STSM SCIENTIFIC REPORT – COST ACTION ES0904: GLIDER CTD PROBLEMS AND GLIDER SIMULATION CODE

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Approved by: ……………………………
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1. Details of the STSM

STSM Applicant:	Riccardo Gerin
COST Action:	ES0904
STSM title:	Glider CTD problems and glider simulation code
Reference:	ECOST-STSM-ES0904-211013-036369
STSM dates:	from 21-10-2013 to 31-10-2013
Location:	Helmholtz-Zentrum Geesthacht
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2. Introduction

The main purpose of the Short Term Scientific Mission (STSM) was:

- to make progress in the correction of glider CTD data (correction of errors induced by T and S gradients due to sensor lags and thermal inertia);
- to implement a code already used for the simulation of the Slocum glider path during a mission.

The first 3 days of the STSM were dedicated to the participation of the workshop on the issues related to the CTD glider data and routines used to correct the errors with particular attention to the thermal lag problems of the conductivity cell. The applicant shared the glider data collected in two different glider experiment (Tirrmount09 and Lidex10) and successfully tested and used the existing algorithm on his data.

The week after the workshop was dedicated to the code that estimates the behaviour and the dynamics of Slocum glider considering also the information from numerical model. The code requests as input the values of several variables of the Slocum glider. Not all these variables are available for the SeaGlider, therefore the iRobot SeaGlider dynamic was studied and all the parameters that the SeaGlider send on land were considered in order to “convert” them from the SeaGlider point of view into the Slocum one. The code was implemented and make functioning with the SeaGlider.

The report is divided in two paragraphs: a first one displaying the main results of the thermal lag correction applied on the Lidex10 glider data and a second one depicting the preliminary results of the SeaGlider simulation.

3. CTD glider problems

During the workshop about the CTD glider problems (22-24 November 2013), several issues were touched and, in particular, the CTD timestamp and the thermal lag correction.

3.1. CTD timestamp

The CTD timestamp is a parameter that is fundamental for the right comprehension of the scientific variables, but not all the glider recorded it. Since June 2013 the CTD timestamp is logged on the glider by default, but in the past it was recorded only if the operator had activated the corresponding option, while for the very first version of the Slocum gliders (i.e. Trieste1 shallow water glider) the parameter cannot be logged at all.

Slocum gliders have two processors, one for the navigation and one for the science. For some glider versions, the science processor only deals with the acquisition of the scientific parameters, it does not send them, rather it passes all the parameters to the navigation processor that gathers all the data and takes care of the transmission of them.

The CTD makes a measurement M_{CTD} at a certain time T_{CTD} (sci_m_present_time for the Slocum gliders). Data are sent to the navigation processor that store the M_{CTD} measure after dealing with the navigation issues, let’s say at T_{NAV} (m_present_time for the Slocum gliders). T_{CTD} and T_{NAV} of course are different, the delay is about 2 sec for the recent gliders and can be higher for the older glider versions. Additionally, the delay is not constant and sometimes measurement and storage go out of sync and some scientific data can be lost. Therefore the storage and the transmission of the T_{CTD} is of primary importance for the analysis of the scientific data. During the workshop the difference between the T_{CTD} and the T_{NAV} were examined for two Slocum glider. The time difference of the “Tenuse” shallow water Slocum glider during the LiDEx10 experiment is between 0 and 4 seconds during a 200 m dive (Fig. 1).

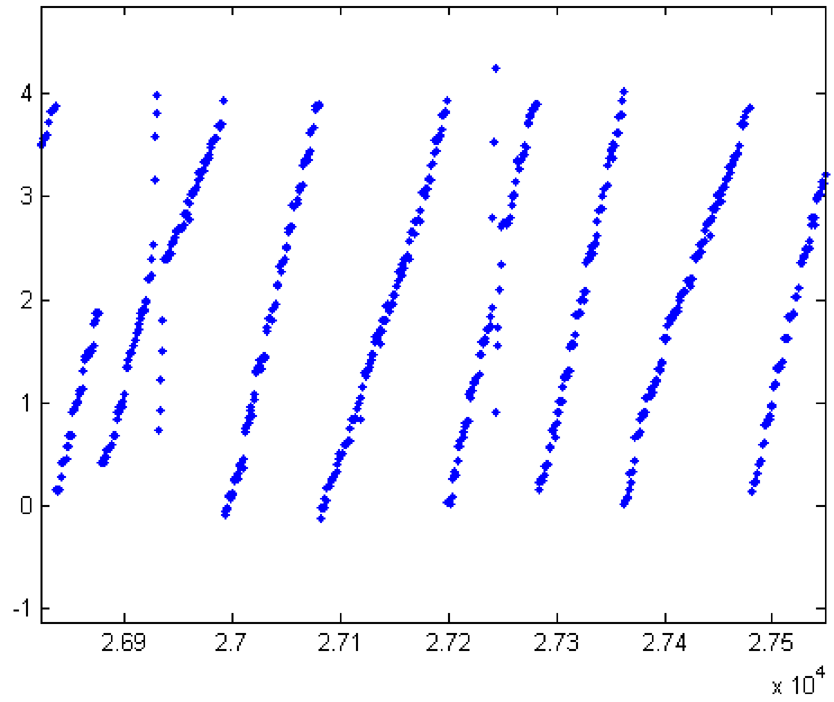

Fig. 1. Time difference of the “Tenuse” during the LiDEx10 experiment.

The time difference of an older version of Slocum glider (“Trieste1” during Tyrrmount09) is higher and can reach 20 seconds for a 200 m dive (Fig. 2), causing possible large errors while interpreting the data (see for example the different indication of the pressure in Fig. 3).

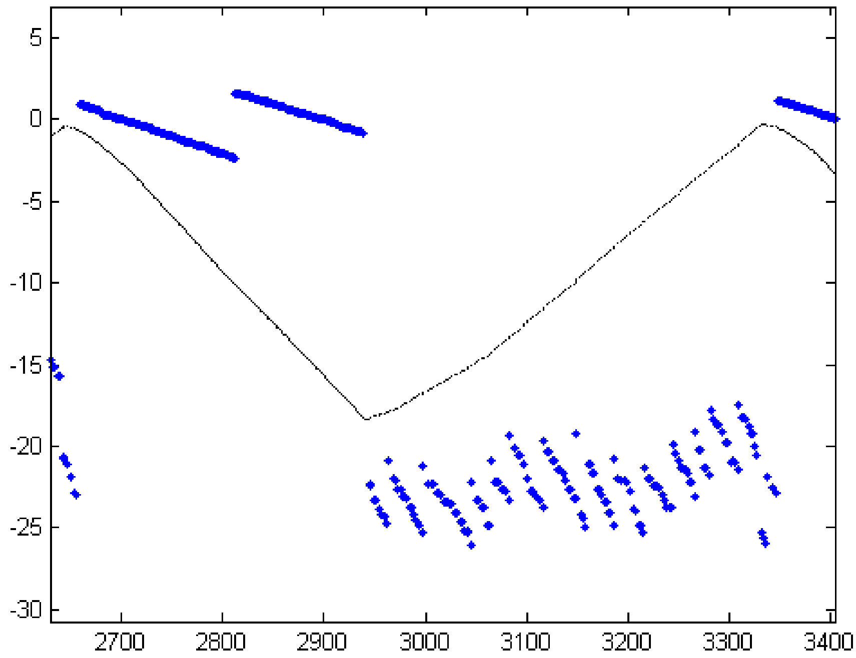

Fig. 2. Time difference of the “Trieste1” during the Tyrrmount09 experiment.

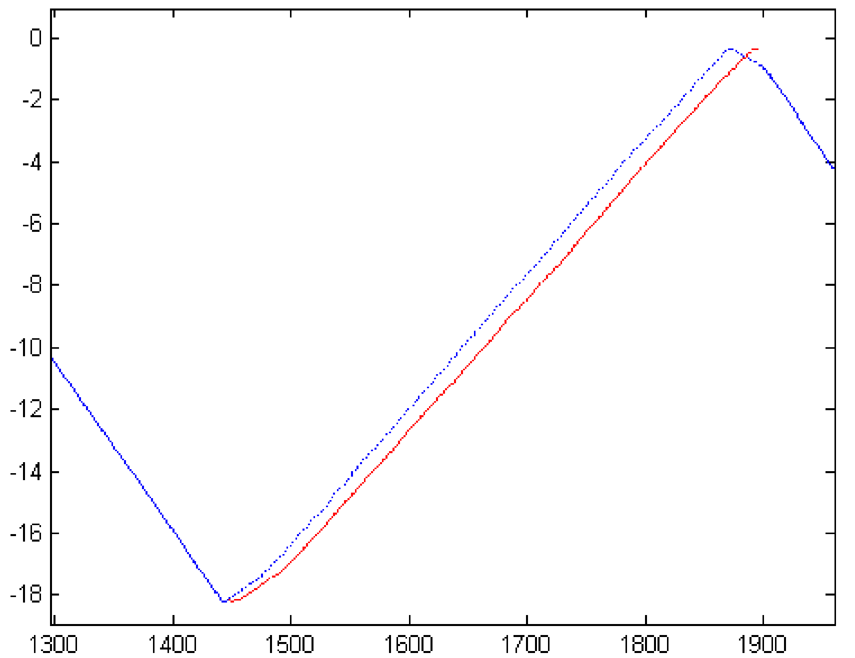

Fig. 3. Different pressure plot. Blue line: pressure referred to the T_{NAV}. Red plot: pressure referred to the T_{CTD}.

3.2. Thermal lag correction

As explained in Garau el al. (2011), to obtain accurate salinity data, the CTD instruments require corrections for temporal and spatial mismatches in the temperature and conductivity sensor responses. A temperature sensor measures seawater temperature outside of the conductivity cell while a conductivity sensor measures seawater conductivity inside of the conductivity cell.

All conductivity cells have mass and, therefore, the capacity to store heat. When a conductivity cell moves through temperature gradients, heat is lost to/gained from the surrounding water (based on gradient direction). Depending on cell design, varying amounts of the heat stored in (released from) the cell body warm (cool) the water within the cell, changing its conductivity. Because temperature sensors are located outside the conductivity cell, the temperature reported by the CTD will be slightly different from the actual temperature inside the conductivity cell. Therefore, when those measurements of temperature and conductivity are used in the salinity equation, the computed salinity will be erroneous, especially when crossing strong temperature gradients (thermocline).

The thermal lag correction is therefore compulsory. The Sea-Bird CTD installed on some Slocum gliders has additional problems that make traditional techniques of correction difficult to apply. Indeed the CTD on board Slocum gliders is unpumped, and therefore the flow speed depends on glider surge speed. Moreover, the gliders' CTD sampling has a low temporal resolution (0.5 Hz) in comparison to the high resolution of CTD sampling as operated from ships and the glider CTD sampling interval is irregular.

The approach followed at the workshop tries to estimate the temperature inside the conductivity cell for the purpose of calculating salinity with measured conductivity. The temperature correction (T_T) is computed using the following expression:

$$T_T(n) = -bT_T(n-1) + a[T(n) - T(n-1)],$$

where coefficients *a* and *b* are computed as follows:

$$a = \frac{4 f_n \alpha \tau}{1 + 4 f_n \tau},$$

$$b = 1 - \frac{2a}{\alpha}.$$

Morison et al. (1994) showed that there is a relation between the correction parameters α and τ and the flow speed through the conductivity cell. In the case of pumped CTDs, the flow speed is either known or, at worst, it can be estimated by observing the misalignment between the sensors' signals. The flow speed is then assumed to be constant and the correction parameters a and t are also constant.

Garau et al. (2011) proposes a generalization of the method developed by Morison et al. (1994), where the relation between a and t and the flow speed is computed throughout the profile, so that the assumption of constant flow speed is no longer required.

Following Morison et al. (1994), the relation between the correction parameters and the flow speed is:

$$\alpha(n) = \alpha_o + \alpha_s V_f(n)^{-1},$$

$$\tau(n) = \tau_o + \tau_s V_f(n)^{-1/2},$$

where V_f is the velocity of the flow, based on the glider surge speed, which is variable over the profile, *o* and *s* are the offsets and slopes for α and τ, respectively.

The correction relies on finding values for the four parameters: α_o, τ_o, α_s, τ_s by minimizing an objective function that measures the area between two T–S curves given by two CTD profiles, one upcast and one downcast. The main hypothesis is that the compared profiles correspond to the same water mass (assuming a low horizontal advection). In each iteration of the minimization process, a polygon is built using the two profiles to describe its perimeter. The polygon area is computed through the summation of the areas of the forming triangles (Fig. 4), avoiding problems with concavities and self-intersections. The minimization is carried out using the optimization toolbox from MATLAB, finding the minimum of a constrained nonlinear multivariable function by means of a medium-scale optimization that uses a sequential quadratic programming (SQP) method.

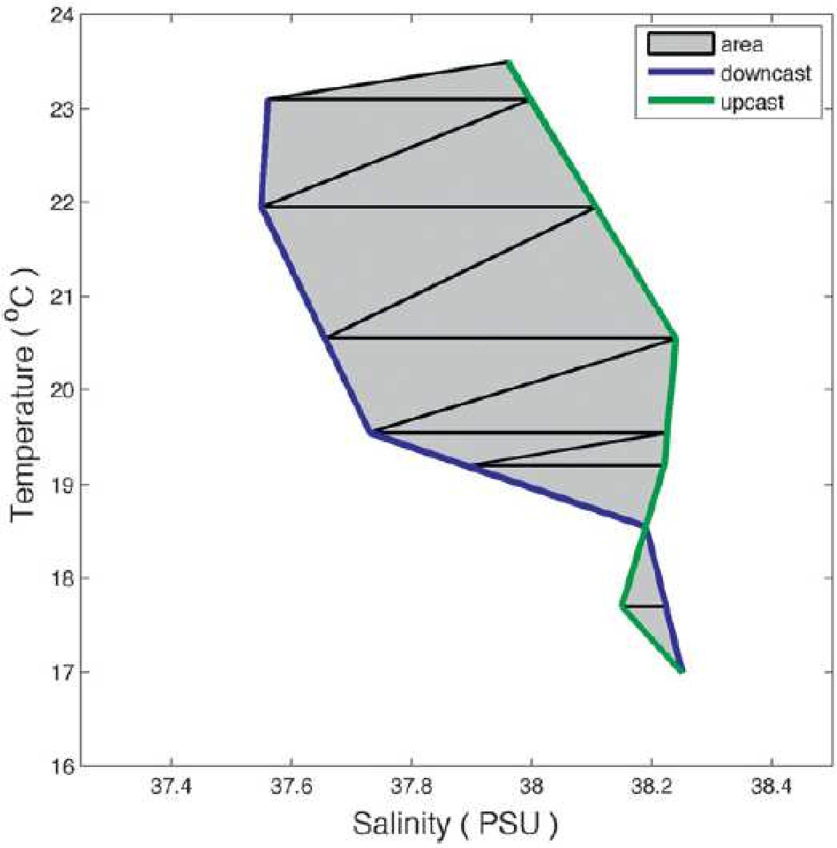

Fig. 4. Polygon built from two profiles and forming triangles.

The Garau et al. (2011) method was applied to the data collected during the LiDEx10 experiment considering consecutive up & down cast profiles rather than consecutive down & up cast profiles in order to be sure to compare profiles corresponding to the same water mass (Fig. 5, the thermal lag effect is much more evident at the thermocline).

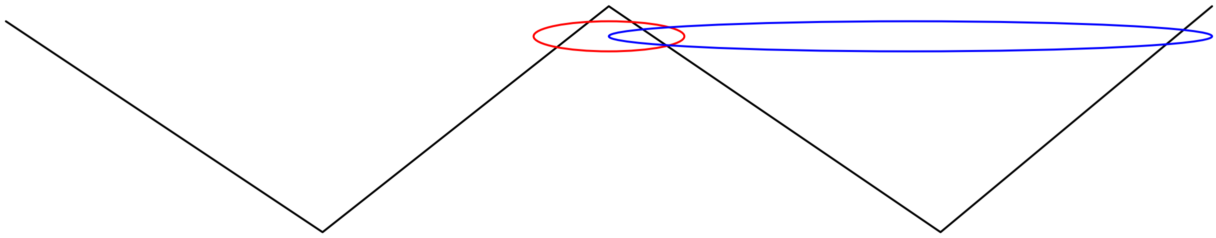

Fig. 5. At the thermocline depth the up & down cast profiles (red circle) are closer in space and time with respect to the down & up cast profiles (blue circle), especially in the case of deep profiles.

The offsets and slopes for α and τ were computed and the median was considered. The thermal lag correction provided a despiked and less noisy series of profiles (compare Fig. 6 with Fig. 7).

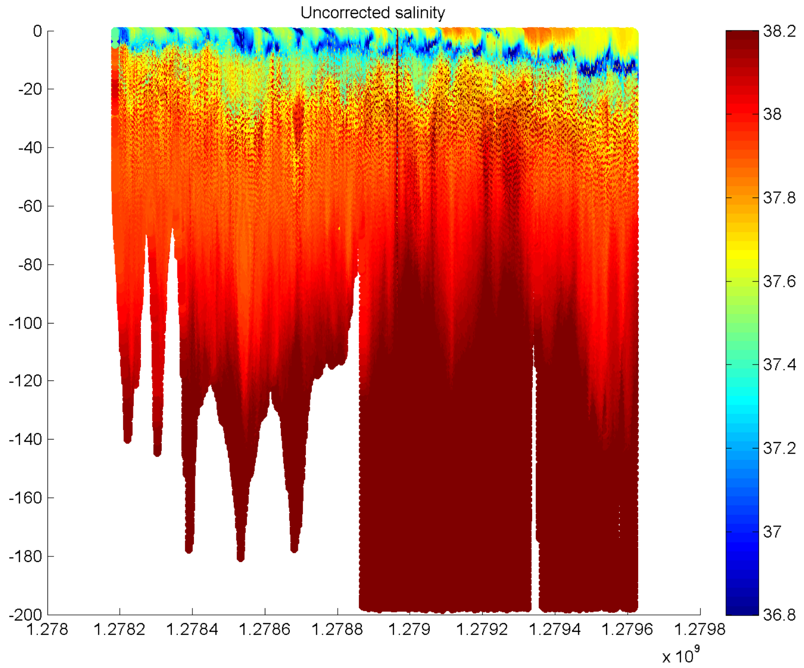

Fig. 6. Uncorrected salinity

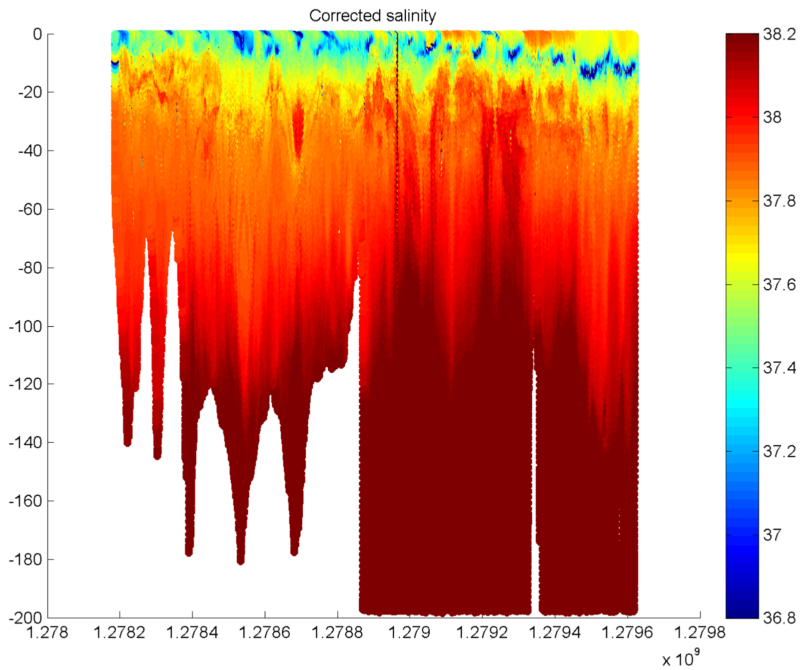

Fig. 7. Salinity corrected for the thermal lag.

The correction magnitude is up to o.2 PSU (Fig. 8). Some evident spikes still remain.

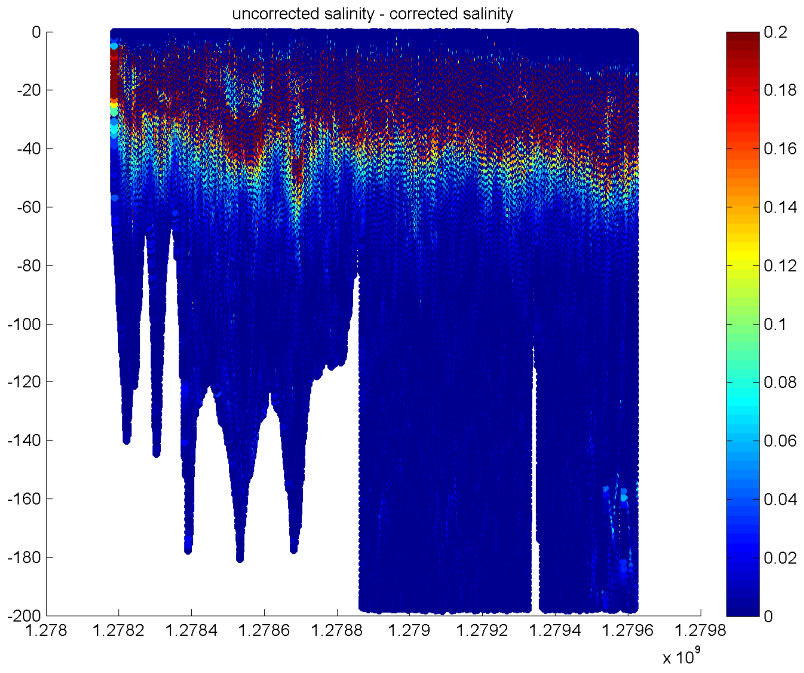

Fig. 8. Difference between the uncorrected and the corrected salinity.

4. Glider simulation code

During the second part of the STSM, the issue of making the code for the estimation of the behaviour and the dynamics of Slocum glider working also with the was faced. The code considers the hydrodynamic modelling of the Slocum glider and a series of parameters (as recorded by the Slocum glider; i.e. Slocum philosophy) and information from numerical model as input. The numerical model adopted is the Mercator, but the code can be modified in order to accept products from different numerical models. The fact that the code was written considering the hydrodynamic characteristic of the Slocum and requests as input some parameters in the Slocum philosophy, induced to adapt the SeaGlider to the Slocum philosophy rather than deeply modify the code. This means that the parameters as recorded by the SeaGlider were converted to the corresponding Slocum parameters.

The hydrodynamic characteristics of the SeaGlider (Fig. 9: drag coefficient, Fig. 10: wing area, Fig. 11: median of pitch, angle of attach, ...) were evaluated. The code was modifyied considering the range of these variables and proceeding by trials.

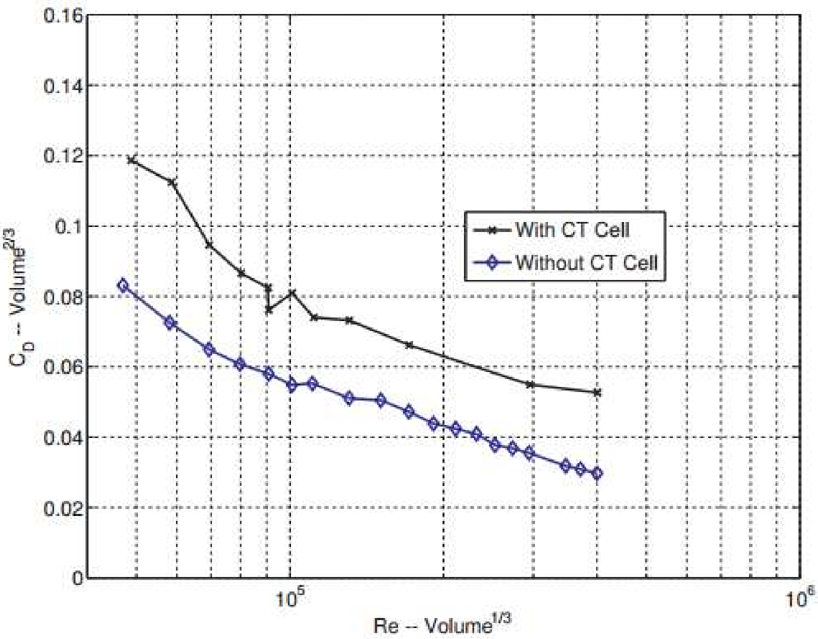

Fig. 9. Drag coefficient for a SeaGlider.

Fig. 10. Wing area for a SeaGlider and a Slocum glider.

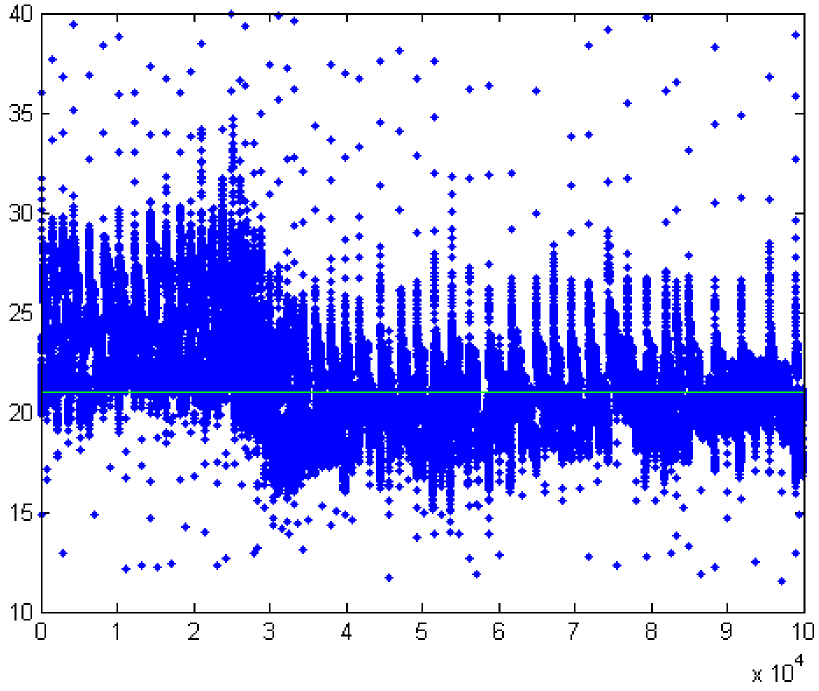

Fig. 11. Median of the pitch of the SeaGlider “Amerigo” during a recent mission in the Southern Adriatic Sea.

The results are very promising. The path of the SeaGlider “Amerigo” during a recent mission in the Southern Adriatic Sea was replicated correctly (compare the portion of the path in Fig. 12 with the one in Fig. 13).

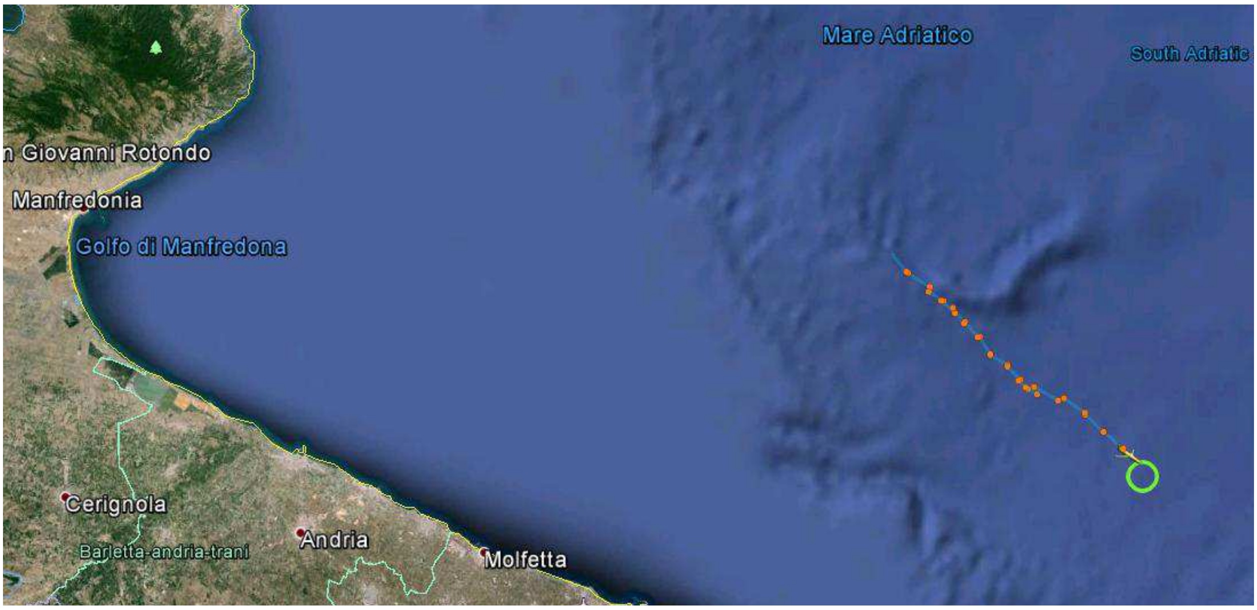

Fig. 12. Path of the SeaGlider “Amerigo” in the Southern Adriatic Sea (orange dots: glider at surface).

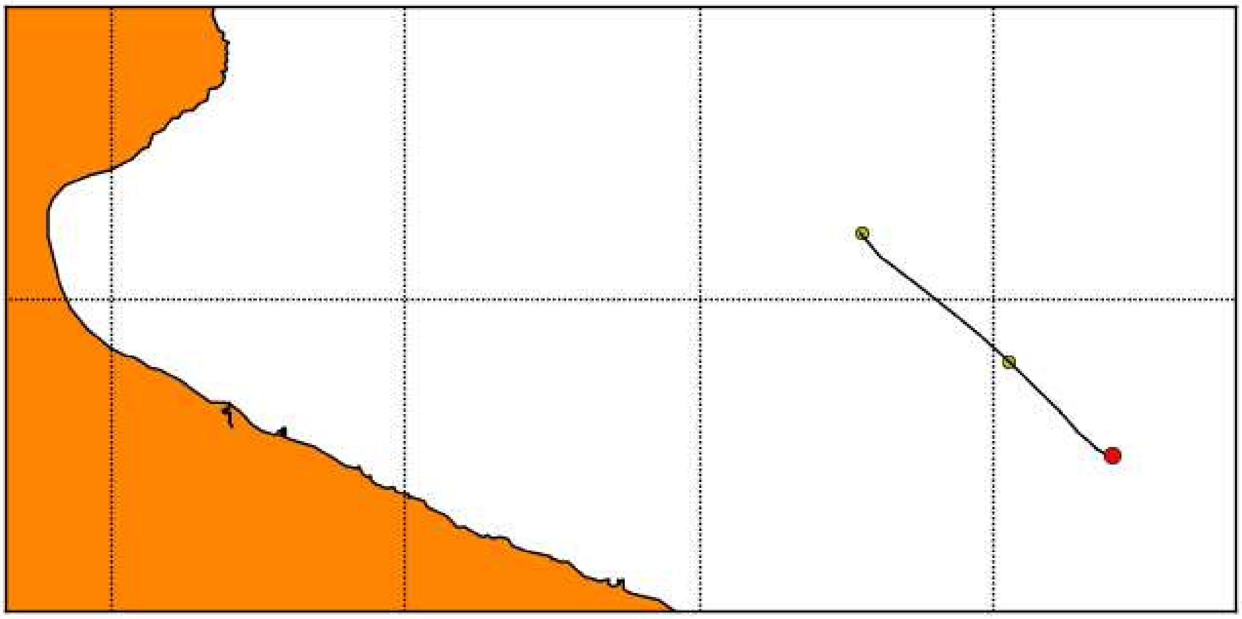

Fig. 13. Path of the synthetic glider (yellow dots: day 0 and day 1; red dot: end of mission).

The synthetic glider completed the path in 43 h, making 12 underwater yos (Fig. 14). The real glider employed 47 h and made 15 underwater yos.

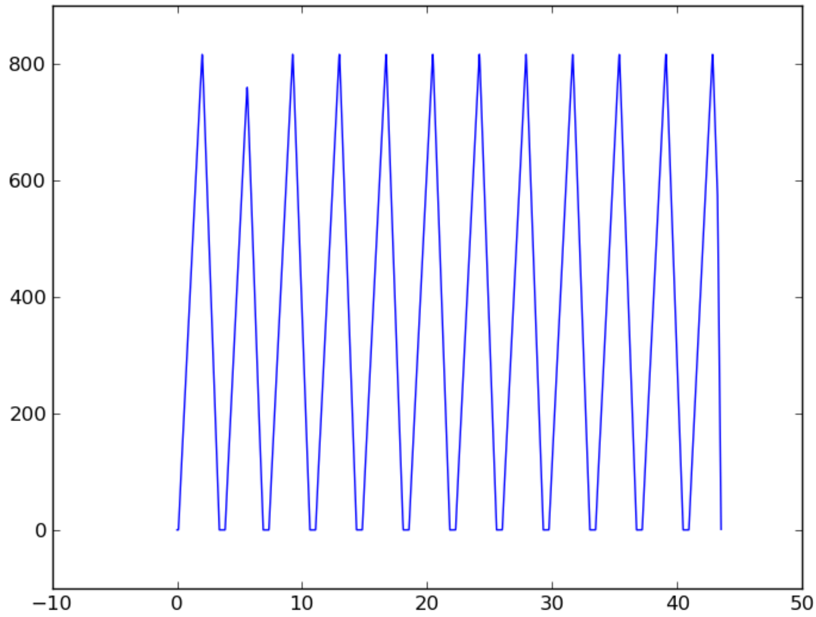

Fig. 14. Underwater yos of the synthetic glider (x axes: time in hours; y axes: depth).

The yo trend is correctly replicated. It takes about 3 h and the glider remains at the surface transmitting data for about 30 min (Fig. 15) almost exactly as the real glider.

The glider simulation code was also run considering the currents of the numerical models at all levels and considering a one-level sea with a current corresponding to the one at the surface or at different depths. The total time to complete the mission and the number of yos slightly varied at each run, suggesting that the difference between the synthetic and the real glider is probably due to the imprecision of the numerical model in predicting the currents (mainly the surface current).

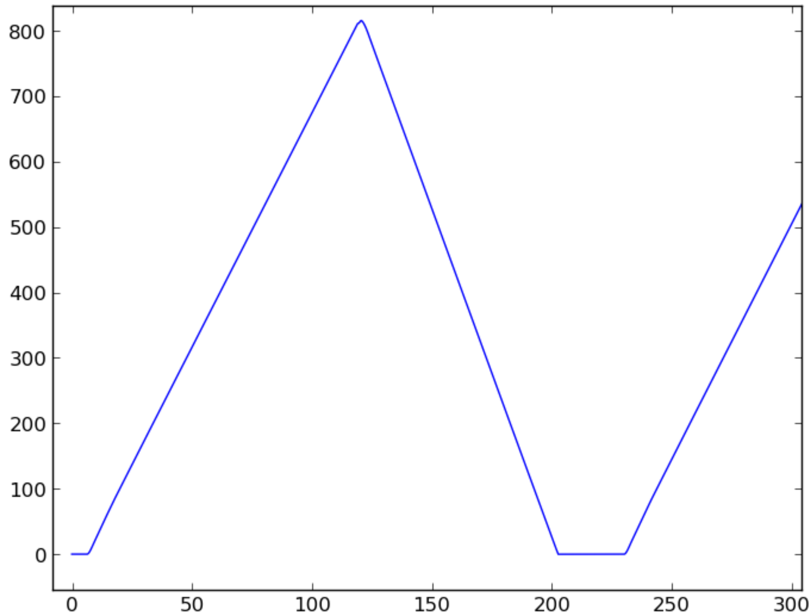

Fig. 15. Zoom of one underwater yo of the synthetic glider (x axes: time in minutes; y axes: depth).

5. Acknowledgements

I would like to greatly thank the Cost Office for allowing me to visit the Helmholtz-Zentrum Geesthacht in Germany and Lucas Merckelbach for his precious collaboration.

6. References

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