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A New Geometrical Approach to Eulerian Transport: An Application to the Ocean Circulation

Final Report

PF-477

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A. OBJECTIVES

The main objective of this work is to investigate the transport processes in the large-scale ocean circulations using the new transport theory. We focus on the mid-latitude ocean circulation, especially the Gulf Stream, because it is recognized as a most energetic ocean current and plays a crucial role in maintaining the earth's climate system. A fundamental question concerning the transport is whether or not the Gulf Stream serves as a barrier or blender between the cold and warm waters across its axis. To answer this question, we apply the new transport theory called the "TIME" (transport induced by mean-eddy interaction; Ide and Wiggins, 2002a) to the high-resolution North Atlantic Ocean model at JPL that can realistically simulate the Gulf Stream. Moreover, we wish to provide a new direction for estimating the transport in the large-scale oceans and atmosphere.

B. PROGRESS & RESULTS

The TIME theory was reformulated from the Eulerian transport theory, in order to better describe its hybrid nature between the Eulerian and Lagrangian transport methods. It was first tested for the intergyre transport across the ocean-jets axis using the numerical simulation of the idealized mid-latitude quasi-geostrophic ocean model (Figure 1). The TIME theory showed the spatially nonlinear mean-eddy interaction that induced the instantaneous flux and explained the spatio-temporal interaction processes that lead to the transport. The dynamic eddy activity in the upstream region of the ocean jet was identified as the main source of the intergyre transport. The theory demonstrated how the variability of the flow dynamics can be directly linked to the transport in the large-scale flows (Ide and Wiggins, 2002b).

The TIME theory was then applied to the high-resolution North Atlantic Ocean model that has much realistic ocean flow dynamics. The empirical orthogonal function (EOF) analysis showed that the variability had some similarities to that observed in the idealized model. Figure 2 shows the spatial component of the first two leading EOFs that explained about 10% of the total variance. The instantaneous flux fields induced by the two EOFs revealed quite different transport processes in the high-resolution model from the idealized model. Most of the high flux regions aligned off the Gulf-Stream axis and only a few high flux regions were located on the axis. Therefore, the variability mixed the cold waters in the north of the Gulf-Stream axis and the warm waters in the south; the cross-stream transport occurs only intermittently in the limited regions (Ide et al., 2002). The spatio-temporal analysis suggested that the characteristic time-scale of the dynamic eddies in the variability was too slow for the fast Gulf Stream to cause significant cross-stream transport.

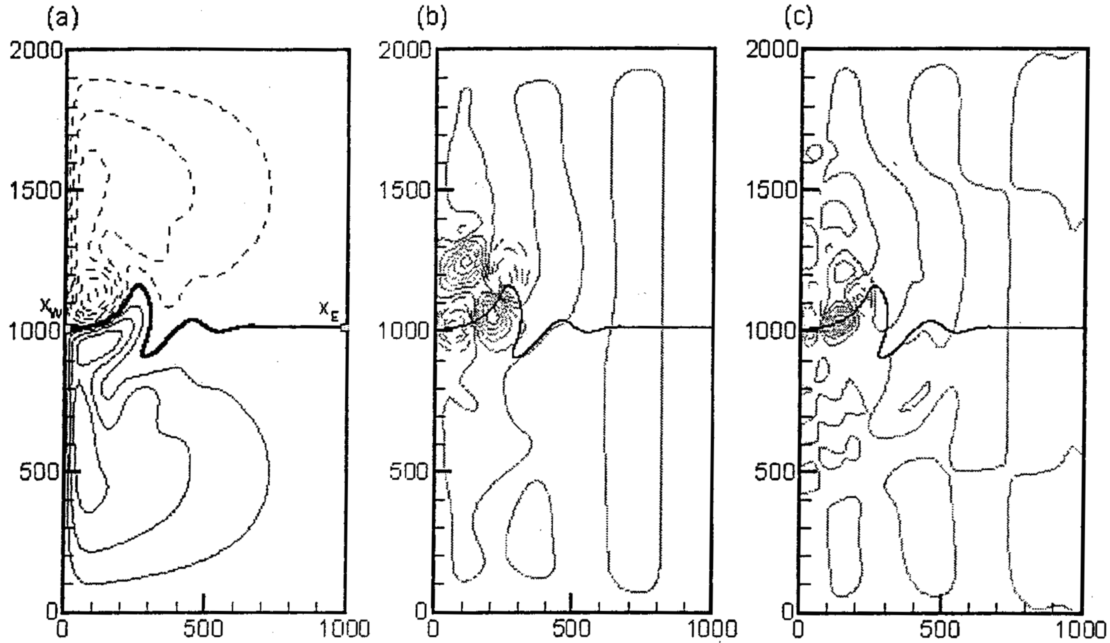

Figure 1: a) The mean streamline field of the mid-latitude ocean circulation using the quasi-geostrophic model. The streamline connecting the western boundary ($\mathbf{x}_W$) to the eastern boundary ($\mathbf{x}_E$) is the ocean-jet axis representing the Gulf-Stream axis. b) Instantaneous eddy streamline field showing the Rossby-wave mode variability. In the western basin near the separatrix (upstream region of the jet), the four eddies rotate counter-clockwise. In the eastern basin (downstream region), the Rossby waves are identified by the longitudinally elongated features. Dynamics of the rotating eddies and that of westward propagating Rossby waves are synchronized. c) Instantaneous flux field across the mean streamlines induced by the dynamic eddies.

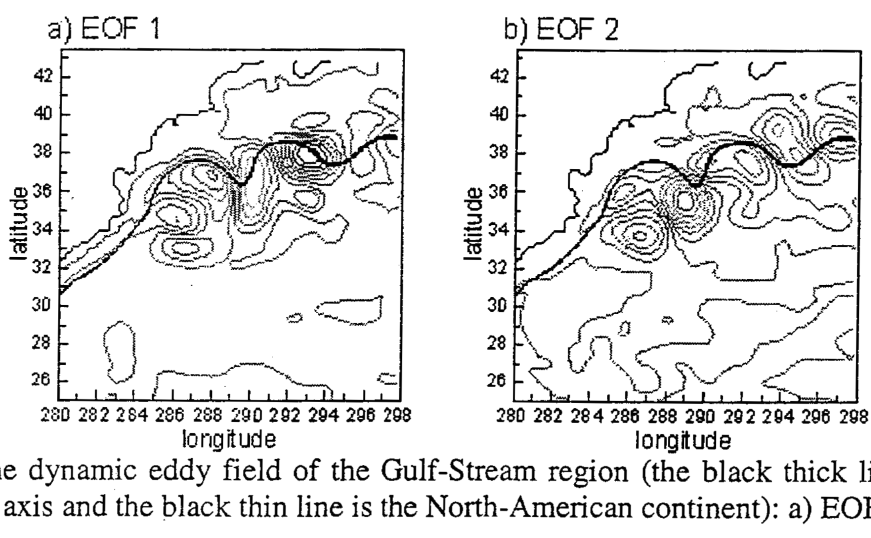

Figure 2: The dynamic eddy field of the Gulf-Stream region (the black thick line is the mean Gulf-Stream axis and the black thin line is the North-American continent): a) EOF 1; and b) EOF

2. The most prominent variability is the clockwise recirculation in the upstream (west of 289°): the eddies flow along the Gulf-Stream between 285° to 289°, separate from near 290 $^{\circ}$ and continue clockwise motion to rejoin the Gulf Stream about 285° The other is the westward propagation of the Rossby waves in the downstream (east of 289°). The recirculation eddies and the Rossby waves encounter near 289° where the eddies separate from the Gulf Stream.

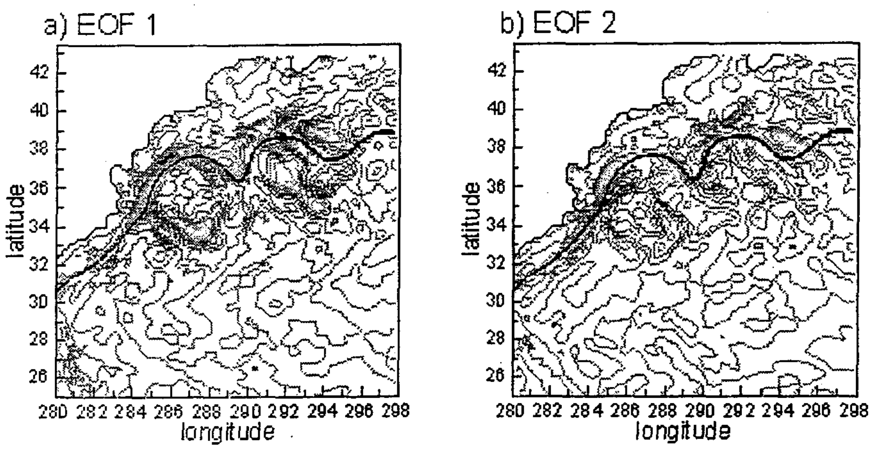

Figure 3: The instantaneous flux field of the Gulf-Stream region corresponding to Figure 2: a) EOF 1; and b) EOF 2.

C. SIGNIFICANCE OF THE RESULTS

By applying the new transport theory to the high-resolution North Atlantic Ocean model at JPL, we offered the answer to the fundamental question concerning the transport: the Gulf Stream acts as an effective blender of the cold and warm waters only intermittently in the limited regions. The spatio-temporal analysis developed in this study can be used to study the role of variability in transport for the large-scale oceans and atmosphere.

D. PERSONNEL

This work has been performed by the collaboration between the UCLA and JPL group. In addition to the investigators, Kayo Ide at UCLA has applied and refined the methodology.

E. PUBLICATIONS

Ide, K., Y. Chao and J.C. McWilliams (2002): Cross-stream transport across the Gulf Stream in the high-resolution North Atlantic Ocean model, *J. Geo. Res.*, in preparation.

Ide, K. and Wiggins, S. (2002a): A new approach to transport induced by mean-eddy interaction for ocean circulations, *J. Phys. Oceanogr.*, Submitted.

Ide, K. and Wiggins, S. (2002b): Role of variability in transport of the large-scale planetary flows, *J. Atmos. Sci.*, in preparation.