Potentiality of Glider Data Assimilation in the Solomon Sea: Control of the Mass Field & Parameter Estimation

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1. Context and objectives

Among the recent ocean observing systems are the steerable underwater gliders. Gliders were notably deployed in the Solomon Sea as part of the SPICE program (*Ganachaud et al., 2007*) to improve our knowledge of this potentially important region for the Pacific climate. Indeed, the western boundary currents (WBC) of the Solomon Sea ***(Fig 1)*** represent a major tropics-equator connection. Therefore, they may impact the equatorial Pacific heat and transport. The purpose of this study is to explore the potentiality of glider data assimilation to:

- control numerical simulations according to different scenarios of glider observations,
- estimate key parameters of physical processes parameterized in current ocean general circulation models.

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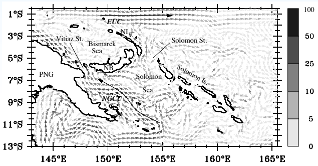

Fig 1. Modeled thermocline circulation for January, 1993.

3. Glider data

Glider monitoring of the Solomon Sea circulations has been operated since 2007. Gliders are autonomous underwater vehicles who repeatedly submerges and resurfaces ***(Fig 5)***. At the beginning and at the end of each dive, the glider obtains and records its position by a GPS antenna, and sends the information it collected during its rise. Researchers control the glider trajectory by giving it waypoints to specified locations; the glider steers to them by controlling its buoyancy and orientation.
Gliders provide high temporal and along-trajectory resolution temperature and salinity data down to about 1000 m, which might be of interest for the control of meso-scale variability.

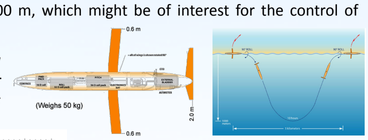

Fig 5. Schematic diagrams of a Spray glider (left) and of a glider dive cycle (right) (illustrations by J. Doucette, WHOI).

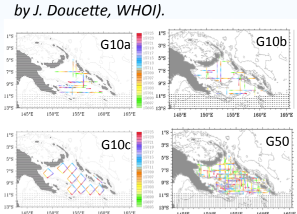

Fig 6. Geographic location and date (color, julian days from 01/01/1950) of our different synthetic gliders configurations.

In this study, we made progressive assumptions on the gliders trajectories ***(Fig 6)***. We first assumed idealized randomly defined zonal or meridional trajectories with 50 gliders (G50), 10 poorly (G10a) and moderately (G10b) homogenously deployed gliders. Then, we used a simplifiied glider simulator *(L'hévéder et al., 2009)* to design a coordinated, homogenous sampling with a fleet of 10 gliders (G10c). For the sake of simplicity, glider trajectories are not impacted by surrounding currents.

5. Tidal mixing parameter estimation

As an alternative, we then intend to directly correct the source of error, ie the tidal efficiency parameter, q. The erroneous parameter is estimated by assimilating data provided by the 10 coordinated gliders (G10c, ***Fig 6***) over one day (01/01/1993) using the method of the augmented state vector. To assess the sensitivity of the model to the parameter and to parameterize the error covariance matrix, a 100-member ensemble is used. The 100 values for q are randomly sampled in a prior Gamma distribution ***(Fig 10)***. The closest value to the median of the distribution is chosen for the false ocean (q≈0.8). Each of the 99 remaining member provides a different true value for q, so that 99 parameter estimation experiments are performed. This method allows an accurate estimation of q, with a mean absolute relative error on the estimated value of q of (1.7 ± 10.6) % ***(Fig 11)***.

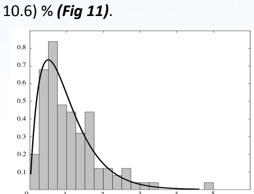

Fig 10. Prior probability distribution for the tidal efficiency parameter (solid curve) as compared to the histogram of the 100-member random sample.

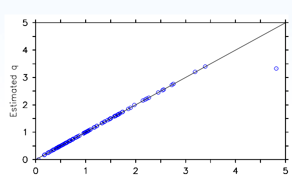

Fig 11. Result of the estimation of the tidal efficiency parameter q without (blue) and with (red) anamorphosis as a function of the true value for q.

2. Multigrid and multivariate data assimilation

To handle the complex bathymetry of the Solomon Sea, a hierarchy of **nested models** based on the NEMO-OPA code has been implemented. A 1/12° model of the Solomon Sea is interactively nested (AGRIF software, 2-way) in a regional 1/4° model of the southwest Pacific, itself embedded in a 1/4° global simulation (Drakkar project) ***(Fig 2)***.

Gliders T, S data are sequentially (1 day cycle) assimilated in the 1/12° model using a reduced rank Kalman filter (derived from the SEEK filter, *Brasseur et Verron, 2006*) whose methodology has been extended here to deal with multigrid models ***(Fig 3)***.

As a first step, an observing system simulation experiments (**OSSE**) strategy is implemented to explore the potentiality of glider data assimilation. The unique source of error in our idealized experiments is chosen to be related to a misrepresentation of the vertical mixing due to the breaking of internal tides. Indeed, mixing is not easily accessible from observations and strong **tidal mixing** occurs in this region. Including a parameterization of this physical process (Kz_{tides}) in our numerical simulation improves its realism *(Melet et al., 2011)*.

$$Kz_{tides}(x,y,z,t) = \frac{q\Gamma \mathbf{E}(x,y)\mathbf{F}(z)}{\rho(x,y,z,t)\mathbf{N}^2(x,y,z,t)}$$

q: tidal dissipation efficiency N: Brunt-Väisälä frequency ρ: density
E(x,y): surface energy transfer from barotropic to baroclinic tides
Γ=0.2 : mixing efficiency F(z): vertical structure of E(x,y)

Uncertainties exist on the parameter q, and its value constitues the source of error in the thermohaline characteristics in our OSSE. Errors are maximum in the thermocline.

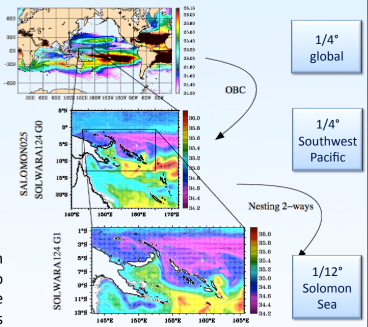

Fig 2. Hierarchy of models used to reach high-resolution modeling of the Solomon Sea.

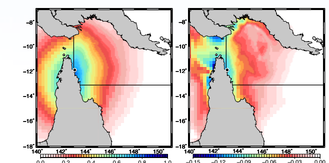

Fig 3. Multigrid and multivariate local analysis increment for T (left) and S (right) resulting from the assimilation of one single perfectly accurate observation of T (black dot). The delimitation of the 1/12° grid is drawn as a black rectangle.

4. Control of the thermohaline characteristics

A first exploration of the potentiality of gliders to control thermohaline (T,S) misfits in the Solomon Sea due to a misrepresentation of tidal-driven mixing is performed according to different scenarios of gliders deployment ***(Fig 6)***.

<u>Experimental set-up :</u> the false ocean (to be corrected) is run with q=0 while the true ocean from which gliders data are extracted (distribution of data in Fig 6) is run with q=1. To parameterize the forecast error covariance matrix, an ensemble of 6 simulations has been run with a varying q ***(Fig 7)***. The error covariance matrices are stationary and constructed from the first 15 EOF vectors of 18 daily means of the ensemble run (96 states). Assimilating experiments last 1 month (Jan, 1993).

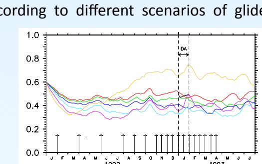

Fig 7. Root mean square differences (RMSD) to the true ocean in the thermocline for the false ocean (q=0) and the ensemble simulation (q=0.1, 0.2, 0.4, 0.8, 1.6, 3.2) .

<u>Results :</u> Non-surprisingly, the ability of gliders to control the Solomon Sea T, S fields strongly depends on the design of the fleet. As for the size of the array, a fairly good control is achieved with a fleet of 50 gliders (G50, ***Fig 8, 9 & Table 1***). When the observationnal array is impaired by reducing its size to 10 gliders, the space and time distribution of the data is decisive (G10a, G10b, G10c in ***Table 1***). The reduction of errors is significantly improved when glider trajectories are coordinated to collect information-rich data (G10c). A substantial control can be achieved in this case (***Fig 8 & 9***). Mass field errors are further reduced when assimilating sea surface temperature (SST) in addition to glider data (***Table 1***).

Run	G50	G10a	G10b	G10c	G50+SST	G10c+SST
T	67%	140%	123%	97%	60%	87%
S	41%	105%	78%	64%	41%	59%

Table 1. Remaining percentage of the false ocean thermocline T and S RMSD over the Solomon Sea.

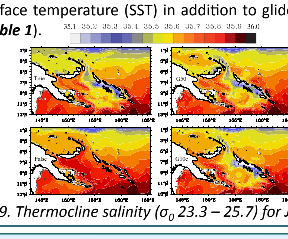

Fig 9. Thermocline salinity (σ_0 23.3 – 25.7) for Jan, 1993.

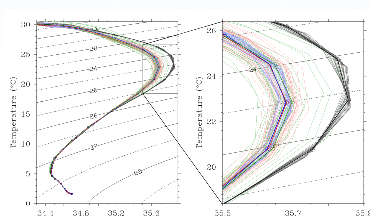

Fig 8. Northern Solomon Sea daily (thin lines) and monthly (thick dotted lines) T-S diagrams for the true, false oceans and the assimilating experiments G50 and G10c.

6. Conclusions

This exploratory study provides an insight of the ability of gliders to control model errors due to a misrepresentation of tidal mixing in the Solomon Sea through multigrid and multivariate sequential assimilation of glider temperature and salinity observations. Idealized experiments (OSSE) are performed to study the influence of the design of fleets of gliders (size of the array and distribution of data) and the complementarity with other data (SST here) to constrain the mass field. A significant reduction of errors can be achieved with an array of 10 gliders if their time and space distribution is rather homogeneous. An alternative method consisting in a direct estimation of the erroneous tidal-mixing parameter through gliders data assimilation, using an ensemble simulation method has also been implemented. This promising strategy allows an accurate estimation of the mixing parameter and yields to an efficient correction of the Solomon Sea thermohaline characteristics errors.

<u>**References :**</u> ***Brasseur et Verron 2006***, «The SEEK filter method for data assimilation in oceanography: A synthesis», Ocean Dynamics, 56, 650-661; ***Ganachaud et al. 2007***, «Southwest Pacific ocean circulation experiment.», NOAA OAR Special report/International CLIVAR Project office, CLIVAR publication Series N0111; ***Koch-Larrouy et al. 2007***, «On the transformation of Pacific Water into Indonesian Throughflow Water by internal tidal mixing », Geophys. Res. Lett., 34; ***L'hévéder et al. 2009***, «Operationnal forecast of glider trajectories during EGO 2008 operations in the Mediterranean Sea using Mercator Ocean Forecast», Mercator Quaterly Newsletter, January 2009; ***Melet et al. 2011***, «Solomon Sea water masses pathways to the Equator and their transformations», J. Phys. Oceanogr., 41, pp 810-826.