Physics > Atmospheric and Oceanic Physics

Transport Induced by Mean-Eddy Interaction: I. Theory, and Relation to Lagrangian Lobe Dynamics

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In this paper we develop a method for the estimation of {\bf T}ransport {\bf I}nduced by the {\bf M}ean-{\bf E}ddy interaction (TIME) in two-dimensional unsteady flows. The method is built on the dynamical systems approach and can be viewed as a hybrid combination of Lagrangian and Eulerian methods. The (Eulerian) boundaries across which we consider (Lagrangian) transport are kinematically defined by appropriately chosen streamlines of the mean flow. By evaluating the impact of the mean-eddy interaction on transport, the TIME method can be used as a diagnostic tool for transport processes that occur during a specified time interval along a specified boundary segment. We introduce two types of TIME functions: one that quantifies the accumulation of flow properties and another that measures the displacement of the transport geometry. The spatial geometry of transport is described by the so-called pseudo-lobes, and temporal evolution of transport by their dynamics. In the case where the TIME functions are evaluated along a separatrix, the pseudo-lobes have a relationship to the lobes of Lagrangian transport theory. In fact, one of the TIME functions is identical to the Melnikov function that is used to measure the distance, at leading order in a small parameter, between the two invariant manifolds that define the Lagrangian lobes. We contrast the similarities and differences between the TIME and Lagrangian lobe dynamics in detail. An application of the TIME method is carried out for inter-gyre transport in the wind-driven oceanic circulation model and a comparison with the Lagrangian transport theory is made.

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