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Dynamics of nonlinear error growth and season-dependent predictability of El Nino events in the Zebiak-Cane model

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With the intermediate-complexity Zebiak-Cane model, we investigate the "spring predictability barrier" (SPB) problem for El Niño events by tracing the evolution of conditional nonlinear optimal perturbation (CNOP), where CNOP is superimposed on the El Niño events and acts as the initial error with the biggest negative effect on the El Niño prediction. We show that the evolution of CNOP-type errors has obvious seasonal dependence and yields a significant SPB, with the most severe occurring in predictions made before the boreal spring in the growth phase of El Niño. The CNOP-type errors can be classified into two types: one possessing an SSTA pattern with negative anomalies in the equatorial central-western Pacific, positive anomalies in the equatorial eastern Pacific, and a thermocline depth anomaly pattern with positive anomalies along the equator, and another with patterns almost opposite to those of the former type. In predictions across the spring in the growth phase of El Niño, the initial error with the worst effect on the prediction tends to be the latter type of CNOP errors, whereas in predictions through the spring in the decaying phase, the initial error with the biggest negative effect on the prediction is inclined to be the former type of CNOP errors. Although the linear singular vector (LSV)-type errors also have pattern similar to the CNOP-type errors, they cover a more localized area than the CNOP-type errors and cause a much smaller prediction error, yielding a less significant SPB. Random errors in the initial conditions are also superimposed on El Niño events to investigate the SPB. We find that, whenever the predictions start, the random errors neither exhibit an obvious season-dependent evolution nor yield a large prediction error, and thus may not be responsible for the SPB phenomenon for El Niño events. These results suggest that the occurrence of the SPB is closely related to particular initial error patterns. The two kinds of CNOP-type errors are most likely to cause a significant SPB. They have opposite signs and, consequently, opposite growth behaviors, a result which may demonstrate two dynamical mechanisms of error growth related to SPB: in one case, the errors grow in a manner similar to El Niño; in the other, the errors develop with a tendency opposite to El Niño.