Can we predict ENSO using a simple model?

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Jin, Fei-Fei. "An equatorial ocean recharge paradigm for ENSO. Part I: Conceptual model." *Journal of the atmospheric sciences* 54.7 (1997): 811-829.

1) Introduction

- **Question: Can we simulate and predict the irregular oscillation of ENSO?**

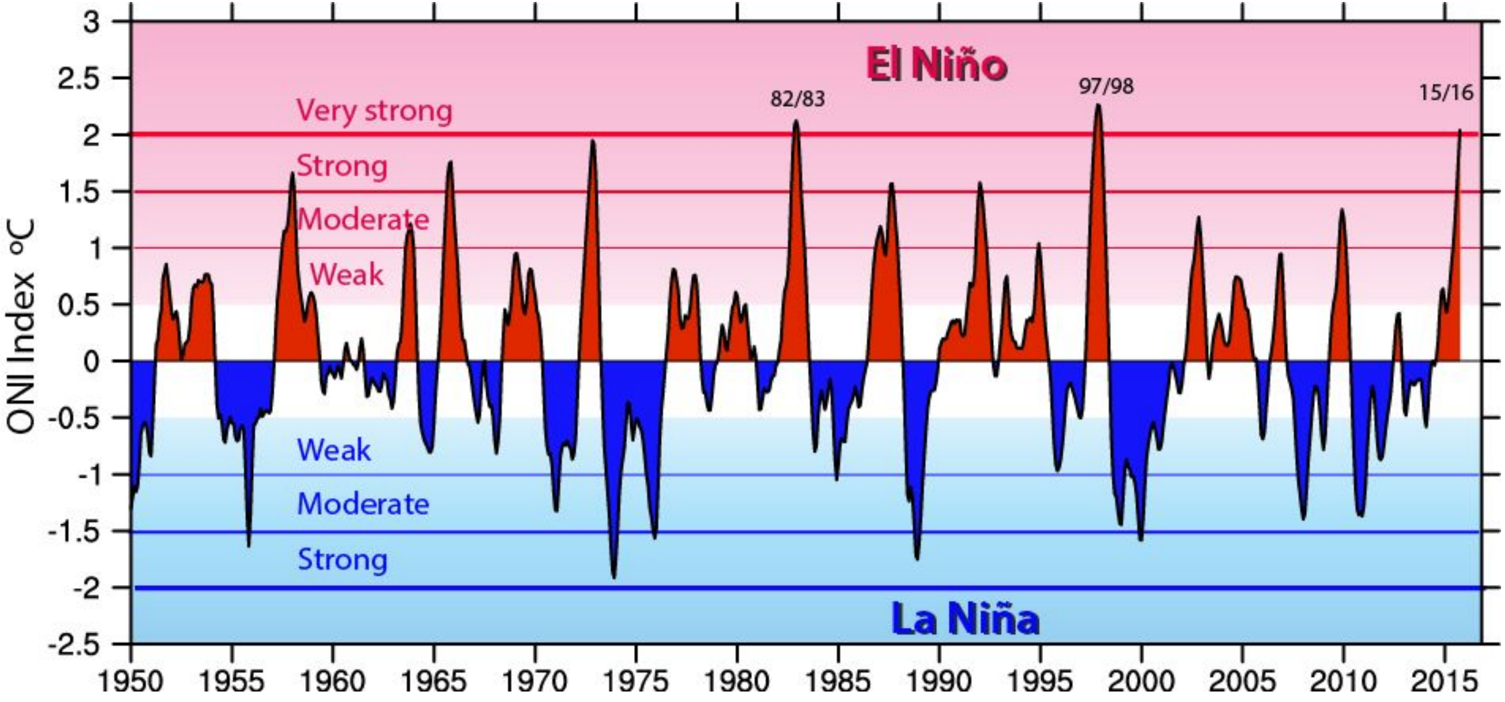
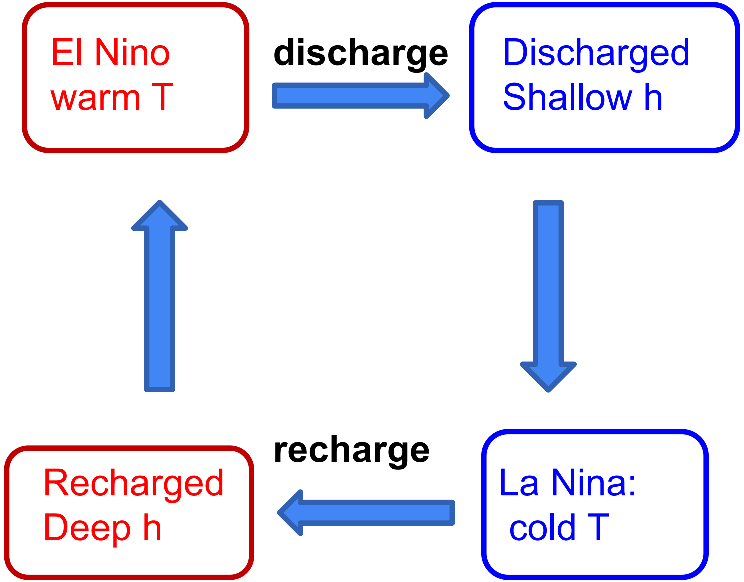


Fig. 1: ENSO index (Source: NCAR)

2) ENSO Recharge oscillator



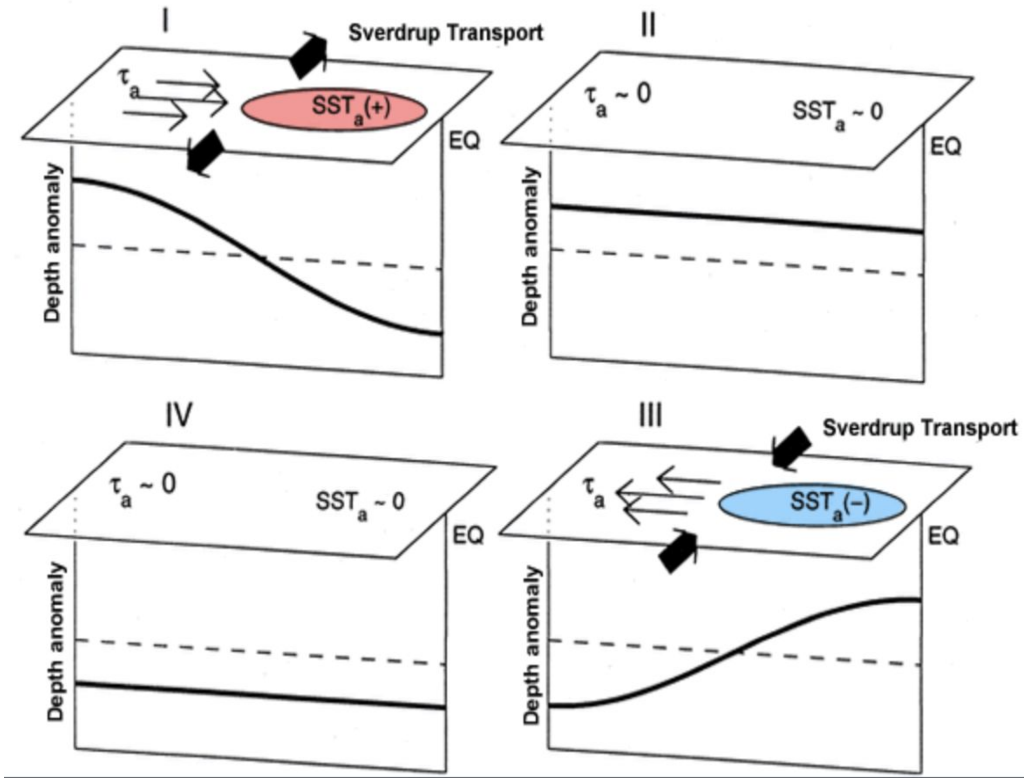
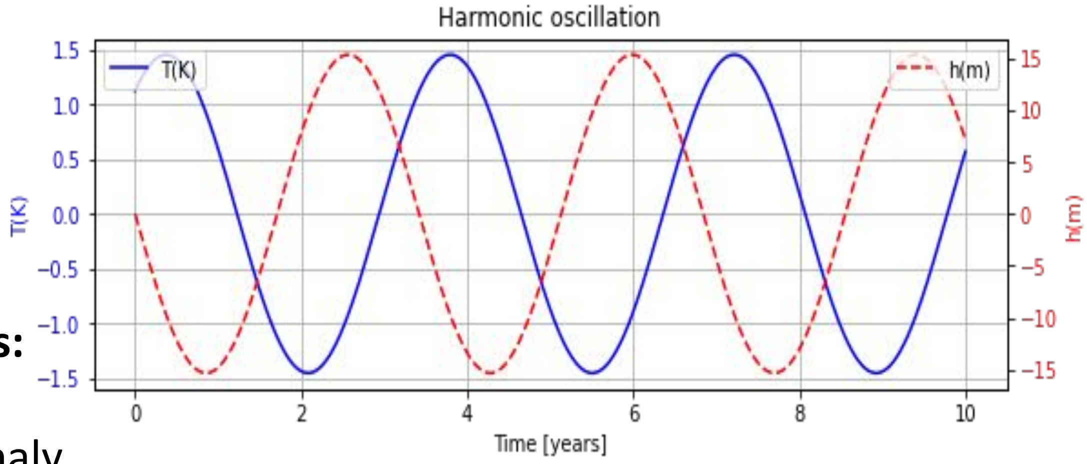


Fig. 2: Recharge-discharge mechanism (Meinen & McPhaden, 2000)

3) A conceptual model

$$\frac{dT}{dt} = RT + \gamma h$$
$$\frac{dh}{dt} = -rh - \alpha bT \quad (1)$$

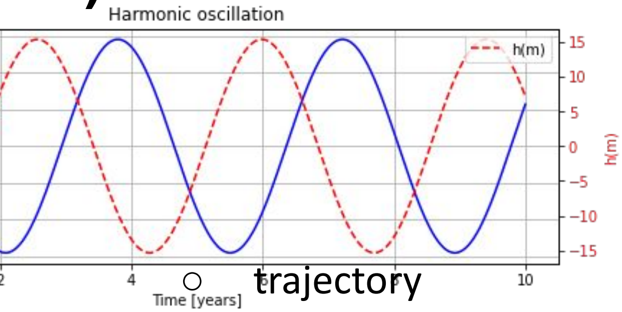


- **Coupled equations with two variables:**
  - *T*: East Pacific SST anomaly
  - *h*: West Pacific thermocline anomaly

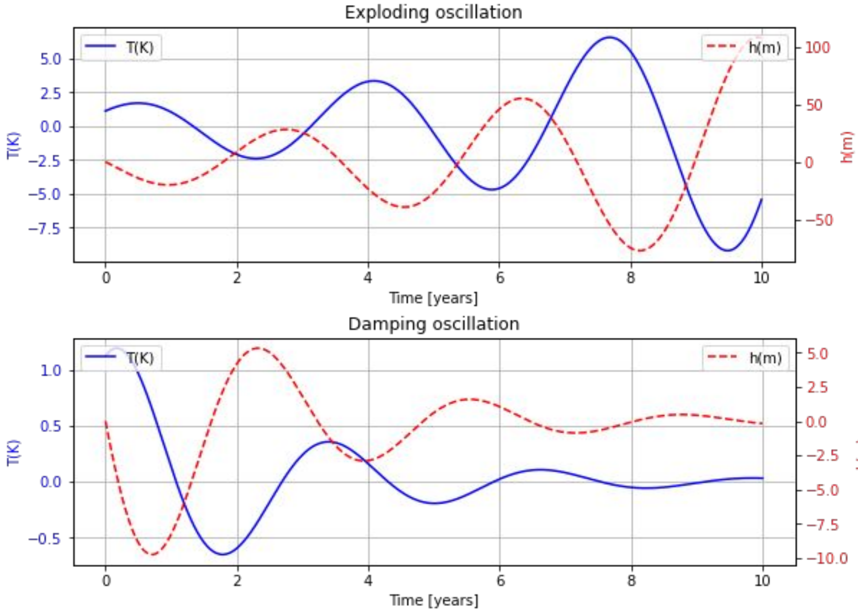
- *R*: Growth rate of T
- γ: Coupling of T to h
- *r*: Damping rate of h
- αb: Coupling of h to T

- How do we decide each parameters value?
  - based on statistic regression from observation data
- How to solve equations numerically?
  - Runge Kutta 4th
  - Time step: 1 day

4) Model results:



- trajectory



- Bad things:
  - Unstable if strongly coupled
  - Decays if weakly coupled
  - Pattern is regular
  - Period is fixed

Fig. 3: Numerical solutions with varying coupling intensity

- **Add nonlinearity:**
  - Nonlinear dependence of T on h

$$\frac{dT}{dt} = RT + \gamma h - \epsilon(h + bT)^3$$
$$\frac{dh}{dt} = -rh - \alpha bT \qquad \textbf{(2)}$$

- **Add wind stress:**
  - Annual cycle wind

$$\frac{dT}{dt} = RT + \gamma h - \epsilon(h + bT)^3 + \gamma\xi$$
$$\frac{dh}{dt} = -rh - \alpha bT - \alpha\xi \qquad \textbf{(3)}$$
$$\xi = f_{ann}\cos\left(\frac{2\pi t}{\tau}\right)$$

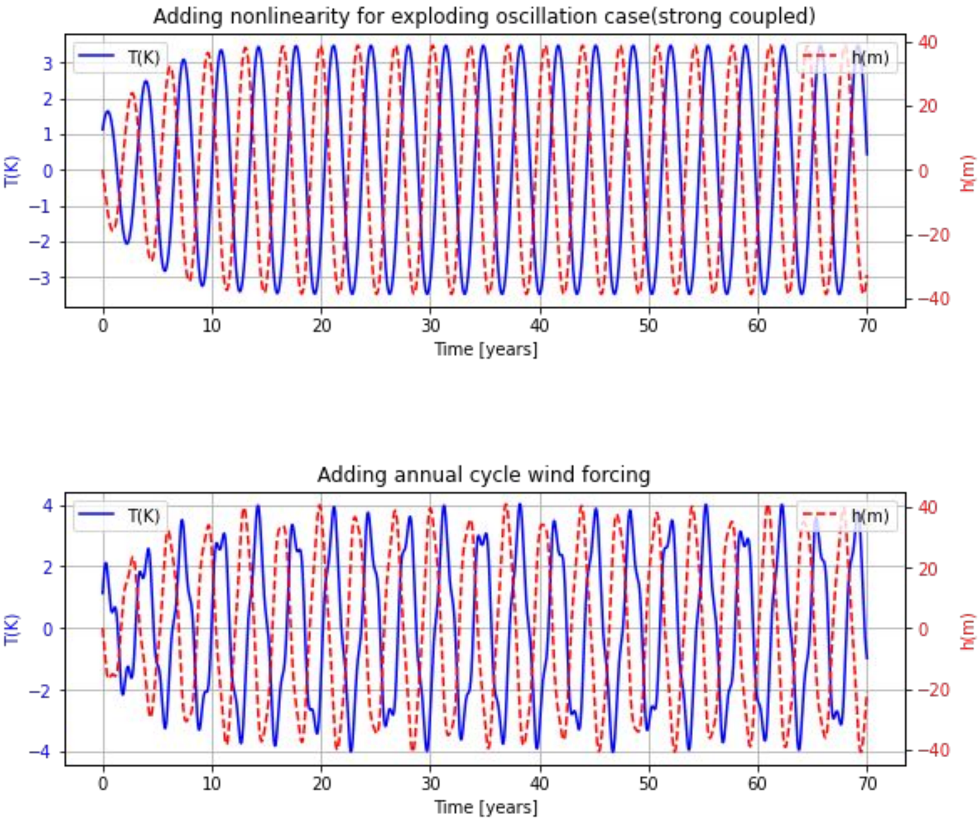


Fig. 4: Numerical solutions after adding nonlinearity (above) and both nonlinearity and annual cycle wind forcing (below)

Stochastic Forcing

$$\xi = f_{ann} \cos\left(\frac{2\pi t}{\tau}\right) + f_{ran} W \frac{\tau_{cor}}{\Delta t} \quad \textbf{(4)}$$

White noise

$$x_1 = w_1$$
$$x_{j+1} = r x_j + \left(1 - r^2\right)^{1/2} w_{j+1}, j \geq 1 \quad \textbf{(5)}$$

Red noise

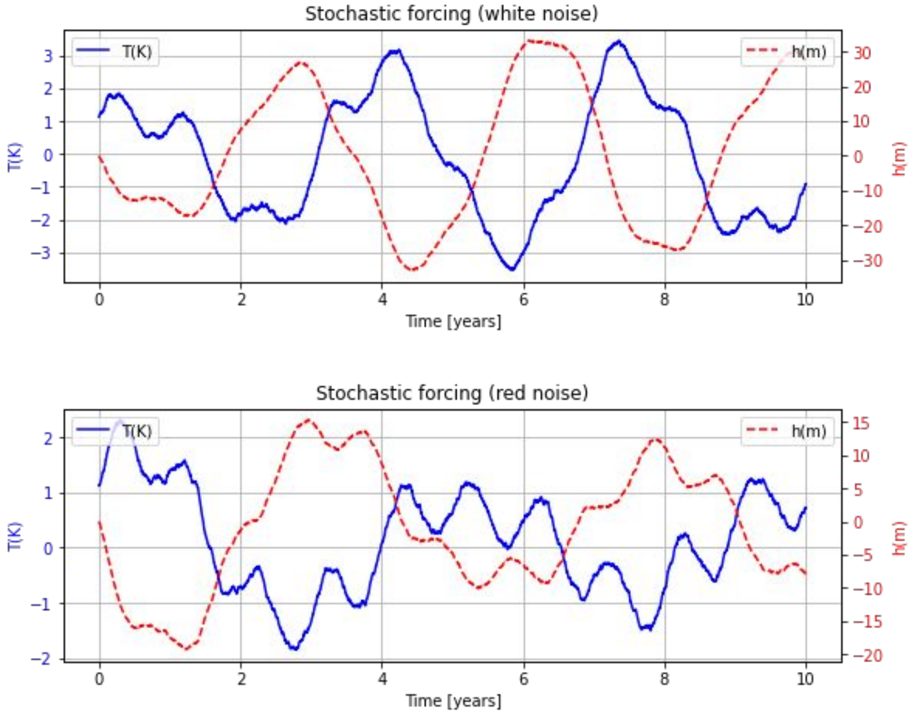


Fig. 5: Numerical solutions with white noise (above) and red noise (below)

Observed

- ONI, ~70 years

White noise

- Period and amplitudes are (too) uniform
- More events than observed

Red noise

- More chaotic
- Correct no. of events
- Period and amplitudes less uniform

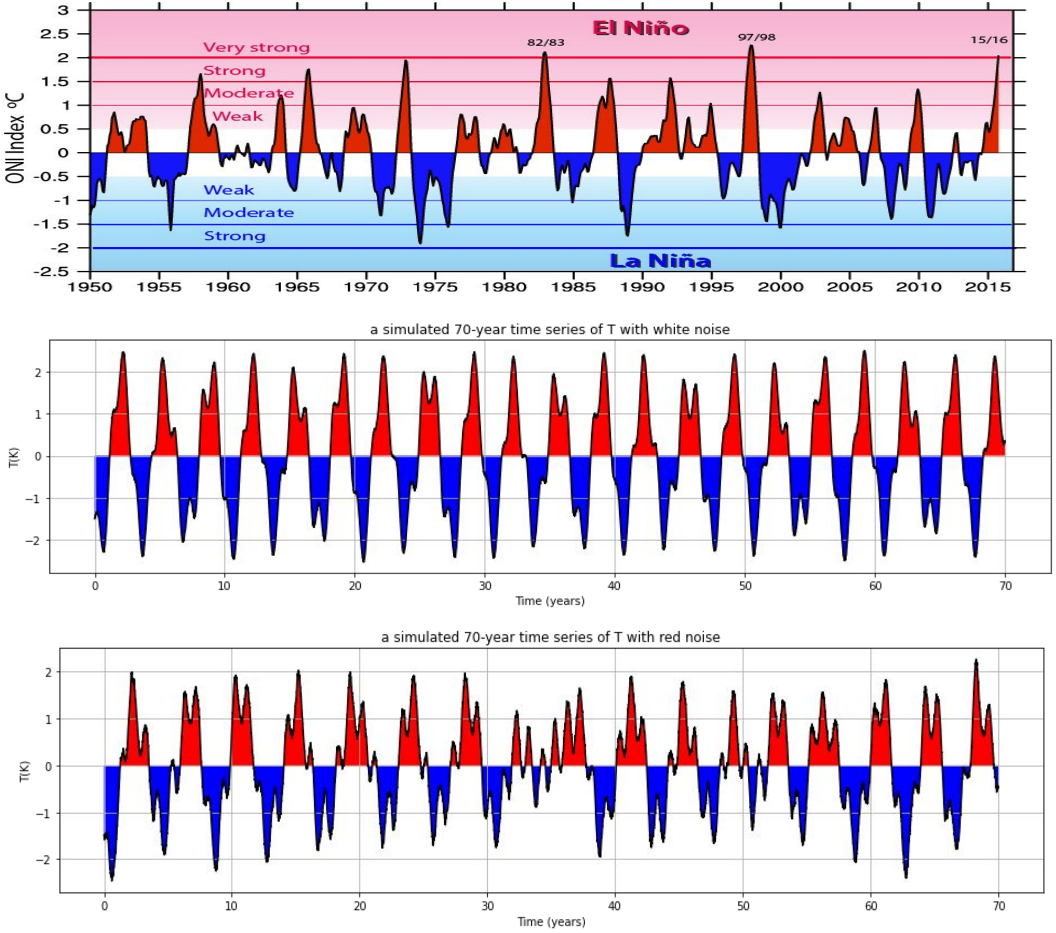


Fig. 6: 70-year time series of ONI and model data

Ensemble Model (Red Noise)

Steady oscillation

Not sensitive to initial conditions

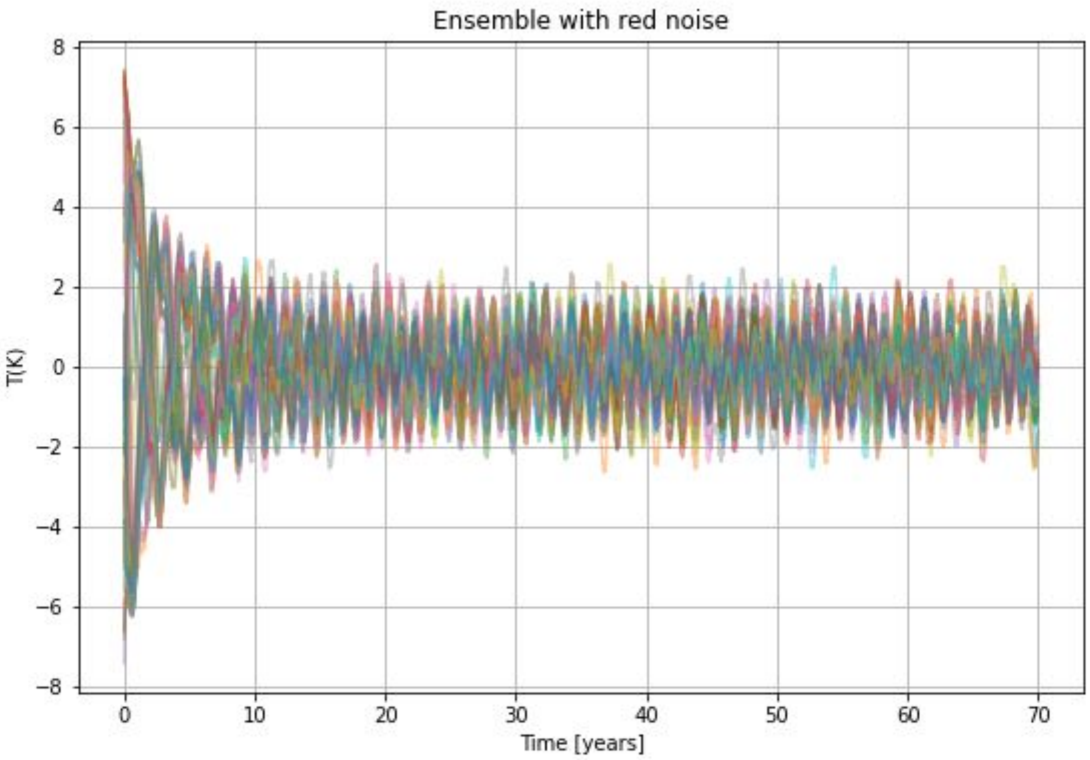


Fig. 7: Ensemble with red noise (70 years).

Comparison of Ensemble with Reality

Grey: white noise
Red: red noise
Blue: NINO34 data

Model matches observations

Note spread of white noise

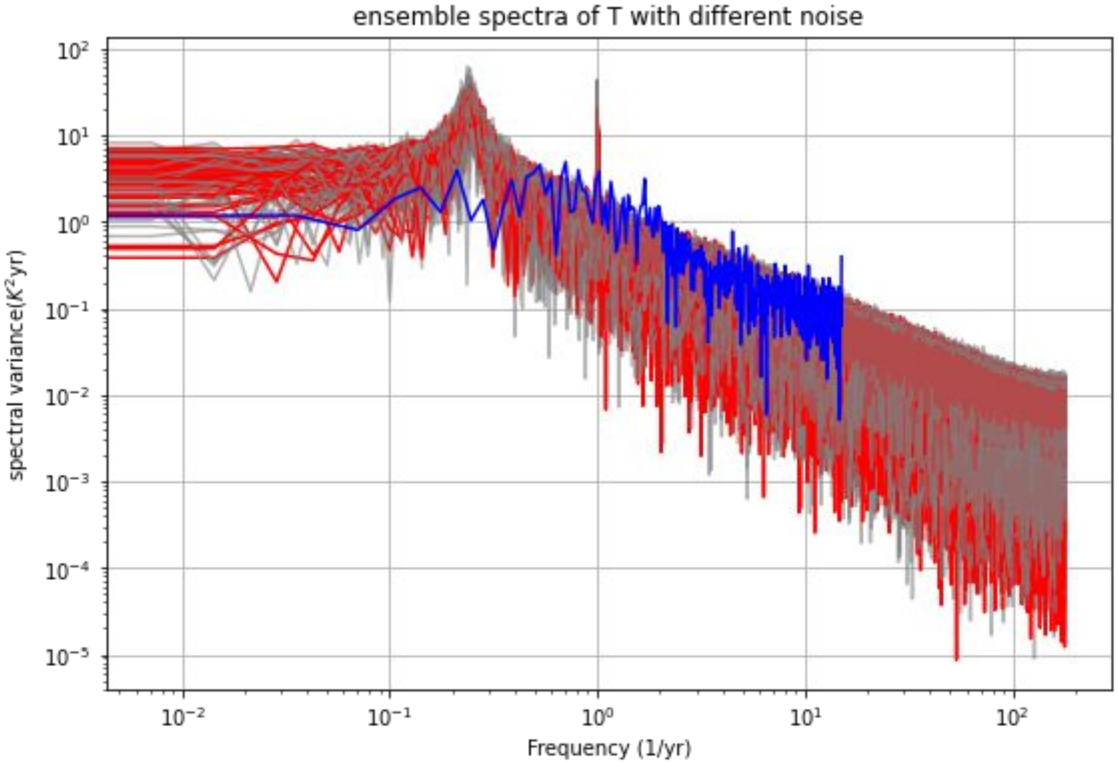


Fig. 8: Fourier spectra for real ENSO and model with white/red noise

5) Summary and Discussion

$$\frac{dT}{dt} = RT + \gamma h$$
$$\frac{dh}{dt} = -rh - \alpha bT \qquad (1)$$

- Model is a coupling between thermocline height and SST.
- Model simulates key features
    - Period, duration, amplitude,trajectory
- Nonlinearity and red noise are important
- ENSO predictable on short timescales
- Simple, old model. More complex interpretations now. [See Timmerman et al, 2018]

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