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Investigation of the optimal precursors for ENSO events by conditional nonlinear optimal perturbation

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Abstract The approach of conditional nonlinear optimal perturbation (CNOP) is employed to investigate the properties of the optimal growth for a theoretical coupled ENSO model with an annual cycle. The results show the existence of the CNOPs of annual cycle and local CNOPs. In phase space, CNOPs are quite different from the linear singular vectors (LSVs) for the long optimization time intervals and large amplitude of perturbations. Furthermore, their nonlinear and linear evolutions remain significant differences. Owing to the presence of nonlinearity of the model, the nonlinear evolutions of CNOPs (local CNOPs) are notably larger (smaller) than their linear counterparts for the large initial perturbations. Further studies find out that the CNOPs (local CNOPs) of annual cycle are of the robust pattern with negative (positive) SST and positive (negative) thermocline depth anomalies qualitatively. These patterns tend to evolve into El Nino (La Nina) event most potentially, which can therefore be regarded as the optimal precursor of El Nino (La Nina). This theoretical result is verified against the 22-year NCEP reanalysis data qualitatively. The robust optimal precursors of ENSO are explained physically. It is shown that the optimal precursors occur in the ENSO transition phase variation robustly, in which the thermocline depth displacement takes a phase lead to SST variation and provides a negative feedback that turns the coupled system from one state to another state. In addition, the nonlinear behaviors of them reveal the nonlinear effect of temperature advection to ENSO oscillation: the nonlinear temperature advection enhances the instability of El Nino, and suppresses that of La Nina, which results in the asymmetry of them about the SSTA normal state.