The Wind-Driven Ocean Circulation: Bifurcations, Simulations and Observations

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The large-scale, near-surface flow of the mid-latitude oceans is dominated by the presence of a larger, anticyclonic and a smaller, cyclonic gyre. The two gyres share the eastward extension of western boundary currents, such as the Gulf Stream or Kuroshio, and are induced by the shear in the winds that cross the respective ocean basins. The boundary currents and eastward jets carry substantial amounts of heat and momentum; the jets also contribute to mixing in the oceans by their "whiplashing" oscillations and the detachment of eddies from them.

We study the low-frequency variability (LFV) of the wind-driven, double-gyre circulation in mid-latitude ocean basins, subject to time-constant, purely periodic and more general time-dependent wind stress. Both analytical and numerical methods of nonlinear dynamics are applied in this study. Symmetry-breaking bifurcations occur, from steady to periodic and aperiodic flows, as time-constant wind stress increases or dissipation decreases. The first bifurcation is of pitchfork or perturbed-pitchfork type, depending on the models degree of realism. Oscillatory instabilities arise by supercritical Hopf bifurcation, with periods from a few months to a few years. Numerical evidence points to homoclinic orbits that connect high- and low-energy branches of steady-state solutions and induce interdecadal variability.

These results are shown to be robust across a full hierarchy of models quasi-geostrophic, shallow-water, and primitive-equation ones including multi-layer and eddy-resolving ocean models. Coupled oceanatmosphere models show the basin-scale variability to be still dominated by the intrinsic ocean variability. High resolution is necessary in the atmospheric component of these models in order to allow for proper coupling of the intraseasonal variability with the interannual one. Given such resolution, we obtain a promising explanation of the North Atlantic Oscillation.

Recent work has focused on the application of non-autonomous and random forcing to double-gyre models. We discuss the associated pullback and random attractors and the non-uniqueness of the invariant measures that are obtained.

The numerical results are compared with decade-long in situ and satellite observations of three ocean basins, the North and South Atlantic, and the North Pacific. Based on this comparison, we discuss what is and isnt known about the oceans role in climate variability.

This talk reflects collaborative work with a large and still increasing number of people. Please visit http://www.atmos.ucla.edu/tcd/ for their names, affiliations, and respective contributions.

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