A Hierarchy of Multi-level Regression ENSO Models

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We have constructed empirical, linear and nonlinear, inverse stochastic models for the
analysis of global SST evolution with an emphasis on ENSO variability. Our method
generalizes the so-called linear inverse model approach, which considers the dynamics
to be linear and stochastically forced, and estimates the linear deterministic propagator,
as well as the structure of the stochastic forcing directly from observations by multi-
ple linear regression (MLR), while assuming the latter forcing to be white in time. A
multi-level generalization of the MLR is used, where the residual stochastic forcing at a
given level is subsequently modeled as a function of variables at this, and all preceding
levels. The number of levels is determined so that the lag-0 covariance of the residual
forcing converges to a constant matrix, while its lag-1 covariance vanishes. Another
novel aspect of our models is the inclusion of the additive, as well as multiplicative 12-
month-periodic forcing into the first level of each model forcing to account for ENSO
seasonal dependence.

Linear and quadratic, one-level and two-level models are obtained in the phase space of
the leading EOFs of 1950–2003 global SST record. The number of components to in-
clude in each model, as well as the order of model’s nonlinearity, has been determined
by cross-validation to maximize the model’s performance, either in terms of the cross-
validated forecast skill, or in terms of other statistical properties such as the structure of
the PDF and spectra of the observed and modeled SSTs. The best model is shown to be
the 20-component quadratic two-level model, which outperforms the two-level linear
model in predicting the magnitude of extreme SST anomalies. The latter property is
due to the ability of the quadratic models to mimic the observed asymmetry between
the positive El Niño and negative La Niña events. In addition, both models’ simula-
tions are characterized by the presence of two oscillatory modes with periods close
to the observed ones, that is quasi-quadiennial (QQ) and quasi-biennial (QB) modes.
Stability analysis of the linear model, as well as that of a linearized quadratic model
shows that the two oscillatory modes are associated with the models’ most robust linear
eigenmodes. The QQ mode is the least-damped one in winter, but disappears in sum-
mer, while the QB mode is identifiable throughout the whole year, but is much more
strongly damped. Such seasonal dependence is consistent with the so-called ‘spring
barrier’ in ENSO predictability.