Bibliography: Stochastic models

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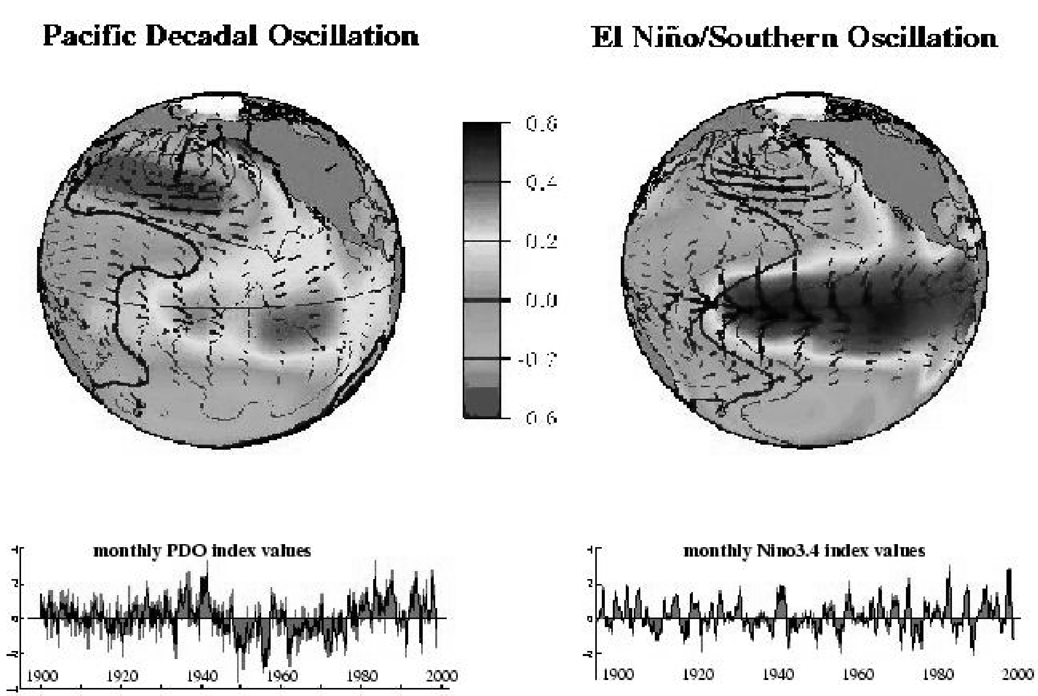
Hasselmann, K., 1976: Stochastic climate models, Part I. Theory. Tellus, 28, 473-484.


Pacific Decadal Oscillation
El Niño/Southern Oscillation
0.6
0.4
0.2
0.0
-0.2
-0.6
monthly PDO index values
monthly Nino3.4 index values
1900
1920
1940
1960
1980
2000

Hasselmann 1976

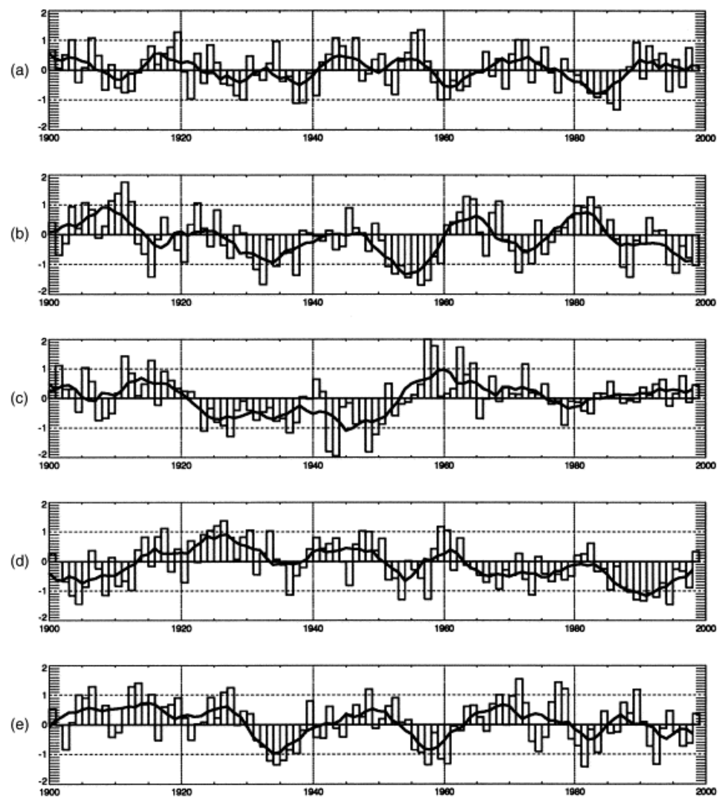
- Assume that the climate system can be split into two subsystems, that are characterized by strongly differing response times (for example 'weather' and 'climate'.
- The evolution of the slow component is then determined its own state, and by the statistics of the 'weather' system for a given climate state, that is retained as a forcing term.
- The slow climate variable then integrates this stochastic forcing and leads to 'red' variance spectra.
- In the absence of a negative feedback, the variance of the slow climate variable increases with time (as the square root of ~).
- The problem of climate variability "is not to discover positive feedback mechanism that enhance small variations of external forcing and produce instabilities, but .. to identify the negative feedback that .. balances the continual generation of climate fluctuations by random driving forces"

Stochastic Forcing

$$\frac{dT}{dt} = -\lambda T + F$$

$$T(t) = \int_{t_0}^{t} dt' \; F(t') \, e^{-\lambda(t-t')} + e^{-\lambda(t-t_0)} \, T(t_0)$$

$$\tilde{T}(\omega)\tilde{T}^{\star}(\omega) = \frac{\tilde{F}(\omega)\tilde{F}^{\star}(\omega)}{\lambda^2 + \omega^2}$$



Pierce 2001

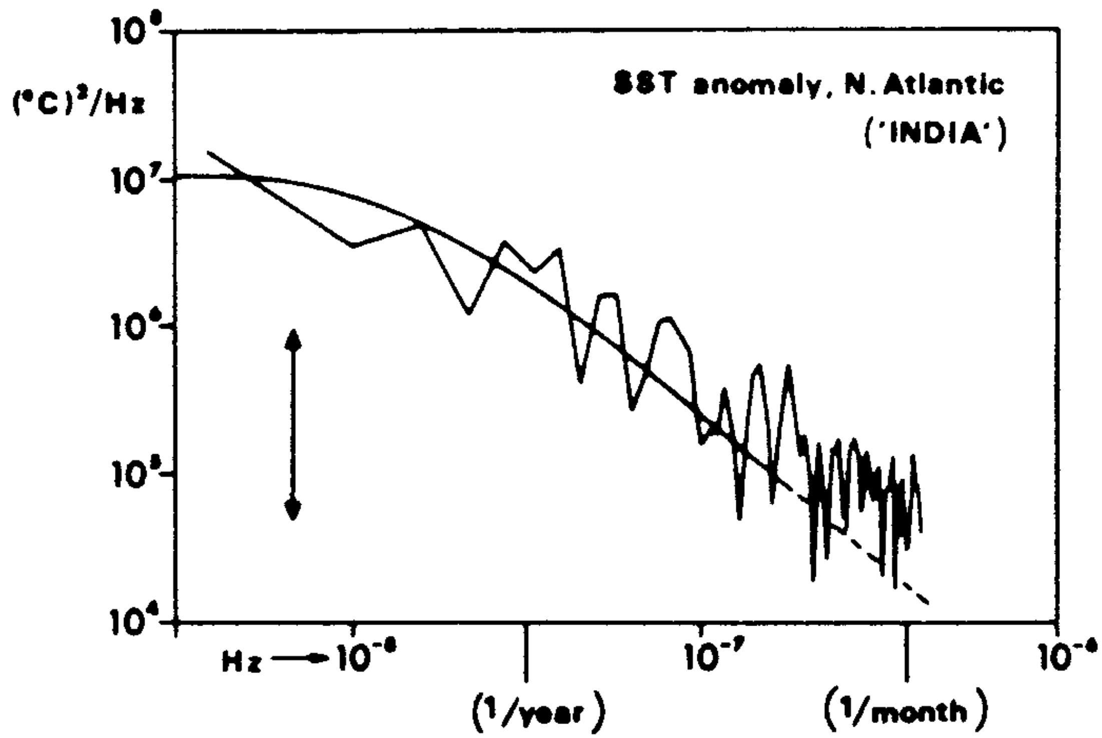


Fig. 17. SST anomaly spectrum at weathership I (59°N, 19°W) for the period 1949–1964, with 95% confidence interval. The smooth curve was estimated from relation (24) using sensible and latent heat flux forcing only, and $\lambda = (4.5 \text{ month})^{-1}$ [after *Frankignoul and Hasselmann*, 1977].

Frankignoul 1985

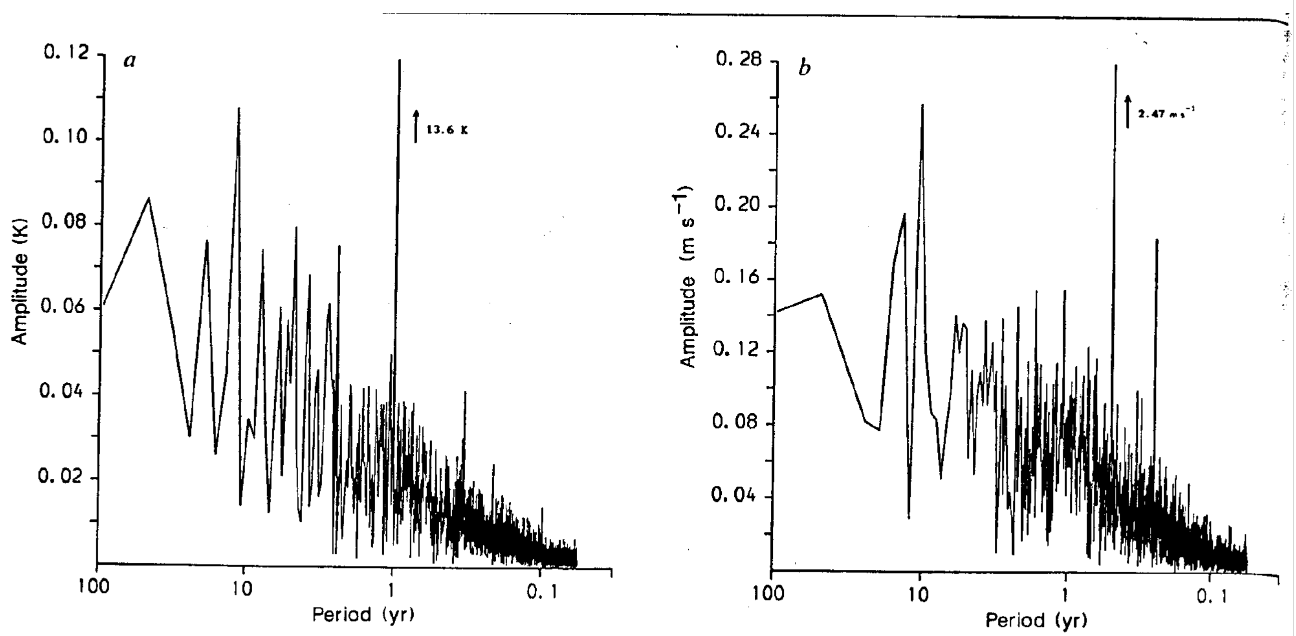


FIG. 2 Spectrum of the time variations of two selected spherical harmonic coefficients during the last 96 years of the model integrations. *a*, The Y_1^0 temperature coefficients, averaged with respect to pressure, giving the mean pole-pole temperature difference. *b*, The Y_1^0 vorticity coefficient, averaged with respect to pressure, giving the mean solid-body rotation component of the atmospheric motion relative to the Earth.

James and James 1989

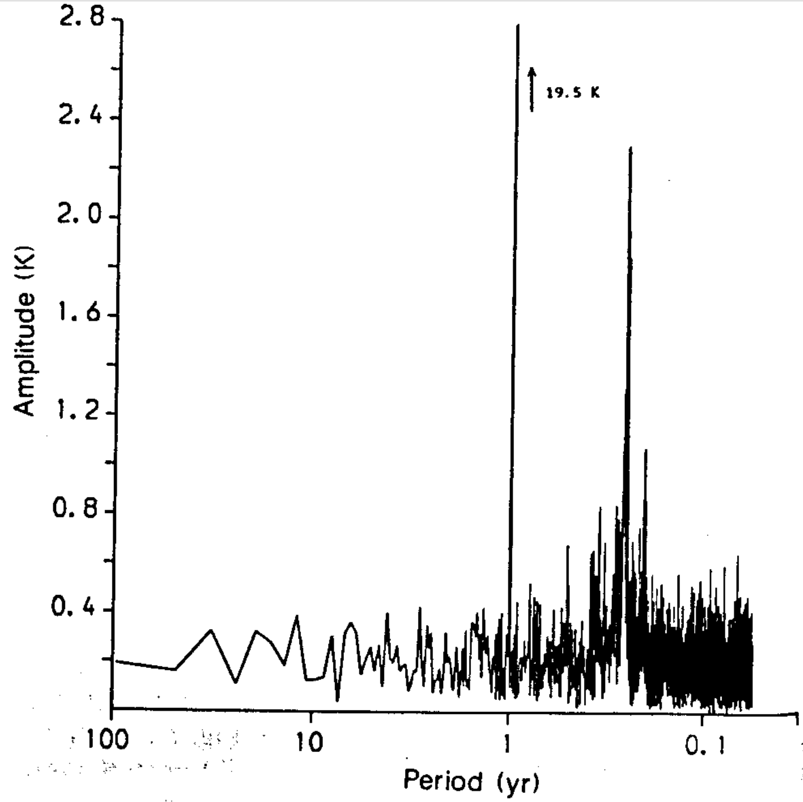


FIG. 3 Spectrum of the time variations of the surface temperature at a grid point at 47°N in the model.

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James and James 1989

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Fig. 5. Spectrum of SST anomaly at Ocean Weather Ship India for the period 1949–1964 (after Frost, 1975). The arrows indicate the 95% confidence interval. The smooth curve was calculated from relation (4.1) with h = 100 m, $\lambda = (4.5 \text{ month})^{-1}$.

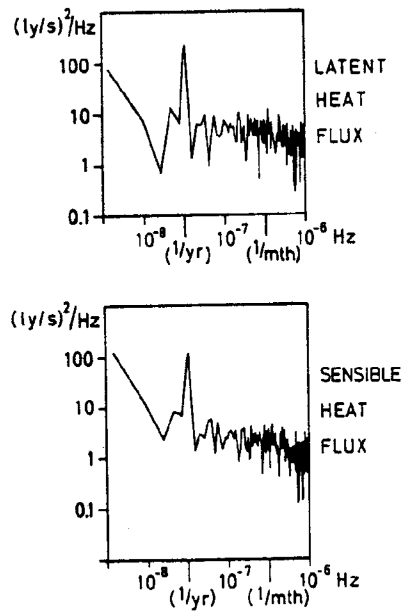


Fig. 6. Spectra of latent and sensible heat flux at Ocean Weather Ship India for the period 1949–1964 (after Frost, 1975).

Frankignoul and Hasselmann 1978

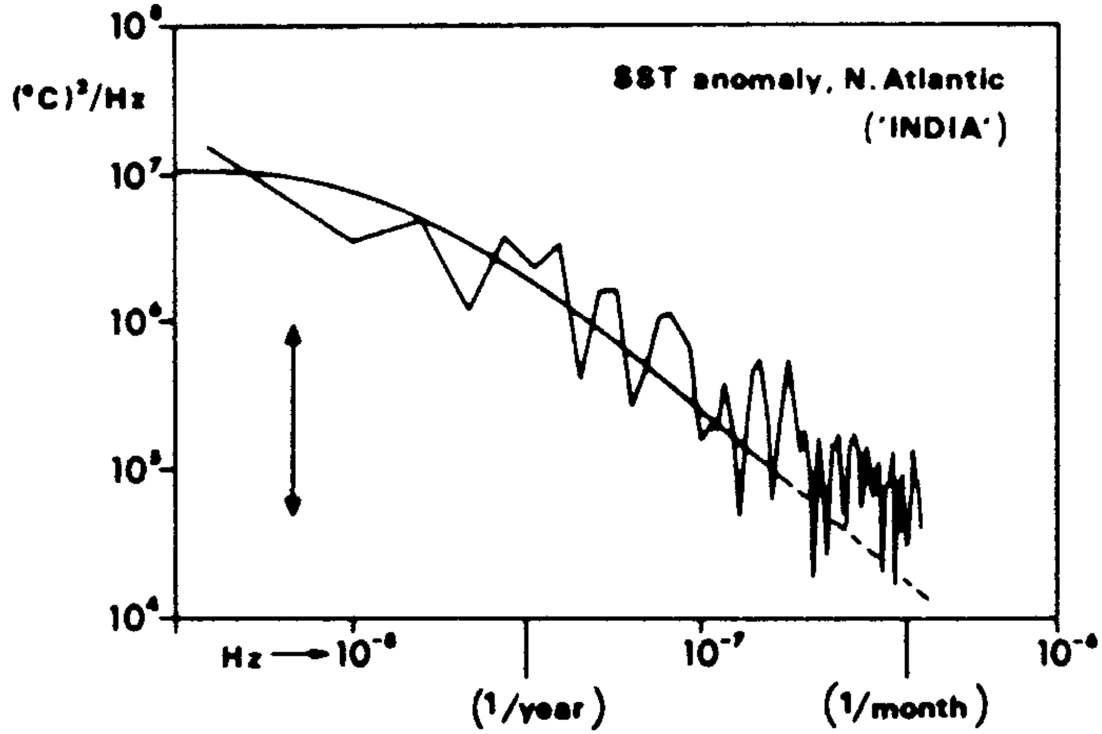


Fig. 17. SST anomaly spectrum at weathership I (59°N, 19°W) for the period 1949–1964, with 95% confidence interval. The smooth curve was estimated from relation (24) using sensible and latent heat flux forcing only, and $\lambda = (4.5 \text{ month})^{-1}$ [after *Frankignoul and Hasselmann*, 1977].

Frankignoul 1985

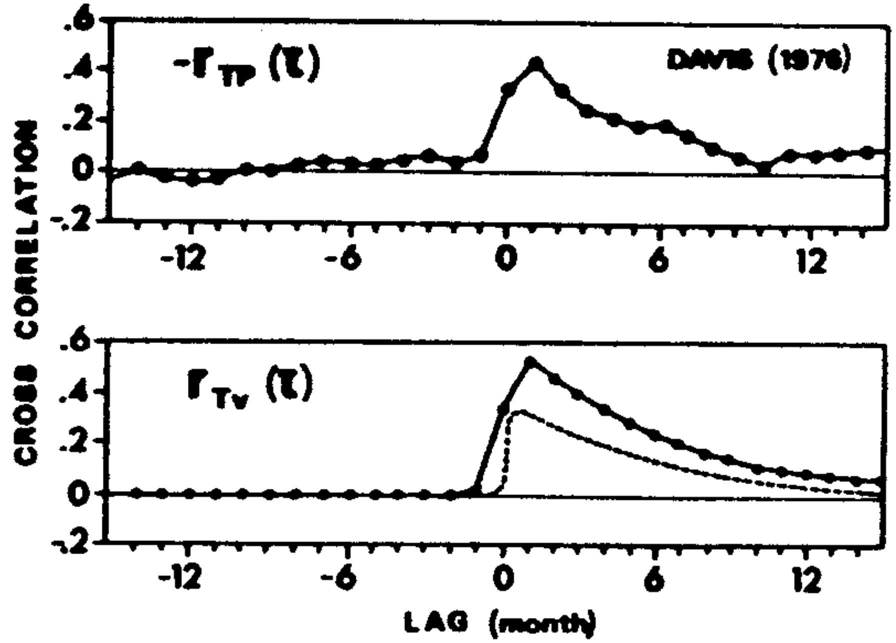
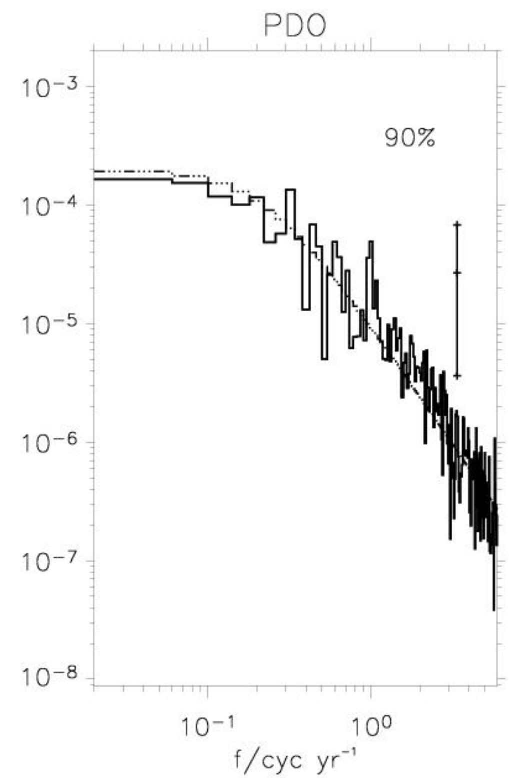


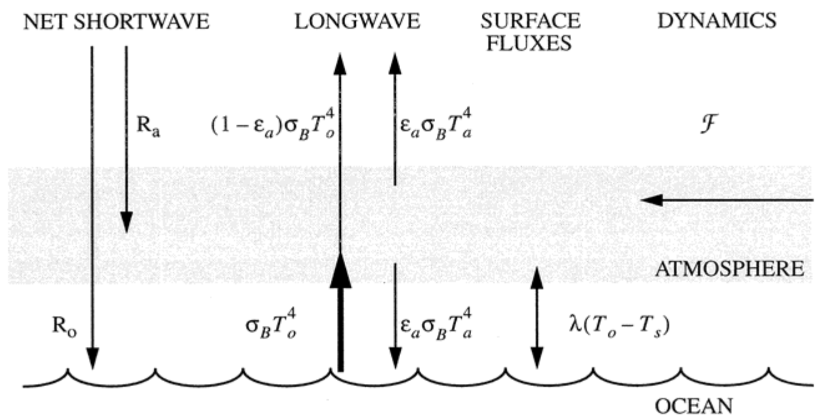
Fig. 20. (Top) Observed correlation between the dominant empirical orthogonal function of SST and sea level pressure anomalies over the North Pacific as estimated by *Davis* [1976]. (Bottom) Theoretical correlation for $\nu = (8.5 \text{ day})^{-1}$, $\lambda = (6 \text{ month})^{-1}$ without smoothing (dashed line) and as estimated from monthly averaged data (continuous line).

Frankignoul


PDO
90%
10−3
10−4
10−5
10−6
10−7
10−8
10−1
100
f/cyc yr−1

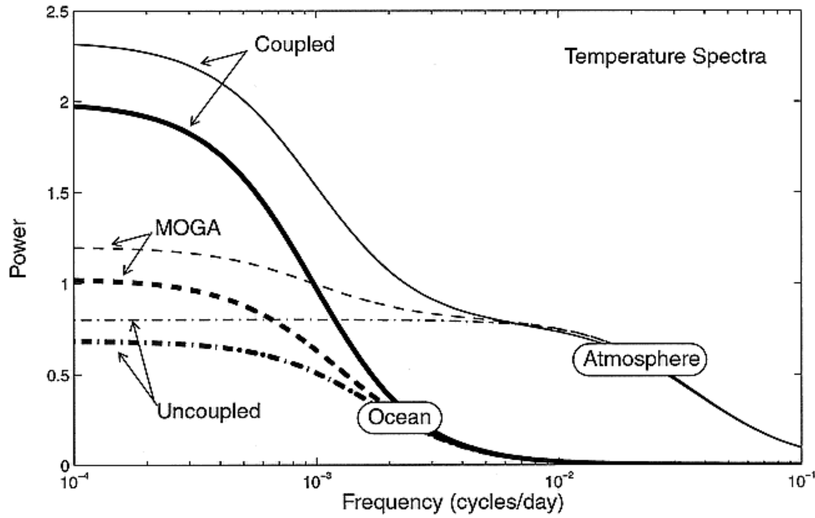
Ocean-Atmosphere Thermal Coupling

Barsugli and Battisti (JAS, 1998) model

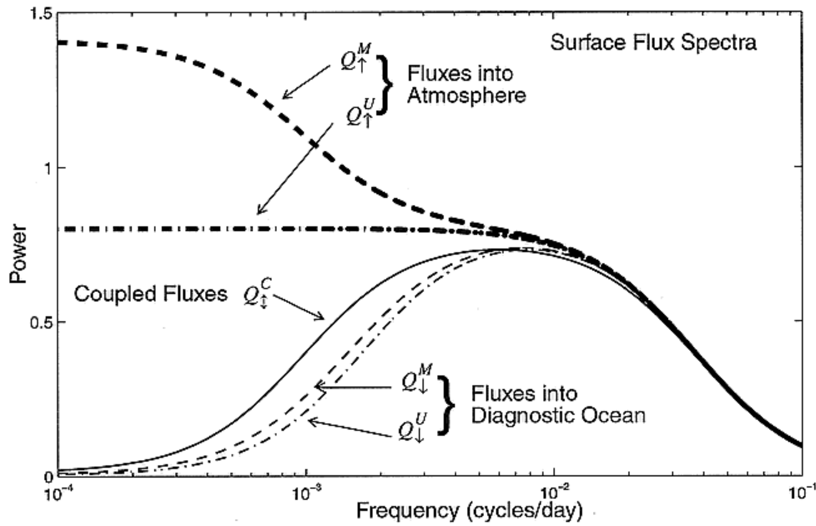


$$\gamma_a \partial_t T_a = -\lambda_{sa}(T_s - T_o) - \lambda_a T_a + F$$

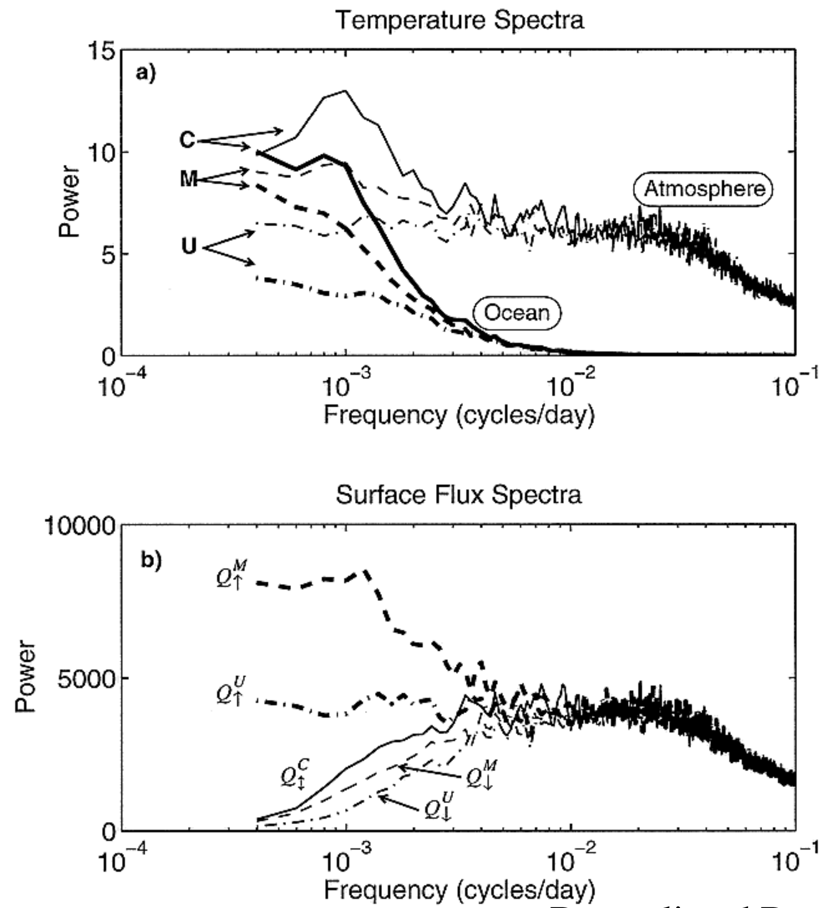
$$\gamma_o \partial_t T_o = -\lambda_{so}(T_s - T_o) - \lambda_o T_o$$



Barsugli and Battisti JAS 1998

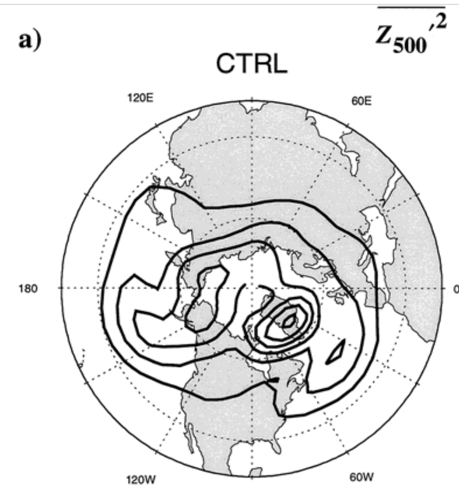


Barsugli and Battisti JAS 1998

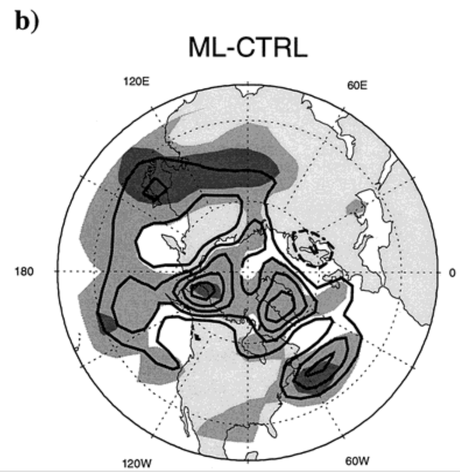


Barsugli and Battisti JAS 1998

Variance of 90 day mean geopotential height at 500 mb in AGCM forced with climatological (fixed) SST. Contour is 600m^2

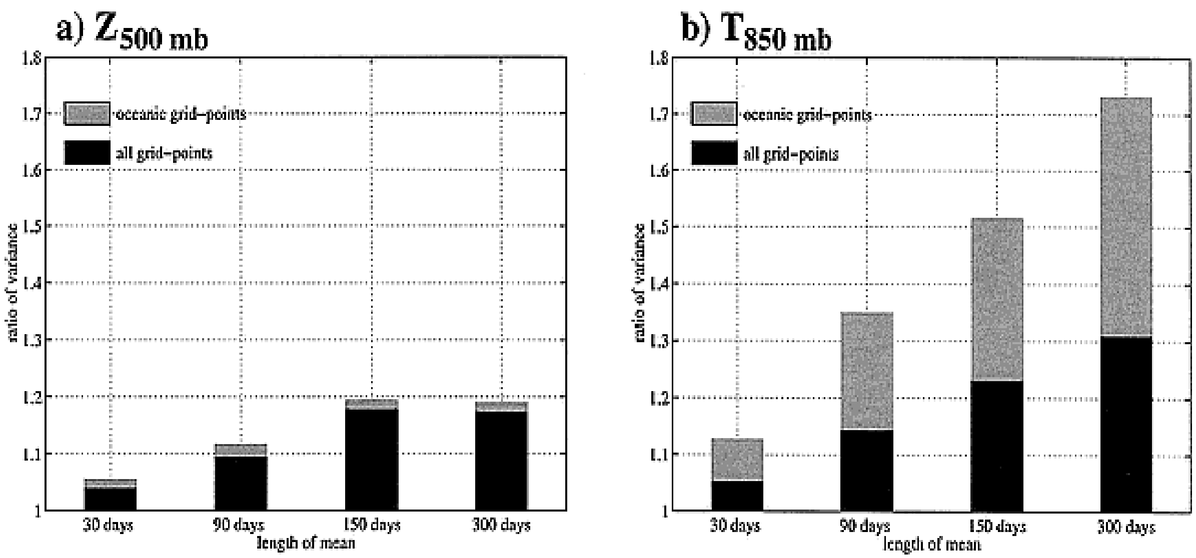


Difference of 90 day mean variance between AGCM coupled to a slab mixed layer ocean and CNTR. Contour 100m^2, neg. dashed. Shading is 10% and 20% relative difference.

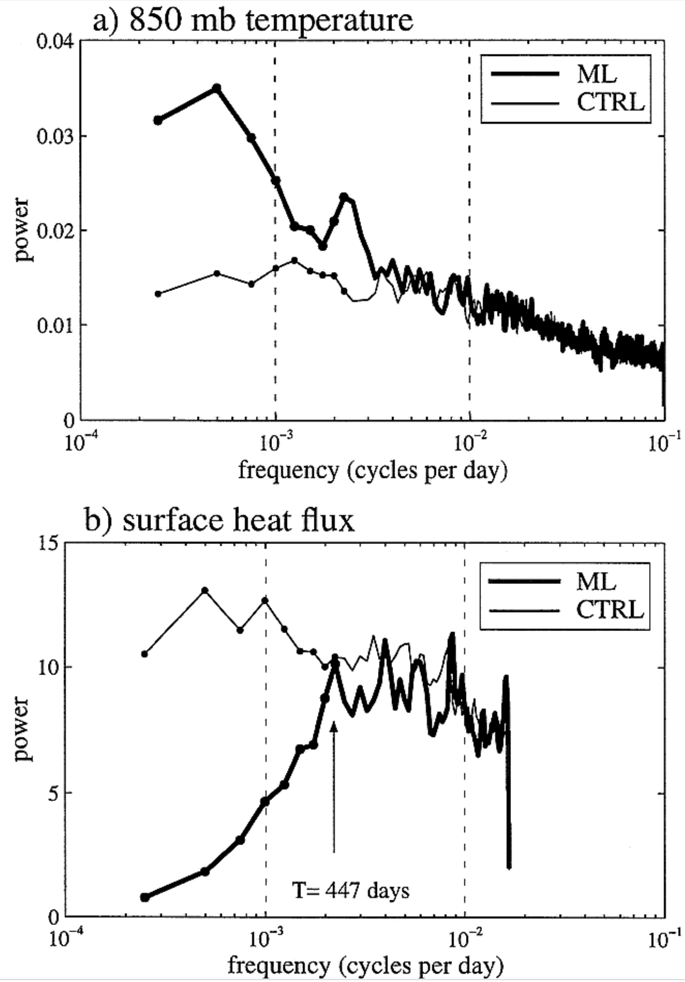


Blade 1997

ML to CTRL ratio of integrated NH variance

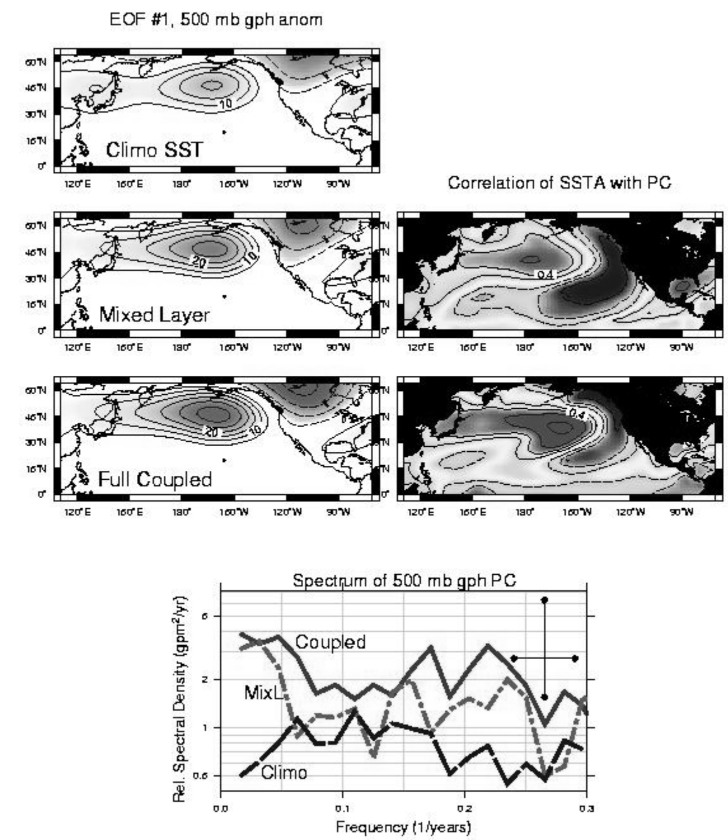


Blade 1997


a) 850 mb temperature
0.04
0.03
0.02
0.01
0
power
ML
CTRL
10^{-4}
10^{-3}
10^{-2}
10^{-1}
frequency (cycles per day)
b) surface heat flux
15
10
5
0
power
ML
CTRL
T= 447 days
10^{-4}
10^{-3}
10^{-2}
10^{-1}
frequency (cycles per day)

Blade 1997

Leading mode of N. Pacific Variability, CCM3



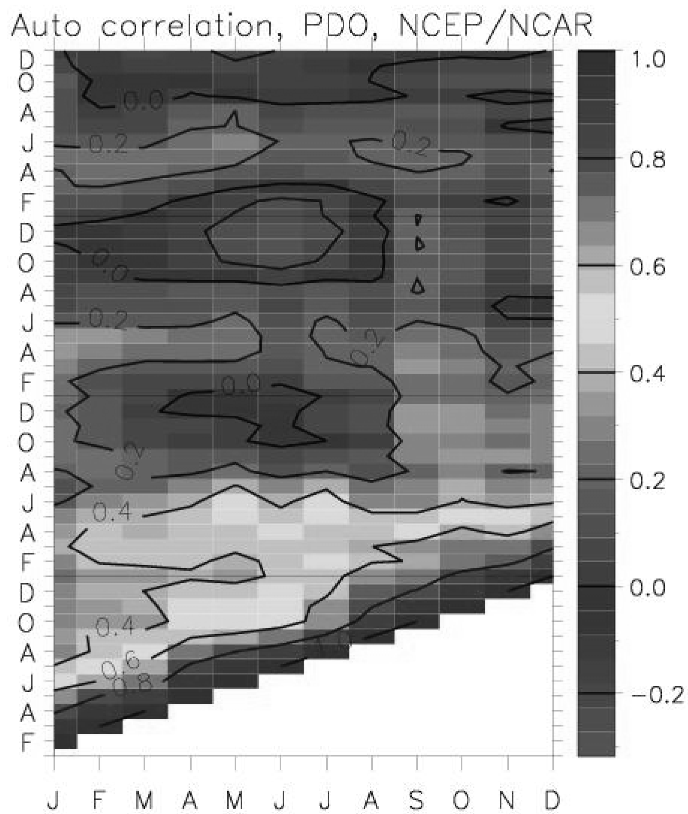
from Pierce, Prog. Oceanogr., 2001

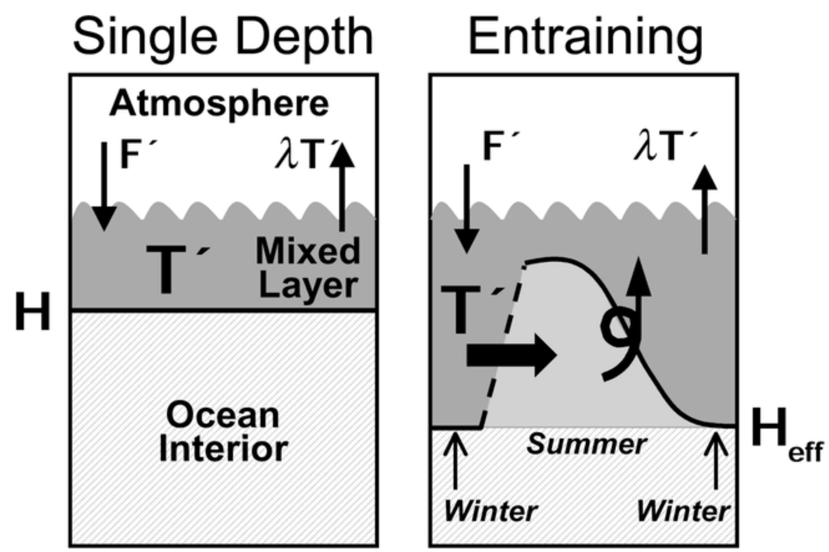
Basic effect of atmosphere-ocean thermal coupling:

- increases variance in both media, while patterns are largely unchanged
- decrease energy flux between them
- prescribing SST does not yield the proper simulation of low frequency variance in the atmosphere (will yield the atmospheric mode least damped by the damping at the surface)

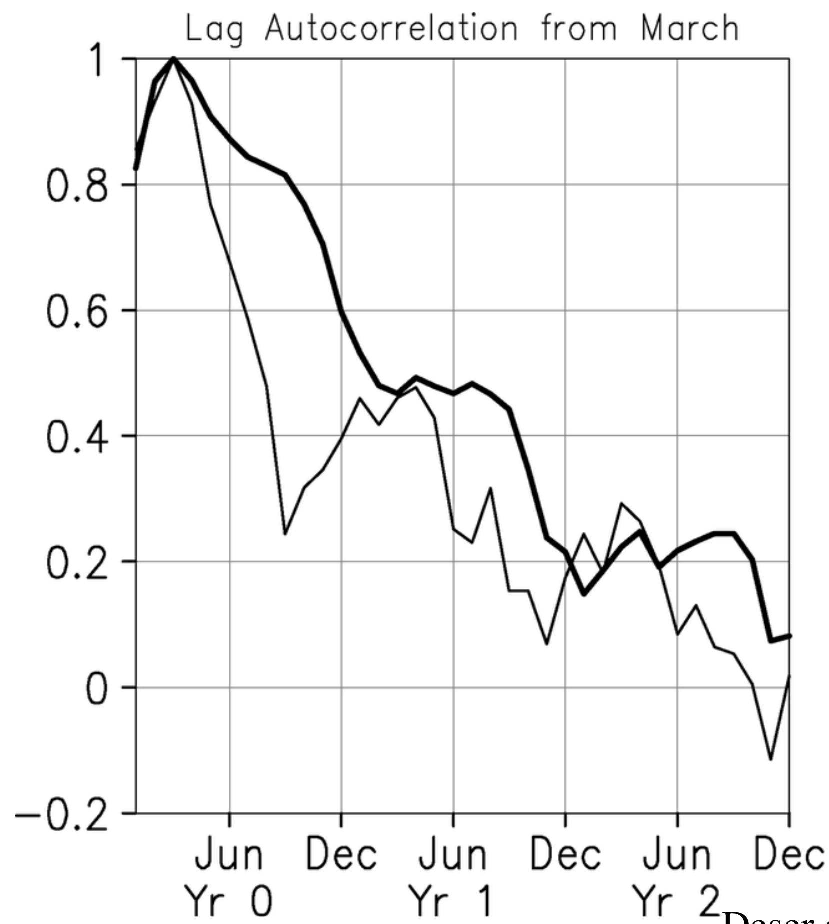
Processes contributing to increased persistence of SST:
Reemergence

$$\frac{dT}{dt} = \frac{-\lambda T \;+\; F \;-e\Delta T}{h}$$

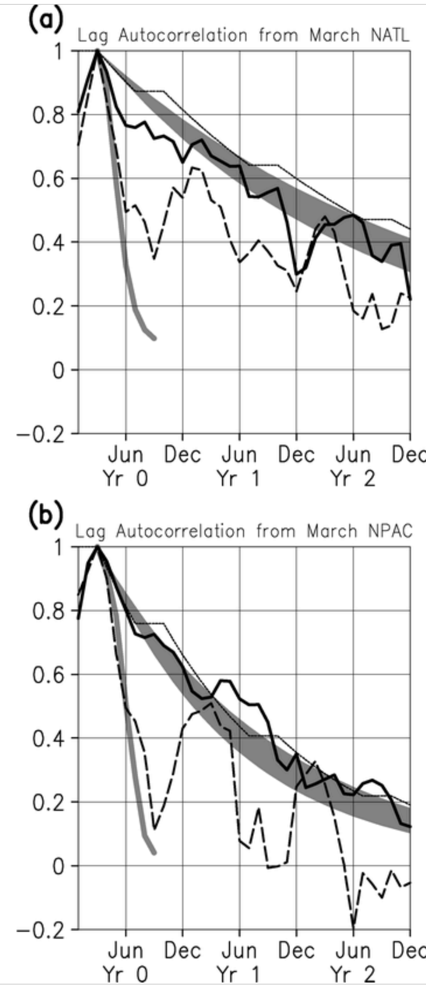

Auto correlation, PDO, NCEP/NCAR
D
O
A
J
A
F
D
O
A
J
A
F
D
O
A
J
A
F
D
O
A
J
A
F
J F M A M J J A S O N D
1.0
0.8
0.6
0.4
0.2
0.0
−0.2
0.0
0.2
0.4
0.6
0.8



Deser et al. JC, 2003



Deser et al. JC,



Deser et al. JC, 2003

Nonlocal Response to Stochastic Forcing

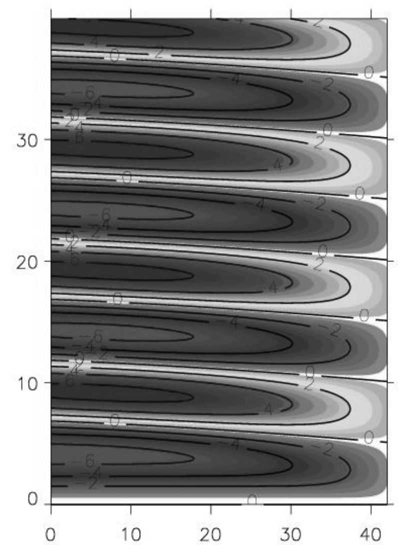
Stochastic forcing of ocean pressure or advected temperature

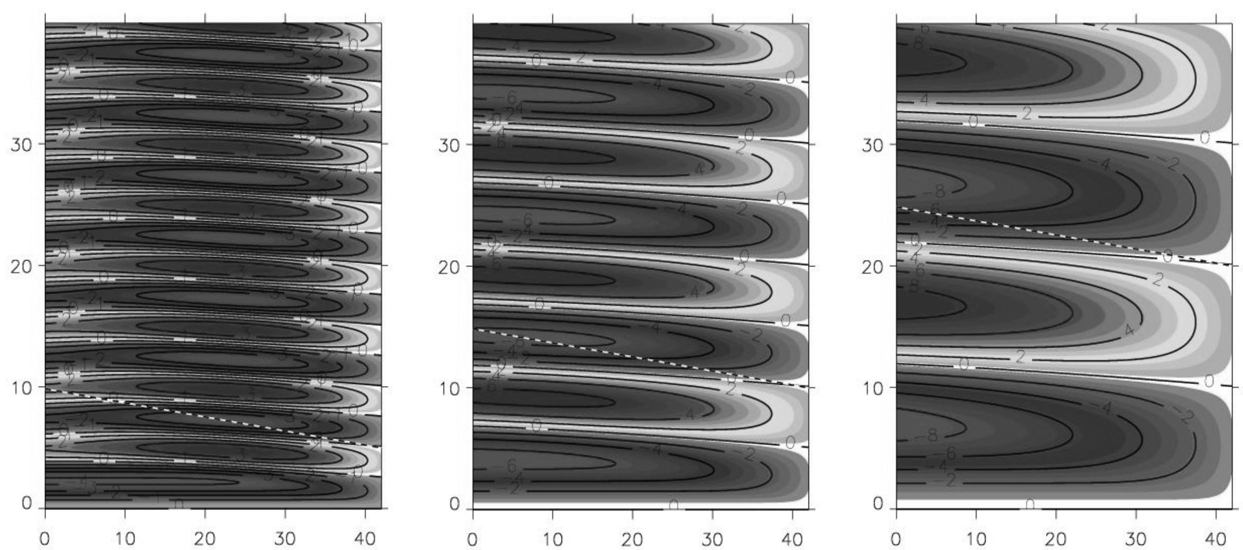
$$\partial_t T \; + \; u\partial_x T \; = \; F(x,t)$$

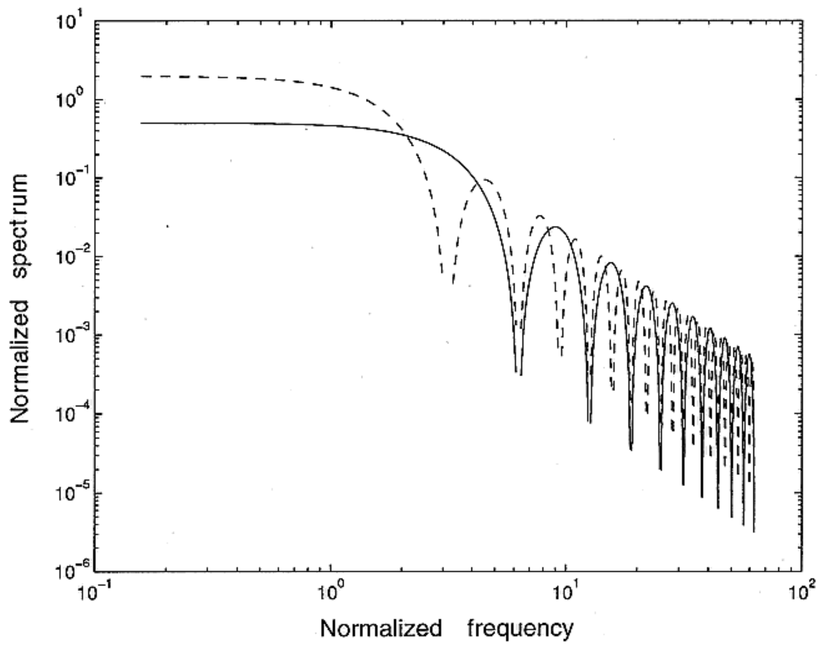
$$\partial_t P \; + \; c\partial_x P \; = \; F_{EK}(x,t)$$

$$P(x,t) \; = \; \int_{x_0}^{x} \frac{dx'}{c} \, F_{EK}(x', t - \frac{x-x'}{c}) \; + \; P(x_0, t - \frac{x-x_0}{c})$$

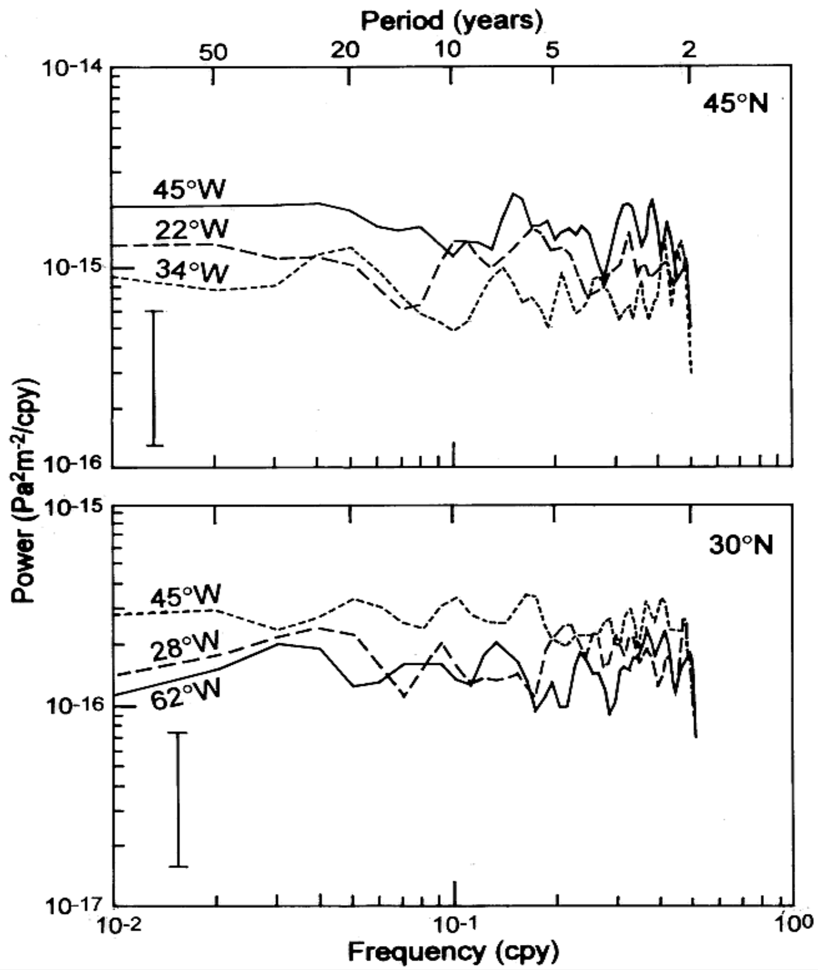
$$P(x,t) \; = \; \int_{t-\frac{x-x_0}{c}}^{t} dt' \, F_{EK}(x \; - \; c(t-t'), t') + P(x_0, t - \frac{x-x_0}{c})$$


30
20
10
0
0
10
20
30
40



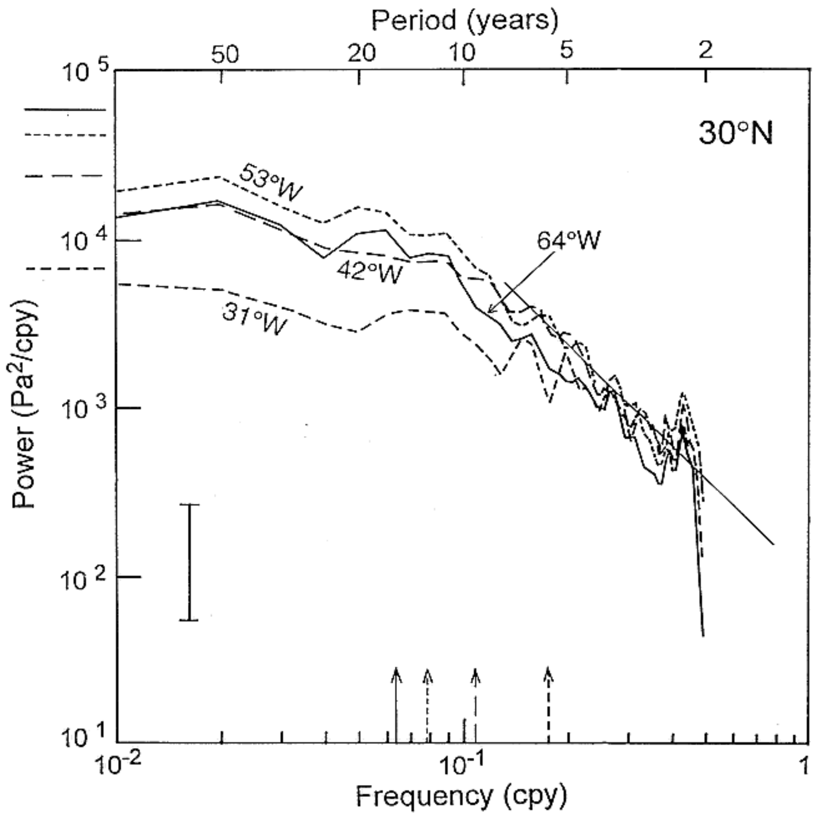


Frankignoul et al. 1997



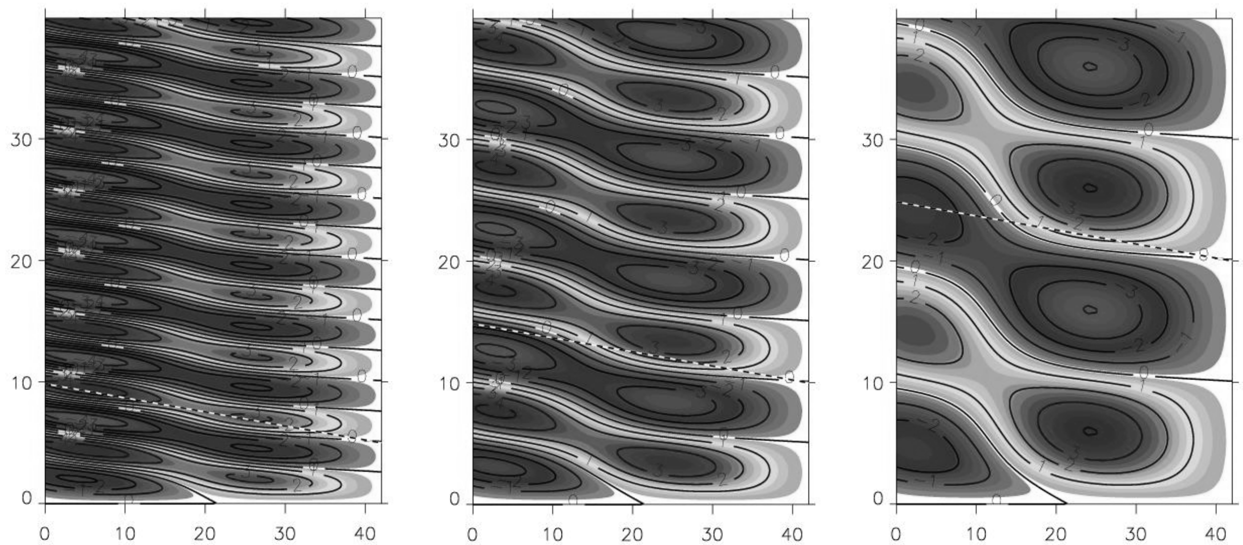
Spectra of wind stress curl in N Atlantic (coupled model output).

Frankignoul et al. 1997

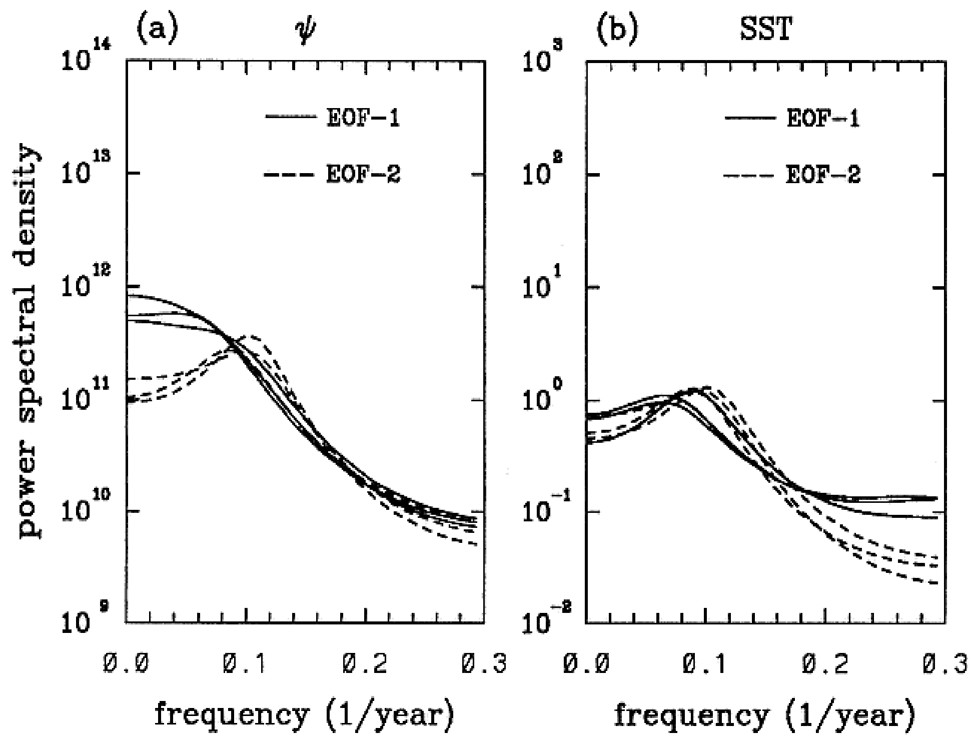


Frankignoul et al.

Stochastically forced spatial resonance



Response of ocean to stochastic forcing only



Neelin and Weng 1999