Predictability of Particle Trajectories in the Ocean

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LONG TERM GOALS

The long term goal of this project is to determine optimal sampling strategies for drifting buoys, in order to enhance prediction of particle motion in the ocean, with potential applications to ecological, search and rescue, the floating mine problems, and design of observing systems.

OBJECTIVES

The specific scientific objective of the work done has been to determine the effectiveness of using in-situ Lagrangian measurements and data assimilation techniques in improving the prediction of particle trajectories.

APPROACH

The work is based primarily on simple probabilistic models of particle motion and data assimilation strategies. It also involves the use of OGCMs and processing of oceanic data.

WORK COMPLETED

A comprehensive testing and validation of a new method developed to address the problem of prediction of Lagrangian trajectories has been completed. The underlying concept relies on the fact the Lagrangian data are especially suitable for practical applications since they move with the currents and they can be easily released in situ. This method employs a data assimilation scheme, via a simple Kalman filtering, to incorporate information from nearby buoys in order to estimate the turbulent flow characteristics and to improve the prediction of particle trajectories. This method has been initially developed using synthetic drifters released in the oceanic flow field generated by an OGCM, and then applied to real surface drifters in the Adriatic Sea and WOCE drifter clusters in the Tropical Pacific Ocean, leading to 3 papers (Ozgokmen et al., 2000a; Castellari et al., 2000; Ozgokmen et al., 2000b).

RESULTS

The main results can be summarized as follows:

1) To test the new prediction scheme with real drifter data, predictability of Lagrangian particle trajectories in the Adriatic Sea (a semi-enclosed sub-basin of the Mediterranean Sea) is investigated using three clusters consisting of 5-7 drifters each over a period of 1-2 weeks.

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The results are described using the data density N_R defined as the number of drifters within a distance on the order of the Rossby radius of deformation from the particle to be predicted. The clusters are inherently different with respect to this characteristic property with values ranging from $N_R < 0.5$ to $N_R > 2.0$ over the analysis period, depending on the initial launch pattern of the clusters and the dispersion processes. The results indicate that during the period when $N_R > 1$, the assimilation of surrounding drifter data leads to an improvement of predicted trajectories with respect to those based on advecting the drifters with the mean flow. When $N_R < 1$, the drifters are too far apart to exhibit correlated motion, and the assimilation method does not lead to an improvement. The effects of uncertainties in the mean flow field and initial release position are quantified. The results are also compared to simple estimates of particle location by calculating the center of mass of the cluster, which is seen to be useful for tightly-released clusters.

2) To complement the OCGM and small-scale application (the Adriatic Sea) studies of the new method, predictability of particle motion in the ocean over a time scale of one week is studied using 3 clusters of buoys consisting of 5-10 drifters deployed in the tropical Pacific Ocean. The analysis is conducted by using three techniques with increasing complexity: the center of mass of the cluster, advection by climatological currents, and the data assimilation technique, which is improved to assimilate both velocity and position data from the surrounding drifters into a Gauss-Markov model for particle motion.

The results from this study (see also Figures 1 and 2) indicate that cluster predictability can be characterized using the data density N_d, defined as the number of drifters over an area scaled by the mean diameter of the cluster. The data density N_d decreases along the drifter trajectories due to the tendency of particles to disperse by turbulent fluid motion. In the first regime, which corresponds to the period after the release of drifters in a tight cluster when $N_d >> 1$ drifter/degree^2, the center of mass and the data assimilation methods perform nearly equally well, and both methods yield very accurate predictions of drifter positions with rms prediction errors less than 15 km up to 7 days. When a cluster starts to disperse, i.e., in the regime where N_d is approximately 1 drifter/degree^2, the data assimilation technique is the only method that gives accurate results. Finally, when $N_d << 1$ drifter/degree^2, no method investigated in this study is found to be effective. It is also found that advection by the mean flow field is not a good indicator of drifter motion. Uncertainties in the knowledge of initial release positions and the frequency of data assimilation are shown to have a strong impact on the prediction accuracy.

IMPACT/APPLICATIONS

The investigation of the predictability of particle motion is an important area of study, with a number of potential practical applications at very different scales, including searching for persons or valuable objects lost at sea, tracking floating mines, ecological problems such as the spreading of pollutants or fish larvae, and design of observing systems.

The PIs of this project are organizing a scientific meeting called "Lagrangian Analysis and Predictability of Coastal and Oceanic Dynamics - LAPCOD", that is funded by this grant and will take place in Italy in October 2-6, 2000 (http://www.rsmas.miami.edu/LAPCOD). The purpose of the LAPCOD meeting is to conduct a review of Lagrangian data, present new results on nonlinear aspects of Lagrangian dynamics, and to accelerate future development in predictability and multi-disciplinary aspects, by bringing together different research communities and different analysis. Workshop participants, totaling 80 scientists, include experimentalists and theoreticians involved in data analysis and model development, as well as predictability experts (not necessarily all oceanographers), biologists and ecologists using Lagrangian instruments and approaches.

TRANSITIONS

Employment of other data, such as in-situ wind forcing from US Navy Operational Global Atmospheric Prediction System (NOGAPS), is being investigated.

A new algorithm for short-term prediction (2-3 days) is being developed with L. I. Piterbarg (University of Southern California) for the purpose of addressing the question of optimal sampling strategy and periodic replenishment of drifters.

RELATED PROJECTS

Lagrangian turbulence and transport in semi-enclosed basins and coastal regions. PIs: A. Griffa, T. M. Ozgokmen.

Statistical Problems in Ocean Modeling and Prediction. PI: L.I. Piterbarg.

PUBLICATIONS (1999-2000)

Ozgokmen, T. M., A. Griffa, L. I. Piterbarg, and A. J. Mariano, 1999: Predictability of trajectories in the ocean and Lagrangian data assimilation. International Liege Colloquium on Ocean Hydrodynamics.

Castellari S., A. Griffa, T. M. Ozgokmen, and P.-M. Poulain, 1999: Prediction of particle trajectories in the Adriatic Sea using Lagrangian data assimilation. International Liege Colloquium on Ocean Hydrodynamics.

Ozgokmen, T.M., A.J. Mariano, A. Griffa and L. Piterbarg, 2000: Predictability analysis of drifter clusters in the tropical Pacific Ocean. EOS Trans. AGU, OS11F.

Ozgokmen, T. M., A. Griffa, L. I. Piterbarg, and A. J. Mariano, 2000a: On the predictability of the Lagrangian trajectories in the ocean. J. Atmos. Ocean. Tech., 17/3, 366-383.

Castellari, S., A. Griffa, T. M. Ozgokmen and P.-M. Poulain, 2000: Prediction of particle trajectories in the Adriatic Sea using Lagrangian data assimilation. J. Mar. Sys., revised.

Ozgokmen, T. M., L. I. Piterbarg, A. J. Mariano, and E. H. Ryan, 2000b: Predictability of drifter trajectories in the Tropical Pacific Ocean. Submitted to J. Phys. Oceanogr.

Molchard, A., L. Gervasio, A. Griffa, G. P. Gasparini, L. Mortier, and T. M. Ozgokmen, 2000: Numerical investigation of the Sicily Channel dynamics: density currents and water mass advection. Submitted to J. Phys. Oceanogr.

Ozgokmen, T. M., L. I. Piterbarg, A. J. Mariano, and E. H. Ryan, 2000: Predictability of drifter trajectories in the Tropical Pacific Ocean. Lagrangian Analysis and Predictability of Coastal and Oceanic Dynamics meeting.

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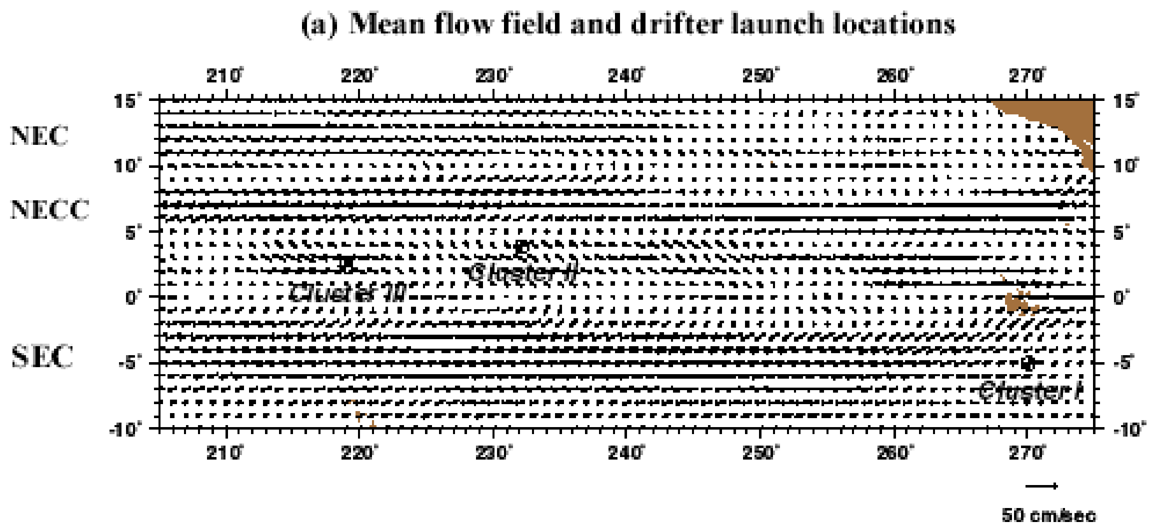

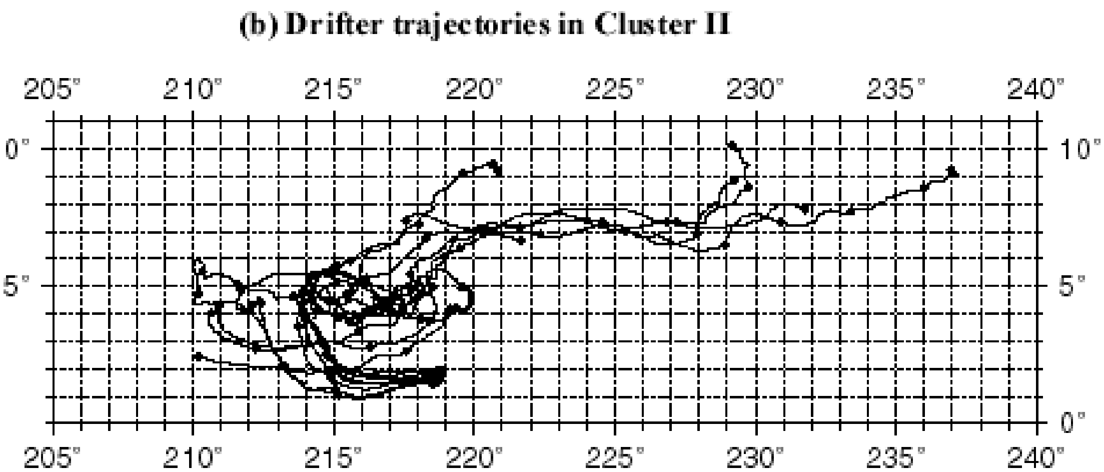

Figure 1: (a) Mean flow field in the Tropical Pacific Ocean, calculated from 1988-1996 WOCE drifter data set. The main current system emerge clearly: North Equatorial Current (NEC), North Equatorial Counter Current (NECC) and South Equatorial Current (SEC). Initial locations of the drifter clusters are marked. (b) Trajectories of drifters in one of the clusters.

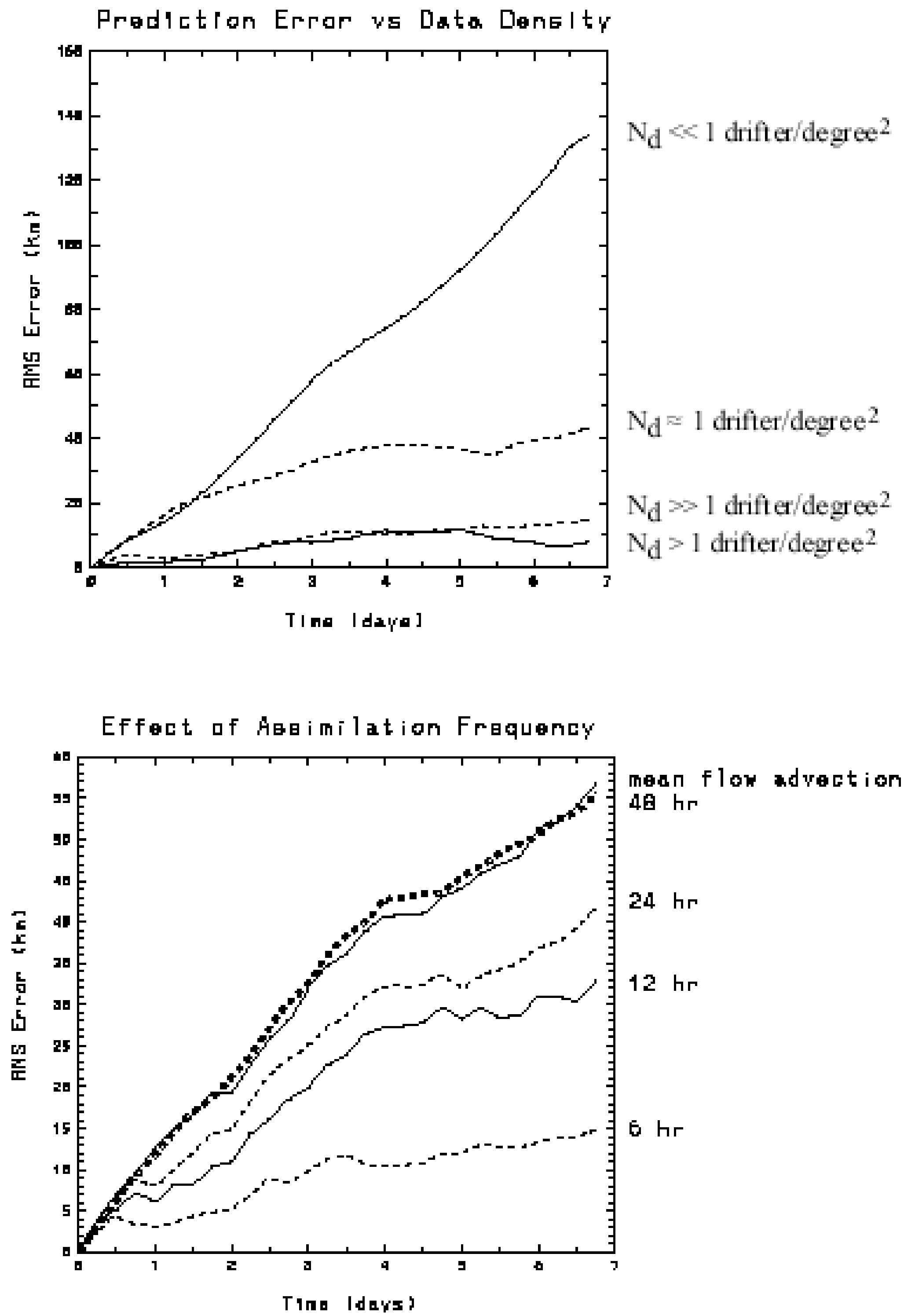

Figure 2: Rapid increase in the accuracy of the prediction method as the drifter data density (upper panel) and frequency of data assimilation (lower panel) are increased.