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RESEARCH

Assimilation of Radar Measured Surface Current Fields into a Numerical Model for Oil Spill Modelling

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In summer 1996, surface current fields were measured in the central Strait of Georgia using the SeaSonde, a portable shore-based HF radar system. The objective of the study was to assess the feasibility of blending SeaSonde currents with numerical model fields to fill gaps in the measured fields and reduce noise. Our eventual goal is to assimilate the blended SeaSonde fields into a three-dimensional numerical model to improve short-range current forecasts.

The first part of the study involved using the blended current fields as input to a set of auto-regressive moving-average (ARMA) statistical models. The blended fields were found to give forecasts comparable in terms of RMS error with forecasts using raw SeaSonde measurements. Moreover, the blended fields were smoother and more spatially complete than the raw data. The second part of the study examined the suitability of using the SeaSonde current fields to update the surface layer of Seaconsult's C3 hydrodynamic model. A simple nudging method is presented as an economical way to drive the model surface layer using operationally gathered SeaSonde information. © 1997 Elsevier Science Ltd

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Introduction

Accurate prediction of surface currents depends greatly on the quality of the meteorological and oceanographic data available, and the limitations of the forecasting model used. The SeaSonde surface current mapping instrument, a two-site, portable HF radar system (Hodgins, 1994), provides data over a coverage area of up to 2500 km^2 with a resolution of approximately 2 km. While the quality of the data is generally high, the data can be gappy and coverage may be limited by the exposure of the available siting.

Previous studies have investigated methods of using the SeaSonde data as a basis for current forecasting (Hodgins *et al.*, 1993). Past prediction methods using the SeaSonde relied on auto-regressive moving-average (ARMA) techniques, which used SeaSonde-derived currents and the local wind field to predict the non-tidal component of the currents. The ARMA models showed some skill in predicting currents up to 48 h in the future, but the results contained enough uncertainty to limit their usefulness for oil spill response. Because the ARMA models are statistical in nature, they are limited in their usefulness as predictors for ocean dynamics.

The goal of this study is to investigate methods of directly assimilating blended SeaSonde and model-generated current fields into a three-dimensional numerical model (C3). The first step was to examine the characteristics of blended C3 and SeaSonde data.

In order to test blending methods, a study was undertaken for Environment Canada and a new data set was acquired in the Strait of Georgia (Tinis & Hodgins, 1997).

Statistical prediction methods using SeaSonde measured currents

The objective of the 1996 study, supported jointly by Environment Canada (60%) and Seaconsult (40%), was to investigate how blending SeaSonde measurements with modelled current fields could be used to interpolate gappy SeaSonde fields, reduce noise and improve the accuracy of statistically predicted currents.

The Seasonde

The SeaSonde system gathers radial current information autonomously from each of two radar sites and combines the information to form a surface current field. Radial velocity vectors are derived from the Doppler shift of sea-echo spectra (Hodgins, 1994). Fifteen 256-s ensembles of radar wave cross-spectra are averaged each hour, and the radial velocities are extracted from these hourly averaged cross-spectra using a least-squares direction finding method described by Lipa & Barrick (1983). Spurious velocities were removed using two thresholds: (1) $v > 250$ cm/s; and (2) $\delta v > 80$ cm/s, where v is the speed and δv is the measurement uncertainty (Lipa & Barrick, 1983). The radial data from both sites are first filled by using a cubic spline interpolation (restricted to gaps no larger than the velocity decorrelation length scale (8 km)) then combined to form total surface current vectors.

The numerical model

Seaconsult's C3 model is a non-linear primitive equation model that applies the layer-integrated Reynolds equations for turbulent flow on a three-dimensional grid. C3 is presently implemented on a uniform 1-km grid covering the Strait of Georgia, Puget Sound and Juan de Fuca Strait (Fig. 1). Boundary conditions for the model are provided by harmonic tidal constituents at the open boundaries (Juan de Fuca Strait and Johnstone Strait), wind stress over the surface layer and daily fresh water discharge from the Fraser River. The density field is initialized using historical CTD data, primarily composed of a 1967–1968 set of monthly casts published by Crean & Ages (1971).

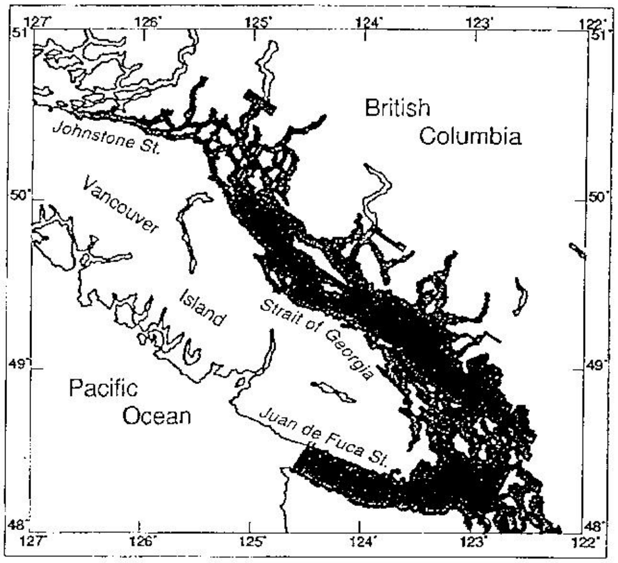

Fig. 1 The 1-km C3 numerical model grid for the Georgia-Fuca waterway.

The experiment

The SeaSonde was deployed between 10 July and 6 August 1996, with one radar unit located at the Entrance Island light station (near Nanaimo), and the other near Gibson's on the Sunshine Coast. This cross-strait configuration resulted in a near-baseline gap in the computed currents, where the angle between measured radial currents from both sites was too acute to combine into a total vector (Fig. 2a). The C3 model was hindcast over a 28 day period coincident with the SeaSonde deployment.

A simple method of blending model and SeaSonde currents was chosen; Seasonde vectors within a zone of influence (4 km) around a model cell were vector averaged using a 1/distance^2 weighting, and the resultant vector was averaged with the model cell velocity (equal weight given to each). If no SeaSonde vectors were present inside the zone of influence, then only the model velocity was used. The resulting blended fields (e.g. Fig. 2b) were smoother and more spatially complete than the measured fields. A set of blended fields from the 1996 SeaSonde deployment period was selected and used as input to a set of ARMA forecasting models.

The auto-regressive model

The ARMA models use velocity auto-correlations and wind velocity cross-correlations to predict the non-tidal surface layer velocity. Forecasting of the SeaSonde data was performed for one 5-d and one 7-d period; in each period, the final 48 hours were taken as the forecasted portion of the record. The

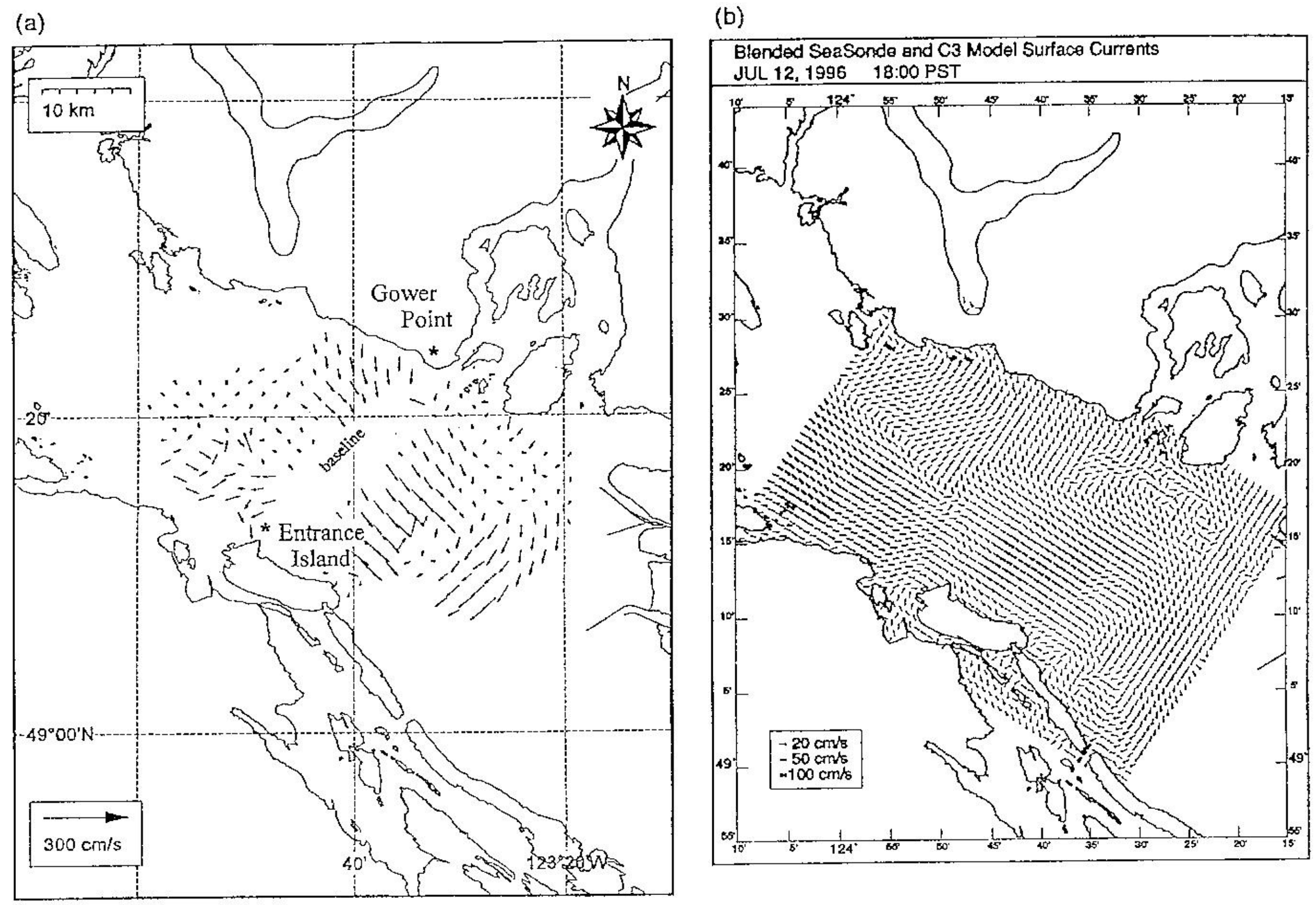

Fig. 2 Surface currents on 12 July 1996 (18:00 PST): (a) as measured by the SeaSonde; and (b) SeaSonde measurements blended with C3-generated currents.

ARMA forecasts were made using measured currents and measured winds. Measured SeaSonde currents over the 48-h forecast period were compared with: (a) ARMA projections using SeaSonde data as input; (b) ARMA projections using blended SeaSonde/C3 currents as input; and (c) C3 model predictions.

The largest RMS differences (30–32 cm/s) were found for (c) (C3 model forecasts compared with SeaSonde measurements). Although the modelled currents (not shown) and the measured current field have similar scales of variability (5–10 km), the SeaSonde field contains more small-scale spatial eddy features and current shear than the model. SeaSonde currents also contain more temporal variability than the model.

Comparisons between the measured SeaSonde data and the ARMA forecasts based on both raw and blended SeaSonde current input were better: the RMS differences for forecasts (a) and (b) (ARMA projections compared with SeaSonde measurements) were 18–24 cm/s and 19–26 cm/s, respectively. Although the ARMA forecasts made using the blended data were less noisy than those made using the raw data, the RMS differences between both forecasts and the measured currents were not significantly different. The similarity in RMS error suggests that the smoothing obtained with the blending procedure does not necessarily translate into a closer fit to measurements.

The blending of SeaSonde and model fields was effective in filling data gaps to provide a more spatially complete and smoother surface current field. Our findings suggest that the Seasonde measured fields can be filled with reasonable accuracy by blending the measurements with a properly formulated hydrodynamic model for a coastal area, and that the blended fields can then be used as input to ARMA forecasting models without significant loss of accuracy over using directly measured data.

Data assimilation

The next phase of our work was to assess methods of assimilating blended SeaSonde/C3 fields into the C3 model. Assimilation methods fall into two basic categories (Ghil & Malanotte-Rizzoli, 1991; Smedstad & Fox, 1994): (1) simple methods (e.g. data insertion, nudging and blending); and (2) complex methods (e.g. inverse and adjoint methods). Because of the large amount of data and the computational expense involved with complex assimilation methods, our first choice was to test a simple nudging method similar to that described in Smedstad & Fox (1994).

The initial assimilation tests began by replacing the entire model surface layer with a test field at regular time intervals. The test fields were created by extracting model fields from a control model run and adding random noise with an RMS difference of 1 cm/s. Test fields were injected at hourly intervals for 4 h after the start of the model run, then the model was allowed to run normally for the remainder of the 12-h simulation. The RMS difference between the assimilation and control model east–west (*u*) velocity component is shown in Fig. 3 (the *v* component shows similar characteristics)—the data insertion times are identified by the sharp peaks at time steps 1, 15, 30 and 45 (the model time step is 240 s). Because the assimilated fields are not in dynamic balance with the model density and vertical velocity structure, the model 'relaxes' towards the control solution between assimilation intervals.

After the final injection at time step 45, the model begins to relax towards the control solution, but appears to approach a new dynamic equilibrium likely brought about by changes in the density structure caused by the velocity nudging. Of particular interest is the rate at which the surface layer information is propagated to deeper layers (e.g. layers 2 and 5 shown in Fig. 3) not directly updated at the assimilation time steps. Smedstad & Fox (1994) noted when assimilating pressure fields into a two-layer Gulf Stream model that it was necessary to update the lower layer at the same time as the surface layer using a statistical inference technique. Similarly, a scheme based on an empirical orthogonal function (EOF) analysis of the vertical profiles of model velocity could be used to directly update the C3 lower layer velocities. Since surface layer information appears to be diffusing to depths well below the pycnocline over only a few hours, direct updating of the lower layer velocity fields may not be required.

The second test involved updating a portion of the C3 surface layer using actual SeaSonde measurements: because of the relatively noisy nature of the 1996 SeaSonde data set, a 1993 SeaSonde data set covering the Fraser River plume (Hodgins *et al.*, 1994) was selected for assimilation testing. The surface layer velocities were updated hourly over a 7-d period with SeaSonde currents where available; if no valid SeaSonde data existed within a given model cell, the velocity was computed as normal. RMS differences between the assimilation and control runs show a rapid diffusion of surface information down to 50 m (similar to the first test). Although the RMS error was relatively large at times, the model remained stable throughout the test assimilation period.

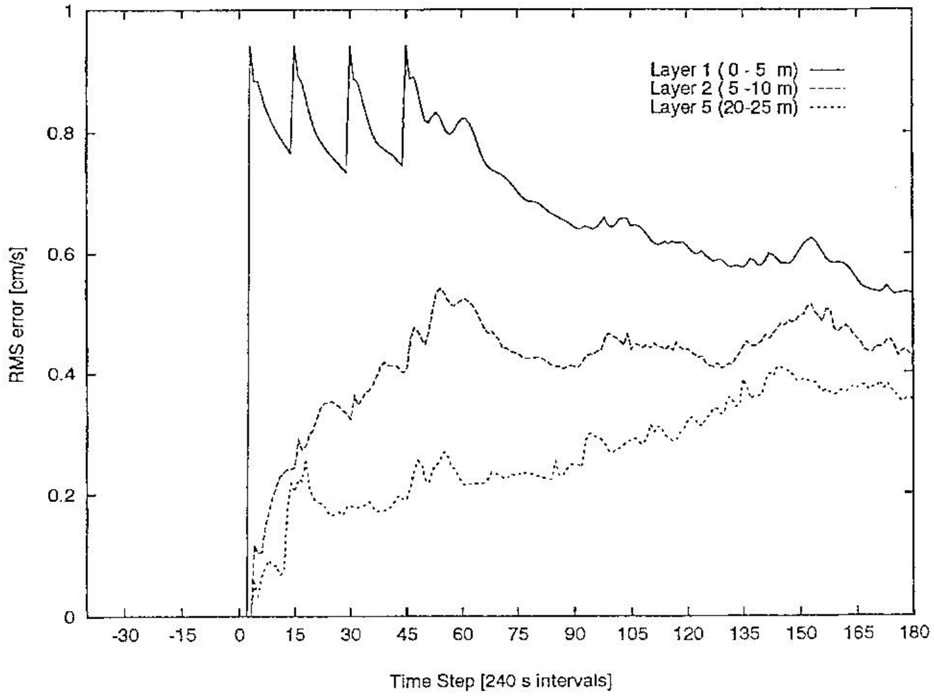

Fig. 3 RMS difference between the 12-h test assimilation model run and the control model run.