ASAP Team Adaptive Sampling Plan for Gliders
in 2006 Field Experiment

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Objectives

A. The sampling plans for the gliders should be designed for data collection that
   a. Gives data that is understandable (in the oceanographic context) without a model, including estimates of data error covariances if possible.
   b. Provides a good map regardless of model.
   c. Yields good field and parameter estimates when combined with a dynamical model, including nowcast, prediction and smoothing estimates.

B. *It is a central goal of the ASAP program to demonstrate both our ability to adapt and the consequences of adaptation.* Adaptation here includes responding to changes in the ocean, model uncertainty, changes in operations and unanticipated challenges to sampling as desired. Sampling plans should
   a. Be fully adaptive under operational constraints.
   b. Be allowed to change in response to the optimization of an integration of coverage metrics and uncertainty metrics.

C. The gliders will be operated as a cooperative fleet, meaning that they will be controlled for *coordinated* sampling. Accordingly, to maximize sampling performance of the fleet, adaptation of an individual glider will typically imply adaptation of all the gliders.

D. The ASAP program is a team effort and this should be reflected in the sampling plan design. The process of coming to a consensus should be streamlined to accommodate all team members (independent of their location during the experiment).

In the following we describe categories of feedback and adaptation, structure of candidate trajectories, and a voting system for consensus on adaptive strategies to be implemented.

[Note: We have not yet addressed in this document the following: "a separate brigade of gliders who purpose is to avoid and/or follow gradients so as to stay in the interior of a cold filament and monitor local changes." (SR)]

Categories of Feedback and Adaptation

A coordinated sampling pattern for the glider fleet that has been optimized with respect to the above objectives is referred to as an Optimal Coordinated Trajectory (OCT). Coordination refers to prescription of the relative location of all gliders (as a function of

time). The plan assumes a minimum of 9 or 10 gliders, all to be coordinated as part of every OCT. Details on the proposed structure of trajectories is provided in the next section. The following are the three ways in which feedback is proposed to be used for control and adaptation. The three feedback loops are nested such that the first (completely automated) feedback loop is performed most frequently whereas the latter two are performed less frequently.

I.   *Feedback to maintain OCT.* Given an OCT, feedback control will be applied with a feedback interval on the order of two hours to keep gliders in their coordinated arrangement on their tracks in spite of flow and other disturbances. Input to the control law includes

1. average current estimates from all the gliders,
2. GPS measurements from all gliders,
3. forecasts of flow as available.

Output of the control law consists of waypoint updates to each glider at surfacings (on the order of every two hours as necessary).

II.   *Feedback to switch to new OCT.* A new OCT can be selected when it is necessary or desired to adapt. For example, a new OCT may be deemed useful for adaptation to explore a small-scale feature. Similarly, a new OCT can be selected to reduce model uncertainty. Additionally, a new OCT may be needed in the event of a loss or addition of a glider. An input to this step is the state of the ocean from other observations. Step I will then be used to control to the new OCT. In case the gliders have to make significant changes to get to the new OCT, an interval of optimized re-direction may be necessary (see Step III).

III.   *Feedback to Large Changes and Disturbances.* In the event that one or more gliders is significantly far from its desired place in the OCT, a new plan will be computed to re-direct the glider(s) into a reasonable position so that Step 1 can be (re-) initiated. For instance, when gliders are initially deployed, they will be far from their assigned tracks and will need to be directed to locations close to the OCT. For switches in Step II, gliders may require a period of time for steering optimized to reach a neighborhood of the OCT. Similarly, in case of challenging ocean flows, it is possible that gliders will stray from desired tracks and need re-planning and re-direction.

Structure of Candidate Trajectories

To meet objective 1, we propose to limit glider trajectories to motion around rectangles defined by a grid of the 20 km by 40 km ASAP box. Figure 1 illustrates a possible grid. Any large or small rectangle, drawn with black lines in the ASAP (light blue) box, is a candidate track for a glider.

Between 3 to 5 cross-shelf lines will be assigned highest priority, i.e., it will be attempted to adapt the tracks while still covering these lines. Further, a default baseline set of tracks will be defined that consists of around 3 to 5 nearly rectangular tracks (see example of 3 dotted blue tracks in Figure 1). Corresponding to the set of default tracks will be a specification of coordinated positions of gliders on these tracks. This default pattern will be selected by optimization and therefore referred to as the default OCT. In the illustration of Figure 1, we show a possible default OCT in which there are 3 gliders (yellow and red diamonds) on each of 3 default tracks with prescribed coordinated positions across all tracks.

A new OCT shall be computed (Step II above) from among the possibilities of gliders moving around the rectangles that make up the grid. Suppose, for instance that it has been predicted that there is a feature in the southwest corner of the ASAP box that should be sampled at increased resolution. Alternatively, suppose that it has been determined that model uncertainty can be decreased by sampling more intensively in the southwest corner. An input to Step II would be the request for sampling at increased resolution (or density) in the southwest corner or equivalently the request for gliders to move around selected rectangles in the southwest corner. The result would be an update to the complete OCT to meet this need and to redistribute the remaining gliders so that they continue to provide good sampling in the rest of the ASAP box. See Figure 2 for an example of what the new OCT in this case might look like.
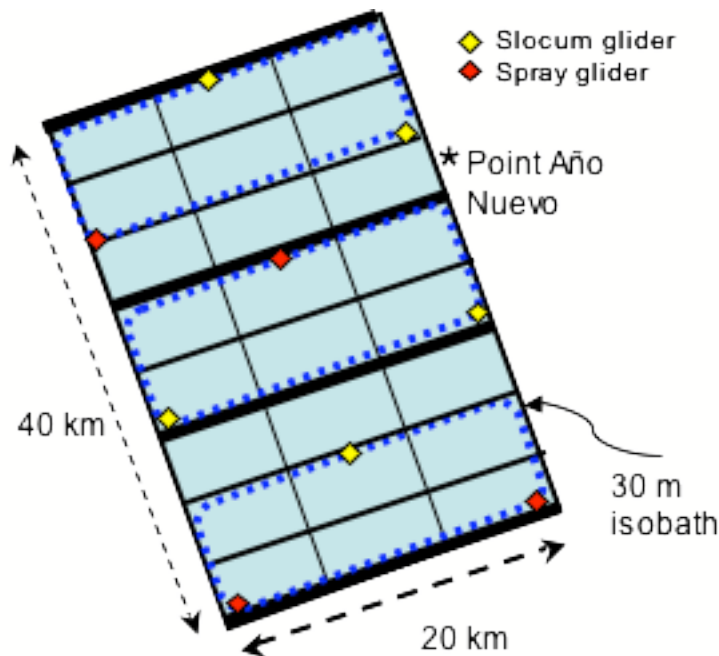

Figure 1: Possible candidate grid for glider tracks and default OCT. The black lines outline possible rectangles for gliders. Each diamond represents a single glider; yellow signifying Slocum and red signifying Spray. The gliders move along the blue dotted lines. In this illustration of the default OCT, there are three gliders moving around the northernmost blue-dotted rectangle. Similarly, there are three gliders moving around a

rectangle that is in the middle of the ASAP box and the remaining three gliders are moving around the southernmost blue-dotted rectangle. Each blue-dotted rectangle is 20km by 10 km. The relative position of gliders on their rectangles has a regular fixed inter-vehicle spacing. The heavy black lines are lines that have been given highest priority for sampling.
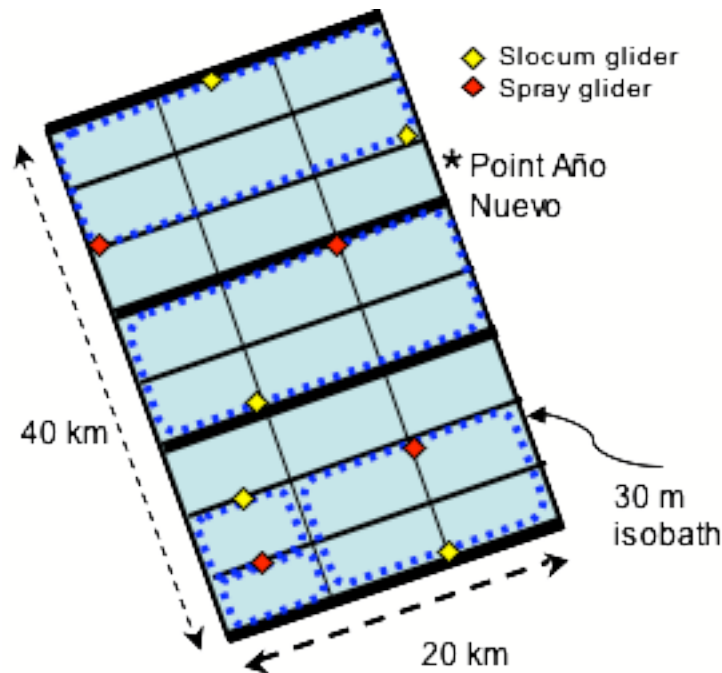

Figure 2: Illustration of new choice of OCT for increased sampling in the southwest corner of the ASAP box. Each diamond represents a single glider; yellow signifying Slocum and red signifying Spray. The gliders move along the blue dotted lines. Note that the southwest corner gets sampled more intensively and at higher resolution.

Voting System

A web site will be created in which anyone from the team can propose a new area of the ASAP box for special sampling attention (i.e, propose a rectangle or rectangles from the candidate grid with corresponding time period of interest) and provide a justification for their proposal. There will then be a vote (on-line). Each group has a vote and will even be given the opportunity to vote strongly or weakly as they wish. Rules for voting are to be determined, but the idea is that a total number of chits will be allotted to each group and one or more can be used per proposal to weight the strength of the endorsement. A time interval will be imposed between consecutive proposals so that the ASAP team is not reviewing proposals too frequently. The goal will be to implement the adaptation proposals that are of greatest interest/importance to the ASAP team. However, it will be important to follow through on the range of reasons for adaptation (model uncertainty reduction, sampling features, etc.). Before any adaptation is initiated it will first be checked to see if it is physically possible to implement as requested. The final decision

will be made by a designated person who reviews all of the input. To this end it will be important for anyone who strongly endorses or strongly rejects a particular proposal to provide a justification. The final decision should be justified. This will also provide constructive feedback to the proposer(s).