and sensor networks" project and gives a brief description of a number of issues identified (but not addressed) during the course of this study. More detailed description of the project developments and achievements is available through the attached milestone reports. The project goal was to develop the state of the art models for South East Tasmania (SETAS) integrating across hydrodynamics, wave dynamics, sediment transport and biogeochemistry. The modelling system is anticipated to run in near real time (NRT) and have the data assimilating capabilities. Tools and platforms developed in this project are to be transferable to other coastal regions.

To achieve objectives of this ambitious project, two operational hydrodynamic models, one of the South-East Tasmania continental shelf region (the SETAS model) and a higher-resolution model of Storm Bay and the Derwent and Huon Estuaries (the STORM model) have been developed. These models run operationally on linux servers in both near-real time and forecast modes, predicting three-dimensional fields of temperature, salinity and currents in Storm Bay and environs, with the results routinely posted onto the public website (http://www.emg.cmar.csiro.au/). The SETAS hydrodynamic model was coupled to the pilot wave, sediment transport and biogeochemical models (Wild-Allen et al., 2010). All these models run in near real time, but only the hydrodynamic model output has been posted on the public web-site; the delivery of the wave, sediment transport and biogeochemical model outputs has been postponed until the corresponding models are calibrated and tested. To facilitate such calibration study, two data assimilation schemes have been developed and implemented. One of these schemes, based on Kalman Filter Optimal Interpolation, was tested with the hydrodynamic model and glider data (Jones et al., 2011). Another scheme, based on statistical surrogates of complex models, has been implemented with the SETAS sediment transport model (Margvelashvili et al., 2010; Margvelashvili and Campbell, 2011). Tools and techniques developed through the LMSN project have contributed to a number of the ongoing WfO projects (GBR, SEQ). The modelling platform established through this project substantially enhances current modelling capabilities in SETAS and underpins further project developments in other regions (eg e-reefs)

Despite the progress we made in this project, a number of issues have been identified critical to the successful operation of the developed system and essential for the further uptake of the developed tools in other areas. SETAS models have not been calibrated and only a trial application of the data assimilation techniques has been carried out. The quality of the modelling products is largely unknown. A preliminary evaluation of the model has been carried out during this project life-time however more rigorous data model comparison and evaluation of the data-assimilation schemes is needed. We have a very limited understanding of capabilities of the assimilation techniques when implemented to complex biogeochemical models. Furthermore the robustness of this recently developed operational system in terms of the failure (and uncertainty) of numerous near real time inputs required by the model is not well known.

To summarise, while the project objectives have been achieved and near real time modelling capabilities for integrated coastal models have been established, the project

study has not been exhaustive. Further research and experimenting is required to refine the modelling system and better understand the quality of final products.

Publications and conference presentations

Jones E., P. Oke, J. Parslow. 2010. A data assimilation system for operational coastal hydrodynamic model, Poster presentation submitted to AMSA 2010 conference, Wollongong NSW, 4-8 July.

Margvelashvili N. 2011. Sequential data assimilation in fine-resolution models using error-subspace emulators: theory and preliminary evaluation. Submitted to Journal of Marine Systems.

Margvelashvili, N., J.S. Parslow, M. Herzfeld, K. Wild-Allen, J. Andrewartha, F. Rizwi, E. Jones. 2010a. Development of Operational Data-Assimilating Water Quality Modelling System for South-East Tasmania. Conference paper presented at OCEANS10 conference, Sydney, May 2010.

Margvelashvili N., J. Andrewartha, M. Herzfeld, V. Brando and B. Robson. 2010b. Bayesian assimilation of satellite data into a 3D coastal sediment transport model: preliminary evaluation and results. Paper presented at “Coast to Coast” conference, 20-24 September, Adelaide, 2010.

Jones E., Oke P., Rizwi F., Murray L. 2011. Assimilation of glider and mooring data into the coastal ocean model. Submitted to Journal of Geophysical Research, 37 p.

Margvelashvili N. 2010. Dimension reduction and emulation of computationally expensive models. Conference paper presented at TechFest conference, Hobart, March 2010.

Margvelashvili N. 2010. Dimension reduction and emulation of fine-resolution data-assimilation models. Presentation delivered at Catchment 2 Coast Community of practice workshop, Brisbane, May 2010.

Andrewartha J., M. Herzfeld, E. Jones, N. Margvelashvili., M. Mongin, J. Parslow, F. Rizwi, J. Skerratt, K. Wild-Allen. 2009. Development of an operational data-assimilating water quality modeling system for South-East Tasmania. Poster presentation delivered to Derwent symposium, Hobart, 2009.

Wild-Allen K, Skerratt J , Rizwi F and Parslow J. 2010. ICES Annual Science Conference CD. 20-24th September Nantes France. Theme Session A: Operational oceanography for fisheries and environmental applications. Towards operational biogeochemical modelling for resource management of coastal waters, 43-47.

Annual progress report (June 2011)

Gillibrand P., Andrewartha J., Rizwi F., Jones E., Skerratt J.

1. Hydrodynamic Model Calibration

Background and Rationale

The Coastal Environment Modelling (CEM) Group has developed two operational hydrodynamic models during the LMSN project, one of the South-East Tasmania continental shelf region (the SETAS model) and a higher-resolution model of Storm Bay and the Derwent and Huon Estuaries (the STORM model). These models run operationally on linux servers in both near-real time and forecast modes, predicting three-dimensional fields of temperature, salinity and currents in Storm Bay and environs, with the results routinely posted onto the CEM website.

Although the objective of establishing near-real-time operational models has been achieved, the calibration and performance of the hydrodynamic models has not been quantitatively assessed. That calibration process is now underway, but raises a number of technical issues that need to be addressed. Coastal ocean models are typically calibrated by repeatedly running the model for a specified period of time in the past (i.e. performing a hindcast), and fine-tuning the free parameters in the model until errors between the model predictions and available data are minimised. The errors must be calculated by a quantitative metric. With the SETAS and STORM models, calibration is made more difficult because the models run in near-real time. For the STORM model in particular, running repeated hindcasts is not a feasible option because the model is too computationally expensive. This makes fine-tuning the free parameters in the model more problematic, since the errors must be calculated during on-going near-real-time simulations, when surface forcing and open boundary conditions are changing and also affecting the performance of the model. There is therefore no baseline, or control, against which to assess whether changes to parameter values are improving the model performance through the internal physics. Unlike the STORM model, the SETAS model is computationally efficient enough to repeatedly rerun a chosen hindcast period, and can thus be calibrated in a standard fashion. Once an optimal set of parameter values has been established, those values can be transferred to the operational model. The challenge then is to assess how the optimized parameter values for the SETAS model can be transferred to the operational STORM model. The optimal parameter values for the SETAS model may or may not be optimal for the STORM model. Currently there is no established protocol for transferring parameter settings between the two models, nor an understanding of how the settings in the two models may be related. The best approach to calibrating the STORM model remains an unresolved challenge.

Data Availability for Model Calibration

A number of datasets are available for calibrating and evaluating the performance of the SETAS and STORM models. The prime requirements for a calibration dataset are temporal and/or spatial coverage and, given the need to calibrate/evaluate operational models, on-going observational status. Given these requirements, we are focussing on the following five datasets for model calibration:

1. The glider observations (temperature, salinity) on a transect through Storm Bay;

2. The ICT low-cost sensor network in the Derwent and Huon Estuaries;
3. Deployments of moored instrumentation in Storm Bay and the D'Entrecasteaux Channel;
4. Routine (monthly) water sampling and CTD profiling conducted by the Derwent Estuary Programme (DEP);
5. High-resolution satellite imagery of sea surface temperature available through IMOS.

These data streams are all collected routinely and archived in disparate databases, but can be readily accessed for model calibration.

Calibration of the SETAS Model

We have chosen April 2009 as the period for multiple runs of the SETAS model to optimise parameter values. During this period, the glider was operational for 26 days of the month, by far the best temporal coverage. CTD data at 28 stations from the DEP have also been collated and reformatted into a convenient format for model calibration. Low-cost sensor data are available for the CSIRO Wharf, Cape Deliverance and the Channel sites, and remotely-sensed sea surface temperature are available at about 1 km resolution. No mooring data were available during this period. We intend to use two metrics to quantify model performance: the root-mean-square (RMS) error, and a model "skill" indicator, d_2. The d_2 metric lies in the range $0 \leq d_2 \leq 1$, where a value of zero means there is no agreement between model and data, and a value of one means that there is perfect agreement. These metrics will be applied to all datasets used to calibrate the model, and software has been prepared to accomplish this.
Initial comparisons of model predictions and observed data suggest that the modelled temperature and the strength of the predicted stratification along the glider transect can be improved (Fig. 1). Initially, therefore, the calibration focus will be on:

1. the surface heat flux boundary condition (parameter values of heat transmission, attenuation and seabed absorption), and
2. the vertical mixing scheme deployed in the model. At present a k-e scheme is used in the operational model, but a number of alternative schemes are available and the choice of mixing scheme and associated parameters is known to influence the accuracy of predictions of velocity, temperature and salinity in coastal waters.

The SETAS model takes about 9 hours to run a two-month simulation (the simulation runs from 1 March 2009 – 1 May 2009 to allow the influence of changed parameter values to be assimilated into the model predictions during March before the calibration period of April 2009). This allows only a single calibration simulation to be made each day.

Progress To Date

To date, data have been assembled for the calibration period (April 2009), and software written to calculate the quantitative metrics for the various formats of model output and data that must be compared (Fig. 2). Model calibrations runs have commenced, and are being run daily. Nevertheless, the calibration progress is still in the early stages, and the changes to parameter settings so far have made only marginal differences to the model performance.

Future Plans

Once an optimal parameter set has been established for the SETAS model in April 2009, the parameter values will be transferred to the operational SETAS model. In addition, a 16-month-long simulation of the SETAS model, from July 2009 – November 2010 is planned. The purposes of this run are to test the performance of the model over a longer time period, and to provide hydrodynamic forcing for the biogeochemical model to run over the same period.
Once the SETAS model is calibrated, focus will shift to the calibration of the STORM model. It is envisaged that the optimal parameter values for the SETAS model will be transferred directly to the operational STORM model. Further fine-tuning of the STORM model parameter values will necessarily be done in near-real time mode, using the same metrics and datasets as for the SETAS model.

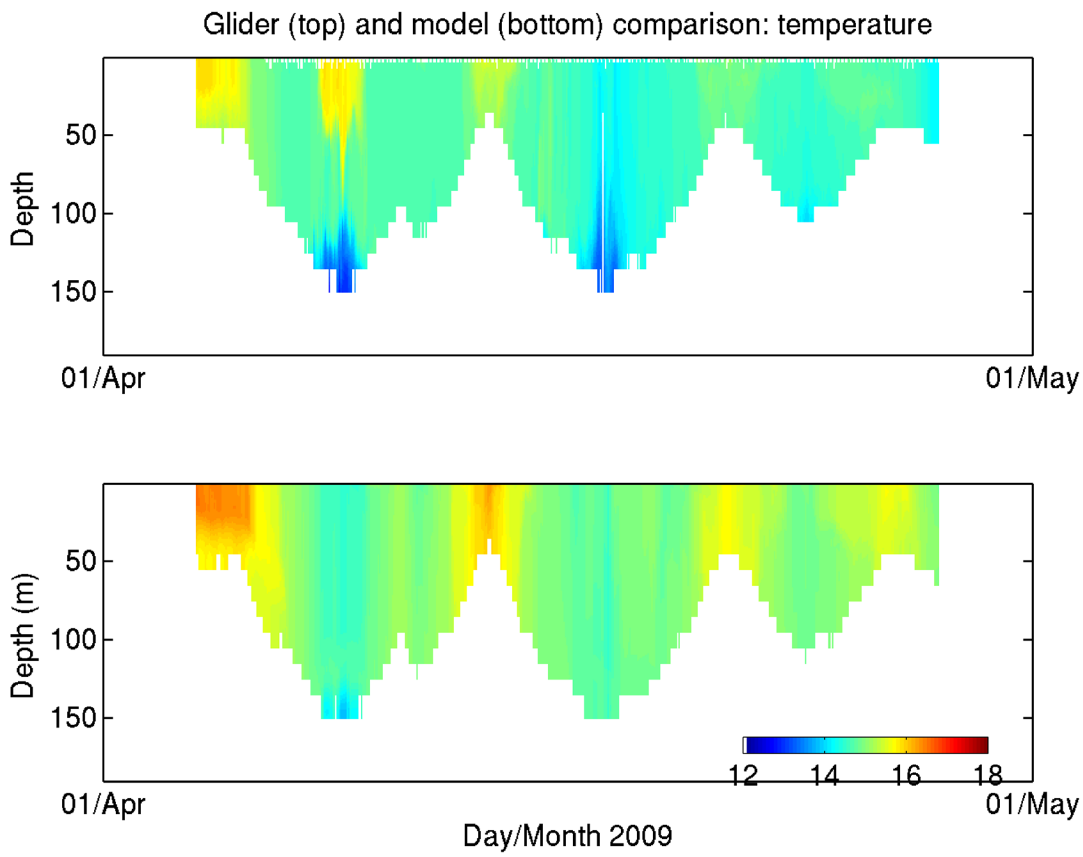


Figure 1. Comparison between observed temperature along the glider transect in Storm Bay for April 2009 (top), and the model predictions at the same times and locations (bottom).

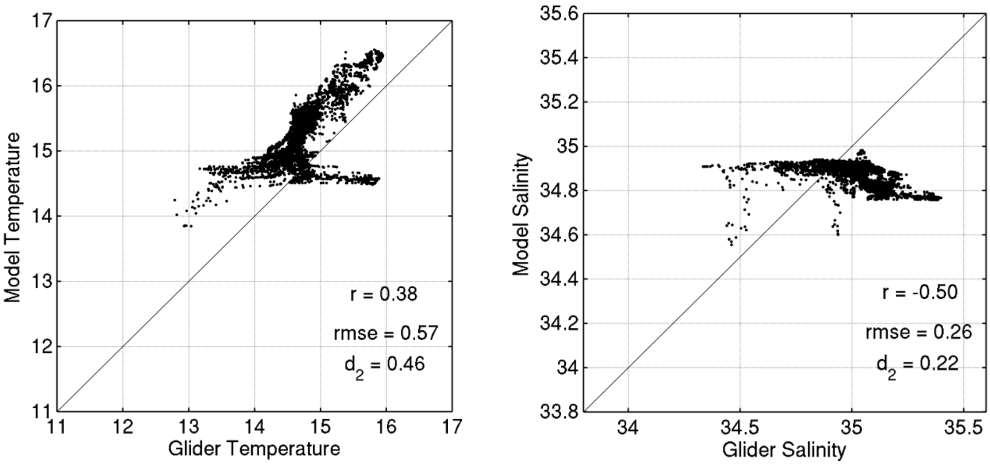


Figure 2. Comparison between glider observed and modelled temperature (left panel) and salinity (right panel) along the glider transect in Storm Bay for April 2009. The calculated correlation coefficient (r), RMS error (rmse) and model skill (d_2) are shown for each variable.

2. Data Assimilation

A new DA library has been developed for EMS and applied to the SETas model. It is based on the application of an Ensemble Optimal Interpolation scheme developed by Emlyn Jones. The scheme uses a large static ensemble to estimate the systems background error covariance matrix. It works by first running in forecast mode to obtain the background fields of the state variables then together with the BEC and observations, calculates the values of the state vector to relax (nudge) to. The model is then re-run over the DA period but this time the state variables are relaxed. At the end of which we restart the forecast run for the next period and repeat the whole process.

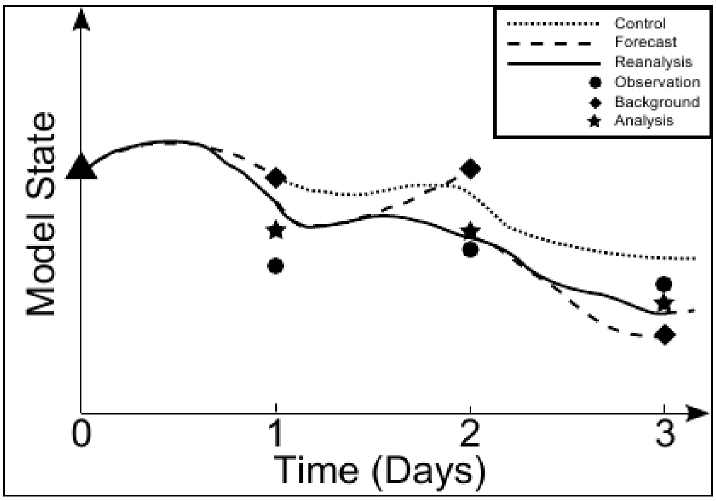
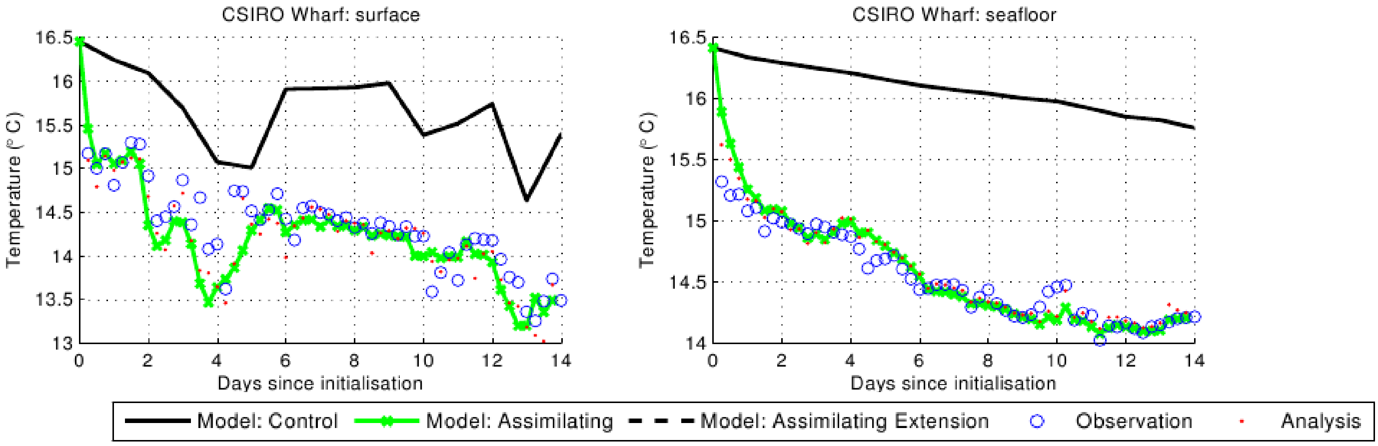


Illustration of the DA cycle

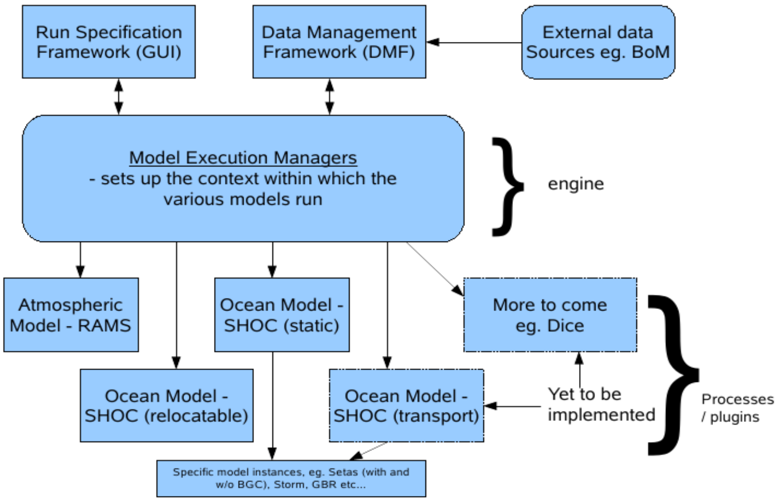
Thus far this scheme has been applied to a hindcast run of the setas model during April '09 with great results. It assimilated the wharf temperature and salinity data as well as some of the glider data in Strom bay for part of the period. One example of the result is shown below where clearly there is excessive heat in the model



The new library allows for automated data assimilation. i.e. the model is setup with DA parameters (in the prm-file) and observation files and it handles all of the calculations online as the model is run, intrinsically implementing the DA cycle without any manual intervention to stop and restart.
The library has been fully tested but still has some minor code corrections that need to be completed before final check-in into the repository. After which time it will be possible to run a parallel near-real time data assimilating version of the setas model. The exact details of which parameters (eg. assimilation period and variables) as well as the data streams (wharf node, huon11 mooring, glider data) are still to be decided.
The formal description of the DA algorithm is contained in a manuscript that will be submitted to Ocean Modelling. We discuss the algorithm, implementation and sources of model error in detail. We intend to trial and Ensemble Kalman Filter scheme that can be extended to parameter estimation and identification of errors in the exogenous model forcing. This will increase the efficiency of model calibration and give quantitative error metrics that can be used in the model validation stage.

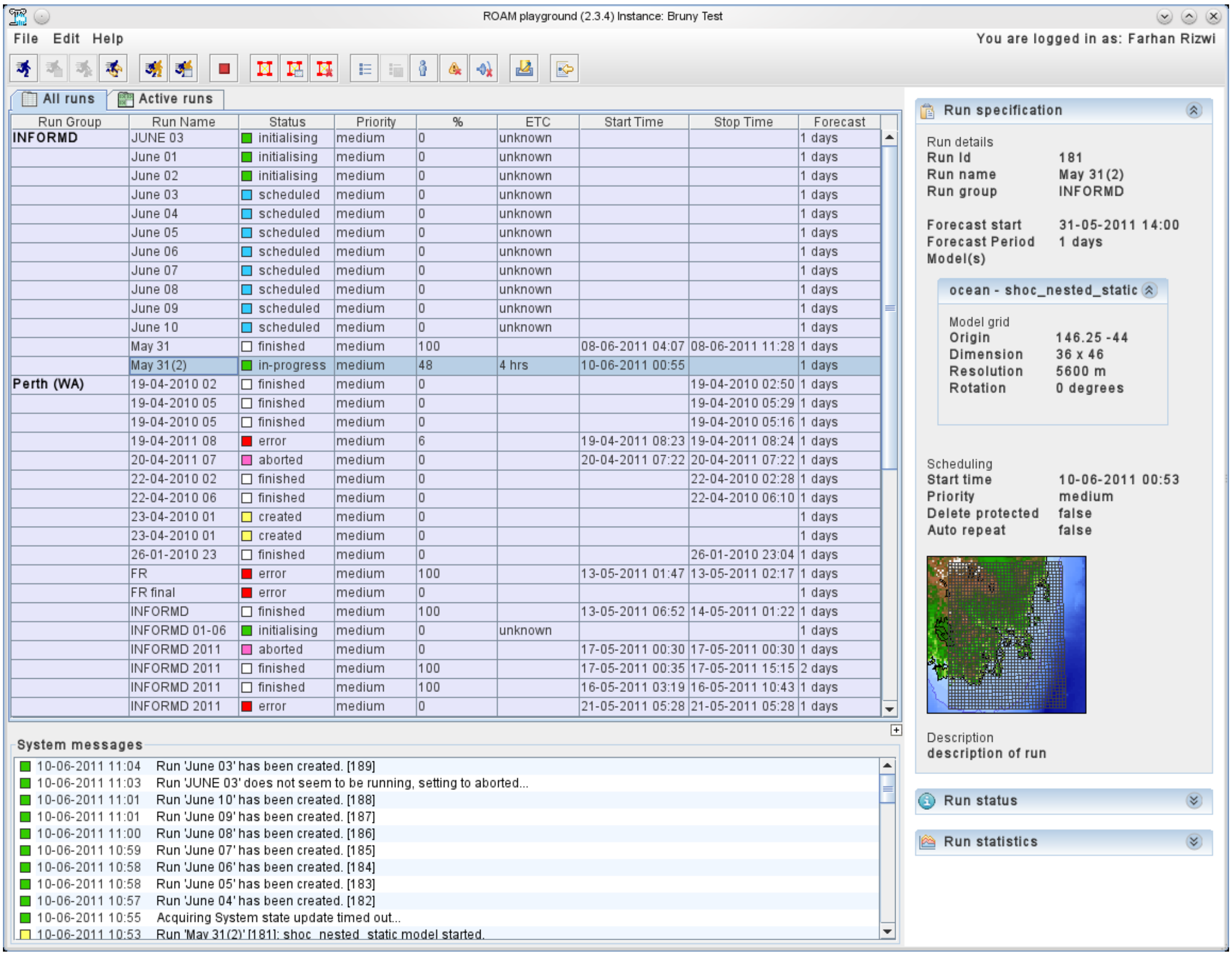
3. Trike

Trike is a model execution framework that was developed out of the Bluelink project that essentially allows for automated model runs. It includes a Data Management Framework (DMF) that handles download and registration of forcing files such as OceanMaps, access, river data etc.



Overview of the Trike environment

An instance of Trike is currently operational on Bruny. It has been set up to automatically run both the Setas and Storm model on a daily basis. It includes a GUI that can be used to configure model runs and track their progress. So far this has largely been a prototyping exercise. Next year will see the addition of an OpenDAP server to allow a convenient mechanism to access the output files, a facility to run hindcasts/scenarios as well as capability for running the transport model.



Example of the Trike GUI running on Bruny

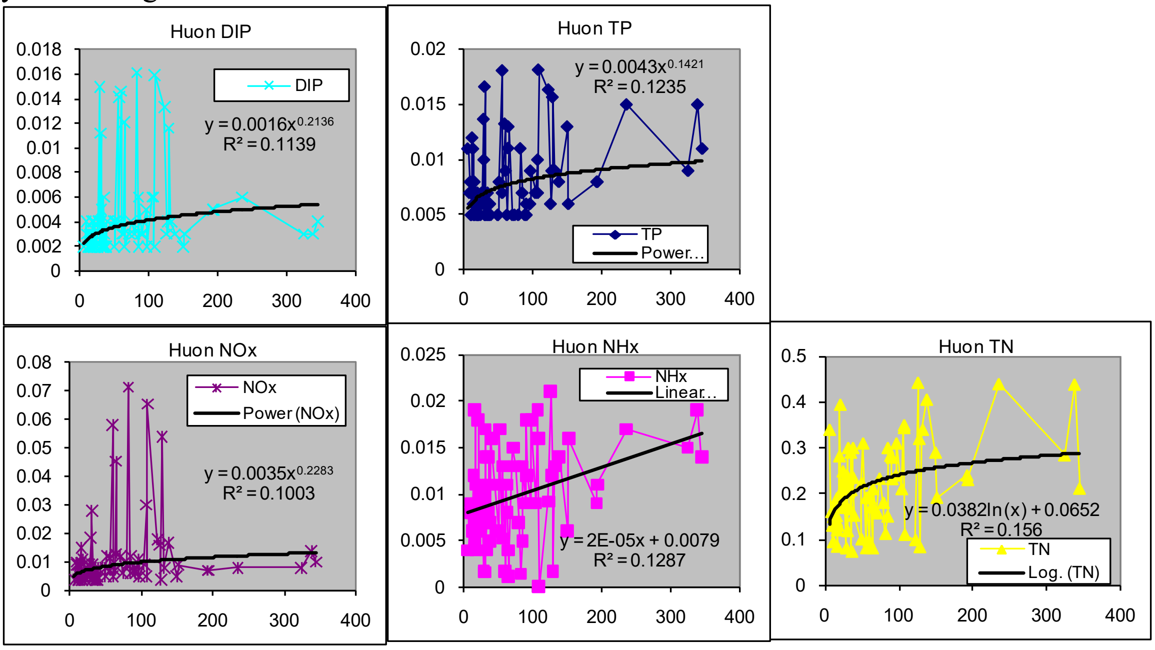
4. Wave Modelling

Presently the wave model is being run offline on Swell, independent to the scheduling set up to run the operation hydrodynamics and BGC. The operational wave model lacks a robust implementation and as such suffers from interruptions arising from power outages, network errors and loss of forcing data. Rather than continue to apply “band-aid” solutions to keep it running, our intention is run it within the Trike framework and register the required data streams with the Trike scheduler.

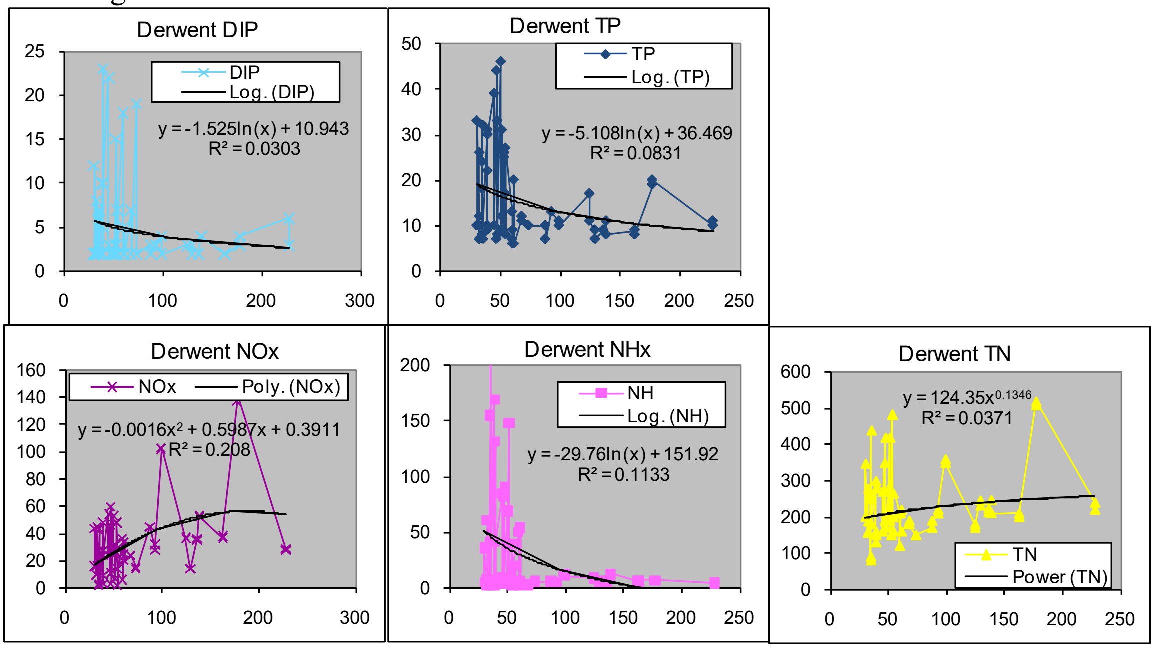
5 Integration of river nutrient and flow relationships into the SETas Model

Historical relationships between river flows and available nutrient data were analysed for the major rivers within the SETas model. A poor relationship was observed for all rivers. The best fitting relationships that were conservative in terms of nutrient against flow were chosen. For the small rivers such as Northwest Bay rivulet Esperance and the Jordan River average concentration per cumec were used due to very limited nutrient data. River flows into the model are automated and in real time.

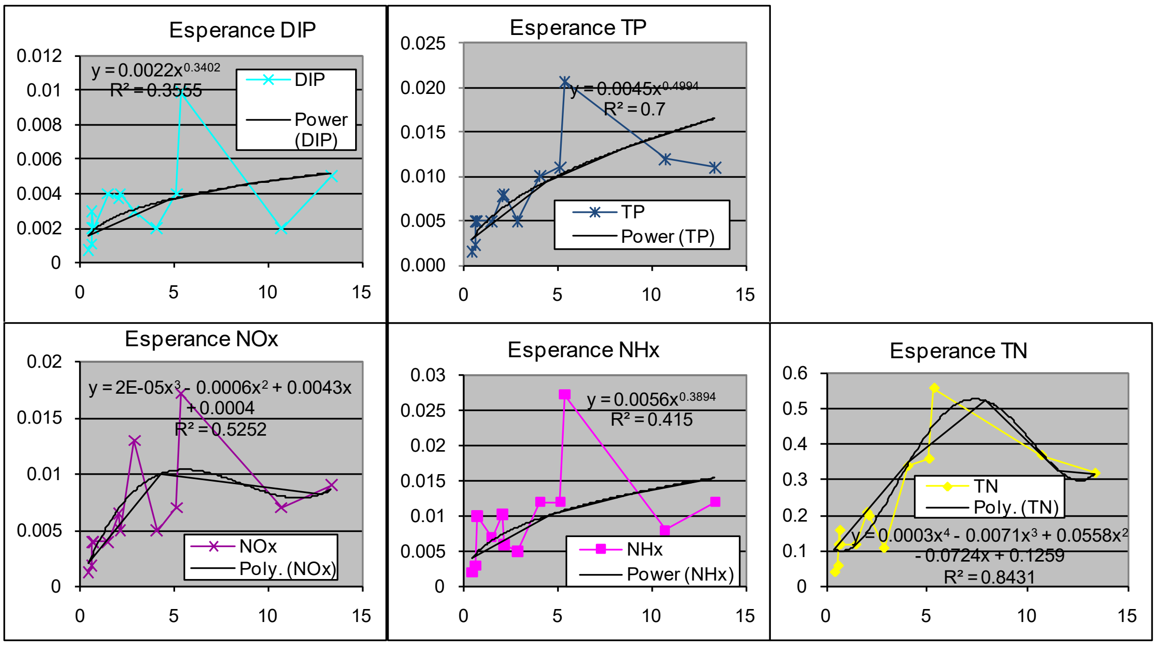
Huon River: Nutrient data from 1997 to 2010 (Frypan Island). Flow x axis in cumecs y axis in mg/L.



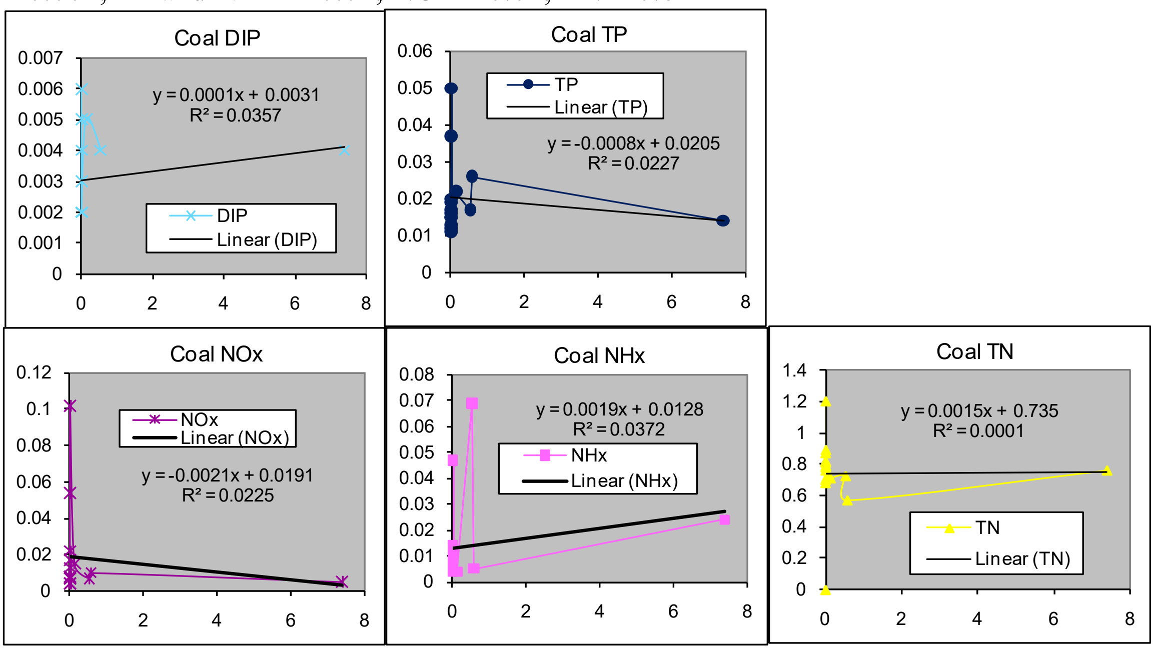
Derwent River: Nutrient data from 2003, 2008 and 2009. Flow x axis in cumecs y axis in ug/L.



Esperance: All nutrient data (Note this only contains 2008 and 2009 sporadic samples). Flow x axis in cumecs y axis in mg/L.



Coal river: All nutrient data from 1996 to 2009 (sporadic sampling). Flow x axis in cumecs y axis in mg/L. Due to limited observations model uses averages mg/L: DIP = 0.004, TP and NHx = 0.02, NOx = 0.04, TN = 0.8



Jordan River: NHx, NOx and TP = 0.1mg/L; DIP = 0.01 mg/L; TN = 1.5 mg/L

North West Bay rivulet (Snug): NOx = 0.1 mg/L; DIP, TP and NHx = 0.01 mg/L; DIP. = 0.003 mg/L, TN= 0.35 mg/L.

Second year progress report (June 2010)

Margvelashvili N., Herzfeld M., Andrewartha J., Jonson E., Wild-Allen K., Rizwi F.

First year of the LMSN project (June 2008-June 2009) delivered operational hydrodynamic models of the SE Tasmanian coast. These models have been successfully operating for more than 10 month, uploading near real time products (temperature, salinity, surface elevation, currents) to the open access public web-site (http://www.emg.cmar.csiro.au/). Second year of the LMSN (June 2009- June 2010) focused on the development of data assimilating capabilities for these models, and the development of a pilot sediment transport and biogeochemical (bgc) reaction models. This year we have also commenced the development of the data assimilating capabilities for the sediment transport model.

A conservative approach, based on established technique (Ensemble Optimal Interpolation), has been taken for the data assimilation into the hydrodynamic model. The developed assimilation scheme was tested through the assimilation of in-situ data from moorings and data from Slocum glider deployments in Storm Bay (Jones et al., 2010). Preliminary results show a substantial improvement between the control (non-assimilating) and assimilating runs of the model with up to 90% reduction in RMS error (fug. 1). There are a number of improvements that are being investigated including assimilating other available data streams such as remotely sensed sea-surface temperature, improving the representation of tides in the analysis scheme and parameter estimation within the HD model. However, our current implementation of the Ensemble Optimal Interpolation scheme has shown a substantial improvement over the non-assimilating control run.

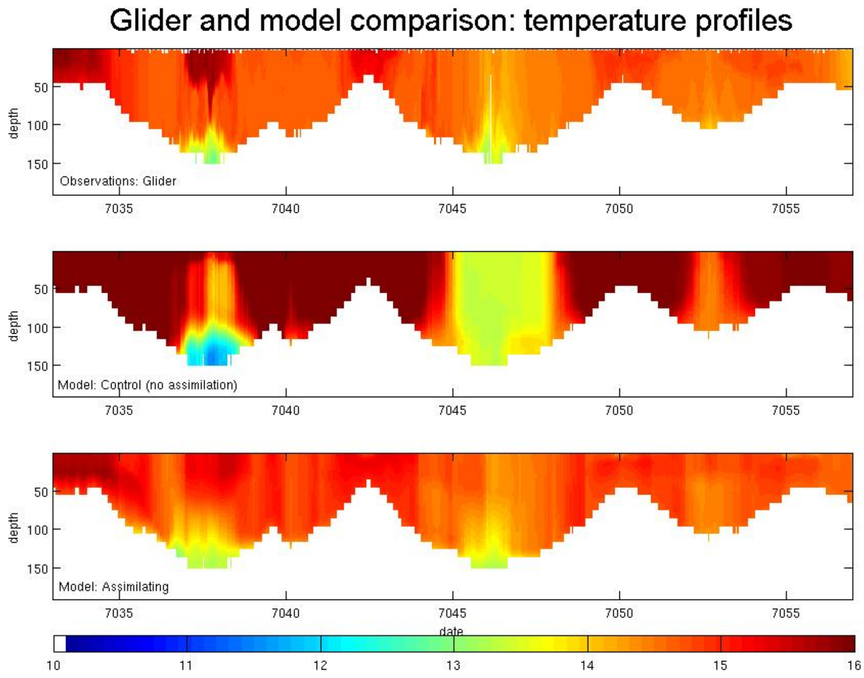
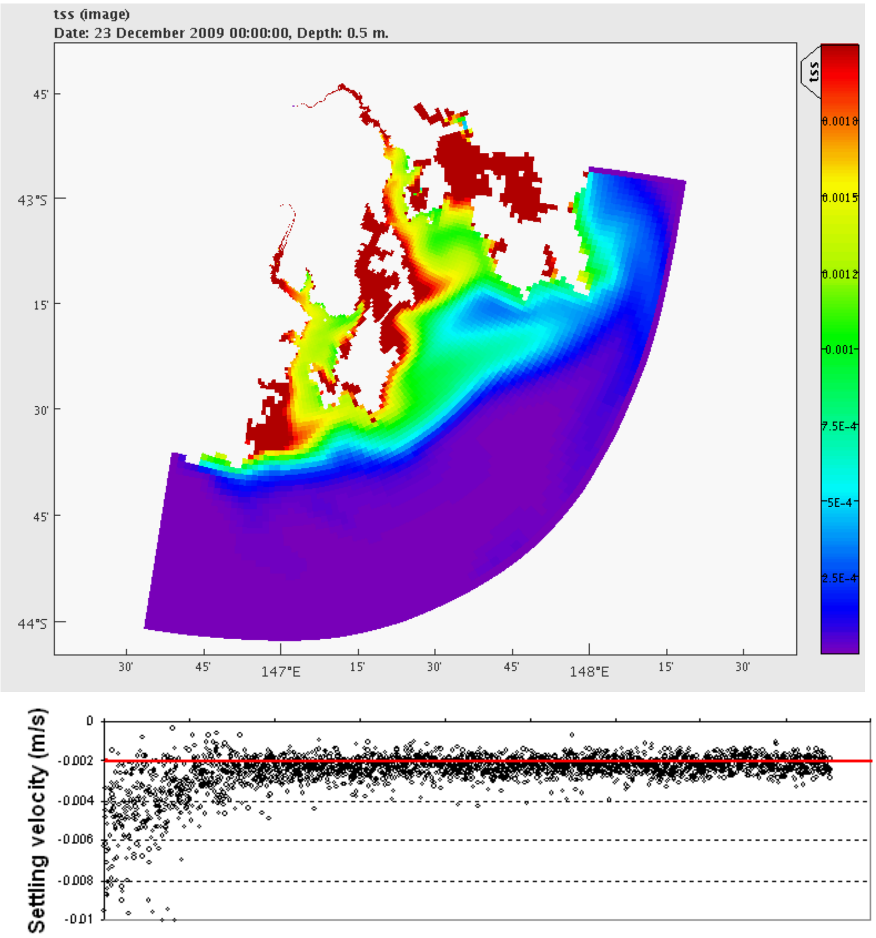


Fig. 1: A comparison of temperature profiles collected along a repeat glider transect through central Storm Bay. Glider Observations (top panel), model: control run (central panel) and model: assimilating run (lower panel).

Sediment and biogeochemical models are often required to deliver evaluations of long-term management scenarios rather than short-term forecasts. Such long-term simulations tend to be more sensitive to the specification of the model parameters and processes rather than initial conditions, and are more analogous to climate modeling than ocean forecasting. Applications of the Ensemble Optimal Interpolation schemes to the problem of the combined parameter-state estimation are much less advanced compared to the state evaluation problem. This prompted us to experiment with an alternative assimilation scheme which is based on fast and cheap statistical surrogates of complex models and is anticipated to be better tailored to the sediment/bgc model needs. In LMSN for the first time this scheme has been implemented and tested with a 3-d fine resolution operational–research coastal model (Margvelashvili et al., 2010b,c). The model simulates transport of two size-classes of the suspended sediment and assimilates 12 hourly sediment concentrations at the surface produced by the “twin” model run. The assimilation procedure updates 3 model parameters (2 settling velocities and the bottom roughness) and 4 state variables (concentration of 2 sediment fractions in benthic and pelagic layers). As illustrated in figure 2, the assimilation system gives reliable estimates of the unknown parameters and concentrations, encouraging further development of the technique.



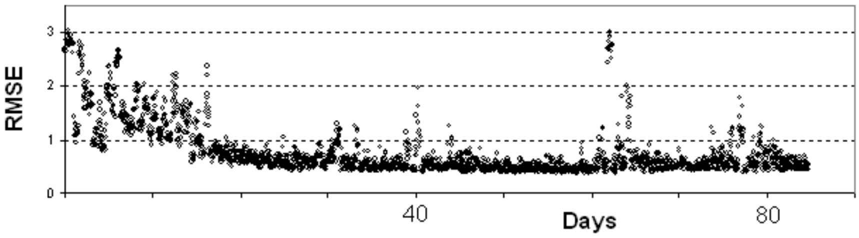


Figure 2. Surface suspended sediment concentration (top) and estimated settling velocity and RMSE (bottom) of the predicted concentrations. The concentration is given in kg m-3, and the red line shows "true" settling velocity.

Both data assimilation into the hydrodynamic model and data-model fusion for the sediment transport model are implemented in off-line mode. Operationalisation of these assimilation schemes is anticipated to evolve through the further development of the ROAM framework. Refinements of the ROAM continued in year 2 of LMSN. Further modifications will be needed in year 3 to switch over to newly established ACCESS instead of Meso-Laps input files to drive the operational hydrodynamic models.

Preliminary analysis on a 7 year record of Tasmanian chlorophyll, CDOM and SST (given by the remote-sensing products) has been completed. Results show a decline in Storm Bay spring bloom amplitude over the 7 year period coincident with an increase in winter temperatures off SW Tasmania. These observations are correlated with the SOI suggesting that changes in El Nino / La Nina conditions over the past 7 years could account for the reduction in Storm Bay spring bloom intensity. Point source nutrient load data for fish farms, sewage treatment plants and rivers throughout the model domain have been obtained to provide input into the bgc model. Application of the pilot bgc model to the study region shows unstable behavior of the code. The reasons of this instability are being investigated.

Progress made in LMSN has facilitated the development of the contaminant project pre-proposal for the SETAS/Derwent estuary region. This pre-proposal, compiled in collaboration with CMAR scientists, is intended as a background material for consultations with the potential stakeholders and clients. The project aims at the development of operational monitoring/ assessments capabilities for heavy metals concentration in the INFORMD region.

Next year of LMSN we plan to consolidate developments of the first two years (ie completion of the ROAM and integration of operational modules) and to refine and further explore the developed data assimilation schemes.

References

Jones E., P. Oke, J. Parslow. 2010. *A data assimilation system for operational coastal hydrodynamic model*, Poster presentation submitted to AMSA 2010 conference, Wollongong NSW, 4-8 July.

Margvelashvili N. 2010a. *Sequential data assimilation in fine-resolution models using error-subspace emulators: theory and preliminary evaluation*. Paper submitted to Journal of Marine Systems.

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Andrewartha J., M. Herzfeld, E. Jones, N. Margvelashvili., M. Mongin, J. Parslow, F. Rizwi, J. Skerratt, K. Wild-Allen. 2009. *Development of an operational data-assimilating water quality modeling system for South-East Tasmania*. Poster presentation delivered to Derwent symposium, Hobart, 2009.

Wild-Allen K, Skerratt J , Rizwi F and Parslow J (2010) ICES Annual Science Conference CD . 20-24th September Nantes France. Theme Session A: Operational oceanography for fisheries and environmental applications. Towards operational biogeochemical modelling for resource management of coastal waters, 43-47.

First year progress report (June 2009)

N. Margvelashvili, M. Herzfeld, K. Wild-Allen, J. Andrewartha, F. Rizwi,
J. Skerratt

1. Summary

This document reports first year progress made in "Linking models and sensor networks" project. The project aims at the development of operational models for South-East Tasmanian region integrating across hydrodynamics, sediment transport and biogeochemistry, and assimilating data from sensor networks and other sources. This fist year of the project targeted three key areas (1) the development of operational hydrodynamic models (2) testing and evaluating transport models and (3) field work involving trial deployment of gliders and evaluation of the nitrate sensor. The data assimilation work and the development of pilot biogeochemical model are planned to commence in the second year of the project.

Operational Hydrodynamic model

The success of operational modelling requires near-real time access to the data streams to force and validate models. This includes global model products, atmospheric products, river flows and assimilation-data to test and improve numerical algorithms. ROAM (Relocatable Ocean and Atmospheric Model) is an initiative developed under BlueLink to provide high resolution ocean forecast products operationally. One of the main features of the ROAM is its tight integration and management of the data streams which provide forcing and domain information (e.g. bathymetry and coastline) for the simulation model. ROAM is a fully automated, self-contained, portable system. It provides a perfect platform to set up and run operational INFORMD models.

During the first year of the project, ROAM capabilities have been extended to allow for the development of operational hydrodynamic models in the INFORMD region nested into BlueLink. This involved integration of new data streams and expanding ROAM capabilities to handle static parameter files, curvilinear grids, as well as building new infrastructure to handle nested model runs. The developed operational models routinely provide daily maps of temperature, salinity, sea level and circulation in the Derwent and Huon Estuaries, D'ntrecasteaux Channel and Storm Bay. The simulation suite consists of an outer coarse resolution model (SETAS) which nests within the global forcing data and which runs the hydrodynamics at run time ratios of ~700:1, and an inner fine-scale model (STORM) which is forced by output from the coarse model, resolving the Huon and Derwent estuaries to about 100 m. The run time ratio of the fine-scale STORM model is ~5:1.

The developed models have been successfully operating in real-time for approximately 10 months. The simulated temperature, salinity and surface elevation

were tested against measurements, including observations from ICT sensors. A trial web-site has been set up to visualise models output in near real time. This web-site is anticipated to open for public access when its design is finalised and CSIRO approval procedures are completed.

Evaluation of Transport model

The hydrodynamic model includes a transport option which invokes the tracer transport based on offline velocities and vertical diffusivities read from file. The advection scheme used in this mode is an unconditionally stable semi-Lagrangian scheme, allowing increased time-steps to be used which dramatically increases run time ratios. This scheme is, however, quite diffusive and, unlike some other schemes, does not guarantee mass conservatio, so some accuracy is forfeited to gain speed. Nonetheless, it is not practical to run fully-coupled biogeochemical models on large high-resolution grids such as the STORM model, so development and testing of the transport model is necessary if we are to realise project goals in this project (and in several other new coastal modelling projects). To test the transport model, we ran numerical experiments with the hydrodynamic and sediment transport models in the Huon Estuary and D'Entrecasteaux channel.

The transport model, running with a 1 hour time-step, has been tested against the fully coupled model running with the time-step of 2 minutes. The results show that the transport model is capable of reproducing key patterns of distribution of the particulate and dissolved tracers in the Huon estuary and D'Entrecasteaux channel. The price for the improved efficiency is a higher uncertainty of the decoupled model. This uncertainty shows up in a random fluctuation of the predicted values as well as in systematic discrepancies, such as the tendency of the decoupled sediment model to underestimate peak suspended sediment concentrations. One of the implications is that parameter values obtained through calibration of the fully coupled model may not be applicable to the transport model, so that sediment and biogeochemical models based on the transport model may need to be calibrated independently.

Simulations reported in this document dealt with the moderate energy environment of the Huon estuary and D'Entrecasteaux channel. The main objective was to assess applicability of the transport model to the INFORMD region. Most of the simulated scenarios show a good match between transport and fully coupled models. However, the transport model gave poor performance for heavy sediments in idealistic scenario of the decoupled benthic and pelagic layers. More numerical experiments in various environments, including macrotidal and off-shore deep waters, are needed to have a better understanding of the transport model uncertainty. In the case of new applications it is recommended first to run trial scenarios testing the transport model against the fully coupled code.

Field work

During the first year of the project two field programs have been carried out. One of those involved trial deployment of gliders in Storm Bay and the other involved evaluation of an in situ nitrate sensor in a short-term deployment off the CSIRO wharf and a 3-month deployment in Storm Bay.

Gliders

The CSIRO's Slocum Glider, designed for coastal deployments, is capable of moving to specific locations and reaching depths of up to 200 meters by tracking controlled spatial and temporal grids for a maximum duration of about four weeks. The glider moves both vertically and horizontally, sampling saw-tooth vertical profiles by varying its buoyancy.

The first glider deployment in Storm Bay, commenced in mid November 2008, was terminated after 4 days due to malfunctioning of the instrument component. During the second deployment in June 2009 the glider completed a successful 26-day monitoring of Storm Bay and covered 490 km in its voyage of north–south transects criss-crossing the bay and diving to depths of 15 to 160 metres. During the voyage, onboard sensors collected 400 megabytes of data including: temperature, salinity, dissolved oxygen, chlorophyll A, and backscatter of suspended materials at both 470 and 700 nm wavelengths. Highlights from the glider deployments have been given in CSIRO "Monday mail" of 1 December 2008, and in "Wealth from oceans flagship: oceans insider" of June 2009.

ISUS Evaluation.

The influx of nutrients, particularly nitrate, into coastal biogeochemical models at the marine boundary is currently poorly constrained by traditional monthly sampling programs. Modern instrumentation such as the In-Situ Ultraviolet Spectrophotometer (ISUS), have the potential to provide nutrient concentrations with high temporal resolution, which is particularly relevant in the context of operational modeling.

Having successfully completed 2-months trial deployment of ISUS off the CSIRO wharf in October-November 2008, a bottom mounted mooring frame with attached ISUS has been deployed in Storm Bay in May 2009. The frame also accommodated a multi-sensor CTD including dissolved oxygen and chlorophyll sensors, and an ADCP. The ISUS mooring was successfully recovered in June 2009 after ~3 month deployment. However due to failure of internal clocks, the ISUS instrument only logged 2.5 days of nitrate data at the start of the deployment. Communications with manufacturers are underway to further investigate the logging problem. The Storm Bay mooring also collected 3 months of ADCP data and 20 days of temperature, conductivity, PAR, pressure, fluorescence, and oxygen data.

2. Operational Hydrodynamic Models

(M. Herzfeld, J. Andrewartha, F. Rizwi)

Over the last decade CMAR has applied hydrodynamic models to a variety of coastal regions throughout Australia. Usually the interest in these regions from stakeholders focuses on sediment transport or biogeochemical issues, consequently the hydrodynamic applications are developed to facilitate coupling with sediment transport or biogeochemical models. To date the approach has been to nominate a study period, usually an annual cycle, and collect data during this period to force and calibrate the models. The drawback of this approach is that at the project's termination, the model products are applicable only to the nominated year, and as time goes by these products may lose their relevance. Often stakeholders are interested in what is happening now, not what has happened 5 or 10 years previously. To update the models to the present day situation often requires considerable effort. However, this approach has been of value in the past, since the nominated year may be easily simulated to correspond to various management scenarios (e.g. increased river flow, increased nutrient input) that project trends and assist managers in decision making.

The recent advent of numerous global operational products (e.g. BlueLINK) allows the current approach to be substantially improved. Rather than collect data to force the model for a defined period, products are now available in near-real time. Utilising these data, this allows for near-real time modelling products to be developed. The strategic focus of modelling is now beginning to shift from hindcasts for a fixed period to operational nowcasts and even forecasts. The advantage of this approach is that, once the system is operational, a picture of the ocean state relevant to the last 24 hours can be generated indefinitely, potentially allowing many years of modelling output to be archived. A secondary advantage is that the resolution used by the models may be substantially increased. Traditionally annual simulations require run-time ratios of ~100:1 (100 model days in 1 day real time) so that the simulation completes in ~3 days, which is a manageable timeframe for calibration and analysis purposes. A nowcast model product only requires the previous 24 hours to be simulated in ~12 hours or less, i.e. runtime ratios of ~2:1 are acceptable allowing model speed to decrease hence resolution to increase. Calibration and analysis would become ongoing in this environment.

The success of this methodology requires near-real time access to the data streams required to force and validate the model. This includes global model products, atmospheric products and river flows. Additionally, data assimilation techniques have been developed for regional hydrodynamic models (within BlueLINK) which are transportable to such an operation system, potentially leading to improvement of the accuracy of model predictions. Again, for this data assimilation to be successful a robust real-time data measurement, retrieval, quality assurance and delivery system must be in place.

The Derwent / D'Entrecasteaux region seems a perfect environment to pilot such a near-real time operational system. There has been considerable experience gained previously by applying hydrodynamic, sediment and biogeochemical models to the region (Aquafin Phase I and II, Derwent CCI). The ICT initiative aims to provide real-time data via a sensor network throughout the region. Numerous stakeholders have expressed a desire to access high resolution modelling products of the region.

This report describes the development of a near-real time modelling system capable of providing currents, temperature, salinity and sea level distributions over the area encompassing Storm Bay, Derwent Estuary, D'Entrecasteaux Channel and Huon Estuary at high resolution (~100 m). Boundary conditions will be provided by OceanMAPS products and measured river flow. Surface fluxes are to be provided by the Bureau of Meteorology's model product MesoLAPS (http://www.bom.gov.au/nmoc/bulletins/39/opsbul39.shtml#skip) in near-real time. The ICT is to provide temperature, salinity and sea level data that will be assimilated into the hydrodynamic model. The model will simulate the previous 24 hours over an ~12 hour period every day (e.g. model runs from 6pm to 6am). Detailed maps of temperature, salinity, sea level and circulation will be available for the previous day. It is possible that the forcing conditions from the previous day may be extrapolated into the future, allowing the model to be run in forecast mode.

Sediment transport and biogeochemistry (BGC) are also of interest to end users. Due to run-time constrains it will not be possible to fully couple these models to the hydrodynamic model. Rather, offline velocity and mixing data saved from the hydrodynamic model simulation will be used in a transport model to facilitate advection and diffusion of sediment and biogeochemical variables. This transport model is many orders of magnitude faster than the fully coupled models, hence allowing near-real time sediment and biogeochemical products.

2.1. Modelling Strategy

The operational model aims to provide daily maps of temperature, salinity, sea level and circulation in the Derwent and Huon Estuaries, D'ntrecasteaux Channel and Storm Bay (Figure 2.1) at resolution down to 100 m. Due to the requirement that the ratio of the global ocean grid size to that at the boundary of the regional model should be ~5:1, and given the global products have a resolution of 10 km, it was not possible to cover this region with a single model and a two-tiered nesting strategy was developed. This suite consists of an outer coarse model (SETAS) which nests within the global forcing data and which runs the hydrodynamics at run time ratios of ~700:1, and an inner fine-scale model (STORM) which is forced by output from the coarse model, resolving the Huon and Derwent estuaries to about 100 m, and which runs the hydrodynamics at about 5:1. The high speed achieved by the coarse model allows run-time ratios of ~100:1 to be achieved when coupled to the biogeochemical model, thus enabling year-long scenarios to be run in say 3 days.

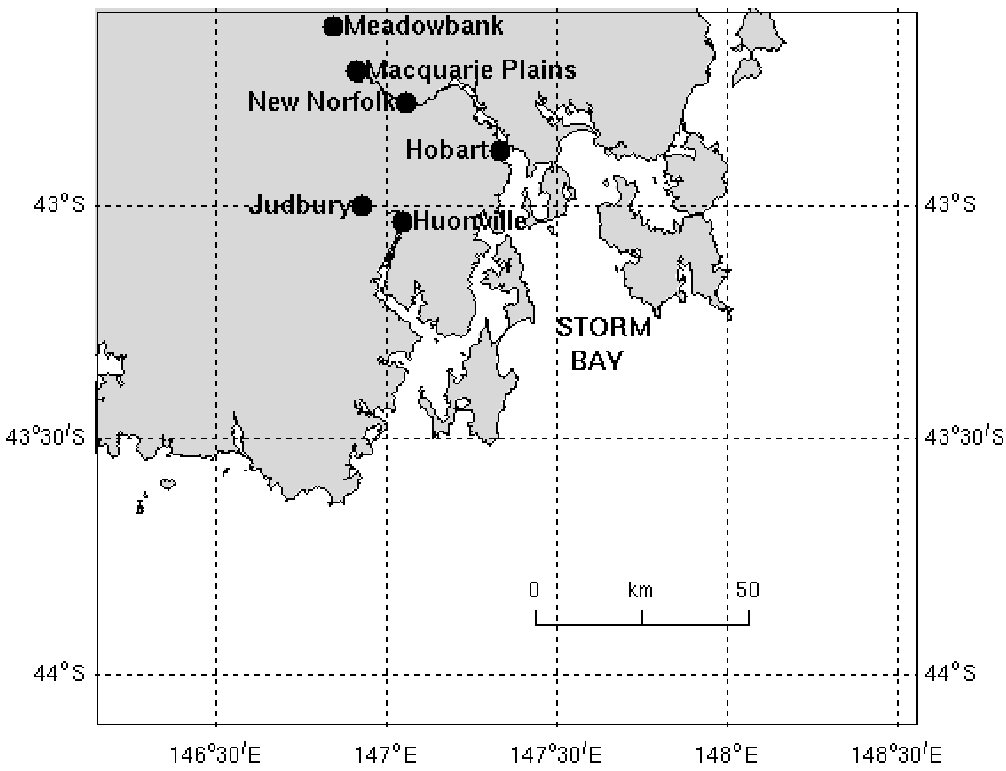

Figure 2.1. Map of the study region.

2.2. Topography Data

Coastline data was required to providing a land-sea mask when creating the model grid, and for clarity when presenting model results. The coastline data used originates from the Tasmanian State Government, originally obtained in 1999. This data set was supplied in AMG coordinates, and subsequently converted to WGS84 coordinates. The horizontal resolution is approximately 5-10 metres. Coastline data is plotted in Figure 1. It extends up the Derwent River to Macquarie Plains (beyond New Norfolk which is the accepted limit of the tides), and it extends up the Huon River to a point approximately 5km upstream of Huonville. This point is estimated to coincide with the tidal limit for the Huon River.

Bathymetry data for the South-East Tasmania region was obtained from a number of different sources listed below:

- Australian Hydrographic Office charts AUS171, AUS172 and AUS173
- Geoscience Australia (GA) 2km gridded bathymetry of 2002
- DPIWE measurements
- CSIRO measurements
- HEC measurements
- Huon River Study (Griffin)

The GA 2002 data set was used in preference to GA's more recent and higher resolution products due to the presence of anomalous data in Storm Bay in the latter. Also, the current model does not demand such high data resolution in that region.

Since a number of data sets are used, and many of them overlap spatially, the best non-overlapping portions of each data set were extracted (relative to a common datum) and concatenated into a single bathymetry data base for the region. Figure 2.2 shows how the different data sets were delimited, while Figure 2.3 gives an indication of the data density in each region.

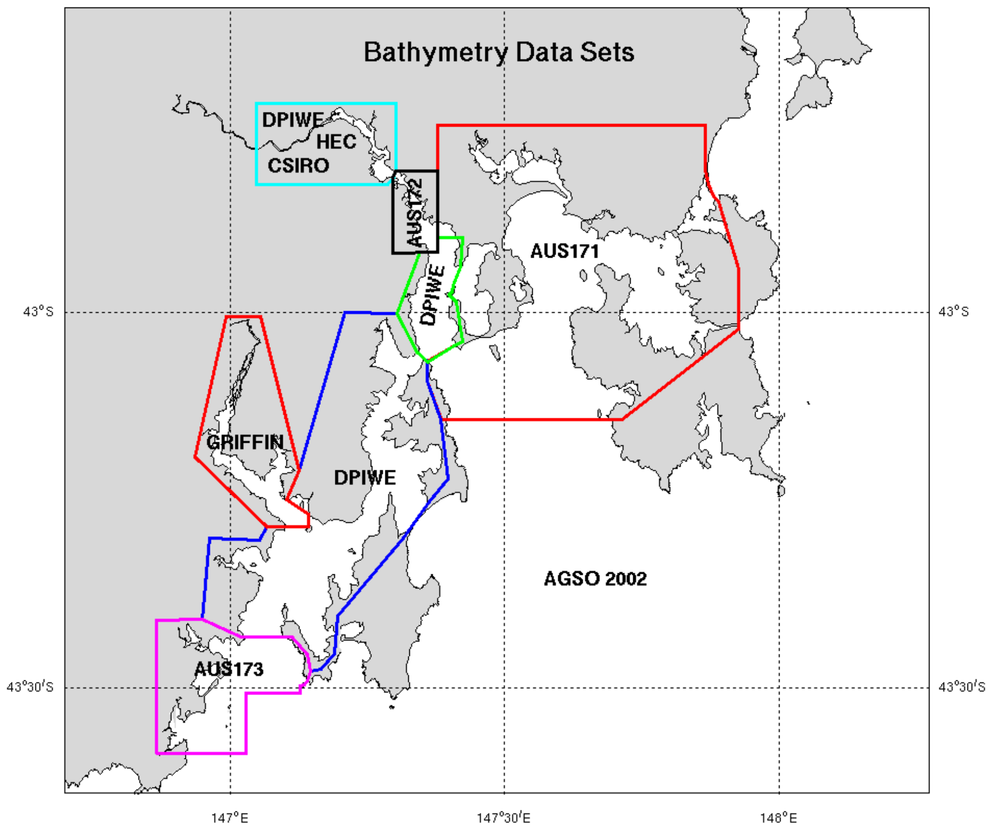

Figure 2.2. Map of the various sources used to compile the bathymetry data.

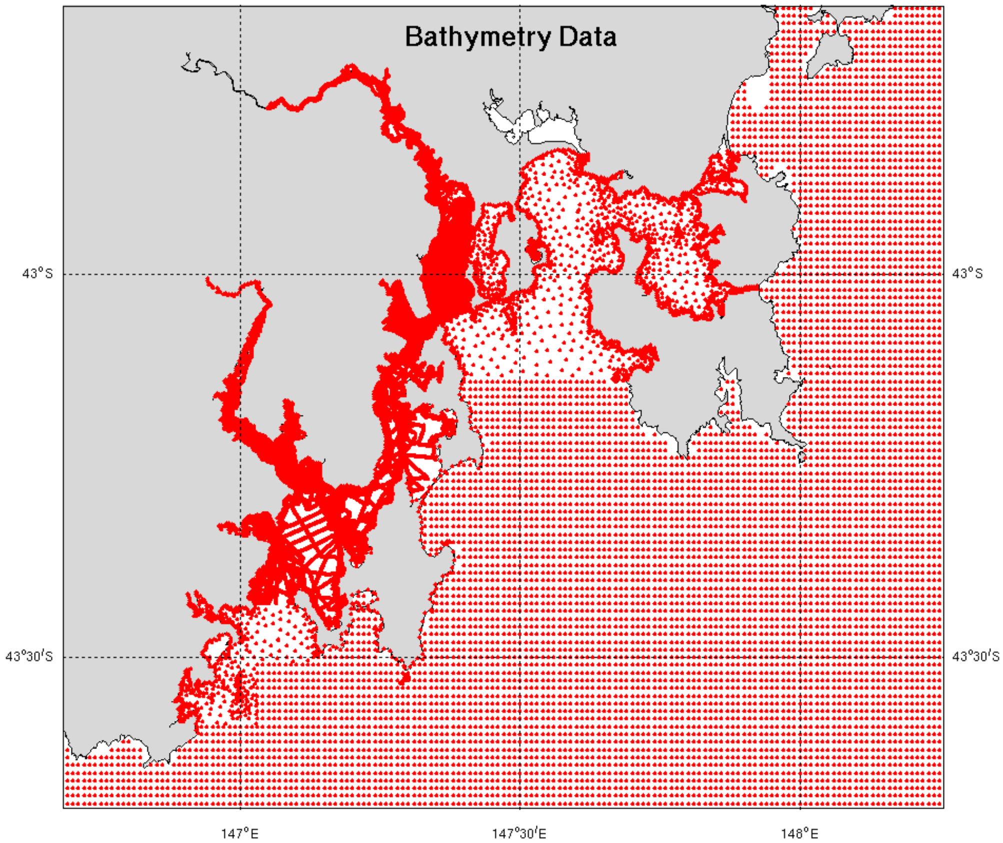

Figure 2.3. Bathymetry data dendity.

2.3. Meteorological Data

Meteorological data is available for the study region in both real-time and as a 48-hour forecast, from the MesoLAPS model which is operated by the Bureau of Meteorology. The resolution of these data is 0.125 degrees, which is coarser than desired for the inner regions of the Derwent & D'Entrecasteaux. However, compared to meteorological station derived measurements it has the advantage of superior spatial coverage, and it contains all variables used in calculating air-sea fluxes for the model (i.e. wind, pressure, air temperature, dew-point, cloud cover & precipitation). MesoLAPS also includes net heat flux if required and has the added bonus of including a 48-hour forecast.

Every 12 hours, an analysis record plus 48 forecast records are uploaded by BoM to an OpenDAP server. These records are then downloaded to CSIRO, and the previous 12 hours of data are proportionally 'nudged' by the difference between the analysis record and the previously forecast record for the same time. These 12 hours of data are then converted to an input format accepted by the hydrodynamic model, and appended to a netCDF file. The 48 forecast records are converted to the appropriate format and overwritten to a separate file which may be used if model forecasting is required.

An example of Mesolaps winds and pressure is given in Figure 2.4 for the time of a severe low pressure system passing along the south coast of Tasmania.

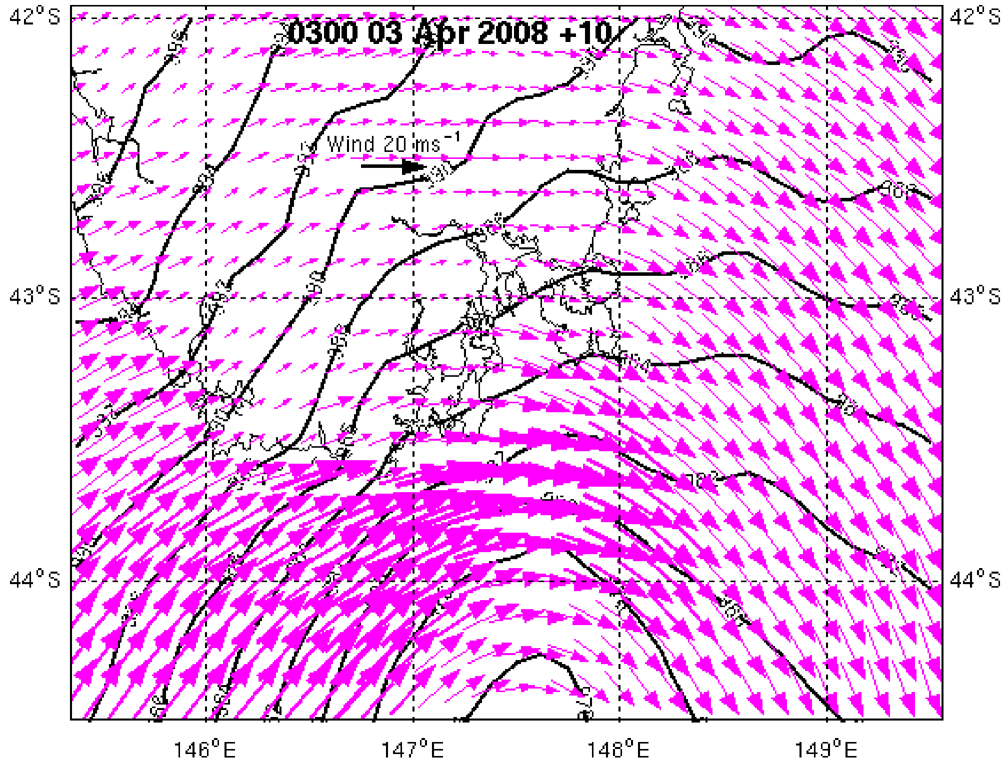

Figure 2.4. Example plot of wind vectors & atmospheric pressure contours from the MesoLAPS data base.

Currently, MesoLAPS data is available from 09th Feb 2008 to the present.

2.4. Ocean Forcing Data

The SETAS model contains 3 offshore open boundaries which require forcing with sea-level, salinity and temperature. These data are available in real-time, and as a 7-day forecast, from the OceanMAPS model operated by the Bureau of Meteorology. Resolution is 0.1 degrees over the study region. Four products are downloaded every 3-4 days from BoM's OpenDAP server. They are as follows;

- BODAS Analysis cycle, time interval of 3-4 days, last record= NRT minus ~10 days
- OCGM Analysis cycle, time interval of 1 day, last record = NRT minus ~5 days
- OCGM NRT cycle, time interval of 1 day, last record = NRT minus 0-3 days
- OCGM Forecast cycle, time interval of 1 day, last record = NRT plus ~5 days

Example plots of OceanMAPS salinity and temperature are given in Figures 2.5 and 2.6.

OceanMAPS data also contain an estimate of sea-level (which excludes both the tides and the effects of atmospheric pressure). Salinity, temperature and sea-level are also available from SynTS, provided by CSIRO. This data is also produced daily, but is not as close to real-time as OceanMAPS, lagging by about 1 week, and it is also provided on a courser 0.25 degree grid. An example is plotted in Figure 2.7. The sea-level product from SynTS (gridded sea-level anomaly) does not contain a Mean Sea Level component, hence an MSL product derived from the OFAM model is added. Similar to OceanMAPS, tides and atmospheric pressure are not included.

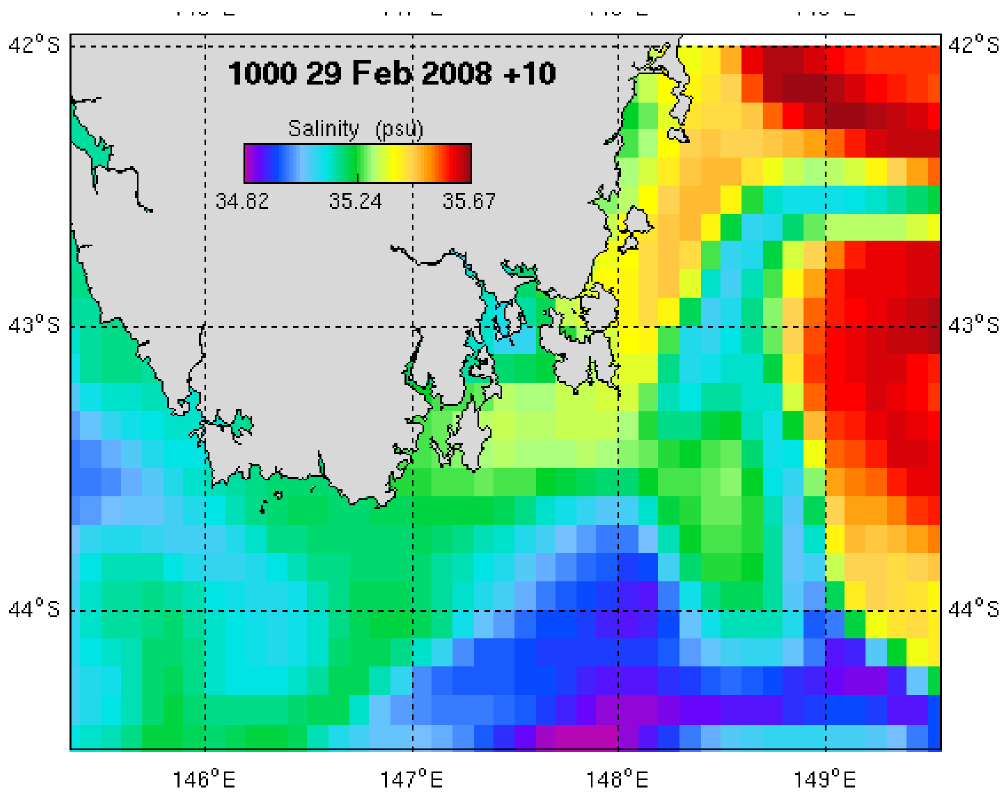

Figure 2.5. Example plot of surface salinity from the OceanMAPS data base.

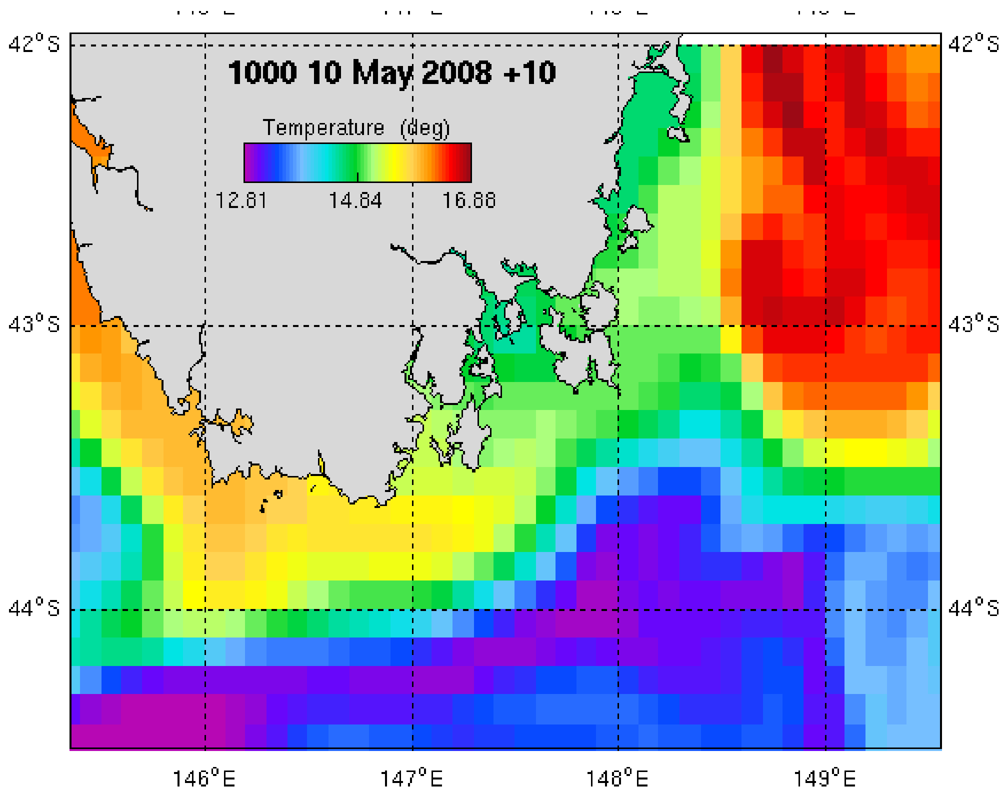

Figure 2.6. Example plot of surface temperature from the OceanMAPS data base.

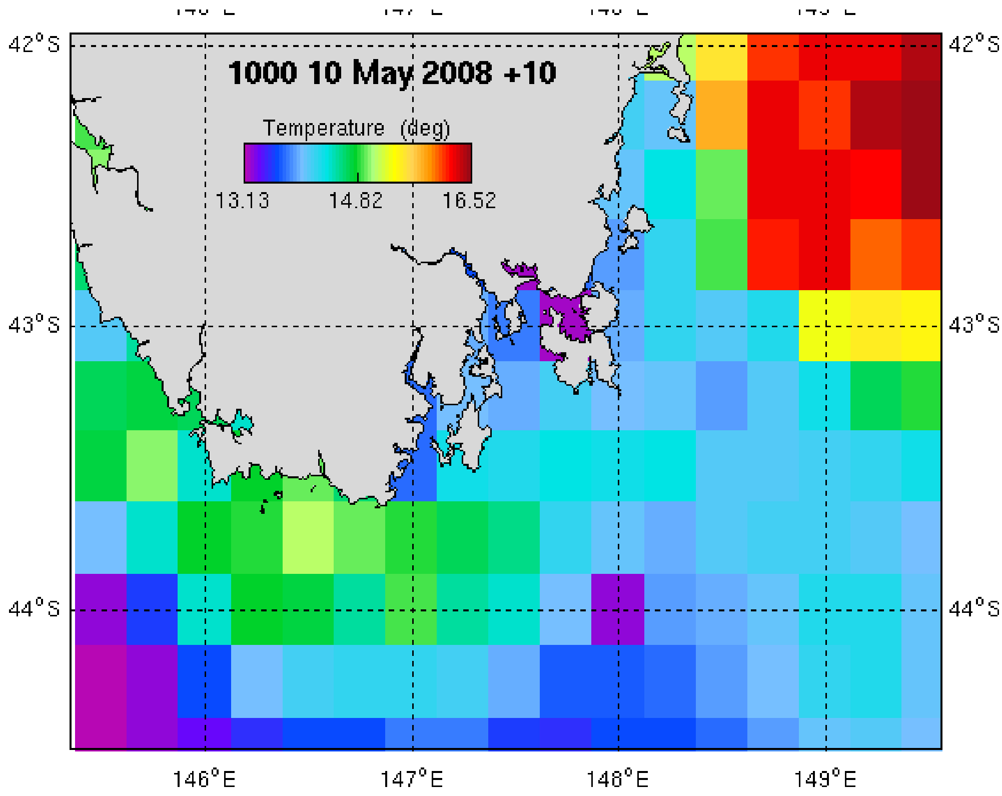

Figure 2.7. Example plot of surface temperature from the SynTS data base.

Currently, OceanMAPS data is available from 1st Jan 2008 to the present.

2.5. River-Forcing Data

Both the SETAS and STORM models contain a single open boundary at the upper end of each of the two major rivers; the Derwent and the Huon. These boundaries have been placed upstream of the tidal limits in order that the inflowing water can be assumed fresh. The boundary conditions then only require that the river flow and water temperature be known.

For the Derwent, the accepted tidal limit is at New Norfolk (Figure 2.8). No flow data are recorded for this location, but further upstream at Meadowbank Dam, flow and water temperature are measured in near real–time by Hydro Tasmania. These data are not readily accessible in real-time, however, a reduced data set of 4-hourly records of river level are available from the BoM Flood Warning Centre web-site. BoM also maintain another river-level gauge further downstream at Macquarie Plains (Figure 2.8), and this data is available from the above web-site at a higher rate of approximately 15-minute intervals.

The Meadowbank Dam and Macquarie Plains river level data are both currently being downloaded to CSIRO each hour. Once per day, data from river level is converted to river flow using rating curves supplied by BoM. River temperature is not currently available from either site, so air temperature from the MesoLAPS data at a point near the upper Derwent is low-pass filtered as an approximation to water temperature. A disadvantage of using Macquarie Plains over Meadowbank in the long term is the absence of temperature, but an advantage is that it is closer to New Norfolk and accounts for flow from the Tyenna River. (The Styx, Plenty, Lachlan & Jordan Rivers are the major tributaries that would still not be included. No suitable real-time data for these sources is available.)

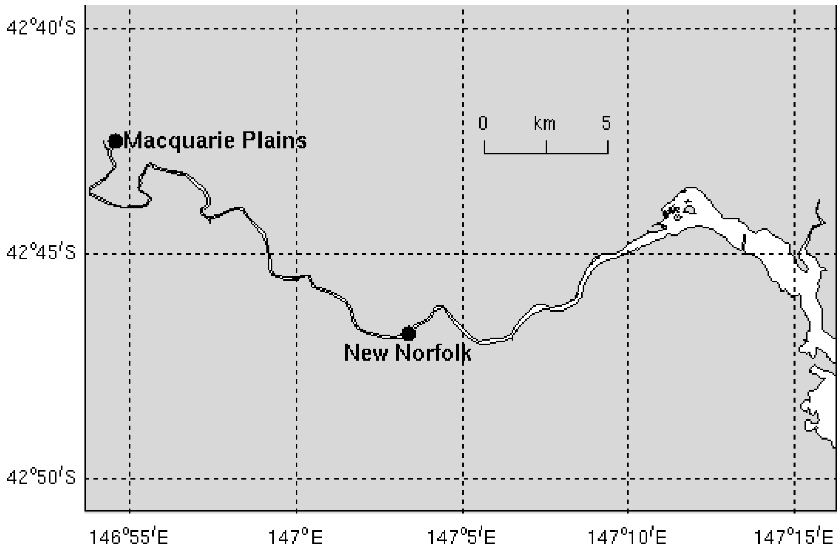

Figure 2.8. Map of Derwent River near region of tidal limit.

The Huon River has an up-river tidal limit that is less well known, but it is estimated to lie approximately 4-5 km upstream of Huonville. Huonville is definitely tidal, whereas Judbury is definitely not (Figure 2.9). Data supplied from BoM indicates that the riverbed at Judbury is approximately 10m above MSL, while at Huonville, it is approximately 5m below MSL. Assuming a constant grade from Huonville to Judbury, this would infer the point at which the riverbed passes through MSL is approximately 1/3 of the way from Huonville to Judbury ie. the tidal limit should be approximately 4-5km upstream of Huonville. The Judbury site does not account for a major tributary – Mountain River. At present the Judbury flows are magnified by 1.04 to account for this extra inflow.

Flow data is not recorded in real-time for the Huon, however, river level is available from BoM in near real-time for Judbury. BoM take recordings at 15 minute intervals and upload them to their web-site at least twice a day. This data is then handled in exactly the same way as is the Derwent data described above. River temperature is not currently available for the Huon, so air temperature from the MesoLAPS data at a point near the upper Huon is low-pass filtered as an approximation to water temperature.

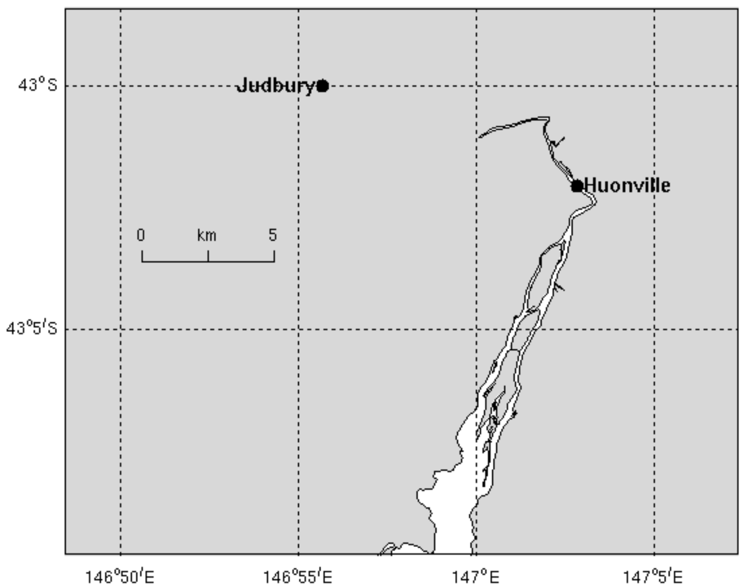

Figure 2.9. Map of Huon River near region of tidal limit.

River level data has been archived for the Huon from 1st Jan. 2008 to mid-Dec 2008, and for the Derwent from mid-April to mid-Dec 2008. These data are plotted in Figure 2.10. The calculated flows (and water temperature from MesoLAPS) are plotted in Figure 2.11.

Flow in the Derwent is regulated at Meadowbank, and has a base value of 38-50 cumec. This is higher than the low flows of approximately 10 cumec experienced by the Huon, but the latter has by far the higher flows at times of flood or high rainfall. Since the Derwent data begins later than the Huon data, the former has been backfilled from mid-April to mid-February with a constant 38 cumec, to enable spin-up runs of the models over this period.

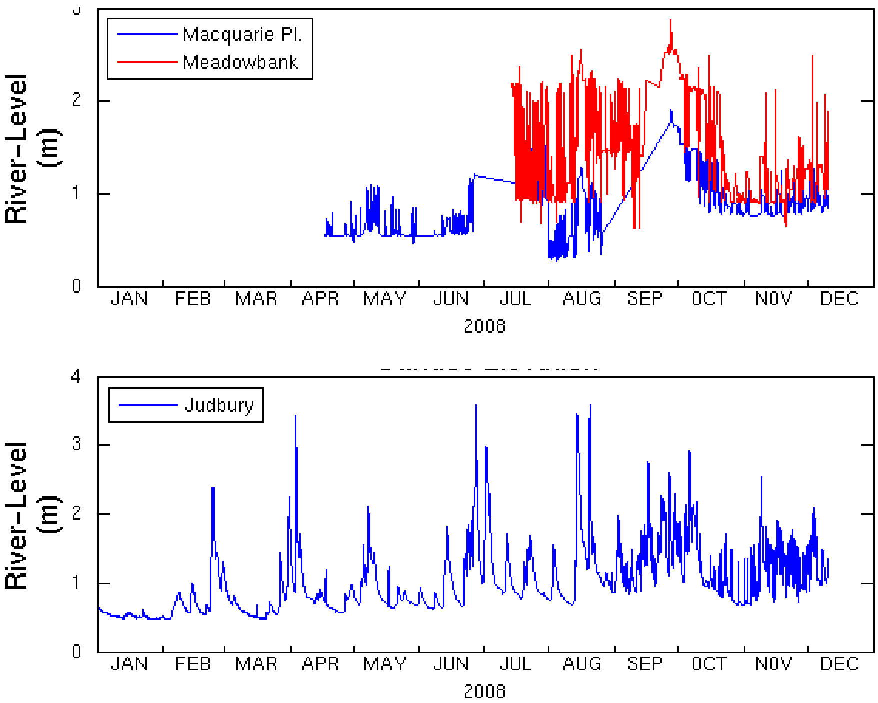

Figure 2.10. River level for the Derwent & Huon Rivers.

Comparison of the Meadowbank and Macquarie Plains flows in Figure 5 shows some large gaps, particularly with Macquarie Plains which appears to be the more unreliable. Also, since late June there appears to be an offset in the minimum Macquarie Plains flow which is currently reading approximately 75 cumec instead of the expected 38 cumec given by the Meadowbank data. As a result of the above discrepancies, the Meadowbank data is currently being used as Derwent input for the models.

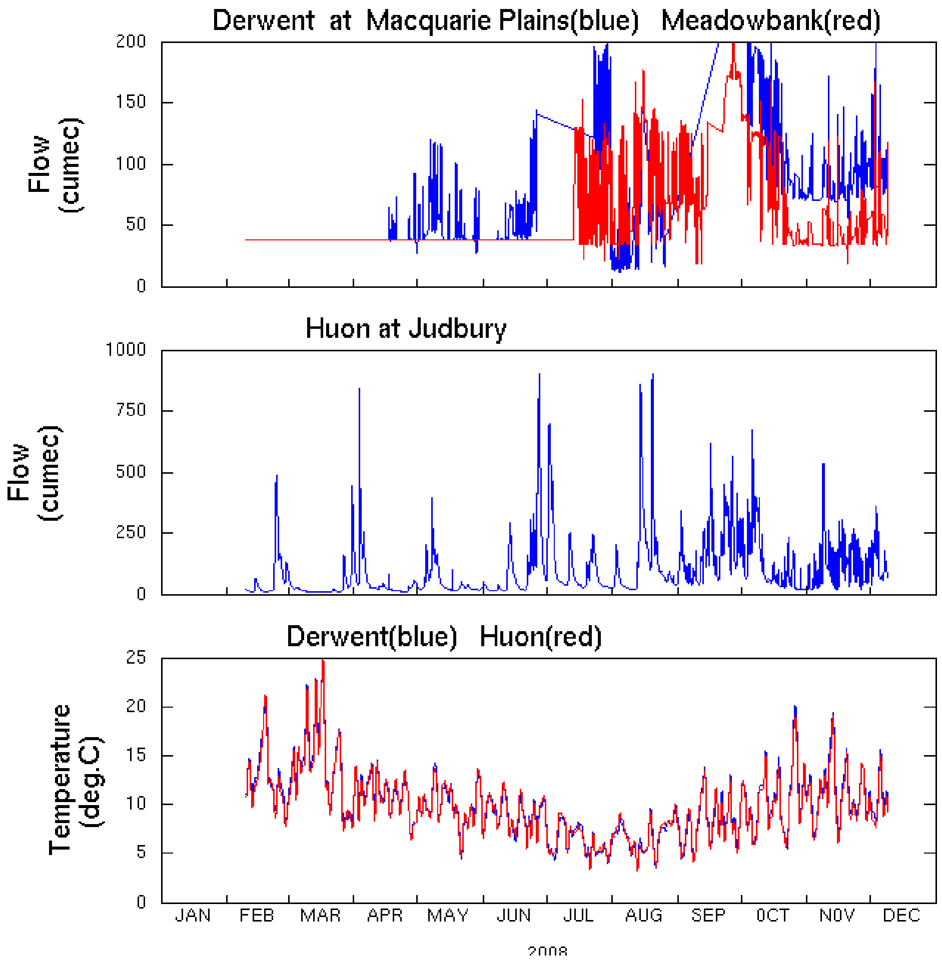

Figure 2.11. River flow & water temperature for the Derwent & Huon Rivers

2.6. Sea-Level Data

Sea-level data (excluding tides and the effects of atmospheric pressure) for forcing the coarse model is provided by OceanMAPS,. Measured sea-level data for comparison with model output, is only currently available from a BoM river-level gauge at Huonville (where it lies within the tidal regime), and from 2 sensors deployed by ICT near the mouth of the Derwent River.

The Huonville data is recorded at 15-minute intervals, and is uploaded by BoM to their web-site twice a day as per the Judbury river level data described above. The data tends to be somewhat spiky, possibly due to wave action since it is not measured from within a stilling well. Also, there appears to be some clipping associated with the data, where the river level is never recorded below -0.5m. The raw data is plotted in Figure 2.12 and has also been low-pass filtered and plotted in Figure 2.13.

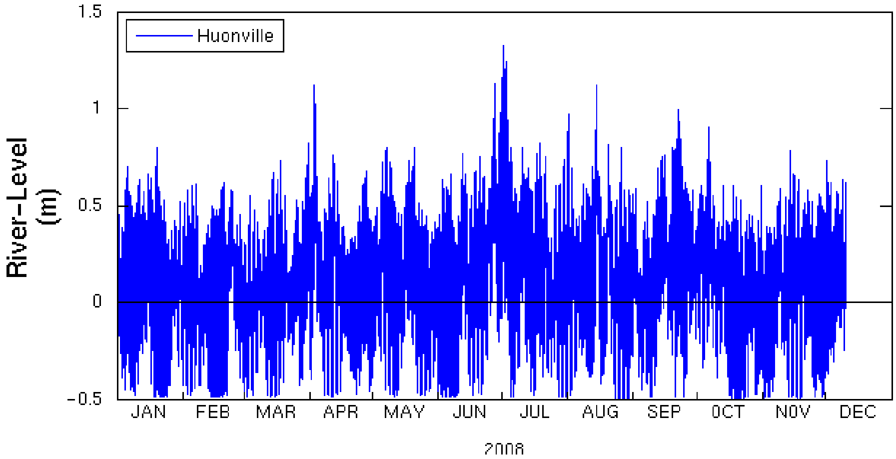

Figure 2.12. Sea-level at Huonville.

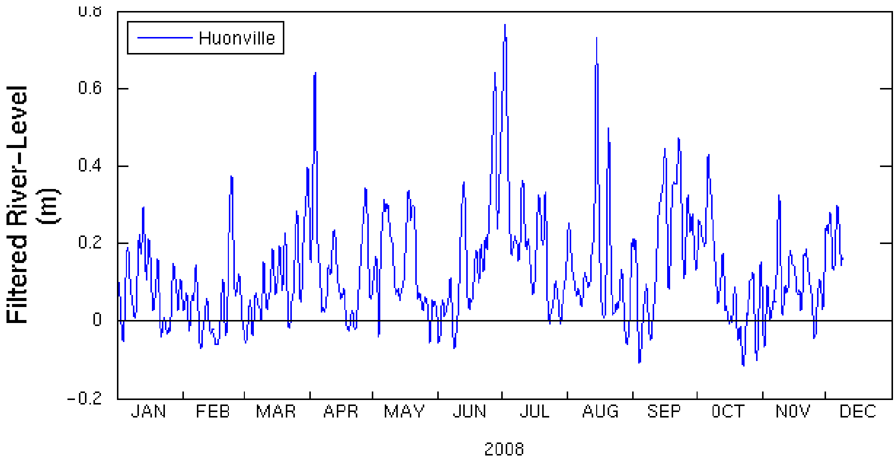

Figure 2.13. Low-pass filtered sea-level at Huonville.

The ICT data from the 2 sensors at the mouth of the Derwent is not currently available in real-time.

2.7. Salinity/Temperature Data

Salinity and temperature data for forcing the coarse model is provided by OceanMAPS. Several products are available; an analysis product which spans the period ending a week before the present time and has been subjected to data assimilation; a near-real time (NRT) product which spans the period ending on or just before the present day; and a forecast product available up to 7 days into the future. The analysis product is most accurate.

Continuously measured S and T data for comparison with model output is currently available from two sensors deployed by ICT adjacent to the CSIRO Wharf in Hobart and from two sensors deployed by ICT near the mouth of the Derwent River. At the Wharf, one sensor is positioned just below the surface, and the other just above the sea-bed. The data is recorded in near real-time and is available from 19th February 2008 (Figure 2.14).

At the river mouth, one sensor is deployed at Tinderbox, just above the seabed in 17m of water. The other sensor is deployed in the mouth of the Channel just above the seabed in 18m of water. The data from these two sensors is not currently available in real-time.

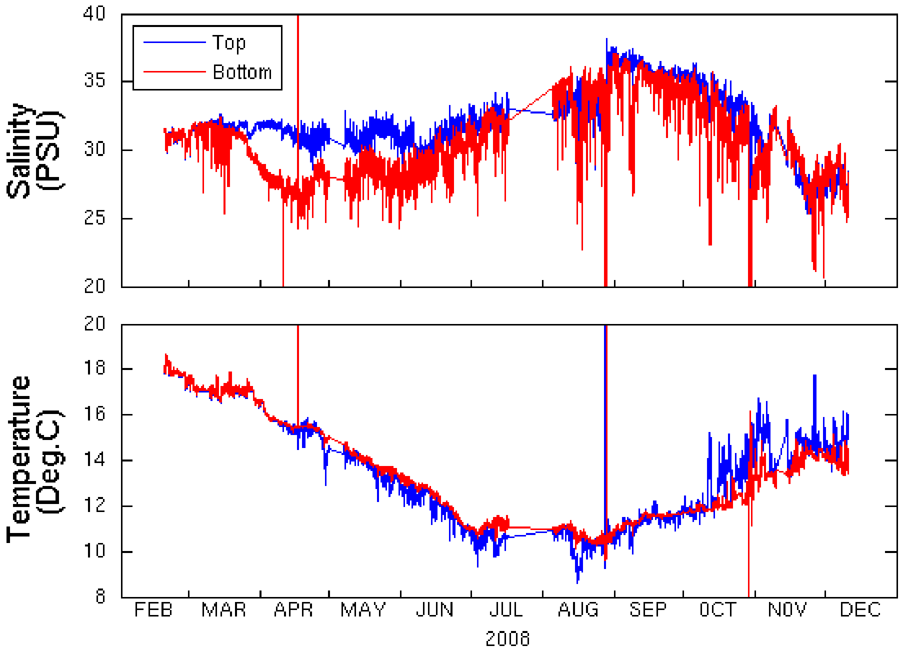

Figure 2.14. Measurements of salinity and temperature from 2 sensors at the CSIRO Wharf.

2. 8. Model Grids

The SETAS model grid is a curvilinear grid with 175 x 120 = 21000 horizontal grid cells (Figure 2.15). The grid resolution ranges from 2.5 km on the south-east offshore boundary, to 1.4 km on the boundary of the fine-scale (STORM) grid, 400m in the Derwent at Hobart, 300 m at Bridgewater, and 250 m in the middle Huon (see Figures 2.16 & 2.17). The water depth over the model domain ranges from 0 to just over 200 m, however a bathymetric range of 2 to 200 m has been imposed for all model runs (Figure 2.18). There are 21 model layers in the vertical. The model time-steps are 6.4 seconds for the 2D component, and 90 seconds for the 3D component. The model runs at approximately 650 x real-time using 4 processors.

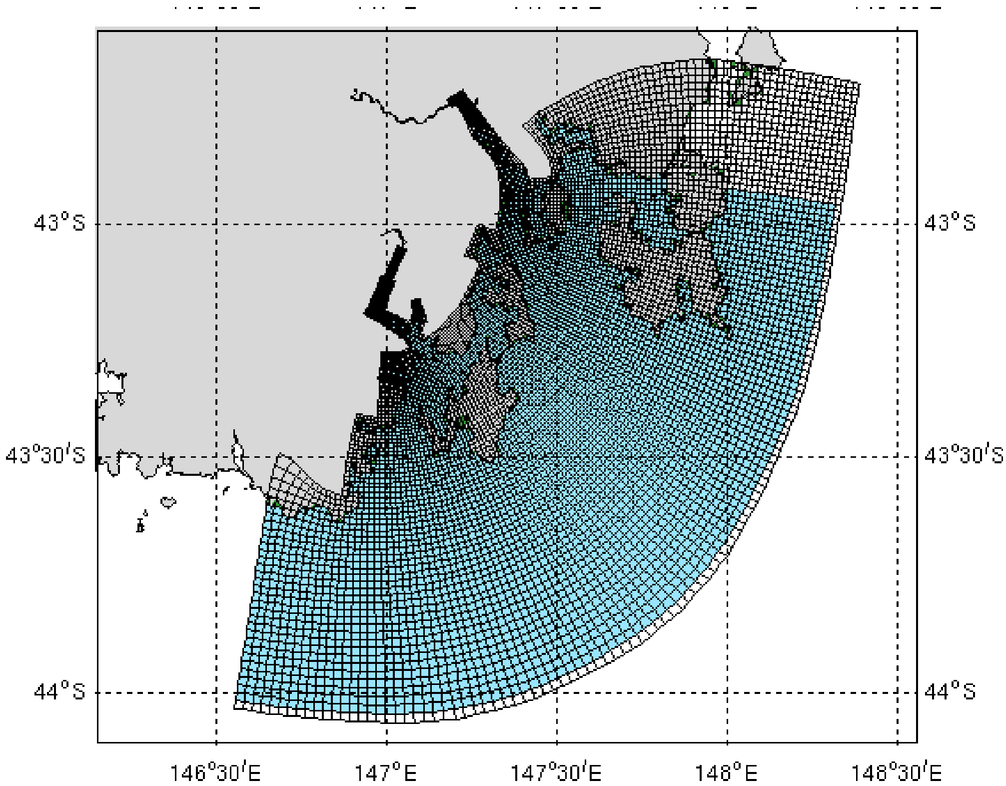

Figure 2.15. SETAS model grid.

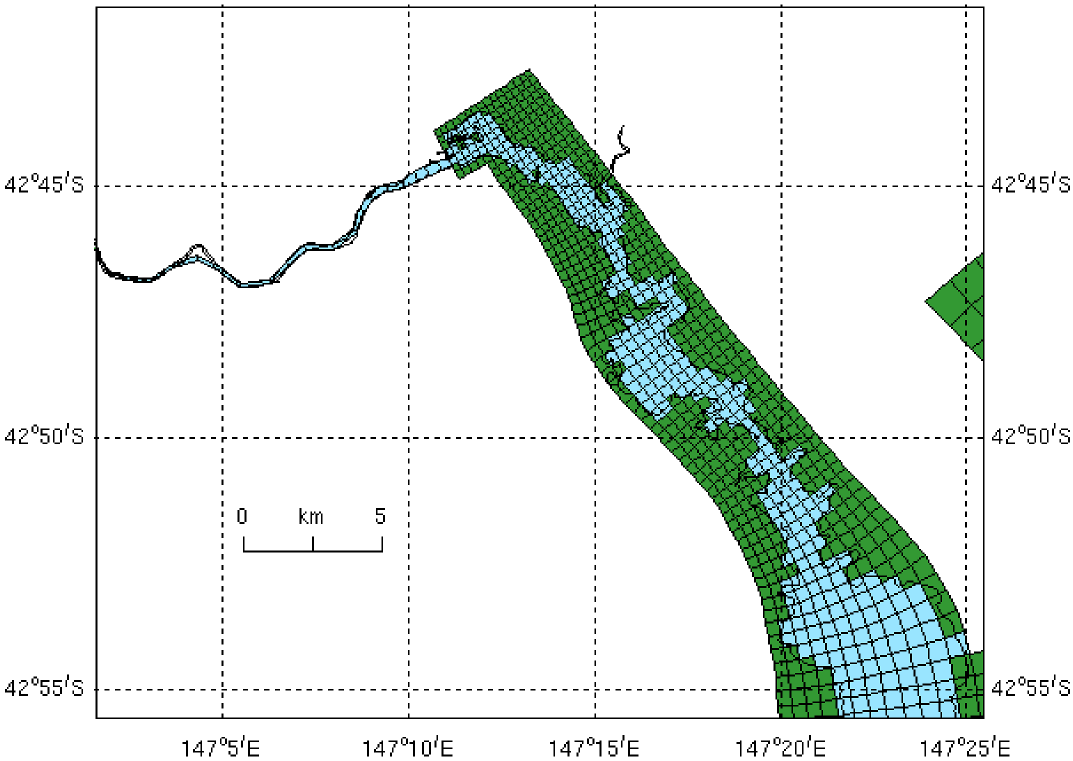

Figure 2.16. SETAS model grid in the Derwent region.

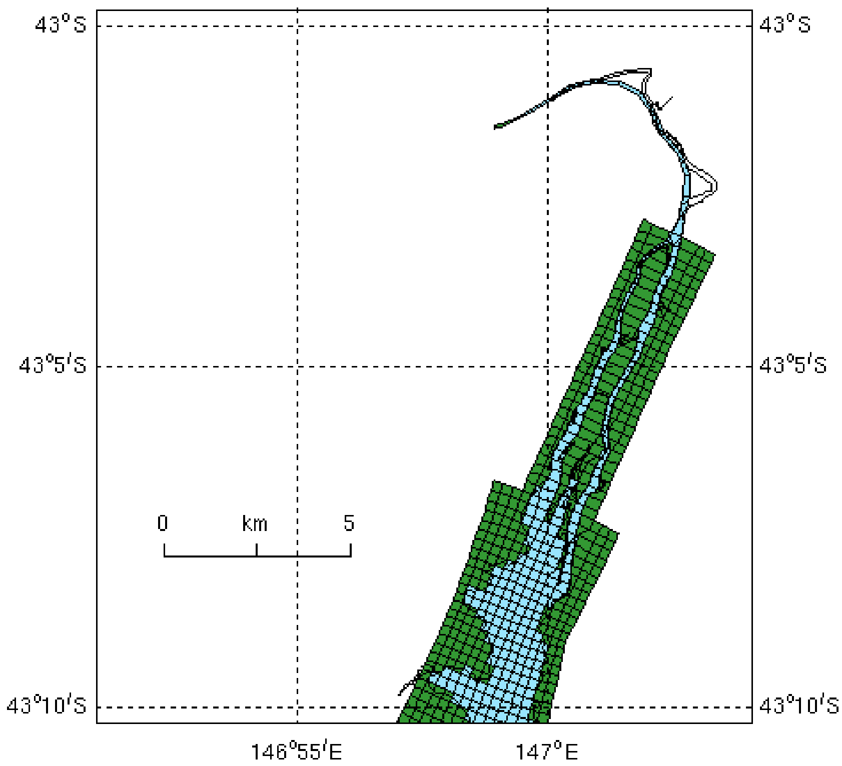

Figure 2.17. SETAS model grid in the Huon region.

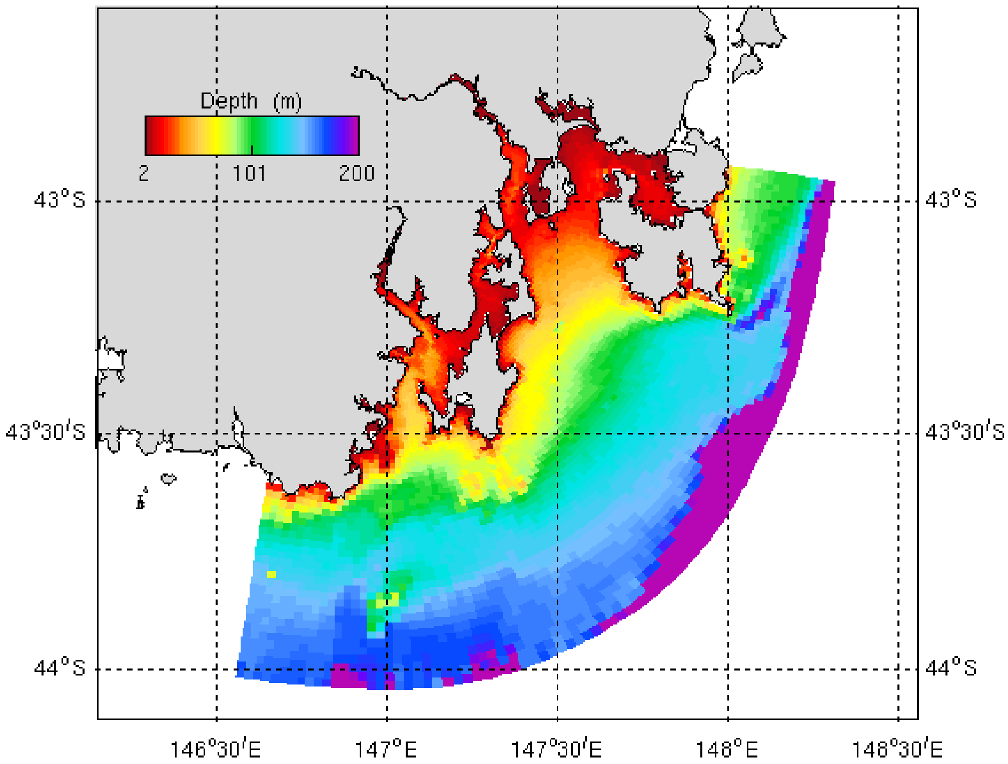

Figure 2.18. SETAS model bathymetry.

The STORM model grid is a curvilinear grid with 700 x 398 = 278600 horizontal grid cells (Figure 2.19). Grid resolution ranges from 600 m on the south-east offshore boundary, to 100 m in the Derwent at Hobart, 120 m at Bridgewater, and 125 m in the middle Huon (see Figures 2.20 & 2.21). The water depth over the model domain ranges from 0 to 145 m, however a depth minimum of 2 m has been imposed for all model runs. The model bathymetry is shown in Figure 2.22. There are 24 model layers in the vertical and the model time-steps are 1.5 seconds for the 2D component, and 9 seconds for the 3D component. The model runs at approximately 5 x real-time using 8 processors.

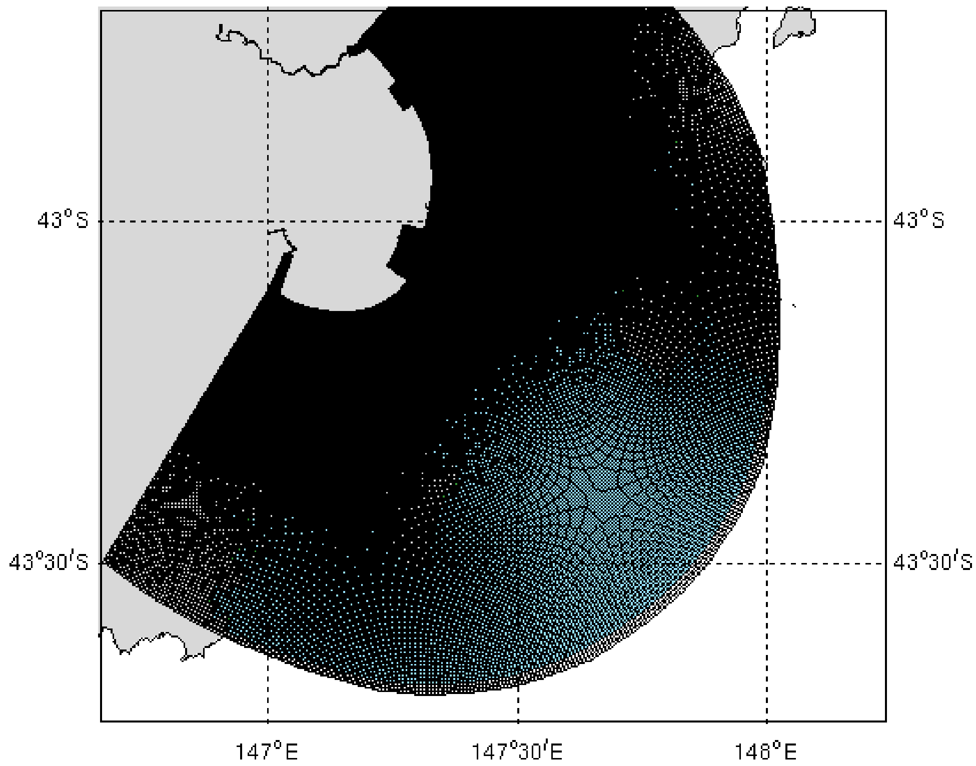

Figure 2.19. STORM model grid.

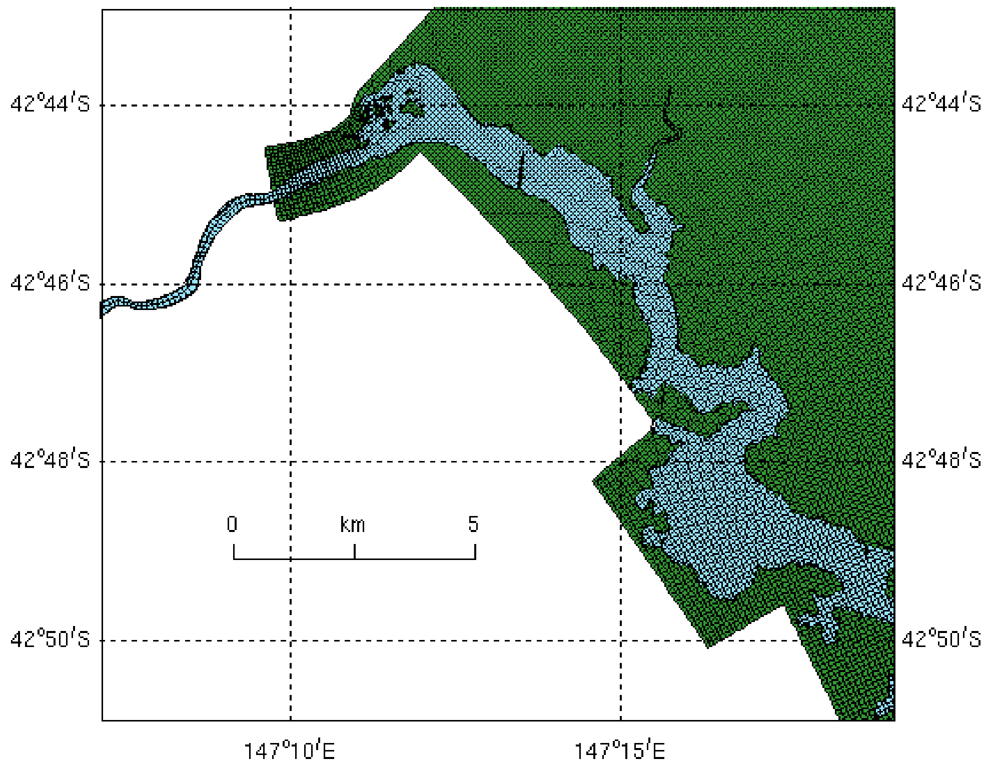

Figure 2.20. STORM model grid in the Derwent region.

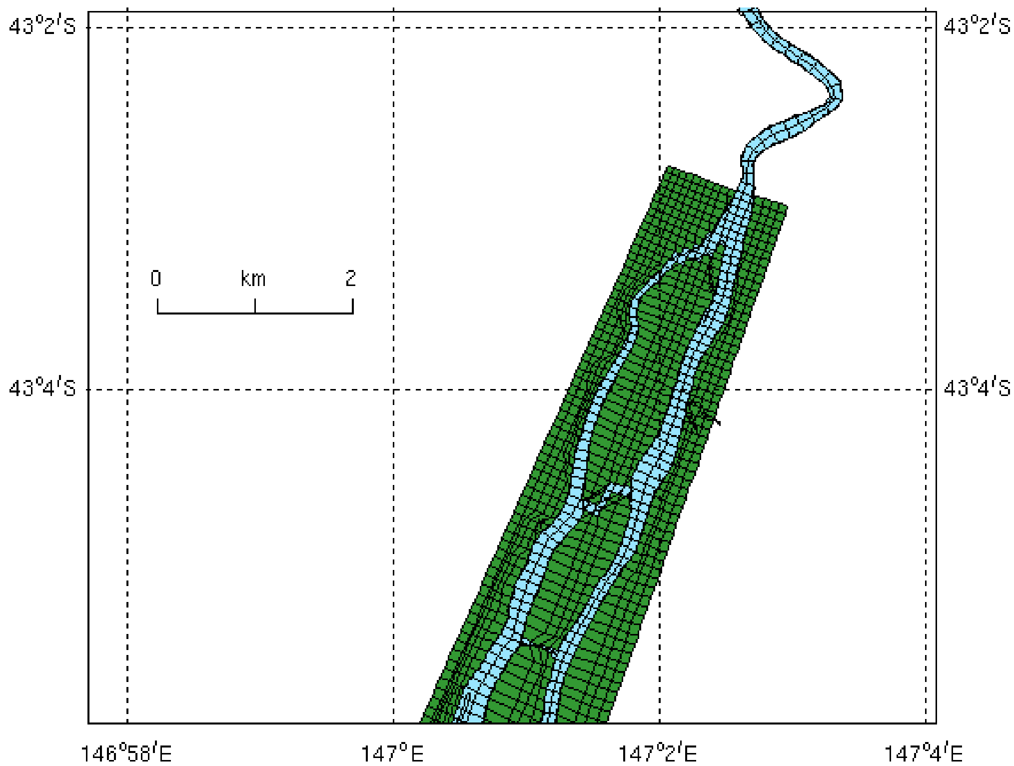

Figure 2.21. STORM model grid in the Huon region.

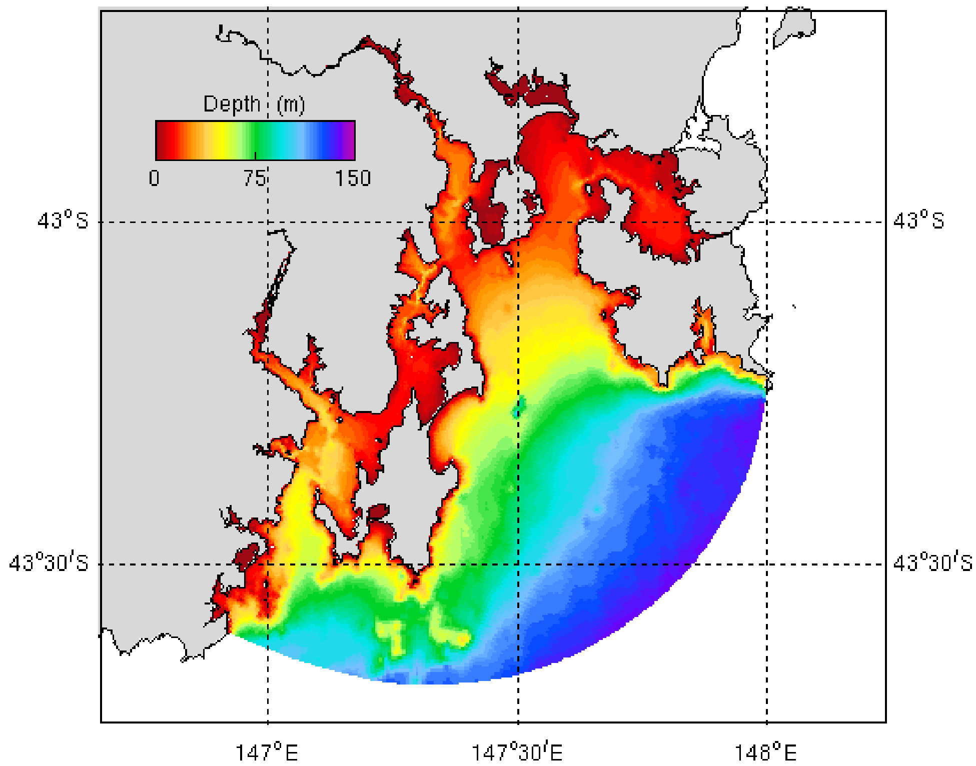

Figure 2.22. STORM model bathymetry.

2.9. Model Run Set-Up

The SETAS model has a total of five open boundaries. Two of these are the Derwent and Huon upstream boundaries which are forced using the river flow and temperature data described above. These open boundaries are adjusted to allow for the 'inverse barometer' effect on sea level. The remaining three boundaries are offshore boundaries (Figure 2.15) which are forced in a similar manner using a velocity open boundary condition (Herzfeld, 2009). The global tidal model of Eanes and Bettadpur (1995), using the methodology of Cartwright and Ray (1990), was used to generate amplitudes and phases of 14 tidal constituents at every open-boundary node. These are then used to reconstruct the tide at every time-step. Additionally, sea level is adjusted for the inverse barometer effect computed from the MesoLAPS pressure data. The resulting sea level distributions therefore contain the background mean state, low frequency oscillations, variability on sub-diurnal time-scales and 'inverse barometer' components. Salinity and temperature forcing for the offshore boundaries is provided by OceanMAPS. The meteorological forcing is provided entirely from the MesoLAPS data, and both salt and heat fluxes across the air-sea interface are included.

The STORM model has a total of 3 open boundaries. Two of these are the Derwent and Huon upstream boundaries which are forced as for the SETAS model. The other boundary (Figure 2.19) is an offshore boundary which is forced with velocity, salinity and temperature provided by the SETAS model. The local flux adjustment described by Herzfeld (2009) uses sea level data from the SETAS model. The meteorological forcing is provided entirely from the MesoLAPS data, and both salt and heat fluxes across the air-sea interface are included. Neither the SETAS or STORM model have undergone a calibration procedure.

Output from the SETAS model currently consists of a daily record of all variables (used for hot-starting subsequent runs), hourly records of all surface variables, and 12-minute records of elevation, salinity and temperature along the path of the STORM offshore boundary.

Output from the STORM model currently consists of a daily record of all variables (used for hot-starting subsequent runs), hourly records of all surface variables and also hourly records of hourly means of transport variables in a sparse format file for the purpose of subsequently running the transport model.

2.10 ROAM control framework

ROAM (Relocatable Ocean and Atmospheric Model) is an initiative jointly developed by CSIRO Marine and Atmospheric Research (CMAR), the Bureau of Meteorology (BoM) and the Royal Australian Navy (RAN) in the BlueLink project to provide high resolution ocean forecast products operationally. Although this system uses simple rectilinear grids, many of the data management, run management, model execution and synchronization capabilities required to operate the SETAS and STORM models exist within this framework. ROAM is also a self-contained, portable system. For these reasons, ROAM was modified to handle the run, data, and execution aspects of the near-real time operational system.

One of the main features of ROAM is its tight integration and management of the data streams which provide forcing and domain information (e.g. bathymetry and coastline) for the various models. Its modular design consists of 4 main components, of which some have been extended to accommodate the requirements of this project. In particular the Data Management Framework (DMF) which manages data-streams in its repository and manipulates them to suit the requesting model, the Run Control Framework (RCF) which manages the scheduling and monitoring of model runs, and the Model Execution Framework (MEM) which controls a particular model run and its workspace. Extensions to ROAM involved integration of data streams for Meso-Laps data and river-flow to the DMF. Some new tools were written to query OpenDAP servers as well as interface to ICT's database (for the Meadowbank river-flow). The MEM was extended to handle static parameter files (as opposed to an auto generated one) to allow for the specialised grid and fine tuned calibration values as well as new infrastructure to handle nested models; STORM inside SETAS, in this case. A new machine 'bruny' has been setup to host this and to run operational models.

2.11 Model output and testing

The operational model has been successfully operating in real-time for approximately 10 months. Outputs in near-real time have been downloaded to the web-site which is anticipated to open for public access once the design is completed and the CSIRO approval procedures are finalised. Example snapshots of sea-level, surface currents, temperature and salinity are given in Figures 2.23 to 2.28.

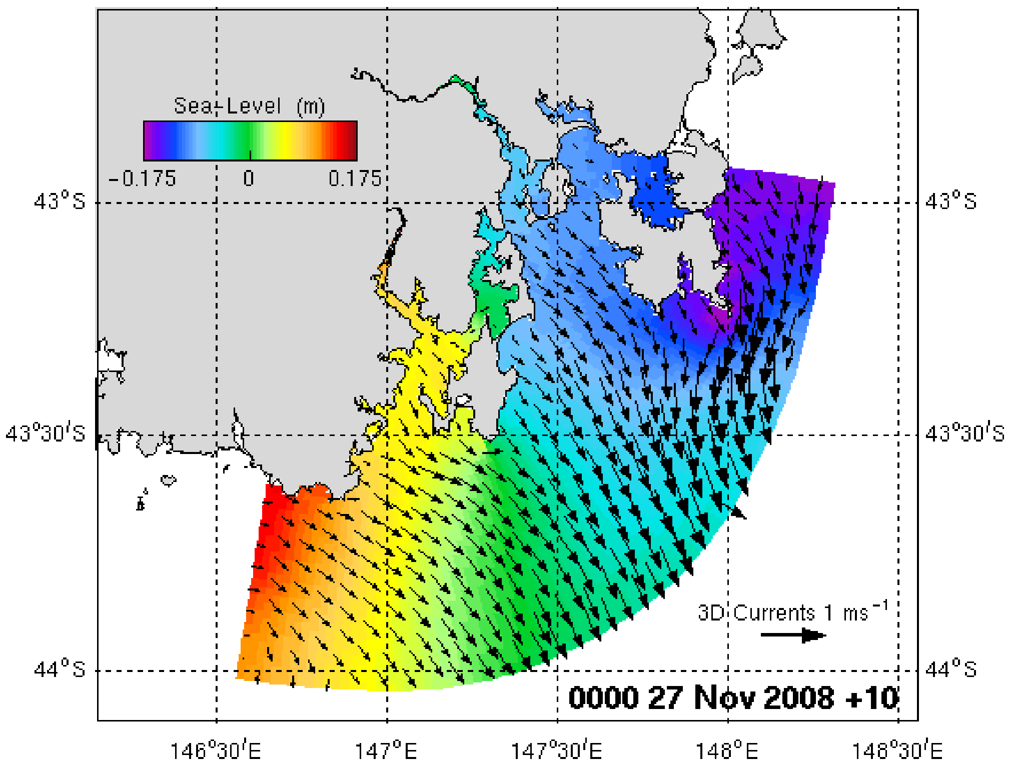

Figure 2.23. Surface elevation and currents from the SETAS model.

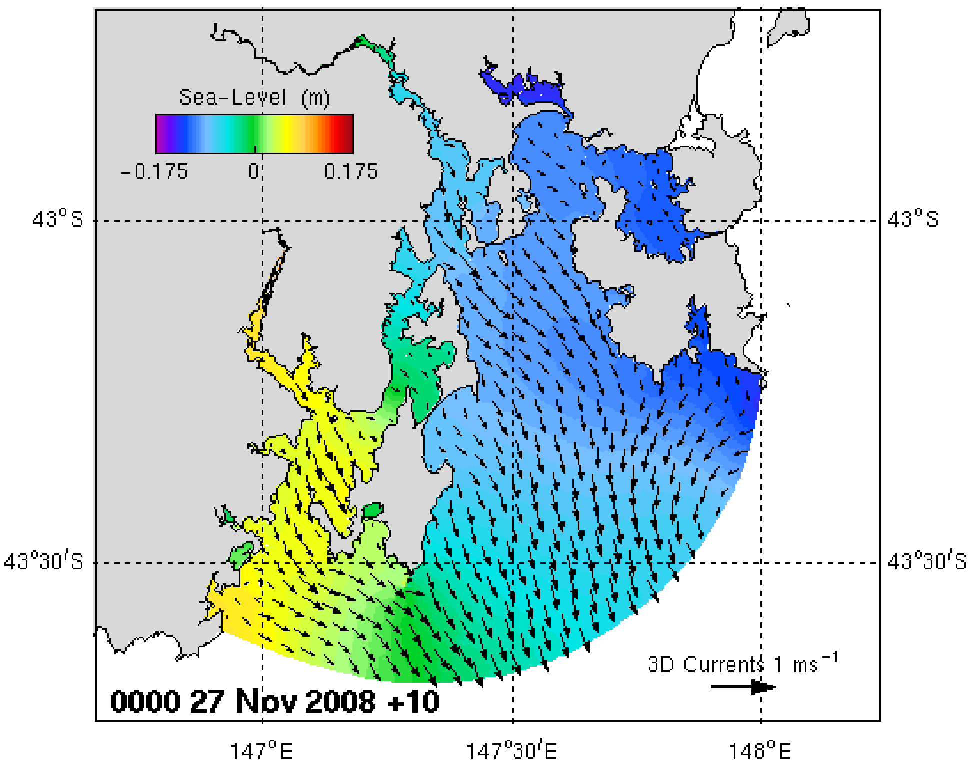

Figure 2.24. Surface elevation and currents from the STORM model.

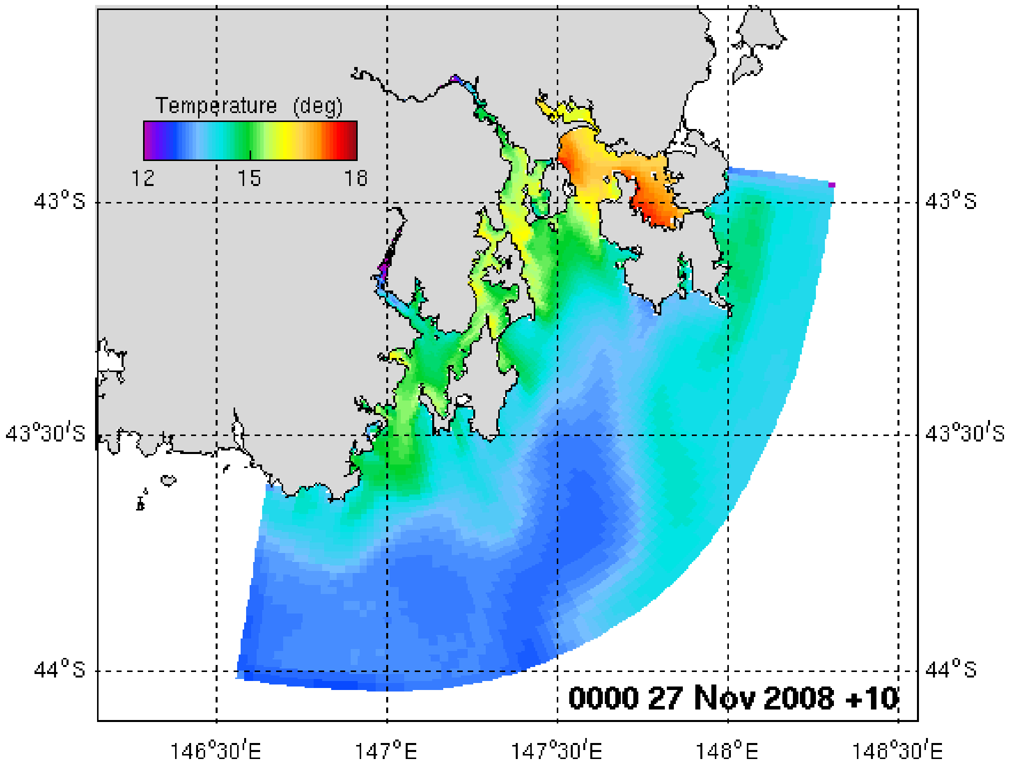

Figure 2.25. Surface temperature output from the SETAS model.

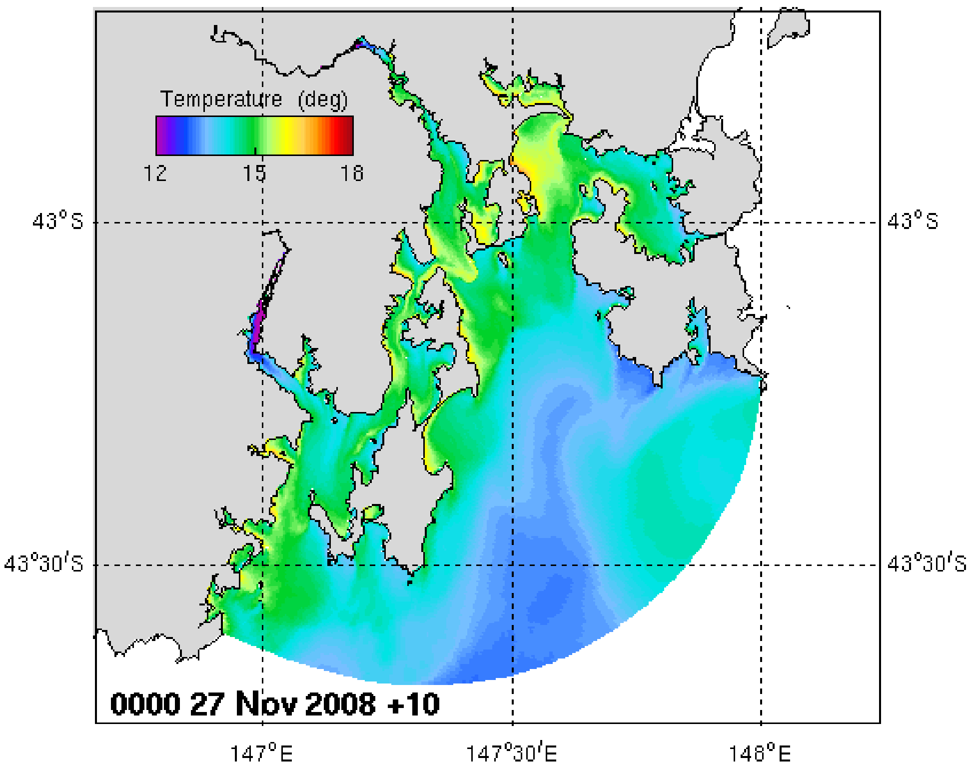

Figure 2.26. Surface temperature output from the STORM model.

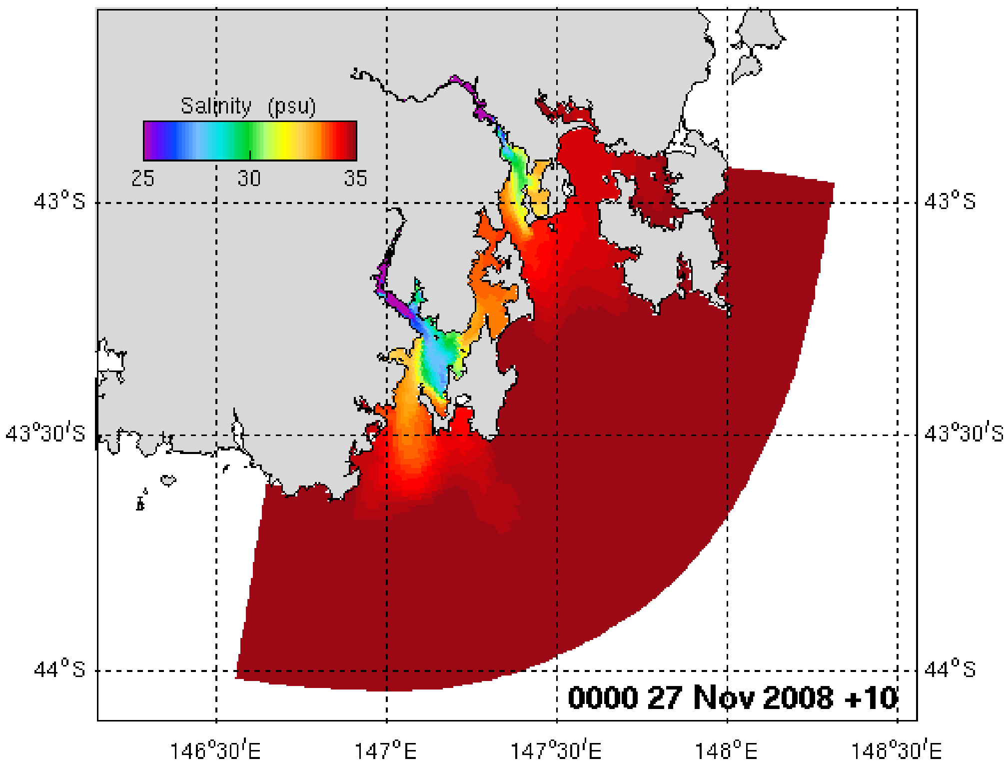

Figure 2.27. Surface salinity output from the SETAS model.

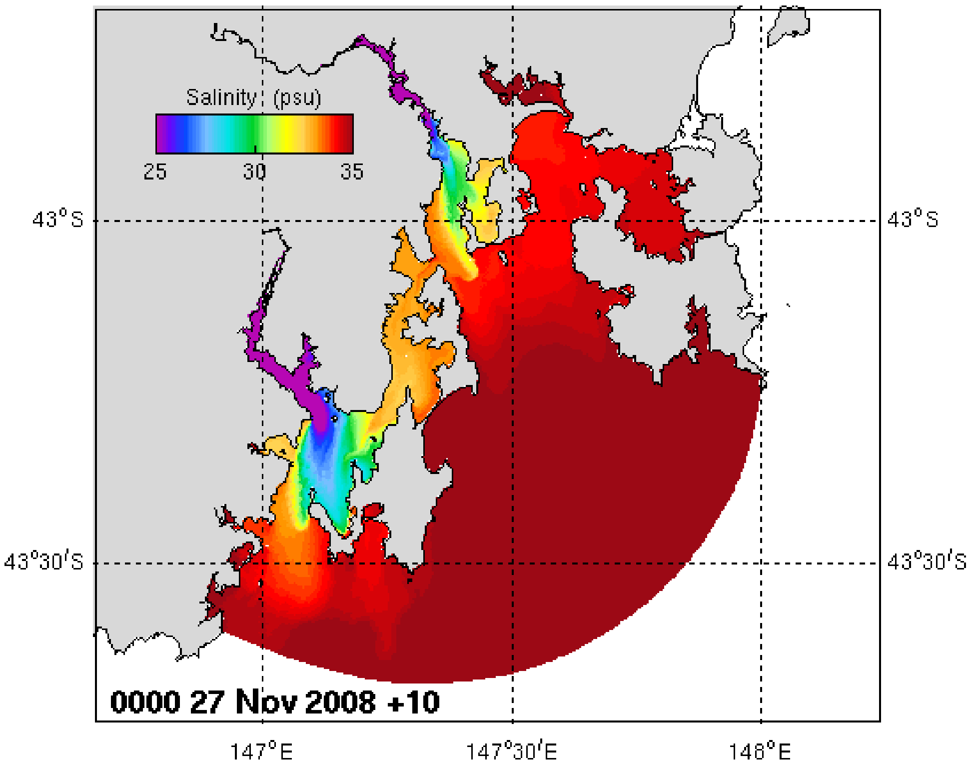

Figure 2.28. Surface salinity output from the STORM model.

Comparisons of SETAS sea-level using the NRT and forecast OceanMAPS products, with measurements from the BoM Huonville site, are given in Figure 2.29. Examples of comparisons using low-pass filtered sea-level from both models are shown in Figures 2.30 and 2.31. In the next phase of the project, these comparisons will be used to adjust parameters in the model so as to optimize correlations between model output and measurements.

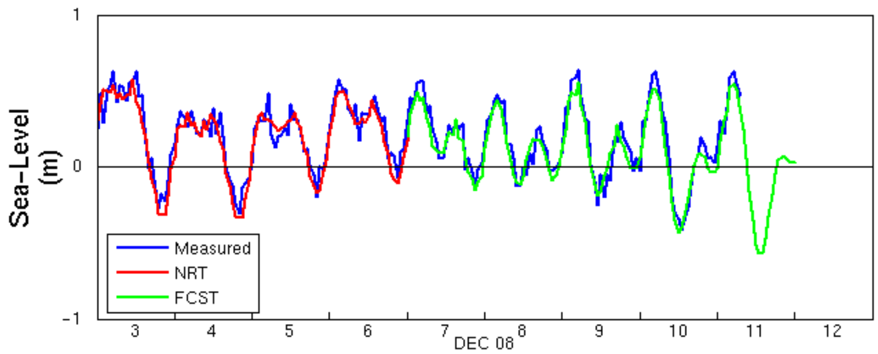

Figure 2.29. Comparison of sea-level between BoM measurements and the SETAS model, for the Huonville site.

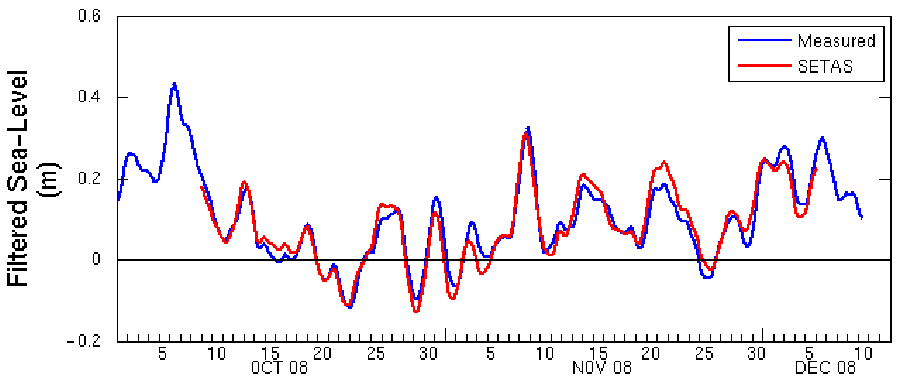

Figure 2.30. Comparison of filtered sea-level between BoM measurements and the SETAS model, for the Huonville site.

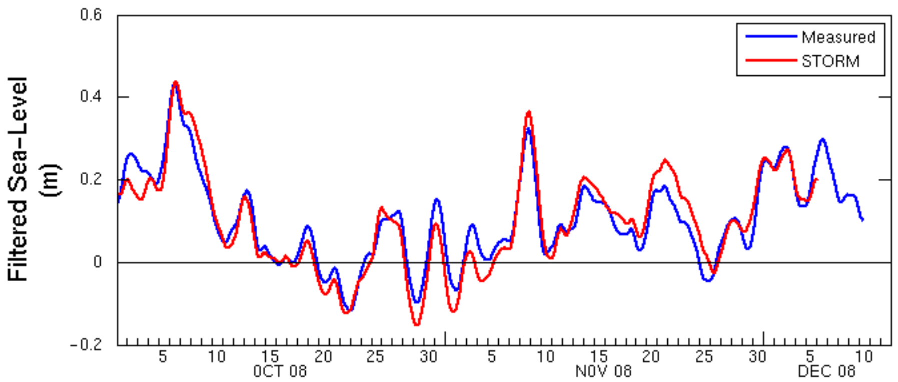

Figure 2.31. Comparison of filtered sea-level between BoM measurements and the STORM model, for the Huonville site.

Comparisons of SETAS modelled sea-level with measurements from the ICT sensors at the Tinderbox and Channel sites are given in Figure 2.32. These comparisons demonstrate an inferior agreement to that obtained for Huonville, which is subject to investigation when model calibration proceeds.

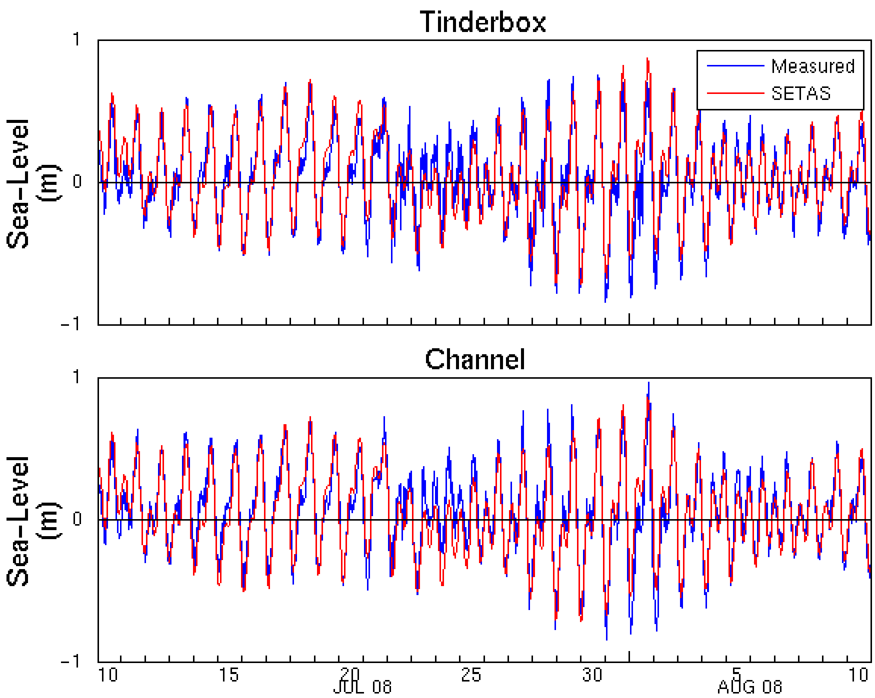

Figure 2.32. Comparison of sea-level between sensor measurements and the SETAS model, for the Tinderbox & Channel sites.

Comparisons of SETAS NRT and forecast modelled salinity and temperature, with measurements from the ICT sensors at the Wharf top and bottom sites, are given in Figure 2.34. The equivalent comparison for the STORM model is given in Figure 2.35. These comparisons are quite good for the top sensor site, but for the bottom site the models do not yield the fluctuations in the observed signal. As expected, due to the higher resolution the higher resolution STORM model is performs better the SETAS model.
Note that the STORM model was still undergoing its spin-up phase for the beginning of the comparison period, so only the last few days of the comparison should be considered. Also, the salinity data from the ICT sensors is subject to a calibration issue and a scale factor of 0.8 was suggested for the processing of this data. For the purposes of this comparison however, a scale factor of 0.9 was actually used. Comparisons of SETAS salinity/temperature with the archived measurements from the ICT sensors at Tinderbox and Channel, could not be made because model output was not obtained for the appropriate depths.

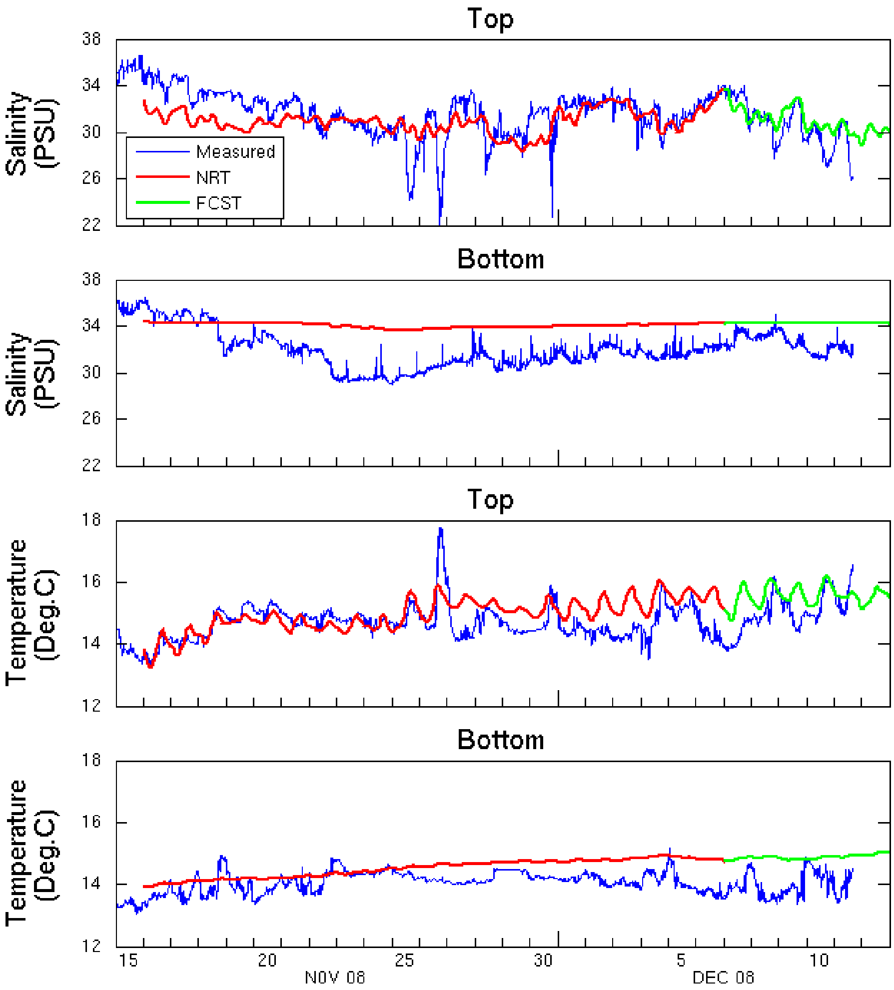

Figure 2.34. Comparison of salinity & temperature between sensor measurements and the SETAS model, for the Wharf site.

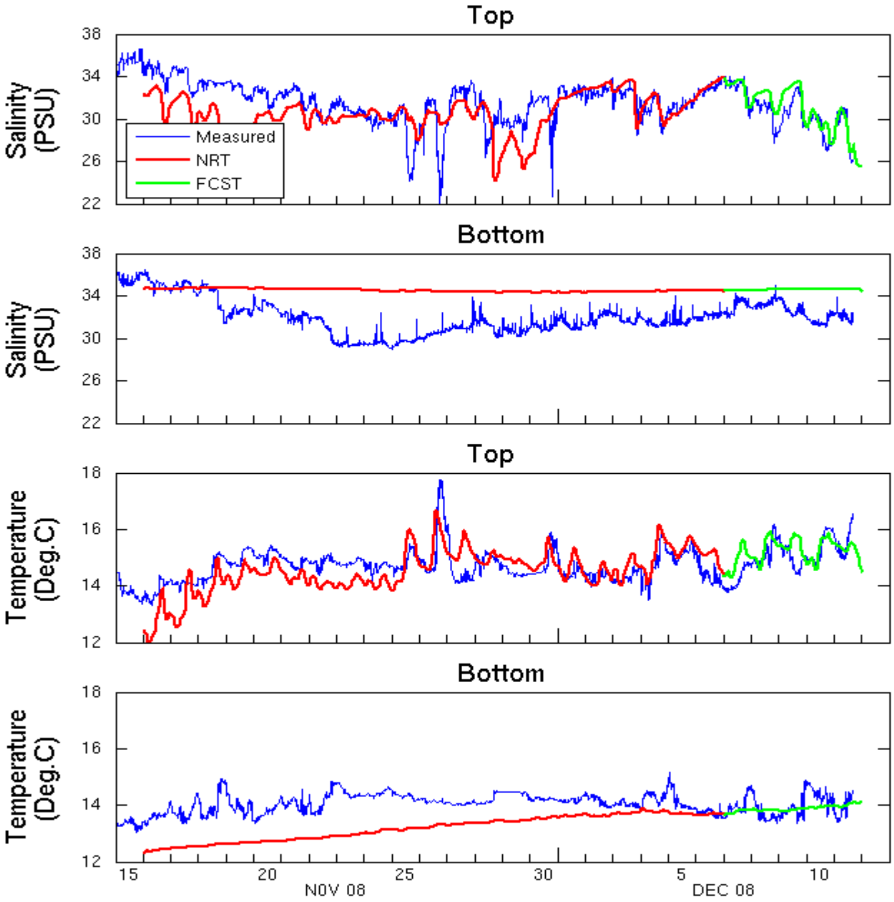

Figure 2.35. Comparison of salinity & temperature between sensor measurements and the STORM model, for the Wharf site.

3. Evaluation of Transport Models

(M.Herzfeld, N.Margvelashvili)

The hydrodynamic model includes a transport option which invokes the tracer transport only using offline velocities and vertical diffusivities read from file. All tracer diagnostics, including sediment transport, biogeochemistry, tracer statistics, source/sinks and particle tracking will function in the transport mode. The advection scheme used in this mode is the unconditionally stable semi-Lagrangian scheme, allowing increased time-steps (e.g. 1 hour) to be used which dramatically increases run time ratios. This scheme is, however, quite diffusive and does not possess as good mass conservation characteristics as other schemes, hence some accuracy is forfeited at the expense of speed. The semi-Lagrangian scheme is unconditionally stable because it traces streamlines back in space from the point of origin (e.g. cell centres) using velocity information, then interpolates tracers using the origin location.

The concept of using offline velocities to drive a transport model is not new, however, in practice it is rarely used due to the enormous amounts of disk space required to run for extended periods. This problem is circumvented by generating the offline velocity/diffusivity

files with a ‘sparse’ file format which eliminates land and can lead to large saving in disk space (savings up to 90% are possible). I/O overhead can be reduced if the sparse format file is read into SHOC without interpolation.
The transport model is non-conservative for two reasons:

1. The semi-Lagrange scheme is cast in advective form and is non-conservative.
2. Continuity is not achieved when using snapshots or temporal averages of velocity and surface elevation fields. For a snapshot this is obvious; continuity is only achieved if the velocity is constant over the transport time-step. For temporal means, the elevation change over the model time-step is *not* equal to the horizontal divergence of depth averaged mean velocity multiplied by mean total depth, i.e.
   $$\Delta\eta = \int_{t1}^{t2} \eta dt \neq \nabla_H \int_{t1}^{t2} D dt \int_{t1}^{t2} \vec{u} dt$$
   hence continuity is also not achieved.

A global filling algorithm has been developed for the transport model which attempts to compensate for these effects and ensure conservation. This method computes the mass before advection, and the mass after advection accounting for input of mass through the open boundaries and due to source/sinks. If the scheme is conservative then mass before and after should equal. If not, then the excess or shortage of mass is distributed over all cells equally. This excess/shortage mass usually results in very small (multiplicative) adjustments to the concentrations in each cell. Furthermore, the mass adjustment may be computed so that resulting tracer values remain monotonic, i.e. the adjusted concentrations are not greater or less than the local maximum or minimum concentrations.

Continuity dictates that total volume in the whole domain at the end of the time-step is equal to total volume at the start of the time-step plus volume fluxes into the domain. Volume is not subject to errors from 1) above, so ideally (assuming volume fluxes are due to *n* open boundaries only):

$$V^t + \sum_n OBC_n = V^{t+1}$$

Any error from 2) can be compensated by adjusting the boundary fluxes by some factor *f;*

$$f = \frac{V^{t+1} - V^t}{\sum_n OBC_n}$$

This factor may then be optionally applied to mass fluxes for tracers in the transport model, so that the global fill factor is adjusted to reflect extra mass that would need to be added (or subtracted) if volume conservation were achieved in the domain. In practice continuity is not achieved in the 3D model at open boundary locations since velocity and elevation are prescribed independently via open boundary conditions (OBCs), and these OBCs rarely honour continuity. For example, a radiation condition is often used for elevation in conjunction with a no-gradient condition on normal velocity and zero tangential flow. This leads to zero divergence but non-zero change in elevation, i.e. continuity is not obeyed. This can corrupt the above computation, therefore *f* is computed excluding open boundary cells, with boundary fluxes computed at the first interior location to open boundaries.

The transport model may optionally provide a diagnostic which contains the volume error of each water column expressed as a percentage of total volume in each water column. This volume error is the difference between the volume at the end of a time-step and the sum of volume at the start of the time-step and volume flux divergence into the water column.

Additionally, a diagnostic representing the mass that must be added (or subtracted) to the domain for each tracer to achieve mass conservation, and the corresponding multiplicative fill factor is created in a time series file. Included also is the total domain volume error and open boundary scaling factor.

This project contributed to extending the functionality of the transport model, by allowing the input circulation data and output tracer distributions to reside on different grids. A sub-set of the input data grid can be used to generate output tracer distributions. Since the STORM model is large and contains high resolution, potentially making sediment or biogeochemical coupled simulations slow, it is advantageous if only a smaller sub-region of the storm model is simulated with the transport model. Additionally, an intermediate step has been included to create transport files that contain information regarding the streamline origin, rather than velocities used to calculate the streamline. This approach may increase execution speed since the streamline origin is no longer required to be calculated. If multiple grids are used, then potentially slow input of velocity information for the source grid may also be avoided.

Several options are available to the user in order to generate output with the transport model, including:

- Frequency of data read into the transport model,
- Whether input fields are snapshots or temporal means,
- The OBC used for tracers,
- If global filling is used;
    - Boundaries included in the global fill
    - Boundary flux compensation is invoked
    - The global fill is monotonic

The implementation of these options was optimized by comparing transport model output with hydrodynamic model output for the same region, over the same period. Owing to the considerable experience gained in other studies, the region chosen was the Huon / D'Entrecasteaux Channel.

A number of scenarios with varying time-step, advection schemes, simulation parameters and filling options have been executed. The simulations were based on two models: transport model fully coupled to the hydrodynamic model and stand-alone decoupled transport model driven by pre-calculated velocities and diffusion coefficients. The time step of the coupled model was 2 min, the decoupled model simulated transport with the time step of 1 hour. Additional scenario has been run with the time step of 0.5 hours. Both coupled and decoupled models simulated transport of salinity fields, resuspension and deposition of sediments and distribution of conservative dissolved tracer. Sediments were represented by two size classes one representing heavier particles (silt) and another one representing very fine particles (clay). The dissolved tracer has been released from point source at site 8 (see the location map in figure 3.1) with the constant release rate.

At the open lateral boundaries the concentrations of all tracers have been set to predefined values in the case of the incoming flow. A free flow boundary condition was applied when the water flow was directed out of the study area. All tracers in benthic layer were initialised with the constant concentrations. The initial concentrations of the suspended sediments and conservative tracer in the water column were zero. The salinity field was initialised from the regional scale model run.

Figure 3.2 shows total masses of tracers simulated with the coupled and decoupled transport models. The coupled model is based on Van Leer advection scheme. The time step of the decoupled transport model is 1 hour. The data show overall good agreement between models.

A persistent discrepancy between models in the mass balance of silt is attributed to the uncertainties of the mass filling algorithm. And agreement between models is particularly good for the salinity and for the dissolved tracer.

Concentrations of the simulated tracers at site 5 and site 10 are illustrated in figures 3.3 and 3.4. The transport models reliably tracks the evolution curves predicted by the fully coupled model, but tends to underestimate peak sediment concentrations particularly for the heavier fractions of sediments. This behaviour of the transport model was expected, since the hourly mean velocities filter out high-frequency components including peak values of the velocity. The reduced velocity translates into reduced bottom shear stress which in tern reduces peak levels of sediments. The time series of concentrations also suggest that the decoupled model tends to underestimate temporal variability of the dissolved tracer released from point source. The simulations with one-hour mean velocities, 30 minute mean velocities and with the velocity snap shots (rather than mean values) show similar accuracy in approximating fully coupled model.

Spatial patterns of the distribution of tracers are illustrated in figures 3.5 – 3.8. The plots show surface and vertical cross section of concentrations as simulated by the coupled and decoupled models. The data suggest that the decoupled model captures key patterns of distribution of simulated fields, and show particularly good agreement for the salinity distribution (figure 3.5). The decoupled sediment model tends to underestimate suspended sediment concentrations in the mid-channel while overestimating it in the southern part of the modeling domain (figures 3.6 and 3.7). A conservative tracer released from point source (figure 3.8) when simulated with the decoupled model tends to have lower concentrations levels than the tracer predicted with the fully coupled model. This discrepancy between concentrations of the dissolved tracers released from point source was found to be consistent throughout the simulation period. The reasons for the discrepancy are currently under investigation.

Simulations with varying advection schemes for fully coupled models show that the model uncertainty due to varying advection schemes in fully coupled models is similar to the uncertainty of the decoupled transport model (not shown here).

Additional scenarios have been simulated to investigate the model performance under idealised conditions of isolated benthic and pelagic layers. Constant initial concentrations have been specified for all tracers in water and in sediments. The suspended sediments in this experiment were allowed to settle down due to gravity force and accumulate in the near bottom cell but the particles were not allowed to cross the sediment water interface. The simulation results indicate that the decoupled model reproduces the distribution and evolution for most variables but gives poor performance for the heavier sediment particles (not shown in this report).

The numerical experiments suggest that the transport model is capable of reproducing key patterns of distribution of the particulate and dissolved tracers in the Huon estuary and D'ntrecasteaux channel. The price for the improved efficiency is a higher uncertainty of the decoupled model. This uncertainty shows up in a random fluctuation of the predicted values as well as in systematic discrepancies, such as the tendency of the decoupled sediment model to underestimate peak suspended sediment concentrations. One of the implications is that parameter values obtained by calibrating the fully coupled model may not be applicable to sediment and biogeochemical models based on the transport model, and these models may need to be recalibrated .

Simulations reported in this document dealt with the moderate energy environment of the Huon estuary and D'ntrecasteaux channel. The main objective was to assess the applicability of the transport model to the INFORMD region. Most of the simulated scenarios show a good match between transport and fully coupled models. However, the transport model gave poor performance for heavy sediments in an idealised scenario with decoupled benthic and pelagic layers. More numerical experiments in various environments, including macrotidal and off-shore deep waters, are needed to gain a better understanding of the transport model uncertainty. In the case of new applications it is recommended first to run trial scenarios testing the transport model against the fully coupled code.

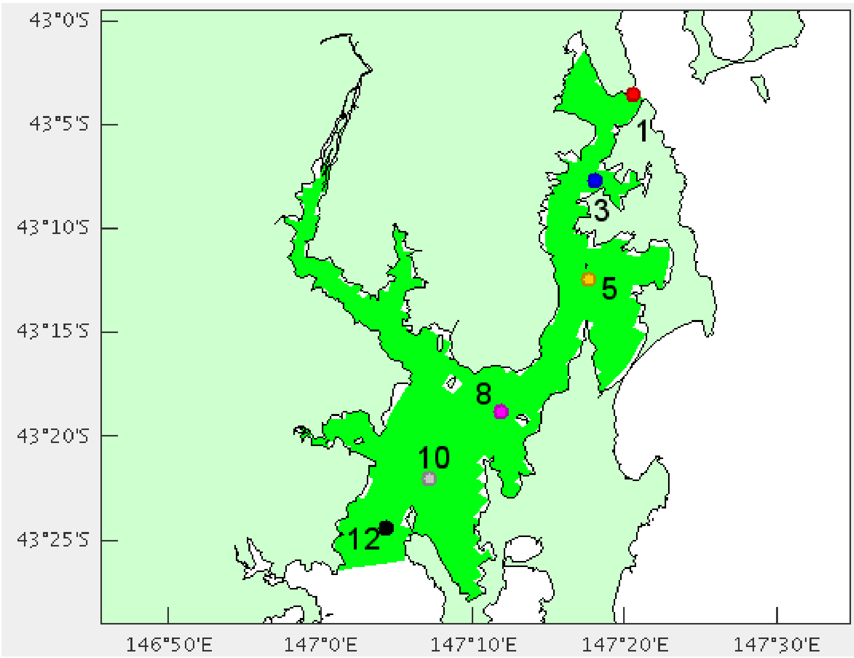

Fig ure 3.1. Location map for the point source (site No. 8) and observation sites (sites No. 1,3,5,10,12)

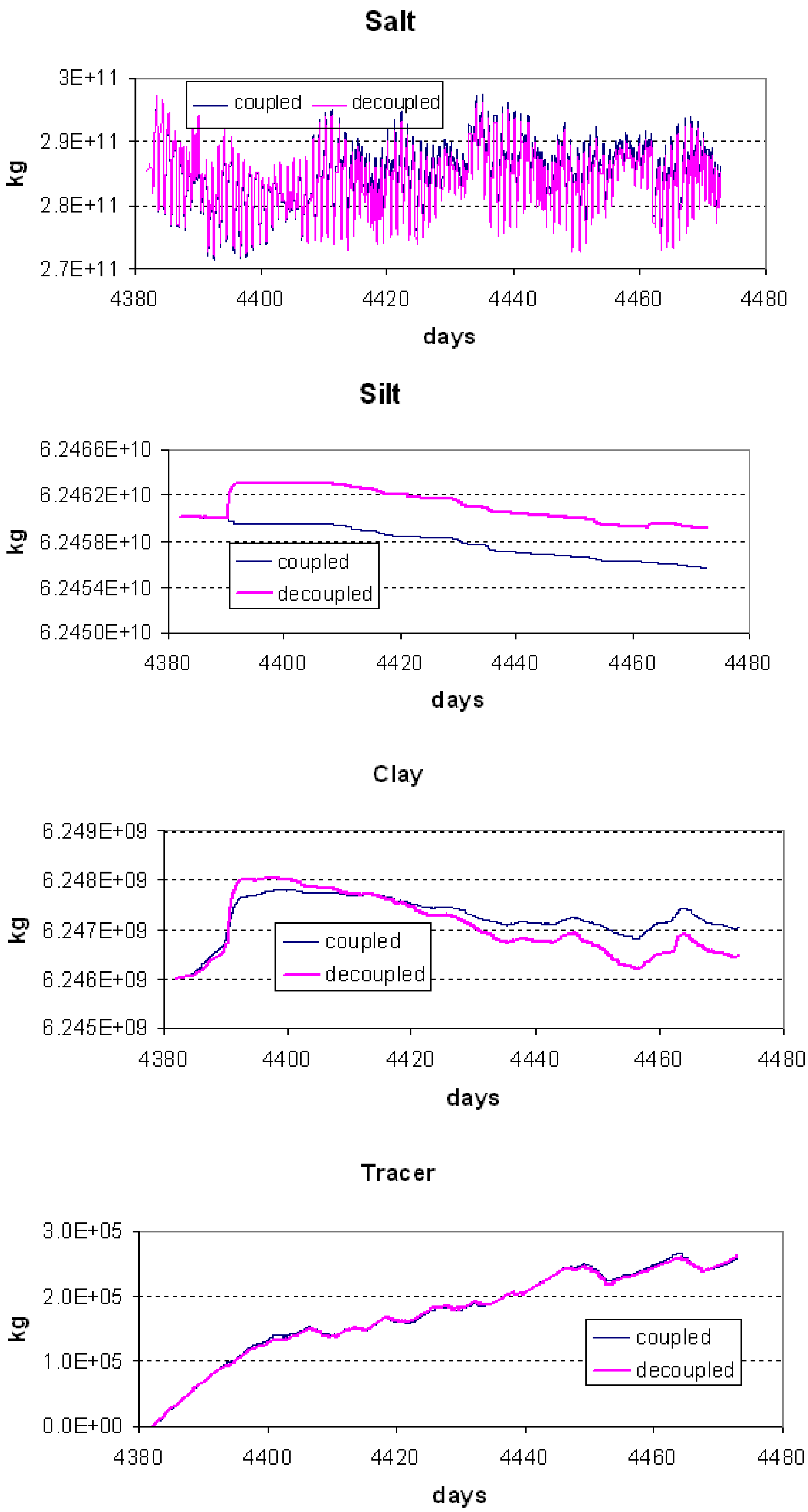

Figure 3.2 Total mass simulated with fully coupled and decoupled (transport) models

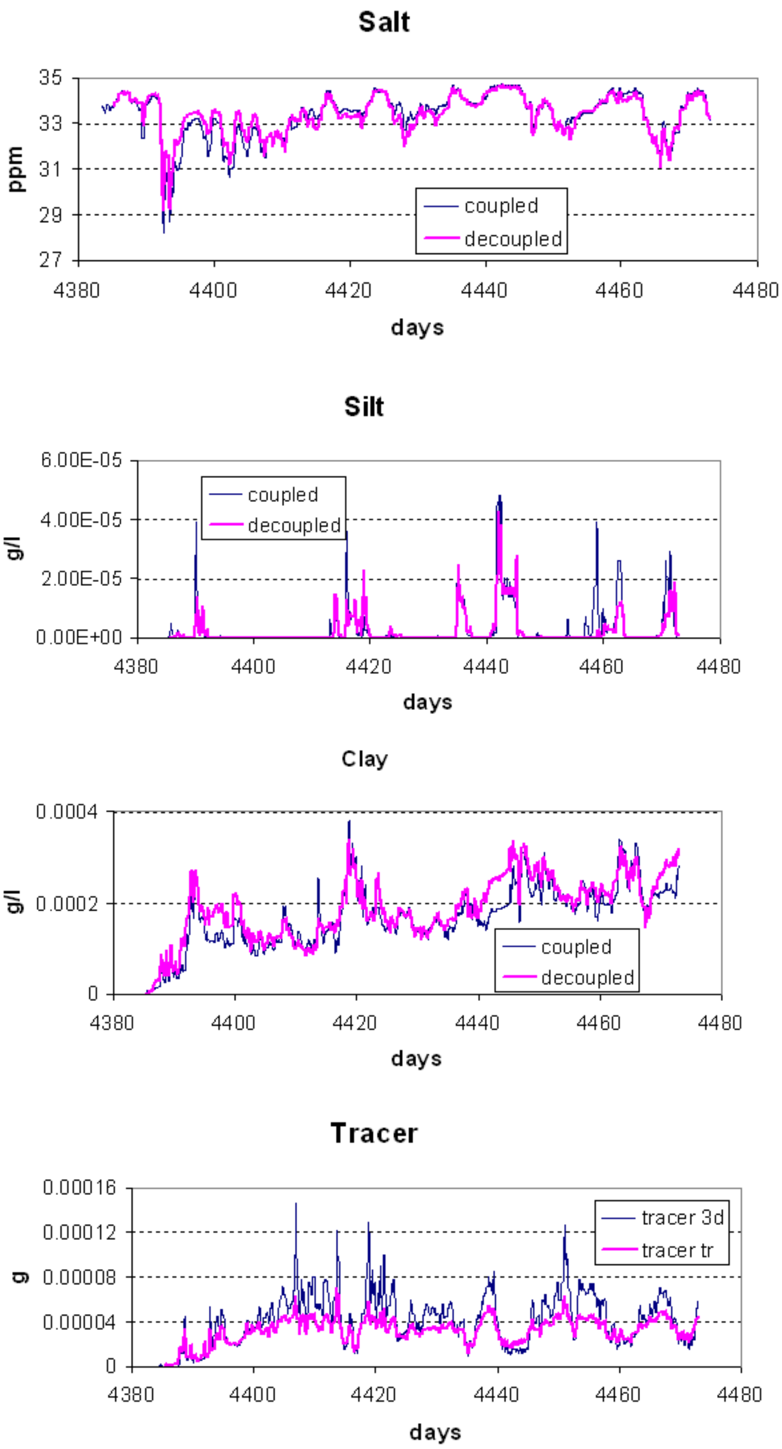

Figure 3.3 Time series of concentrations simulated with fully coupled and decoupled (transport) models at site N 10 (see location mat in Fig. 5.1)

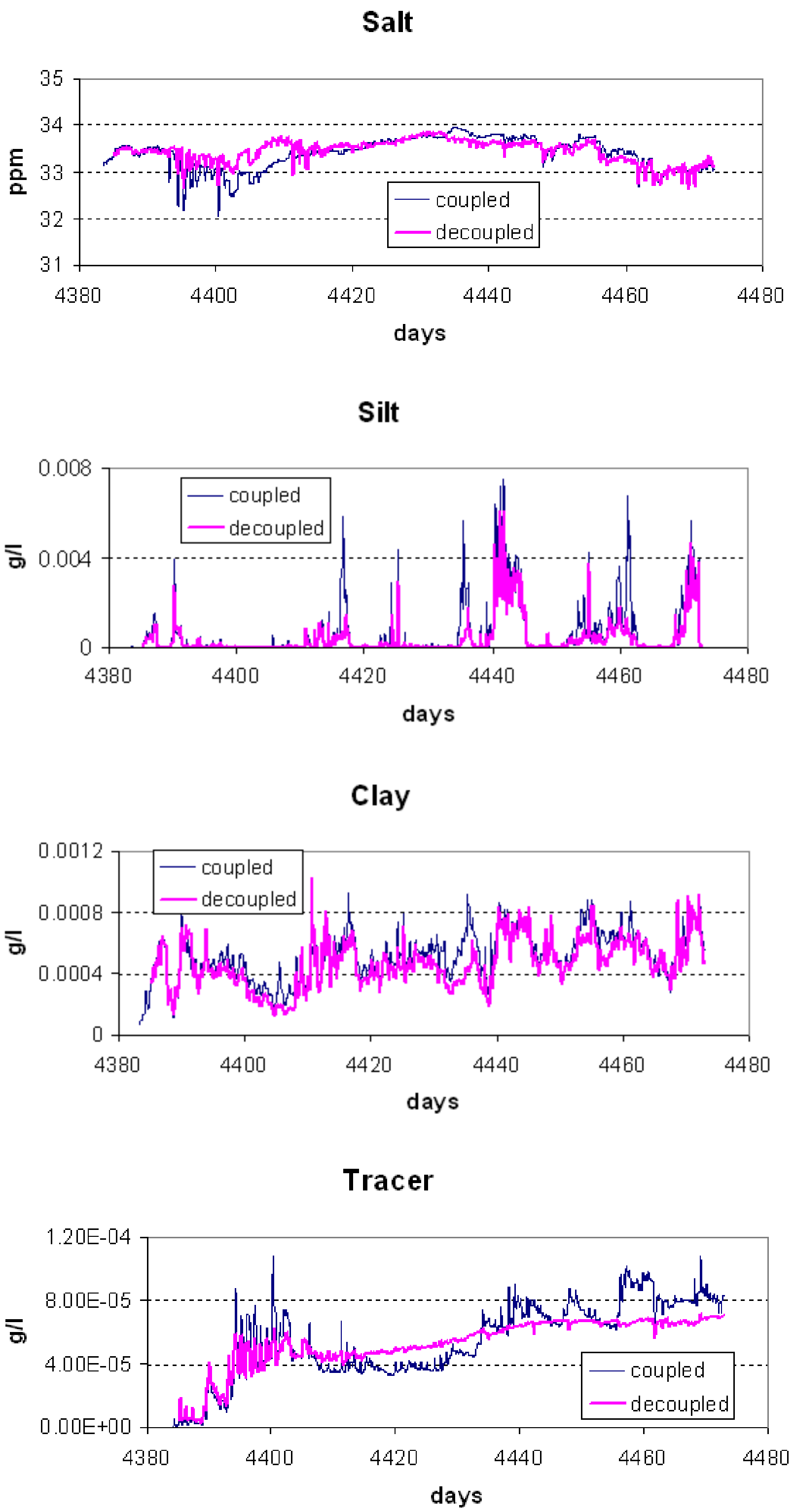

Figure 3.4 Same as in figure 5.3 but site No 5

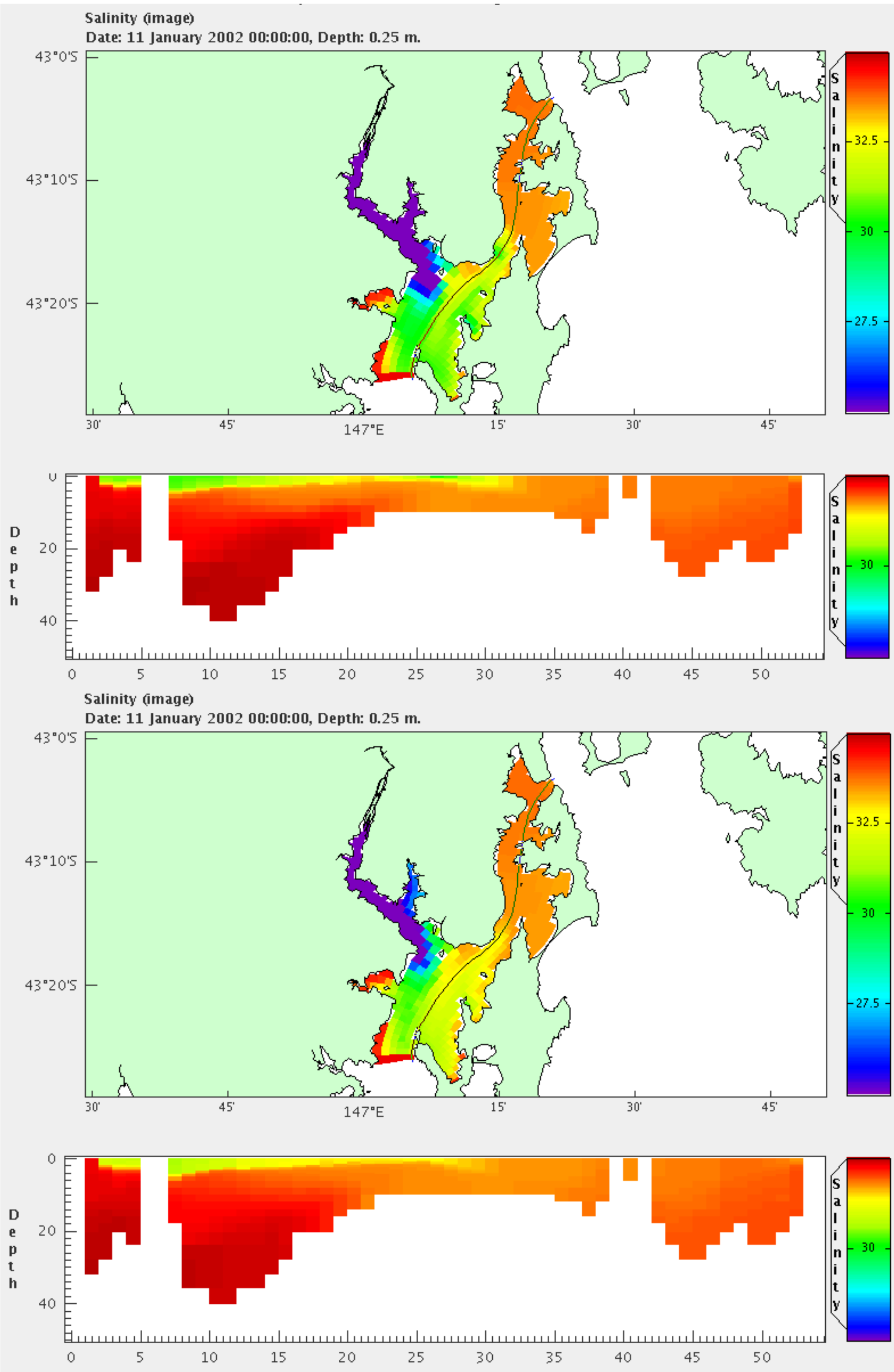

Figure 3.5 Surface and vertical cross-section of salinity simulated with fully coupled (top plots) and decoupled (bottom plots) models. The cross-section line is shown on the surface plot.

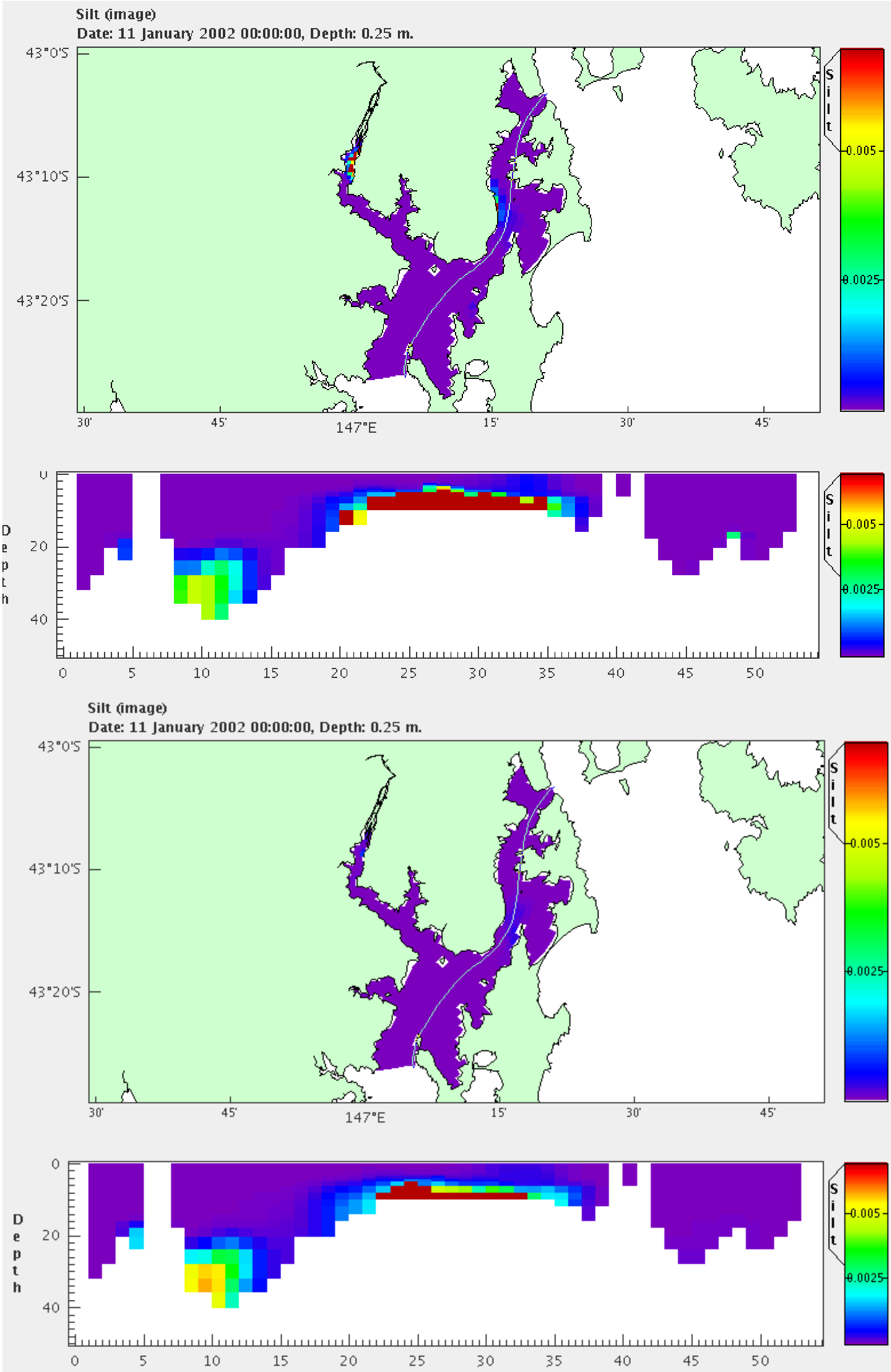

Figure 3.6 Same as above for the silt fraction of sediments.

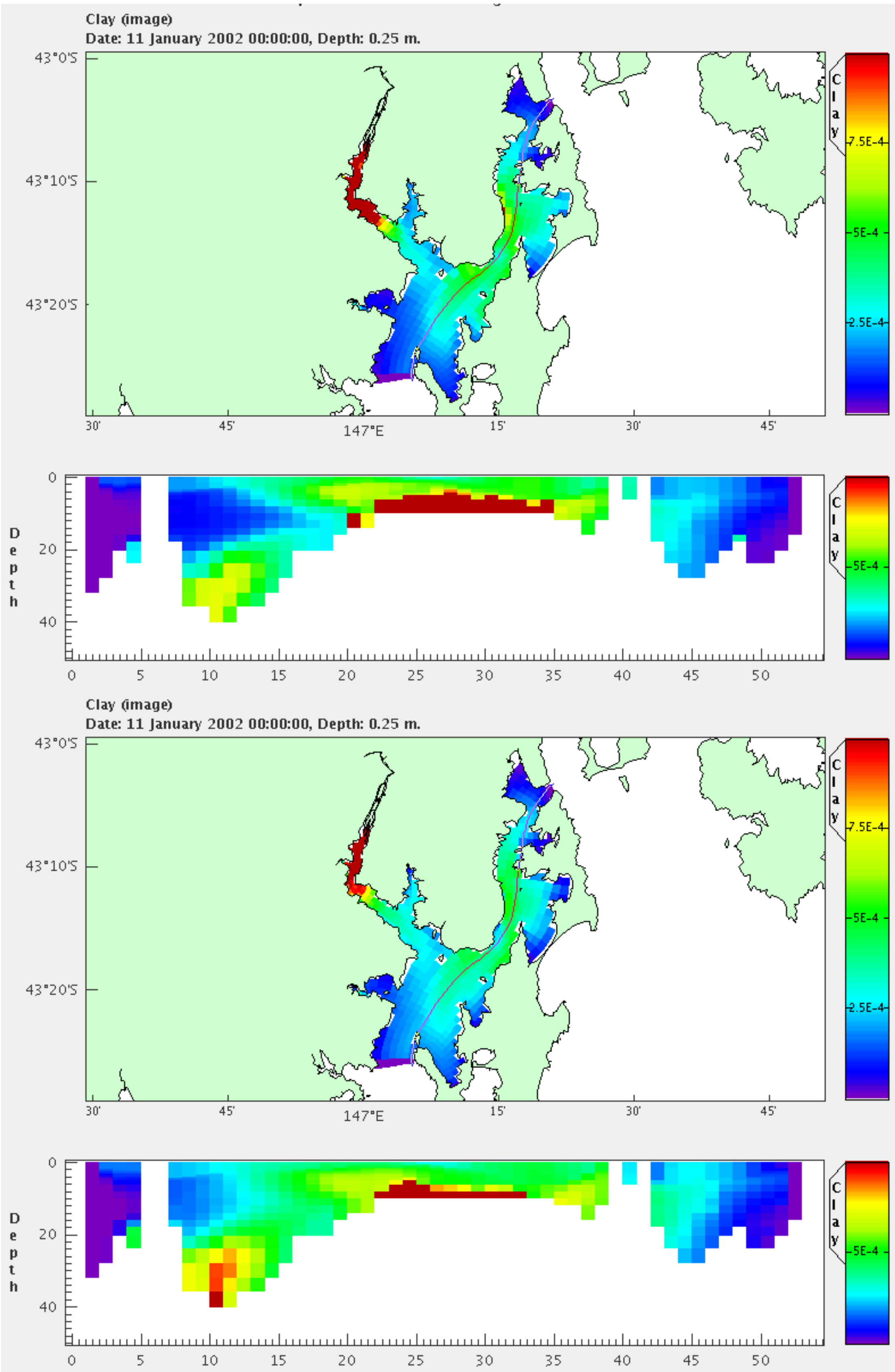

Figure 3.7 Same as above for the clay fraction of sediments.

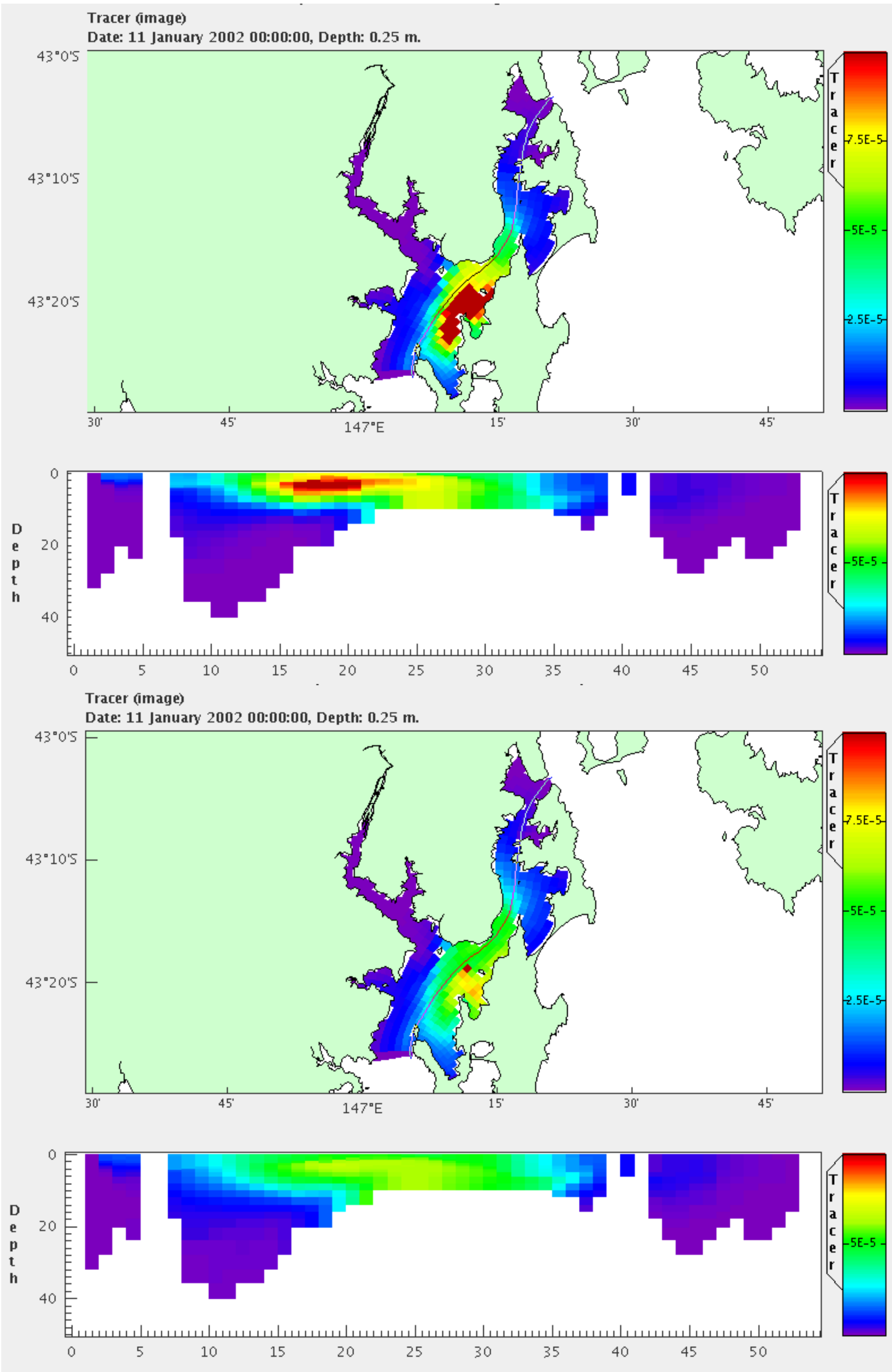

Figure 3.8 Same as above for the conservative dissolved tracer released from point source.

4. Field programs

During the first year of the project two field programs have been carried out. One of those involved trial deployments of gliders in Storm bay and another involved the evaluation of an in-situ Nitrate sensor through a short term deployment at the CSIRO wharf and a 3-month deployment of mooring in Storm Bay.

4.1 Gliders

The CSIRO's Slocum Glider, designed for coastal deployments (figure 4.1.1), is capable of moving to specific locations and reaching depths of up to 200 meters by tracking controlled spatial and temporal grids for a maximum duration of about four weeks. The glider moves both vertically and horizontally, sampling saw-tooth vertical profiles by varying its buoyancy.

The first glider deployment carried out in November 2008 was terminated after 4 days due to malfunctioning of the instrument component. During the second deployment in June 2009 the glider completed a successful 26-day monitoring of Storm Bay and covered 490 km in its voyage of north–south transects criss-crossing the bay and diving to depths of 15 to 160 metres (Figure 4.1.2). During the voyage, onboard sensors collected 400 megabytes of data including: temperature, salinity, dissolved oxygen, chlorophyll A, and backscatter of suspended materials at both 470 and 700 nm wavelengths. Highlights from the glider operations have been given in CSIRO Monday mail of 1 December 2008, and in "Wealth from oceans flagship: oceans insider" of June 2009.

Figure 4.1.1 Coastal glider

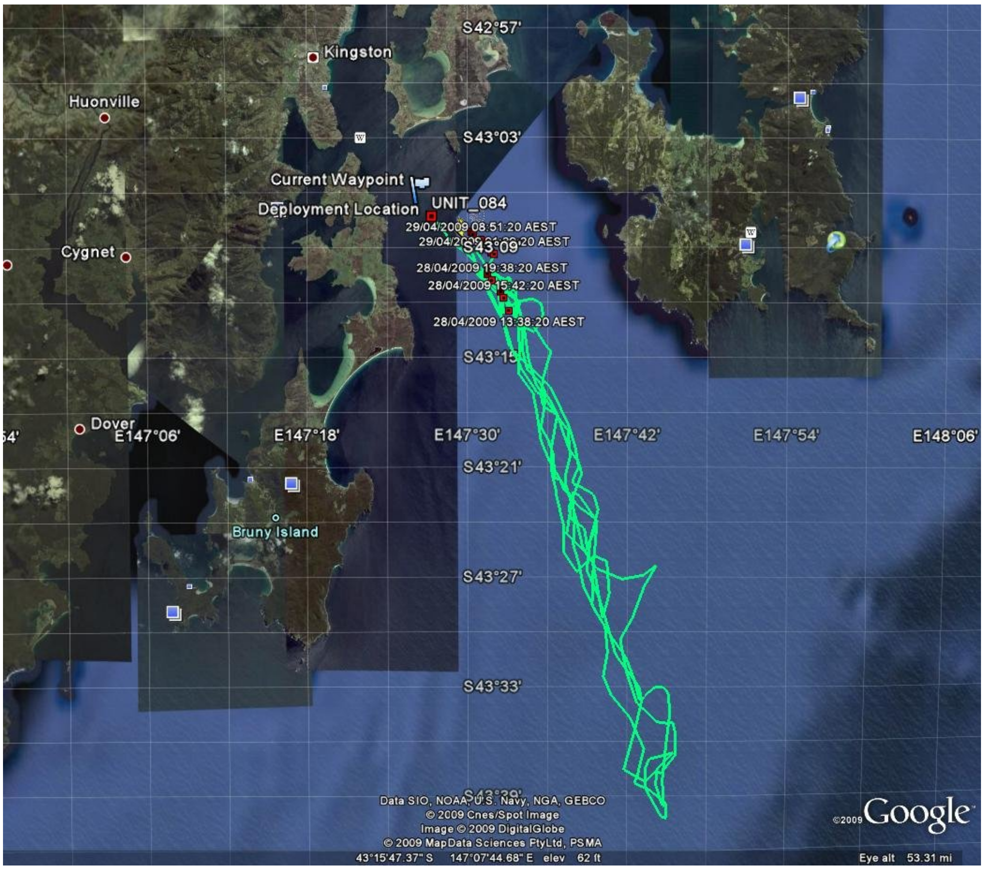

Figure 4.1.2 Glider track in Storm Bay

4.2 Evaluation of Nitrate Sensor

The influx of nutrients, particularly nitrate, into coastal biogeochemical models at the marine boundary is currently poorly constrained by traditional monthly sampling programs. Modern instrumentation such as the In-Situ Ultraviolet Spectrophotometer (ISUS), has the potential to provide nutrient concentrations with high temporal resolution, which is particularly relevant in the context of operational modeling.

Having successfully completed a 2-month trial deployment of ISUS off the CSIRO wharf in October-November 2008, a bottom mounted mooring frame with attached ISUS was deployed in Storm Bay in May 2009. The frame also accommodated a multi-sensor CTD including dissolved oxygen and chlorophyll sensors, and an ADCP. The ISUS mooring was successfully recovered in June 2009 after ~3 month deployment. However due to failure of internal clocks, the ISUS instrument only logged 2.5 days of nitrate data at the start of the deployment. Communications with manufacturers are underway to further investigate the logging problem. The Storm Bay mooring also collected 3-month data of ADCP and 20-day data of temperature, conductivity, PAR, pressure, fluorescence, and oxygen.

The chapter below describes phase1, wharf deployment and evaluation of ISUS.

Evaluation of an In-Situ Ultraviolet Spectrophotometer (ISUS) for detection of nitrate in coastal waters
Phase 1: Wharf Deployment

PI: *Karen Wild-Allen*
SE&T: *Tim Lynch, Phil Adams, Dave Hughes, Dave Cherry, Danny McLaughlan, Phil De Boer.*
Samples: *Jenny Skerratt, Pru Bonham, Val Latham, Peter Thompson*

Introduction

The influx of nutrients, particularly nitrate, into coastal biogeochemical models at the marine boundary is currently poorly constrained by traditional monthly discrete water sampling programs. Modern instrumentation such as the ISUS, and similar devices, have the potential to provide nutrient concentrations with high temporal resolution which will result in substantial improvements in model simulations by reduction of uncertainty. Coupling of nitrate sensor deployments into sensor networks could provide near-real time data and facilitate operational biogeochemical modeling of coastal waters.

This ISUS instrument owned by CMAR was originally used as a bench-top flow through device on southern ocean research cruises. In 2007 the ISUS was configured for profiling deployment and integrated into the CTD and rosette system of the RV Southern Surveyor. Approximately 120 profiles were obtained off WA between Freemantle and Dampier, however the device demonstrated significant thermal hysteresis which impacted on the stability of the spectrophotometer light source and calibration of the instrument against bottle samples was non-trivial.

The primary objective of this deployment was to evaluate the accuracy and long term stability of the Satlantic ISUS on a mooring deployment in coastal waters. An important associated objective was to familiarize ourselves and SE&T technical support staff with the configuration of hardware and software for a moored deployment of the instrument.

Instrument configuration

The ISUS was linked to an external battery pack and mounted on a board to facilitate deployment on 2 vertical wires hanging under the wharf (part of the ICT TASMAN sensor network infrastructure). A large external anode was manufactured by SE&T and attached to the end-cap of the instrument to minimize corrosion damage to the case whilst submerged in sea water. It was technically possible to link the instrument to the surface by a data cable and log real-time data through the ICT system on the wharf, however the additional resources were difficult to justify for the relatively short deployment period of ~2 months, so this option was not pursued. The ISUS was attached to the ICT vertical wires and lowered by rope to ~9m similar to the depth of their deeper temperature and salinity sensor deployment. Periodically the instrument was raised to the surface to download data files via cable connection to a laptop.

Figure 4.2.1: ISUS deployment on wires under CMAR wharf. Inset image shows copper sensor cover (with fine mesh insert).

The instrument was configured to sample at hourly intervals using the default ‘schedule mode’ and save instrument parameters plus 2 light and 1 dark full spectrum scan from 190 - 400 nm. [Nitrate concentration is calculated by an algorithm that de-convolutes the absorption spectra of salinity, bromide and nitrate from the in-situ full spectrum scan].

Water samples

Water samples were taken adjacent to the ISUS at ~9m depth using a Niskin Bottle and messenger by hand. Nutrient samples were frozen and analyzed in the CMAR hydrochemistry laboratory for nitrate, phosphate and silicate concentration. Parallel samples were taken at ~ weekly intervals for phytoplankton identification. Samples were preserved in Lugols Iodine and counted under the microscope by Pru Bonham.

Laboratory Results

During the October – November 2008 nitrogen and phosphorous concentrations at ~9m under the CSIRO wharf were generally low although silicate concentrations were higher.

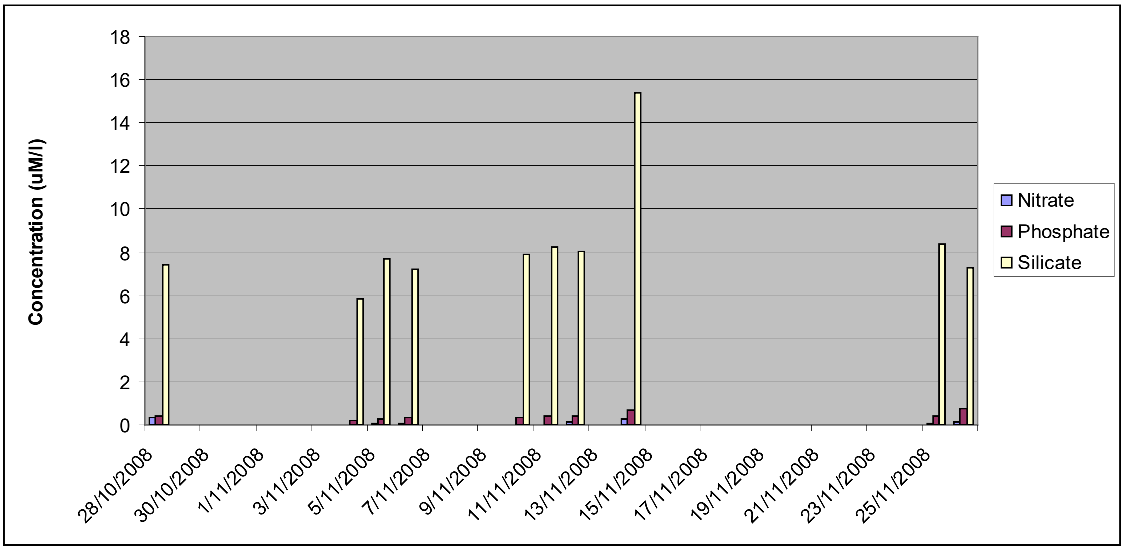

Figure 4.2.2: Nutrient concentrations at ~9m under the CSIRO wharf in October-November 2008

Nitrate was the nutrient with lowest availability and with respect to the Redfield ratio of 1P:16N:106C (which represents the typical composition of phytoplankton) would likely have limited phytoplankton growth. The average N:P ratio was 0.25 molN/molP well below 16 indicating that Derwent waters carry significant loads of P in excess of the requirement for phytoplankton growth.

During the study period the phytoplankton community included a diverse population of diatoms, dinoflagellates and flagellates. Cell counts were similar to September 2008 but biomass was elevated by the larger proportion of dinoflagellates (in September diatoms were in greater abundance). The community was typical of post spring early summer with a declining diatom population and increasing concentration of dinoflagellates. Dinoflagellates can accumulate under low ambient nutrient concentrations due to their ability to vertically migrate to access both light and elevated concentrations of nutrients at depth. The large heterotrophic dinoflagellate Noctiluca increased in concentration following stormy weather in the south and produced a few short lived red-tide slicks in Constitution Dock, off Bellerive and in Lindisfarne marina.

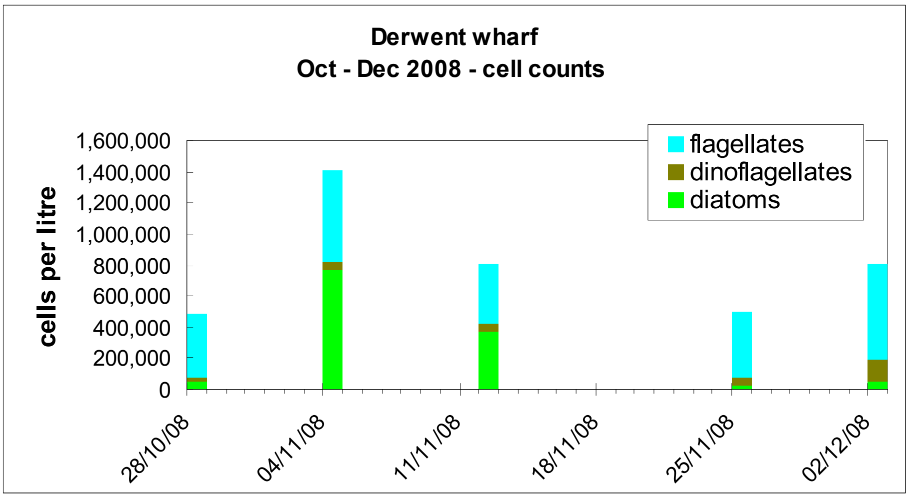

Figure 4.2.3: Phytoplankton cell counts at ~9m off the CMAR wharf in October-November 2008.

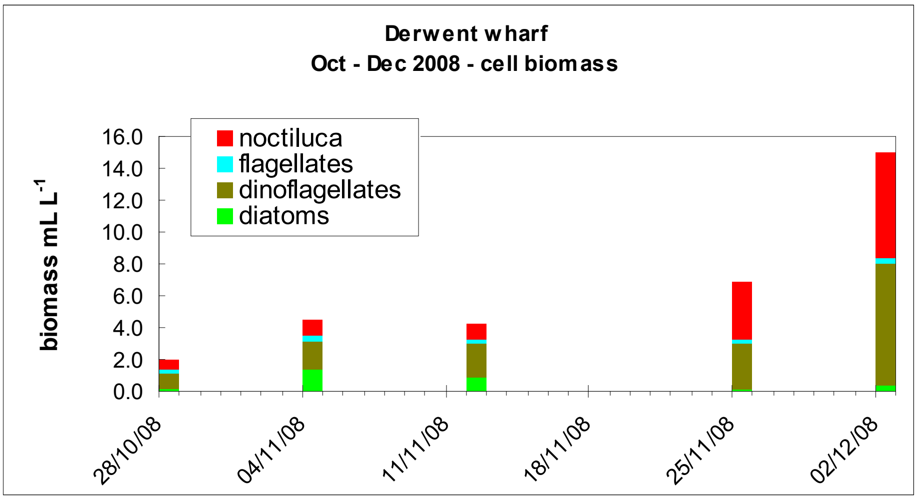

Figure 4.2.4: Phytoplankton cell biomass at ~9m off the CMAR wharf in October-November 2008.

ISUS Results

The ISUS instrument logged daily files which included instrument parameters (internal voltages, humidity, battery voltage, etc), calculated nitrate concentration and a full UV spectral scan from 190 – 400 nm.

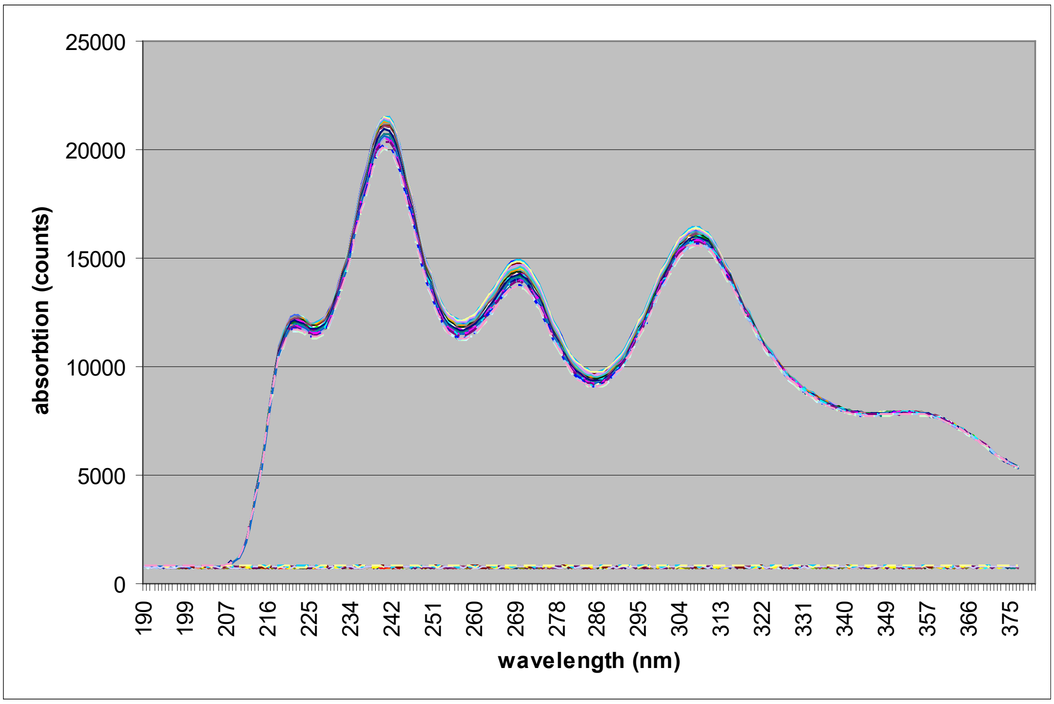

Figure 4.2.5: Daily UV spectral scans of absorption for light and dark shutter readings [includes absorption due to salinity, bromide, CDOM and nitrate].

Initial nitrate values returned from the instrument were in the range – 10 to -13 uM/l which suggested a poor instrument baseline calibration. Satlantic suggested updating the distilled water spectra (with zero salinity, bromide, CDOM, nitrate) in the calibration file. This was initially attempted on the wharf by cleaning the sensor head and submerging it in a basin of miliQ water. Flow through the copper anti-fouling sensor guard and fine mesh lining was however limited and the miliQ water became contaminated rendering the re-calibration attempt unsuccessful.

The ISUS instrument was then transported into the lab and the copper sensor guard and mesh lining removed. Both items were found to be fairly well clogged with copper and marine debris after only 3 weeks of in-situ deployment limiting flushing of the probe head. Once removed the spectrophotometer probe was found to be clean of marine fouling but was wiped with alcohol for certainty. The probe was then dipped in miliQ water and a laboratory standard nitrate solution 1 uM/l for calibration. Using Satlantic software the distilled water spectra was updated in the calibration file (ISUS076D.cal) and the daily data files were successfully reprocessed to give positive nitrogen values.

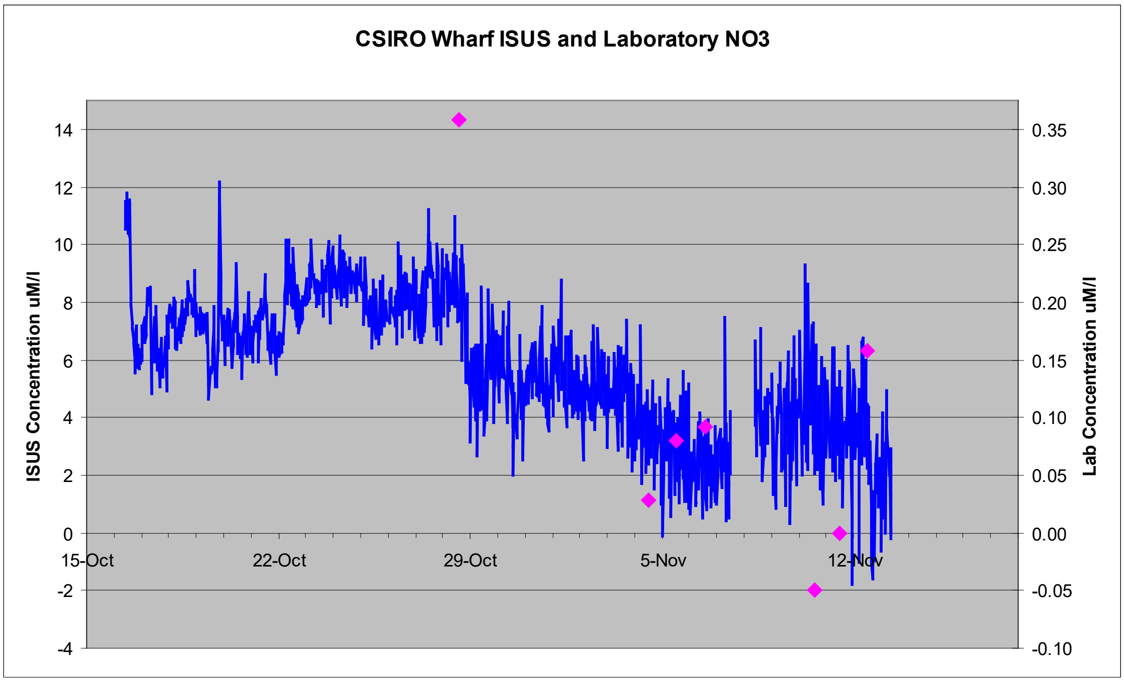

Figure 4.2.6: Raw ISUS and laboratory nitrate concentration (plotted on contrasting y-axis scales).

The ISUS instrument consistently over estimated the concentration of nitrate in-situ compared with samples analyzed in the laboratory. Instrument documentation indicates that the derivation of nitrate from in-situ UV absorbance spectra has little skill at concentrations of nitrate less than 2 uM/l. A scatter plot of all samples analyzed and ISUS readings shows that the instrument is pretty unreliable at low concentrations of nitrate as experienced in this trial.

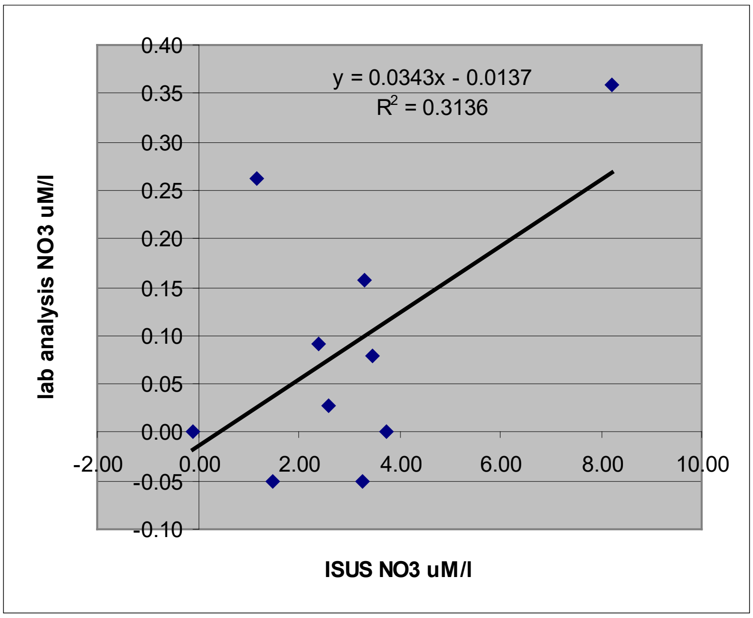

Figure 4.2.7: Comparison of laboratory and ISUS determined nitrate concentration for all samples analyzed. A linear trend line is fitted with R2 value of 0.3 .

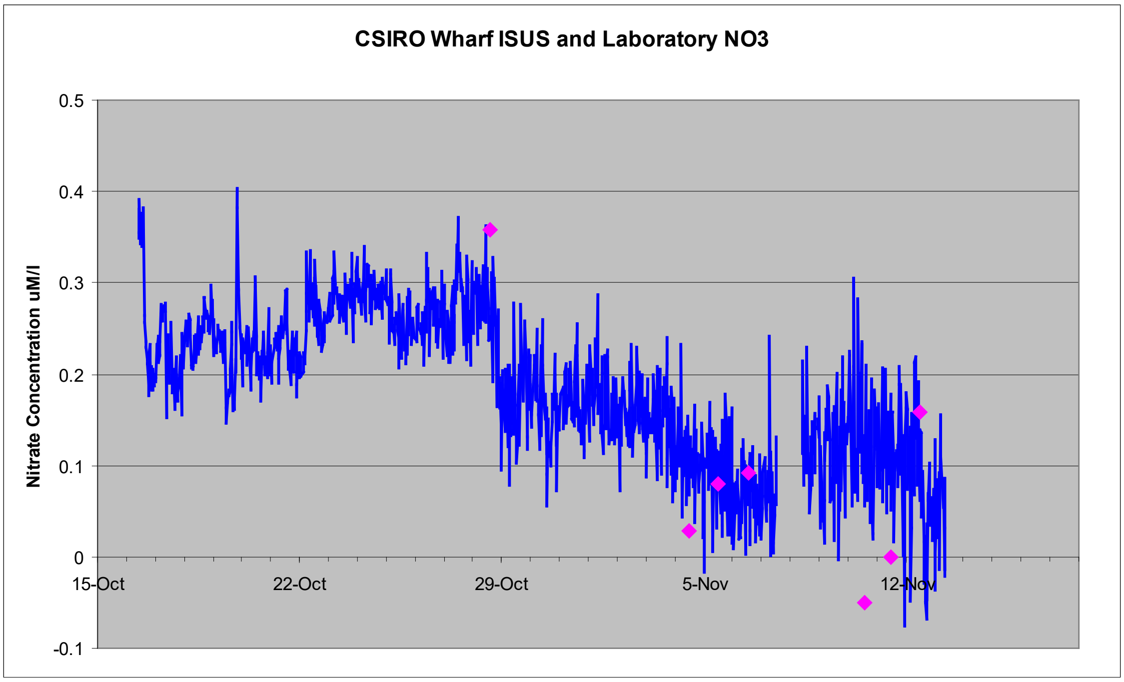

Figure 4.2.8: Re-scaled ISUS nitrate concentration and laboratory nitrate concentration for the deployment period.

Using the linear relationship established in figure 4.2.7 the ISUS data was rescaled to a more realistic range of values. During the deployment period nitrate fluctuated considerably on hourly and weekly timescales. Hourly fluctuations are considered to be primarily noise, but weekly fluctuations may reflect real changes in ambient nitrate concentration. During the deployment period nitrate concentrations appeared to decline in both the ISUS data and the laboratory samples. This could be realistic due to phytoplankton utilization of nitrate.

ISUS nitrate data were compared with the wharf ICT bottom mounted temperature sensor (raw data). On the 19 and 22 October intrusions of slightly warmer water may correspond to an increase in nitrate concentration (with slight delay). The delay in nitrate sensor response could result from poor flushing of the sensor chamber associated with the copper anti-fouling cover and fine mesh lining.

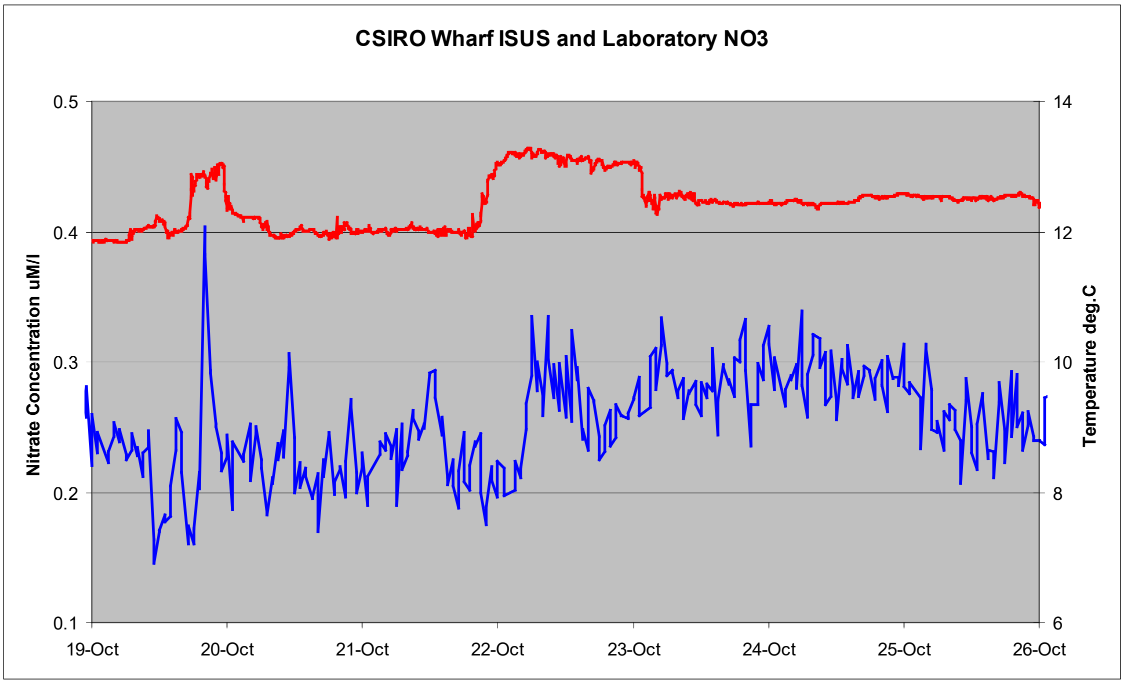

Figure 4.2.9: Concurrent ISUS nitrate and raw data from the wharf ICT bottom temperature sensor.