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

Annalisa Griffa
Division of Meteorology and Physical Oceanography
Rosenstiel School of Marine and Atmospheric Science
4600 Rickenbacker Causeway, Miami, Florida 33149
phone: 305 421 4816, fax: 305 421 4696, email: agriffa@rsmas.miami.edu

Tamay M. Özgökmen
phone: 305 421 4053, fax: 305 421 4696, email: tozgokmen@rsmas.miami.edu

Award: # N00014-05-1-0094
http://www.rsmas.miami.edu/LAPCOD/research/

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 and other emerging in-situ and remote instruments (drifters, gliders, HF radar and satellite) that provide information on upper ocean advection. Special attention is given to the development of new techniques for data fusion and assimilation of data in Eulerian numerical 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 new techniques for assimilation of Lagrangian data and of other tracers in ocean circulation models.

2) To develop methods to improve prediction of upper ocean advection in coastal areas.

3) To apply and test the methodologies using recently collected data sets in the framework of Marine Rapid Environment Assessment (MREA) experiments.

APPROACH

The work involves a combination of analytical, numerical and data processing techniques. The method development has been carried out in collaboration with L. Piterbarg (USC), A. Molcard (LSEET Universite' of Toulon), A. Poje (CUNY), V. Taillandier (CNRS, Paris)

WORK COMPLETED

1) Final revision and publication of a paper on a coastal application of Lagrangian data assimilation using drifter data (Taillandier et al., 2008)

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE	2. REPORT TYPE	3. DATES COVERED
30 SEP 2008	**Annual**	**00-00-2008 to 00-00-2008**

4. TITLE AND SUBTITLE
Lagrangian Turbulence And Transport In Semi-Enclosed Basins And Coastal Regions

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Rosenstiel School of Marine and Atmospheric Science,Division of Meteorology and Physical Oceanography,4600 Rickenbacker Causeway,Miami,FL,33149

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

10. SPONSOR/MONITOR'S ACRONYM(S)

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES
code 1 only

14. ABSTRACT
The long-term goal of this project is the development and application of new methods of investigation for the use of Lagrangian data and other emerging in-situ and remote instruments (drifters, gliders, HF radar and satellite) that provide information on upper ocean advection. Special attention is given to the development of new techniques for data fusion and assimilation of data in Eulerian numerical models.

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			
unclassified	**unclassified**	**unclassified**	**Same as Report (SAR)**	**10**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

2) Development and testing of a method for tracer data assimilation in collaboration with L. Piterbarg.

3) Participation in 2007-2008 Marine Rapid Environmental Assessment (MREA) experiments in a coastal area of the Mediterranean Sea (Ligurian Sea, Gulf of La Spezia). Indications on drifter release strategy have been provided.

4) Publication of a paper on particle spreading based on MREA results using drifters and HF radar data (Molcard et al., 2008), in collaboration with A. Molcard and P.Poulain.

5) Publication of a paper on coastal dynamics in presence of a cape (Magaldi et al., 2008)

RESULTS

i) Assimilation and velocity estimation from Lagrangian and tracer data.

The assimilation methods developed during the present and previous grant period for Lagrangian data are based on correcting the model velocity field by minimizing the difference between the observed positions of Lagrangian instruments and the model forecasted positions from numerical trajectories. In other words, the Lagrangian nature of the data is taken into account introducing an appropriate observational operator based on particle advection.

Applications of the method, based on a variational approach that optimally blends model outputs and Lagrangian data, have been performed in a coastal area of the central Adriatic Sea (Taillandier et al., 2008), a sub-basin of the Mediterranean Sea. Data from surface drifters have been used together with outputs from a state of the art model (ROMS) during the experiment DOLCEVITA in 2002. The area is especially challenging since it is characterized by a swift boundary current (Western Adriatic Current, WAC) flowing along the shelf with high shear and by an interior flow with high variability and intense mesoscale activity. The assimilation has been applied for a period of 45 days between October 1 and November 15 2002, when there is good drifter coverage of the WAC in the vicinity of the Gargano Cape, providing a time series of corrected velocities (estimates). The results show that the assimilation is quite effective. The error on the particle prediction is significantly reduced and the estimates of residence times and export rates from the WAC appear significantly impacted by the analysis, indicating an improvement over the first guess with respect to the measured quantities.

An approach conceptually similar to the one used for the Lagrangian data assimilation, has been recently developed also for other data that provide advection information, such as tracer data from satellite and glider data. The approach takes into account the appropriate observational operators, i.e. the fact that the tracer evolution can be described as a forced advection-diffusion equation and glider positions can be modeled as a combination of forced drift and advection. Preliminary work on the tracer data has been performed in collaboration with L. Piterbarg. The method, based on "confidence regions" provides velocity estimates by combining observation of a continuously distributed tracer and a circulation model output, and is presently tested using the twin experiment approach with realistic velocity fields from a Mediterranean OPA model. The area of interest corresponds to

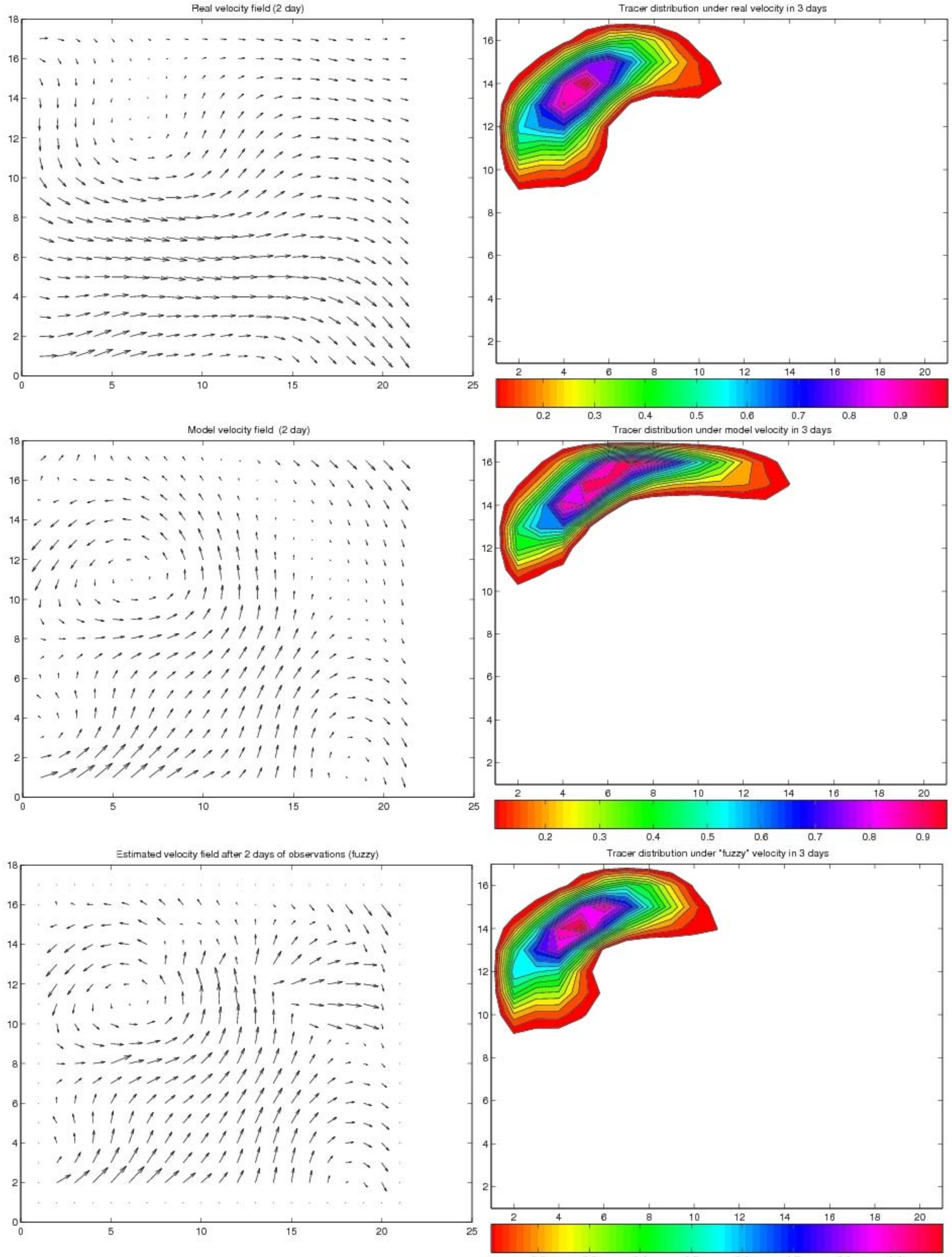

Figure 1: Example of velocity correction using consecutive information from tracer. The left panels show snapshots of velocity, while the right panels show the tracer distribution after three days, for the real (upper), model (middle) and corrected (lower) fields. The corrected fields are significantly more similar to the real ones than the model ones.

the 2007-2008 MREA experiment in the Ligurian Sea, where in situ and satellite data have been collected and are available for future applications and real data testing.

An example of results using the twin experiments is shown in Fig.1. A tracer is released from a gaussian initial condition, and let free to be advected by the ``real'' velocity field for three days. The tracer distribution is observed daily and the model velocity field is corrected using consecutive tracer information. Snapshots of velocities are shown in Fig.1 (left panels), for the real (upper), model (middle) and corrected (lower) fields, while the right panels show the tracer distribution after three days. The corrected fields are significantly more similar to the real ones than the model ones.
The method can be envisioned to be used for satellite visible or SAR data, for instance in the case of oil spill detection, or also for thermal data, provided that the forcing term of the advection-diffusion equation is sufficiently known. We are presently working on the error analysis, starting from theoretical estimates provided by Piterbarg (2008), and improving them using realistic twin experiment settings.

ii) Participation in MREA experiments

In June 2007, we have participated in a Marine Rapid Environmental Assessment (MREA) experiment, in collaboration with NURC-NATO, NRL, OGS, CNR, INGV (Italy) and LSEET-University of Toulone (France). The experiment called LASIE (Ligurian Air Sea Interaction Experiment) included a coastal component focused on the Gulf of La Spezia (POET, Predictive Oceanographic Environmental Trial). A further MREA experiment is presently underway (September-October 2008) in the Ligurian Sea, funded by ONR and NASA. The experiment is mostly targeted to optical measurements in the frontal area of the Ligurian current, but it also has a significant physical oceanography component. In particular, a glider fleet is operating during the experiment.

During the experiments, a number of drifters have been and will be released in clusters of 3-5 units, with average initial distance of approximately 1 km or less. We have participated in the planning and in the real time strategy for drifter launching. The launching in tight clusters is very useful for the ODDAS-DRI purposes, since it allows to investigate the properties of drifting arrays and of their dispersion. In particular, since the initial distance between drifters is small, it provides information on processes of dispersion at various scales, from submesoscale to mesoscale and up. Two main areas have been chosen for successive cluster launches. One area is in the open Ligurian Sea, next to a moored buoy (ODAS buoy) with meteo-marine sensors, while the other area is much closer to the coast, in the Gulf of La Spezia. In this way, the effects of coastal dynamics and smaller scale processes can be specifically investigated.

We are also presently contributing to the ongoing MREA, in collaboration with NRL providing diagnostics based on the NRL NCOM model forecasts. In particular, we provide maps of Finite Size Layapunov Exponents (FSLE) that give direct information on regions of high particle spreading and concentration, therefore indicating fronts and barrier structures. These information *can be of interest for glider navigation,* signalling possible critical areas and/or interesting sampling regions.

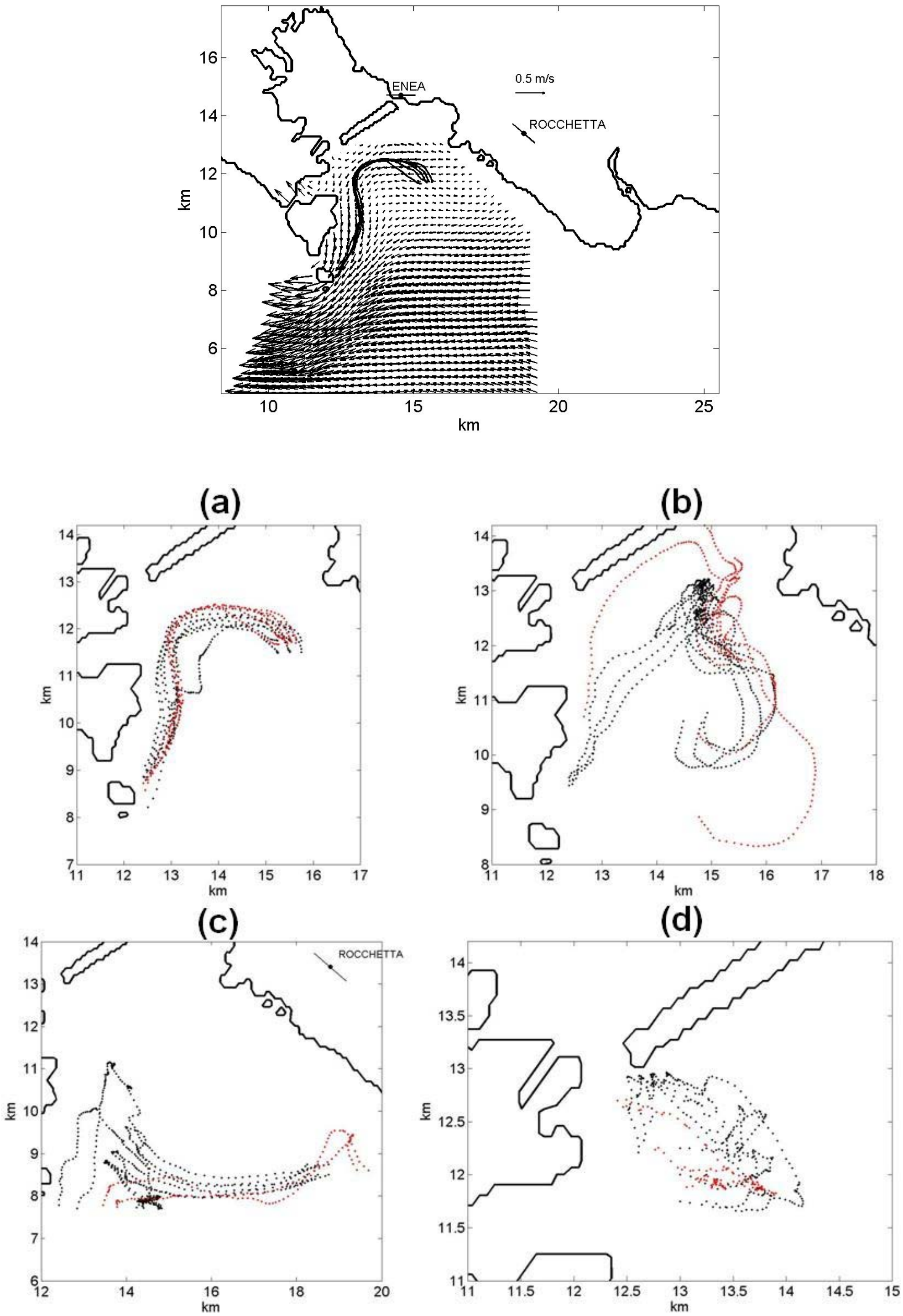

Figure 2: Example of snapshot of VHF radar velocity in the Gulf of La Spezia with superimposed drifter trajectories (upper panel). Comparison between trajectories of drifters (red dots) and synthetic trajectories computed from VHF radar (black dots) for four clusters launched in the Gulf. In all cases the VHF radar based trajectories are able to capture the cluster spreading. a) and b) correspond to launches from the same point two days apart (June 18 and 20) showing completely different dispersion behaviours

The participation to the MREA experiments has been very fruitful in many ways, providing us with a great opportunity to test methodologies and allowing collaboration with a number of investigators and institutions. They include NURC-NATO (Michel Rixen, J. Texeira, Alberto Alvarez), NRL (P. Martin, R. Allard, G. Peggion, E. Coelho), OGS (P.Poulain), University of Toulon (A.Molcard). In particular, the collaboration with A. Molcard, is sponsored by ONR Global, and she has already visited RSMAS in June 2007 to work on data analysis and planning for the oncoming experiments. The visit was very successful, and three more visits are planned in the next two years. Results from the analysis of the MREA07 data, performed in collaboration with A. Molcard are presented in *iii).*

iii) Particle spreading and analysis of drifters and HF radar data

During the MREA07 coastal component POET experiment, a VHF Radar WERA data set (with resolution of 250 m) has been collected in the period 15-30 June by A. Molcard (LSEET-University of Toulone) in the Gulf of La Spezia (Fig.2). The data have been processed and analyzed together with coastal surface drifter data collected by P.Poulain (OGS) (Molcard et al., 2008). The drifters have been launched in clusters of 6-3 units, aimed at investigating the significant time and space variability of flow dispersal. In particular, two clusters launched in the same location two days apart (Fig.2 a,b) show strikingly different patterns of evolution. The first cluster is swiftly advected with little particle spreading, while the second cluster divides into two branches with significant drifter spreading. In-situ drifter trajectories have been compared with synthetic trajectories computed from VHF radar fields. In all cases, the spreading patterns of the in-situ clusters are correctly reproduced by the synthetic clusters, including the dramatic difference between the two launches from the same location (Fig,2). The positive results are likely to be due to a combination of factors and primarily to the high resolution of the radar fields, and they confirm that *radar data are well suited for the study of coastal flows in limited areas with complex patterns of velocity and transport*

The dynamical reasons for the high variability in particle dispersion patterns is presently under investigation, considering the effects of local and large scale dynamics. In order to better characterize the transport structures inside the Gulf we computed the Finite Size Lyapunov Exponents (FSLEs) based on the radar velocity field. FSLEs are a diagnostics indicating areas of highest dispersion (blue-turquoise lines in Fig.3) and concentration (red-yellow lines). These lines, or ridges, separate different Lagrangian structures and are expected to act as particle barriers. During the first launch, occurred in June 18 and characterized by a tight cluster evolution (fig. 2a), the FSLE field is characterized by dominant red-yellow lines (Fig.3, upper panel) that propagate and separate the Gulf interior from the open sea. Visualization of the time evolution of drifter positions superimposed on the FSLE fields shows that the *drifters indeed do not cross the red-yellow lines and exit the Gulf flowing along them.* The situation is very different during the second launch on June 20, characterized by high cluster spreading (Fig.2b). In this case, the FSLE field (Fig.3 lower panel) does not show major ridges or barriers. A hyperbolic point can be detected inside the Gulf, indicated by the crossing of blue and red lines. Indeed, the *drifter trajectories appear to spread at that point, following the out-flowing red lines in the two southward and northward directions.*

In order to investigate possible connections with the large scale dynamics, we considered results from NCOM model simulations in the Ligurian Sea performed by G. Peggion during the MREA07 experiment. The first launch of June 18 occurred during a south-eastern wind (Scirocco) episode, that reinforces the cyclonic boundary current, as shown in Fig.4 (upper panel). This is expected to impact the circulation inside the Gulf, since the boundary current partially penetrates the Gulf as a strong and coherent jet, isolating the inner part. During the second launch on June 20, the wind was weak,

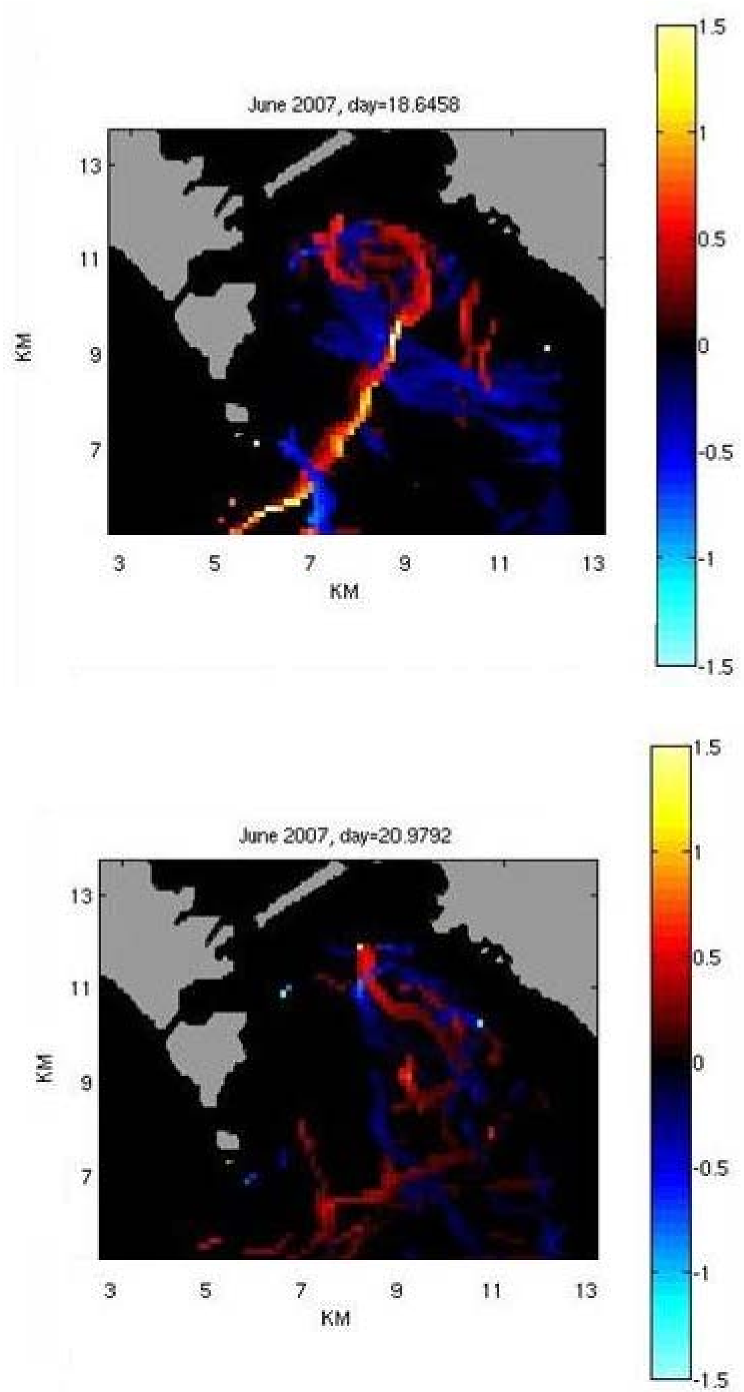

Figure 3: Examples of FSLE fields based on VHF radar data in the Gulf of La Spezia. Red-yellow (blue-turquoise) lines indicate regions of high concentration (dispersion). Upper (lower) panel corresponds to June 18 (20), when the tight (high spread) cluster in Fig.2a (2b) was launched. A dominant ridge or barrier (red-yellow line) is present in the upper panel at the entrance of the Gulf, while in the lower panel the main feature is a hyperbolic point inside the Gulf determined by the intersection of blue and red lines.

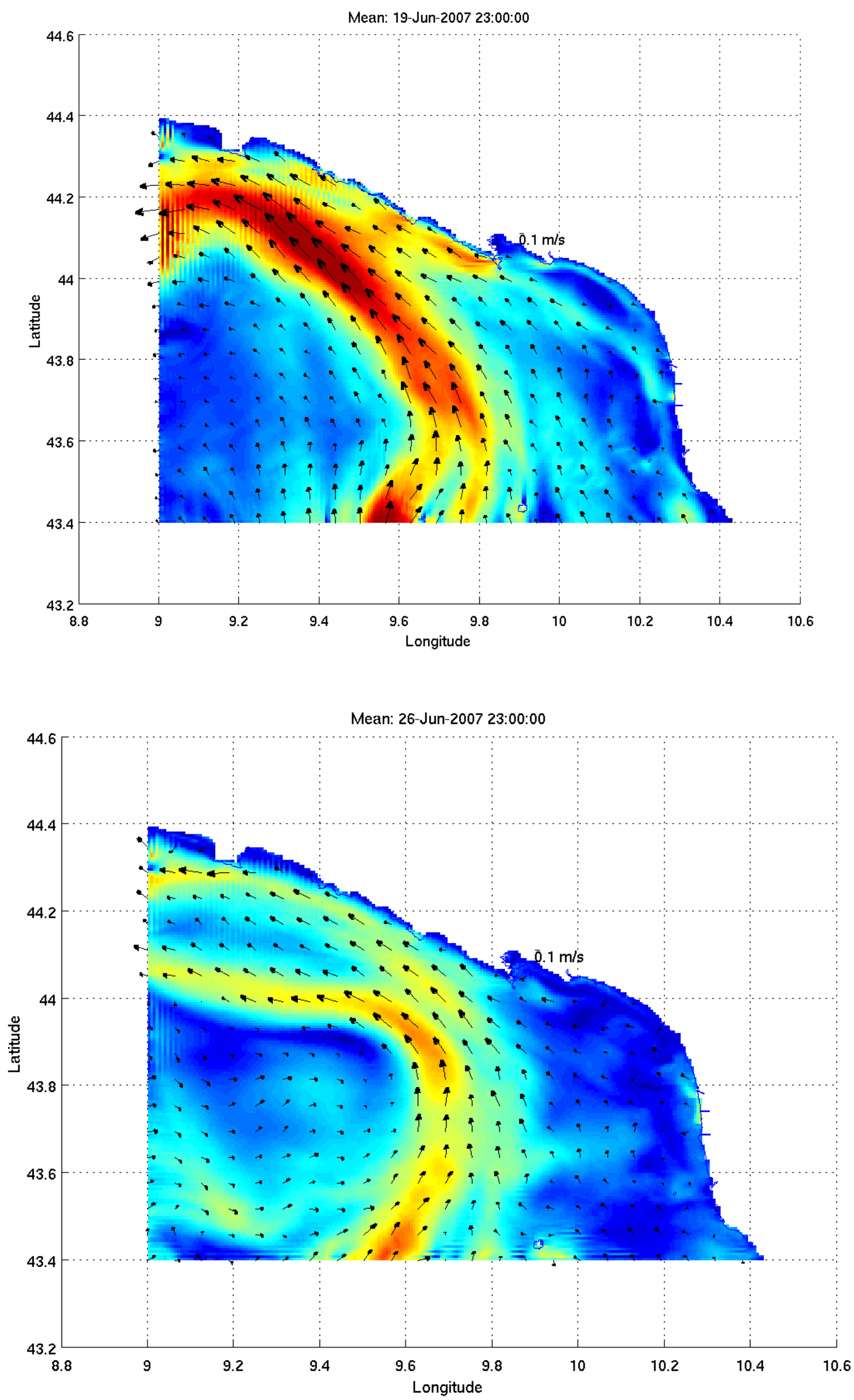

Figure 4: Velocity fields in the Ligurian Sea during the MREA07 experiment from NRL NCOM model (courtesy of G. Peggion). The upper panel shows the response to Scirocco (South-eastern wind) wind, with intensified boundary current, while the lower panel shows the response to Libeccio (South-western) wind, with weaker and less organized boundary current.

transitioning from the Scirocco event of June 18-19 to a Libeccio (South western) event occurring after June 22 (Fig.4, lower panel). During the transition, the Ligurian boundary current is less strong and organized, and this condition is likely to lead to a less coherent circulation also inside the Gulf, that becomes more directly influenced by local dynamics. The large scale dynamics and its impact on coastal processes are under further investigation, using also the MREA08 results where FSLEs are presently computed in real time.

IMPACT/APPLICATIONS

The results on Lagrangian data assimilation have a significant impact for operational systems and they provide additional value to drifters and gliders especially for coastal applications. The results with FSLEs based on VHF radar velocities indicate that the FSLE technique is valid also in presence of small, highly variable structures.

RELATED PROJECTS

Predictability of particle trajectories in the ocean, ONR, PI: T.M. Özgökmen, N00014-05-1-0095.
Statistical and stochastic problems in Ocean Modeling and Prediction, ONR, PI: L.Piterbarg, N00014-99-1-0042.

REFERENCES

Taillandier V., A. Griffa, P.M. Poulain, R. Signell, J. Chiggiato, S. Carniel, 2008: Variational analysis of drifter positions and model outputs for the reconstruction of surface currents in the Central Adriatic during fall 2002. *Geophys. Res*. 113, C04004, doi.1029/2007/JC004148

L.I. Piterbarg, 2008: A simple method for computing velocities from Tracer observations and a model output. *Appl. Math. Modell*, submitted

Molcard A., P.M. Poulain, P. Forget, A. Griffa, Y. Barbin, J. Gaggelli, J.C. De Maistre, M. Rixen, 2008: Comparison between VHF radar observations and data from drifter clusters in the Gulf of La Spezia (Mediterranean Sea). *J. Mar. Sys*., in press

PUBLICATIONS (2007-2008)

Veneziani M., A. Griffa and P.M. Poulain, 2007: Historical drifter data and statistical prediction of particle motion: a case study in the Adriatic Sea,*J. Atmos. Ocean Tech*, 24, 235-254 [published, refereed].

Haza, A., L.I. Piterbarg, P. Martin, T.M. Ozgokmen, and A. Griffa, 2007: A Lagrangian subgrid-scale model and application for transport improvementin the Adriatic Sea using NCOM. *Ocean Modelling*, 17, 68-91 [published, refereed].

Haza, A., A. Griffa, P. Martin, A. Molcard, T.M. Ozgokmen, A.C. Poje, R. Barbanti, J. Book, P.M. Poulain, M. Rixen, and P. Zanasca, 2007: Model-based directed drifter launches in the Adriatic Sea: Results from the DART experiment. *Geophys. Res. Letters*, 34, L10605,doi:10.1029/2007GL029634 [published, refereed].

Piterbarg, L.I., T.M. Özgökmen, A. Griffa, and A.J. Mariano, 2007: Predictability of Lagrangian motion in the upper ocean. In: Lagrangian Analysis and Prediction of Coastal and Ocean Dynamics, Eds: A. Griffa, A.D. Kirwan, A.J. Mariano, T.M. Özgökmen and T. Rossby, Cambridge University Press, 500 pg. [published, refereed].

Molcard, A,T.M. . Özgökmen , A. Griffa, L. Piterbarg, T.M. Chin, 2007: Lagrangian data assimilation in ocean general circulation models. In: Lagrangian Analysis Predictability of Coastal and Ocean Dynamics, Eds A. Griffa, A.D. Kirwan, A.J. Mariano, T.M. Özgökmen and T. Rossby , Cambridge University Press, 500 pg. [published, refereed].

Griffa, A., A.D. Kirwan, A.J. Mariano, T.M. Özgökmen and T. Rossby, 2007: Lagrangian Analysis and Predictability of Coastal and Ocean Dynamics, Cambridge University Press, 500 pg. [published, refereed].

Taillandier V., A. Griffa, P.M. Poulain, R. Signell, J. Chiggiato, S. Carniel, 2008: Variational analysis of drifter positions and model outputs for the reconstruction of surface currents in the Central Adriatic during fall 2002. Submitted to *J. Geophys. Res*. 113, C04004, doi.1029/2007/JC004148 [published, refereed].

Magaldi, M., T.M. Ozgokmen, A. Griffa, E. Chassignet, M. Iskandarani and H. Peters, 2008: Turbulent flow regimes behind a coastal cape in a stratified and rotating environment. *Ocean Modelling*, 25, 65-82 [published, refereed].

Molcard A., P.M. Poulain, P. Forget, A. Griffa, Y. Barbin, J. Gaggelli, J.C. De Maistre, M. Rixen. 2008. Comparison between VHF radar observations and data from drifter clusters in the Gulf of La Spezia (Mediterranean Sea) *J. Mar. Sys.* [in press, refereed].