Oceanic approaches for the control of gliders on two-hourly time scales: Draft I

Pierre Lermusiaux, Naomi Leonard, Ralf Bachmayer,
Eddie Fiorelli, Pradeep Bhatta, Igor Shulman

June 27, 2003

This document summarizes approaches proposed for the control of 3 to 6 gliders on the ``two-hourly'' time-scales. They are based on methodologies employed in ocean modeling as well as schemes for the control of groups of vehicles. Different options are listed, from simple to complex (Sect. 1). The plan is to investigate and test several of these options progressively within the next month. Of course, the ultimate goal for these controlled gliders is to reach the end waypoints suggested on ``daily'' time-scales by the control room. The subject here is only the path between these waypoints and their optimization based on different approaches or criteria. The use of these gliders to estimate the properties of sub-grid-scale processes and scales of chlorophyll patches is discussed in Sect. 2. Two existing schemes (the Princeton Kalman filters and Harvard objective analysis) are part of the control approaches. Their properties and their expected utilization are briefly summarized in Sect. 3 and 4, respectively.

1. Oceanic approaches for the control of gliders

The different options for the control of 3 gliders are summarized. They are organized as a function of the data input to the algorithms that control the gliders and numbered according to complexity.

Option 0. *Two-hourly glider data*: utilize the past <u>two-hourly</u> glider data only. This can involve data filtering and averaging so as to estimate the: i) sub-grid-scale processes not fully resolved by the HOPS and ROMS (internal tides, waves, etc.) and ii) the horizontal and vertical spatial scales of chlorophyll patches (see Sect. 2 for more details).

Option 0.5 *Synoptic glider data*: utilize the <u>synoptic</u> glider data (i.e. the last 24 h of glider data which are local to the current glider operations). This synoptic glider data are utilized as inputs to Kalman filters (see Sect. 3) designed by the Princeton group.

Option 1.0 *OAed two-hourly glider data*: utilize the past <u>two-hourly</u> glider data to create an objectively analyzed (OAed) map, i.e. gridded data. In doing so, data may be filtered to eliminate the scales that are not of interest. The residuals can be utilized to estimate local properties of the sub-grid-scale processes not resolved by HOPS and ROMS (Sect. 2).

Option 1.5 *OAed synoptic gilder data*: utilize objective maps of <u>synoptic</u> glider data. In doing so, the Princeton Kalman filters can be applied to the raw data or to the history of the OAed glider data (objective maps for the last 24 h).

Option 2.0 *OAed two-hourly data*: utilize all two-hourly, multiple, observational asset data to create an objective map of gridded data. All local data available in the last 2 hours are employed to create this map. Data may be filtered to eliminate scales not of interest.

Option 2.5 *OAed synoptic data*. Utilize all synoptic, multiple, observational asset data sampled (in the last 24 h). Again, the Princeton Kalman filters can be trained from these objective maps.

Option 3.0 *Model nowcast*. In addition to what is done in 2 or 2.5, this option utilizes an objective map computed from the existing forecast data and the new observational data. The result of this objective correction of the forecast by the recent data is usually referred to as the nowcast or analysis. The data used to correct the forecast could be glider data only or all data from all assets, depending of the real-time availability.

Different tasks are currently being carried out to investigate these options and select the most useful ones for the real-time experiment:

- Utilize the current HOPS and ROMS simulations to test the options above. We believe that options 0.5, 1.5, 2.5 and 3.0 are going to be the most useful ones.
- Address issues involved in, and investigate schemes for: i) the filtering or estimation of internal tides/waves where they are important in Monterey Bay, and ii), the estimation of the dominant scales of patchiness in the fluorescence data (Sect 2). For the former, the main goal is still to use the gliders to find and collect rich data at fronts, eddies, jets, etc., despite the presence of smaller scales. However, we believe they are opportunities to estimate these smaller scales.
- Harvard is currently studying the properties (location in space, time-scales) of internal tides and waves in the region.

2. Estimating properties of sub-grid-scale processes and scales of chlorophyll patches

The gliders move along a sawtooth path at a glide angle of approximately 25 to 30 degrees. The gliders operate at an average forward speed of 0.4 m/s and an average vertical speed of 0.2 m/s. The maximum glider depth is 200 m and the gliders will automatically turn upwards when they reach this depth. If the water is shallower than 200 m, then the gliders will turn in advance of reaching the bottom. The gliders will be equipped with CTD sensors as well as fluorometers, PAR sensors and bioluminescence sensors (?).

Different research tasks to be carried out are listed below. They are ordered only for convenience: work has been, and can continue to be, started on all of them independently of the others.

1. Summarize the regional properties of internal tides and waves

2. Glider control for sub-grid-scales estimation, e.g., internal tides and waves
    a. Determine simple formulas that give the scales that can be estimated from the glider data, considering first the two 2D problems, i.e. (x, z) for cross-sections and (x, y) for horizontal maps. This will be done using simple filtering criteria (e.g. based on Nyquist-frequencies).
    b. Suggest most promising sampling formations for the gliders in 2D, (x, z) and (x, y).
    c. In carrying-out both a) and b), for the (x, z) problem, the yoyo pattern of the gliders should be taken into account as well as the depth dependence of the internal tide amplitude. For the (x, y) case, only a few formations should be considered for simplicity (e.g. 3 gliders in straight lines at constant distances, 3 gliders rotating, etc)
    d. Extend the results to idealized 3D (x, y, z) cases
    e. To derive and evaluate results, create wave and noisy fields of known properties and find out if the sub-grid-scales in the simulated glider data can be estimated and filtered out. Evaluate also if the results obtained in points a)-d) are ideal for filtering these scales.

3. Scales of chlorophyll patches
    a. Create wave fields (e.g. superposition of two waves, waves of noisy phase and length scales) and noise fields (e.g. red noise) of different known properties and evaluate/calibrate simple scale-estimation schemes (e.g. Auto-Regressive-Moving-Average models).
    b. Once these schemes are tested on simple known wave fields, utilize them on the 2D images of Steve Ramp and in the 3D biological fields of HOPS.

3. Princeton Kalman Filters

The Princeton Kalman Filters are employed to rapidly estimate the fields (and their local gradients) measured by the gilders. They utilize the history of the past measurements to provide an optimal estimate.

There are different versions of this Kalman filter (Ogren et al, 2003). In the currently most useful one, a linear filter model for the measured variables along the gilder path is hypothesized, i.e. dx = Ax dt + B dv. The glider data history (last 24h) is then utilized to estimate the model parameters (i.e. *the "A" matrix*). If the data considered is only temperature, x consists of the local T and gradT, and elements in A are (cross)-correlations. For multiple variables (e.g. T and Fluorescence), multivariate correlations are estimated in a multivariate A.

4. Harvard Objective Analyses

The main Harvard objective analysis scheme (Lozano et al, 1996; appendix in Lermusiaux, 1999) is a two-dimensional and two-scale objective mapping based on minimum error variance estimation (also known as Gauss-Markov estimation, see also Bretherton et al, 1975 and McWilliams et al, 1996). Objective maps are computed in twodimensions (x,y) at select depths, for two successive scales (the largest scales considered are estimated first). For Monterey Bay, the largest scale is the Bay scale, the second scale is the mesoscale. The use of the Harvard 3D objective analysis scheme will only be investigated if time permits.

The computations involved are expected to last 10 to 30 minutes. The current plan is that, at first, Harvard will carry out these objective analyses once the new data is available. The Princeton group will also be trained to use this OA software. Depending on the progress, needs and interests, either Harvard will continue computing the OAs, or Princeton will carry them out, so as to combine the OA scheme with the control schemes.

References

McWilliams, Owens and Hua, 1986. An objective analysis of the POLYMODE Local Dynamics Experiment: Part I General formalism and statistical model. J Phys. Ocean.,16, 483.

Bretherton, F.P., R.E. Davis, and C.B. Fandry, 1975. A technique for objective analysis and design of oceanographic experiments. Deep-Sea Res., 23, 559-582.

Lermusiaux, P.F.J. 1999a. Data assimilation via Error Subspace Statistical Estimation. Part II: Middle Atlantic Bight shelfbreak front simulations and ESSE validation. Month. Weather Rev., 127(7), 1408-1432. (see http://people.deas.harvard.edu/~pierrel/#interda)

Lozano et al, 1996.

Ogren, P., E. Fiorelli and N.E. Leonard, Cooperative control of mobile sensor networks : Adaptive Gradient Climbing in a Distributed Environment, (see http://www.princeton.edu/~naomi/ofl03.html), 2003.