Spectra related to the El Nino Southern Oscillation

CESM workshop, June 20, 2018

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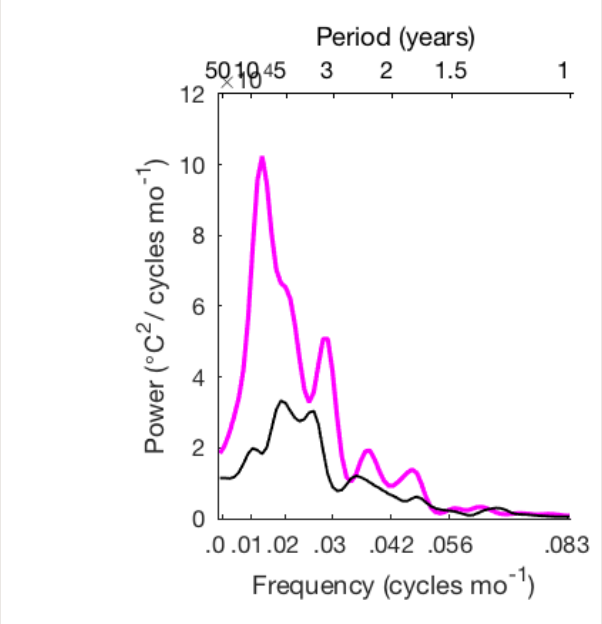
National Center for Atmospheric Research

Spectra of 1PC of tropical SSTs, CESM2.0



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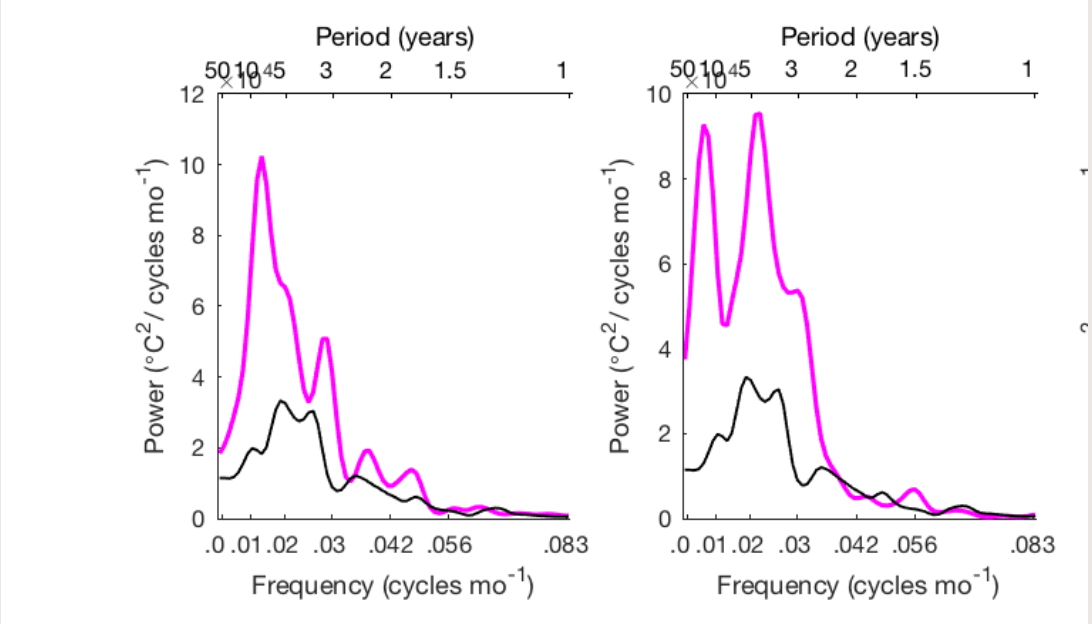
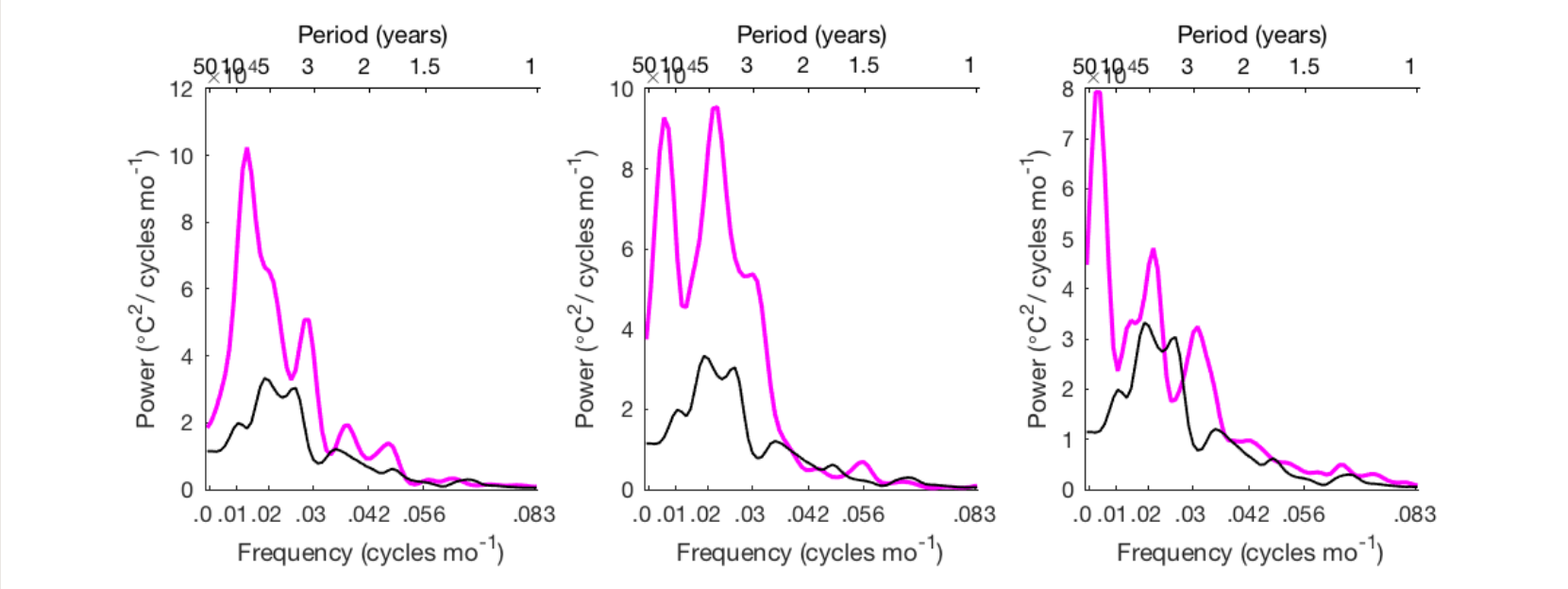


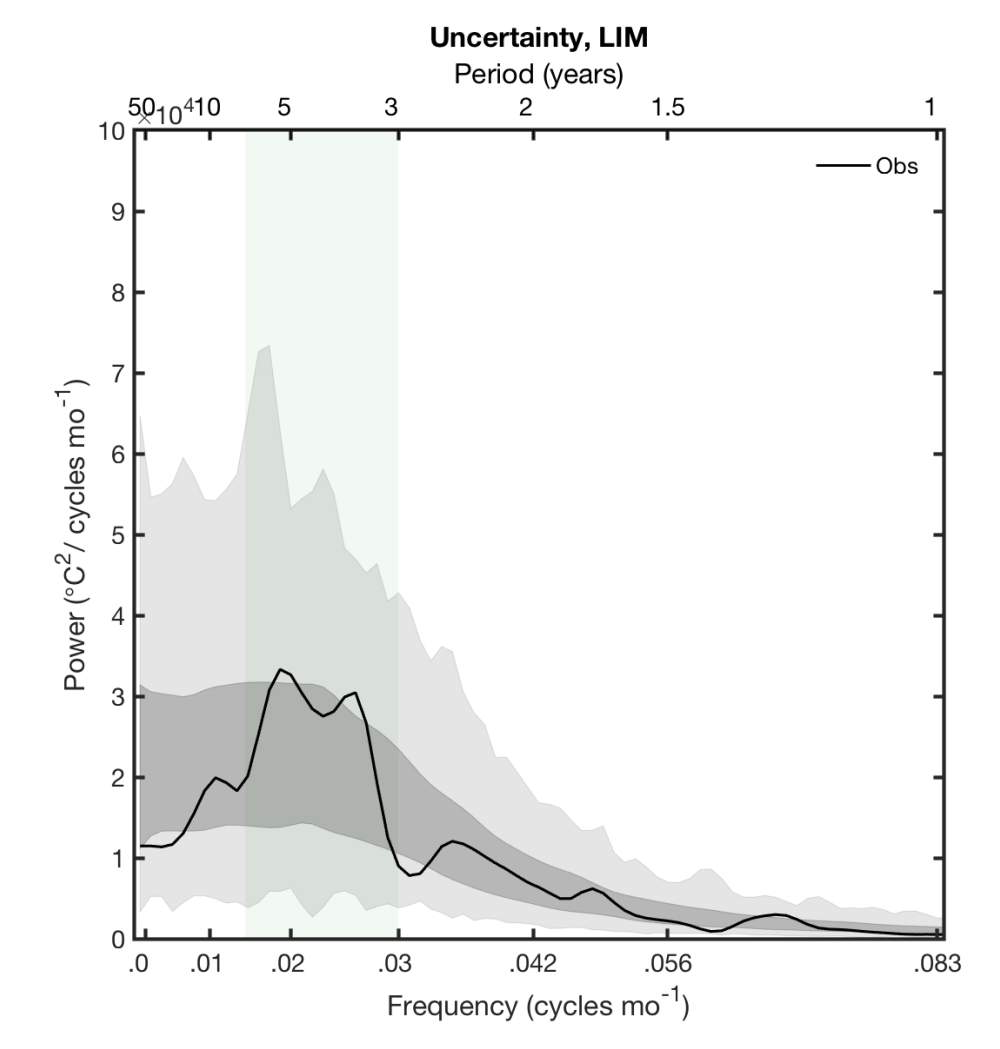
Spectra of 1PC of tropical SSTs , CESM2.0



- We would like to use a statistical model to get uncertainty from an single 100-year run.
- Hypothesis: Observed spectra of interannual variability lie within the uncertainty of those produced by a LIM (Newmann et al 2008)

Spectrum of tropical PC1, OBS

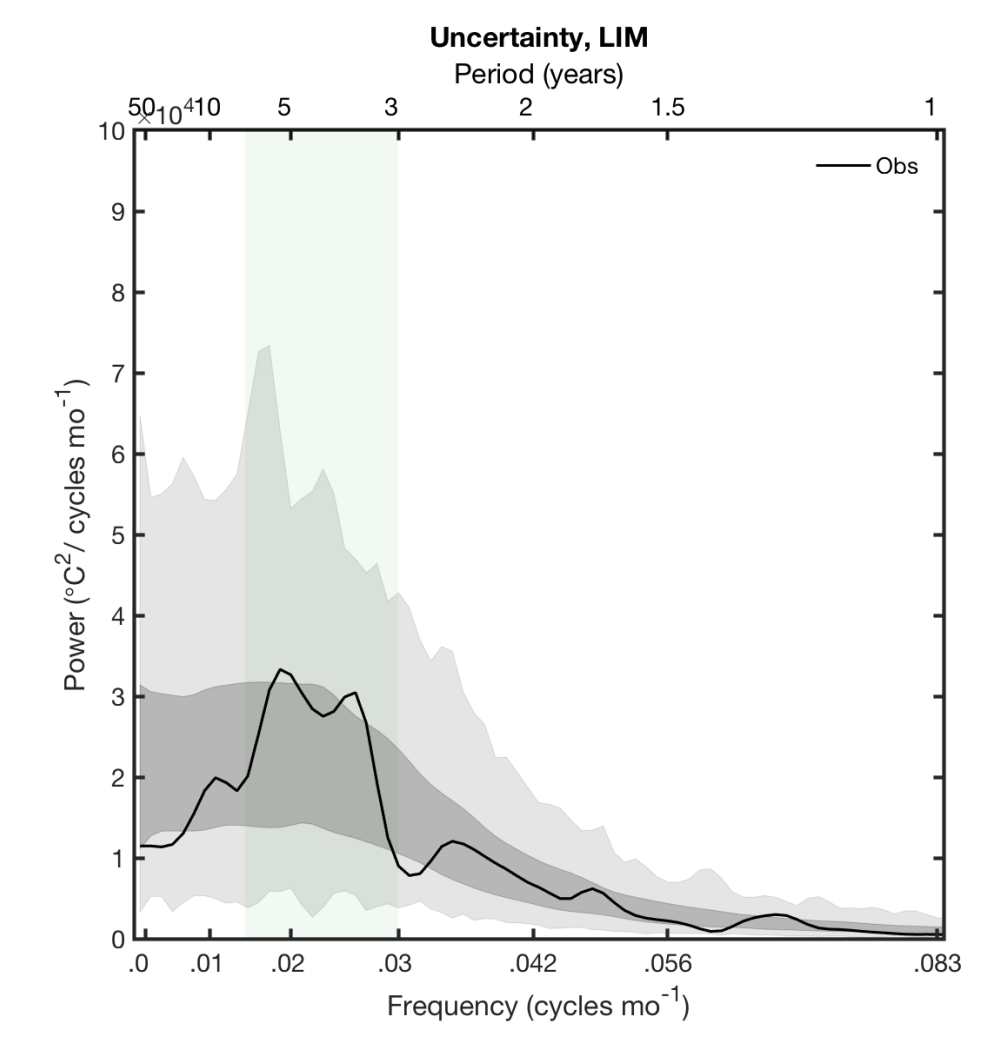
- Fit LIM to monthly means of observed SSTs in tropical band
- Generate 500 samples for 100 years each from the LIM
- **Light shading**: shows max/min power from all samples
- **Dark shading:** standard deviation



Spectrum of tropical PC1, OBS

- For most frequencies the OBS spectrum lies within one standard deviation of the LIM spectra. Nowhere does the observed spectrum lie outside the max/min values of the LIM

- The observed spectrum is not inconsistent with the LIM hypothesis.

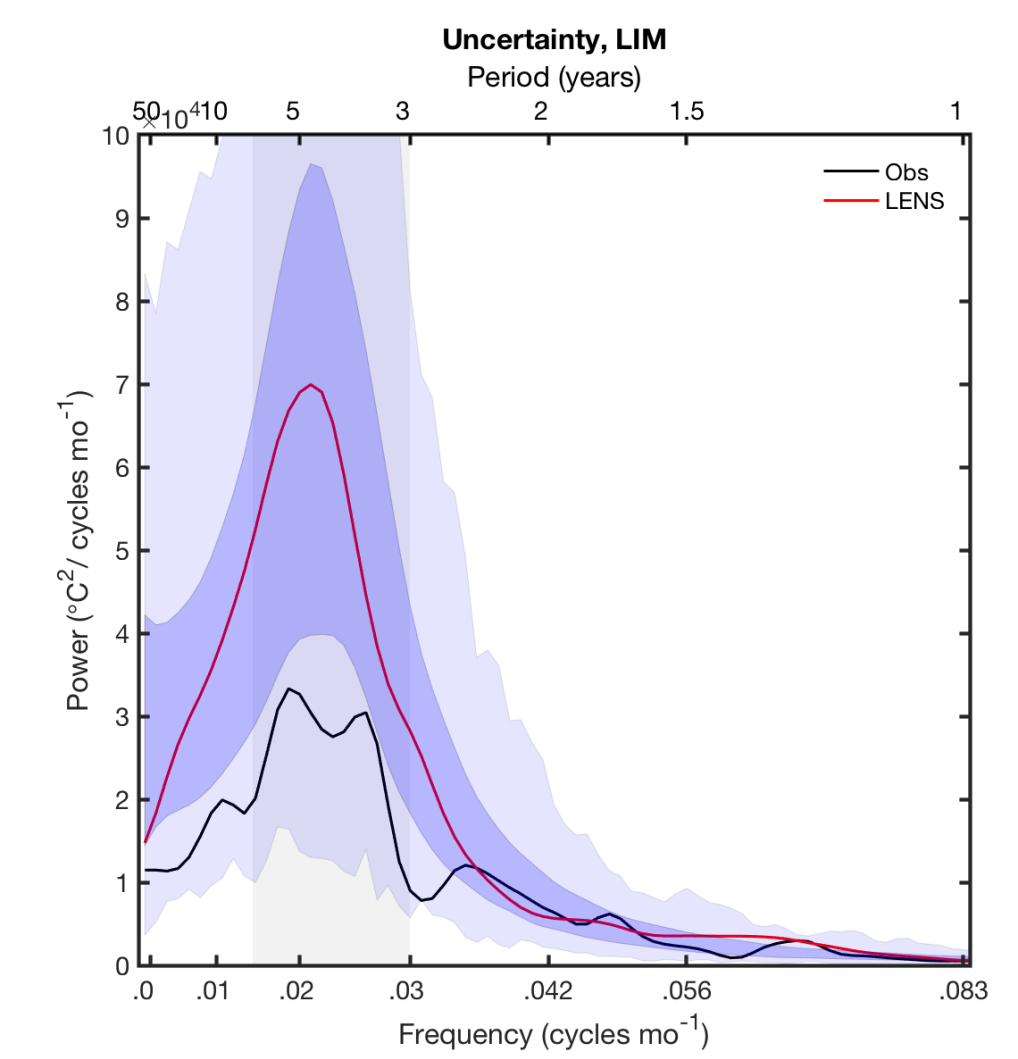


Experiments/Data

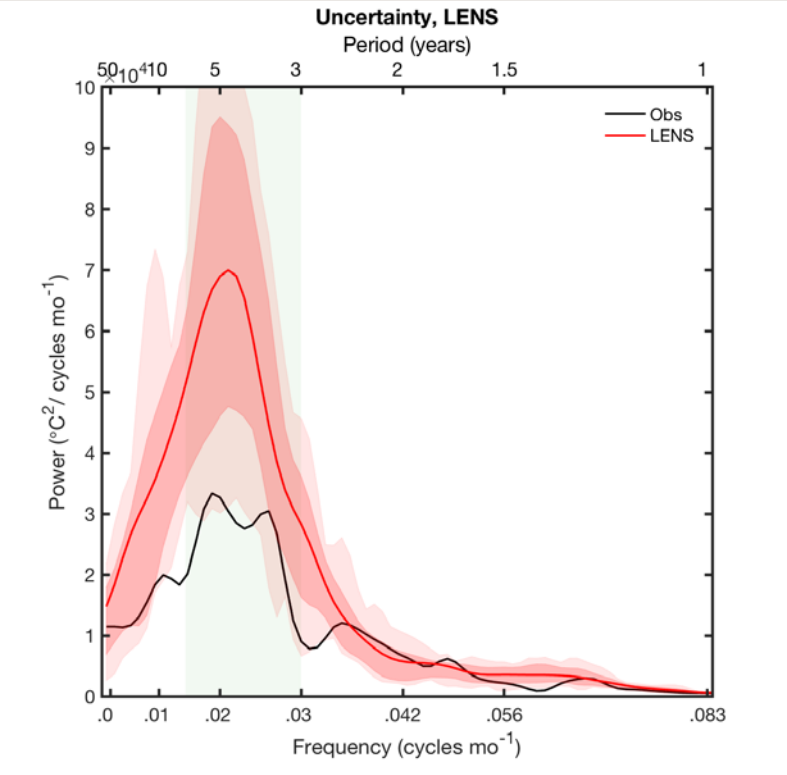
- Experiments:
  - Large Ensemble CESM1.1 (LENS), 1850CNTL
  - CESM2.0, 1850CNTL
- ECMWF reanalysis of 20th-century (ERA-20C) = OBS
  - 1900-2010 => 111 years
- All results based on 100 year subsets
- Caveat: ENSO in experiments with different forcing are compared to each other

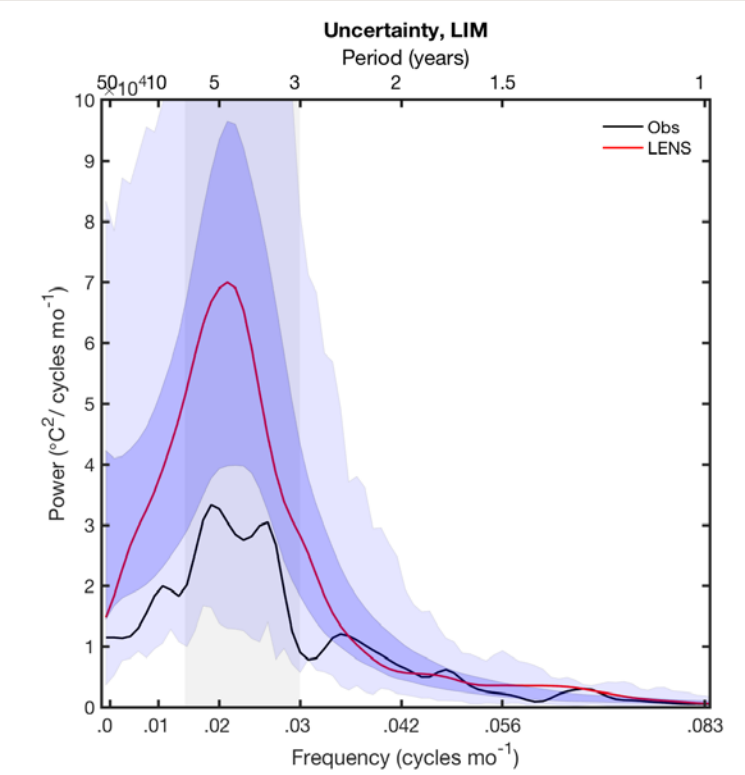
LENS with uncertainty from LIM

- Fit a LIM to the LENS 1850CNTL (1800 years)
- The LENS spectrum is not inconsistent with the LIM hypothesis.



Uncertainty in LIM and LENS

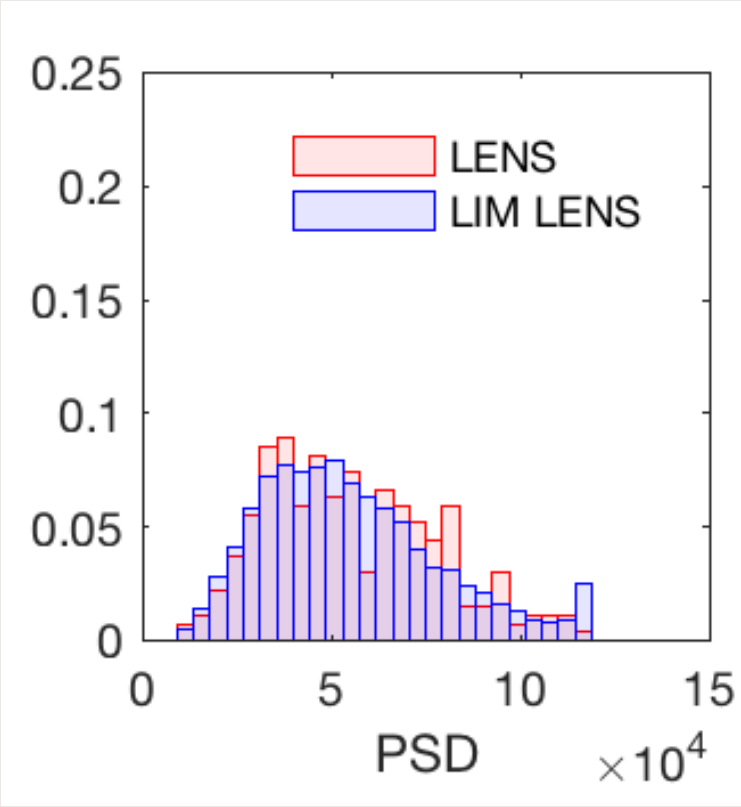




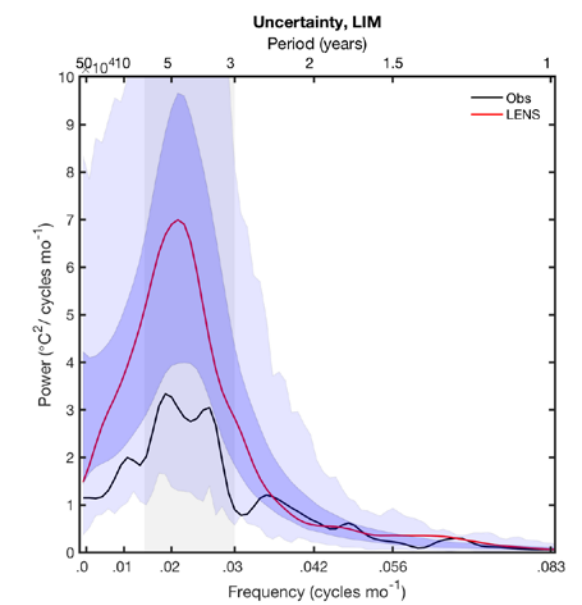
- Left: Uncertainty given by 18 100yr-simulation from LENS
- Right: Uncertainty given as 500 100yr-simualations from LENS

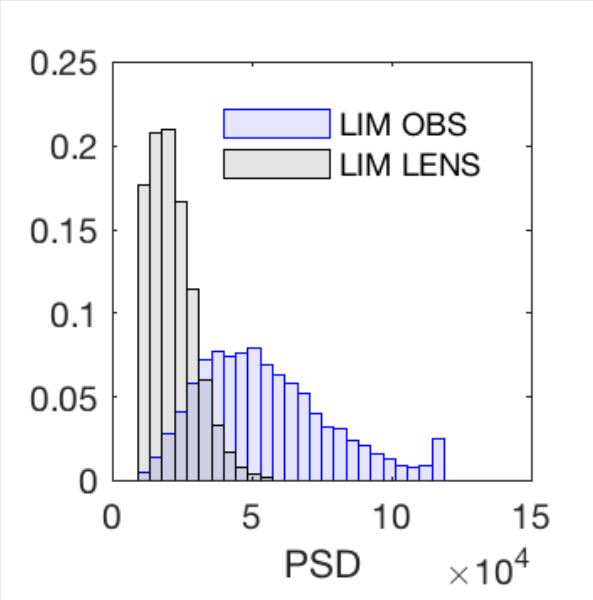
Distribution of power spectral density in ENSO band

- Define ENSO band as spectrum between 3 and 7 years.
- Histogram of power spectral density within ENSO band
- LIM captures uncertainty of power spectra in ENSO band



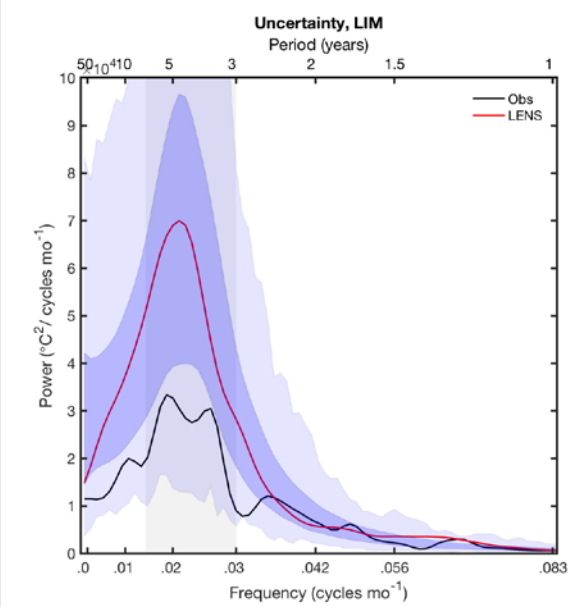
Is the LENS consistent with observations?

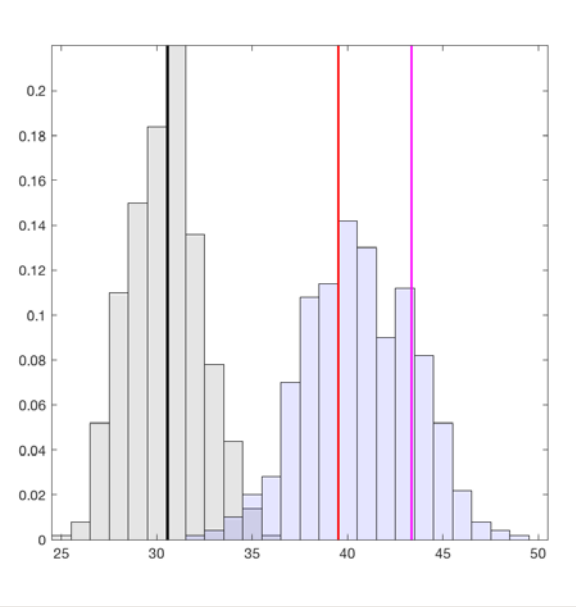




- OBS within light blue shading:
  - We cannot reject the hypothesis that the power spectra density of OBS are within the uncertainty of LENS
- Histogram of power spectral density of LIMs of OBS and LENS do not agree within ENSO band
  - LENS is unlikely consistent with OBS

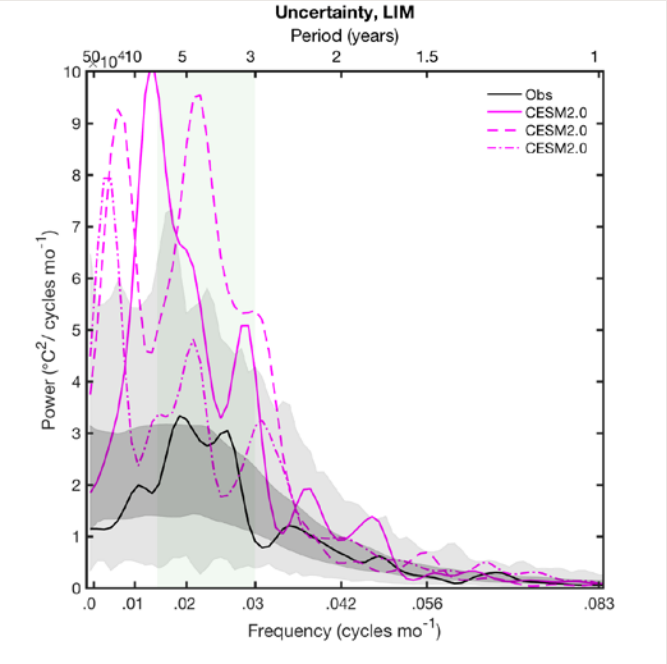
Is the LENS consistent with observations?

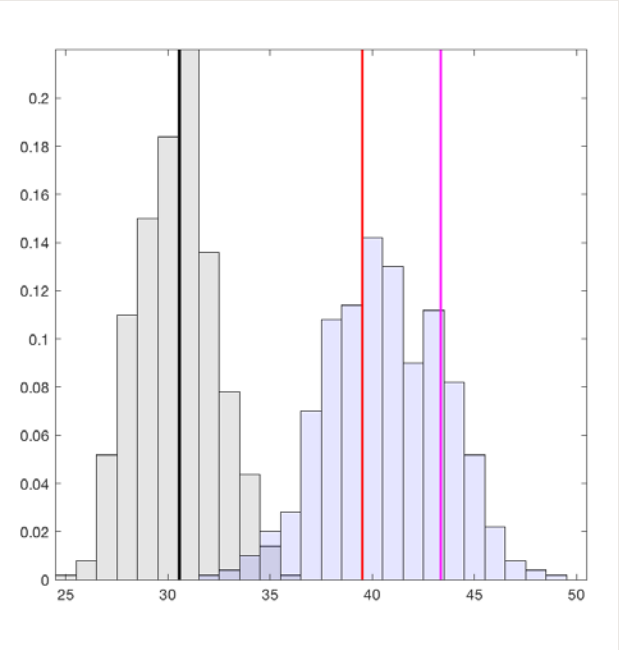




- ❖ Area under spectrum= Variance
- ❖ Variance has to be consistent
- ➢ Variances of PC1 are unlikely consistent, but not impossible

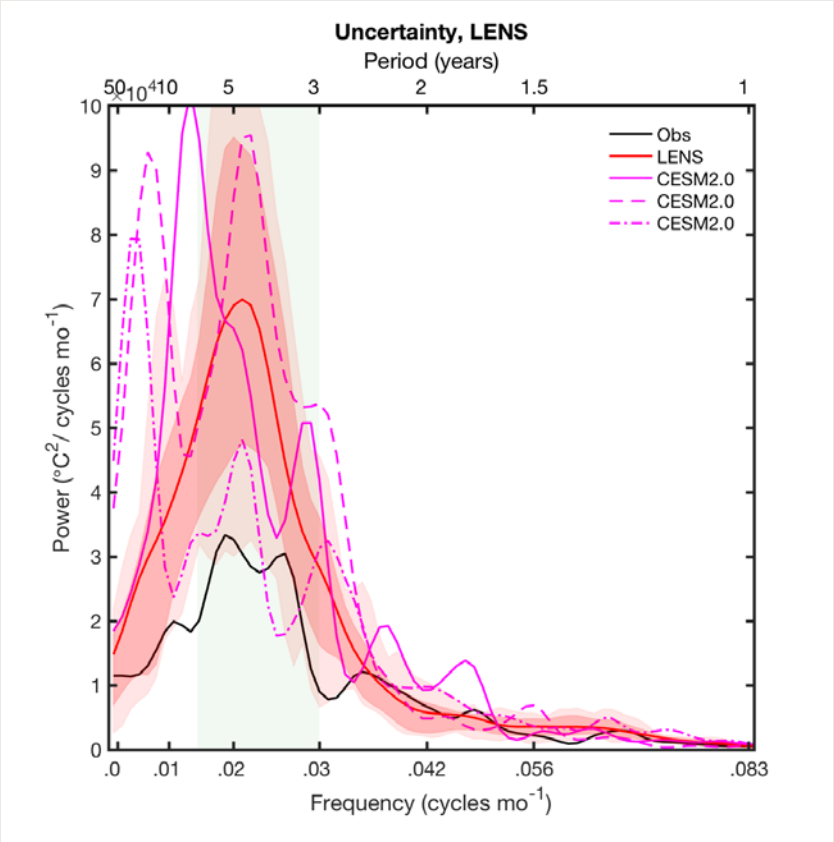
Is CESM2.0 consistent with observations?





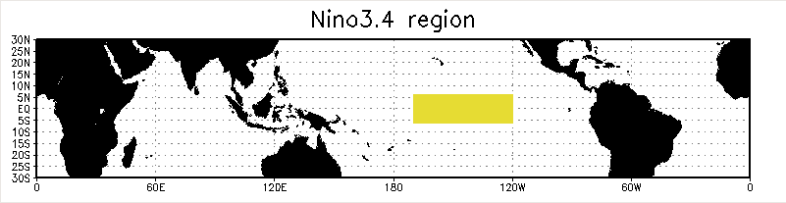
- CESM2.0 outside uncertainty obtained from OBS LIM
- Variance outside variance from OBS LIM
  - CESM2.0 is unlikely consistent with OBS

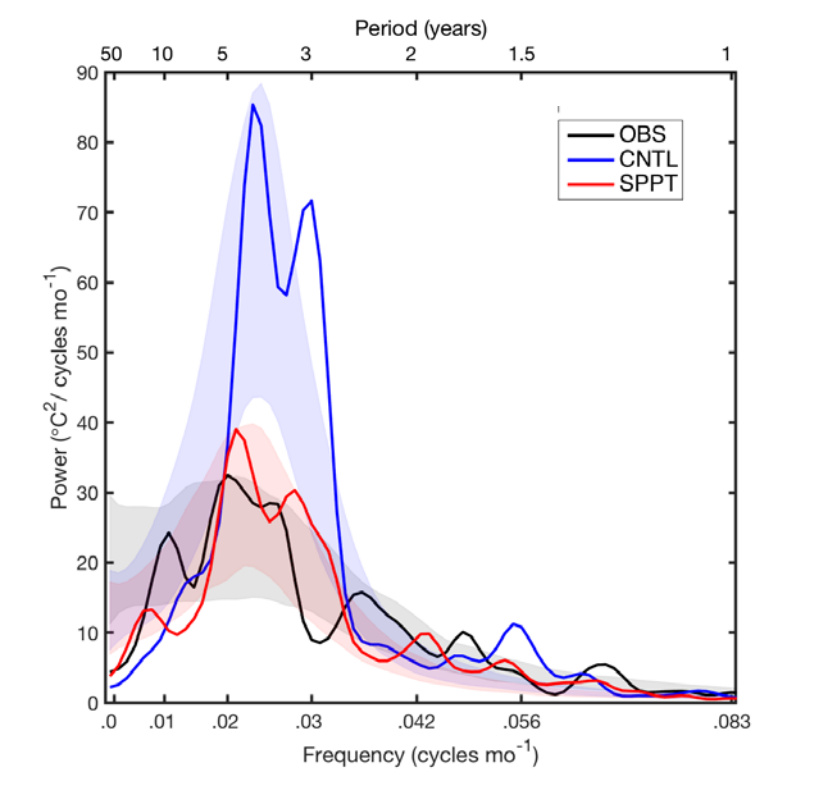
Is CESM2.0 consistent with LENS?



- CESM2.0 outside uncertainty obtained from LENS
  - CESM2.0 is not consistent with LENS

On the dynamical mechanisms governing ENSO regularity

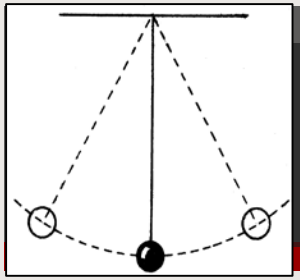




SPPT reduces

- overly regular oscillation
- reduced amplitude of spectral peak

Berner et al. 2018



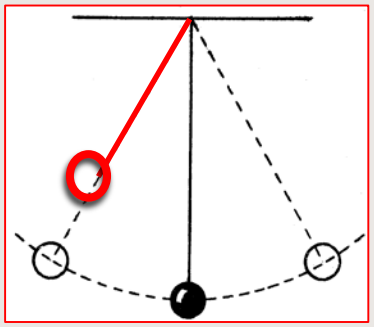
Damped harmonic oscillator forced by white noise

$$\dot{\vec{x}} = L\vec{x} + S\,\vec{\varepsilon}$$

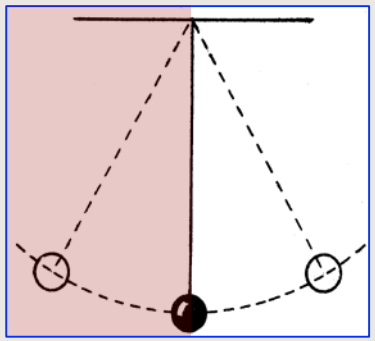
with

$$L = \begin{pmatrix} -\nu & \omega \\ -\omega & -\nu \end{pmatrix}$$

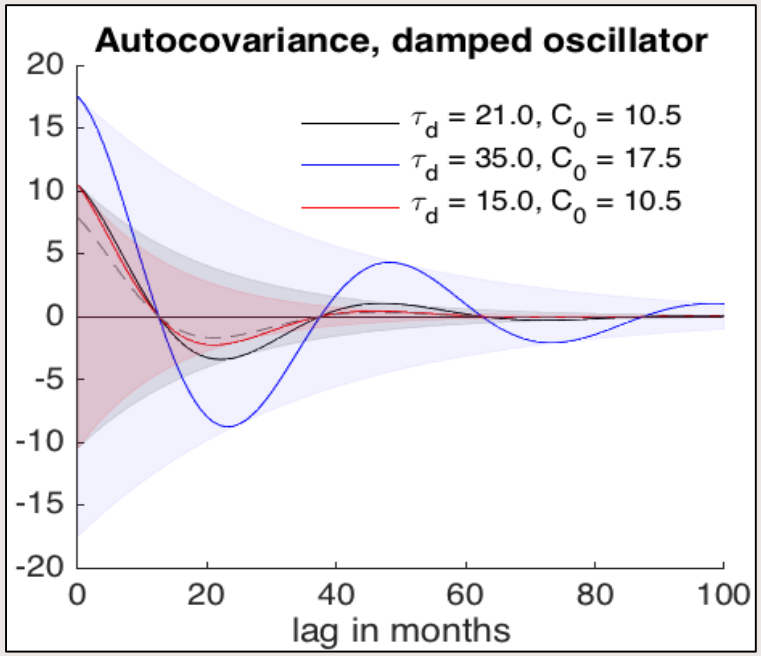
$\vec{x}$	State vector	$\vec{\varepsilon}$	White noise
L	Feedback matrix	S	Noise amplitude matrix
ω	frequency	ν	Damping rate



Perturbing the frequency ω results in decreased memory and no change in variance



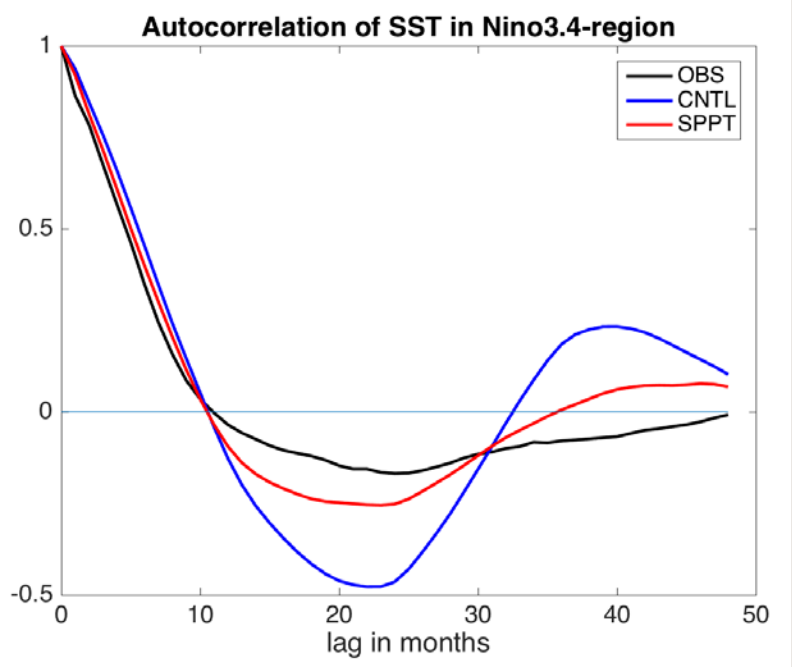
Perturbing the damping rate ν results in increased memory and increased variance



Thank you!

- Christensen, H. M, J. Berner, D. Coleman, Tim N. Palmer: “Stochastic parametrisation and the El Nino-Southern Oscillation”, J. Clim., 2017
- Berner, Sardeshmukh and Christensen, 2018:” Role of perturbed frequency and damping for El Nino Southern Oscillation irregularity, J.Clim,s 2018

Autocorrelation of SST in NINO3.4-region



- **Wiener–Khinchin theorem:** The autocorrelation function of a wide-sense-stationary random process has a spectral decomposition given by the power spectrum of that process.

Linear Inverse Model

Assume the evolution of a system can be described as:

$$\dot{\vec{x}} = \mathbf{L}\vec{x} + \mathbf{S}\vec{\epsilon}$$

L	Feedback matrix
$\vec{\varepsilon}$	White noise
S	White-noise amplitude
C_0	Covariance matrix
C_τ	Lagged covariance matrix
Q	Noise covariance matrix

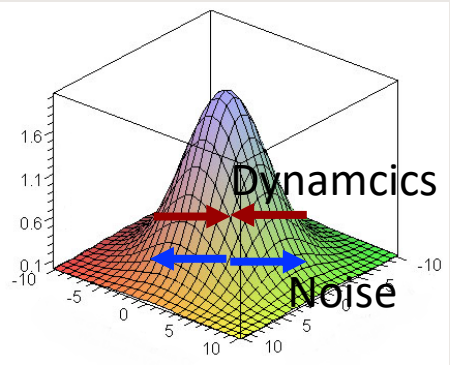
Then, the lagged covariance matrix is given by:

$$\mathbf{C}_\tau = e^{\mathbf{L}\tau}\mathbf{C}_0$$

The fluctuation-dissipation relation (stationary Fokker-Planck equation)

$$\mathbf{L}\mathbf{C_0} + \mathbf{C_0}\mathbf{L}^T + \mathbf{Q} = 0$$

$$\mathbf{Q} = \mathbf{S}\mathbf{S}^T$$



Penland and Sardeshmukh, 1995