

# **New Approaches to Data Assimilation and Transport Processes As Hybrid of Eulerian and Lagrangian Methods**

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## **LONG-TERM GOAL**

My long term goal is to make substantial contributions to enhancement of forecast skills concerning the oceans and atmosphere, by deepening our knowledge for the nature of predictability. I place my emphasis on transition mechanism between dynamical regimes of planetary flows and coherent structures from both Eulerian and Lagrangian points of view.

## **OBJECTIVES**

I wish to develop theoretical frameworks for enhancement of predictability based on dynamical systems theory. To help enhance predictability of sudden and severe events, I wish to investigate transition mechanisms between dynamical regimes. I also wish to throw a bridge between Eulerian and Lagrangian viewpoints and explore impact of severe events on large-scale transport in planetary flows. Knowledge obtained by these predictability studies will lead to a design of comprehensive ensemble-forecast systems and data-adaptive observing systems.

## **APPROACH**

To achieve my goals, I plan to develop new theories and improve already existing methodologies so that they can be combined systematically. I start from assessing and extending individual elements of the theoretical framework, and develop new theories to fill the gaps between them as necessary. My approach involves: identification and detection of the predictability elements, Eulerian and Lagrangian descriptions of the probability density function evolution, treatment of nonlinearity as well as additive and multiplicative stochasticity in data assimilation systems. To improve forecast skills for severe and sudden events, I investigate role played by stochastic noises. Severe events can be viewed as rare extreme bursts and therefore may be related to stochastic noises whose probability distribution has heavy tail. I construct a new innovative methodology for data assimilation systems subject to dynamical and observational noises with heavy-tail distributions. To explore impact of transient flow dynamics on large-scale transport, I combine geometrical approach of dynamical systems theory and spatio-temporal data analysis technique.

# Report Documentation Page

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## **WORK COMPLETED**

During October 2001 to September 2002, my focus was on development of new data assimilation and prediction systems and formulation of new transport methods.

An innovative method for direct assimilation of Lagrangian data in meteorology and oceanography has been formulated based on the extended Kalman filter (Ide, Kuznetsov and Jones 2002a; Kuznetsov, Ide and Jones 2002). The method has been applied to the point vortex systems.

To study predictability concerning transition from oscillatory to singular behavior, an idealized, highly-nonlinear dynamical system has been developed (Ide and Sornette 2002, Sornette and Ide 2002). The model is based on interplay between restoring force and hysteresis in inertia, which can be found in many physical systems. A new method to identify indicators of sudden transition has been presented

A new transport theory (TIME: transport induced by mean-eddy interaction) has been formulated to estimate transport induced by the anomaly in the large-scale atmosphere and ocean flows (Ide and Wiggins 2002a). It has been extended to identify signature and analyze role of variability (Ide and Wiggins 2002b).

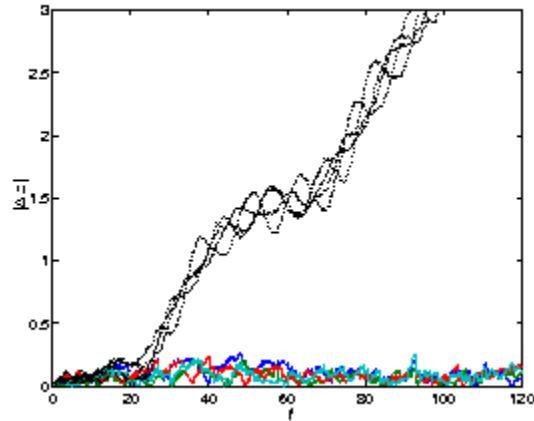
A comprehensive study to analyze transport in the Monterey bay surface flow has been pursued. It requires a comprehensive framework that combines observations, data analysis, modeling, dynamical and statistical systems theory for transport.

A new aspect for computing the stable and unstable manifolds of hyperbolic trajectories of two-dimensional aperiodically time-dependent velocity fields has been studied (Mancho et al. 2002). A skillful and practical numerical method has been presented.

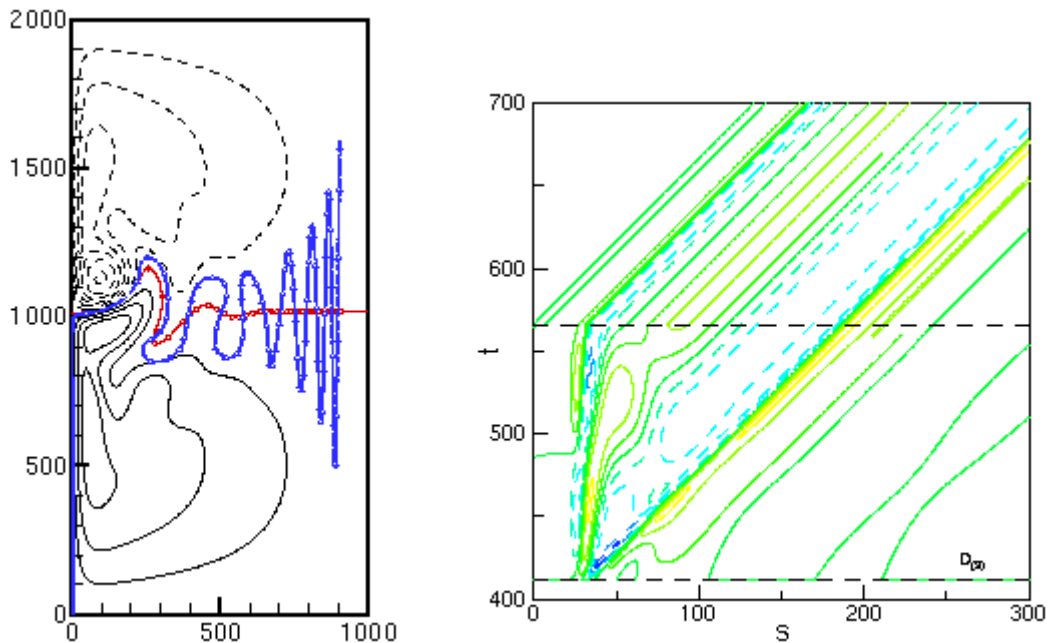
## **RESULTS**

The new Lagrangian data assimilation system augments the state variables with the Lagrangian tracer variables in addition to the prognostic variables of the dynamic model. The extended Kalman filtering computes not only the state variables but also the error covariance matrix. Through the cross correlation, the new assimilation system updates the unobserved prognostic variables using the observed Lagrangian tracers. Figure 1 shows a successful Lagrangian assimilation of the four point vortices (four coherent eddies in a large-scale flow) using two Lagrangian tracer observations.

The TIME theory is a hybrid of the Lagrangian and Eulerian methods. It estimates the leading-order Lagrangian transport using the Eulerian information extracted on the stationary boundary. Transport is presented as spatio-temporal integration of the instantaneous flux, which is induced by the temporally spontaneous but spatially nonlinear mean-eddy interaction. It offers two aspects of transport: accumulation and displacement geometry (left panel of Figure 2). Two complementary approaches are graphic (right panel of Figure 2) and analytic. Analytic approach suggests that the non-dimensional scale ratio defined by the characteristic length-scale of the flux variability in the unit of flight time and the characteristic time-scale of the anomaly in the general circulation.



**Figure 1. Lagrangian data assimilation, time versus difference from the truth [black: without data assimilation with  $t^{2/3}$  divergence; colors: with assimilation]**



**Figure 2. Inter-gyre transport in the wind-driven mid-latitude ocean due to the Rossby-wave mode variability [left: leading-order displacement geometry; right: transport process during one cycle of Rossby-wave oscillation]**

## IMPACT/APPLICATION

The new data assimilation methodology currently being developed in this work can fill the gap between data assimilation and dynamical systems approach to Lagrangian transport theory, which has been one of the focuses in the ONR predictability DRI program. The methodology is general and can

be applied to numerous observations that have not been assimilated using the conventional assimilation methods.

Estimating properties concerning transitory dynamics from oscillatory to singular regimes can help enhance predictability of such systems that have log-periodic critical oscillations. The new framework developed in this work can be generalized for application of many physical systems (Sornette 1998, and references therein).

Extending TIME theory (Ide and Wiggins 2002a,b) offers a variety of new directions for large-scale planetary flows, including analysis of transport processes and mechanism, impact of specific events in the flow dynamics, as well as role played by variability.

## **TRANSITIONS**

Having theoretical framework of the Lagrangian data assimilation system, I plan to start an application to the realistic assimilation of the ocean floats data into an intermediate general circulation models. Extending the TIME theory in the three-dimensional flow should offer new insights to the impact of variability for not only the surface but also the interior of the oceans.

## **RELATED PROJECTS**

1– NASA data assimilation on data assimilation in ocean-atmosphere coupled system, in collaboration with Michael Ghil (UCLA).

2– Caltech President funds on a new geometrical approach to Eulerian transport, as an application to the ocean circulation in collaboration with James C. McWilliams (UCLA) and Yi Chao (JPL).

3– Los Alamos National Laboratory project on data assimilation studies for shock wave physics in collaboration with Jim Kao (Los Alamos National Laboratory ).

## **SUMMARY**

During October 2001 to September 2002, my main contributions to the scientific base were development of new theoretical frameworks in the following fields: sequential data assimilation to incorporate Lagrangian observation and its application to the satellite data; transitory dynamics for the systems with log-periodic criticality; identification of physical processes in transport to enhance predictability. In the next year, I plan to continue my efforts with emphasis on data-assimilation system design by extending the Lagrangian data assimilation system (Ide, Kuznetsov and Jones 2002; Kuznetsov, Ide and Jones 2002) to the real oceanic and atmospheric observations such as floats and balloons, and exploring effect of non-Gaussian stochasticity (Sornette and Ide 2001). I also plan to extend transport theory into new directions with emphasis on observational studies. My institute at UCLA hosts experts in geophysical sciences who work rather independently of each other. Because of this ONR support, Didier Sornette and I have started a collaboration to bring his expertise in earth sciences and mine in dynamical systems and fluid dynamics. Moreover, the predictability DRI has lead to very fruitful collaboration with A.D. Kirwan (University of Delaware) and C.K.R.T Jones (University of North Carolina at Chapel Hill). These collaborations could have not been realized without the support from this ONR program.

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