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Low-frequency variability of the Kuroshio Extension

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It has recently been shown that the sea-surface height patterns associated with a decadal chaotic relaxation oscillation (connecting a weak contracted and a strong elongated jet state) produced by a shallow-water double-gyre model of the Kuroshio Extension (KE) are in good agreement with altimeter observations. In this communication, we present a detailed analysis of the dynamical origin of this low-frequency bimodal oscillation using the concepts of dynamical systems theory. Using an empirical continuation method (imposed also by the large dimension of the domain of integration necessary to provide the correct input of momentum by the wind), many sensitivity experiments with different values of the lateral eddy viscosity coefficient K were carried out by running a parallelized version of a shallow-water model in the framework of a High Performance Computing - Europa project of the EC. For K>400 m2/s the KE state is found to be stationary. At K=400 m2/s a first Hopf bifurcation occurs, when the nonlinear saturation of the linear instability of the stationary solution produces stable small amplitude oscillations. Within the range K=240-400 m2/s two sub-ranges can be identified: in the first one (K=260-400 m2/s) very small amplitude periodic oscillations are found, while in the second one (K=240-260 m2/s) a local transition to chaos occurs through period doubling bifurcations. Higher frequency oscillations (with a period of about 50 days) are due to Rossby modes, while lower frequency oscillations (with periods from 4 to 8 years) are due to gyre modes. Just below K=240 m2/s a global bifurcation occurs, and typical KE relaxation oscillations are obtained: in this case a homoclinic orbit leaves the unstable saddle fixed point corresponding to the weak (contracted) jet state along its unstable manifold, and then

spans a wide region of phase space. The unstable manifold is however reconnected to the stable one, and it is along the latter that the orbit eventually goes back to the original phase space region. It is worth noticing that the chaotic orbit visits occasionally a region (where it remains trapped for some time) in which intermediate energy, small amplitude oscillations of a completely different character arise. Events of this kind are interpreted as heteroclinic connections. Moreover, windows of periodic motion within both local and global chaos appear, as it is typical in chaos theory. Finally, the crucial role played by the basin shape and size in producing the global bifurcation necessary for a realistic KE decadal variability is discussed.