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***COURSE ON "OCEAN-ATMOSPHERE INTERACTIONS IN THE TROPICS"***
***26 May - 6 June 1997***

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# "Phase III: 1994 - ?"

presented by

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**Phase III: 1994-?**

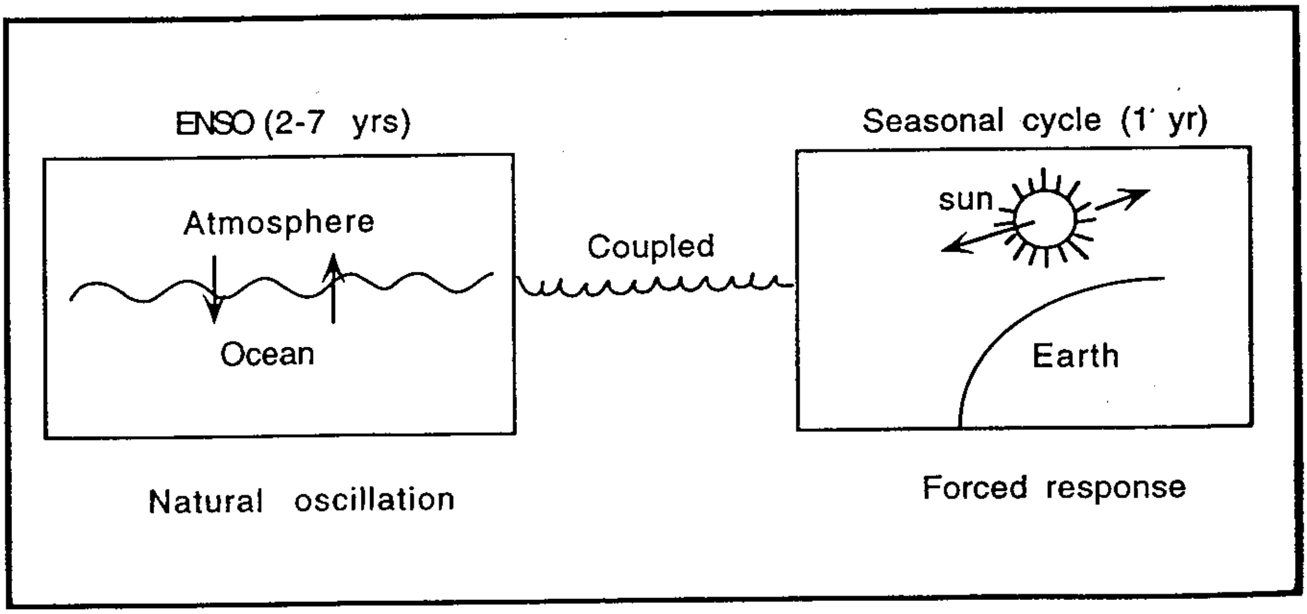
- Developing fully coupled ocean-atmosphere models.
- Understanding irregularity and predicability of ENSO.

So, what causes ENSO irregularity ?

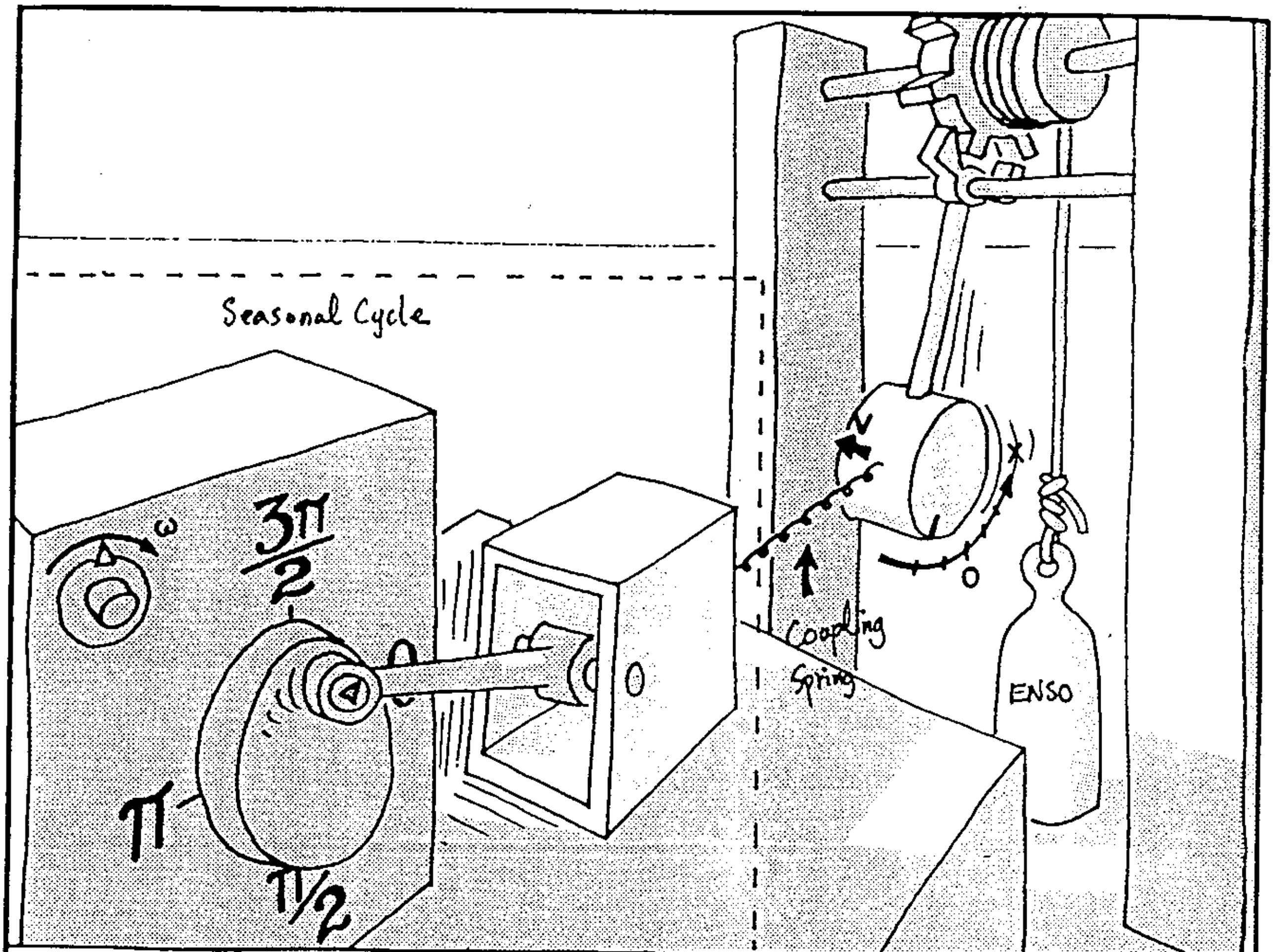
A) Stochastic Processes (Barnett and Hasselmann, 1979, Battisit and Hirst, 1989, Penland and Matrosova, 1994).

B) Interaction between seasonal cycle and ENSO (Jin et al.,1994, Tziperman et al, 1994, Chang et al., 1994).

A forced self-excited oscillator



Van der Pol Oscillator




5.3.1. The turntable motor is so well regulated that its speed, once set with the control knob, is unaffected by the load. The forcing oscillation is coupled to the clock pendulum by a light spring. The stiffer the spring, the greater the effect of the driving oscillation on the periodic motion of the clock pendulum.

from Abraham & Shaw (1992)

# An Intermediate Coupled Ocean-Atmosphere Model

## Atmospheric Component: an Empirical Feedback Model:

1). Obtain leading Empirical-Orthogonal-Function (EOF) modes from observed sea-surface-temperature (SST) and surface wind-stress anomalies.

2). Form a matrix of regression coefficients relating the SST and wind-stress in the EOF space.

3). Given an SST field at time t, project the SST onto the EOFs of the observed SST and then compute empirically the corresponding pattern of wind-stress.

## Oceanic Component: a 1-1/2 Layer Reduced Gravity Model:

Linear Momentum Equations

$$\frac{\partial \mathbf{u}}{\partial t} + f\mathbf{k}\times\mathbf{u} = -g'\nabla h + \frac{\tau}{H} + \mu\nabla^2\mathbf{u} - \alpha\mathbf{u} \tag{1}$$

Continuity Equation

$$\left(\frac{\partial h}{\partial t}\right) + H\nabla\cdot\mathbf{u} = -\gamma h \tag{2}$$

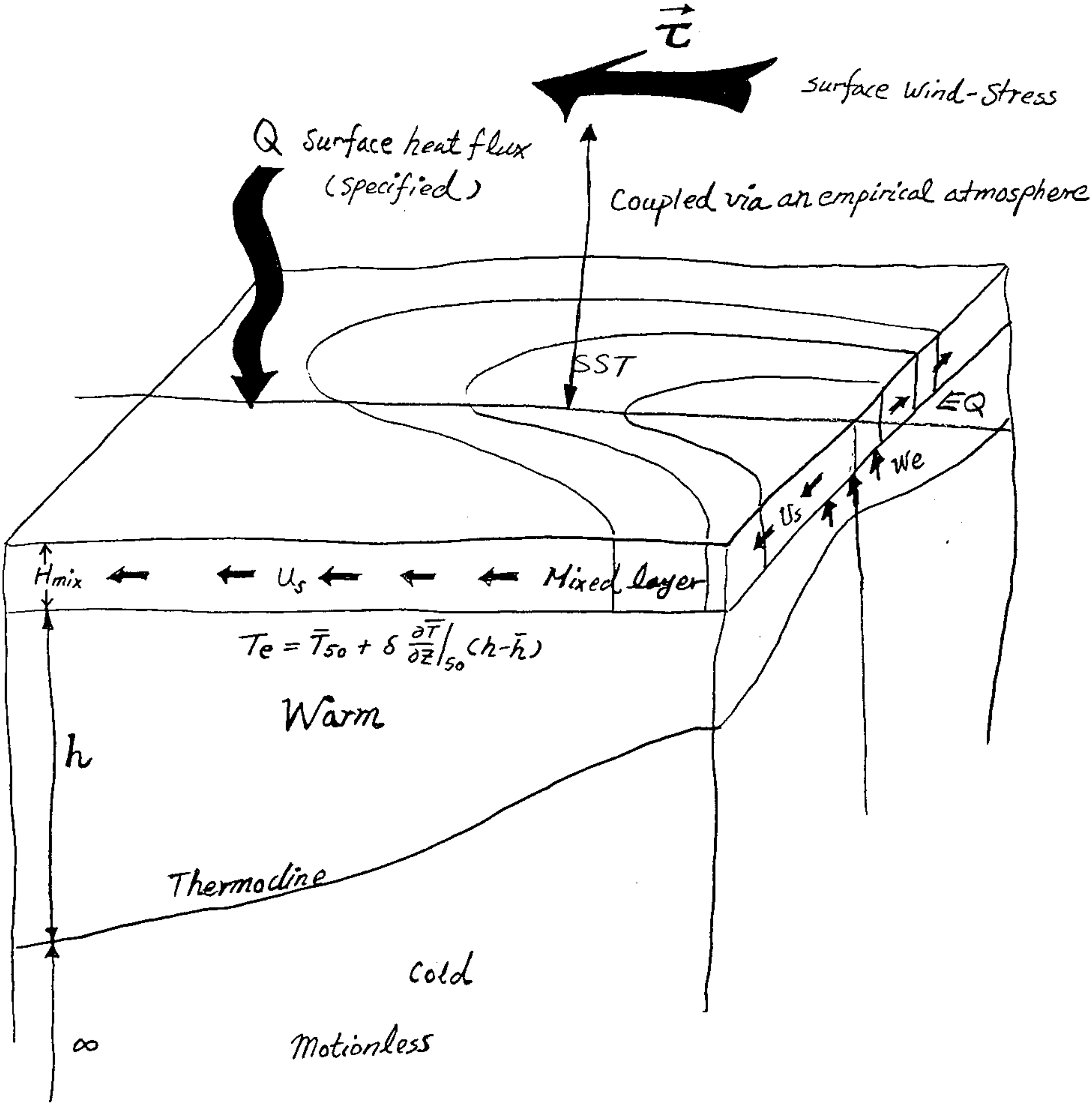
Temperature Equation

$$\frac{\partial T}{\partial t} + \mathbf{u}_s\cdot\nabla T = \frac{Q}{\rho_0 C_p H_{mix}} + \kappa\nabla^2 T - \frac{1}{H_{mix}} w_e H(w_e)(T - T_e) \tag{3}$$

Where Q and t are the seasonal heat flux and wind stress vector in the mixed layer.

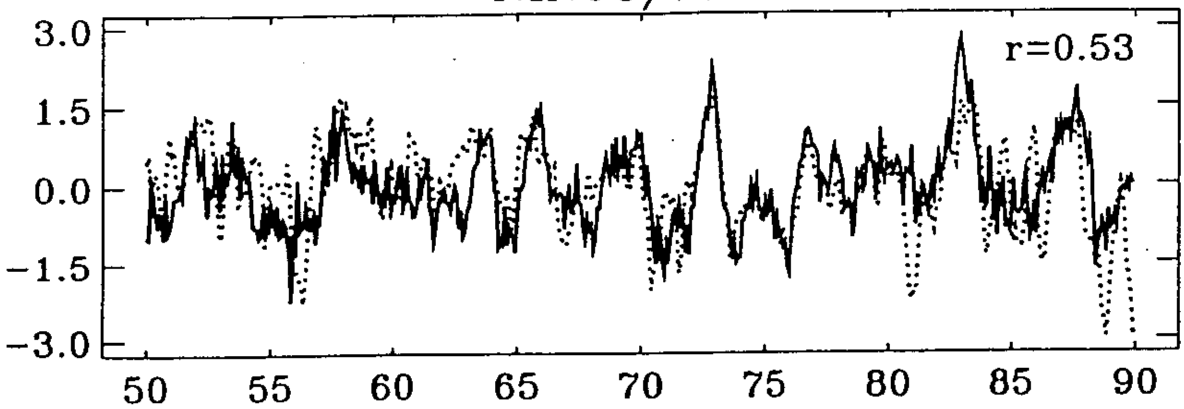
These equations are solved using a finite-difference method.

# A Schematic of Coupled Model

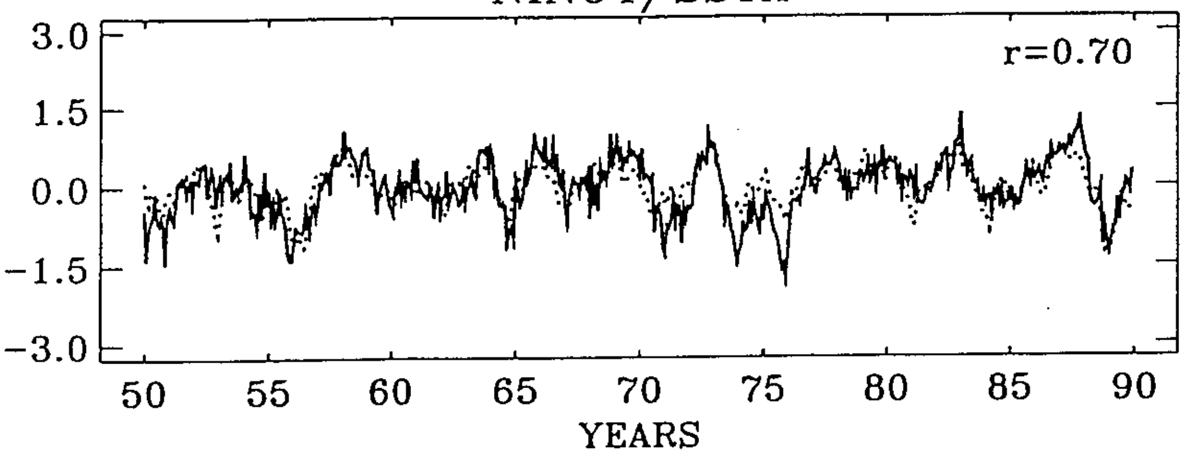


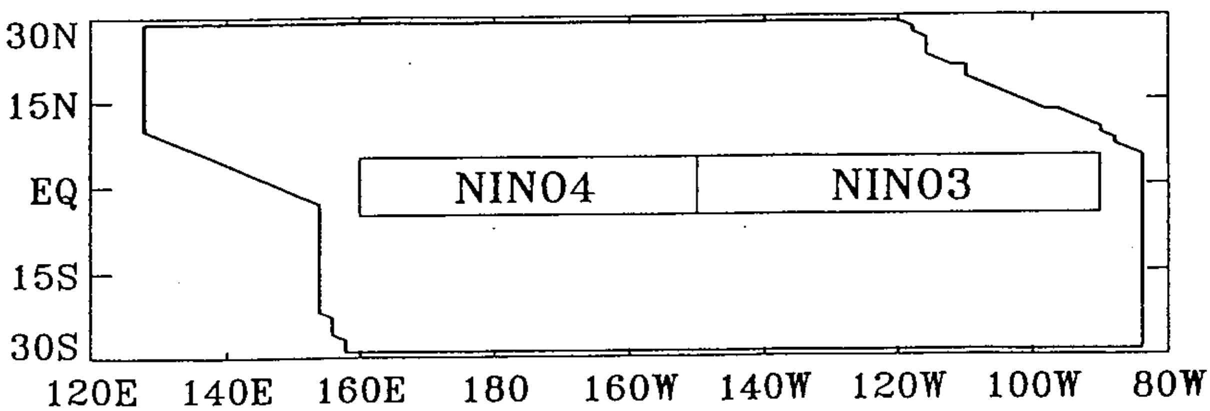
# Oceanmodel forced with observed Winds

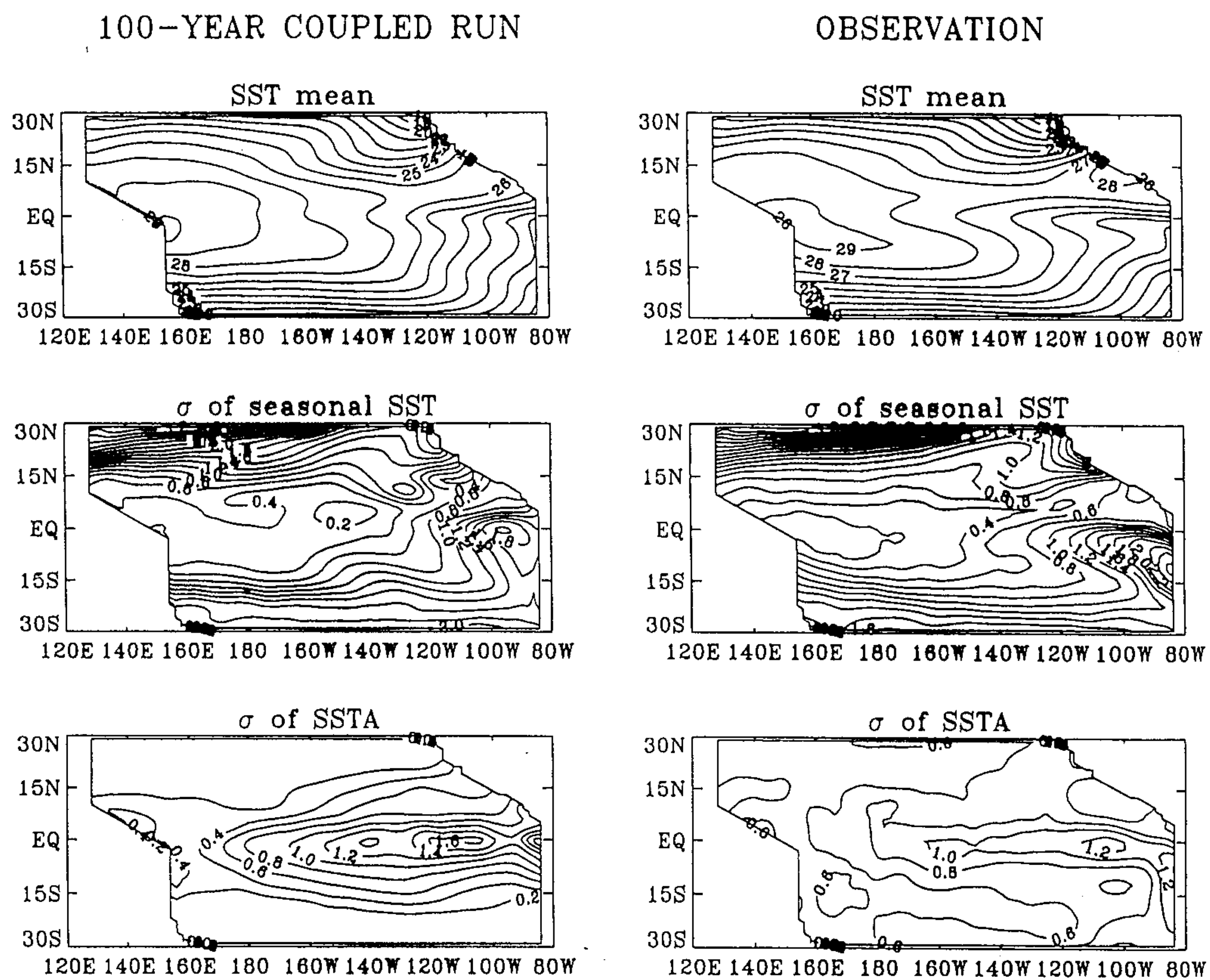
NINO3/SSTA

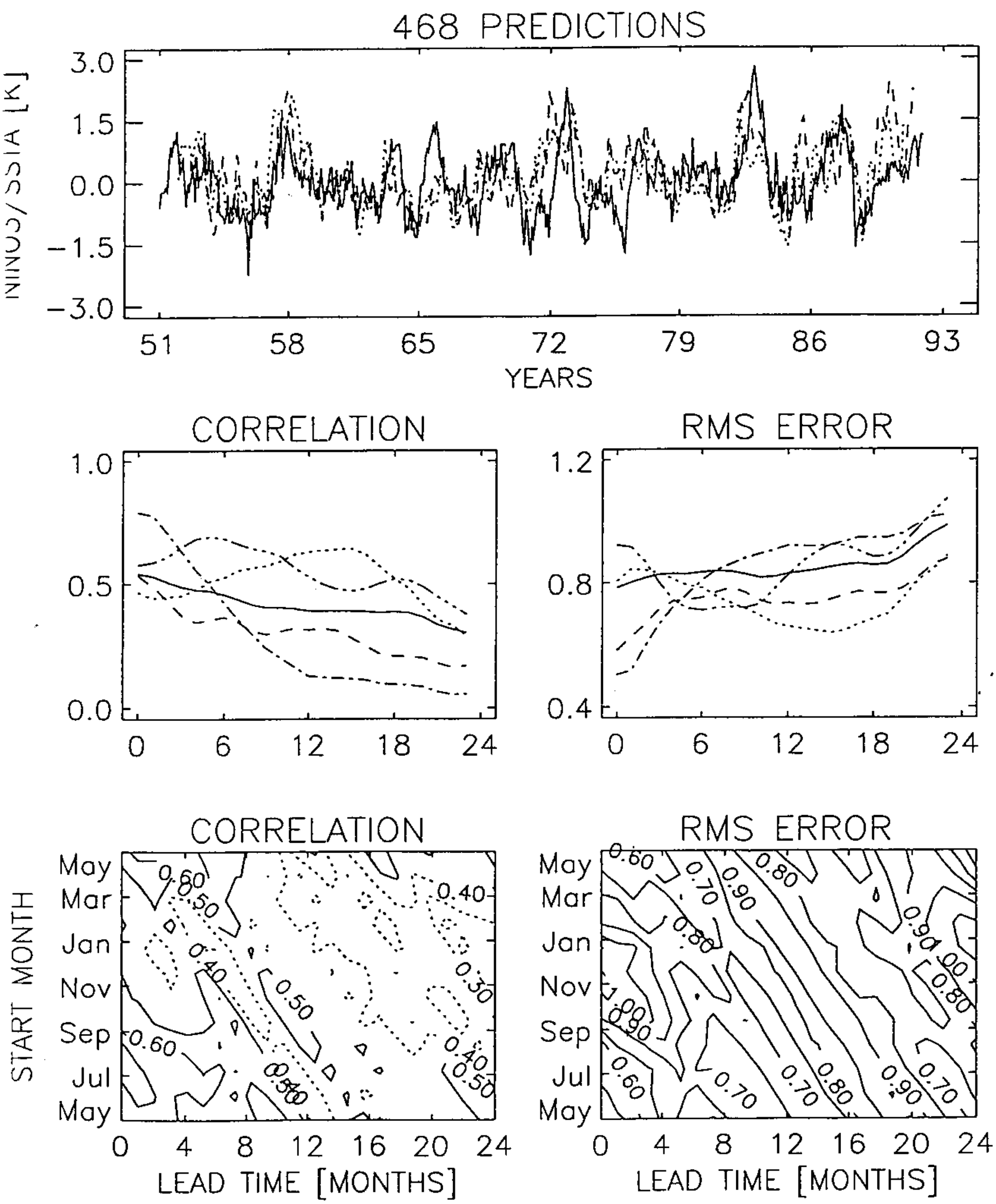



NINO4/SSTA




100-YEAR COUPLED RUN
OBSERVATION
SST mean
σ of seasonal SST
σ of SSTA
30N
15N
EQ
15S
30S
120E 140E 160E 180 160W 140W 120W 100W 80W




STANDARD CASE

# Intermediate Coupled Model Experiments

## I. ENSO chaos (Chang et al., 1995):

1) varying strength of the seasonal forcing with a fixed coupling strength

2) varying coupling strength with a fixed seasonal forcing

## II. ENSO chaos vs. stochastic forcing:

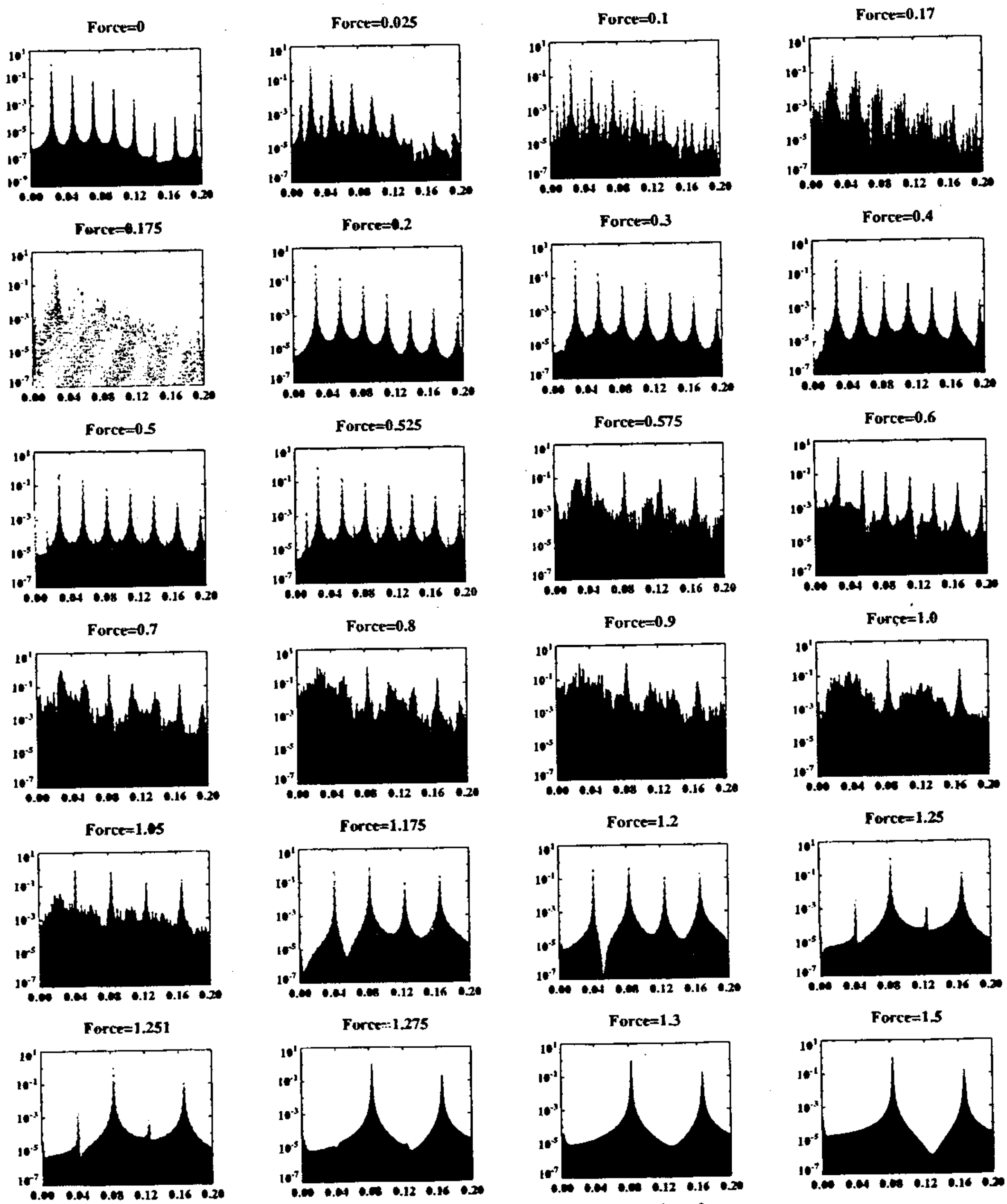
1) chaotic oscillation + noise

2) regular oscillation + noise

3) no oscillation + noise

noise forcing = $R(t) \sum_{n=9,40} E_n(X)\alpha_n(t)$

# Power Spectra of CZ_CPT Model SST




**Longitude=120w, latitude=0**

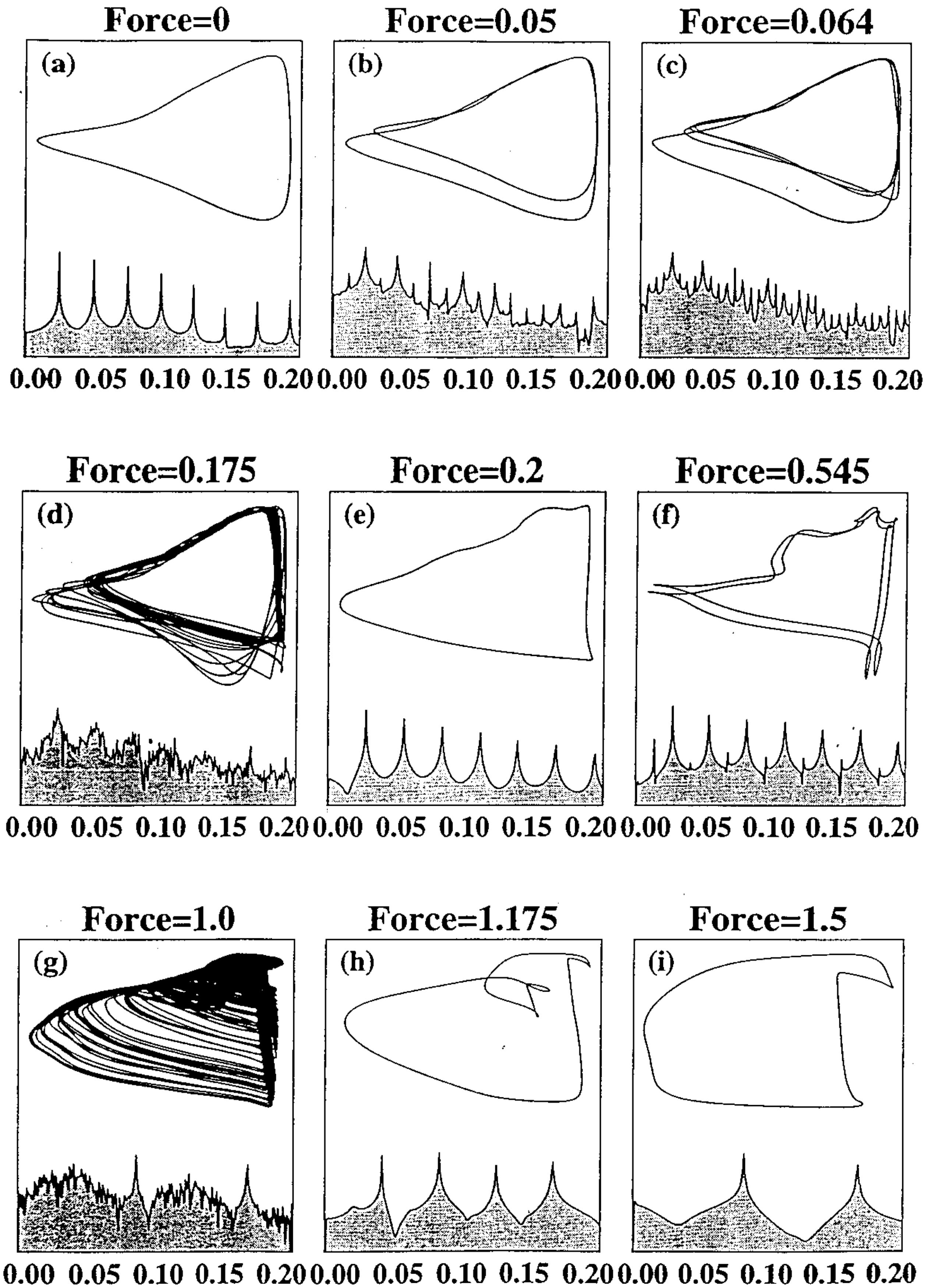
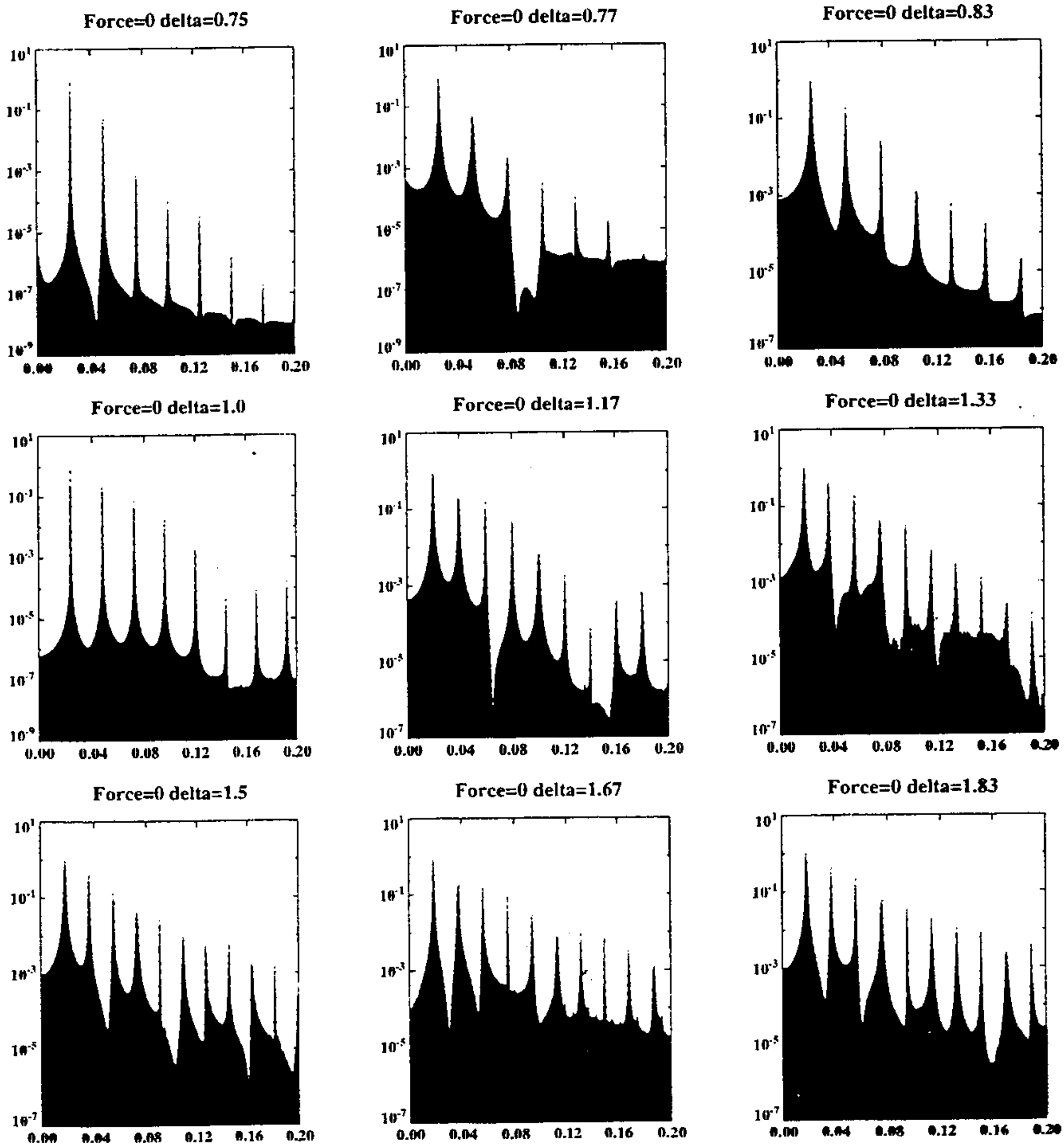



Figure 1. Phase portraits (upper) and power spectra (lower) of the model SST in the eastern equatorial Pacific (0°, 120°W) for various values of the seasonal heat flux forcing amplitude A. The phase portraits are reconstructed using the method of time delay. The delayed time is determined by auto-correlation analysis. The power spectra are shown in log-linear plots and the frequency is in units of $months^{-1}$.

# Power Spectra of CZ_CPT Model SST




## Longitude=120w, latitude=0

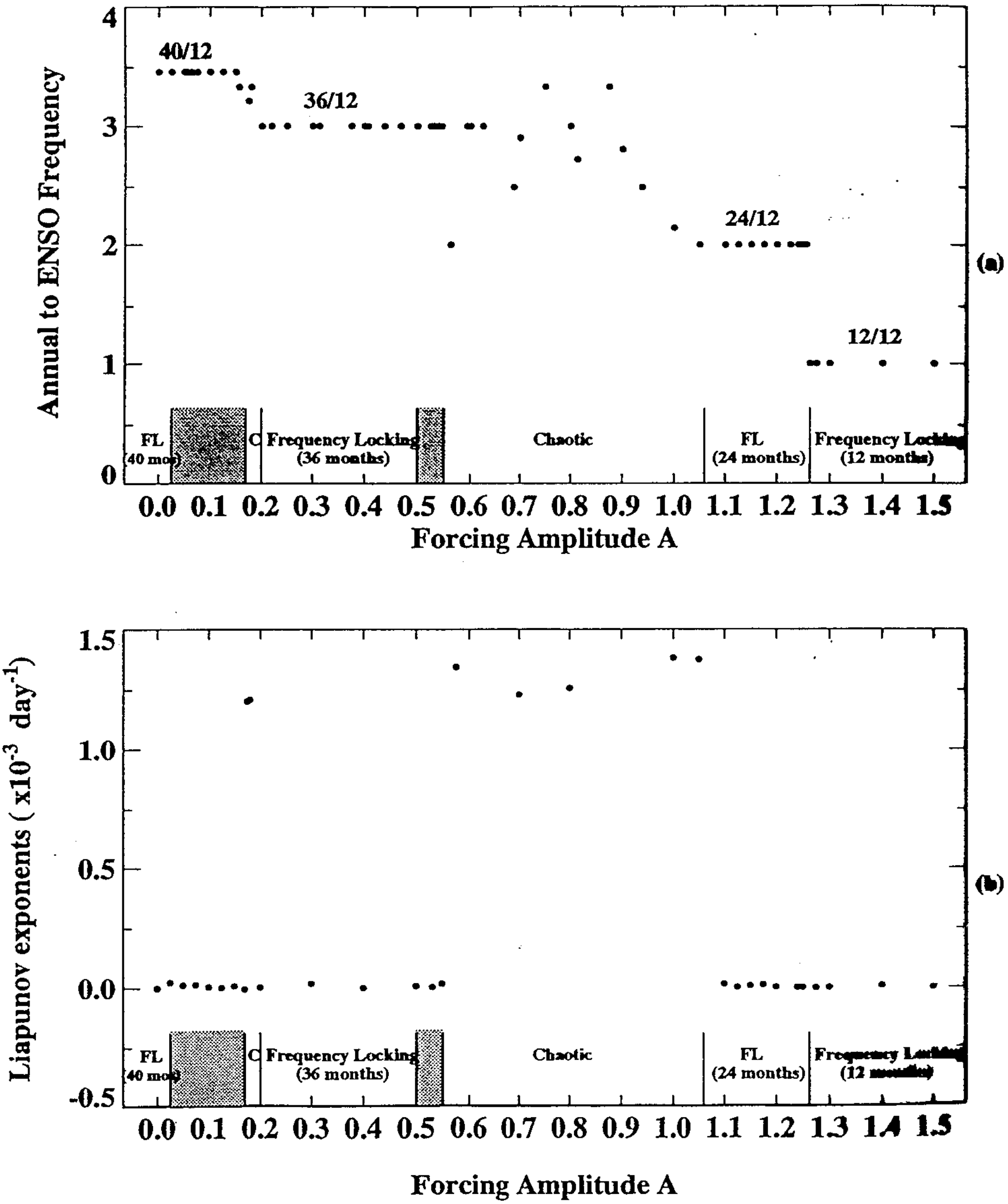
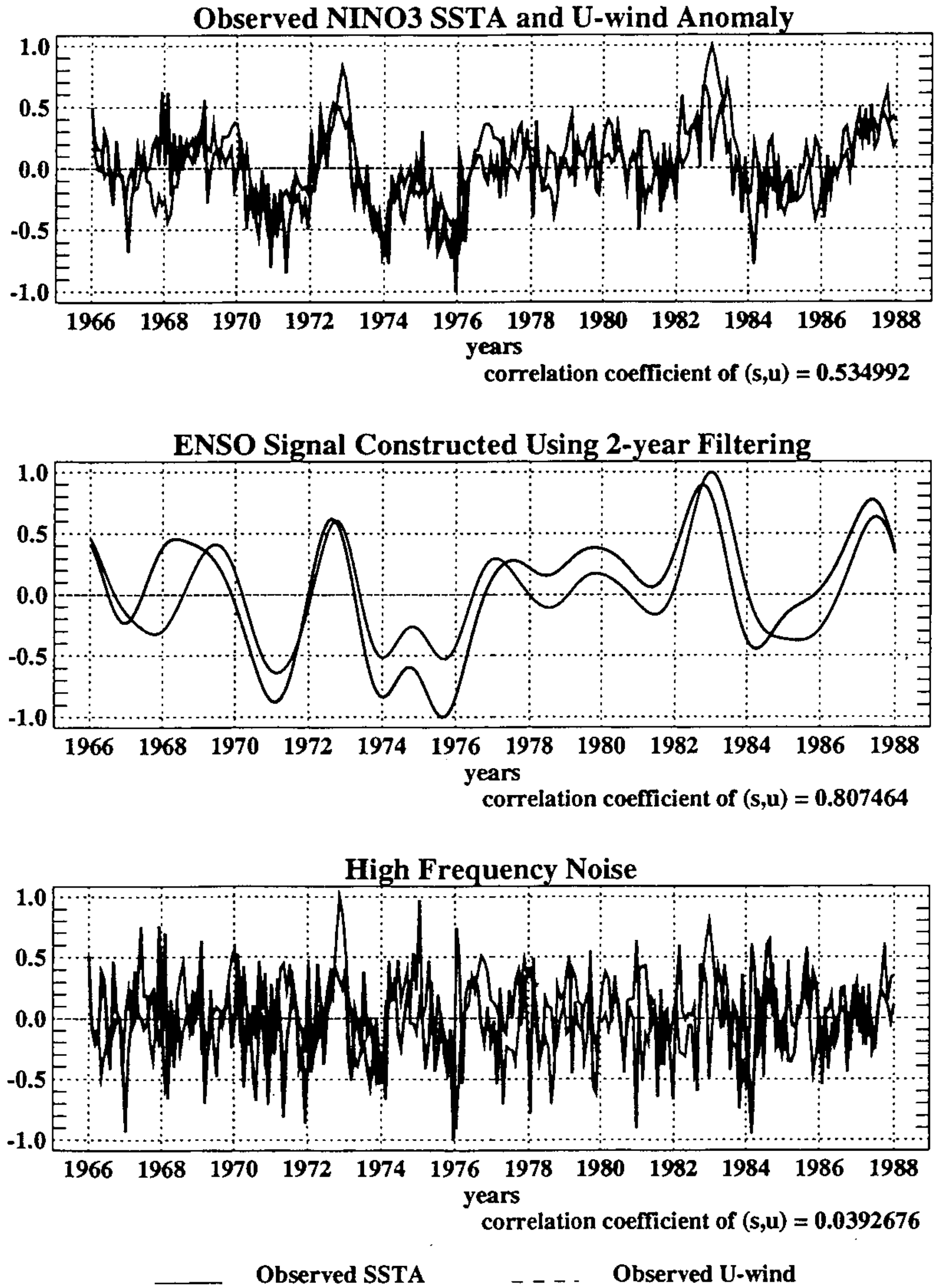

40/12
36/12
24/12
12/12
Annual to ENSO Frequency
FL (40 mos)
C
Frequency Locking (36 months)
Chaotic
FL (24 months)
Frequency Locking (12 months)
Forcing Amplitude A
(a)
Liapunov exponents ( x10^-3 day^-1)
Forcing Amplitude A
(b)

Fig. 7


Observed NINO3 SSTA and U-wind Anomaly
1.0
0.5
0.0
-0.5
-1.0
1966 1968 1970 1972 1974 1976 1978 1980 1982 1984 1986 1988
years
correlation coefficient of (s,u) = 0.534992
ENSO Signal Constructed Using 2-year Filtering
1.0
0.5
0.0
-0.5
-1.0
1966 1968 1970 1972 1974 1976 1978 1980 1982 1984 1986 1988
years
correlation coefficient of (s,u) = 0.807464
High Frequency Noise
1.0
0.5
0.0
-0.5
-1.0
1966 1968 1970 1972 1974 1976 1978 1980 1982 1984 1986 1988
years
correlation coefficient of (s,u) = 0.0392676
Observed SSTA
Observed U-wind

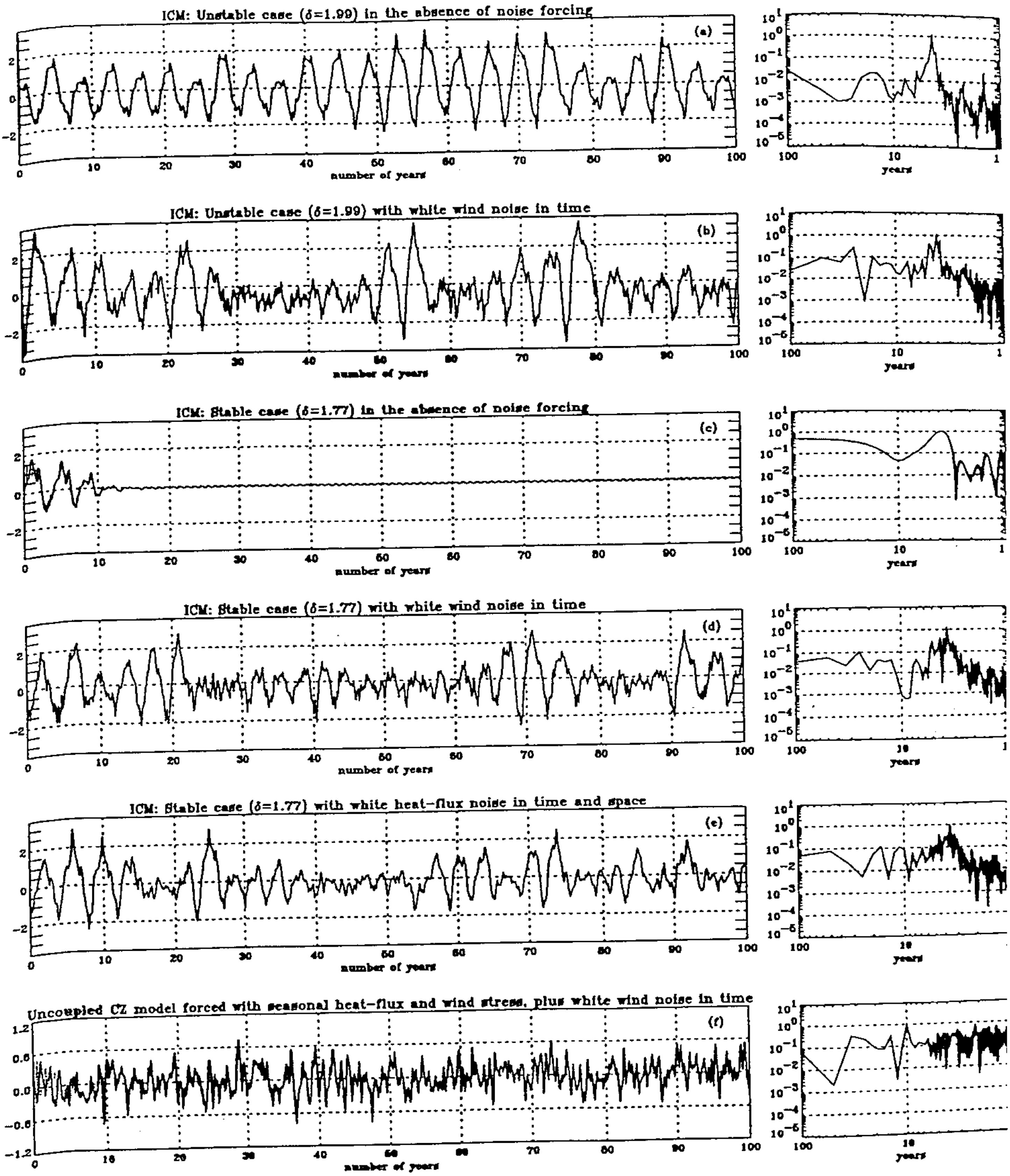



Figure 4. SSTA time series and power spectrum from the ICM simulation in (a) the unstale case $\delta$=1.99 without noise, (b) the unstale case $\delta$=1.99 with white wind noise in time, (c) the stable case $\delta$=1.7 without noise, (d) the stable case $\delta$=1.77 with white wind noise in time, (e) the stable case $\delta$=1.77 with white heat-flux noise in time and space and (f) uncoupled case with white wind noise in time.

# POP OF ICM OUTPUT: UNSTABLE CASE WITHOUT NOISE

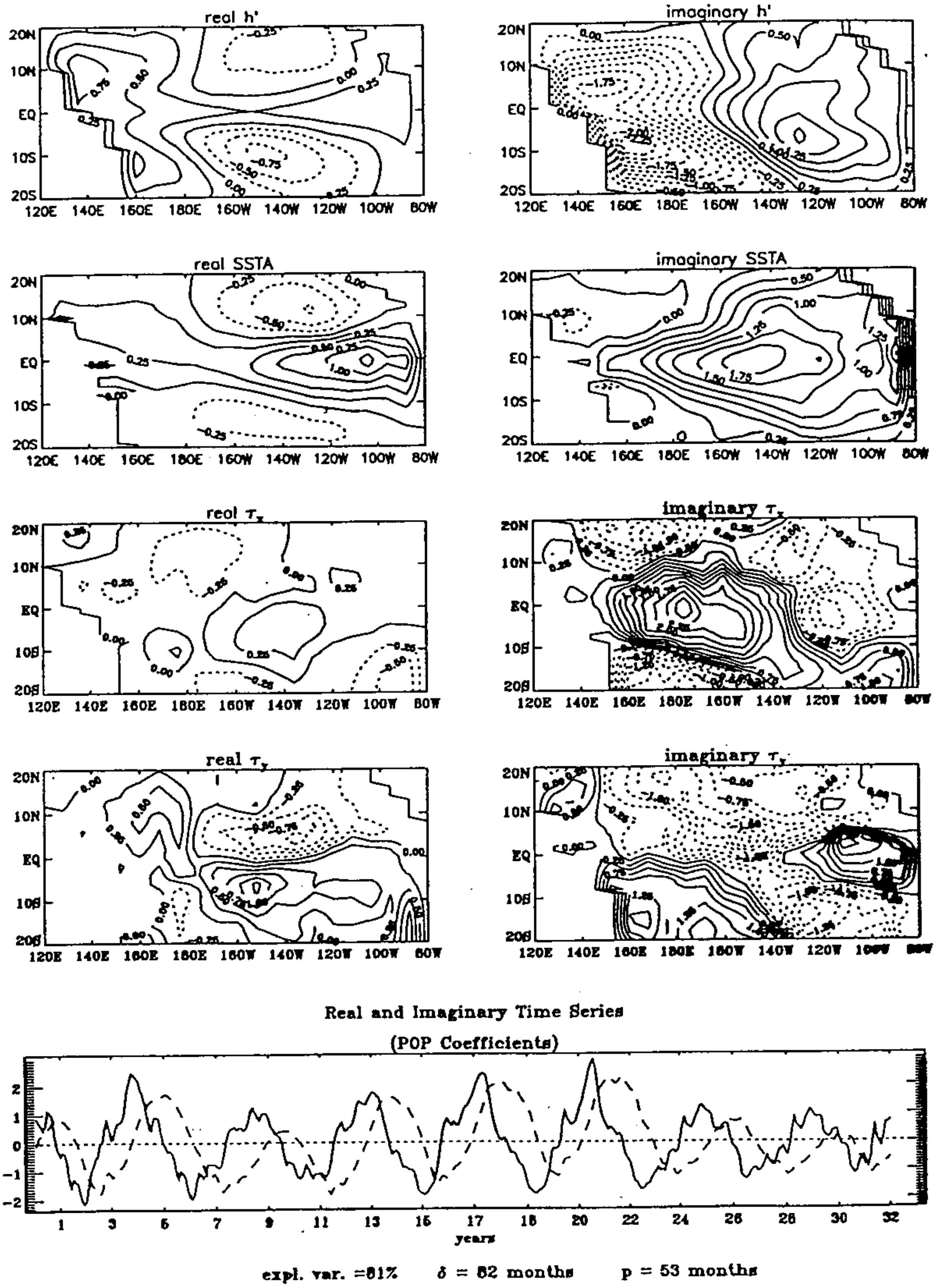



Figure 6. POP analysis of ICM simulated thermocline depth anomaly, SSTA, zonal and meridional wind-stress anomalies in the unstable case without noise. All the avariables are normalized in terms of their area averaged standard deviation. The left and right panels show the real and imaginary parts of the first POP mode. The bottom panel shows the POP coefficient time series.

# POP OF ICM OUTPUT: STABLE CASE WITH WIND NOISE

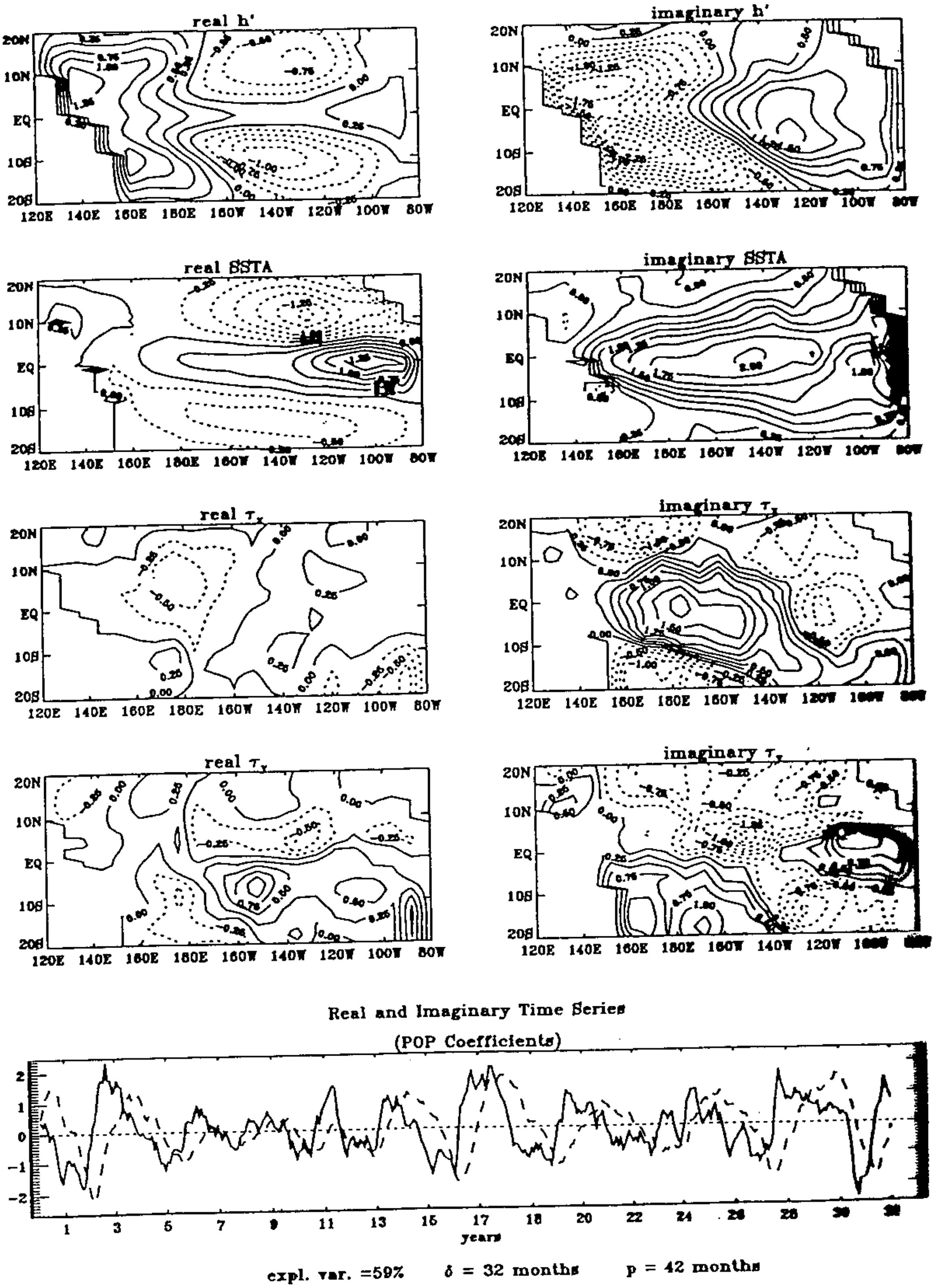



Figure 7. Same as Figure 6 except for the stable case with wind noise.

# POP OF ICM OUTPUT: UNCOUPLED CASE WITH WIND NOISE

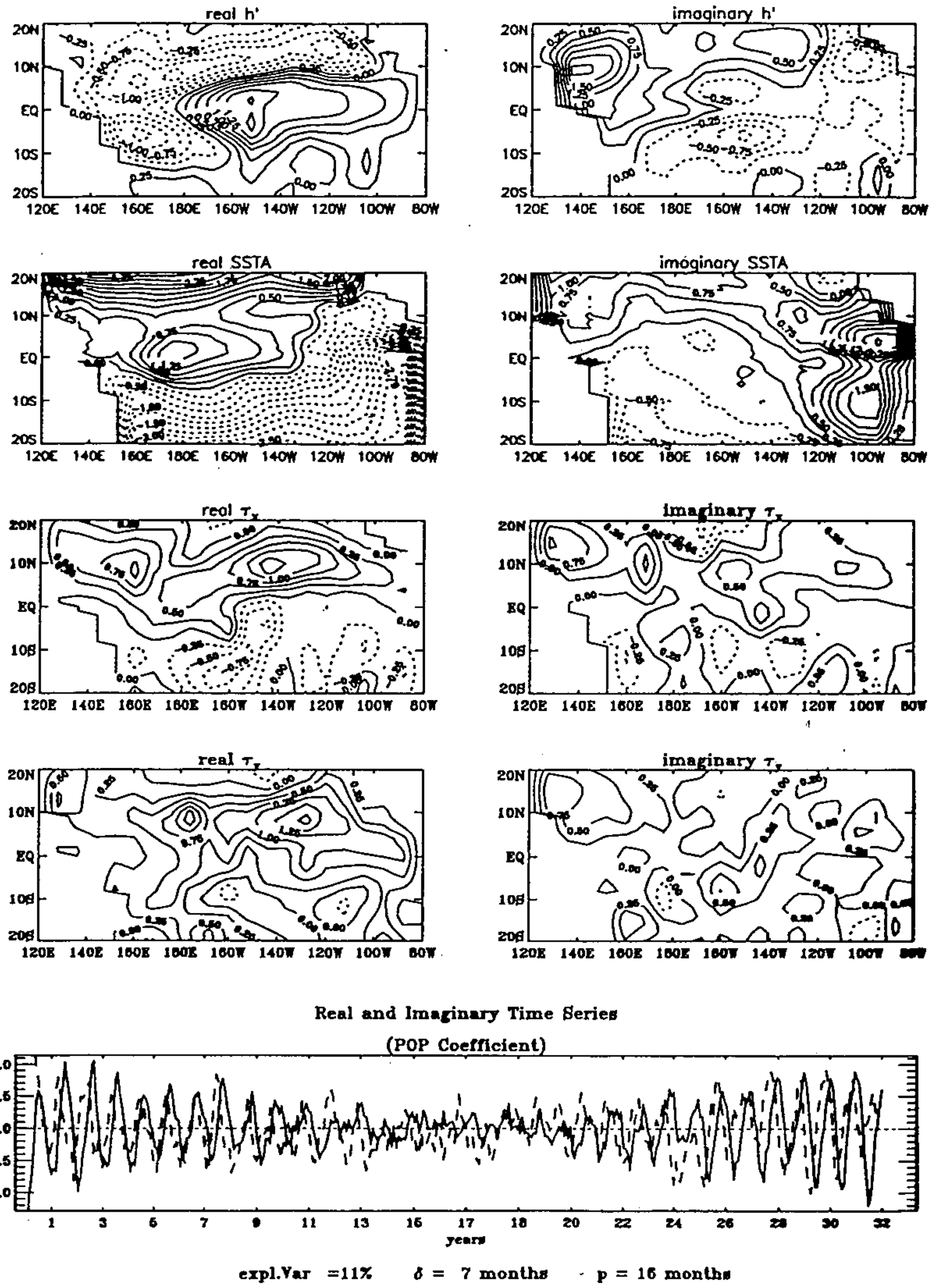



Figure 8. Same as Figure 6 except for the uncoupled case with wind noise.

# Model Intercomparisons

## Intermediate Coupled Model:

A statistical atmosphere + a CZ type of Ocean
First 8 EOF modes for the statistical atmosphere
2°x1° for the CZ ocean
Forced by a seasonally varying surface heat flux
Producing both the seasonal cycle and ENSO cycle
1000-year simulations

## Hybrid Coupled General Circulation Models:

1) The same statistical atmosphere + GFDL MOM
2°x1° and 20 vertical levels for MOM
Forced by a seasonally varying surface heat flux
Producing both the seasonal cycle and ENSO cycle
210-year simulation

2) An anomalous statistical atmosphere + an OGCM
First 5 EOF modes for the statistical atmosphere
3°x0.5° and 13 vertical levels for the OGCM
Fixed seasonal cycle
1000-year simulations
(From Flügel and Eckert)

## Coupled GCMs:

1) A R-15 AGCM + A GFDL OGCM
7.5°x4.5° and 9 vertical level for the AGCM
3.75°x4.5° with 12 vertical level for the OGCM
Producing both the seasonal cycle and ENSO cycle
1000-year simulation
(From Manabe, Stouffer and Knutson)

2) A T21 ECHAM2 + A T42 OPYC
5.6°x2.8° and 19 vertical level for the AGCM
2.8°x1° and 8 isopycnal layers in vertical for the OGCM
Producing both the seasonal cycle and ENSO cycle
210-year simulation (Lunkeit, Sausen and Oberhuber)

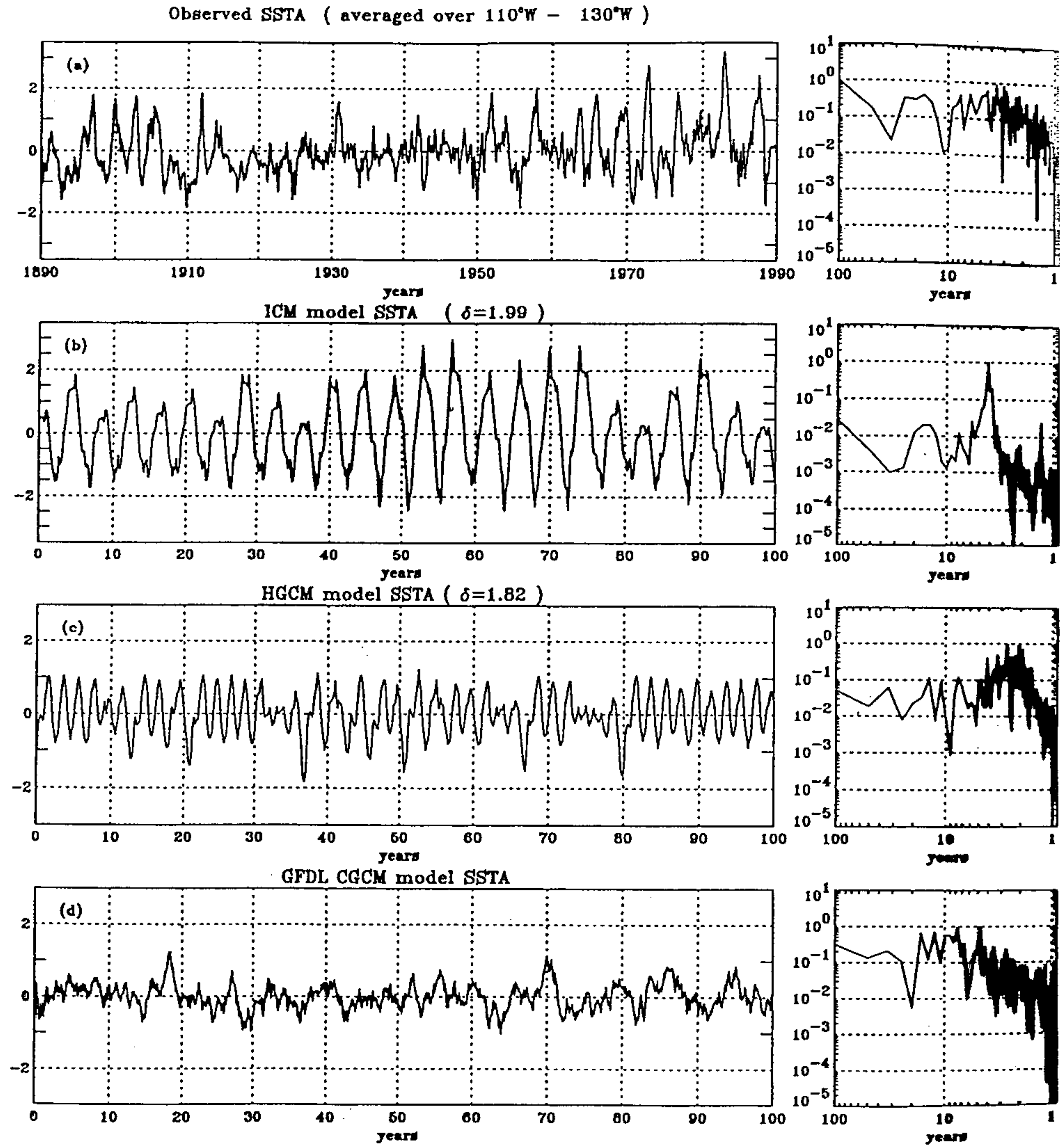



Figure 1. SSTA time series and power spectra from (a) the COADS observation, (b) the ICM simulation with coupling strength $\delta$ =1.99, (c) the HGCM simulation with coupling strength $\delta$=1.82 and (d) the GFDL CGCM simulation. The time series are averaged over a 20°×8° area centered at (120°W, 0°) for (a) and (b) and at (150°W, 0°) for (c) and (d).

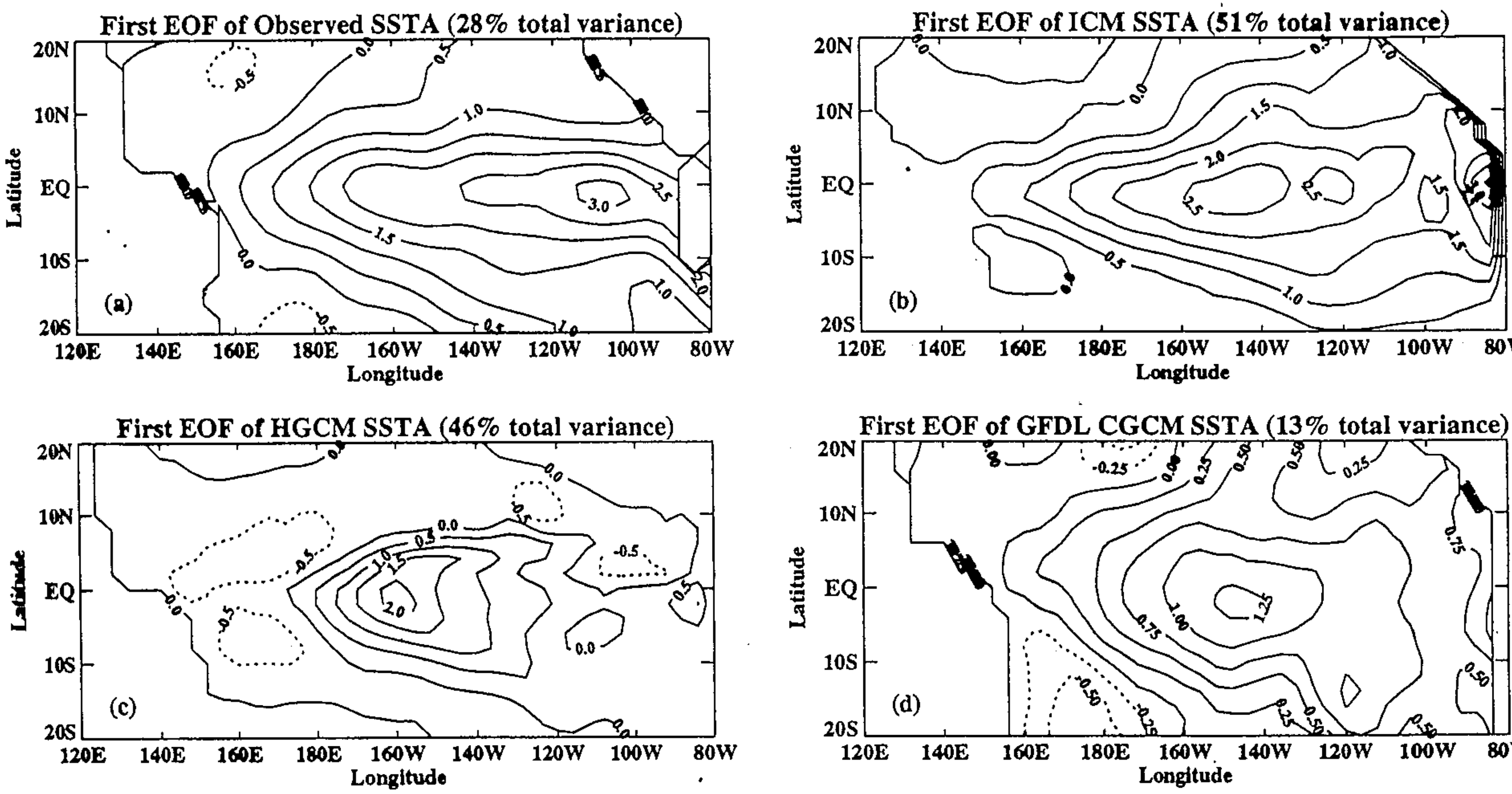



Figure 2. The first leading EOF mode of SSTA derived from (a) the 30-year COADS observation (1960 – 1989) (b) the ICM simulation with $\delta$=1.90, (c) the HGCM simulation $\delta$=1.82 and (d) the GFDL CGCM simulation. The contour intervals are 0.5°C for (a), (b), (c) and 0.25°C for (d).

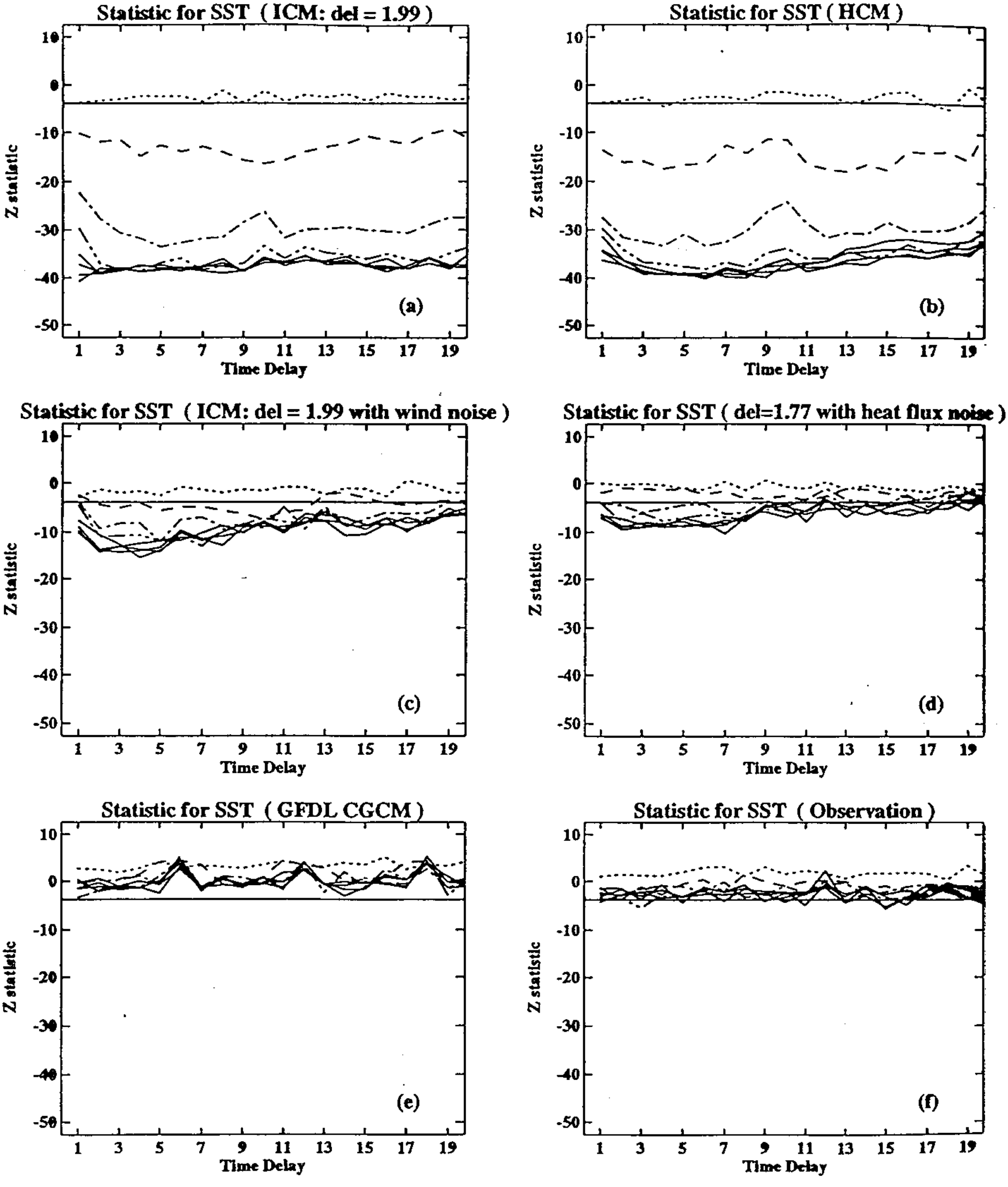



Figure 12. z statistic for SST time series taken from (a) the ICM unstable run without noise, (b) the HGCM run without noise, (c) the ICM unstable run with wind noise, (d) the ICM stable run with heat-flux noise, (e) the GFDL CGCM run and (f) the 100-year COADS observation. Straight horizonal line is 99% rejection threshold.