Geophysical Research Abstracts, Vol. 7, 10193, 2005
SRef-ID: 1607-7962/gra/EGU05-A-10193

Nonstationary variability of the Gulf Stream path. (An analysis of 2D data based on Empirical Mode Decomposition.)

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Motivation.

The Gulf Stream path is significantly nonstationary in both time and space. In addition, Gulf Stream dynamics are believed to be highly nonlinear. On the other hand, in most data analysis studies variability of the path is typically characterized based on assumptions of linearity and stationarity in at least one dimension. In our analysis we relax these assumptions to address the following questions: what is the structure of variability of the Gulf Stream path? In paricular, how does this structure vary on large scales? And how should this varibility be represented for the purposes of climate studies?

Data and Method.

We examine a 2D (time, longitude) data set of satellite-derived latitudinal positions of the Gulf Stream path between Cape Hatteras and the Tail of the Grand Banks for the period from June 1984 through December 2000. The data are separated into several components in accordance with the proposed method of analysis of 2D data which is based on multiple successive application of the 1D Empirical Mode Decomposition (EMD) along the two dimensions. The reason for selecting EMD is that it relaxes the assumptions of stationarity and linearity; and it is explicitly based on scales that emerge during analysis.

Prior to developing the 2D procedure we analyzed 1D EMD to determine its resolving capability as well as the effect of noise on its performance. This analysis showed that nonlinear signals can be properly separated by EMD only if the shortest scale contained in one of the signals is twice as large as the longest scale contained in the other. Also, EMD of noisy data may result in intermittence, in splitting of integral nonlinear features into Fourier-like components, and in accumulation of errors as the EMD advances from extraction of small to large scale fluctuations. The 2D method was designed to reduce these problems.

The algorithmic block of the proposed 2D method consists of the following operations: 1) EMD in both dimensions, which produces the basic structure of the data; 2) the intermittence test, which assures that features of the same range of scales are extracted over the whole observational domain; 3) a properly selected 2D smoothing, which suppresses noise. A single application of this block of operations results in separation of the input data into two 2D fields: one associated with features of the shortest scale available in a given dimension, and the other, a residue. Generally, processing advances sequentially from the shortest to the longest scale in a given dimension. The overall procedure provides a complete decomposition of the original signal into 2D components defined by time and space scales confined to relatively narrow ranges. Signals propagating in opposite directions (e.g., mesoscale Gulf Stream meanders) may be separated by applying the algorithm along the diagonal and the antidiagonal directions of the data matrix.

Main results and conclusions.

The decomposition of the Gulf Stream path data resulted in the following components: east- and westward propagating meander fields; semiannual and annual components; interannual short, intermediate, and basin-scale components; a quasidecadal component and a time and space varying "mean" state (2D trend). The results suggest that meaningful climate scale variations of the Stream path are described mainly by two components: 1) the quasidecadal component, which is characterized by unidirectional (north-south) shifts of the Stream path; it was dominant during 1994-2000 and negligible before this; and 2) the interannual component of intermediate zonal scales, which is characterized by a bi-modal structure (a smooth vs. stationary-wave–like path) confined to a region between Cape Hatteras and the New England Seamount Chain (NESC). The quasidecadal component is correlated with a standard NAO index although only during 1994-2000, i.e. when this component has a significant amplitude. On the other hand, the interannual intermediate component is not correlated with a standard NAO index during any considered time section. Existence of two meaningful components of climate variability of the Stream suggests that the latter should be represented by two indices. Time series of amplitudes of first EOFs computed separately for the two components seem to be a good choice.

In overall, structure of the resulting components suggests that the NESC strongly constrains the Gulf Stream path on time scales larger than annual.