

Abstract

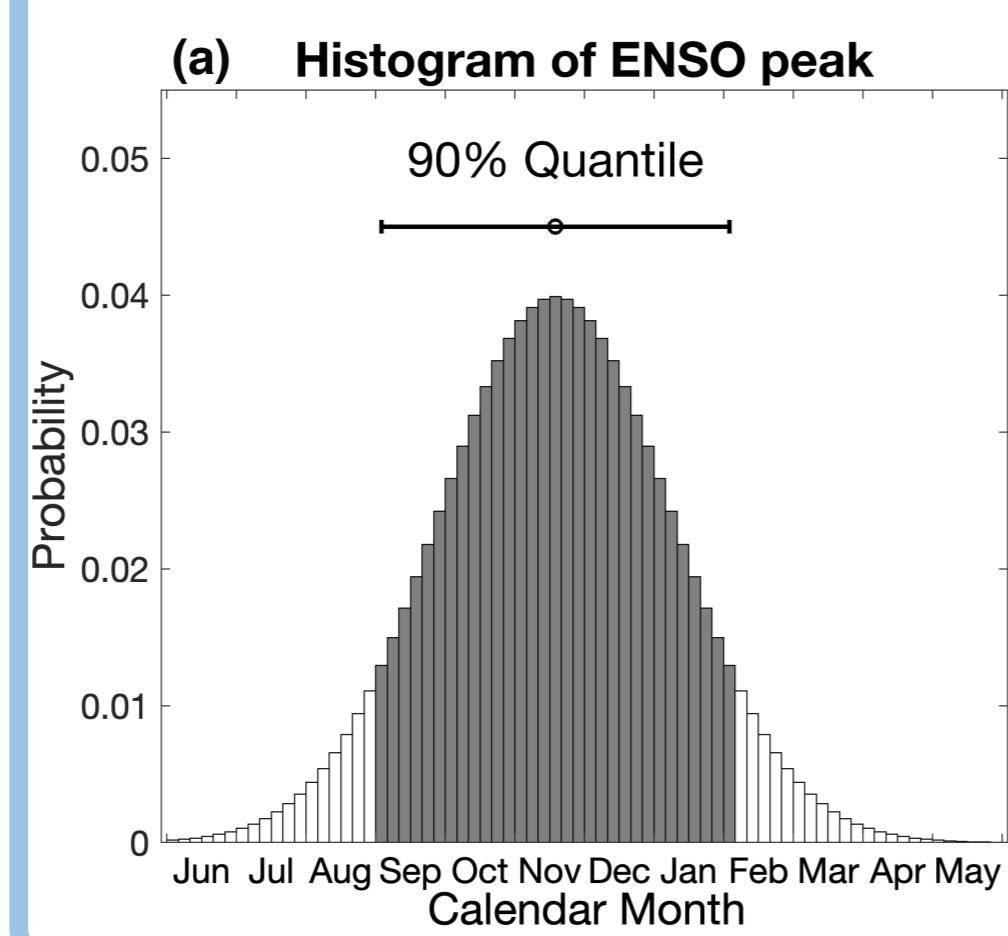
The conceptual ENSO recharge oscillator (RO) model is adopted to examine the ENSO phase-locking behavior. The linear/nonlinear mechanism of ENSO phase-preference/phase-locking is investigated using RO model. The difference between the nonlinear phase-locking mechanism and linear phase-preference mechanism is largely smoothed out in the presence of noise forcing.

The preferred month of ENSO peak time depends critically on the phase and strength of the seasonal modulation of the ENSO growth rate. Furthermore, the strength of phase-locking is mainly controlled by the linear growth rate, the amplitude of seasonal modulation of growth rate, the amplitude of noise, the SST-dependent multiplicative noise, and the linear frequency. The asymmetry of the strength of ENSO phase-locking is induced by the asymmetric effect of state-dependent noise forcing in El Niño and La Niña events.

Parametric recharge oscillator model

$$\begin{cases} \frac{dT}{dt} = RT + \omega_0 h_w + \sigma \xi (1 + BH(T)T) - cT^3 + bT^2 \\ \frac{dh_w}{dt} = -rh_w - \omega_0 T \\ R = R_0 - R_a \sin(\omega_a t - \varphi) \end{cases}$$

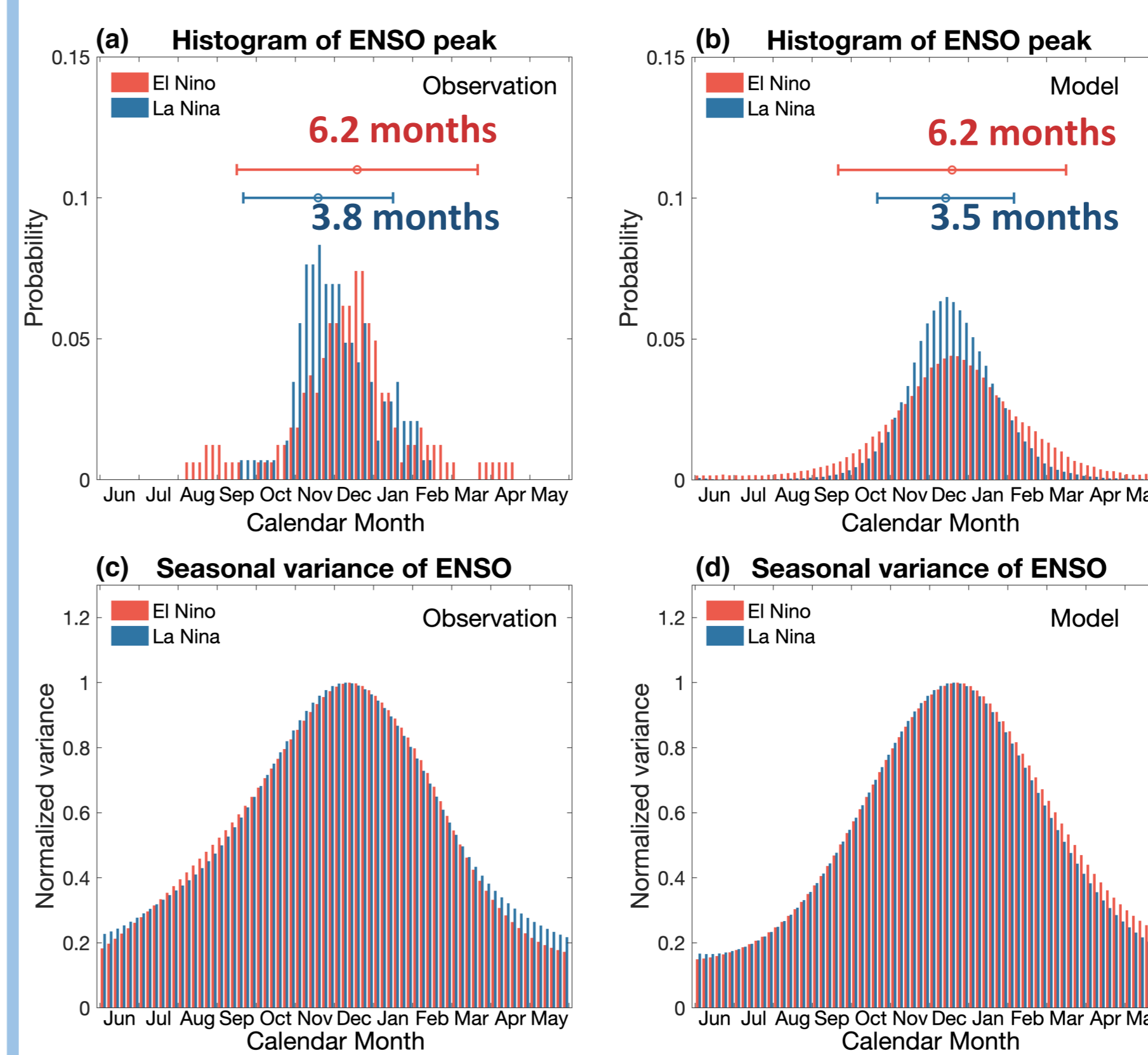
Metrics of phase-locking



Peak time:
maximum peak

Strength:
range of the 90% quantile of the peak time distribution centered on its maxima

Features of ENSO phase-locking



Asymmetry:
ENSO Peak time
Strength of phase-locking

- The RO model reproduces the main characteristics of phase-locking found in observations.
- Histogram of peak time is a more informational method to characterize the asymmetry of ENSO phase-locking

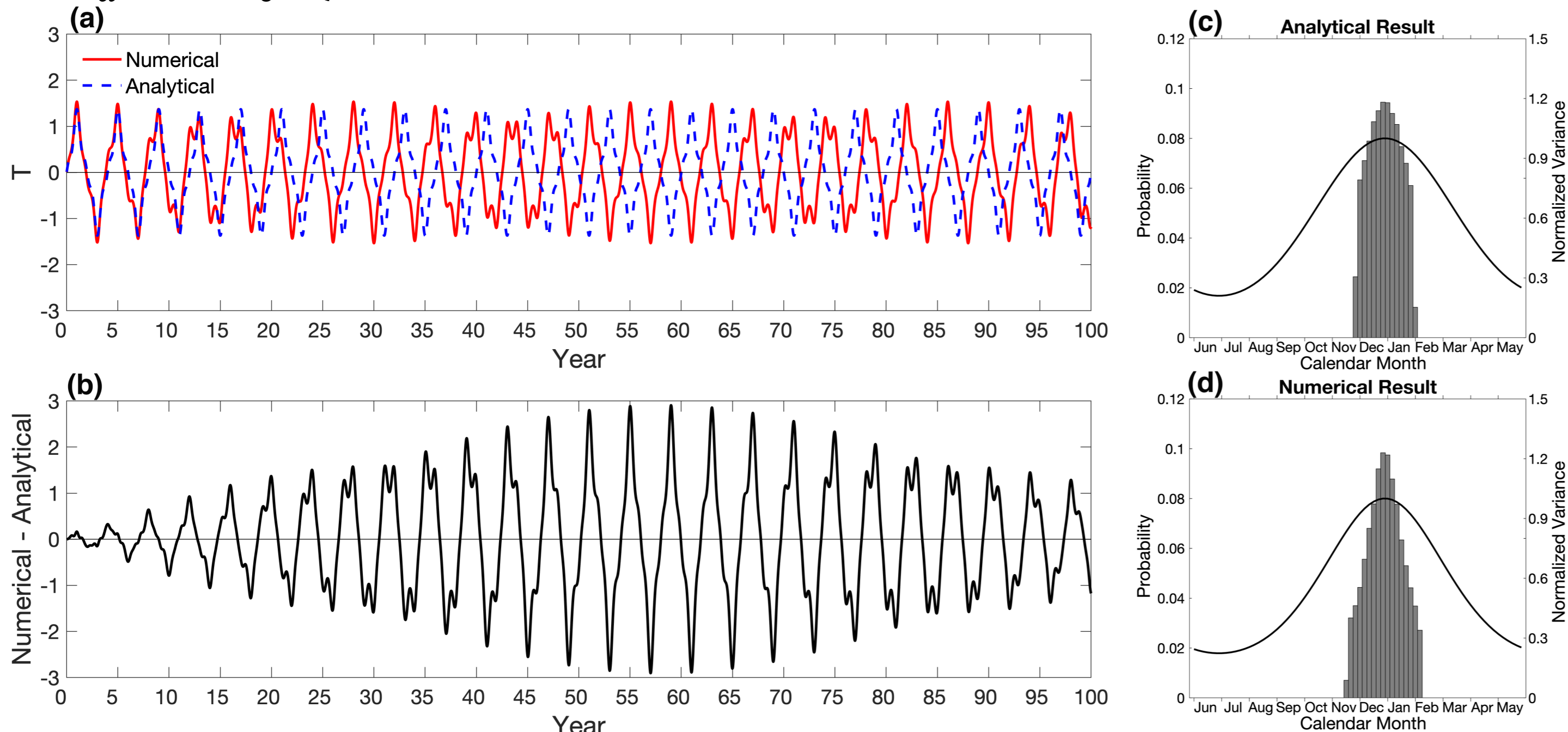
Analytical solution and Numerical solution

- Linear scenario of RO model ($c = 0, b = 0$)
- Unforced case ($\sigma = 0$)
- Neutrally stable regime ($R_0 = 0, r = 0$)

$$\begin{cases} \frac{dT}{dt} = -R_a \sin \omega_a t T + \omega_0 h_w \\ \frac{dh_w}{dt} = -\omega_0 T \end{cases}$$

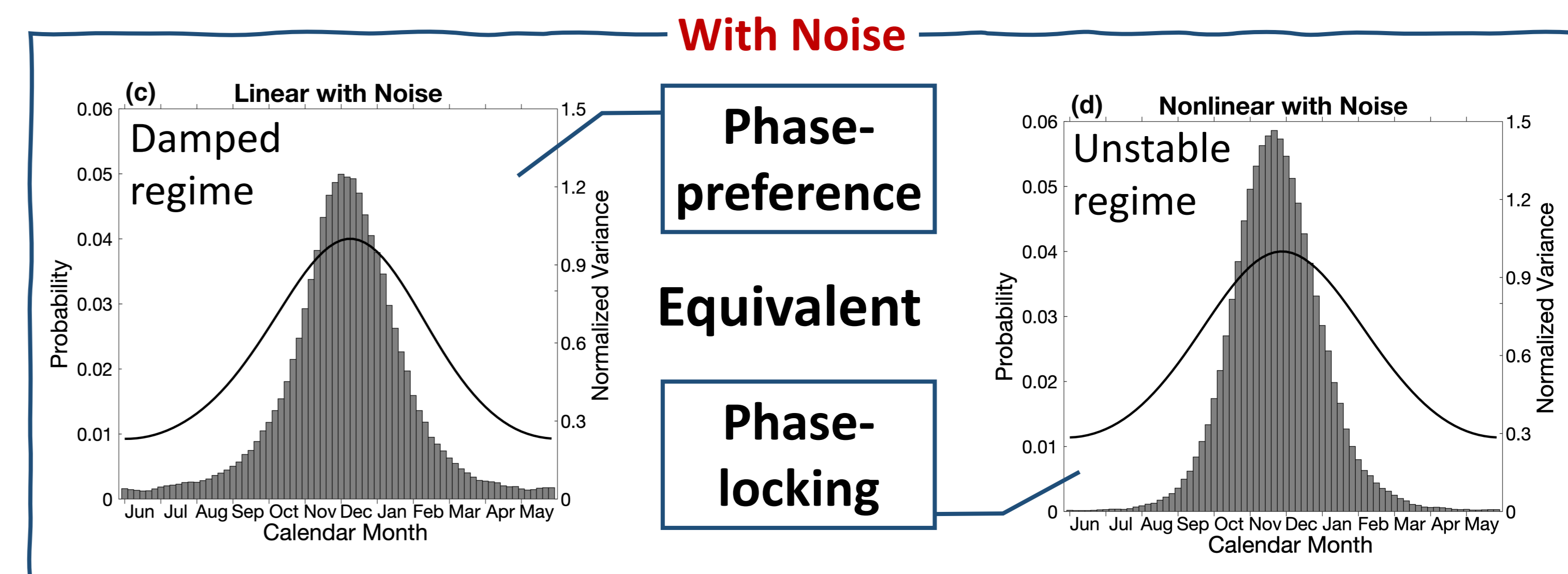
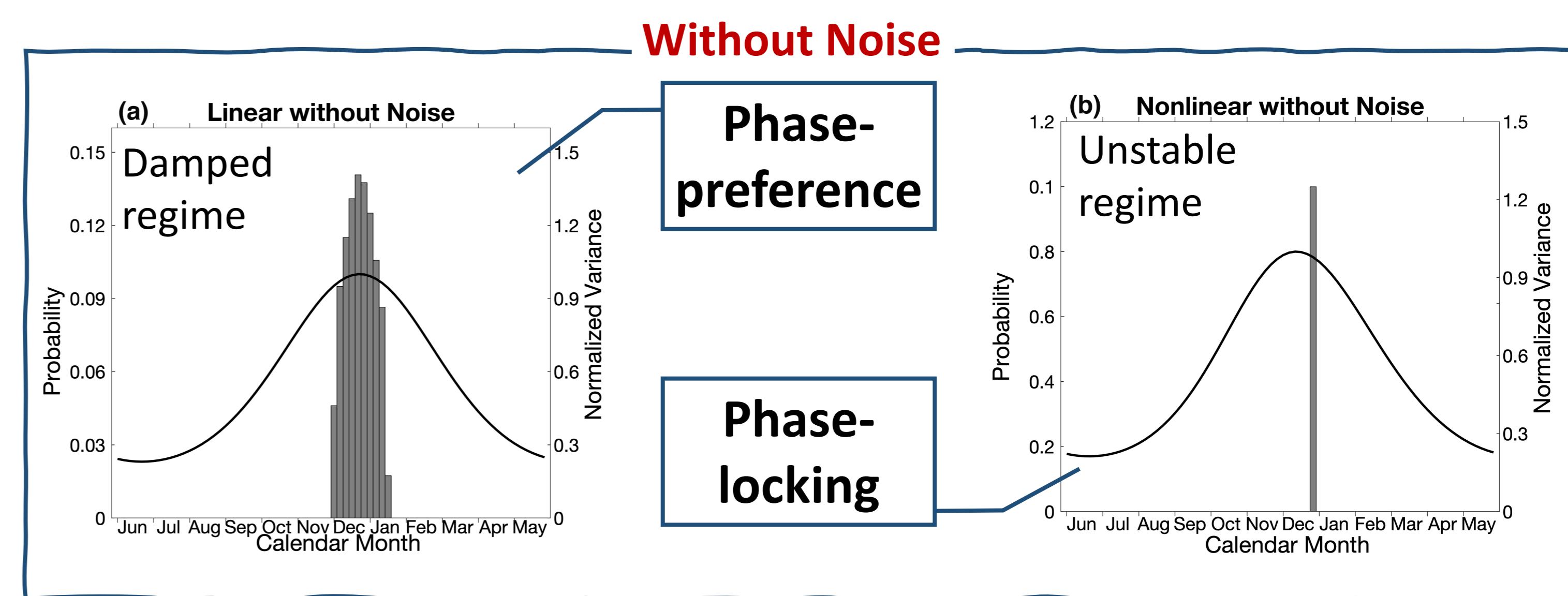
$$T \approx C \left[\sin(\omega_0 t + \phi_0) \right]$$

$$- \frac{R_a}{\omega_a^2 - 4\omega_0^2} \left\{ \omega_0 \sin(\omega_a t) \cos(\omega_0 t + \phi_0) - \frac{\omega_a^2 - 2\omega_0^2}{\omega_a} \cos(\omega_a t) \sin(\omega_0 t + \phi_0) \right\}$$

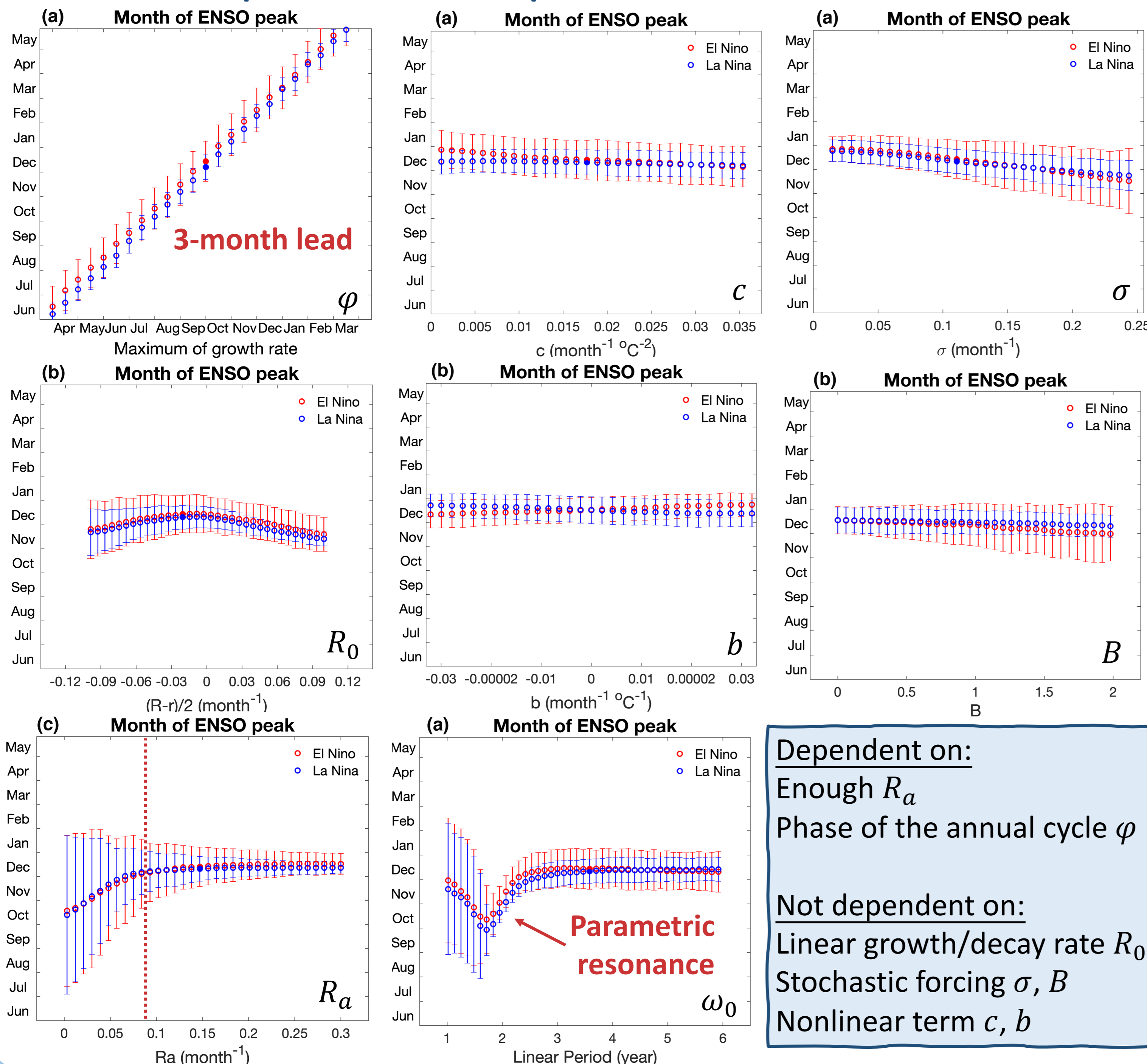


- Considerable differences between numerical and analytical solutions
Due to high order correction to the ENSO frequency
- Similar behavior of ENSO phase-preference
ENSO peak time is mainly controlled by the annual modulation mode (2nd term)

Linear/Nonlinear mechanism with stochastic forcing



Parameter dependence of ENSO peak

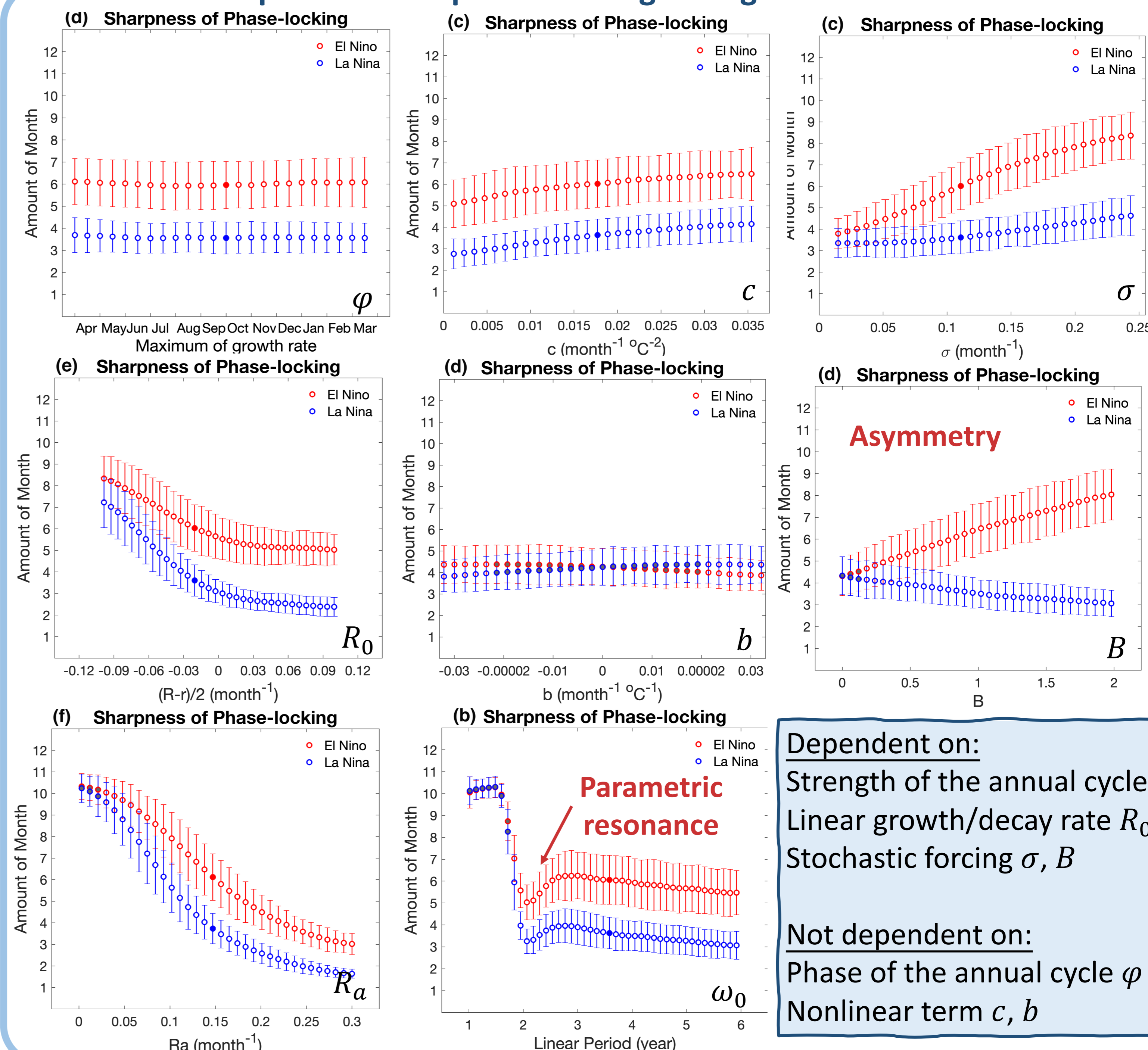


Dependent on:
Enough R_a
Phase of the annual cycle φ

Not dependent on:
Linear growth/decay rate R_0
Stochastic forcing σ, B
Nonlinear term c, b

Parametric resonance

Parameter dependence of phase-locking strength



Dependent on:
Strength of the annual cycle R_a
Linear growth/decay rate R_0
Stochastic forcing σ, B

Not dependent on:
Phase of the annual cycle φ
Nonlinear term c, b

Asymmetry

Parametric resonance

