Final Report

Expert Advice, System Analysis, Programming and Delivery of Deployment Strategy for Rescue, Safety and Environmental Response at the Canadian Coast Guard College, Sydney Nova Scotia

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Abstract

This report presents the results of sensitivity experiment using Ocean Current Mapping System (OCMS) to determine sensitivity of the prediction results to the deployment and number of SLDMB buoys. These conclusions are based solely on the use of OCMS predictions without any additional information, hence the limitations should be recognized. It was found that the optimal number of drifters is between 3 and 5 and that adding additional drifter does not result in significant improvement in drifter trajectory predictions over 48 hours. The experimental data suggest that the initial deployment configuration is not important and that all drifters should be ideally deployed at the same time. Finally, we could not clearly suggest the size of the deployment area due to the limitations of the data and methodology.

Sommaire

Ce rapport présente les résultats de l'expérience de sensibilité en utilisant le système OCMS pour déterminer la sensibilité des résultats de prévision au déploiement et au nombre de bouées de SLDMB. Ces conclusions sont basées seulement sur l'utilisation des prévisions de OCMS sans n'importe quelle information additionnelle, par conséquent les limitations devraient être reconnu. On l'a constaté que le nombre optimal de bouées est entre 3 et 5 et qu'ajouter la bouée additionnelle n'a pas comme conséquence l'amélioration significative des prévisions de trajectoire entre premières 48 heures. Les données expérimentales suggèrent que la configuration initiale de déploiement ne soit pas importante et que tous les pêcheurs devraient être idéalement déployés en même temps. En conclusion, nous ne pourrions pas clairement suggérer la taille du secteur de déploiement dû aux limitations des données et de la méthodologie.

Introduction

Trials conducted by the Canadian Coast Guard, the Department of National Defence and the U.S. Coast Guard have demonstrated that the accuracy of marine search planning is greatly improved by the use of near real-time current information. Recent Canadian Coast Guard R&D projects have shown that the most reliable way of using this information is by inserting data from "Self-Locating Datum Marker Buoys" (SLDMB) into a search planning program.

The Ocean Current Mapping System (OCMS) was developed to facilitate the use of SLDMB data and their transformation into current maps, drifter tracks and error estimates. This enables highly qualified search and rescue personnel to extract the maximum amount of information from SLDMB data. The quality of this information, however, depends on how the SLDMB's are used. More specifically the effectiveness of mapping software depends on, – the number of buoys that are deployed and their initial release pattern. Therefore, it is of critical importance to explore and analyse deployment strategies and their sensitivity to environmental factors such as water depth, wind, and their proximity to the coast.

Previous numerical experiments that formed the basis of OCMS have established that the most useful information can be extracted from SLDMBs configured as person in the water (PIW). This is due to several reasons: (a) The drifter has minimal leeway (assumed 0) and thus represents the best proxy of the surface current; (b) The use of the data does not require and other information such as wind; (c) These drifters have shown more stable performance during deployment because they do not require life raft inflation that represents an additional malfunction risk.

It is important to emphasise that this project relies entirely on the information provided by the SLDMB drifter data and does not incorporate any other information except for the assumptions built into OCMS platform. Therefore, the conclusions that we can reach will be solely based on these measurements without any objective information added during the analysis.

Objectives

The key objectives of this project were to develop (i) a comprehensive approach to the determination of the sensitivity of OCMS (and ultimately success of search and rescue operations) to deployment strategies through a series of numerical experiments, and (ii) a set of deployment guidelines for use in the field.

Project Data Collection and Analysis

Following the initial consultation with the Coast Guard College team of experts it was concluded that 2 existing experiments with 2 trials each (Cabot Strait data set and Scotian Shelf data set) will be used for this project. In addition, the Coast Guard College undertook the responsibility of collecting additional experimental data in the deep water that could be used to verify the OCMS behaviour in a different flow regime. In consultation with the OCMS team and following a discussion during a meeting in Halifax it was concluded that the optimal, yet least expensive, location for the trial would be off Sable Island, just east of the Scotian Shelf break. To complement this offshore data set, the Coast Guard has collected data from the Grand Banks to be used for additional verification and sensitivity analysis. To summarise, the following trials were used in this project:

No.	Experiment	Period	Trials
1.	Cabot Strait	November 1999	2
2.	Scotian Shelf	October 2000	2
3.	Sable Island	November 2003	1
4.	Grand Banks	November 2003	1

All available data were manually checked for errors and outlying values and then plotted to examine any additional unreasonable features or drifter behaviour. This was followed by the analysis of the data using OCMS platform that generated continuous hourly time series for each experiment and computed velocity vector values for each of the drifters available. These data files were immediately made available to the Coast Guard College for their further use in research and education. Furthermore, this data set formed the basis for the sensitivity experiments and analysis that represent the core of this project.

The data were organised in seven experimental data sets, 2 from Cabot Strait, 3 from the inner Scotian Shelf, one off the Sable Island and one on the Grand Banks. One of the inner Scotian Shelf trials was broken up in two data sets because of large separation between the two groups of drifters that were not yielding overlapping current flow-fields. Similarly 2 drifters were excluded from the analysis in one of the Scotian Shelf trials because their separation from the other 5 was too large to generate reasonable interaction. In two cases the drifters had records longer than 5 days, but the analysis was, for consistency sake, limited to 5 days in each experiment. The summary of experimental data sets is as follows:

No.	Data Set	Period	Drifters Used
1.	Cabot Strait I	November 1999	5
2.	Cabot Strait II	November 1999	5
3.	Scotian Shelf I	October 2000	7
4.	Scotian Shelf II	October 2000	8
5.	Scotian Shelf III	October 2000	5
6.	Sable Island	November 2003	8
7.	Grand Banks	November 2003	8

Overall availability of the drifters in each data set ensured that sufficient number of numerical experiments could be performed and adequate conclusions drawn.

Particle Tracking Routine

In order to assess the quality of the predictions that could be obtained using varying number of drifters we have developed a particle tracking routine. To minimize the interference with the existing software, the particle routine was developed as a post-processing external function in Matlab. Though sub-optimal, in the current configuration it remained relatively efficient and did not significantly increase processing time. This approach allowed us to use stored velocity fields without necessarily repeating the complex calculations of OCMS in every case.

Sensitivity Experiments

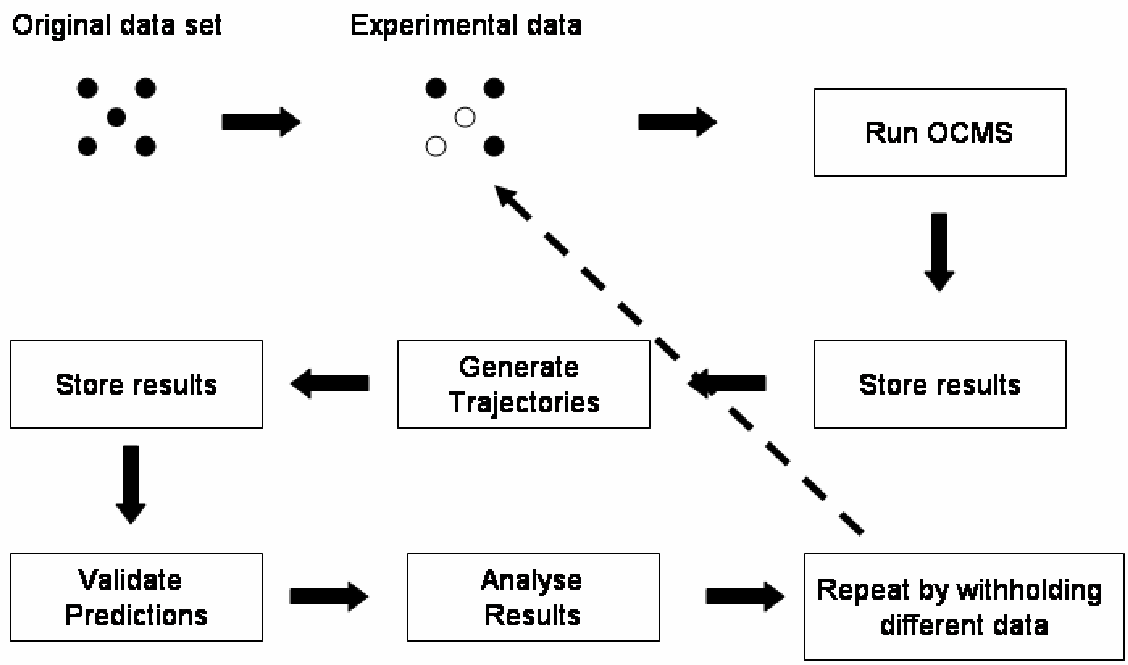
The core of the project was a series of sensitivity experiments performed with each data set using the particle tracking routine.

Goals

1. Establish an objective and uniform method for analysing and comparing prediction capability of SLDMBs.
2. Analyse sensitivity of prediction errors to increase or decrease of the number of drifters used in experiments.
3. Assess the sensitivity of prediction errors to initial drifter configuration.
4. Assess the sensitivity of prediction errors to the size of drifter deployment area and/or their initial separation distance.

Description of the experiments

The core set of the experiments was performed in the following way (see schematic below). Original data set was sub-sampled (i.e. some drifters were withheld) and the data were ran through OCMS system. The system stored a set of velocity fields for the period covered. Then, these velocity fields were used to calculate drifter trajectories for each of the available drifters, but also for a virtual 'patch' of particles defined by a circle around the central data point. These results were stored and experiment repeated by changing the drifters that were being withheld. For each set of data 15-20 different combinations of withheld drifters were used which provided us with a reasonable data set for further analysis. Therefore, a total of about 140 numerical experiments were performed at the end.



Results and Analysis

Cabot Strait I

This experiment took place in the Western part of the Cabot Strait, near the coast of Cape Breton Island. The drifters were advected through the Cabot Strait and remained clustered during entire 5 days. For illustration purposes a comparison between observed and predicted drifter track for this experiment is shown below. The predictions were in this case obtained by using all of the available drifters to calculate the velocity field and then individual particle trajectories.

The results (see aggregate results table at the end of the section) show a clear improvement from the additional information provided to the system as (despite relatively clustered movement of the drifters) prediction error for 24-hour forecast decreases from 11.2 km when one drifter was used to 7.3 km when 3 drifters were used. As the forecast period increased the influence of additional drifters diminished improving the overall error marginally from 12 to 11 km.

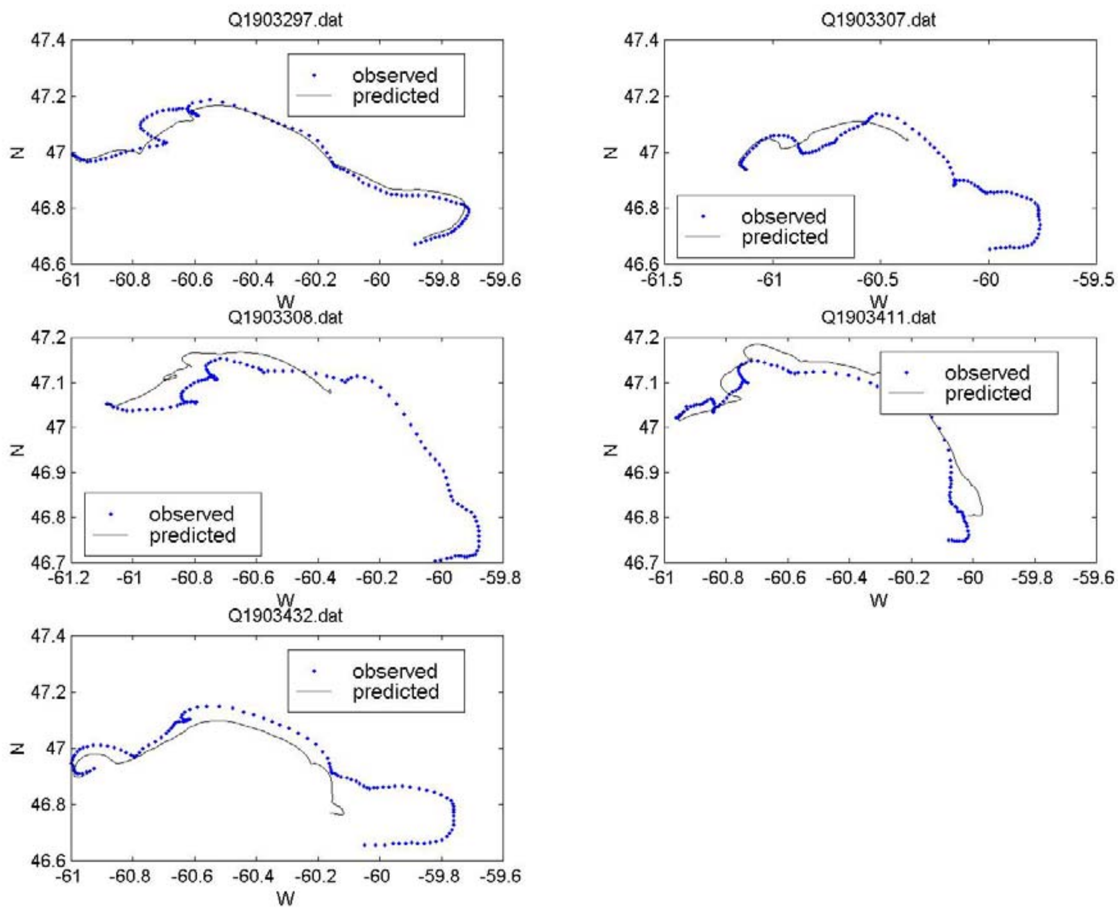


Figure 1. Observed and predicted drifter trajectories for Cabot Strati I experiment. The predictions were obtained using all of the available drifters.

Cabot Strait II

This experiment took place just East of the Cabot Strait and on the edge of the Laurentian Channel. The resulting drifter trajectories were very complicated and highly divergent. This can be witnessed from our numerical experiments' results where the errors were at least 50% higher than in Cabot Strait I experiment. Overall, the error at 24 hours decreases from 18 km when one drifter is used to about 11 km when 3 drifters were used. The impact of more drifters is more dramatic at 48 hours where the error using one drifter stands at 32 km, but is dramatically reduced by the use of 3 drifters to 16 km.

Sable Island

The Sable Island experiment had a key validation role for the use of OCMS in deeper water as this was the first set of drifters tested with the system. In addition, this was an experiment with large number of drifters (8) that allowed us to perform many experiments over different combinations of drifters and assess benefits of having relatively large number of drifters available. The 24-hour forecast experiments show that the prediction error decreases dramatically as up to 4 drifters are used to estimate the flow field. A similar pattern can be found in 48-hour forecast. In both cases adding more than 4 drifters to the set does improve the prediction (as one would expect), but not dramatically. This is very important result as it demonstrates the limits of predictability of the method used. In other words, having unlimited number of drifters would not result in elimination of the prediction error. Looking at absolute prediction error could be misleading to some extent, as this experiment took place in deeper water with relatively dispersed initial configuration of drifters. Overall, this experiment suggests that drifters could be deployed in deeper water with larger separation distance than on the shelf. Generalisation, however, would amount to pure speculation.

Scotian Shelf I

This experiment represented a classical inner shelf situation with tidal steering and wind driven flows. After 24 hours prediction errors were rather similar (5-6km) regardless of the number of drifters, however, at 48 hours the relative importance of the larger number of drifters is clear with errors decreasing from 10.6 km to 7.4 with increased number of drifters. These results are significant as first 24 hours could suggest that a smaller number of drifters is sufficient. However, with strong tidal dispersion and wind driven flows the drifters start to diverge more strongly after the fist day and the benefits of using more drifters in the prediction are clearly demonstrated when looking at 48 hour forecast.

Scotian Shelf II

In this experiment, a large number of drifters was available which again allowed us to perform a number of experiments allowing for different drifter combinations. When comparing this experiment with the one off Sable Island that took place in the deep water, but also had large number of drifters the similarities in results are striking. The prediction errors improve as more drifters are initially added, but little improvement is shown when more than 4 drifters are included. This is very similar to the results obtained off Sable Island and suggests that, indeed, the use of 4 drifters appears to yield optimal results when predicting other drifter trajectories. It should be noted that these conclusions are again drawn from the relatively small sample of experiments and by predicting drifter tracks using drifter data.

Scotian Shelf III

This experiment was conducted at the same time as Scotian Shelf II, however, the drifters were released in a separate cluster and as a result represented a self-contained experimental data set. The area of deployment was characterised with relatively weak currents, so the drifters remained in a tight cluster for a long time (see sample trajectories in the appendix). As a result the predictability of their movement increases. This is clearly illustrated by the prediction error at 24 or 48 hours (2-3 and 3-4 km respectively) which is small and does not decrease significantly with the addition of more drifters. The conclusions that can be drawn from this experiment are twofold: (i) the tight deployment configuration probably requires smaller number of drifter, (ii) but at the same time provides limited results away from the drifter cluster.

Grand Banks

The Grand Banks experiment consisted of 5 drifters. Unfortunately those drifters were dropped in two groupings, one of three and the other of two drifters, that were separated by 20 km or so. As a result, there was no spatial correlation between the two groups. Consequently, the currents generated for the aggregate field did not look reasonable. This experiment represented an excellent test and validation of OCMS capabilities. It effectively confirmed that a statistical tool such as OCMS is only useful if drifter information is available in a relatively small geographic area. These results have a significant impact on our overall conclusions and guidelines, but were not included in aggregate tables as they could not be compared to all other experiments in the same way.

Table 1 Median error of 24-hour forecast in position using OCMS. The errors are show in kilometres. The first column indicates the number of drifters used to obtain the prediction.

24 HOUR FORECAST MEDIAN PREDICTION ERRORS						
Number of drifters	**CABOT I**	**CABOT II**	**SABLE**	**SCOTIA I**	**SCOTIA III**	**SCOTIA III**
1	11.2	18.3	9.8	6.2	7.9	2.8
2	8.6	13.4	7.8	5.5	6.6	2.5
3	7.3	11.4	6.7	5.1	6.0	2.3
4	7.1	10.5	6.1	5.4	5.6	2.2
5			5.6		5.4	
6			5.2		5.5	
7			5.0		5.8	

Table 2 Median error of 48-hour forecast in position using OCMS. The errors are shown in kilometres. The first column indicates the number of drifters used to obtain the prediction.

48 HOUR FORECAST MEDIAN PREDICTION ERRORS						
Number of drifters	**CABOT I**	**CABOT II**	**SABLE**	**SCOTIA I**	**SCOTIA III**	**SCOTIA III**
1	12.7	32.1	17.0	10.6	9.7	4.0
2	11.7	21.2	12.6	8.6	8.9	3.4
3	11.6	16.5	10.5	7.7	8.5	3.2
4	11.7	14.4	9.4	7.4	8.4	3.3
5			9.0		8.2	
6			8.6		8.4	
7			8.4		8.7	

Guidelines

As a result of the experiments described above and their analysis the following set of guidelines has been developed. These guidelines are based on quantitative and qualitative analysis of 7 drifter trials chosen to represent near coast, shelf and deep water conditions. No other information on the physical oceanography of the study regions (e.g. tides, background flow or wind) was incorporated into the analysis. The limited number of trials, and lack of background current information, should be taken into account when reviewing these guidelines.

1. Number of Drifters

Minimum Number of Drifters

Our examination of the forecast skill of OCMS suggests that a minimum of three SLDMB PIW drifters should be used to facilitate SAR operations. This conclusion is based on a quantitative analysis of the 24 hour forecast skill of OCMS over the 6 drifter trials. The assessment clearly shows the benefit of incrementally adding 2nd and 3rd drifter to the analysis.

Maximum Number of Drifters

Based on the 6 trials we conclude that the use of more than 5 drifters in relatively constrained areas, such as those studied here, does not add significant information to OCMS. This conclusion could change if (i) the drifters are deployed in highly structured flow fields (e.g. well-defined Gulf Stream eddies or coastal jets), (ii) the drifters are distributed over larger areas than the present study regions, (iii) relevant physical oceanographic background information was available to add value to the drifter observations, (iv) different scheme was used to analyse the data and extract the information. The final decision on numbers must be made in the operational setting by experienced personnel.

In summary, based on our analysis of the 6 trials, we conclude that the optimal number of drifters that should be used in search and rescue operations using OCMS is between three and five.

2. Initial Drifter Configuration

The analysis of the 6 trials suggests that the initial configuration of the drifters is not critical. Regardless of whether the drifters are configured in a square, triangle or line, the combined spatial-temporal variability of the flow-field quickly rearranges the initial configuration. This is not to say that all drifters should be deployed at the same place, but rather the specifics of the configuration are not critical. It is however important to note (as concluded from the Grand Banks trial) that the initial separation distance between deployed drifters should not bee too large, typically of the order of 5-10 km.

If 3 drifters are available it is suggested they are deployed in a triangle that is centered on the most likely position of the SAR target at the time of deployment. If no other information is available, this should be the last known position (LKP). If 4 drifters are available it is suggested that 3 are deployed in a triangle and the remaining drifter is deployed at the center. As mentioned above, the specifics of the initial configuration are not critical and these configurations should be treated as suggestions only. The actual configuration again should be decided at the operational level, taking into account practical considerations (e.g. aircraft availability, time of LKP).

3. Size of Deployment Area

The size of the initial deployment area ultimately determines the subsequent SAR area. There are several factors that should taken into account when specifying the size of the deployment area: (i) the historical (known) spatial variability of the current field, (ii) the uncertainty about the present position of the SAR target, (iii) the information about the weather conditions at the time of incident and SAR operation. It is therefore impossible to provide clear quantifiable guidance for the size of deployment area based on limited data available. In general, the size of the deployment area will be additionally related to the number of drifters used and it in turn determines the initial uncertainty that is then propagated in time. Some additional information could be, in principal, extracted from realistic numerical models of the ocean circulation. The final decision should be made at the operational level taking into account all relevant factors.

4. Timing of Deployment

The drifters should be deployed as quickly as possible. It is clear that the limitations of an operational nature exist and can result in typical delay of 5-6 hours. However, we are of the view that all drifters should be deployed as quickly as possible. Deploying drifters over a longer period of time would not add value, it would make it more difficult to track them with OCMS. It would also increase costs and operational burden on the aircraft crew without adding significant value.

Conclusions and Recommendations

A number of additional conclusions beyond already presented guidelines can be drawn from this experiment, but we decide to focus on those that could help provide better estimates of the drifter trajectories (as proxy for search and rescue target).

1. It is strongly suggested that OCMS be used with the background field information feature as this can contribute to better accuracy of predicted current fields.

2. It is suggested that ‘person in the water’ configuration continues to be used when launching SLDMB drifter as it provides high quality and easy to interpret data.
3. It is suggested that further experiments are conducted once additional data are collected to validate and strengthen the guidelines presented in this document.

Appendix A: Summary Guidelines for Deployment of SLDMB PIW Drifters

Number of Drifters

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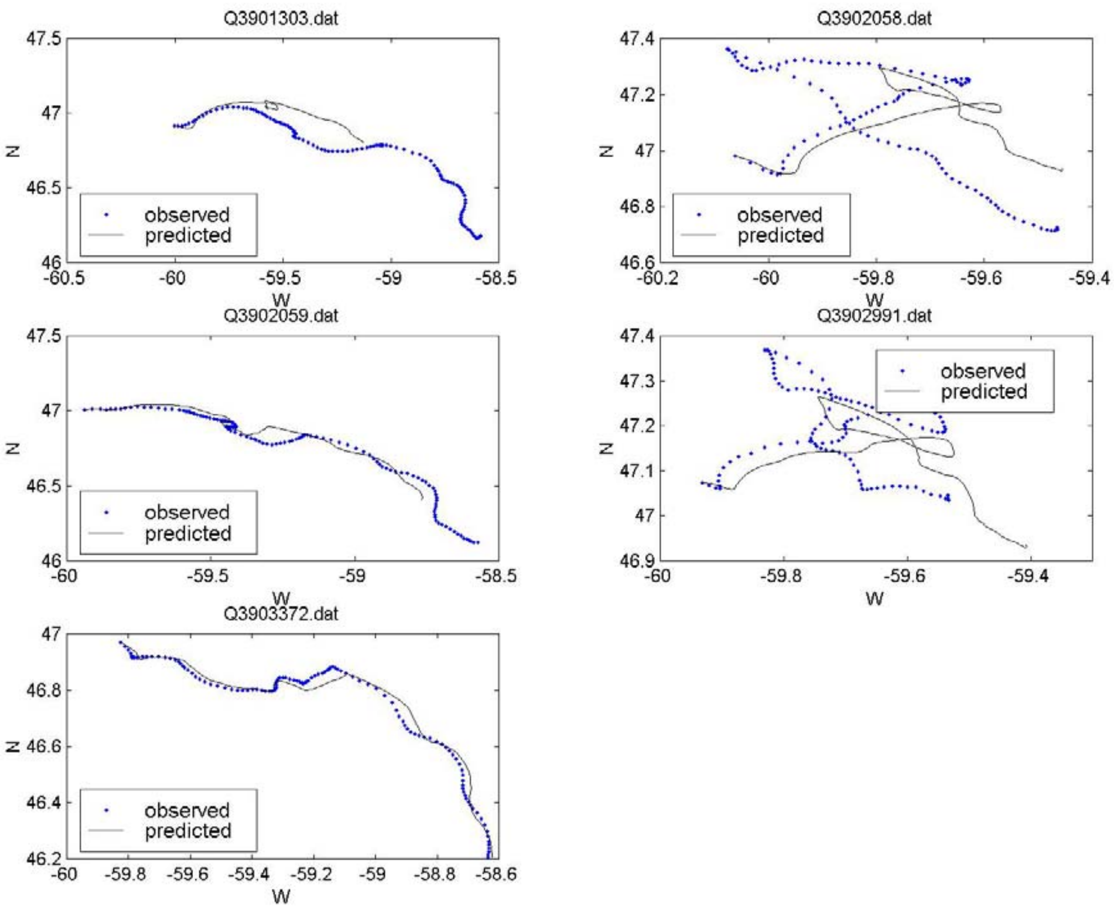
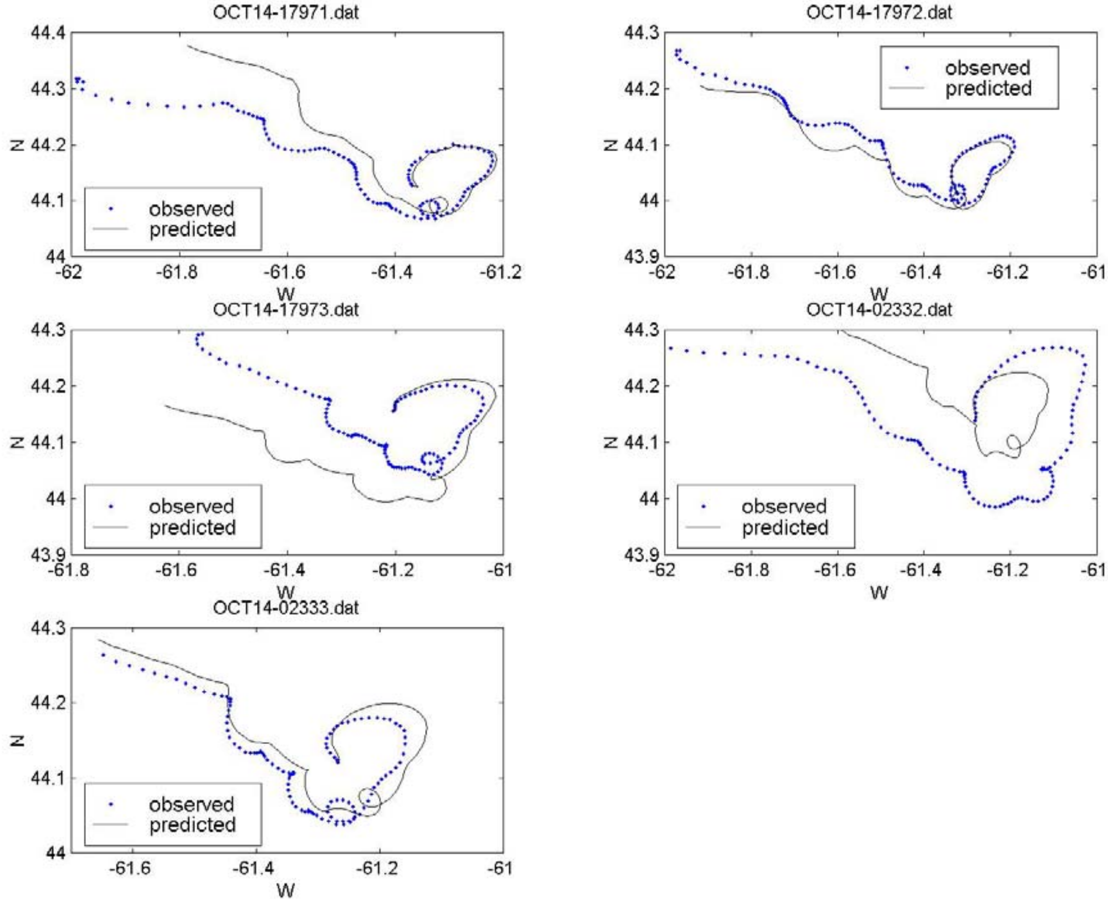
Appendix B: Additional experimental results

Cabot Strait II: Observed and predicted drifter trajectories using all available drifters to predict the flow fields.



Scotian Shelf I: Observed and predicted drifter trajectories using all available drifters to predict the flow fields.



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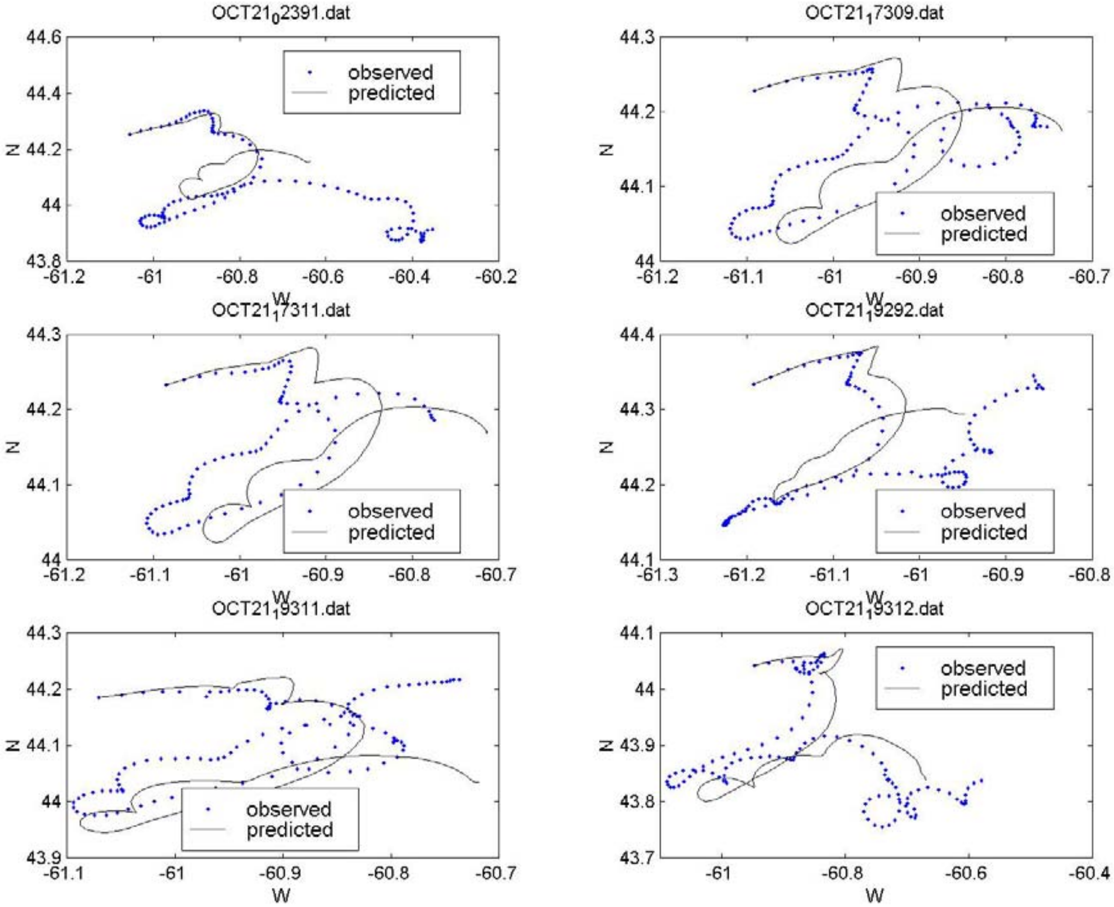

Scotian Shelf III: Observed and predicted drifter trajectories using all available drifters to predict the flow fields.