Ocean Biology-Induced Climate *Feedback* Effects on Interannual Variability in the Tropical Pacific: A Missing Process in the NCEP CFS

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Outline

- Introduction
- A hybrid coupled ocean-atmosphere model (HCM_{OGCM})

  Atmosphere: Wind stress: SVD-based;

  Ocean: The Cane-Gent OGCM

  Ocean biology heating <=> **Hp** <= SVD-based, ocean color data derived:

$$Q(z) = Q_{sr} e^{(-z/H_p)} \longleftrightarrow H_p = \overline{H_p} + \alpha_{H_p} \cdot H_p'$$

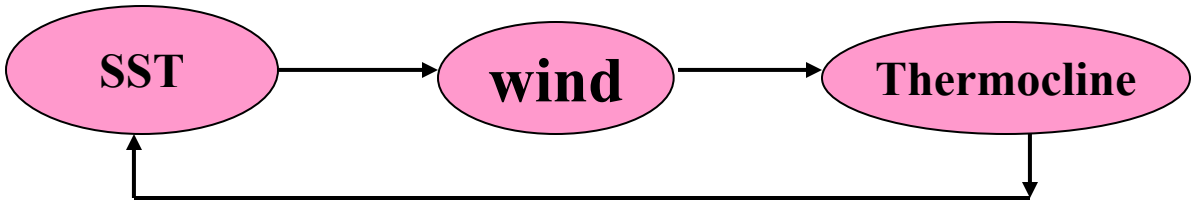
- The standard HCM_{OGCM} simulation: $\alpha_{Hp}=0.0$ → HP17 = 17 m : constant; HPAM = annual mean Hp; HPSC = seasonal cycle of Hp

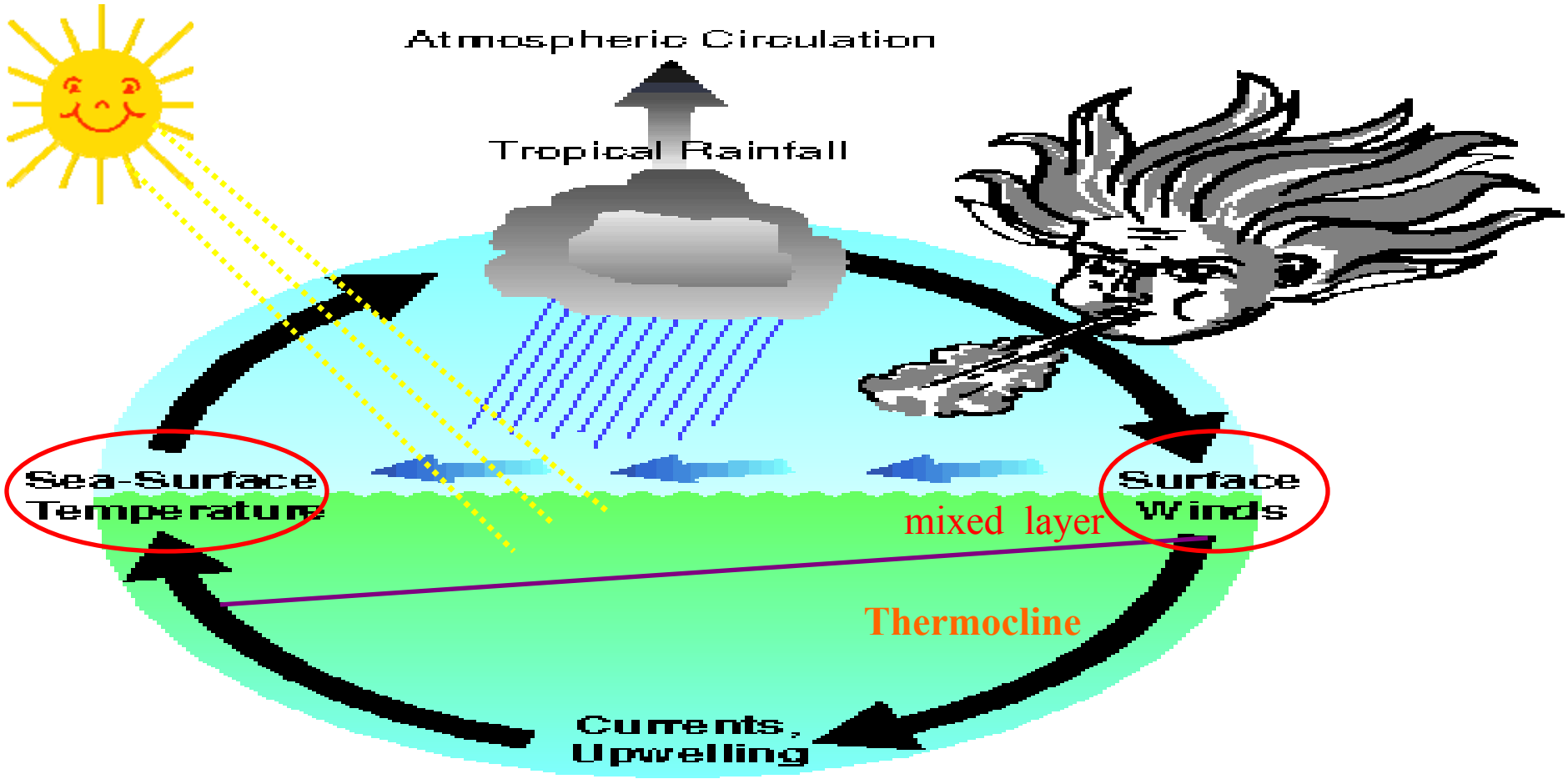
- An ocean biology-induced negative feedback :

  $\alpha_{Hp}=1.0$ $\alpha_{Hp}=2.0$ $\alpha_{Hp}=3.0$

- Sensitivity experiments.
- Potential applications to NCEP CFS
- Summary

Processes involved in ENSO: Forcings & feedbacks



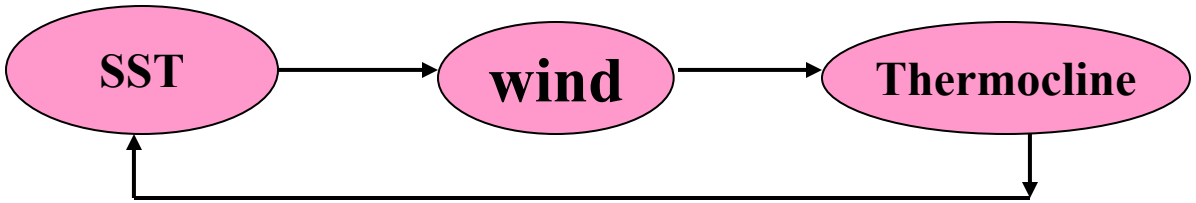


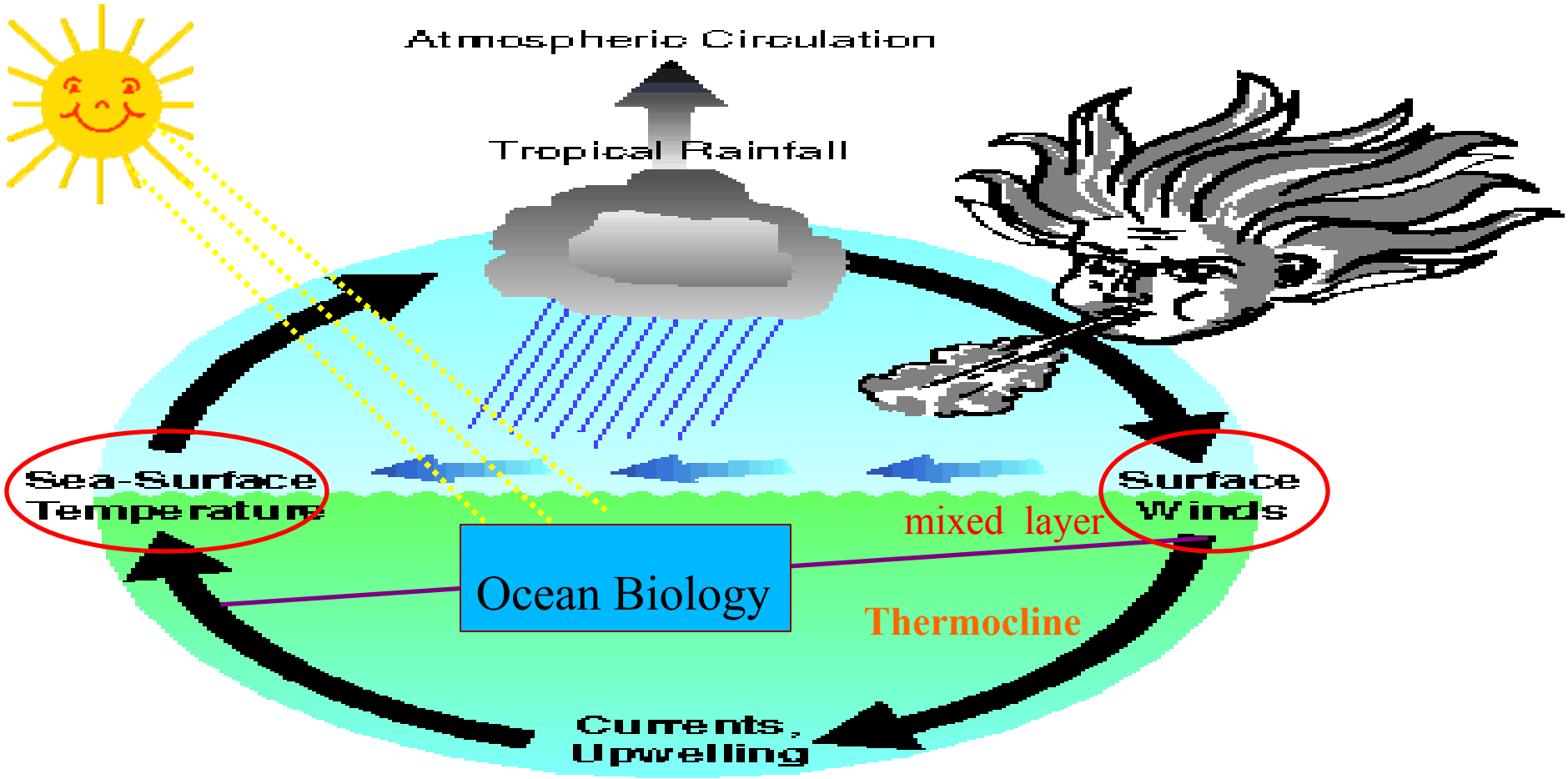
Proposed Mechanisms for ENSO Variability

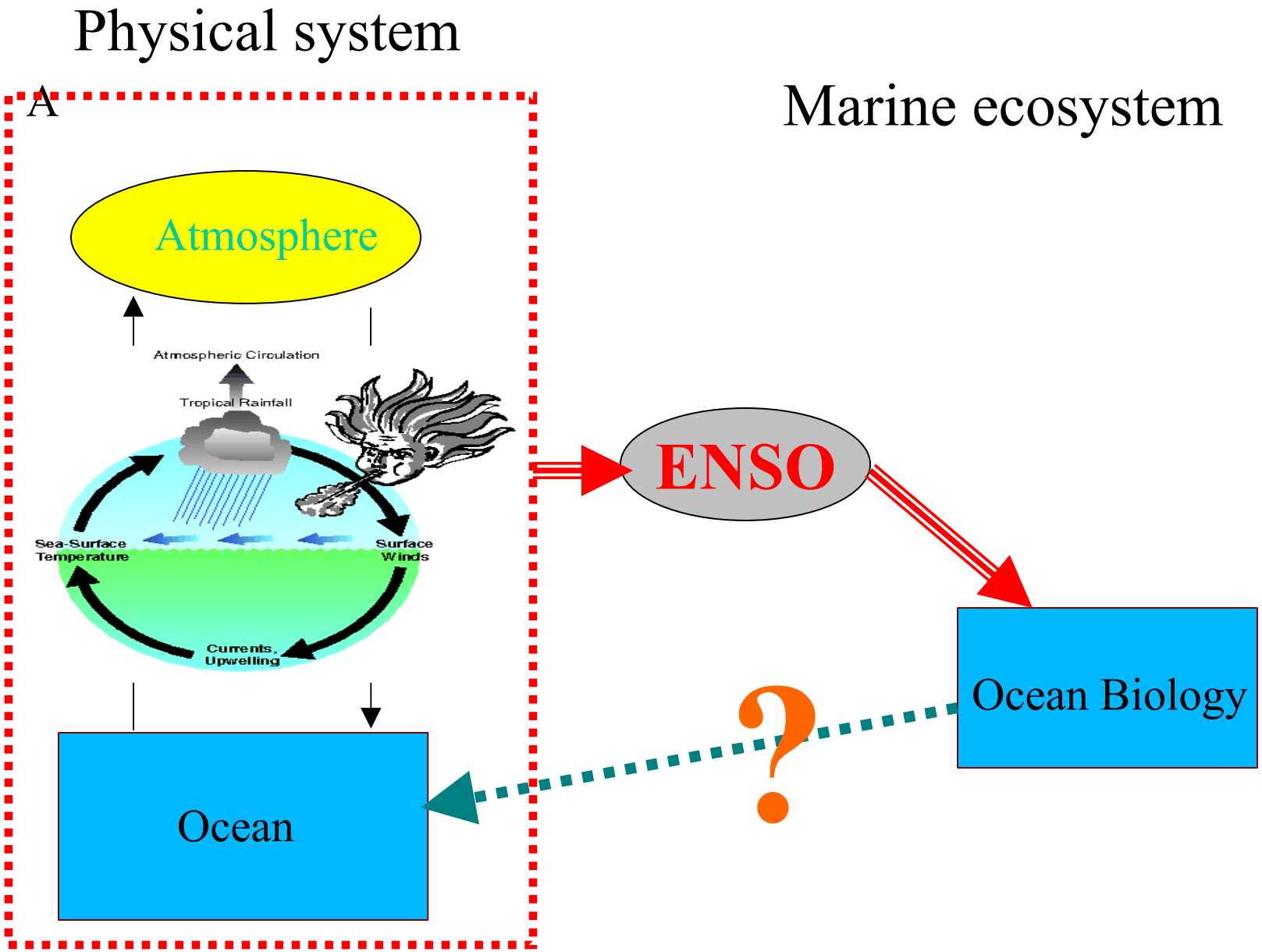
- **Stochastic forcing in the atmosphere;**
- **The influences of extra-tropical processes;**
- **The changes in mean state of the tropical climate system;**
- **The nonlinearity and associated parameter changes;**
- **The residual effects of interannual variability;**
- **Decadal variations in the structure of wind;**
- **Decadal variations in the structure of T_e .**
- **Freshwater flux forcing**

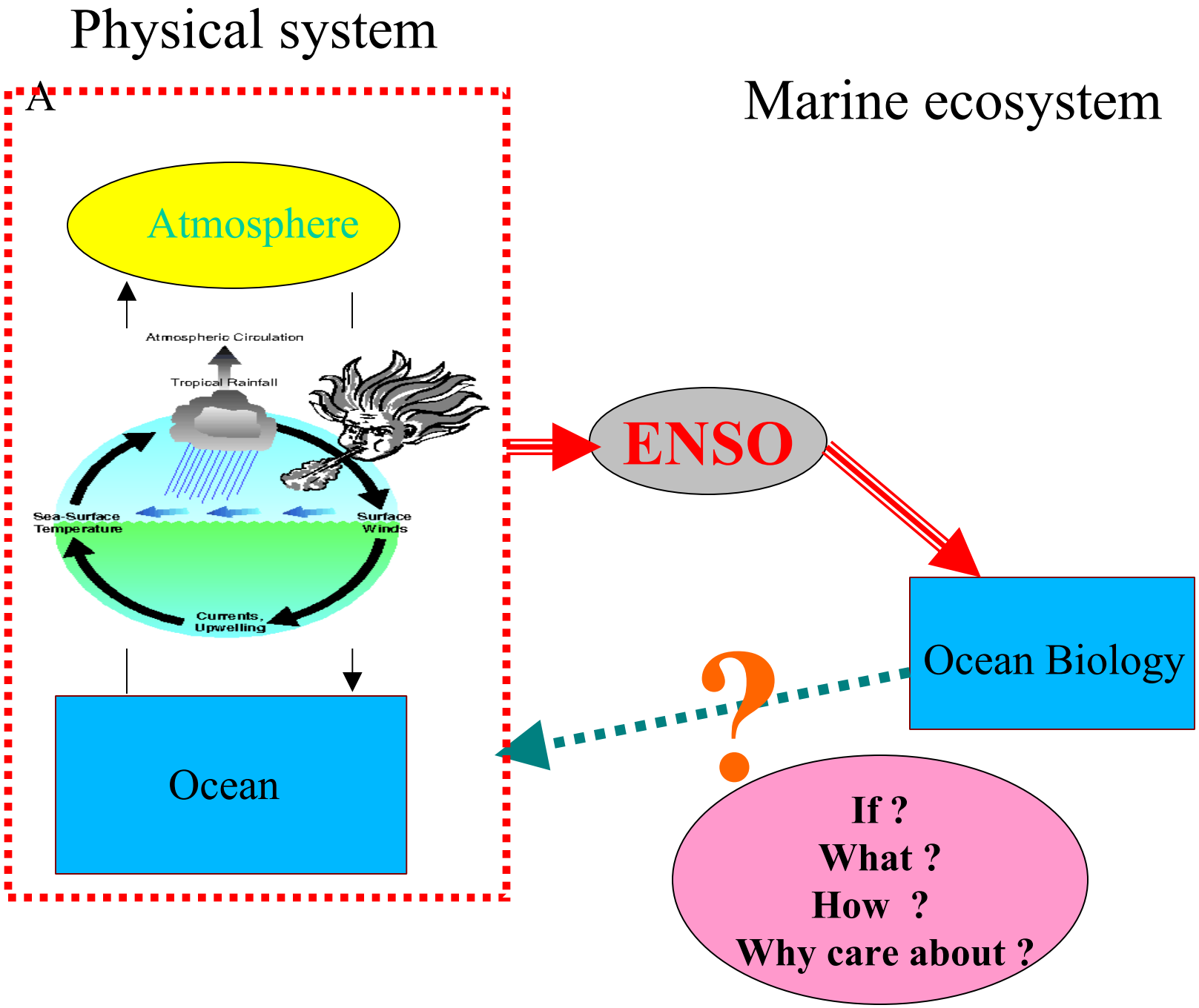
Physical !!!

Processes involved in ENSO: Forcings & feedbacks

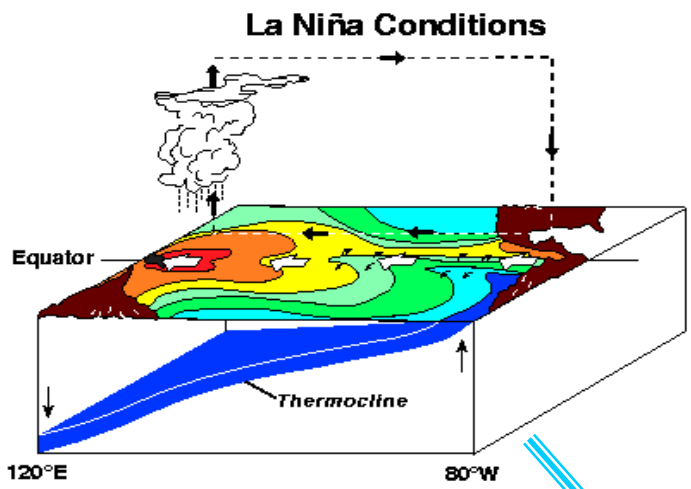


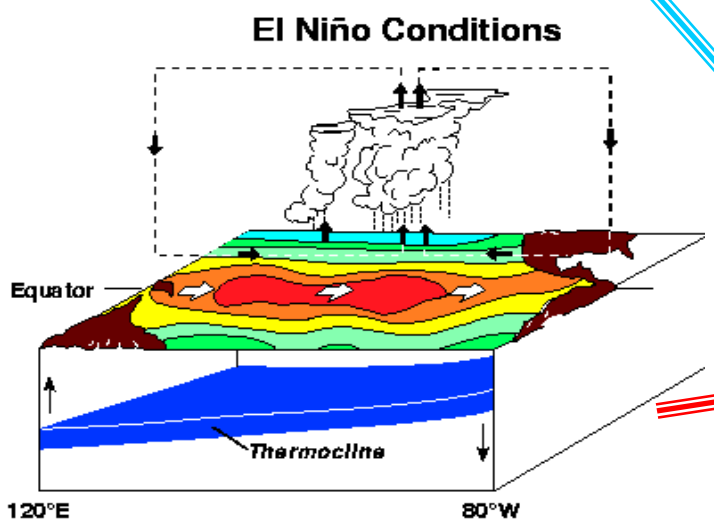


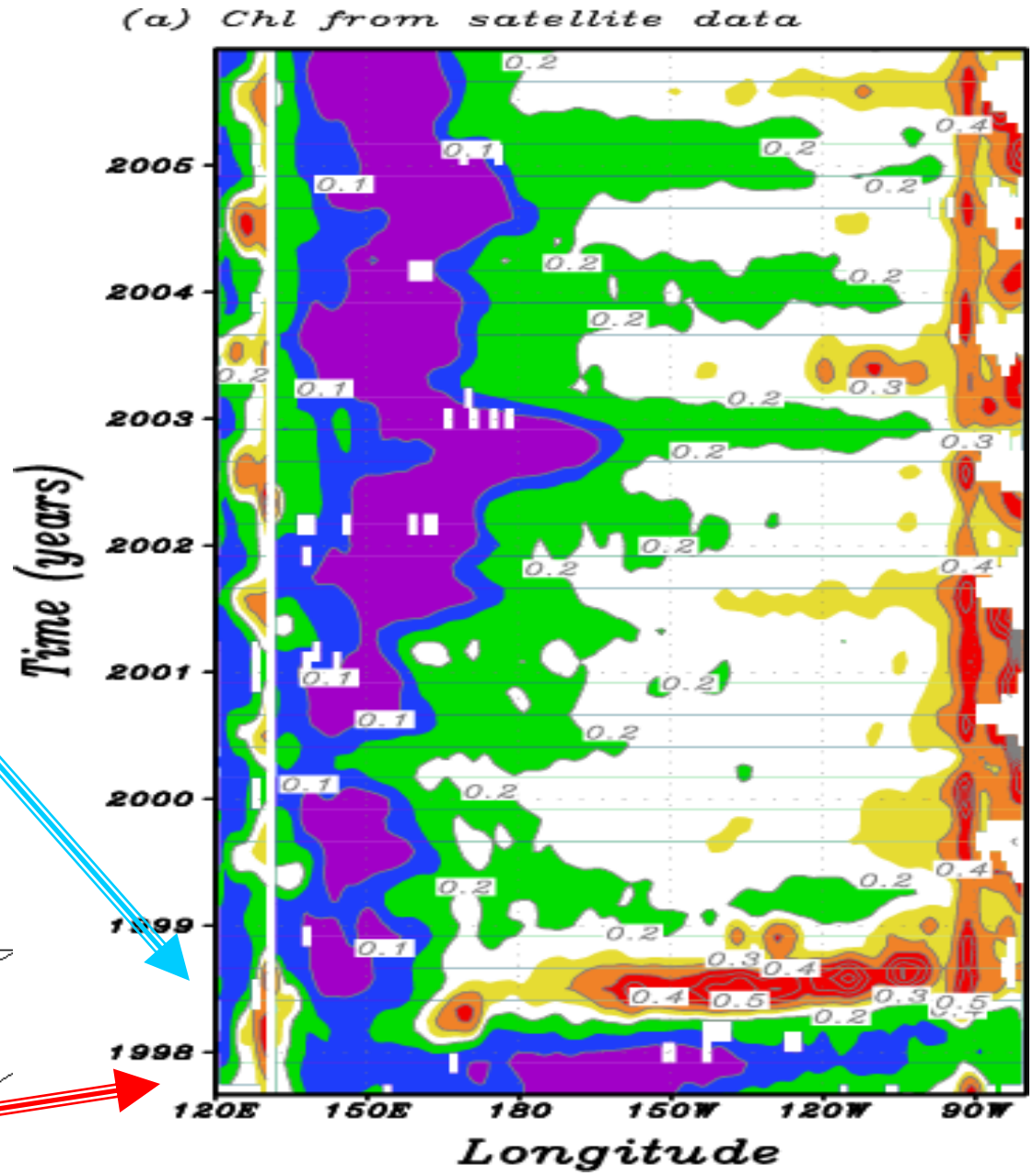

Physical system
A
Marine ecosystem
Atmosphere
Atmospheric Circulation
Tropical Rainfall
Sea-Surface Temperature
Surface Winds
Currents, Upwelling
ENSO
Ocean Biology
?
Ocean

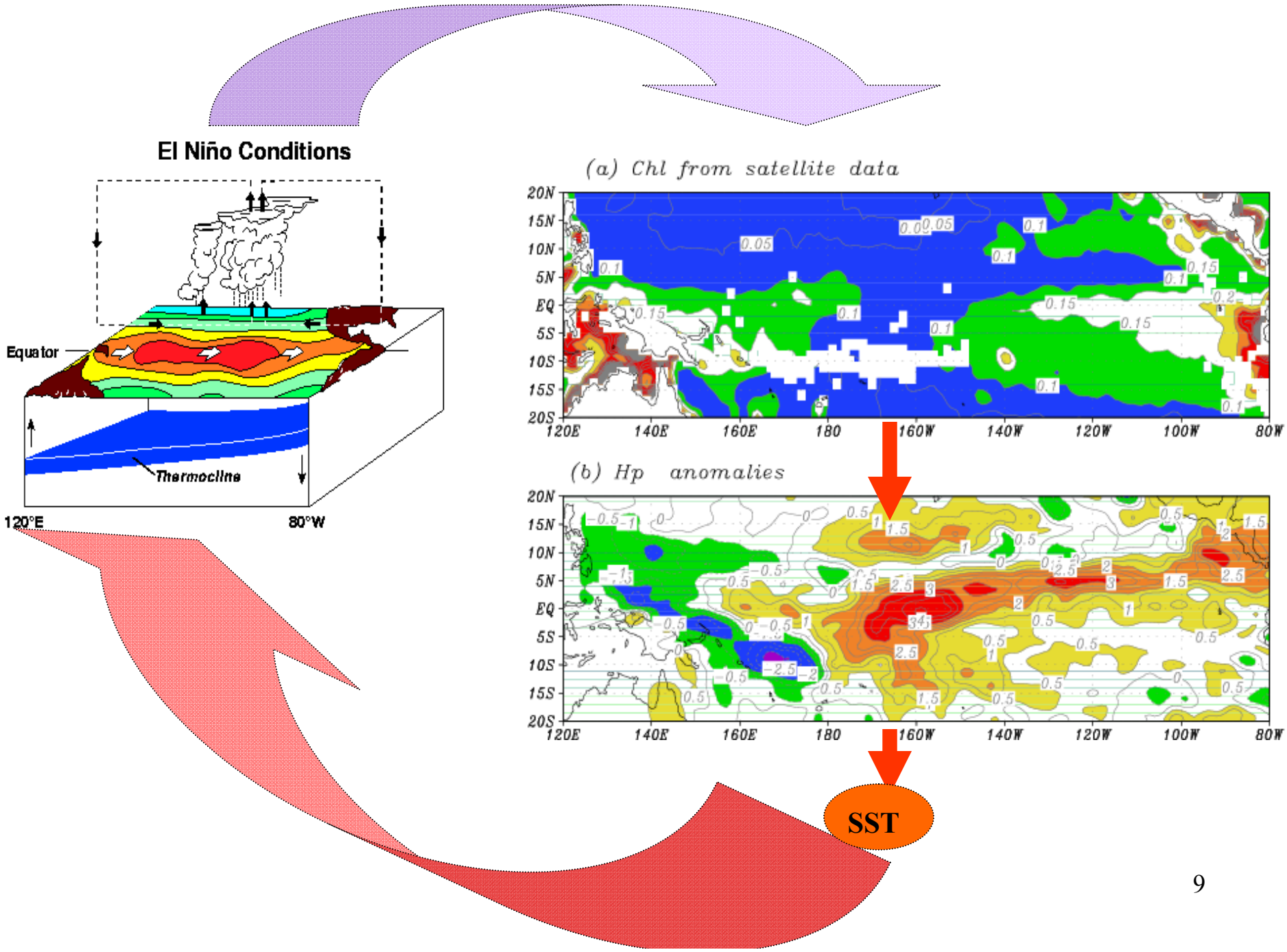

Physical system
A
Atmosphere
Atmospheric Circulation
Tropical Rainfall
Sea-Surface Temperature
Surface Winds
Currents, Upwelling
Ocean
Marine ecosystem
ENSO
Ocean Biology
?
If ?
What ?
How ?
Why care about ?

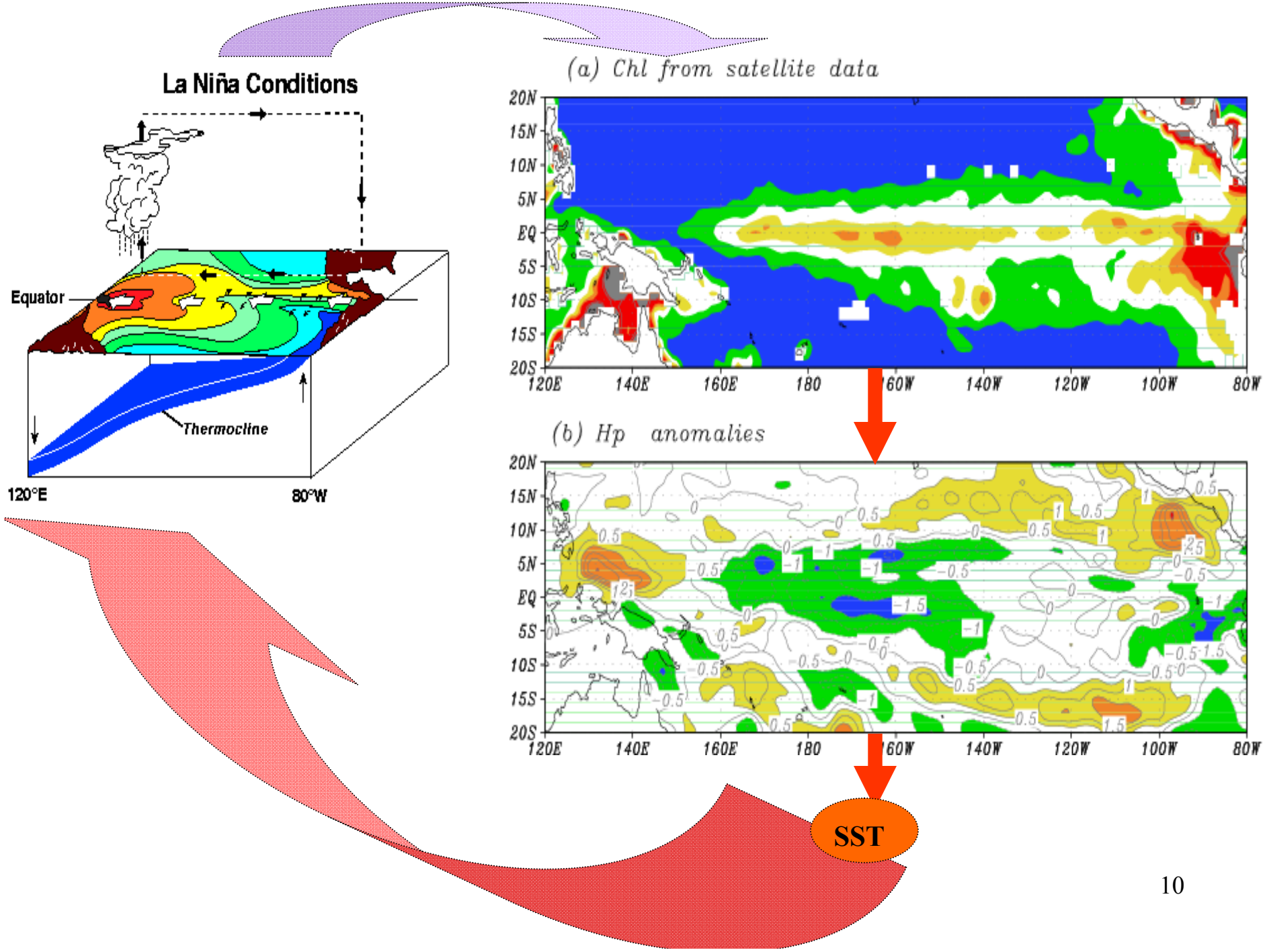
Ocean color data (SeaWiFS)



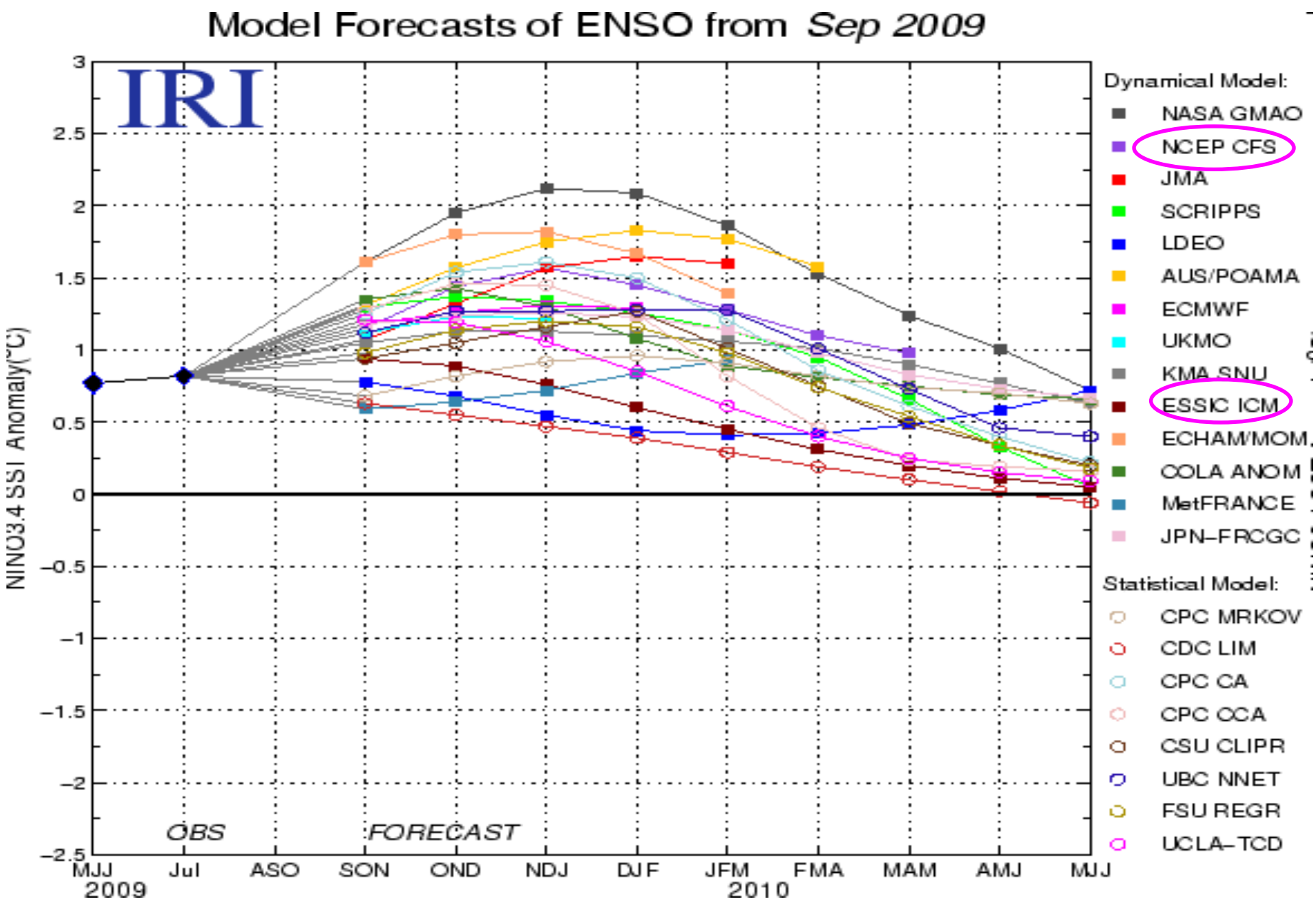





El Niño Conditions
Equator
Thermocline
120°E
80°W
(a) Chl from satellite data
(b) Hp anomalies
20N
15N
10N
5N
EQ
5S
10S
15S
20S
120E
140E
160E
180
160W
140W
120W
100W
80W
SST


La Niña Conditions
Equator
Thermocline
120°E
80°W
(a) Chl from satellite data
(b) Hp anomalies
20N
15N
10N
5N
EQ
5S
10S
15S
20S
120E
140E
160E
180
160W
140W
120W
100W
80W
SST

http://iri.columbia.edu/climate/ENSO/currentinfo

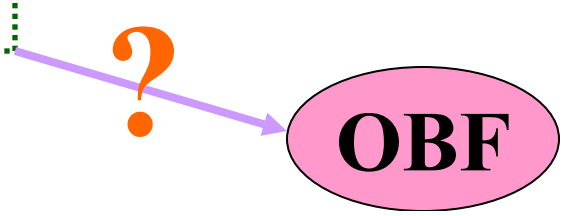


Challenges in ocean biology-induced feedback (OBF)

- **Studies mostly on *ocean physics*, less on biology;**
- **Studies mostly on *results*, less on *process* analyses;**
- **OBF not adequately represented in coupled models;**
- **Uncertainty in parameterization, observations & data products related with OBF;**
- **Strikingly model dependent & conflicting results (Ocean models & Coupled atmos-ocean models)**

  Long-term mean states: **warming or cooling ?**
  Seasonal variations: **enhanced or reduced ?**
  Interannual variations: **negative or positive feedbacks?**

- **Systematic biases & errors in SST simulations:**



This work

Taking into account ocean biological feedback (OBF)

- Using satellite data to explore links between the *climate system* & *marine ecosystem*;
- A simple parameterization for OBF;
- Effects on ocean biology on ENSO;
- Understanding basic processes involved;
- Role as bias sources for SST simulation;
- Improving ENSO simulations & prediction;

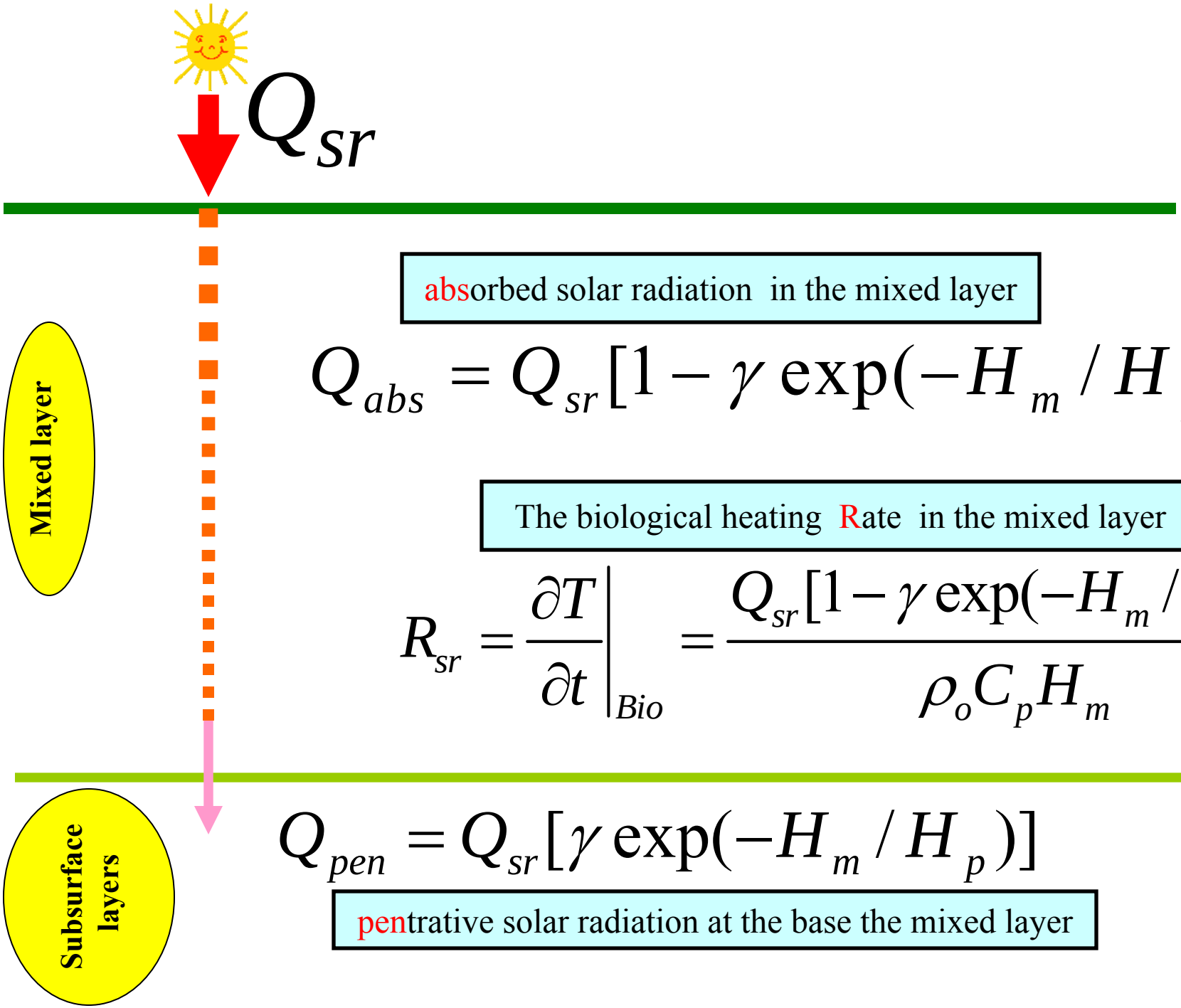
Effects of marine biology on ENSO

Penetration of solar irradiance
in upper ocean

Redistribution of heating in the vertical;
Modification of stratification/stability

Mixing, mixed layer depth,
upwelling,currents

SST



absorbed solar radiation in the mixed layer

$$Q_{abs} = Q_{sr}[1 - \gamma \exp(-H_m / H_p)]$$

The biological heating Rate in the mixed layer

$$R_{sr} = \left.\frac{\partial T}{\partial t}\right|_{Bio} = \frac{Q_{sr}[1 - \gamma \exp(-H_m / H_p)]}{\rho_o C_p H_m}$$

$$Q_{pen} = Q_{sr}[\gamma \exp(-H_m / H_p)]$$

pentrative solar radiation at the base the mixed layer

The penetration of solar irradiance follows an exponential decline with depth:

$$I(z,\lambda) = I_o(\lambda) \bullet e^{(-k(\lambda)\bullet z)}$$

The penetrative bands on the visible part of the radiation (Morel, 1988):

$$\boxed{I(z) = I_o \bullet e^{(-z/H_p)} = I_o \bullet e^{(-K_p \bullet z)}}$$

$$K_w = 0.027 \quad m^{-1}$$
$$a = 0.0518 \quad (mg \cdot m^{-2})^{-1}$$
$$b = 0.4280$$

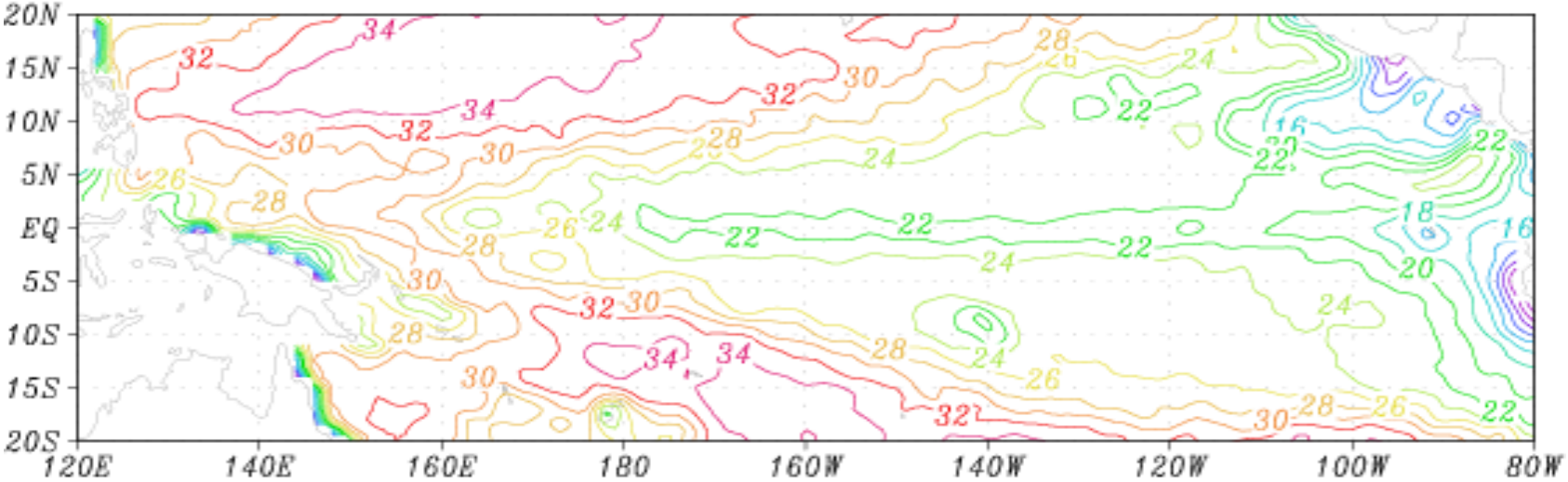
$$K_p = K_w + K_{Chl}$$
$$K_{Chl} = a \bullet Chl^{b}$$

Ocean color data (SeaWiFS)

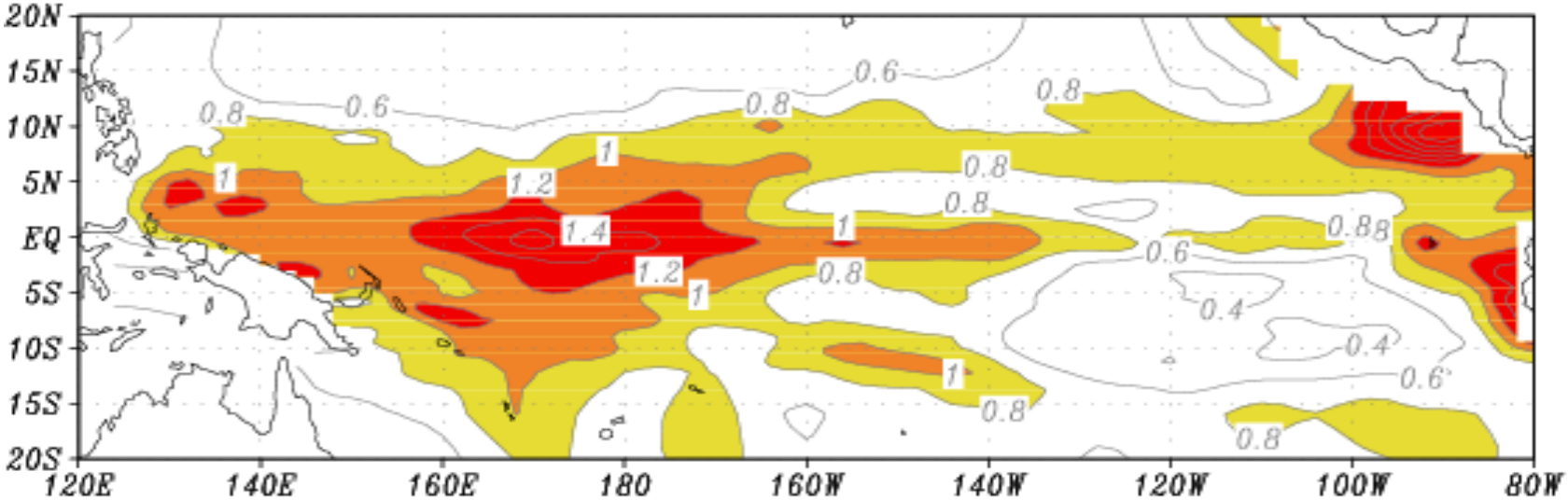
$$\frac{1}{K_p} = H_p$$

$$H_p = \overline{H_p} + H_p'$$

(a) Annual mean Hp field from ocean color



(b) Standard deviation of Hp



σ

Hybrid Coupled Model at *ESSIC/UMD*

- **The Gent-Cane ocean model**

  A sigma-layer, reduced-gravity OGCM **with**

  (1) ***A hybrid mixing scheme***

  Chen, Rothstein & Busalacchi (1995)

  (2) ***Coupling to an advective atmos mixed layer model*** (Murtugudde, Seager & Busalacchi 1995)

  (3) Model specifications:

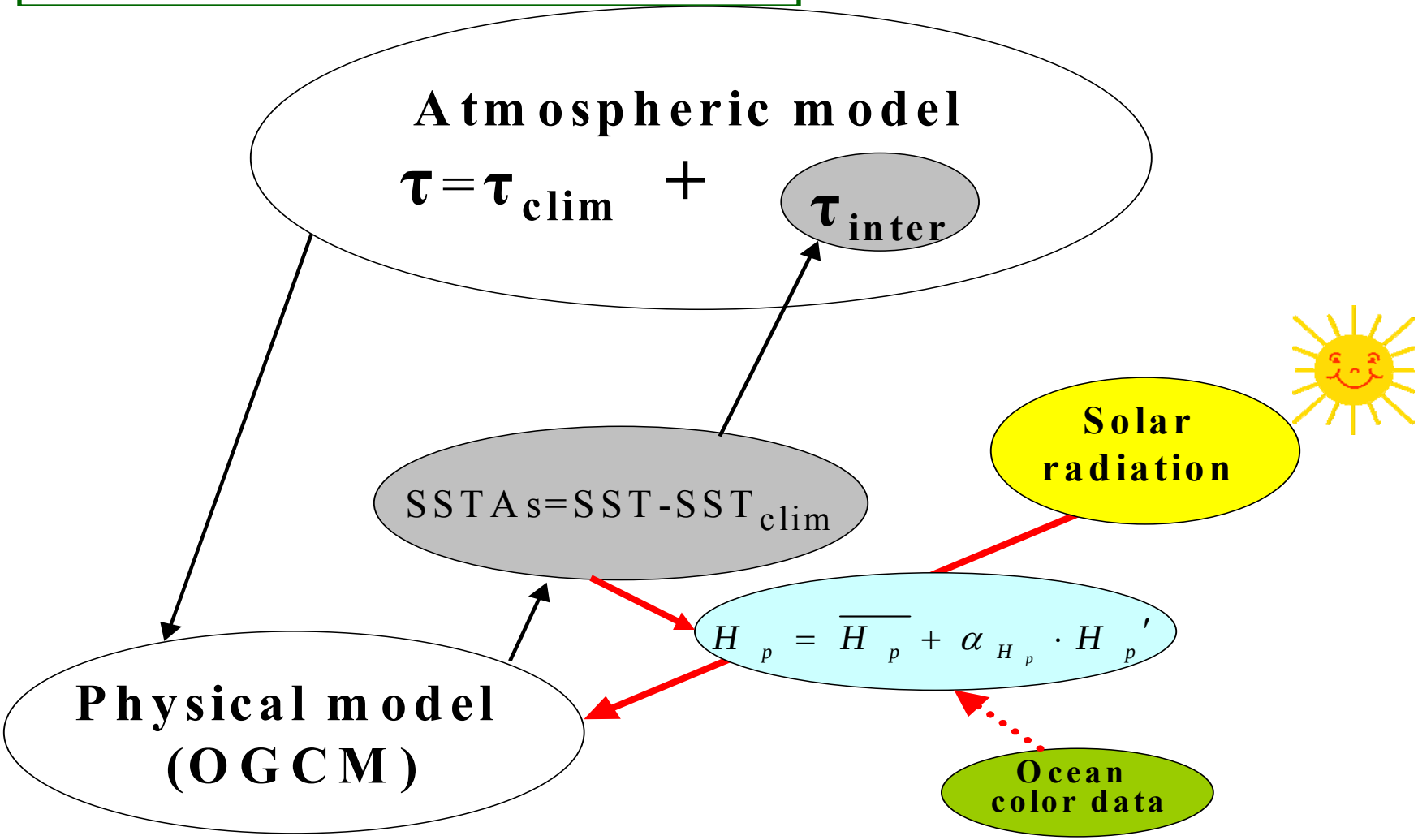
  Tropical Pacific domain: 25N-25S; 31-layers;

  Resolution: 1 deg in longitude and 0.5 deg in latitude

- **An empirical atmospheric wind stress anomaly model (SVD-based)**

Data & Model experiments

- **Ocean color data :** *1997-2007*
- **SST**: Reynolds & Smith



The Role of ocean biology in ENSO

$$H_p = \overline{H_p} + H_p'$$

- **Climatology:**

$\overline{H}_p \Rightarrow$

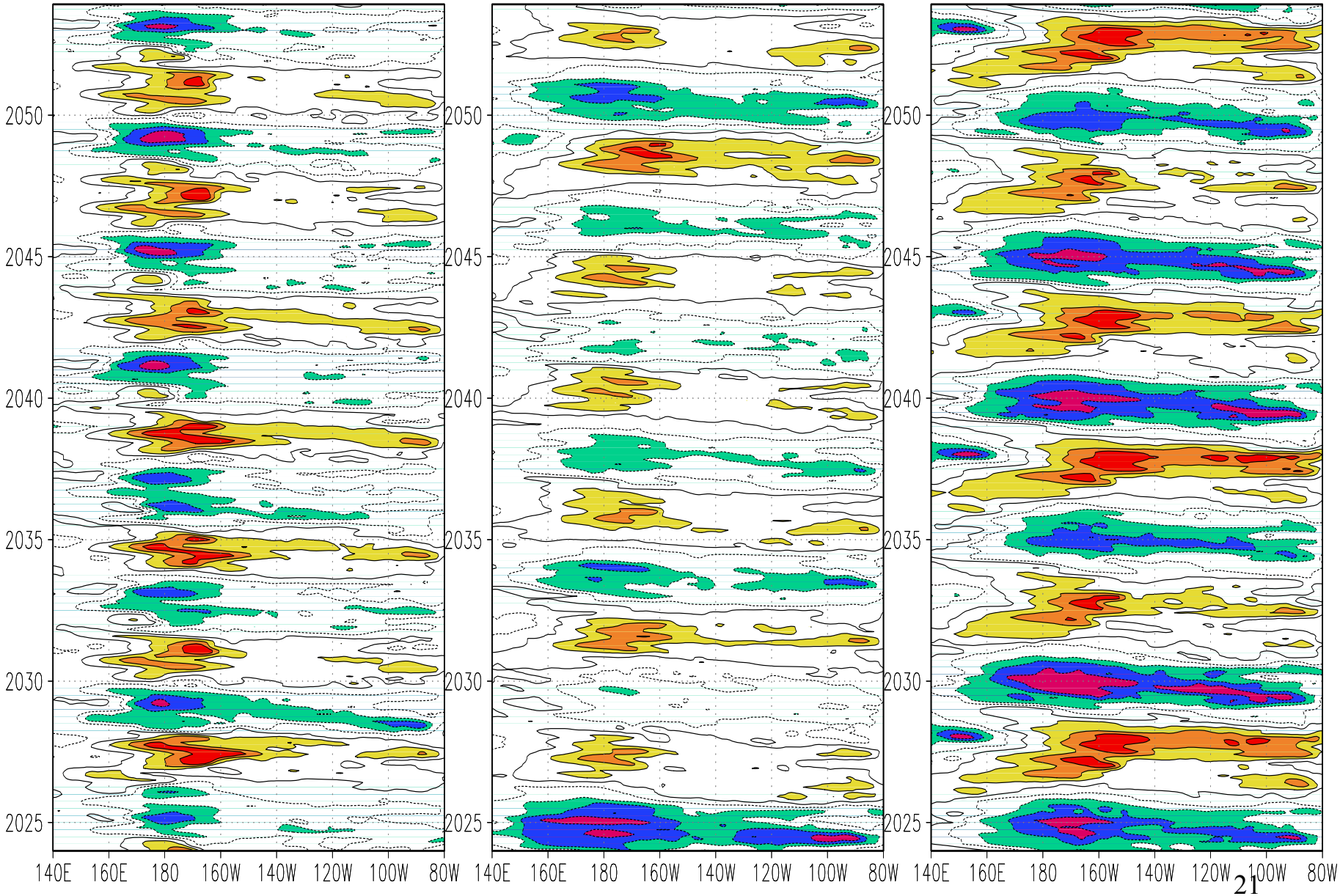
HP17 = 17 m : constant

HPAM = annual mean Hp

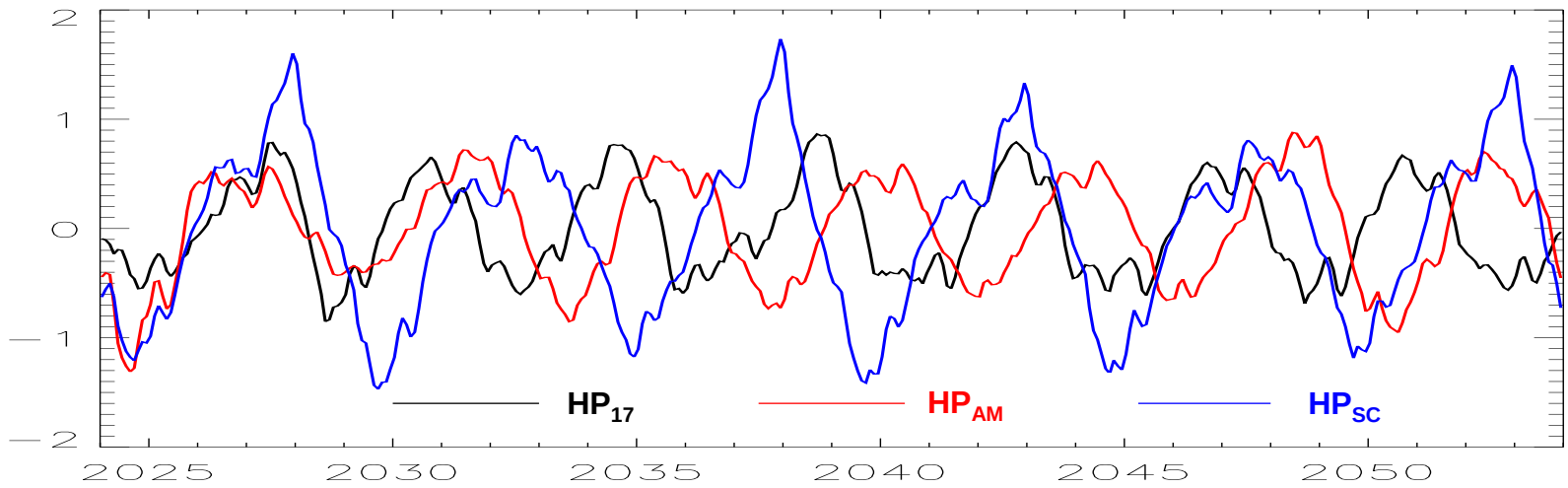
HPSC = seasonal cycle of Hp

Ballabrera-Poy, Murtugudde, Zhang and Busalacchi, *J. Climate*, 2007

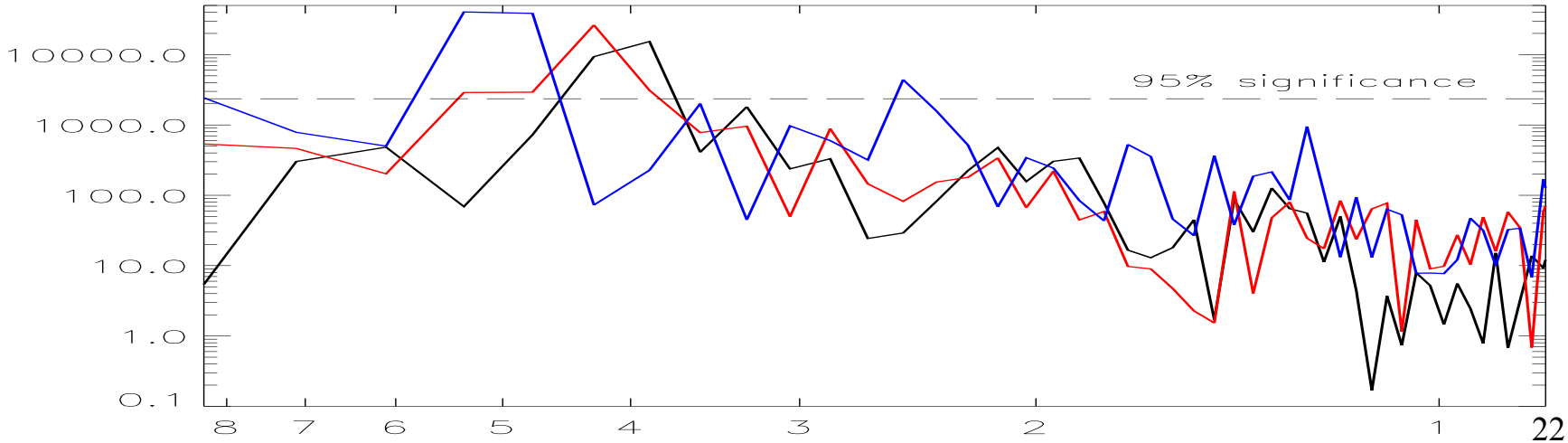
Hp=17 m, constant **HPAM = annual mean Hp** **HPSC = seasonal cycle of Hp**



a) Time series



b) Power spectrum



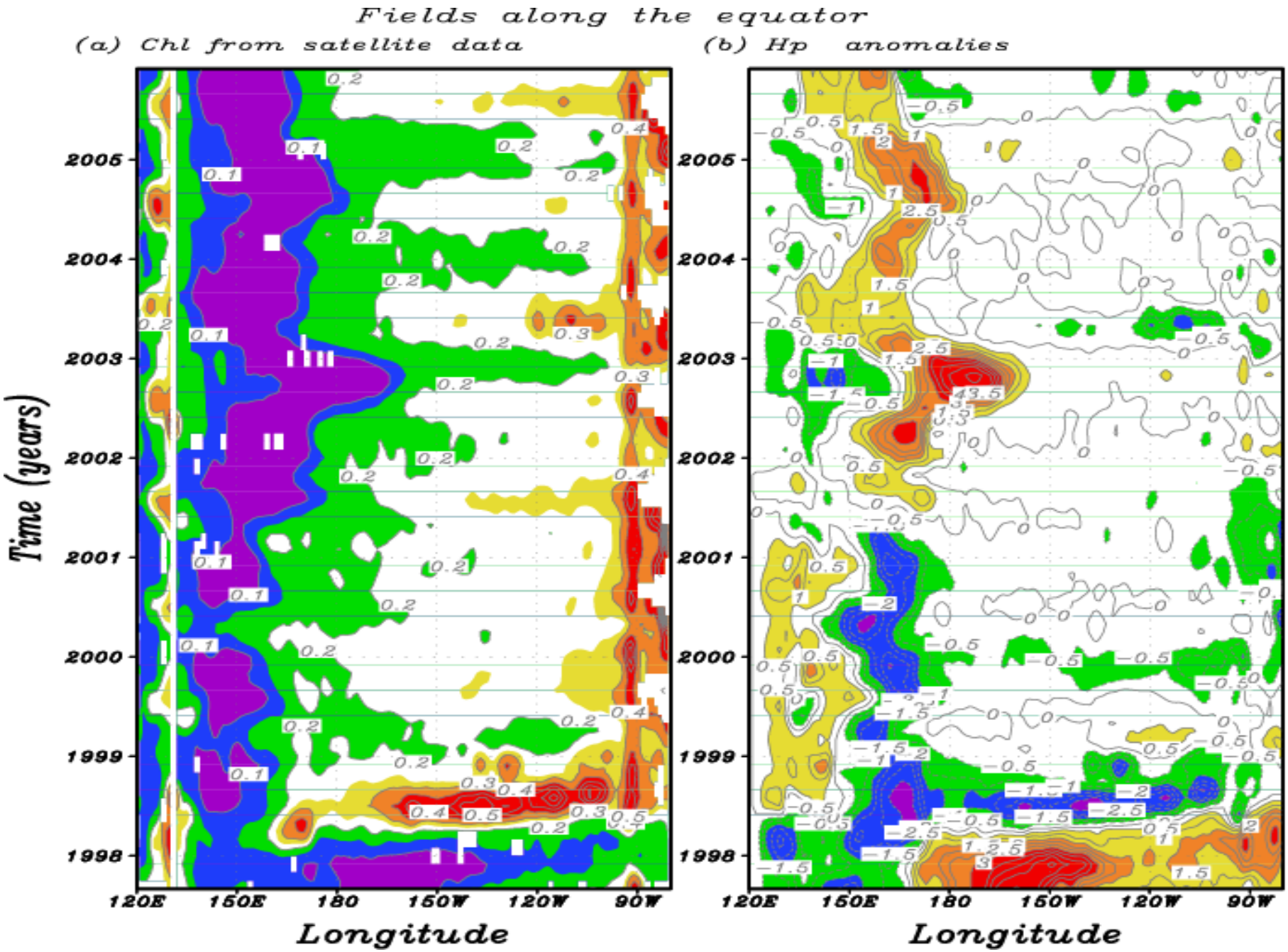
The Role of ocean biology in ENSO

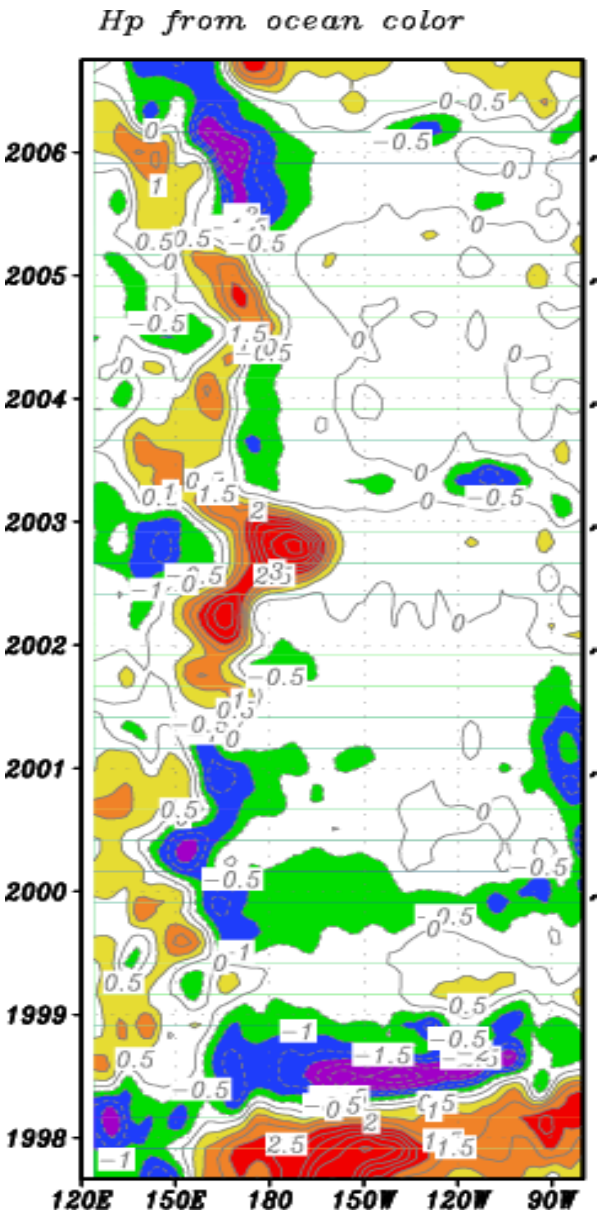
$$H_p = \overline{H_p} + H_p'$$

- **Interannual H_p variability:**

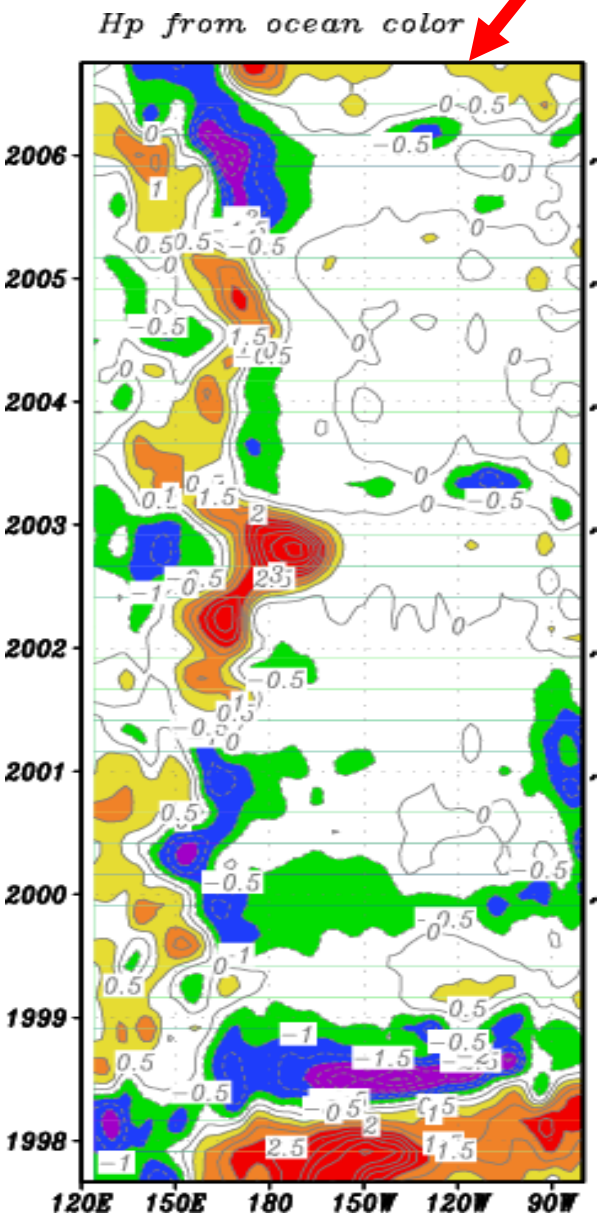
$$H_p' \Leftarrow$$

SVD based empirical model relating to SST anomalies


Fields along the equator
(a) Chl from satellite data
(b) Hp anomalies
Time (years)
2005
2004
2003
2002
2001
2000
1999
1998
120E
150E
180
150W
120W
90W
Longitude
Longitude

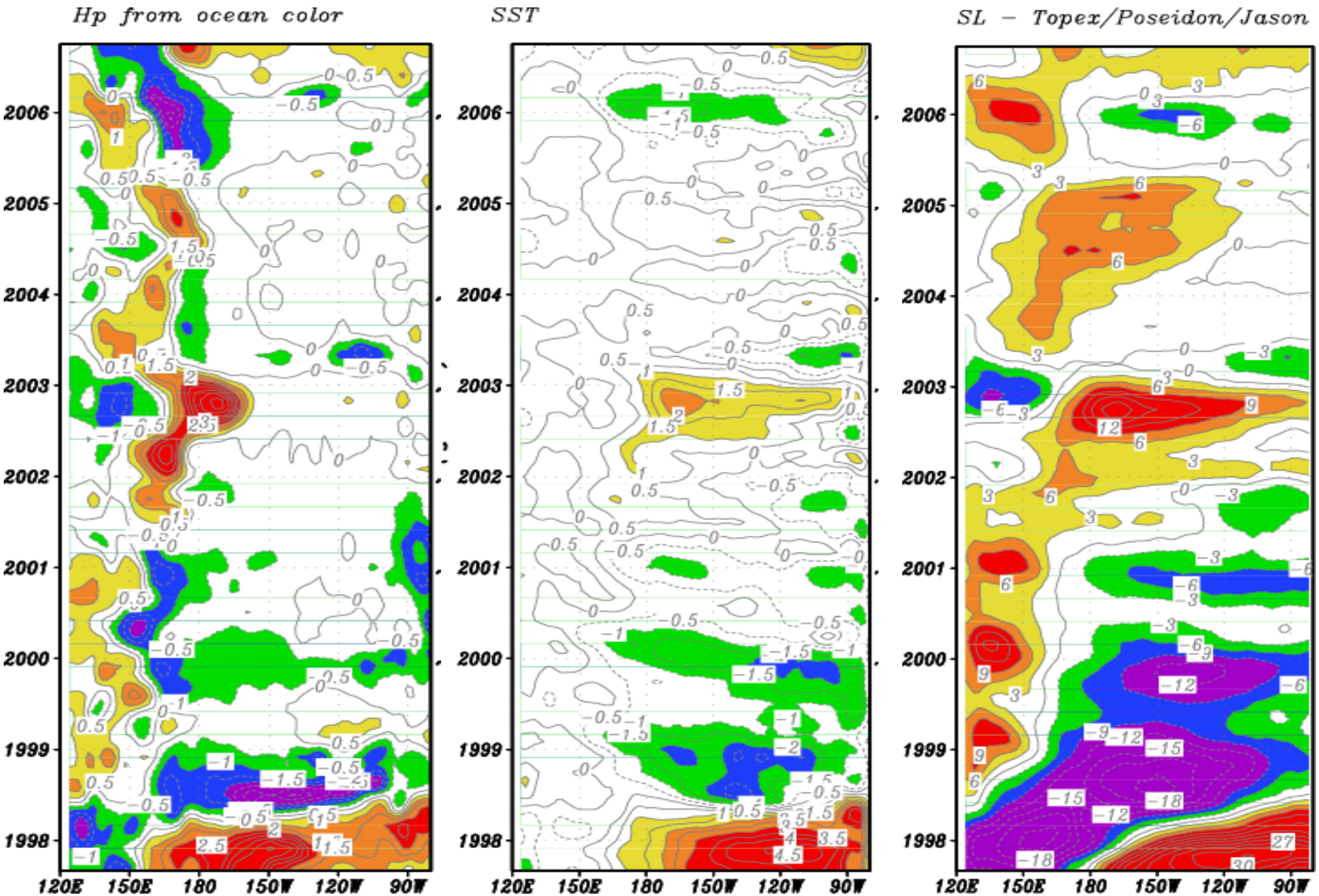

Hp from ocean color
2006
2005
2004
2003
2002
2001
2000
1999
1998
120E
150E
180
150W
120W
90W

Physical fields

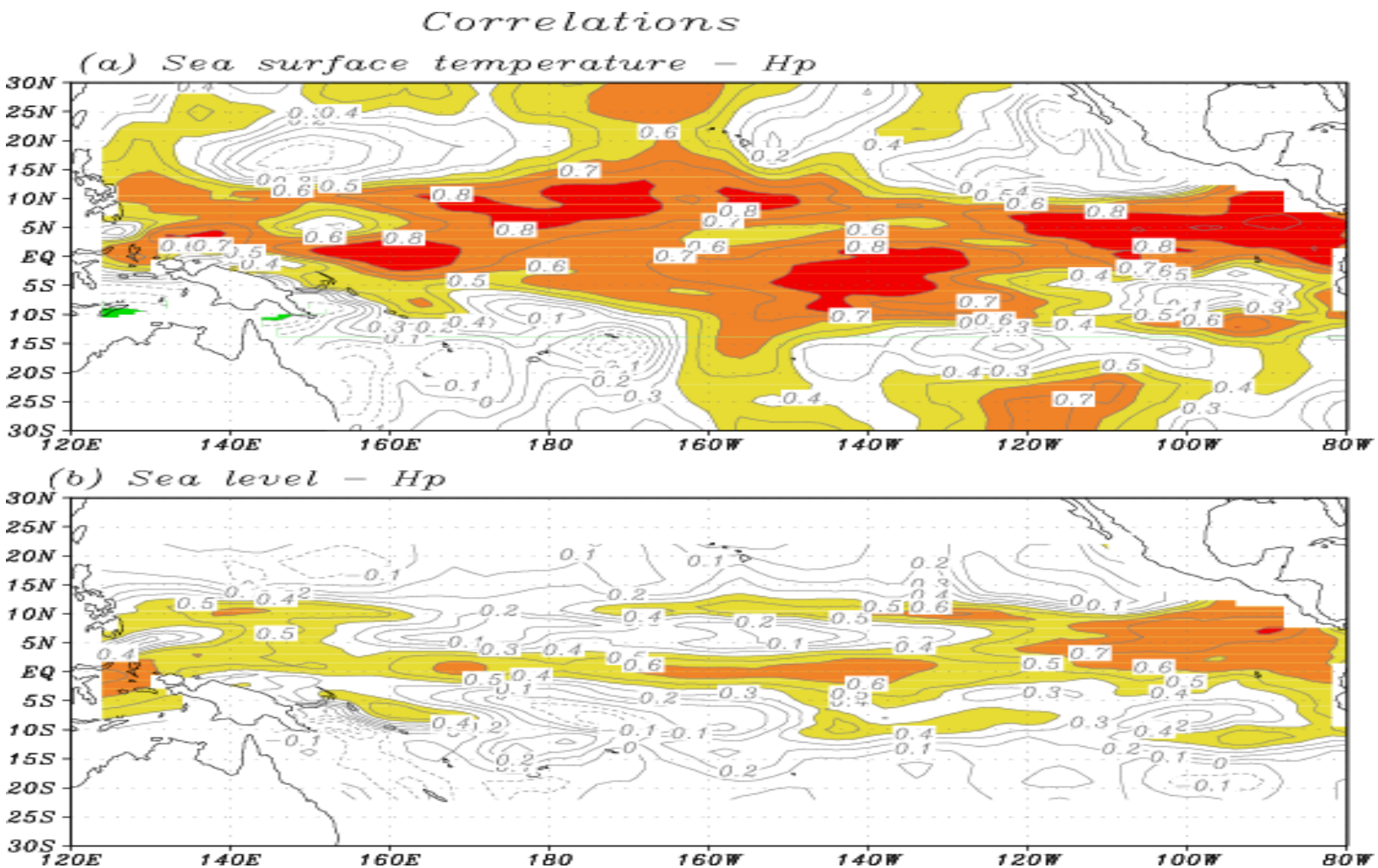


SST

SL from G. Mitchum

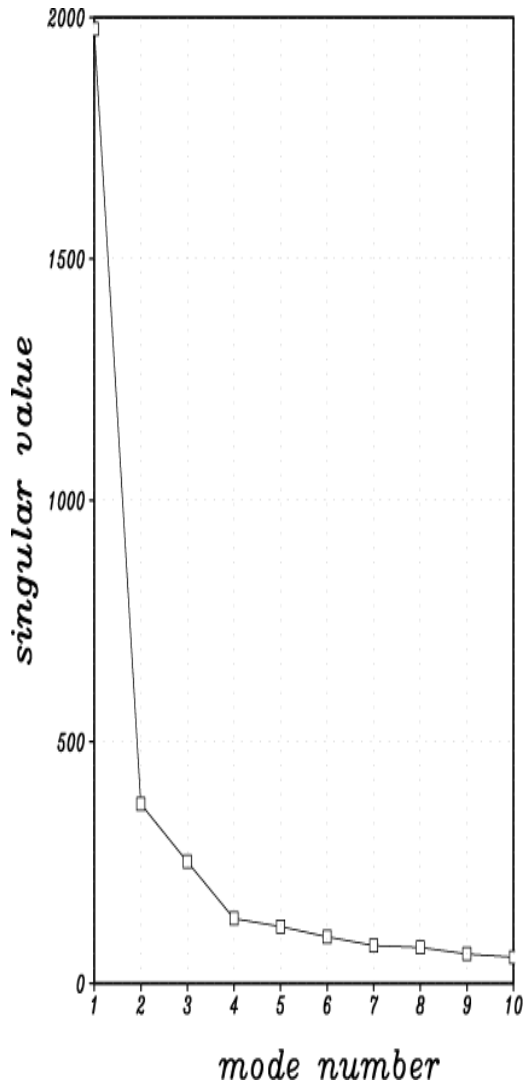


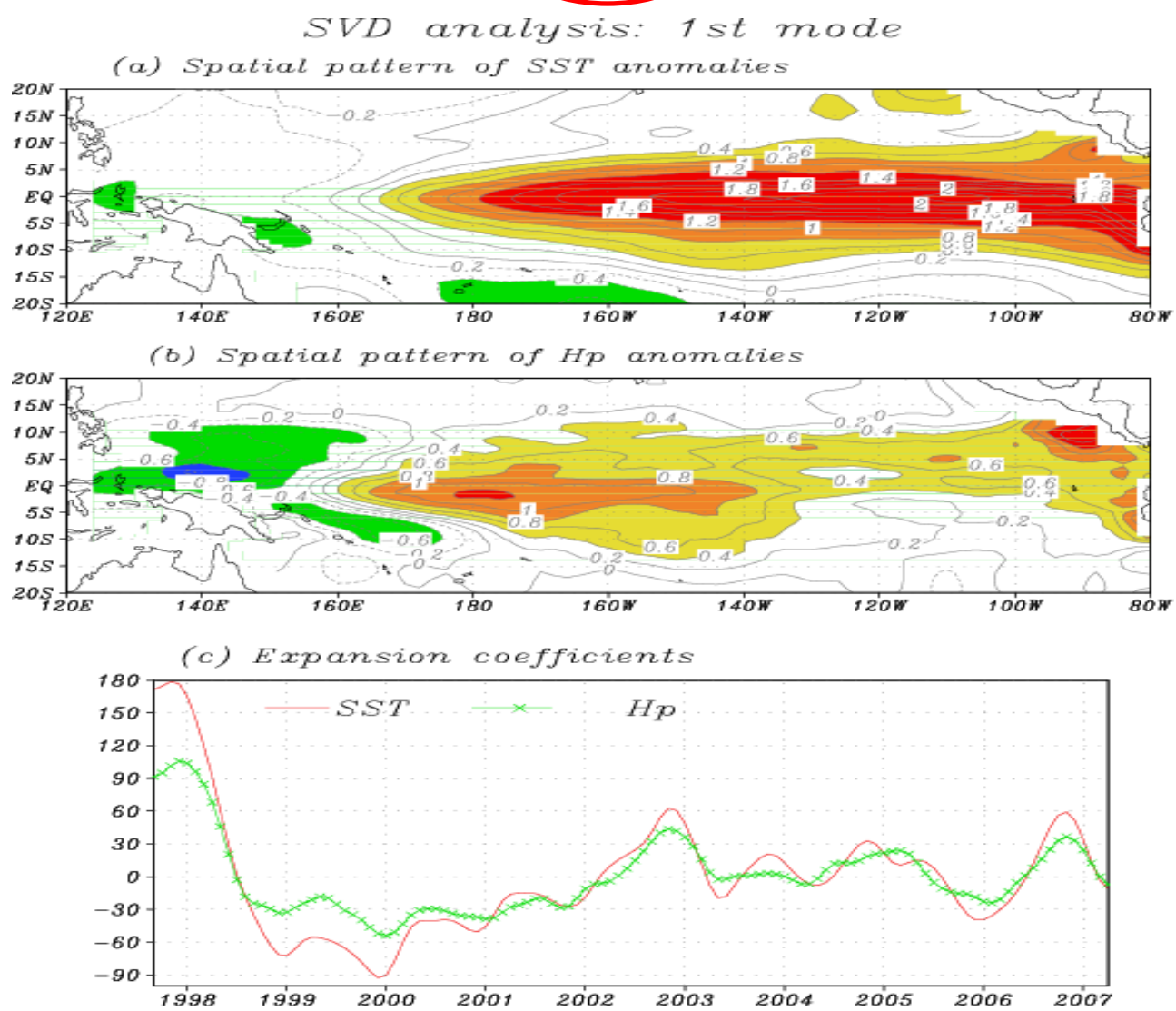
H_p ⟷ physical field : SST, SL



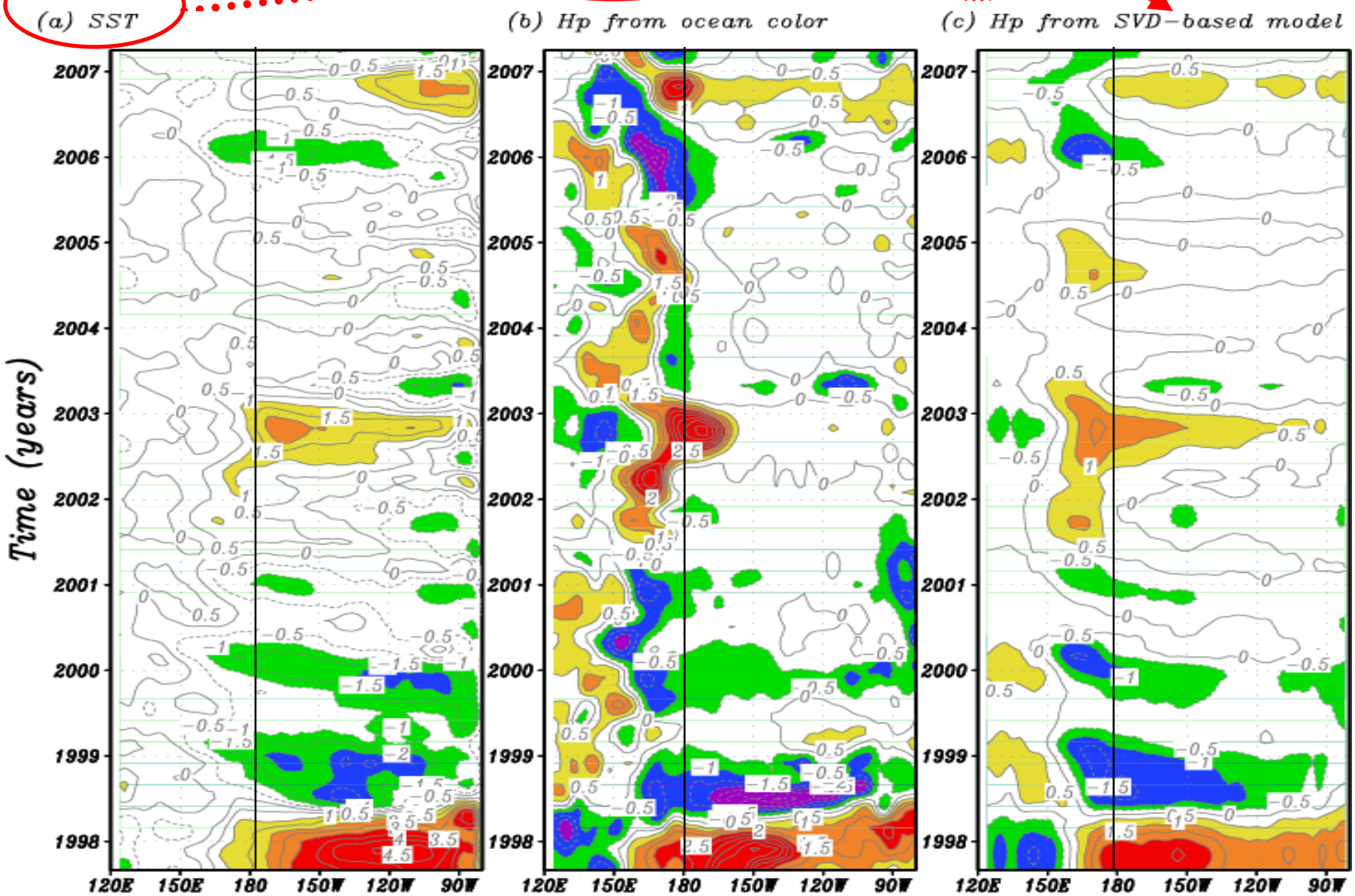
A SVD-based Empirical Model for H'_p

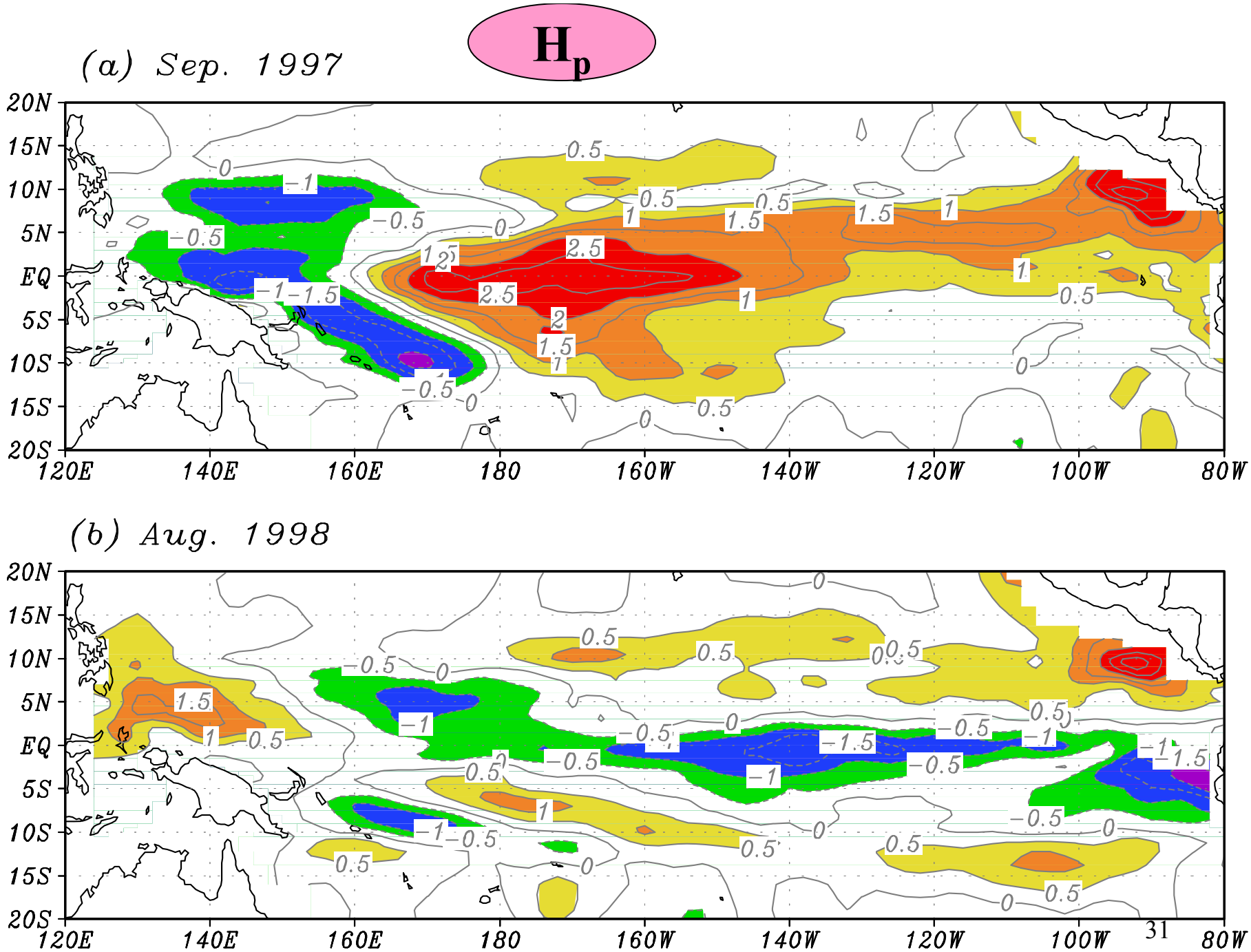
$$H_p = \overline{H_p} + \alpha_{Hp} \bullet S_{vd}(SST_{inter})$$



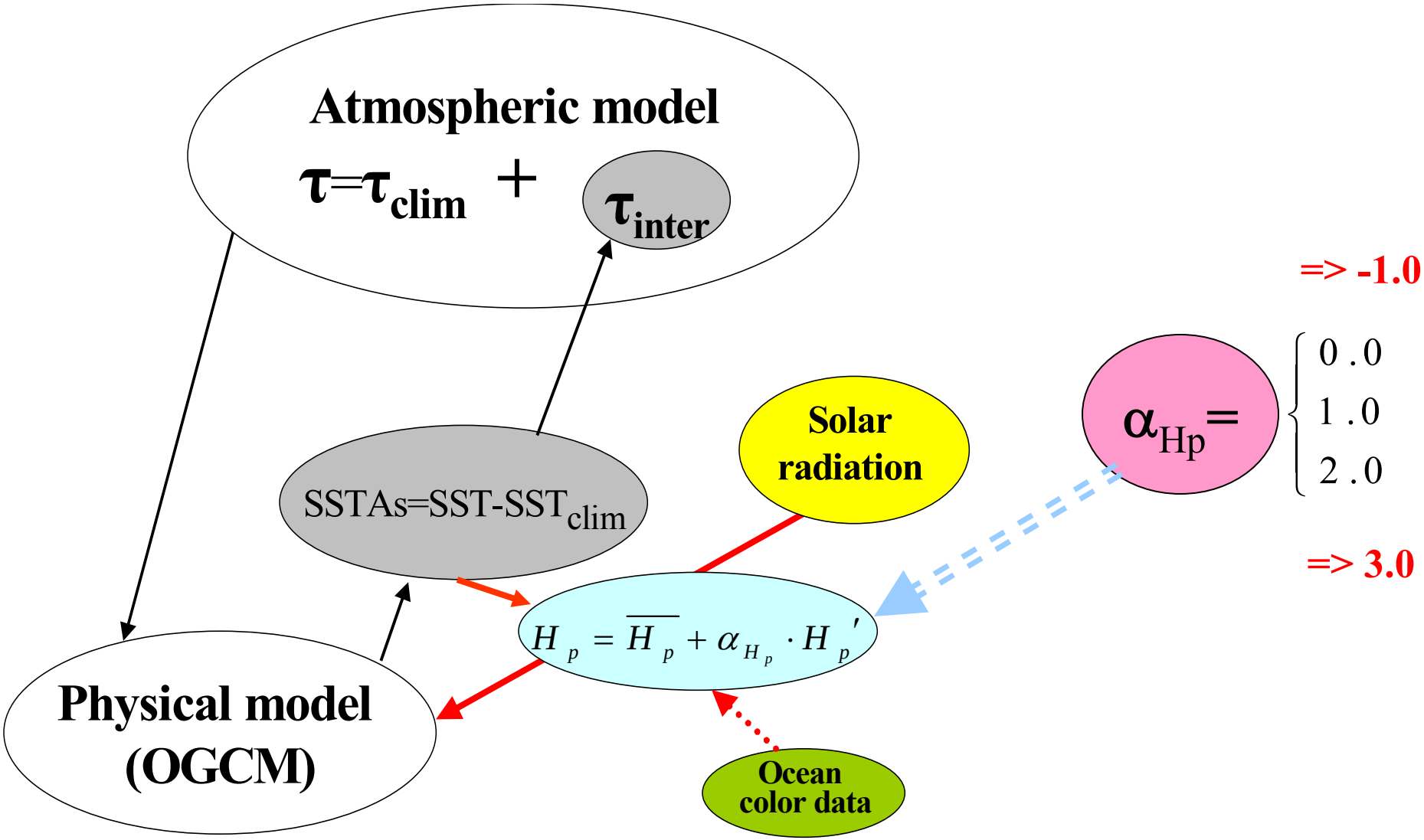


$$S_{vd}(SST_{inter}) = H'_p$$




Hp
(a) Sep. 1997
(b) Aug. 1998
20N
15N
10N
5N
EQ
5S
10S
15S
20S
120E
140E
160E
180
160W
140W
120W
100W
80W

Interannual H_p experiments

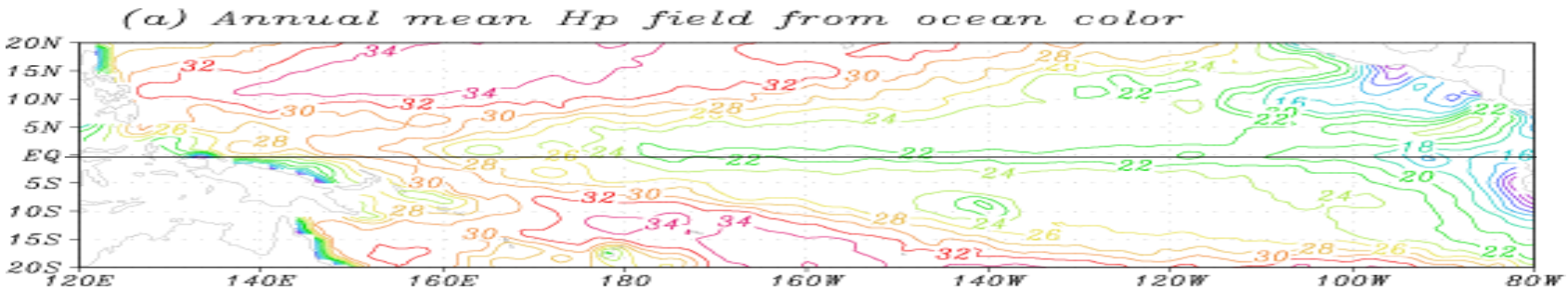


Annual mean fields

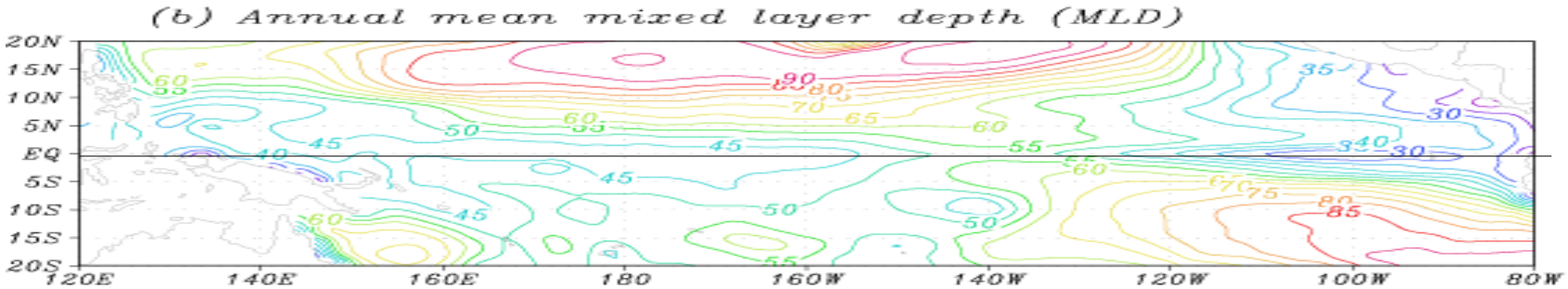
$$Q_{pen} = Q_{sr}[\gamma \exp(-H_m / H_p)]$$

$$Q_{abs} = Q_{sr}[1 - \gamma \exp(-H_m / H_p)]$$

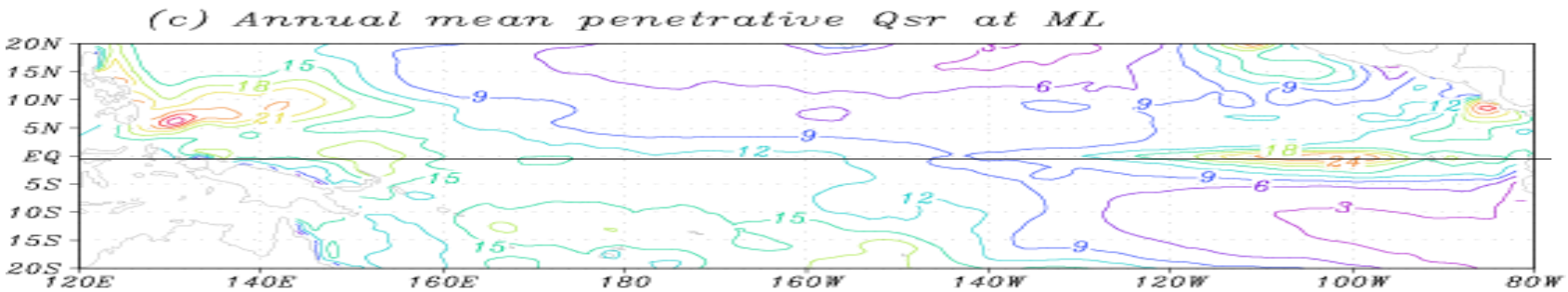
H_p



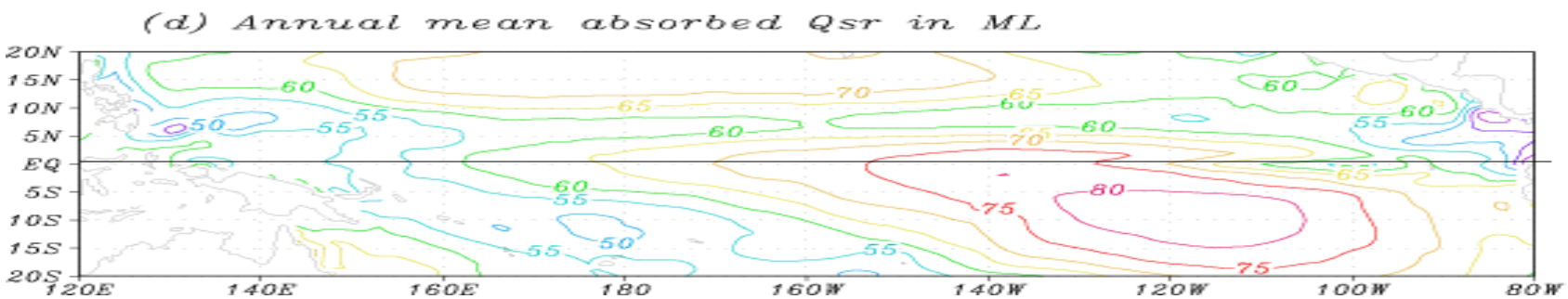
H_m

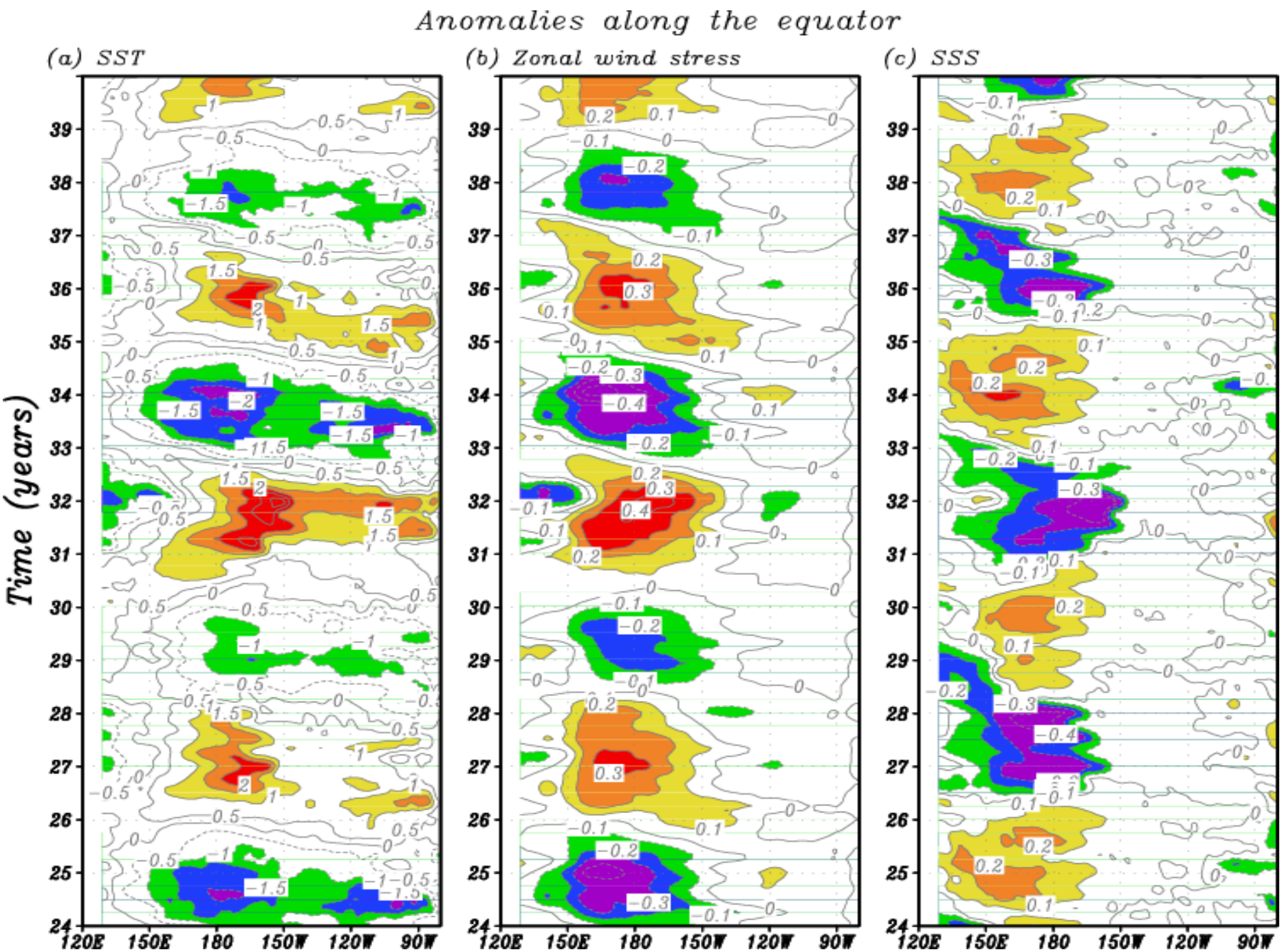


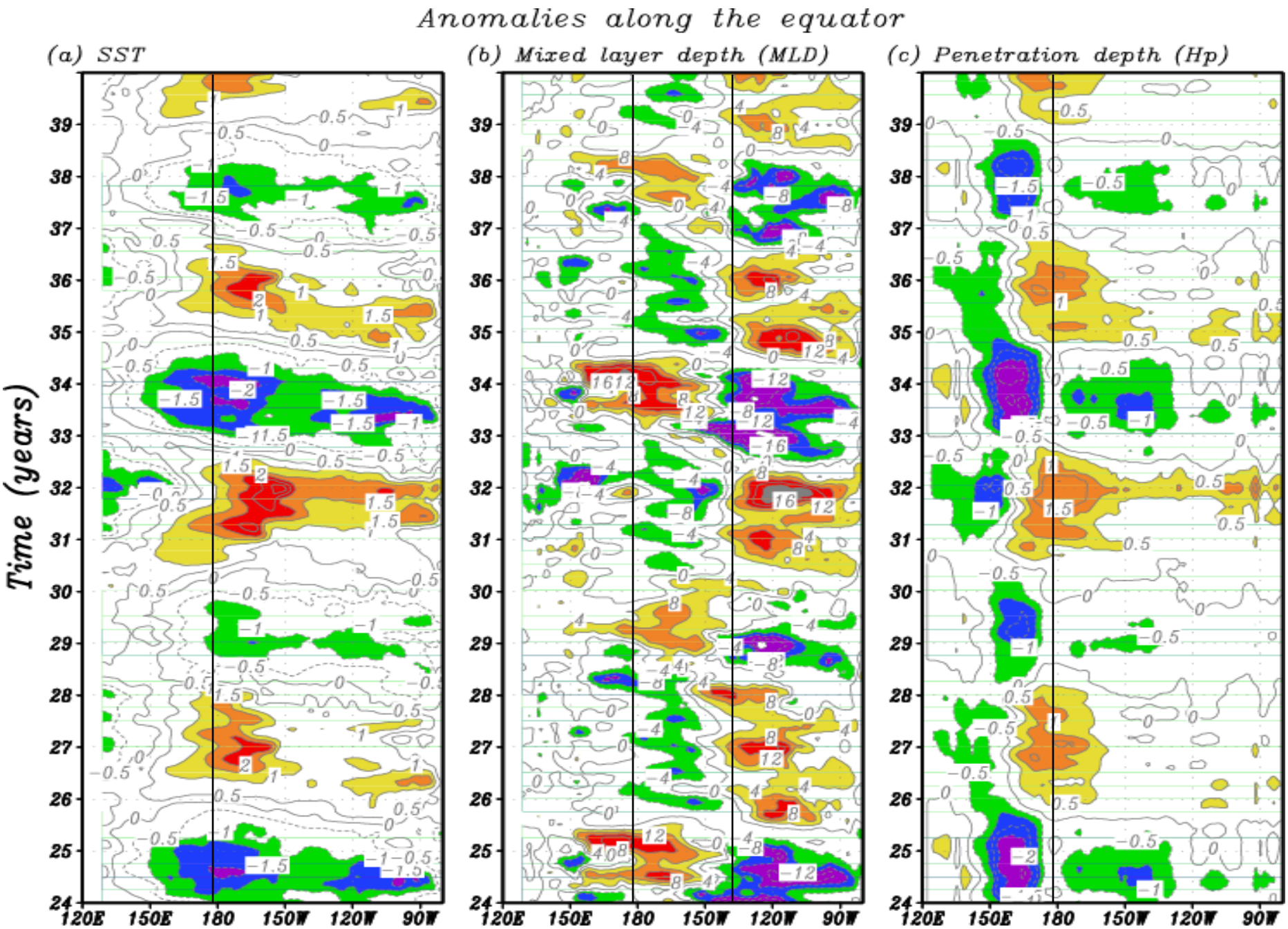
Q_{pen}

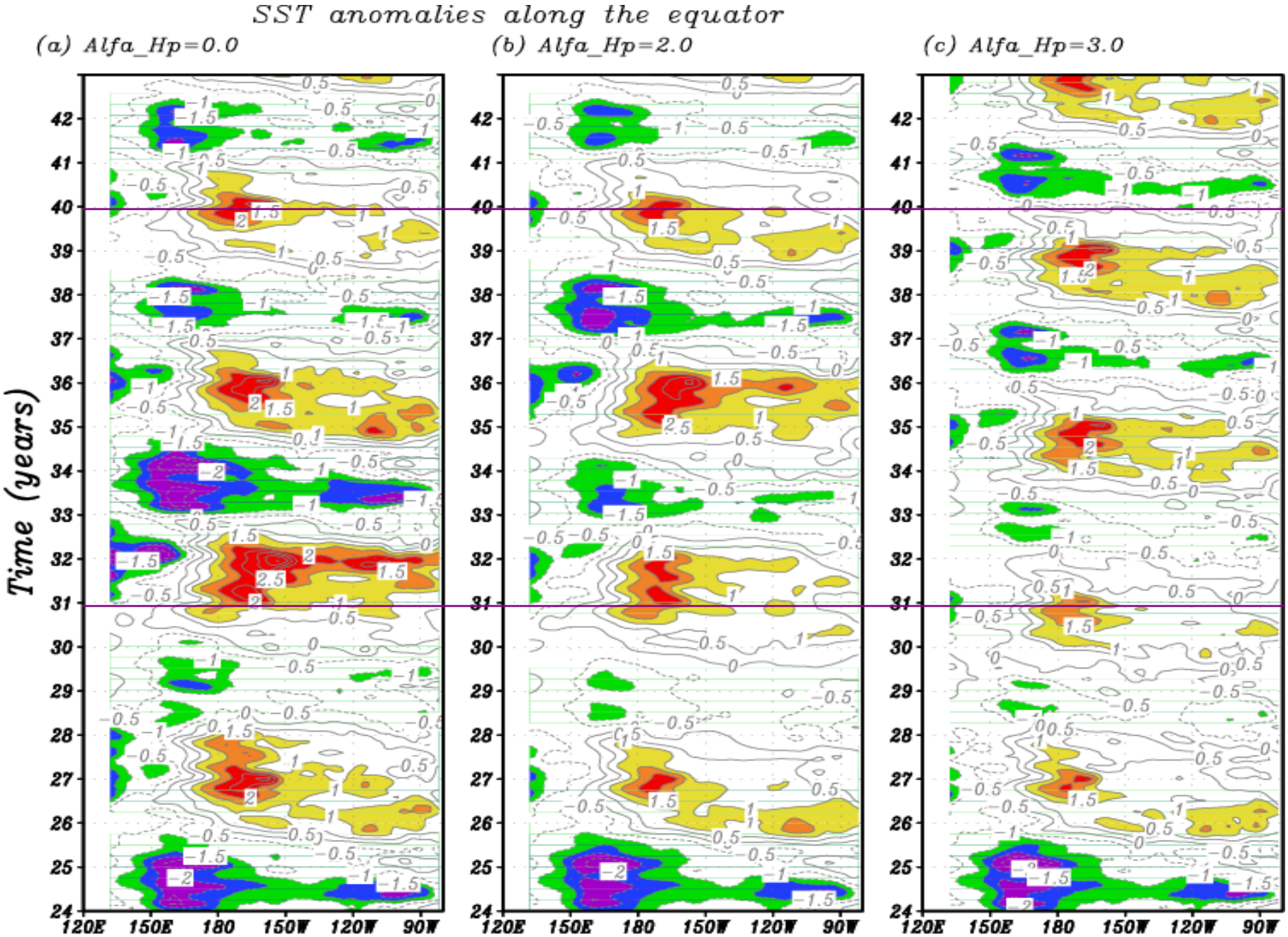


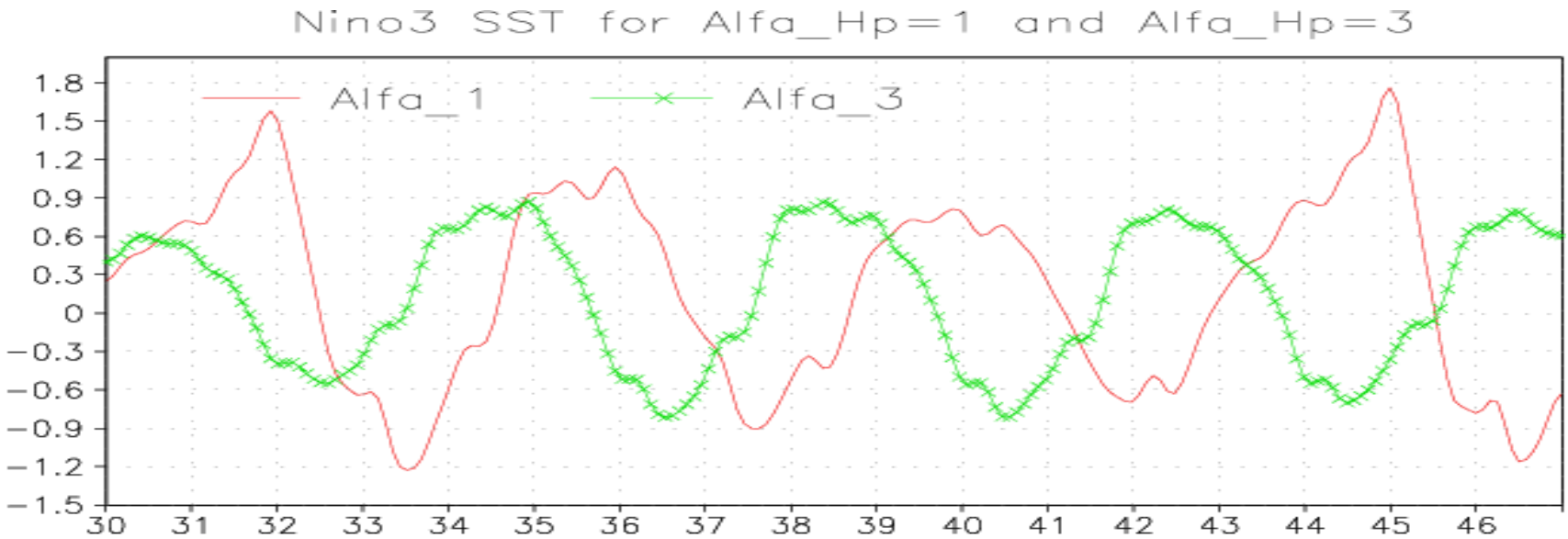
Q_{abs}

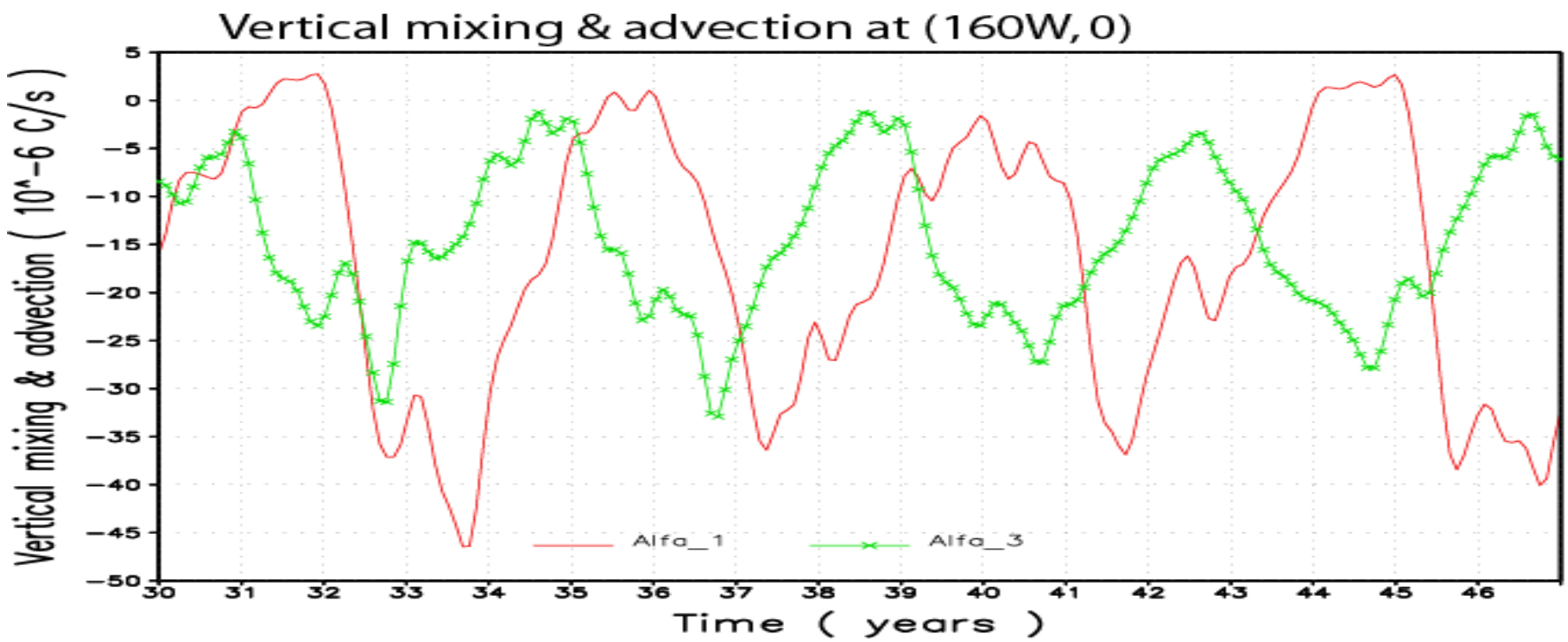


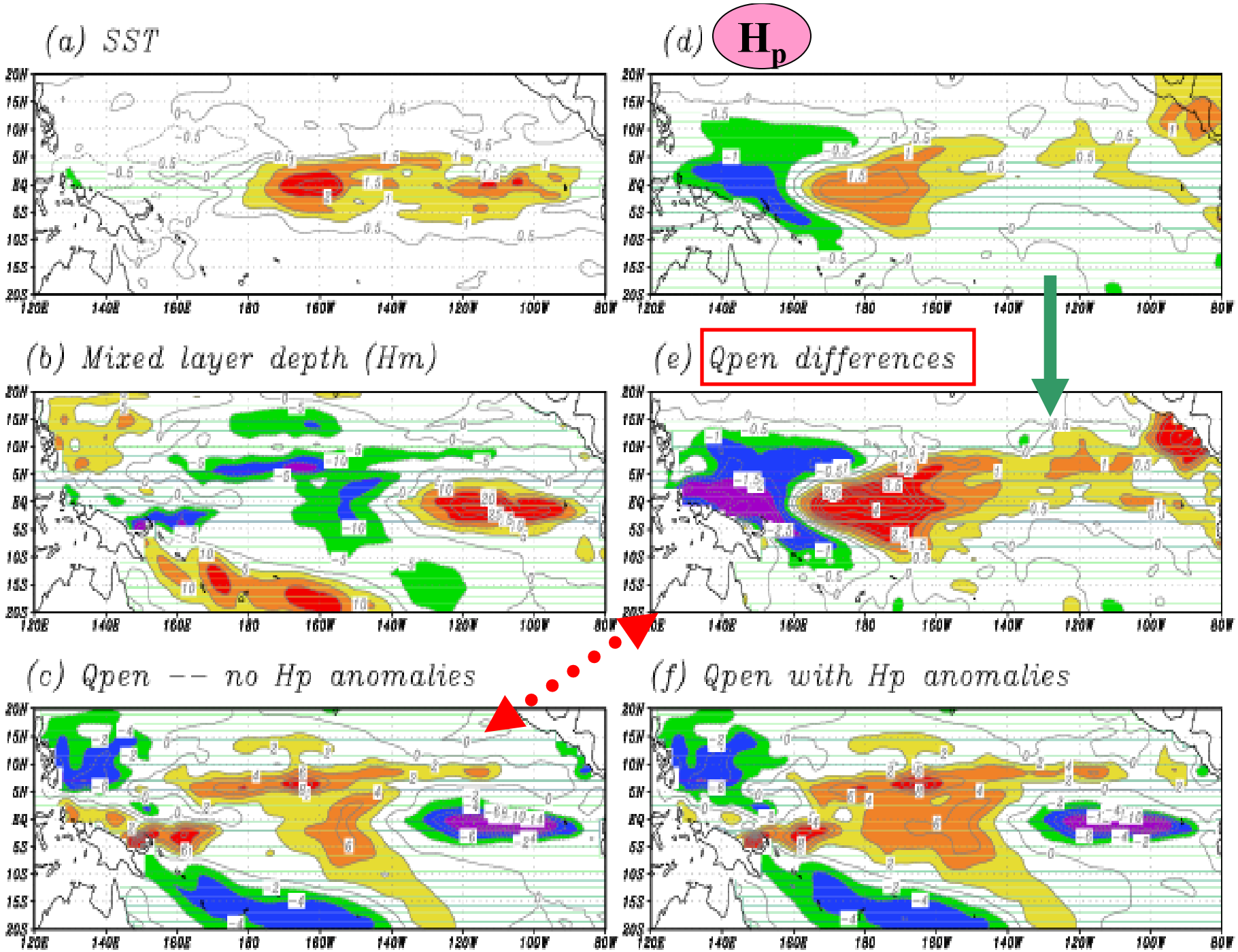

Anomalies along the equator
(a) SST
(b) Zonal wind stress
(c) SSS
Time (years)
39
38
37
36
35
34
33
32
31
30
29
28
27
26
25
24
120E
150E
180
150W
120W
90W

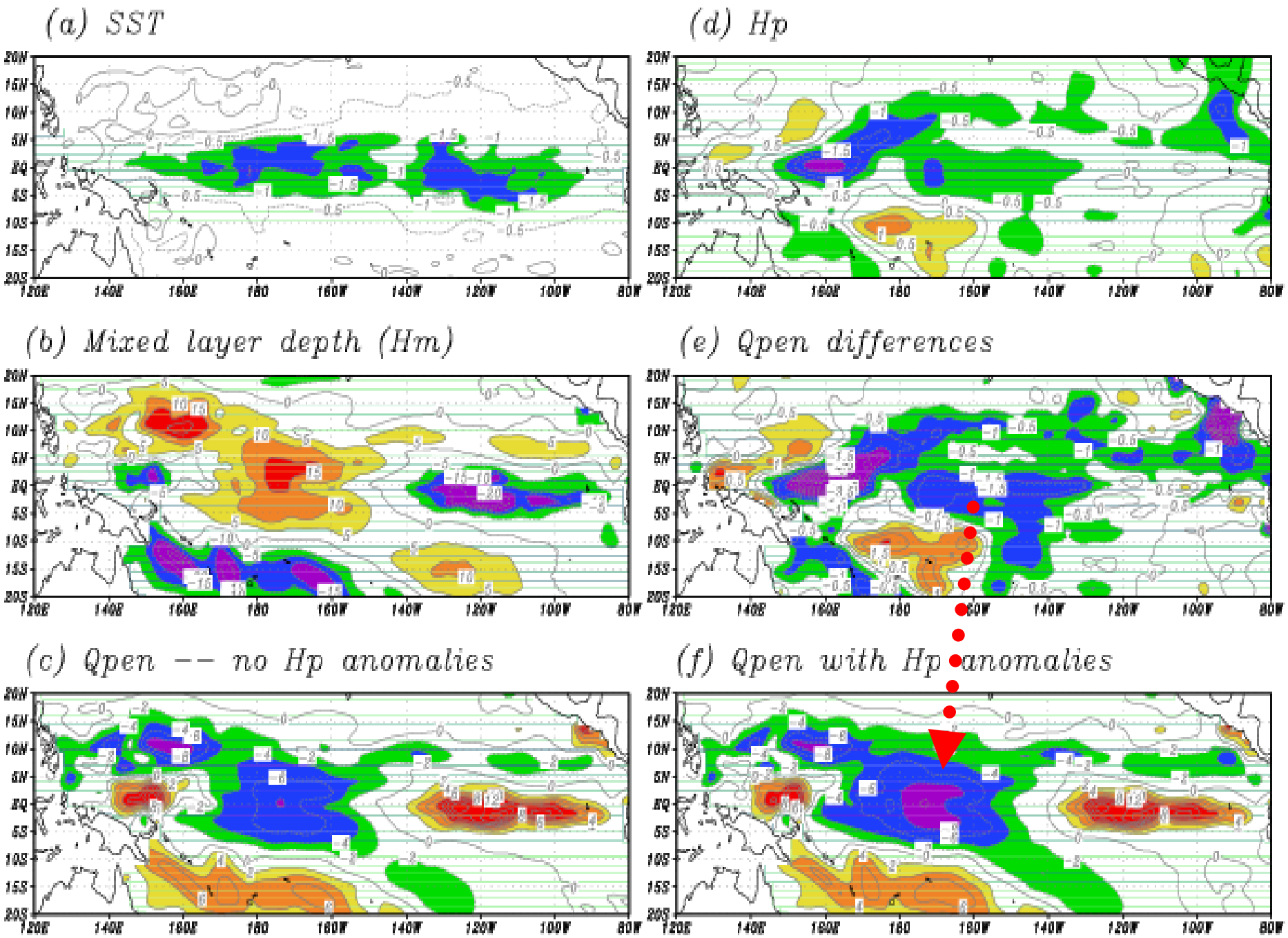

Anomalies along the equator
(a) SST
(b) Mixed layer depth (MLD)
(c) Penetration depth (Hp)
Time (years)
39
38
37
36
35
34
33
32
31
30
29
28
27
26
25
24
120E
150E
180
150W
120W
90W


SST anomalies along the equator
(a) Alfa_Hp=0.0
(b) Alfa_Hp=2.0
(c) Alfa_Hp=3.0
Time (years)
120E
150E
180
150W
120W
90W

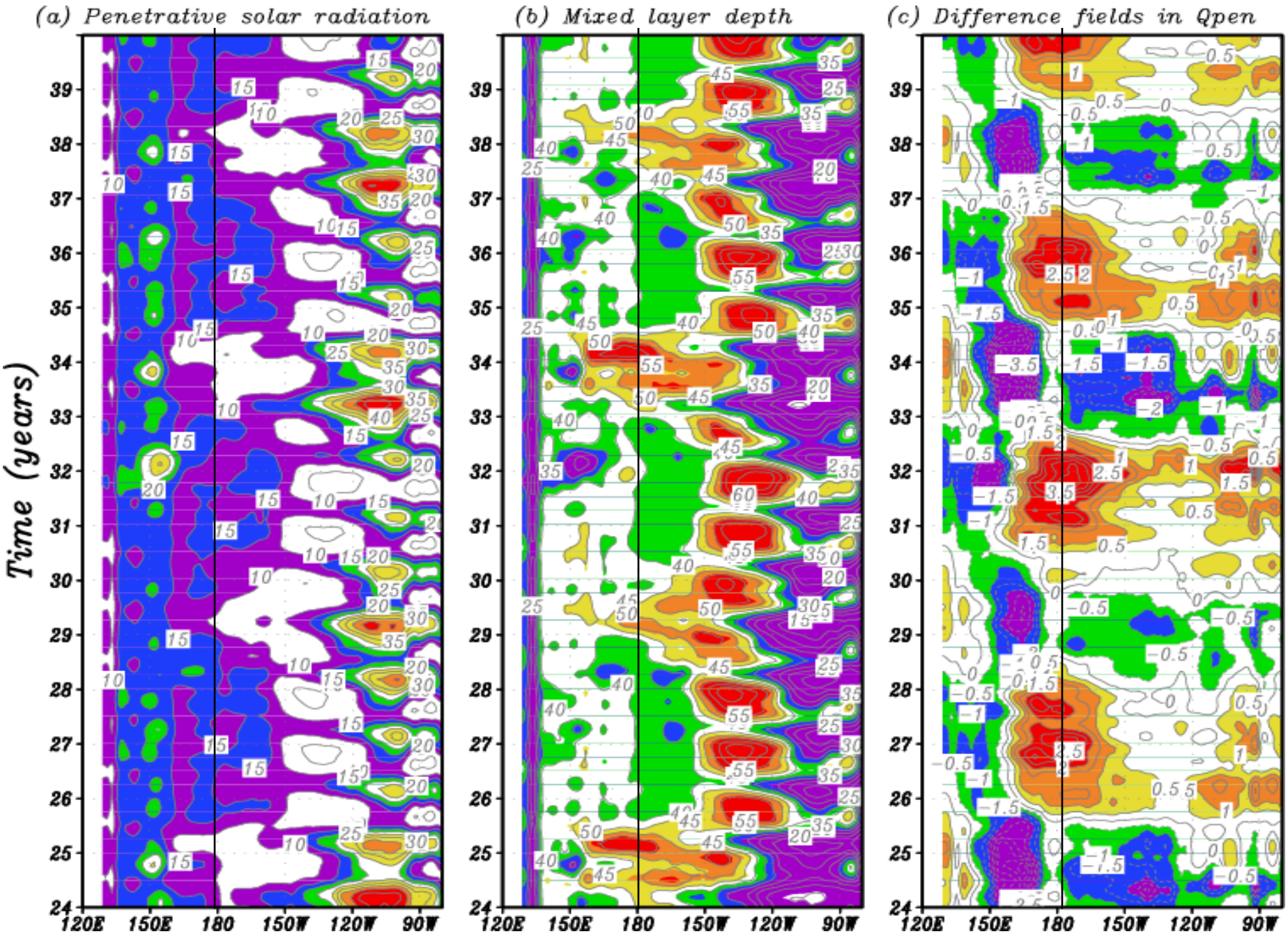

Nino3 SST for Alfa_Hp=1 and Alfa_Hp=3
Alfa_1
Alfa_3
1.8
1.5
1.2
0.9
0.6
0.3
0
−0.3
−0.6
−0.9
−1.2
−1.5
30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46


Vertical mixing & advection at (160W, 0)
Vertical mixing & advection (10^-6 C/s)
5
0
−5
−10
−15
−20
−25
−30
−35
−40
−45
−50
Alfa_1
Alfa_3
30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46
Time (years)


(a) SST
(d) Hp
(b) Mixed layer depth (Hm)
(e) Qpen differences
(c) Qpen -- no Hp anomalies
(f) Qpen with Hp anomalies

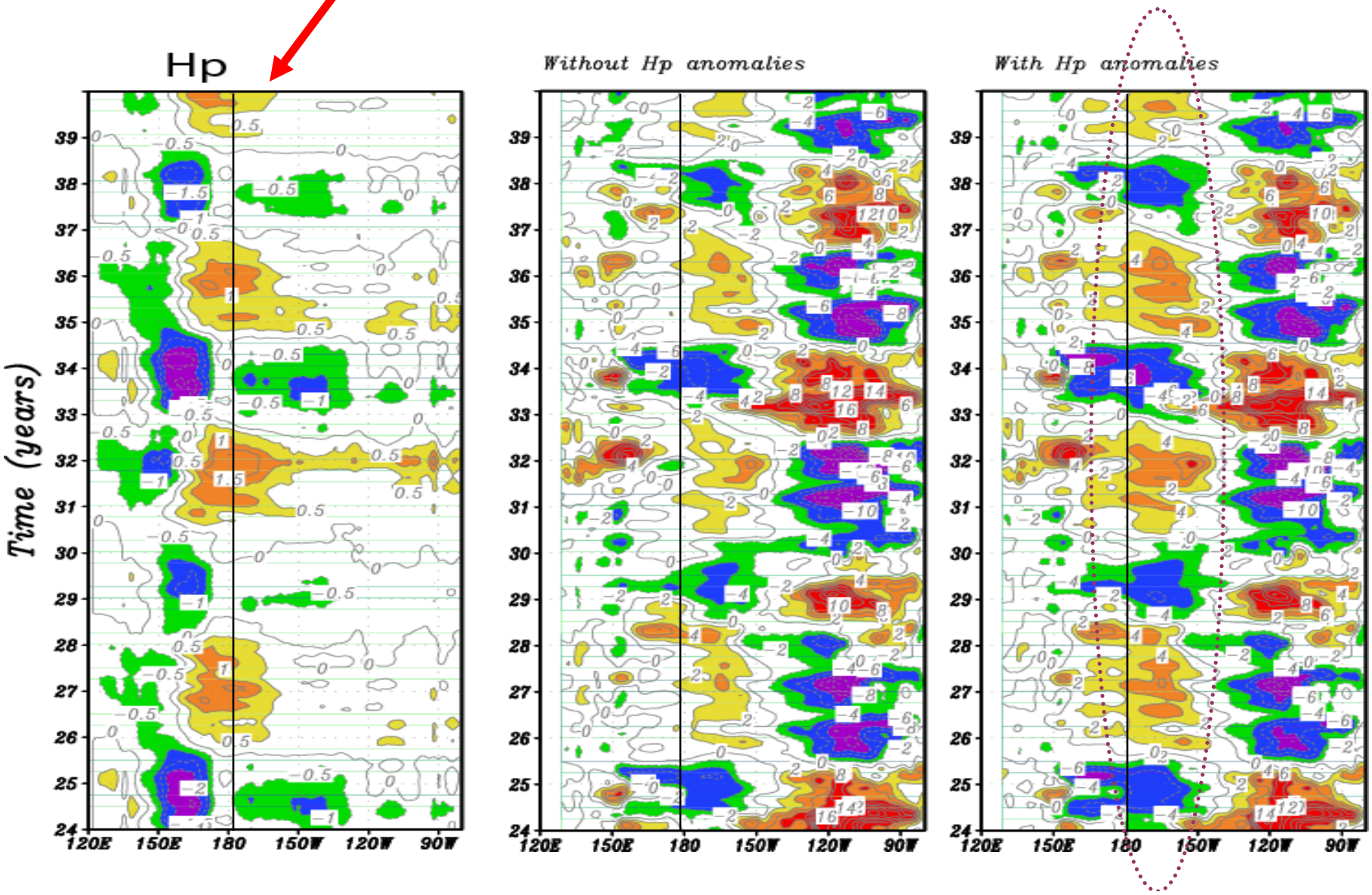

(a) SST
(d) Hp
(b) Mixed layer depth (Hm)
(e) Qpen differences
(c) Qpen -- no Hp anomalies
(f) Qpen with Hp anomalies
20N
15N
10N
5N
EQ
5S
10S
15S
20S
120E
140E
160E
180
160W
140W
120W
100W
80W

$$Q_{pen}(H_m, H_p) - Q_{pen}(H_m, \bar{H}_p)$$



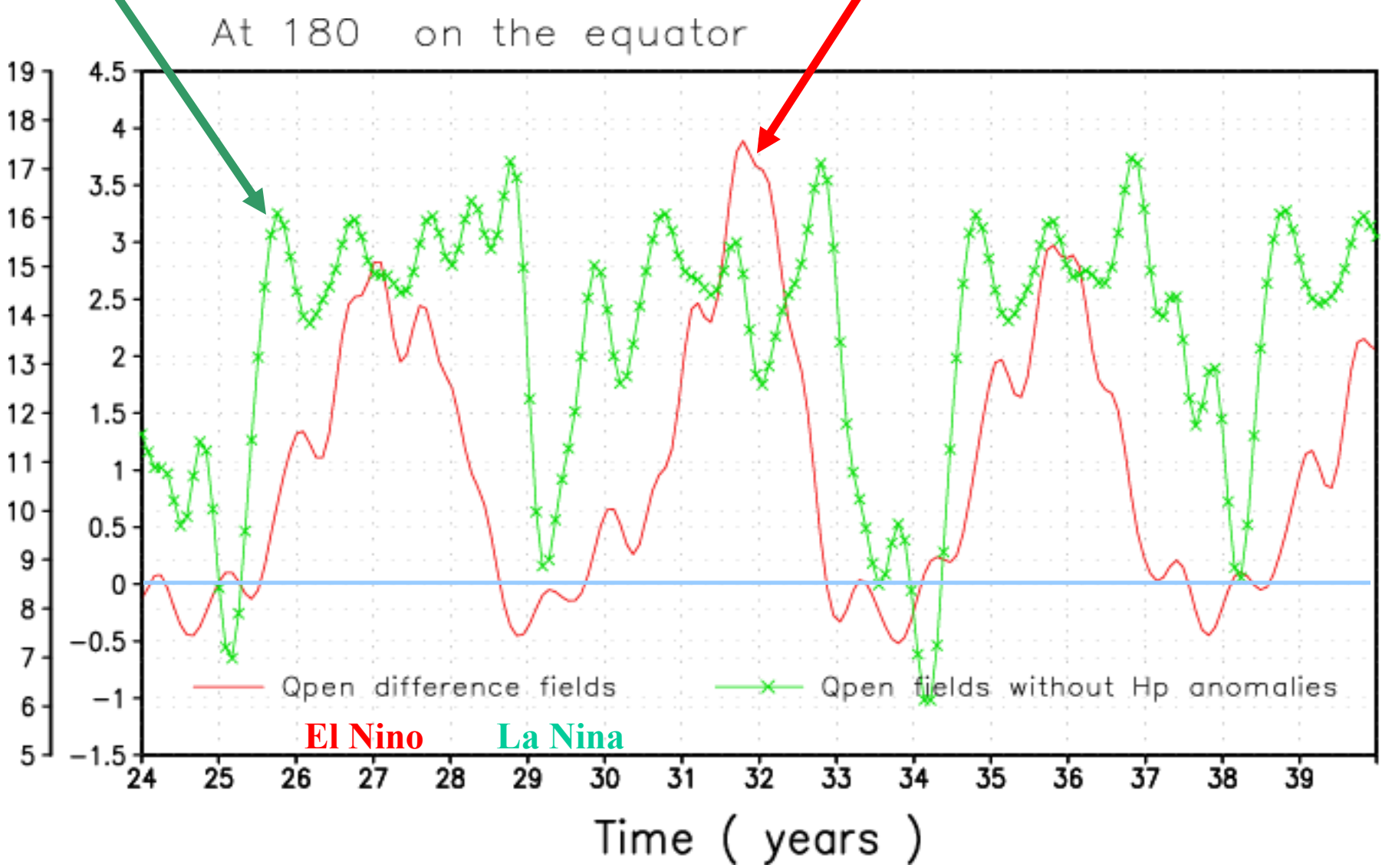
Interannual H_p variations & its effect on Q_{pen}

$$Q_{pen} = Q_{sr}[\gamma \exp(-H_m / H_p)]$$



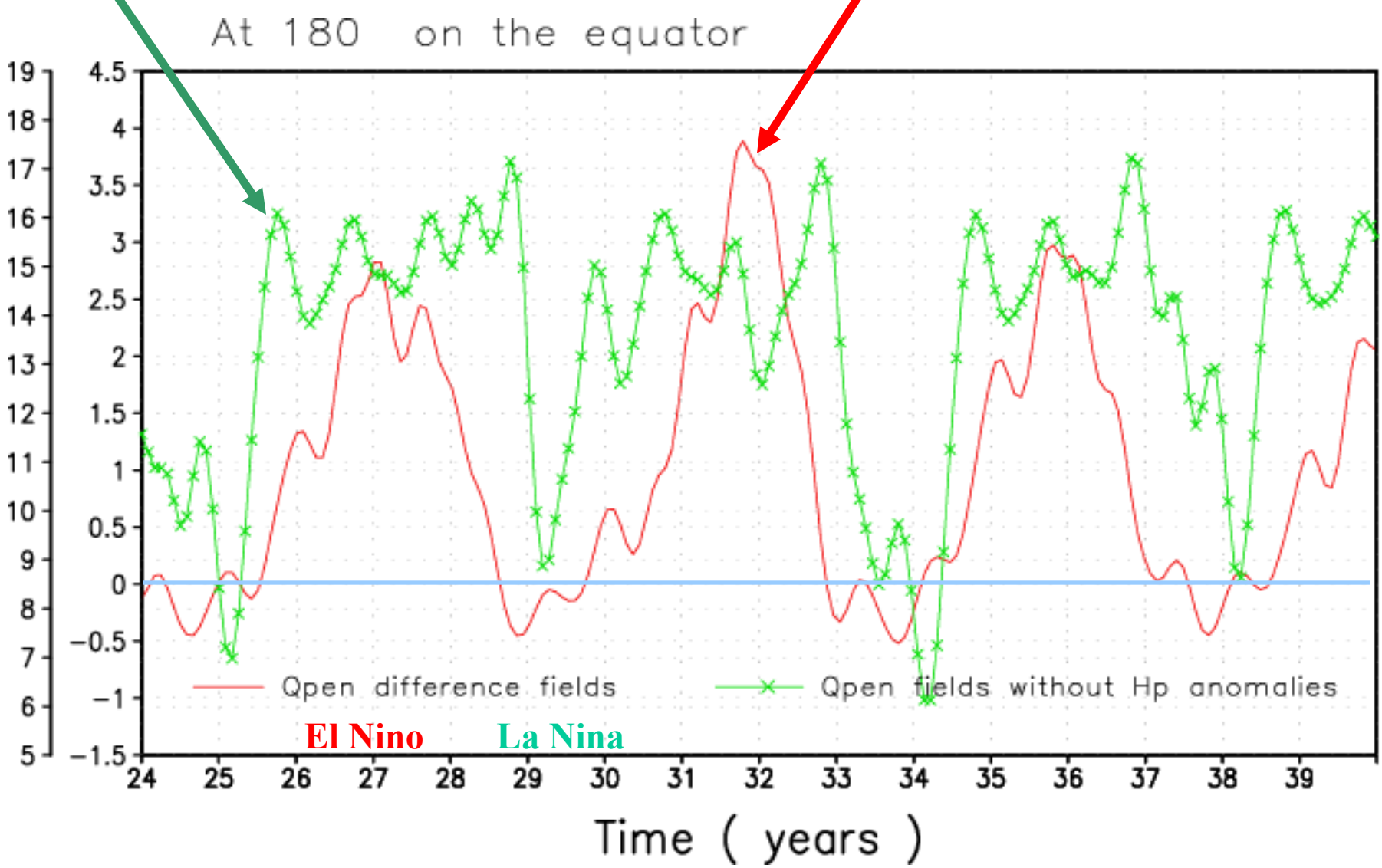
$$Q_{pen}(H_m, \bar{H}_p)$$

$$Q_{pen}(H_m, H_p) - Q_{pen}(H_m, \bar{H}_p)$$



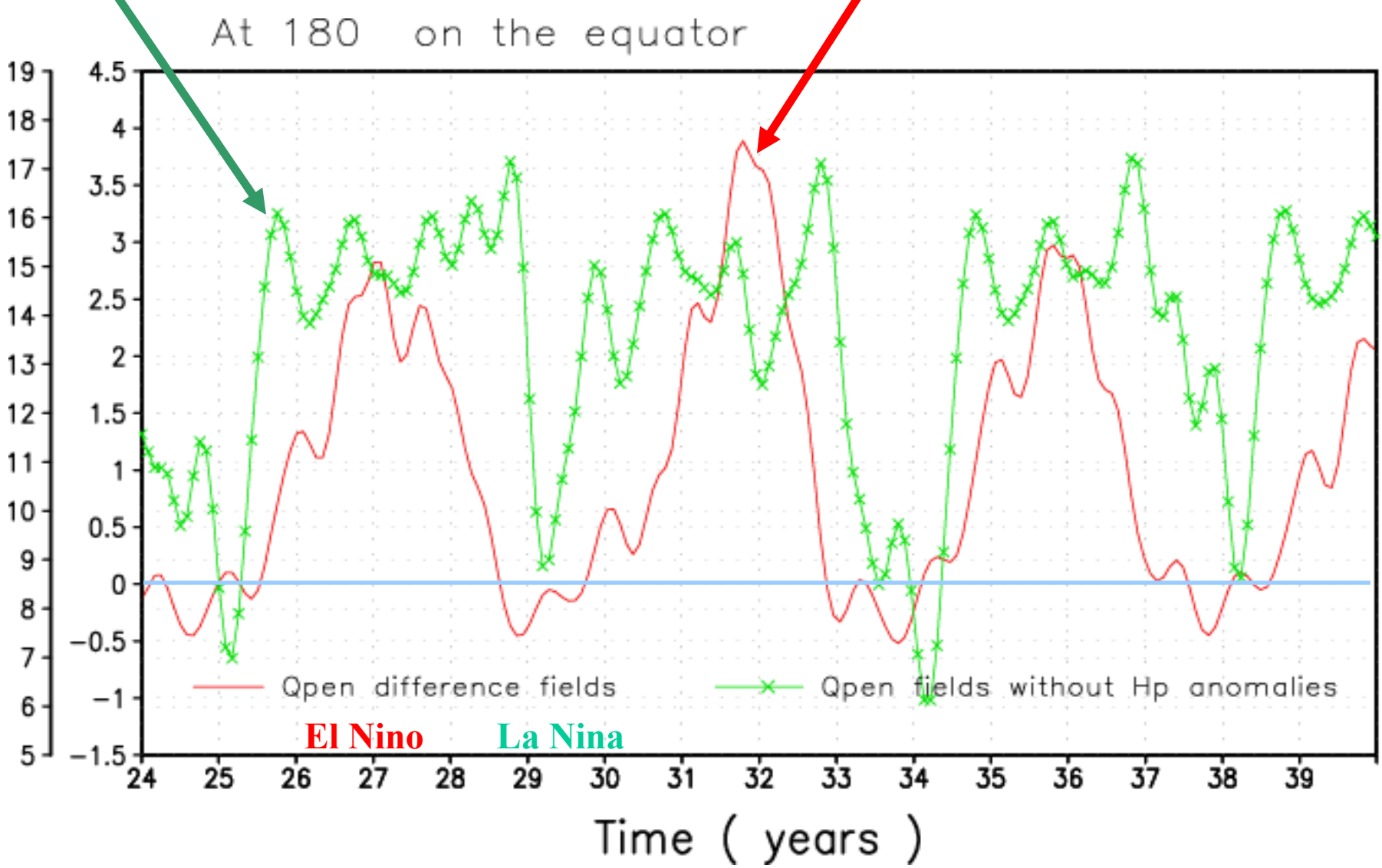
$$Q_{pen}(H_m, \bar{H}_p)$$

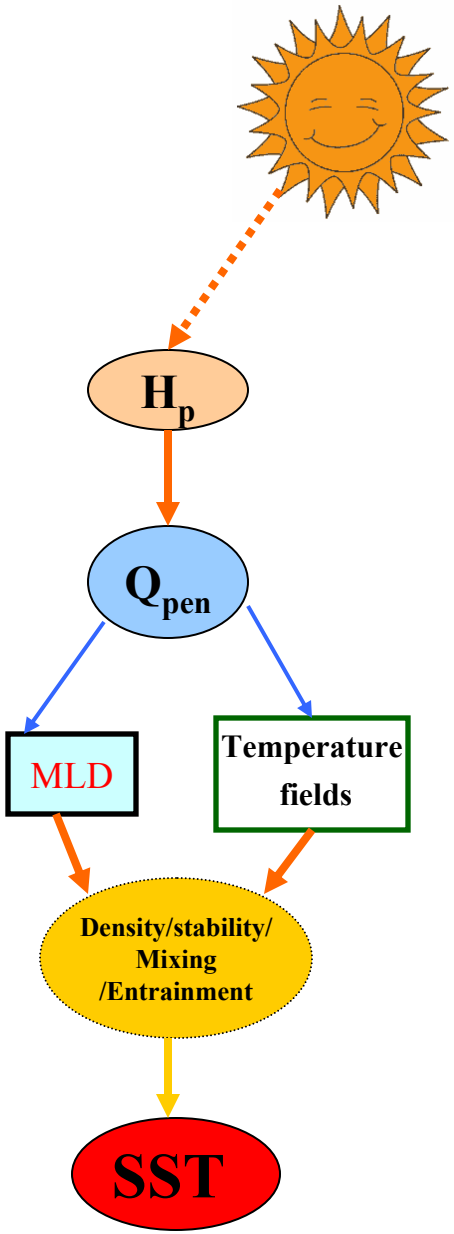
$$Q_{pen}(H_m, H_p) - Q_{pen}(H_m, \bar{H}_p)$$

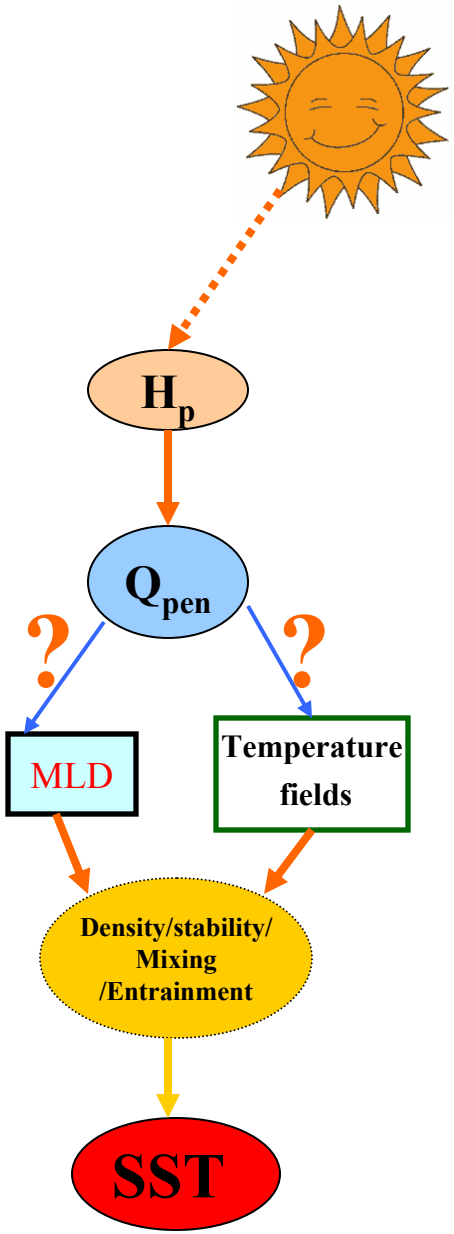


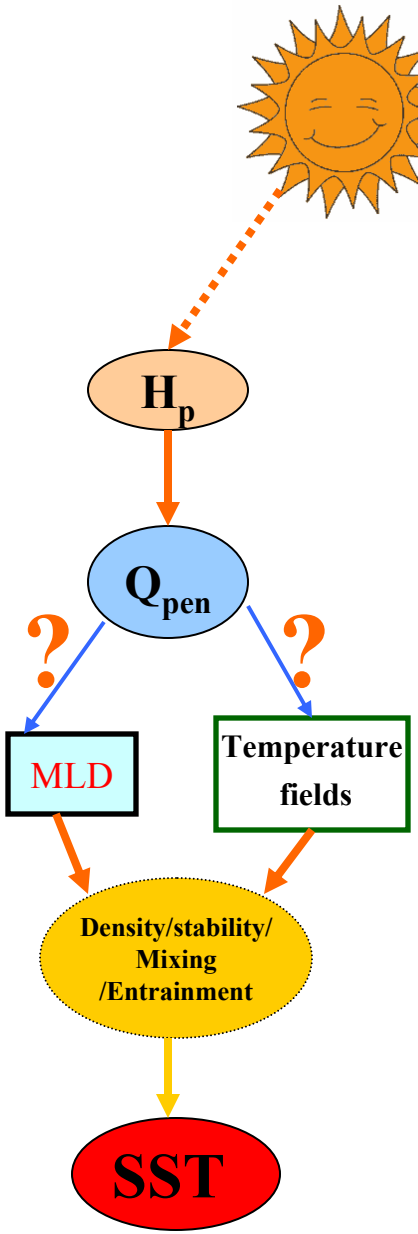
$$Q_{pen}(H_m, \bar{H}_p)$$

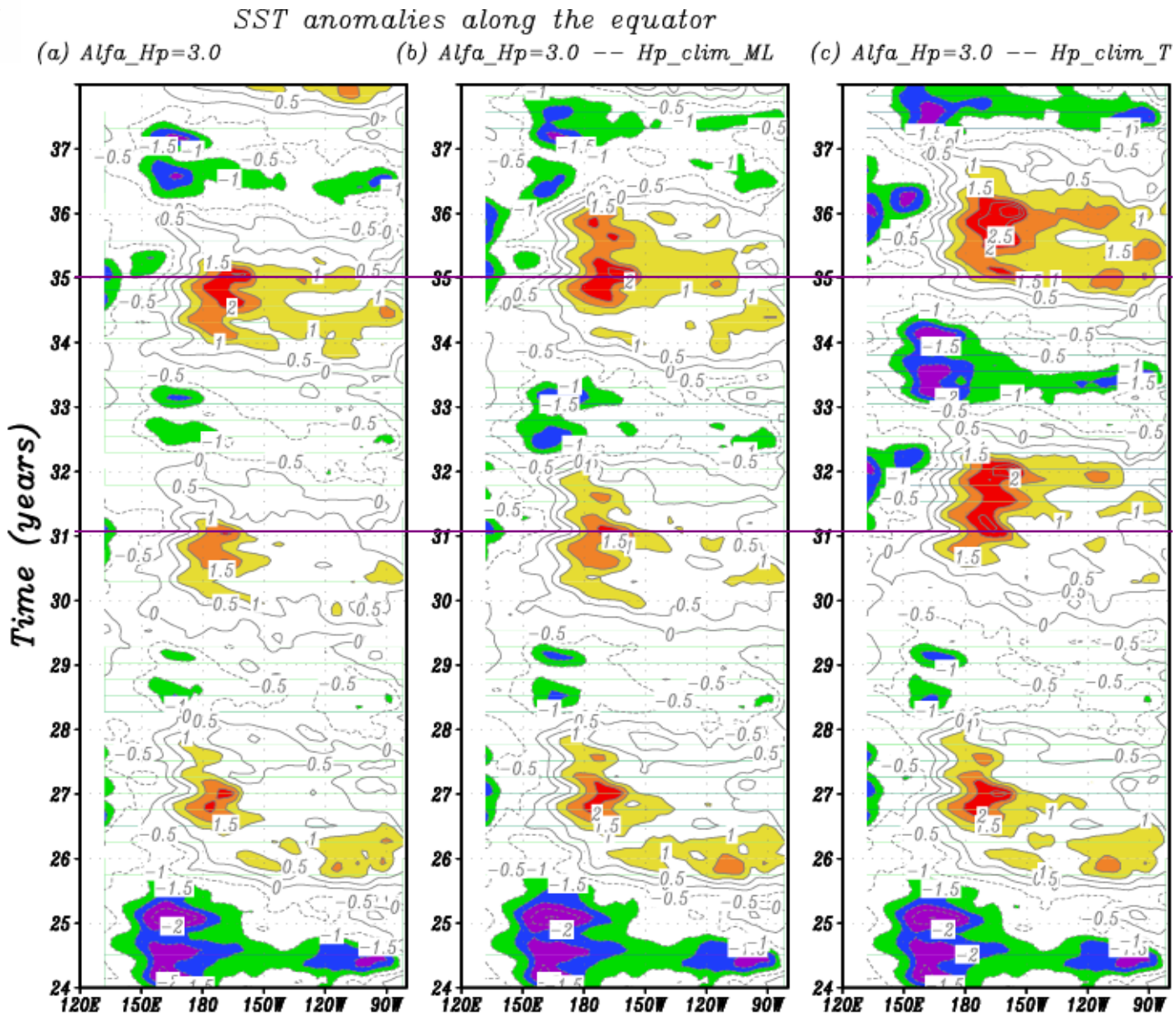
$$Q_{pen}(H_m, H_p) - Q_{pen}(H_m, \bar{H}_p)$$



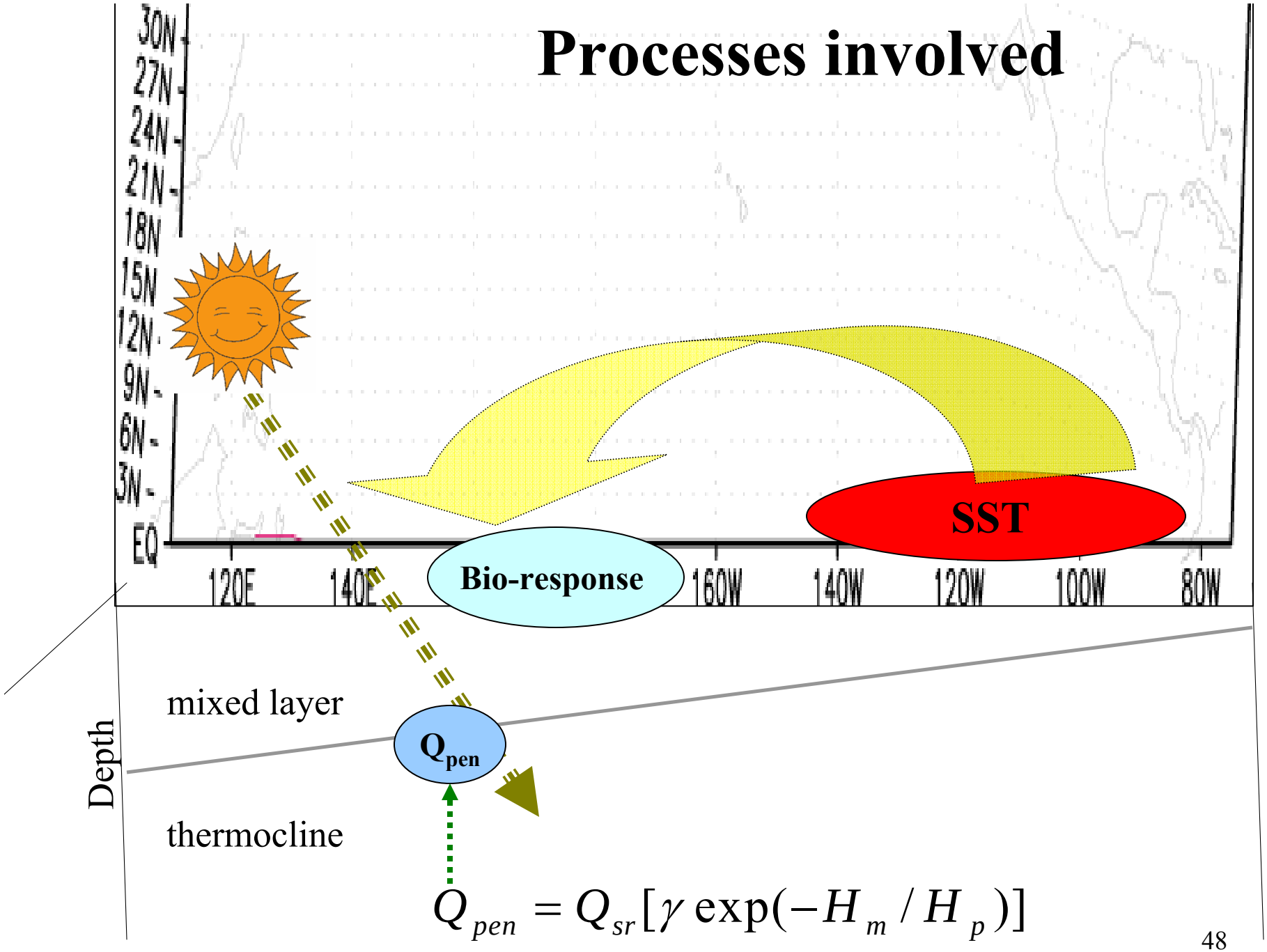

H_p
Q_{pen}
MLD
Temperature fields
Density/stability/ Mixing /Entrainment
SST


H_p
Q_{pen}
?
?
MLD
Temperature fields
Density/stability/ Mixing /Entrainment
SST


H_p
Q_{pen}
?
?
MLD
Temperature fields
Density/stability/ Mixing /Entrainment
SST

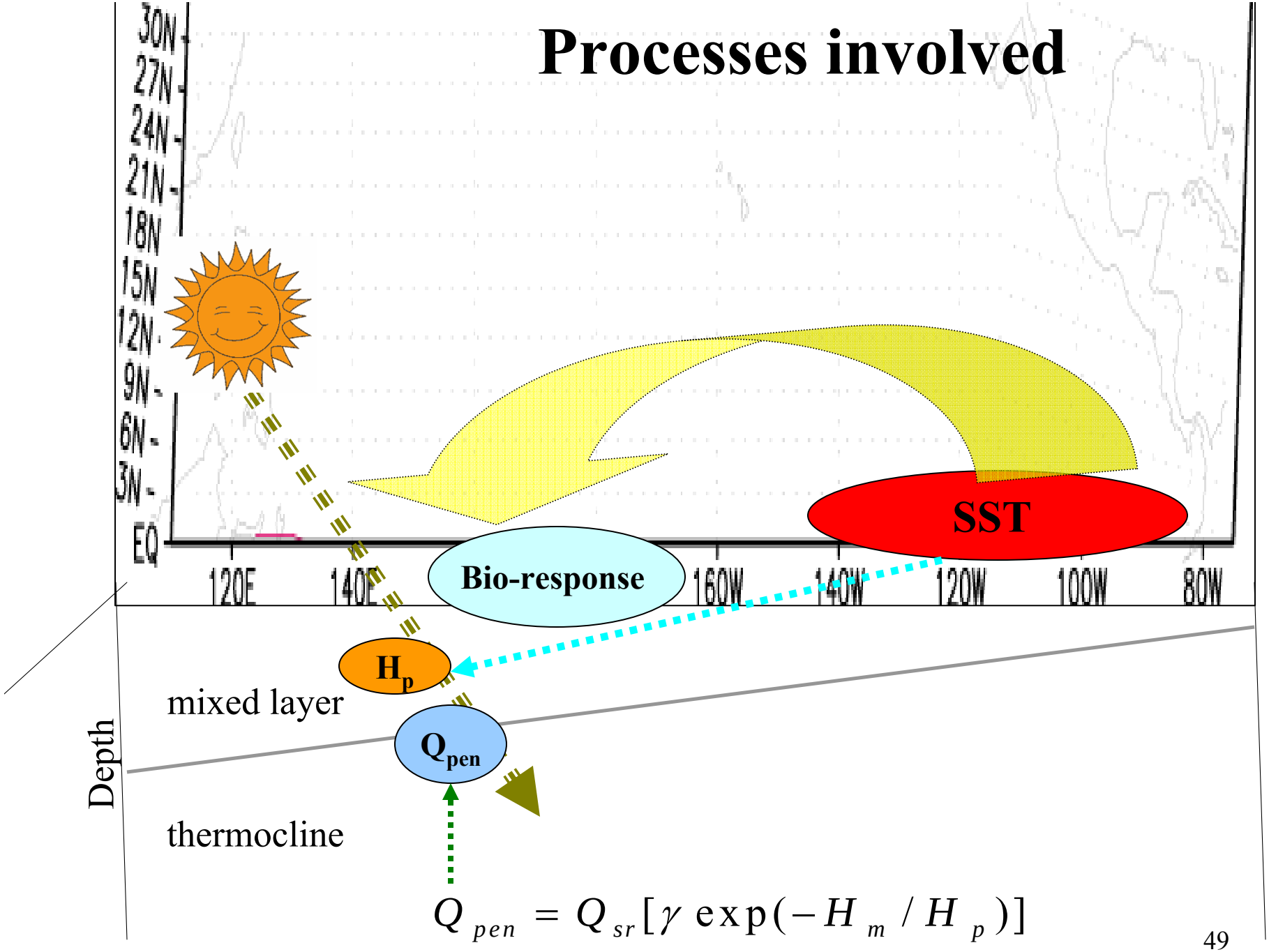

SST anomalies along the equator
(a) Alfa_Hp=3.0
(b) Alfa_Hp=3.0 -- Hp_clim_ML
(c) Alfa_Hp=3.0 -- Hp_clim_T
Time (years)
120E 150E 180 150W 120W 90W

Processes involved



$$Q_{pen} = Q_{sr}[\gamma \exp(-H_m / H_p)]$$

Processes involved



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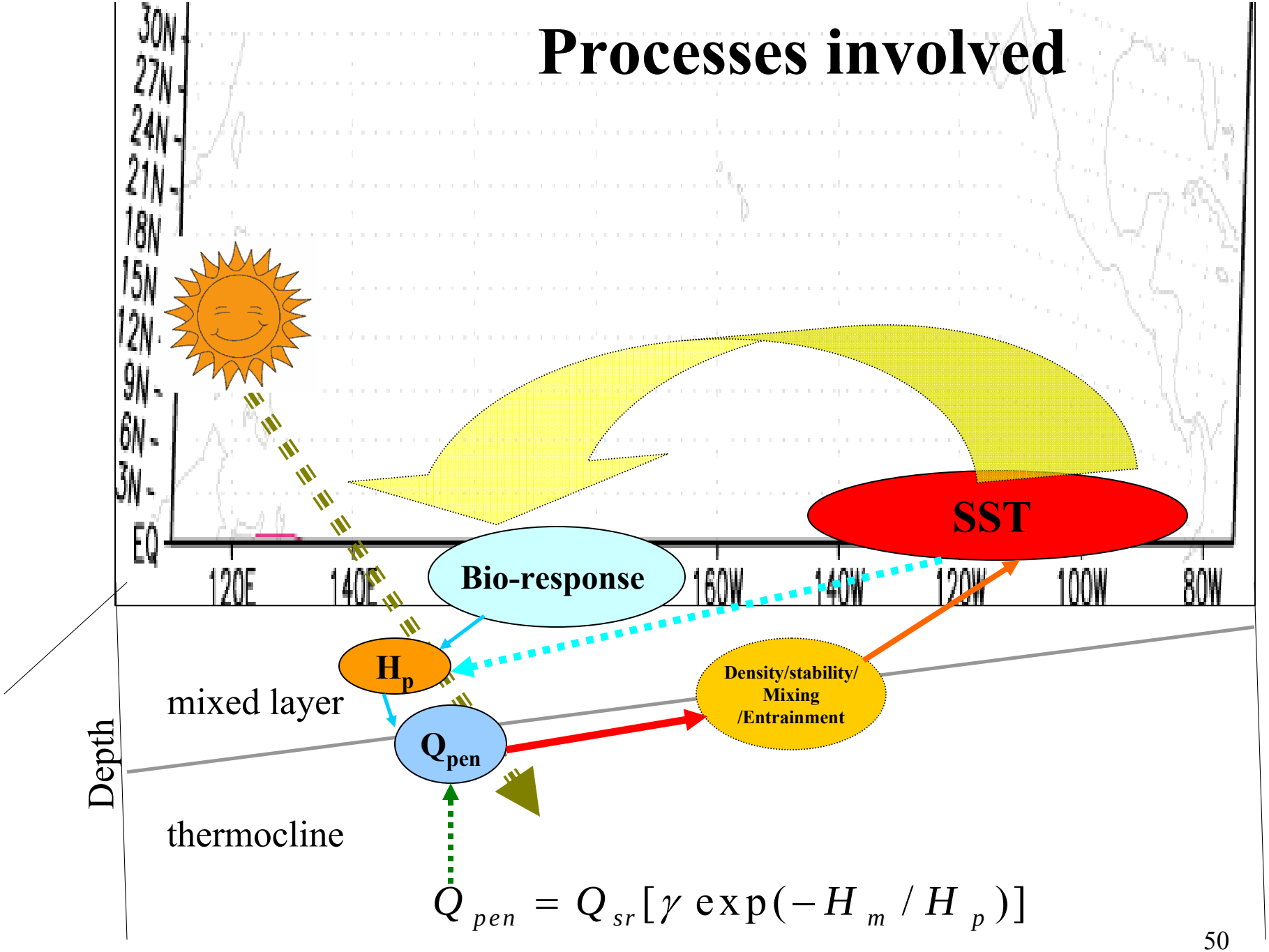
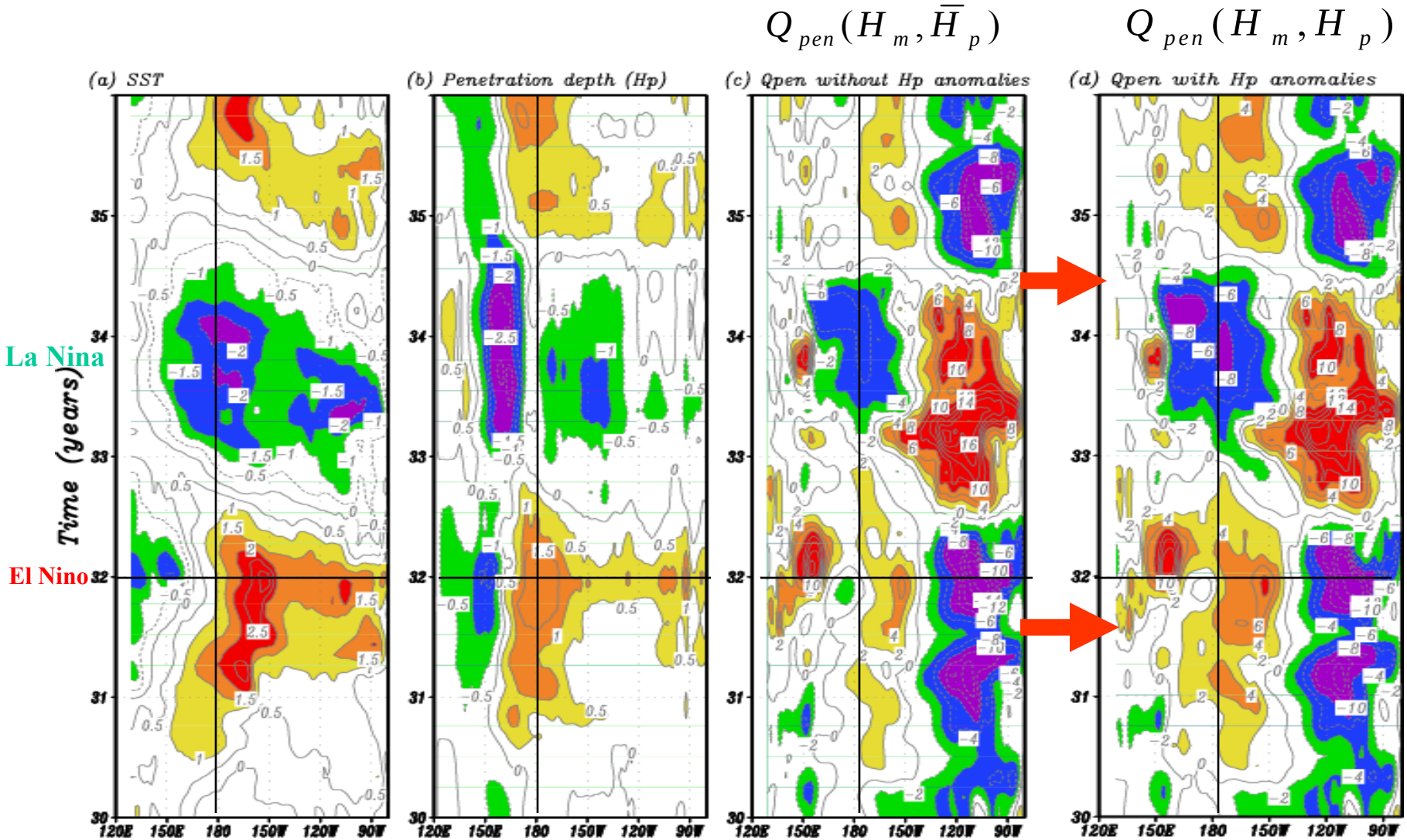
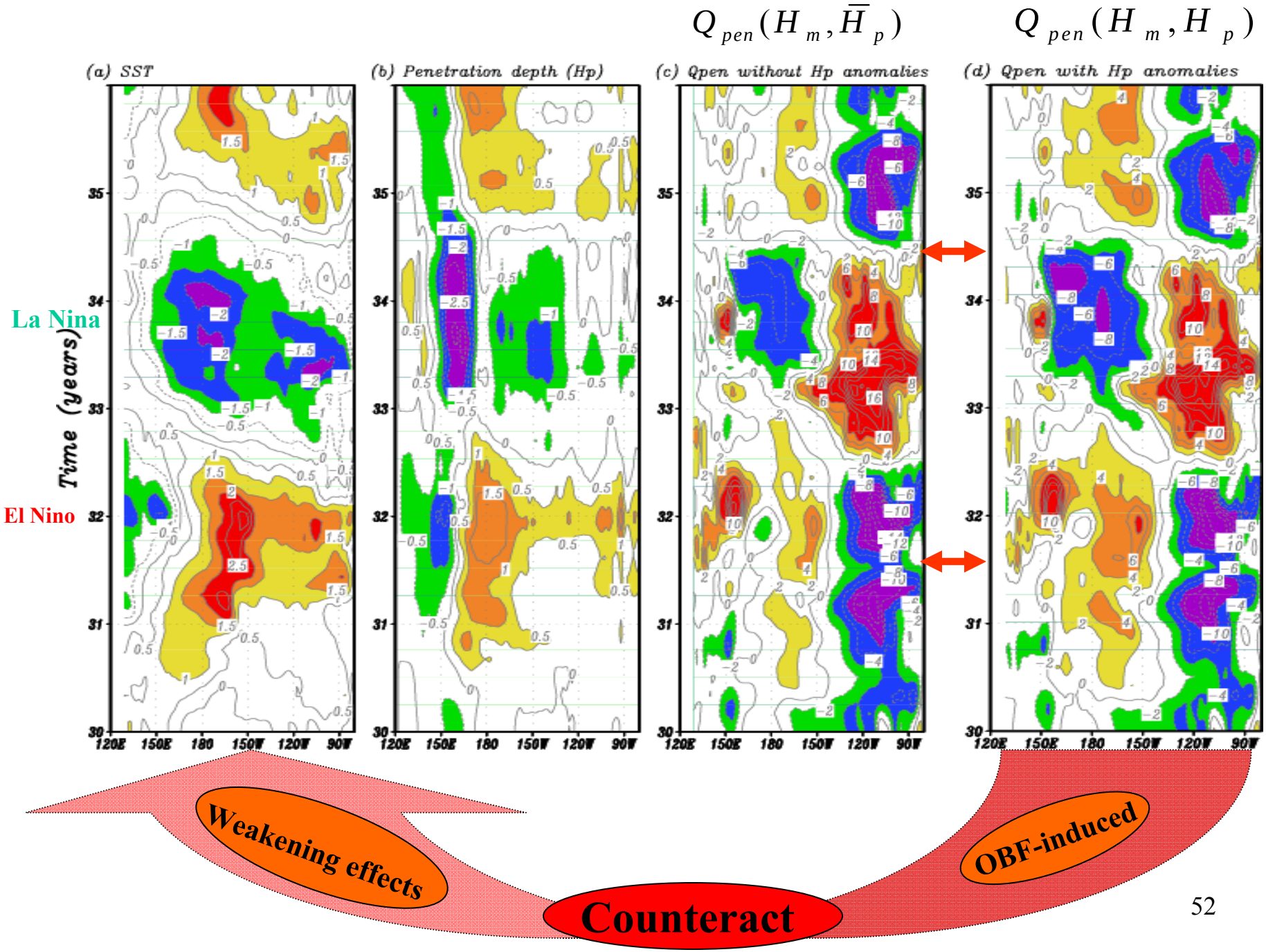
Processes involved



$$Q_{pen} = Q_{sr}[\gamma \exp(-H_m / H_p)]$$


$Q_{pen}(H_m, \bar{H}_p)$
$Q_{pen}(H_m, H_p)$
(a) SST
(b) Penetration depth (Hp)
(c) Qpen without Hp anomalies
(d) Qpen with Hp anomalies
La Nina
El Nino
Time (years)
35
34
33
32
31
30
120E
150E
180
150W
120W
90W


$Q_{pen}(H_m, \bar{H}_p)$
$Q_{pen}(H_m, H_p)$
(a) SST
(b) Penetration depth (Hp)
(c) Qpen without Hp anomalies
(d) Qpen with Hp anomalies
La Nina
El Nino
Time (years)
Weakening effects
OBF-induced
Counteract

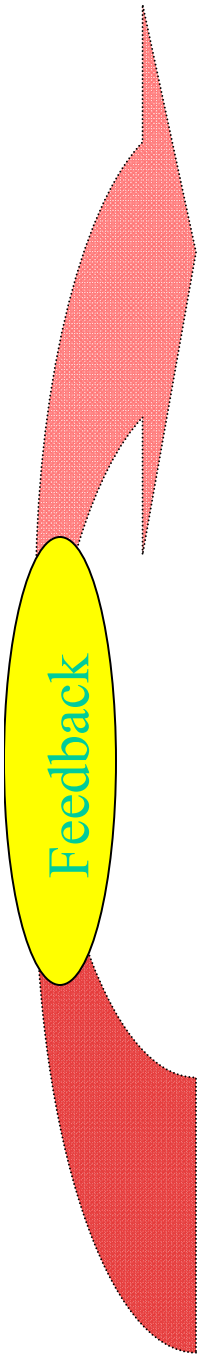
		El Niño		La Niña	
		Central	Eastern	Central	Eastern
SST		+	+	-	-
H_m		-	+	+	-
	$Q_{abs}(H_m, \bar{H}_p)$	-	+	+	-
	$Q_{pen}(H_m, \bar{H}_p)$	+	-	-	+
H_p		+	+	-	-
	$Q_{abs}(H_m, H_p)$ $Q_{pen}(H_m, H_p)$				
	Stability/Mixing				
SST					

		El Niño		La Niña	
		Central	Eastern	Central	Eastern
SST		+	+	-	-
H_m		-	+	+	-
	$Q_{abs}(H_m, \bar{H}_p)$	-	+	+	-
	$Q_{pen}(H_m, \bar{H}_p)$	+	-	-	+
H_p		+	+	-	-
	$Q_{abs}(H_m, H_p)$				
	$Q_{pen}(H_m, H_p)$				
	Stability/Mixing				
	SST				

?

		El Niño		La Niña	
		Central	Eastern	Central	Eastern
SST		+	+	-	-
H_m		-	+	+	-
	$Q_{abs}(H_m,\bar{H}_p)$	-	+	+	-
	$Q_{pen}(H_m,\bar{H}_p)$	+	-	-	+
H_p		+ ?	+ ?	- ?	- ?
	$Q_{abs}(H_m,H_p)$	?	?	?	?
	$Q_{pen}(H_m,H_p)$	?	?	?	?
	Stability/Mixing	? ?		? ?	
SST		?		?	

		El Niño		La Niña	
		Central	Eastern	Central	Eastern
SST		+	+	-	-
H_m		-	+	+	-
	$Q_{abs}(H_m, \bar{H}_p)$	-	+	+	-
	$Q_{pen}(H_m, \bar{H}_p)$	+	-	-	+
H_p		+ *More penetration*	+	- *Less penetration*	-
	$Q_{abs}(H_m, H_p)$	More -	Negligible	More +	Negligible
	$Q_{pen}(H_m, H_p)$	More +	Negligible	More -	Negligible
	Stability/Mixing	Destabilizing More mixing		Stabilizing Less mixing	
SST		Less *warming*		Less *cooling*	



		El Niño		La Niña	
		Central	Eastern	Central	Eastern
SST		+	+	-	-
H_m		-	+	+	-
	$Q_{abs}(H_m, \bar{H}_p)$	-	+	+	-
	$Q_{pen}(H_m, \bar{H}_p)$	+	-	-	+
H_p		+ *More penetration*	+	- *Less penetration*	-
	$Q_{abs}(H_m, H_p)$	More -	Negligible	More +	Negligible
	$Q_{pen}(H_m, H_p)$	More +	Negligible	More -	Negligible
	Stability/Mixing	Destabilizing More mixing		Stabilizing Less mixing	
SST		Less *warming*		Less *cooling*	

Nino4 site	α_{Hp} =0.0	α_{Hp} =1.0	α_{Hp} =2.0	α_{Hp} =3.0
SST	0.85	0.85	0.78	0.69
τ_x	0.19	0.19	0.17	0.15
MLD	6.7	6.3	5.4	4.7
SSS	0.16	0.16	0.15	0.13
H_p	0.0	0.47	0.83	1.09 **(1.14 m)**
Q_T	8.6	8.5	7.4	3.2
Nino3 H_p	0.0	0.27	0.46	0.62
Nino3 SST	0.76	0.74	0.65	0.59
Nino12 SST	0.57	0.56	0.51	0.47

Concluding remarks

- **An empirical model for H'_p ;**

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- **Large effects of H'_p in a climate model :**

  Modulation of ENSO ***by marine biology (amplitude, periods, phase locking …)*** **;**

  Interactions: ***physics*** ⟷ ***marine biology*** **;**

Concluding remarks

- **An empirical model for H'_p ;**
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  Interactions: ***physics*** ⟷ ***marine biology*** **;**

- **A *negative* feedback induced by marine biology:**

  Processes & structure of the effects **identified….**

Concluding remarks

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- **Large effects of H'_p in a climate model :**

  Modulation of ENSO ***by marine biology (amplitude, periods, phase locking …)*** **;**

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- **Importance of H'_p but significant uncertainties exist:**

  Estimate of H_p; modeling ocean ecosystem;

  physics-biogeochemistry coupling ; …

Concluding remarks

- **An empirical model for H'_p ;**
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  Processes & structure of the effects **identified….**

- **Importance of H'_p but significant uncertainties exist:**

  Estimate of H_p; modeling ocean ecosystem;

  physics-biogeochemistry coupling ; …

- **A clear source for biases; this bio-forcing component be taken into account for better ENSO simulation & prediction**

What's new: Representing H_p in climate modeling

- **Step 1: Anomaly model approach to H_p**

$$H_p = \overline{H_p} + \alpha_{H_p} \cdot H_p'$$

- **Step 2: focusing on interannual variability of H_p**

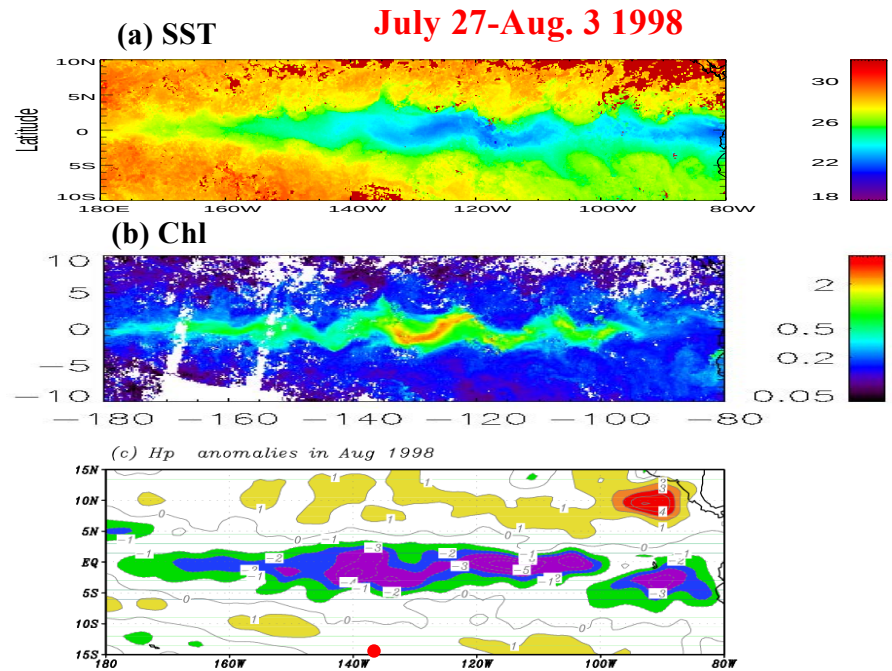
=> statistical methods adopted: ***SVD-based***

A physics-dependent, prognostic representation of H_p in the tropical Pacific

=> Ocean biology-induced feedback

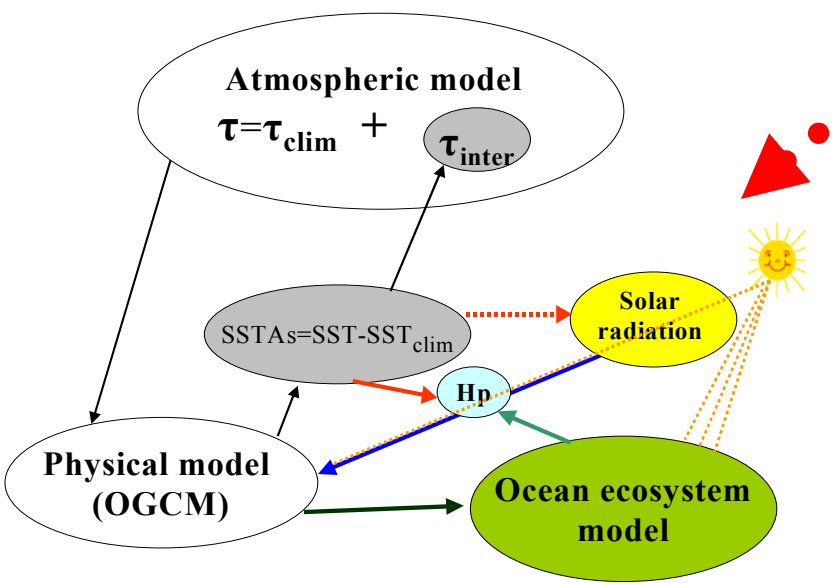
=> Parameterizations for climate modeling

Obserevations



Model

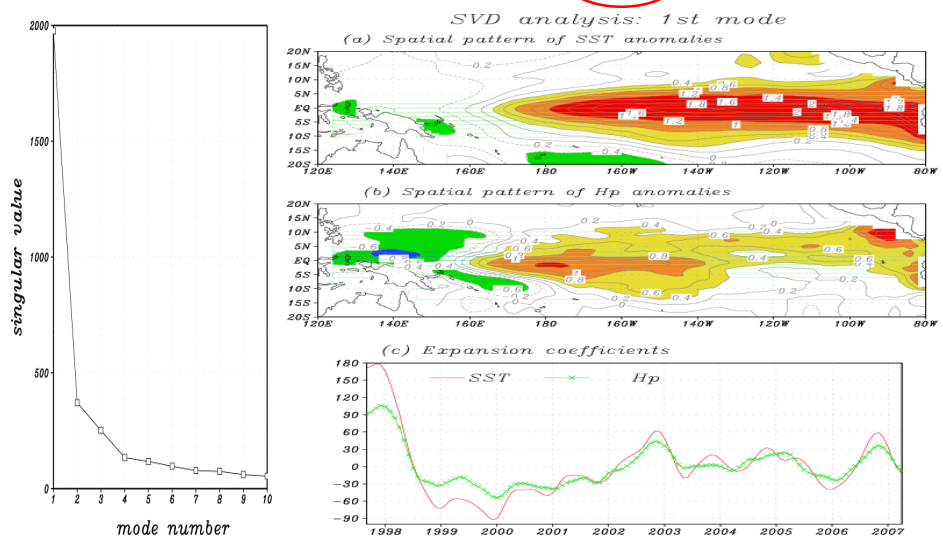
Coupled bio-climate modeling



processes

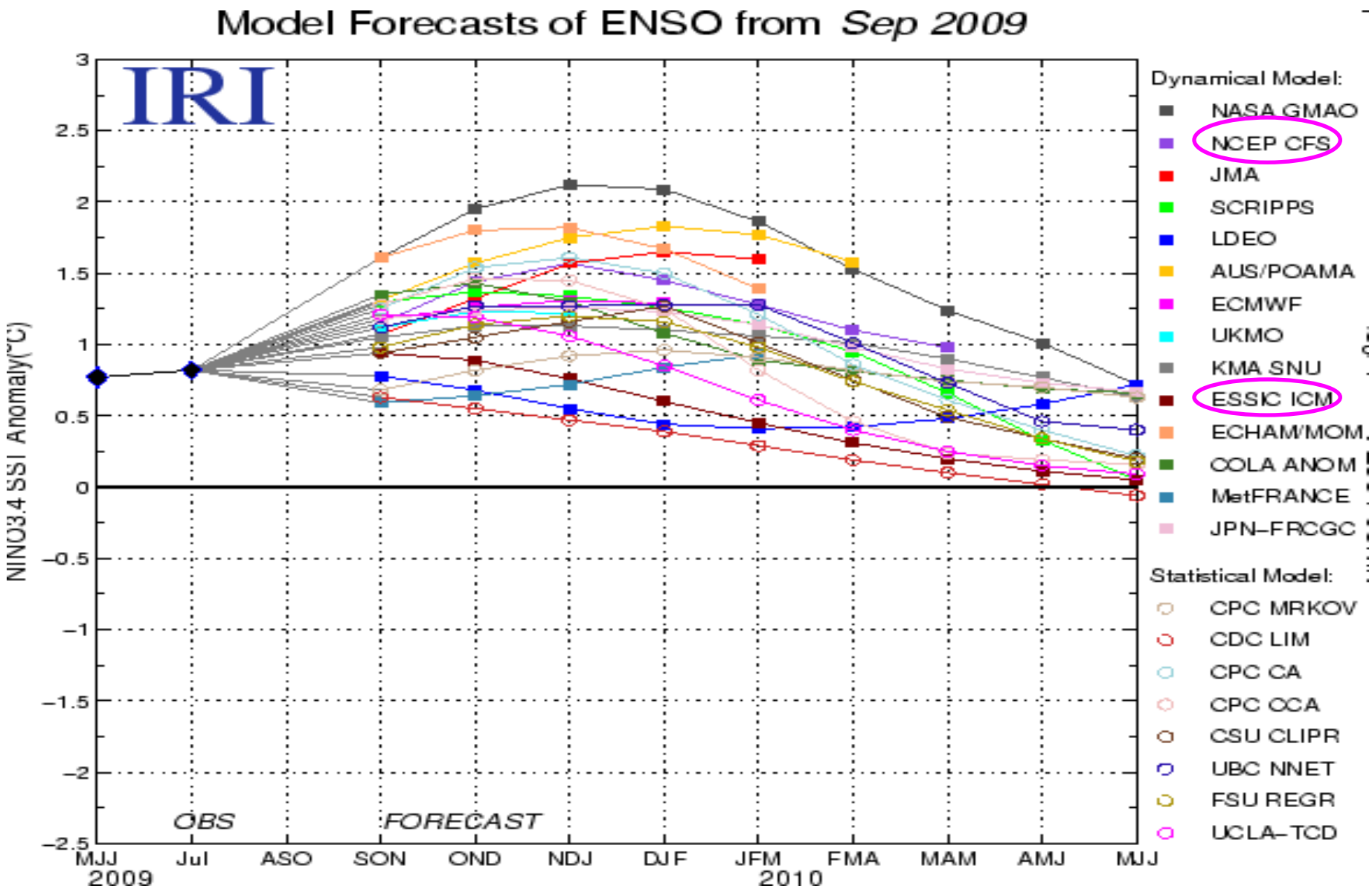
A SVD-based Empirical Model for H'p

$$H_p = \overline{H_p} + \alpha_{Hp} \bullet S_{vd}(SST_{inter})$$



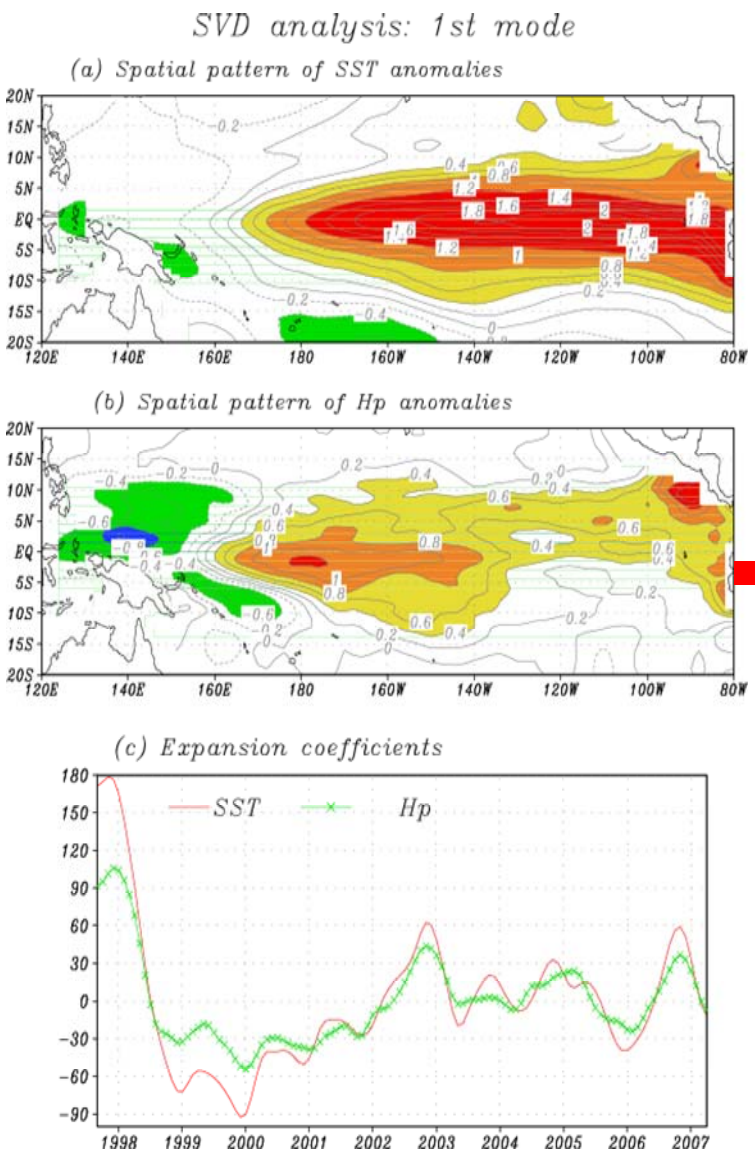
Future work

Impact on ENSO prediction

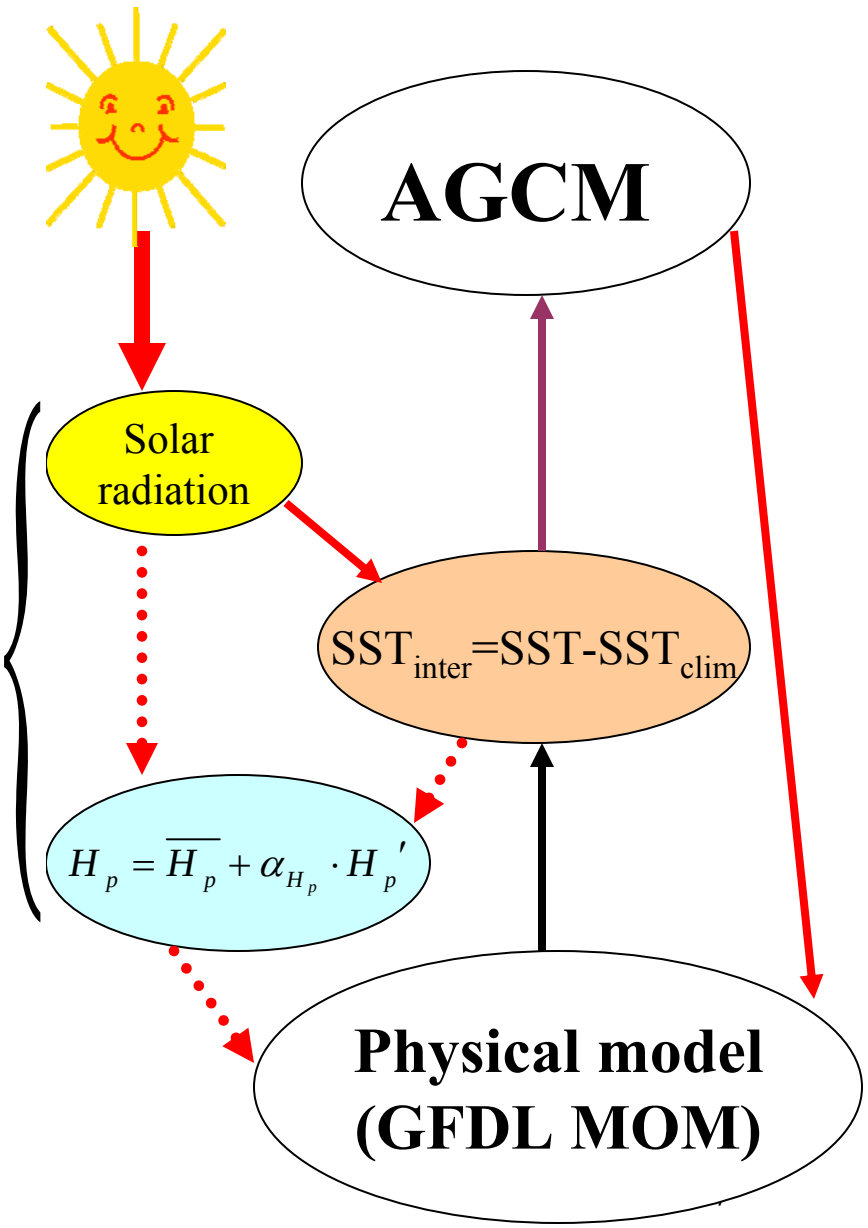


An SVD-based Empirical Model for H'_p

$$H_p = \overline{H_p} + \alpha_{Hp} \bullet S_{vd}(SST_{inter})$$

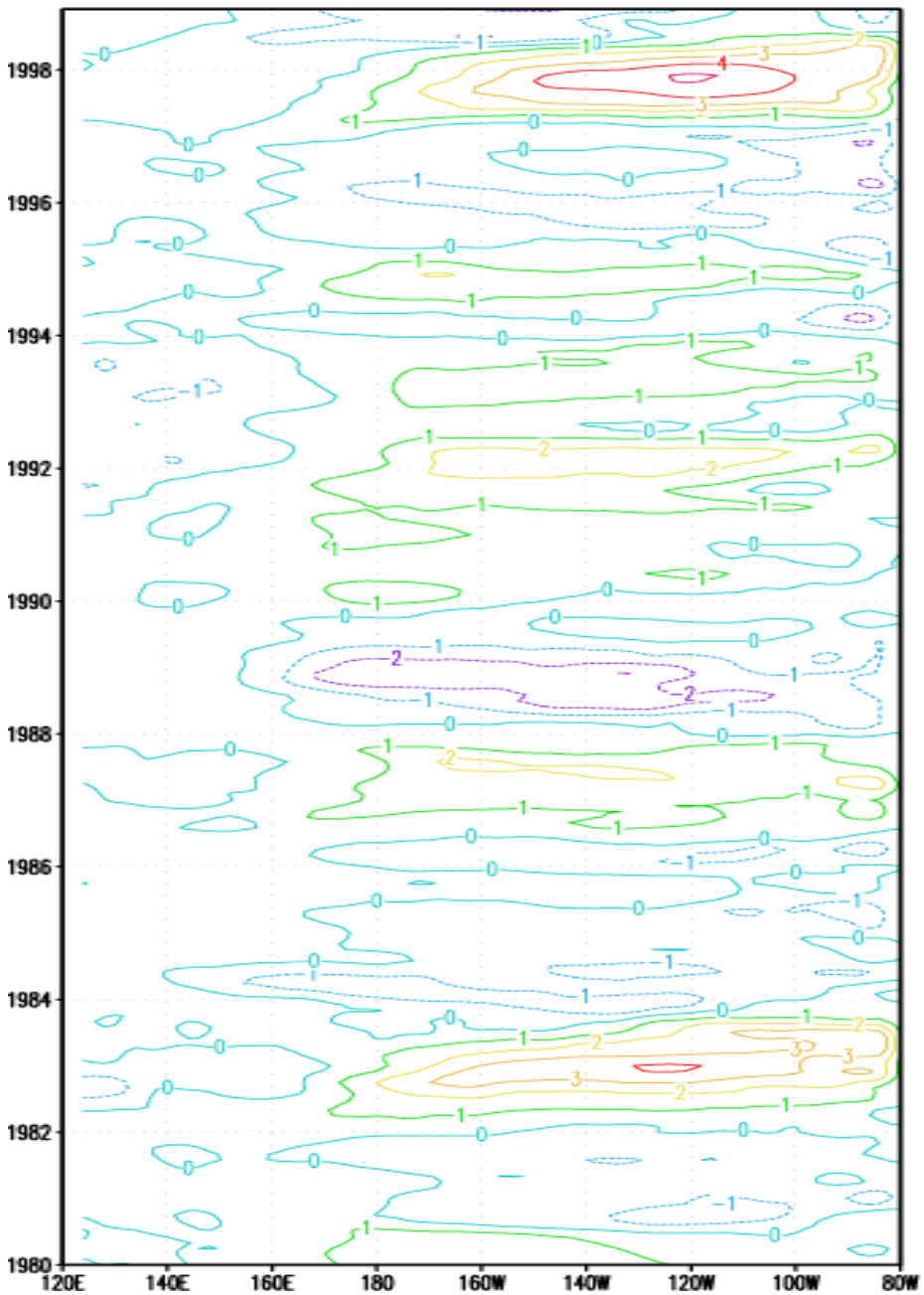


NCEP CFS

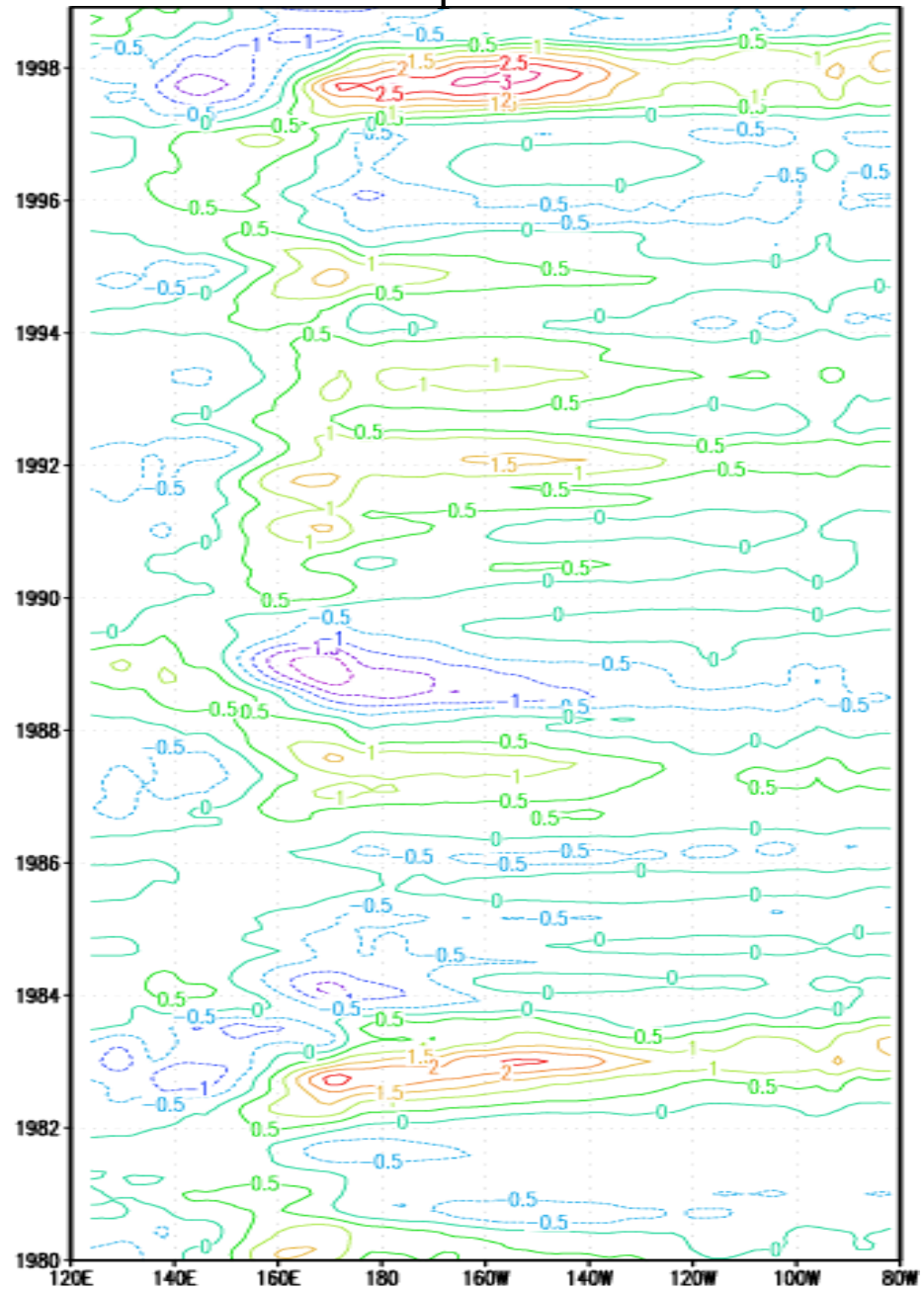


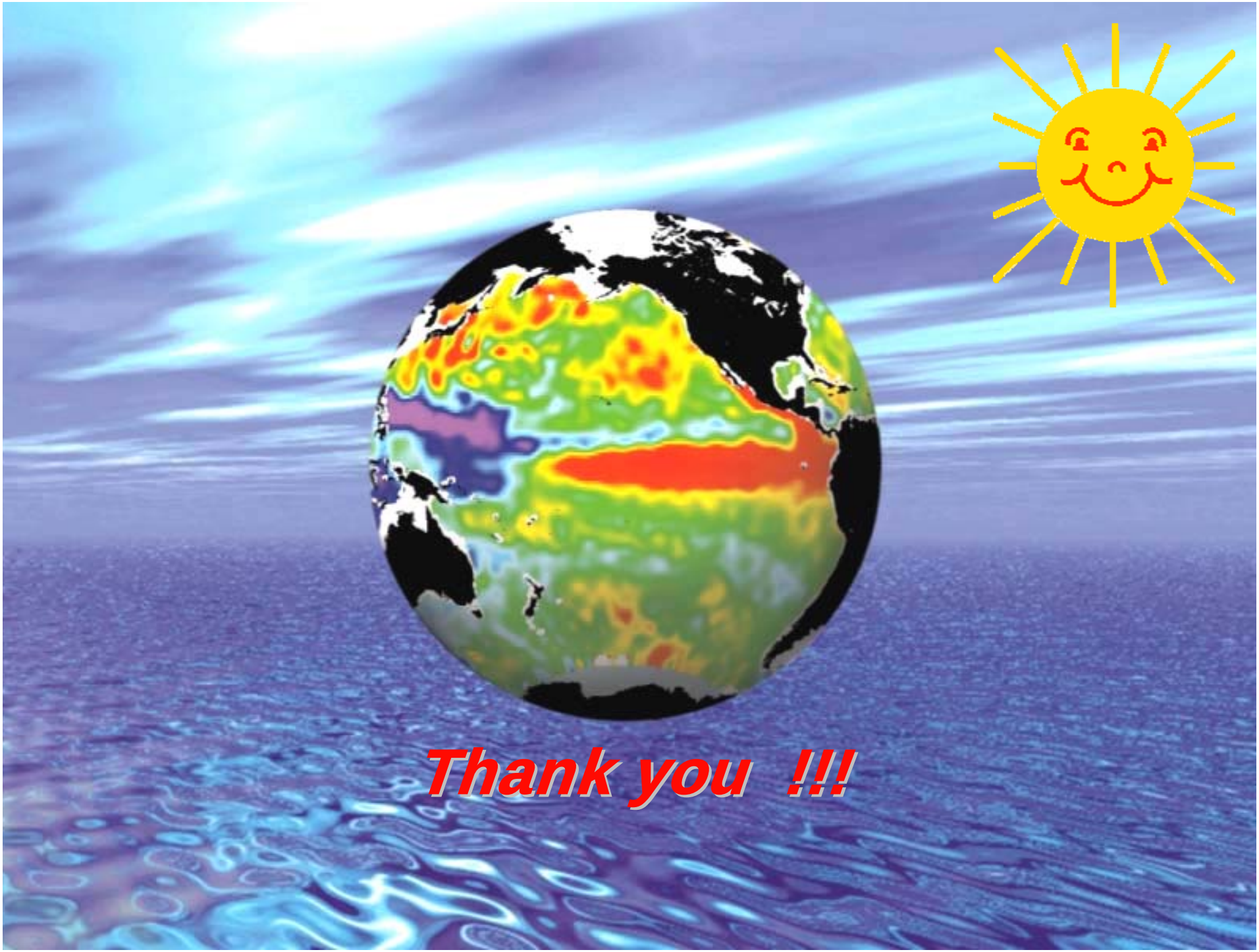
GFDL MOM 3

SST



H_p




Thank you !!!