Lagrangian Turbulence and Transport in Semi-enclosed Basins and Coastal Regions

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LONG-TERM GOALS

The long-term goal of this project is the development and application of new methods of investigation for the use of Lagrangian data. Special attention is given to the development of new techniques for the assimilation of Lagrangian data in Eulerian numerical models. Another objective is to improve previous results on statistical prediction of particle transport using data analysis and stochastic models.

OBJECTIVES

To develop methods in the framework of the ODDAS DRI objectives, namely to use information from drifting sensors to improve the prediction of spreading in the velocity field. The project has the following specific objectives:

1) To develop and apply new techniques for assimilation of Lagrangian data in regional ocean circulation models.

2) To investigate statistical prediction of particle transport using data analysis and stochastic models.

APPROACH

The work involves a combination of analytical, numerical and data processing techniques. The method development has been carried out in collaboration with A. Molcard (CNR, Universite' of Toulon), L. Piterbarg (USC), P. Poulain (OGS), V. Taillandier (CNR, RSMAS) and M.Veneziani (UCSC).

WORK COMPLETED

1) Improvement of the Lagrangian assimilation method for applications to realistic regional ocean models and implementation in a regional model (Taillandier et al., 2006a, Taillandier and Griffa, 2006).

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2) The first application of Lagrangian assimilation using in-situ Argo float data in a regional model (Taillandier et al., 2006b).

3) Participation in the Dynamics of the Adriatic in Real Time (DART) experiment. Indications on experimental strategies for drifter releases have been provided based on probability density functions (pdfs) computed from historical Lagrangian data (Veneziani et al., 2006).

4) Acceptance of the first book on Lagrangian dynamics by the Cambridge University Press for publication in spring 2007. The editors are A. Griffa, A. Mariano, D. Kirwan T. Rossby and T. Özgökmen.

RESULTS

i) Lagrangian data assimilation for multiscale flows and application to in-situ data:

The assimilation method for Lagrangian data has been improved and implemented in realistic regional models. The method, originally developed in the framework of simplified models and idealized configurations (Molcard et al., 2003, 2005), consists of three main steps: a) the Eulerian velocity field **u** is corrected at the level where Lagrangian data are collected, using the information from the float positions **r**=**H**(**u**); b) the velocity correction Δ**u** is projected in the water column using statistical regression coefficients; c) the mass field is adjusted under the requirement of mass conservation and geostrophy.

The first step, i.e. the velocity correction, has been significantly improved by improving the representation of the observational operator **H** (Taillandier et al., 2006a). In the earlier works (Molcard et al., 2003), the velocity was corrected at the location of the float, while now the correction is expanded along the estimated trajectory between two consecutive float positions separated by a time interval Δt. This is done minimizing a cost function which measures the distance between the observed float position at the end of the sequence and the position of a prior trajectory advected in the model (background) velocity field. Shear drifts, such as the ones occurring during vertical motion for Argo floats, can be taken into account in the computation of the prior trajectory. *The methodology is general and can be expanded to consider other types of integrated velocity information, such as for instance information from gliders.* Another significant improvement has been performed in the mass correction technique (Taillandier and Griffa, 2006). Previous applications considered models with simplified stratification (reduced gravity or three layer models), while now the methodology is general enough to be applied to circulation models with realistic stratification expressed in terms of temperature (T) and salinity (S) mass variables. This is done using an inverse technique, where the corrected velocity profile Δ**u** (z) is assumed geostrophically maintained with respect to mass variations in T and S, by enforcing the thermal wind equation and the equation of state.

The method has been implemented in a realistic OPA regional model of the North-Western Mediterranean and it has been tested using the twin experiment approach (Taillandier et al., 2006a, Taillandier and Griffa, 2006). The region is characterized by a vigorous mesoscale field (with time scales longer than a few days), and by as a superimposed strong inertial signal (with time scale of 19h). The assimilation is targeted to correct the mesoscale field, so that the correction Δ**u** applies to velocity averaged over a few days. A further improvement of the method has been introduced to take into account the presence of the higher frequency inertial fluctuations, considering them as a superimposed signal characterized by a simple feature model. Results from twin experiments are shown in Fig. 1, in terms of error in the velocity field reconstruction as function of the number of floats considered and of the sampling interval Δt. The error appears weakly dependent on Δt in the range between 2.5 days (order of the Lagrangian time scale) and 1 day (order of the inertial period). For Δt <1 day, the error increases if the presence of the inertial signal is not considered in the method (blue lines), while it decreases significantly when the improved method including inertial fluctuations is used (red lines).

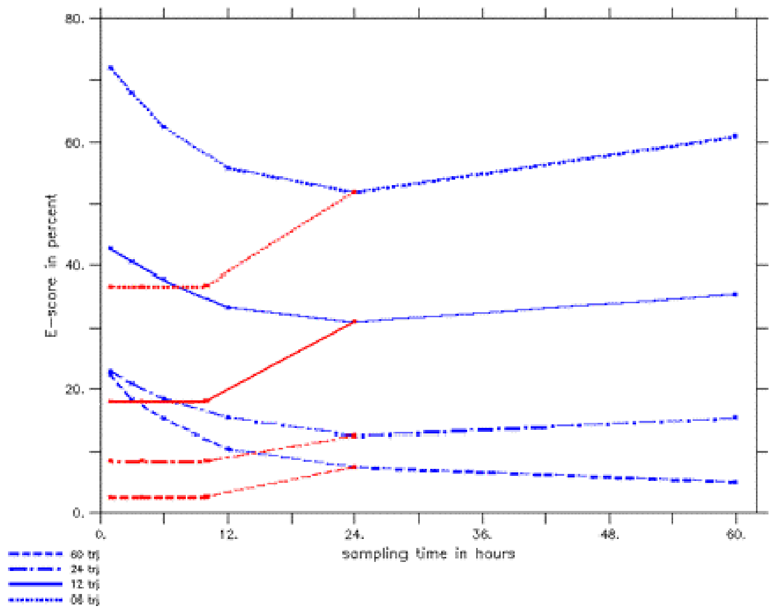

Fig. 1: Error in the velocity field reconstruction versus sampling time Δt. The various blue lines indicate different coverages (i.e. number of floats used) increasing toward the bottom, The red lines indicate results from the improved method taking into account inertial oscillations. The improvement is very effective for Δt <1 day (from Taillandier et al., 2006a).

The method has then been applied to in-situ Argo float data (Taillandier et al., 2006b). *This is the first time that position data from Argo floats are assimilated in a realistic model*, and it is expected to have a significant impact for operational systems. Four Argo floats, released in the North Western Mediterranean in the context of the operational MFSTEP project, have been used during winter 2005. The results are very encouraging, showing significant and consistent changes in the ocean circulation, The velocity and mass fields are locally corrected consistently with the float drift, as shown in the example in Fig. 2 for a float in the Balearic Sea. Also, comparison with independent data of transport through the Channel of Corsica (which is not directly sampled by the floats) indicates that results are more realistic with assimilation (Fig. 3), showing a non negligible impact of the assimilation process on the large scale circulation of the basin.

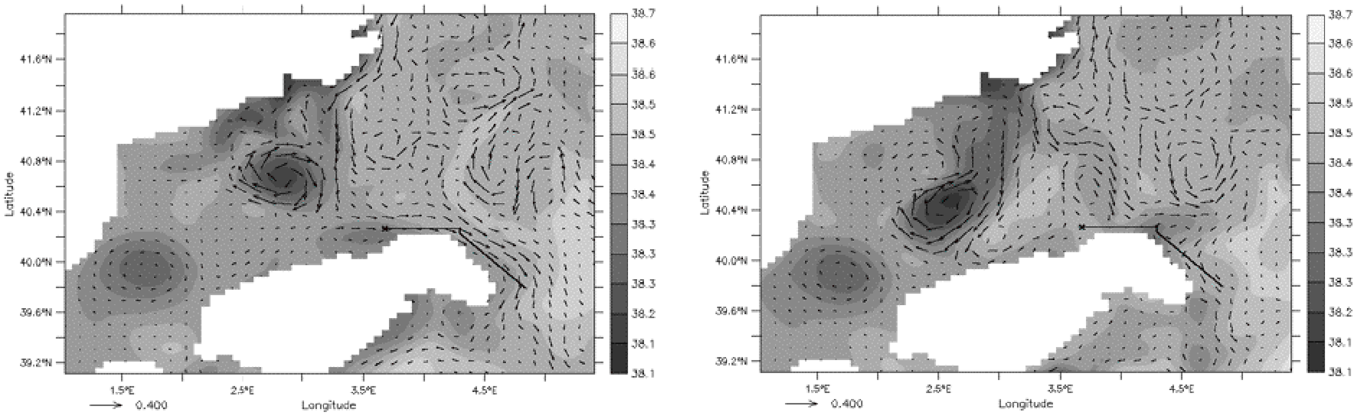

Fig2: Comparison of results from OPA model in the Balearic Sea with (left panel) and without (right panel) assimilation. Snapshots of salinity (shades) and currents (arrows) at 350 m. with superimposed Argo float trajectories corresponding to 10 days. The assimilation tends to modify the fields consistently with the float drift (from Taillandier et al., 2006b).

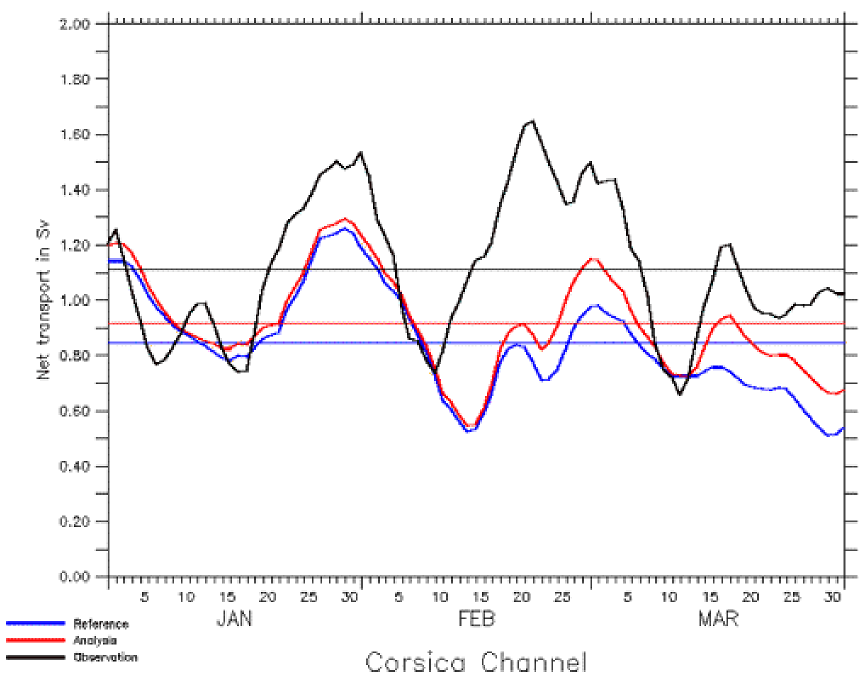

Fig3: Net transport through the Corsica Channel: blue (red) line indicates the model transport without (with) assimilation, while the black line indicates the transport from current meter data (courtesy of G.P. Gasparini). The assimilation tends to bring the model transport closer to the data (from Taillandier et al., 2006b).

ii) Analysis of Lagrangian in-situ data for best launching strategy during the DART experiment:

We are presently involved in the Dynamics of the Adriatic in Real Time (DART06) experiment, a joint experiment coordinated by M. Rixen (NRC/NATO) with the participation of NRL (J. Book, P. Martin) and OGS (P.Poulain). The experiment focuses on a coastal region in the middle Adriatic close to the Gargano Cape. The region is strongly controlled by topography and has significant mesoscale activity arising from the instabilities of the western Adriatic current (WAC). The experiment took place during two periods in 2006, with a winter (March) component and a summer (August) one. During the DART experiment a total of 22 drifters have been launched, 17 in March and 5 in August. In addition to drifters, data from acoustic current meters, hydrographic data and satellite data have been collected in the area.

In preparation to the DART experiment, a study of historical drifters in the Adriatic Sea has been carried out to provide suggestions for Lagrangian sampling strategies. The main goal of the strategy was to provide an extensive coverage of the DART area during the experiment, in order to obtain a satisfactory picture of the dynamics. The mean flow pattern computed from the drifters (Fig. 4) shows the presence of a well defined boundary current along the coast and of a saddle (hyperbolic) point off-shore the cape, separating two recirculating gyres one to the North and the other to the South respectively. Maps of drifter concentration at different times have also been built and interpreted as maps of probability density function (pdf's) of finding a particle at a given time in the neighborhood of a given point in the domain. An example of pdf for particles released in the region of the hyperbolic point (HP) is shown in Fig.5, indicating the presence of a well-defined two-branch pattern. For particles released in the WAC upstream of the cape, the pdf (not shown) indicates that drifters tend to stay in the boundary current moving south. An occasional anticyclonic recirculation is observed in the Gulf of Manfredonia, in the lee of the cape.

Based on these historical data results it was decided to concentrate the launches in three areas: a) the WAC upstream of the Gargano Cape in order to cover the more coastal area, b) the HP region in order to cover the more off-shore region, and c) the Gulf of Manfredonia which appears to be a “shadow zone”. This general strategy have been complemented by a numerical model effort performed in real time during the experiment, in order to identify more closely the launching points in the highly variable regions of the HP and of the Gulf of Manfredonia. The overall goal of the sampling strategy was successfully achieved during the experiment, providing a good coverage of the region.

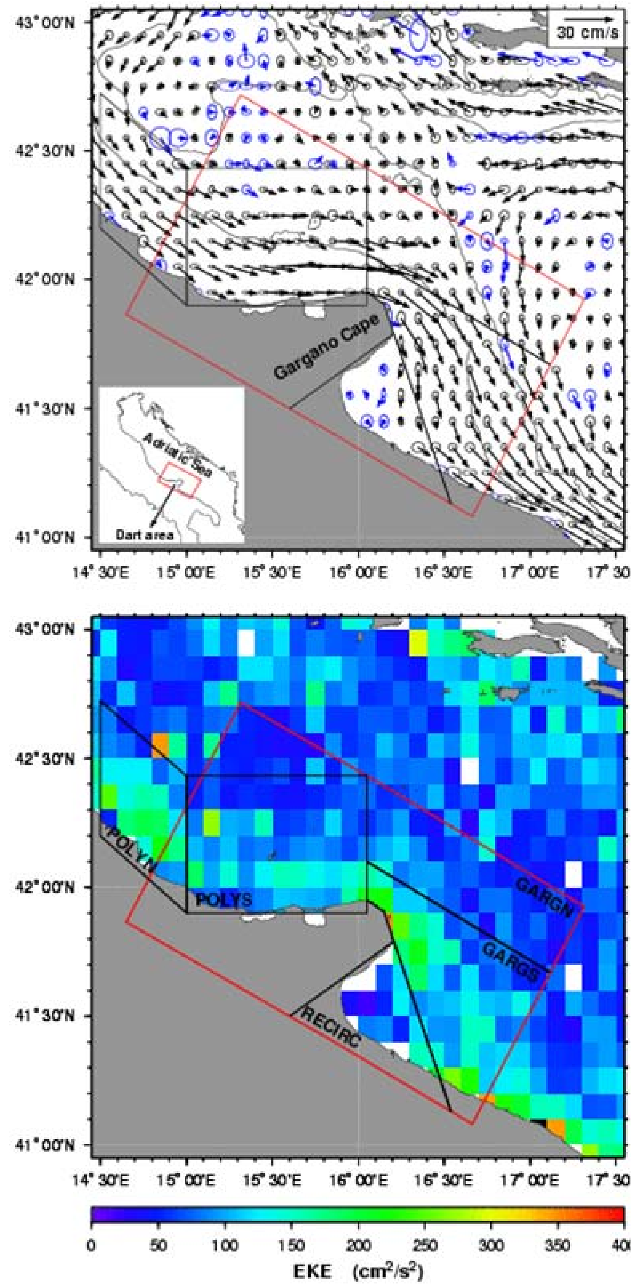

Fig. 4: Maps of mean velocity (upper) and EKE (lower) computed from historical drifter data in the Adriatic close to the DARTO6 region (red box) (from Veneziani et al., 2006). Notice the hyperbolic point in the mean flow off the Gargano Cape.

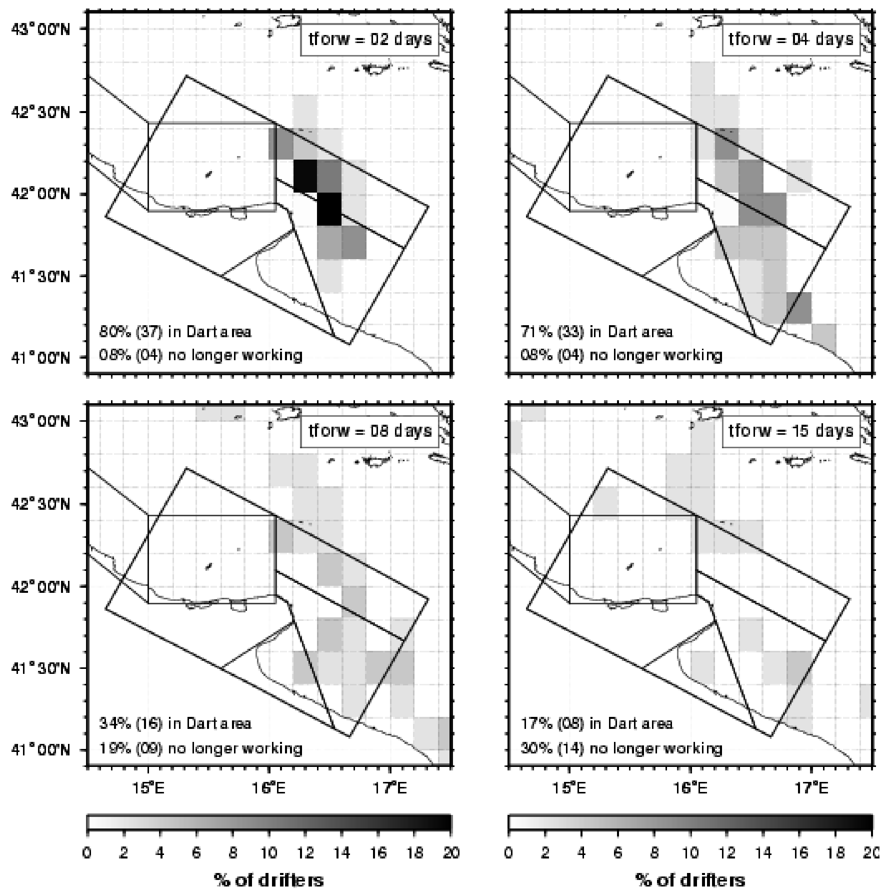

Fig. 5: Maps of drifter concentration (pdf's) at different times computed as percentage of drifters with initial conditions in the region of the hyperbolic point in Fig. 4 (from Veneziani et al., 2006).

IMPACT/APPLICATIONS

The results on Lagrangian data assimilation have a significant impact for operational systems, indicating that position data can be used to significantly and consistently change model velocity fields. These results provide additional value to Argo floats and gliders, which usually provide TS data for assimilation. Using the developed methodologies, also position information can be used as powerful integral velocity information. The results with historical Adriatic drifters indicate that historical data can be advantageously used for planning of Lagrangian experiments, and more in general for statistical prediction of particle motion.

RELATED PROJECTS

1) Statistical and stochastic problems in Ocean Modeling and Prediction, ONR, PI: L.Piterbarg, N00014-99-1-0042.

2) Predictability of particle trajectories in the ocean, ONR, PI: T.M. Özgökmen, N00014-05-1-0095.

3) Mediterranean Forecasting System, EEC, PI: N. Pinardi.

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8) Lagrangian Analysis and Predictability of Coastal and Ocean Dynamics, Eds A. Griffa, A.D. Kirwan, A.J. Mariano, T.M. Ozgokmen and T. Rossby, in press (to be published in March 2007) [in press, refereed].

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