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

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LONG TERM GOALS

The long-term goal of this proposal is the development and application of new methods of investigation for the use of Lagrangian data. Special attention is given to the combined use of data and models, with focus on applications to regional and coastal areas.

OBJECTIVES

The specific scientific objectives of the work done can be summarized as follows:

1) To investigate the use of Lagrangian data for assimilation in Eulerian models.
2) To improve previous results on statistical prediction of particle transport using circulation model and stochastic model results.

APPROACH

The work involves a combination of numerical, analytical and statistical techniques.

WORK COMPLETED

1) The first phase of the assimilation study on Lagrangian data in Eulerian models has been concluded. The results are contained in a paper to be submitted.
2) The study on transport and Lagrangian properties in a regional model of the Sicily Channel has been completed. The results are described in two submitted papers.

RESULTS

The main results, obtained in collaboration with other scientists, can be summarized as follows.

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14. ABSTRACT
The long-term goal of this proposal is the development and application of new methods of investigation for the use of Lagrangian data. Special attention is given to the combined use of data and models, with focus on applications to regional and coastal areas.

15. SUBJECT TERMS

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1) The problem of assimilating Lagrangian data in Eulerian models has been approached, in collaboration with L. Piterbarg (USC), introducing a new formulation which takes directly into account the nature of the observed values, i.e. the drifter positions **x** recorded at time intervals Δt. The difficulty in assimilating **x** stems from the fact that there is a nonlinear relationship, H, between the observed variable, **x**, and the model variable, i.e. the Eulerian velocity **u**, $\mathbf{x}=H(\mathbf{u})$. This problem has been avoided in previous works (e.g. Ishikawa et al., 1996) by treating Lagrangian instruments as moving currentmeters, i.e. by approximating the Eulerian velocity by finite difference of consecutive drifter positions, $\mathbf{u} = \Delta\mathbf{x}/\Delta t$. This approximation is likely to hold for small Δt, but it is certainly not accurate for Δt of the order of the Lagrangian time scale T_L.

In our formulation, the position **x** is directly assimilated using an optimal interpolation scheme (OI). The drifter position is forecasted by the model during the time interval Δt, and the model Eulerian velocity is corrected in order to minimize the distance between forecasted and observed positions (Fig.1). The sensitivity matrix, G=dH/du, entering in the OI formulation, is computed using some simplifying assumptions.

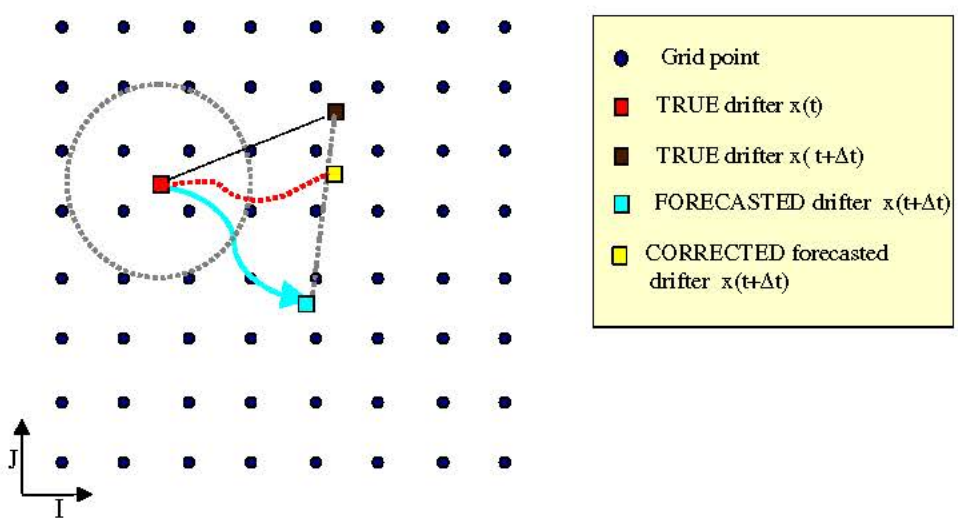

Fig1 Schematic of the position assimilation procedure. The observed drifter positions at time t and $t+\Delta t$, $x(t)$ and $x(t+\Delta t)$, are shown, superimposed on a generic model grid. The model forecast for the drifter path during Δt, is also shown leading to the forecasted position $x_f(t+\Delta t)$. $x(t+\Delta t)$ and $x_f(t+\Delta t)$ are in general different, with difference Δx_f. The model velocity around $x(t)$ is consequently modified, in order to minimize Δx_f.

In order to test the formulation in the simplest possible context, the case of a double-gyre quasi-geostrophic model has been considered. The classical twin experiment approach has been followed. Simulated drifters have been launched in the "truth" and their positions have been assimilated in the "assimilation" run, obtained from a different initial condition than the truth. A "control" run has also been performed, obtained starting from the same initial conditions as the assimilation. Results for a case with 25 drifters initially launched in the energetic region of the jet is shown in Fig.2. As it can be seen, the assimilation is highly effective, showing a significant convergence of the assimilation run toward the truth in less than 3 months. The streamfunction patterns of the solutions are very similar, while the error, computed as rms velocity of the difference, is of the order of 20% (notice that the error in terms of velocity is a much stricter measure than in terms of streamfunction).

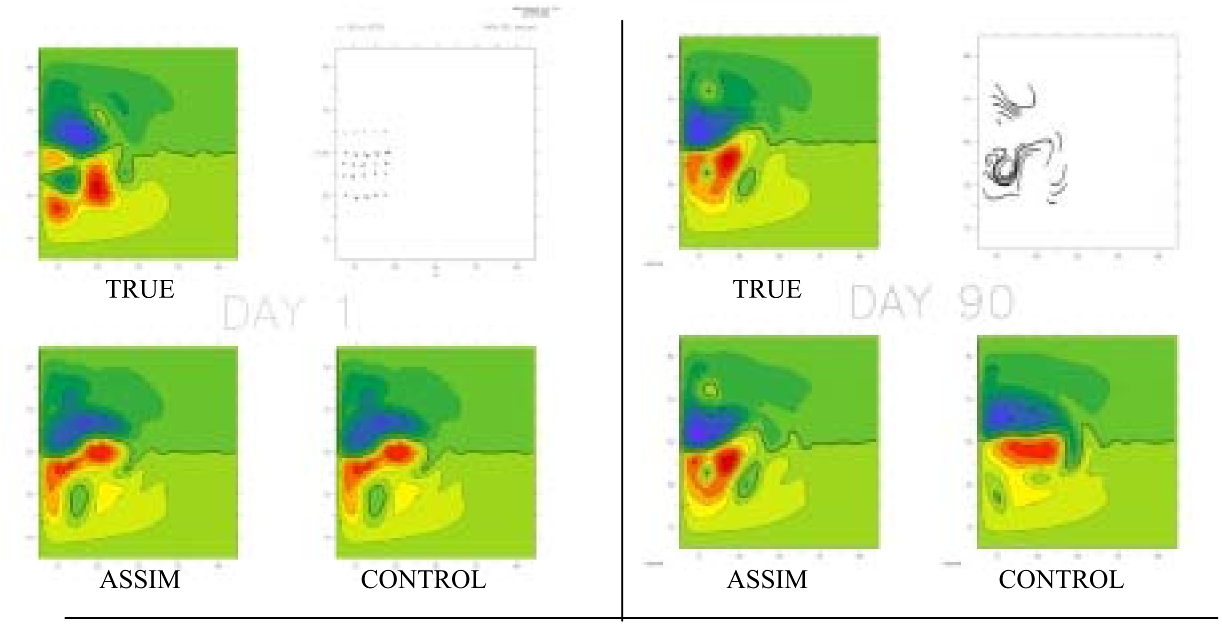

Fig.2 Assimilation results for the case with 25 drifters. The streamfunction initial conditions for truth, assimilation and control are shown in the left hand side of the figure, together with the first day integration of the 25 drifters. Notice that assimilation and control start from the same i.c., distinctively different from the truth. The results at t=90 days (right hand side) show the convergence of the assimilation to the truth, with very similar patterns, while the control maintains completely different. 10 days integration of the drifters at the end of the run are also shown.

A number of sensitivity tests have been performed, varying the forcing, the number and the initial positions of the drifters, and the sampling interval Δt. The results appear robust in a vast range of values for these parameters. As an example, the results obtained varying Δt are shown in Fig.3, for the standard case with 25 drifters , characterized by a Lagrangian time scale T_L=10 days.

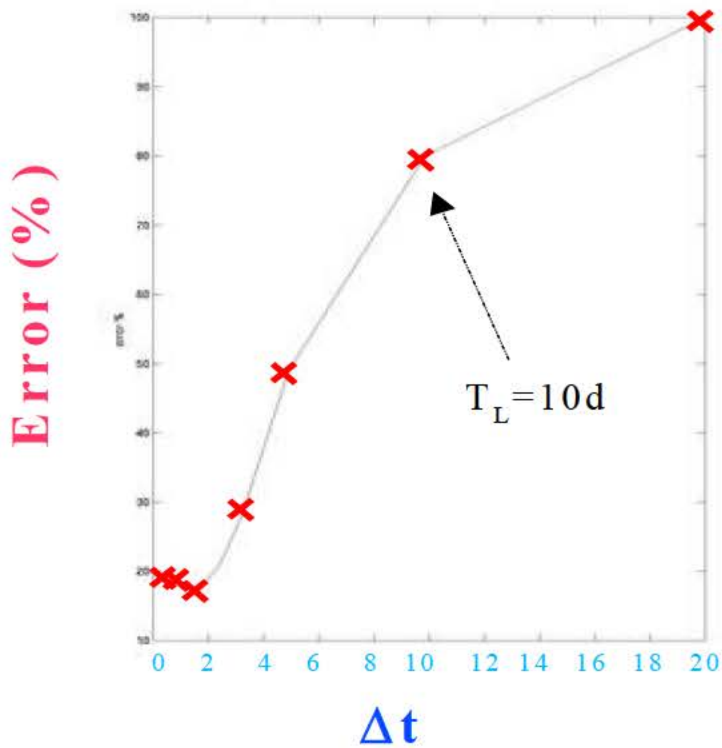

Fig.3 Plot of assimilation error in terms of rms velocity versus sampling interval Δt. Errors maintain around 20% up to Δt=2 days, and then increase to approximately 50% (80%) at Δt=5 (10) days.

The error maintains of the order of 20% up to Δt= 2 days, increasing for higher Δt. For Δt=5, i.e. 1/2 T_L, the error is 50%, but the pattern of the assimilated solution (not shown) is still qualitatively similar to the truth. For $\Delta t = T_L$=10 days, the error is 80%, and the assimilated solution is a mixture between truth and control. These results might provide some guideline on the effectiveness of the assimilation in the real ocean, keeping into account that T_L in the ocean is of the order of 1-3 days at the surface and of the order of 10 days in the subsurface. A comparison with assimilation results obtained using the approximated velocity $\Delta \mathbf{x}/\Delta t$ (Ishikawa et al., 1996) shows that this simplified method is affected by an intrinsic bias and it is significantly less precise than the method using the positions.

2) The study of statistical prediction and particle transport has been carried out in the framework of a regional model of the Sicily Channel, developed in the previous year of the grant (Molcard et al., 2001). The model is forced by remote thermohaline forcing and by large scale wind. Lagrangian particles have been released at the entrance of the Channel, approximately in the same launching region as a set of real drifters deployed by Poulain and Zambianchi during the period 1994-1999 (see http://www.oc.nps.navy.mil). The spaghetti diagram for 80 particles launched in 4 different realizations is shown in Fig.4a. An analysis of particle distribution shows that, even though the particle distribution is initially uniform across the Channel, the probability to find a particle in the next 30-60 days is maximum in the region of the Sicily current (eastern side) while it is minimum in the region of

the Tunisian current (western side). The enhancement of the transport in the Sicily current is due to Channel crossing and particle entrainment, especially from the central region of the Channel, related to both mean flow patterns and to mesoscale variability. The crossing and entrainment occur through two main typical paths, exemplified in Fig.4b. Particles launched on the eastern shelf tends to roughly follow topography without strong meridional variations before being entrained, while particle launched in the deeper western regions show more extensive meridional looping.

A qualitative comparison with the real drifters suggests that the probability distribution of particles is similar, but that the mechanisms of Channel crossing might be different. For the real drifters, in fact, the crossing seems to occur more to the south, involving also the emergence of a "forbidden zone" in the northern part of the Channel close to Sicily, which is absent in the simulations. This is likely to be due to strong upwelling events and associated cyclonic circulations, related to the detailed space and time structure of wind forcing. This result emphasizes the importance of detailed forcing knowledge in regional models.

a **b**

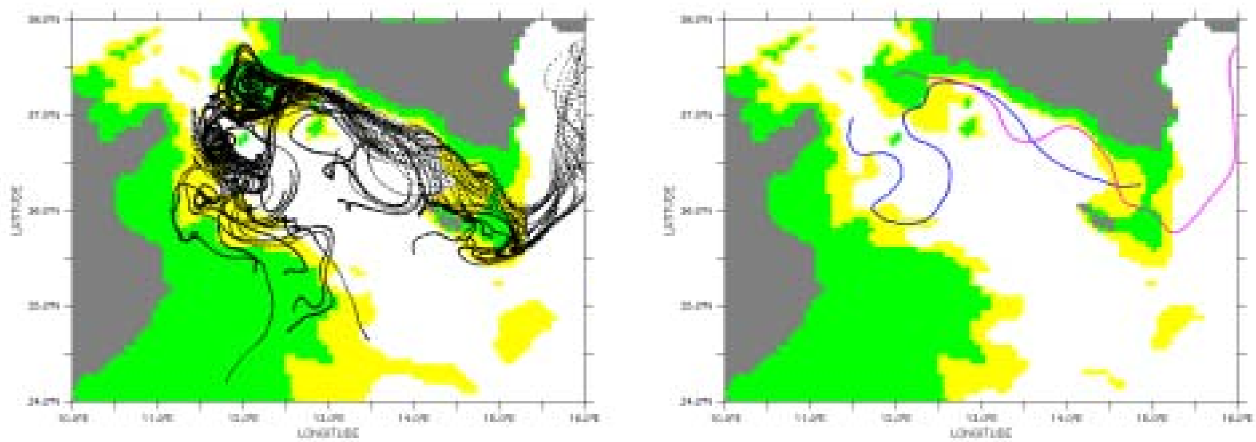

Fig.4 Numerical domain with the 100m and 250m bathymetries (a) spaghetti diagram; (b) two different types of cross channel trajectories.

The possibility to model particle transport and distribution using stochastic models, has also been pursued. In particular, the problem of introducing non Gaussian effects is presently considered. Applications to the Sicily Channel and Adriatic drifter data sets are planned.

IMPACT/APPLICATIONS

The results have the potential to impact current studies for a number of problems. From the methodological point of view, the results indicate the high potential of Lagrangian data for assimilation in Eulerian models and they open a new methodological path for their use. From the point of view of more specific applications to regional Mediterranean studies, the results provide tools for the study of transport and the evaluation of statistical particle predictions.

TRANSITIONS

The Lagrangian assimilation results are planned to be applied and used in the Micom and Hycom primitive equation models in collaboration with L. Piterbarg, A. Mariano (RSMAS), M. Chin (RSMAS), E. Chassignet (RSMAS).

The transport study in regional areas in the Mediterranean Sea will be carried out in collaboration with P.Poulain (NPS) and E. Zambianchi (IUN, Italy).

RELATED PROJECTS

ONR funded related projects are: "Statistical problems in Ocean Modelling and Prediction", PI L.Piterbarg, and "Predictability of Path Trajectories in the Ocean", PI T. Ozgokmen, co-PIs A Griffa and A. Mariano.

Other related projects are carried out with investigators funded by other agencies such as NSF, NOAA, UE and the European Science Foundation.

Lagrangian data assimilation studies will be performed in collaboration with N. Pinardi (University of Bologna, Italy).

Study of Lagrangian data statistics and stochastic model parameterizations are carried out with E. Chassignet , Z. Garraffo (RSMAS) and A. Provenzale (CNR, Italy).

Study of mixing mechanisms and parameter estimation will be performed in collaboration with L. Piterbarg, E. Zambianchi and G. Buffoni (ENEA, Italy).

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