Glider Path-Planning for Optimal Sampling of Mesoscale Eddies

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Abstract. In the present work we propose a method for generating ocean glider trajectories that optimize the sampling of mesoscale eddy structures based on a given objective function and the predictions available from ROMS maps. The eddy structure is modeled as a 3D volume discretized into sectors rotating around its center at different velocities. The objective functions can then be expressed in terms of those temporal evolving sectors. A set of simulation experiments have been carried out in order to validate the proposal.

Keywords: Ocean Gliders, Path Planning, Optimal Sampling.

1 Introduction

An ocean glider is a autonomous vehicle that propels itself changing the buoyancy. The resultant vertical velocity is transformed into an effective horizontal displacement by means of the active modification of the pitch angle and the effect of the control surfaces. The glider motion pattern is constituted by a series of "v" descending/ascending profiles between two target max and min depths, after which the vehicle returns to surface to transmit data and update its target waypoint.

Ocean gliders constitute an important advance in the highly demanding ocean monitoring scenario. Their efficiency, endurance and increasing robustness make these vehicles an ideal observing platform for many long term oceanographic applications [1]. However, they have proved to be also useful in the opportunistic short term characterization of dynamic structures. Among these, mesoscale eddies are of particular interest due to the relevance they have in many oceanographic processes.

Path planning plays a main role in glider navigation [2] as a consequence of the special motion characteristics these vehicles present. Indeed, ocean current velocities are comparable to or even exceed a glider's low speed, typically around 1 km/h (0.28 m/s). In such situations a feasible path must be prescribed to make

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the glider reach the desired destination. This can be accomplished by analyzing the evolution of the ocean currents predicted by a numerical model. The problem is not trivial, as the planner must take into account a 4D, spatiotemporally-varying field over which to optimize.

1.1 Related Work

Different solutions to the glider path planning problem can be found in the literature. Inanc et al. [3] propose a method that applies Nonlinear Trajectory Generation (NTG) on a Lagrangian Coherent Structures (LCS) model to generate near-optimal routes for gliders on dynamic environments. Alvarez et al. [4] use Genetic Algorithms to produce suitable paths in presence of strong currents while trying to minimize energy consumption. Other authors have put the focus on the coordination of glider fleets to define optimal sampling strategies [5].

In the particular case of eddies, the complexity of the path planning scenario is aggravated by the high spatio-temporal variability of these structures and their specific sampling requirements [6]. Garau et al. [7] use an A* search algorithm to find optimal paths over a set of eddies with variable scale and dynamics. Smith et al. [8] propose an iterative optimization method based on the Regional Ocean Modeling System (ROMS) predictions to generate optimal tracking and sampling trajectories for evolving ocean processes. Their scheme includes near real-time data assimilation and has been tested both in simulation and real field experiments.

In the present work we propose a method for generating glider trajectories that optimize the sampling of eddy structures based on the given objective functions and the predictions available from MyOcean-IBI ROM maps.

2 Eddy Path Planning

The Canary Islands eddies system originates, according to Jimenez et al. [9], from a combination of wind and topographic forcing. In our method we use a discretized version of the eddy model proposed by these authors, dividing the structure volume into several sectors rotating at different velocities. Each sector is defined by its min/max limits in depth, radius and angle dimensions (see figure 1).

Our proposal structures the path planning in three phases: detection and identification of eddy model parameters, definition of objective function and path generation.

2.1 Identification

As a first phase, the eddy parameters are identified combining the current, altimetry and temperature maps in a semi-automatic process. MyOcean-IBI provides 3D ocean current outputs only as daily mean maps, so we combine these with the hourly outputs to allow for a better description of the eddy dynamics.

The eddy center and border are marked manually on the SSH maps and then refined using the current and temperature maps.

The eddy marking is assisted by an automatic detection pre-processing that highlights potential eddy candidates.

2.2 Objective Function

Once the eddy has been detected and modeled, the following step is to define the optimization goal. Thus, the objective function is expressed in terms of the eddy sectors (figure 1) that should be sampled and the desired mission duration. This scheme allows to define different sampling strategies such as track eddy center, focus in the border, maximize sampled volume, focus in a particular depth, etc. Time dependent formulations are also possible keeping the same structure.

2.3 Path Generation

Finally, in the last phase, a Genetic Algorithm optimization is applied in order to obtain the trajectory that best meets the specifications. For this stage, a correct glider simulation is required in order to produce realistic results. For this purpose, we have developed a simulator that reproduces with a reasonable accuracy the glider behavior and control scheme.

Additional elements can be easily added to the trajectory generation process. For example, a smoothness factor can be incorporated in the optimization to penalize sharp turns in glider's path.

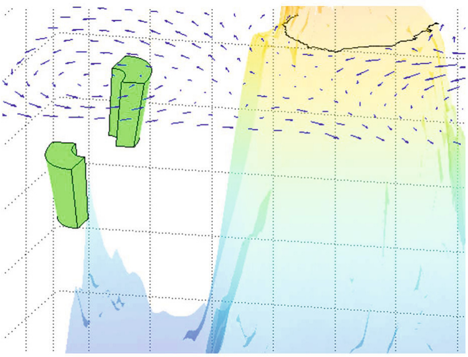

Fig. 1. Examples of eddy volume segmentation

3 Experiments

We have performed several simulations for Canary Islands eddies using MyOcean_IBI prediction maps to test the validity of the proposal. In the figure 2, a 5 days trajectory optimized for an eddy border is shown.

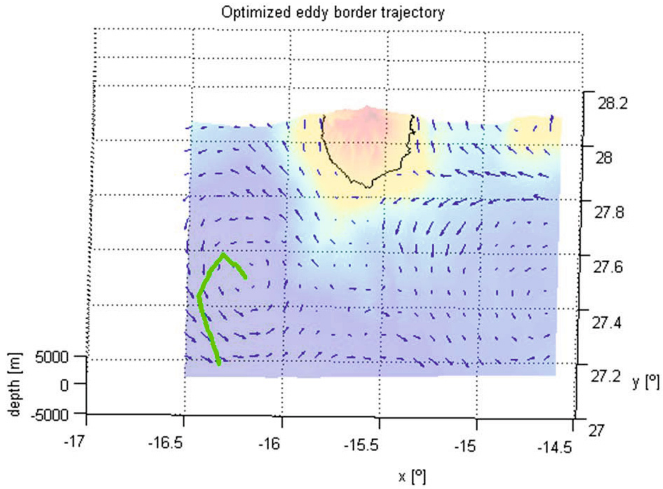

Fig. 2. Example of optimized trajectory for eddy border

4 Conclusions and Future Work

We consider this method to be a valid alternative that would contribute to extend the glider operational capabilities. The best suited applications are one-shot type, due to budget/time restrictions, for example, where a maximization of success probabilities is highly desirable.

Obviously, the results of this method are dependent on the prediction accuracy of the ocean model used. However, in our opinion, is still a reasonable option when a try and error scheme is not admissible.

Our intention is to additionally test the method using maps from other eddy scenarios, such as the Balearic Sea and the southern California System. We are planning to execute also some real field trials.

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