Effects of freshwater flux (FWF) forcing on interannual climate variability in the tropical Pacific

Rong-Hua Zhang

EARTH SYSTEM SCIENCE INTERDISCIPLINARY CENTER

ESSIC

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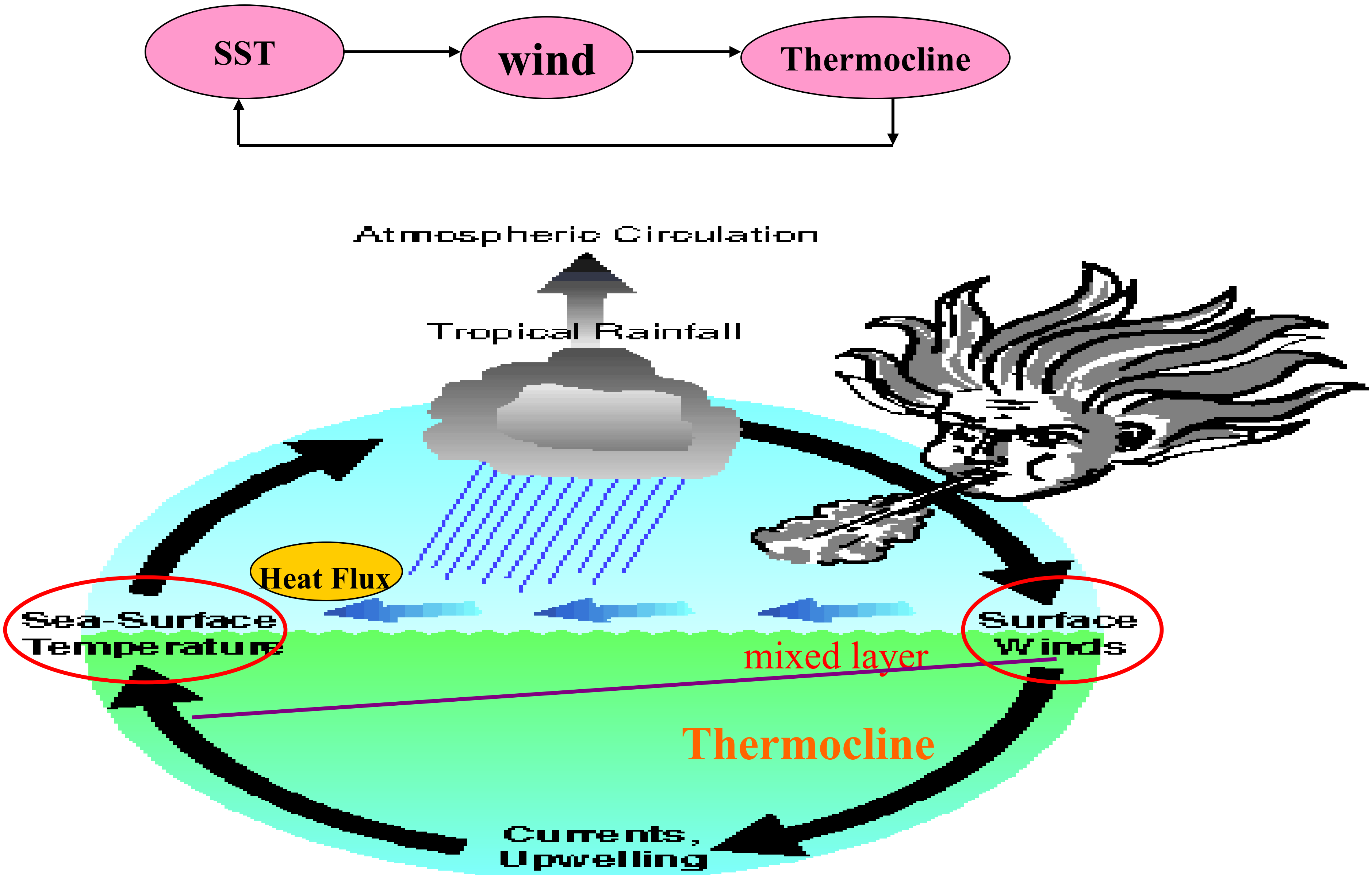
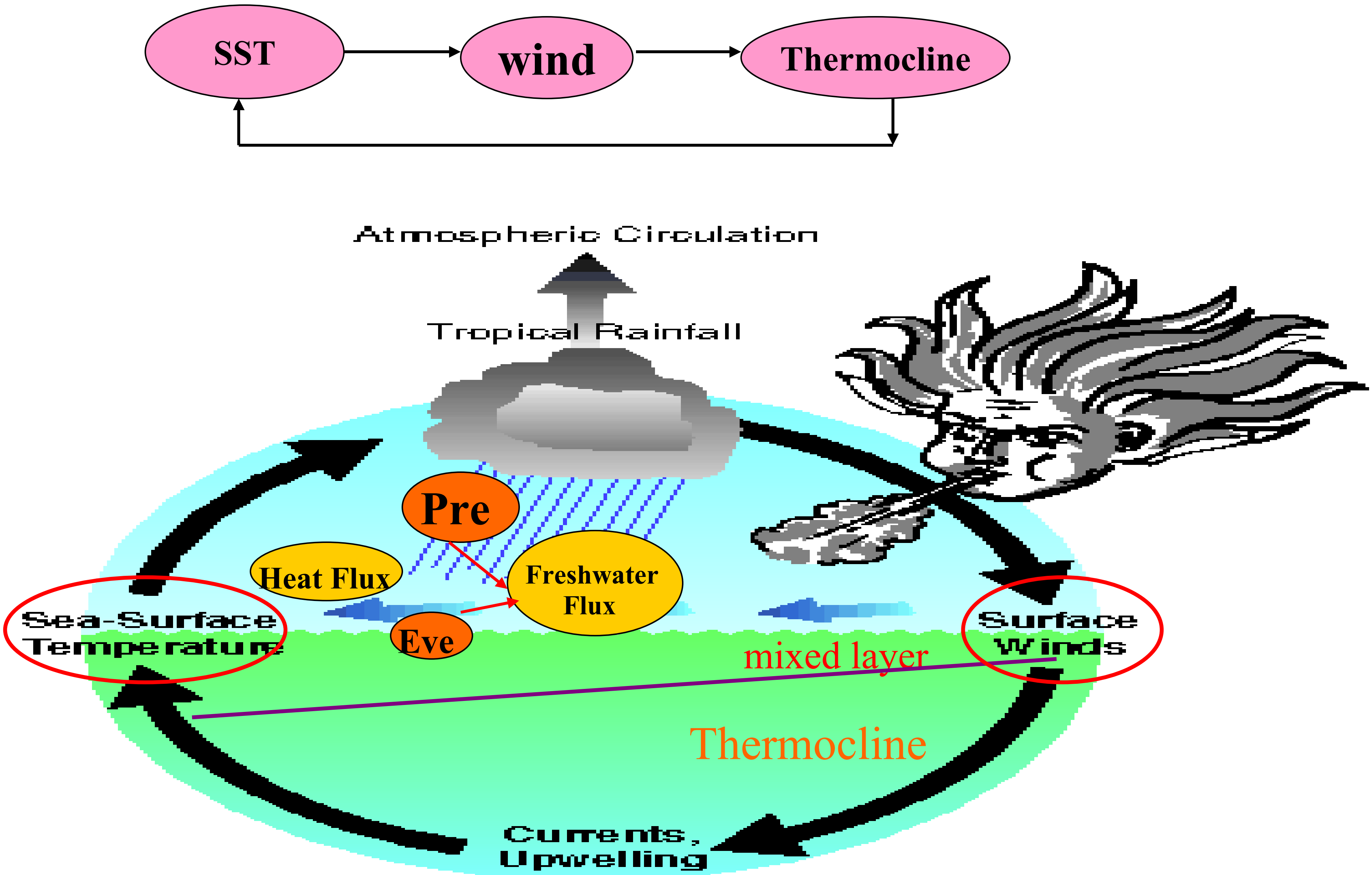
Processes involved in ENSO: Forcings & feedbacks

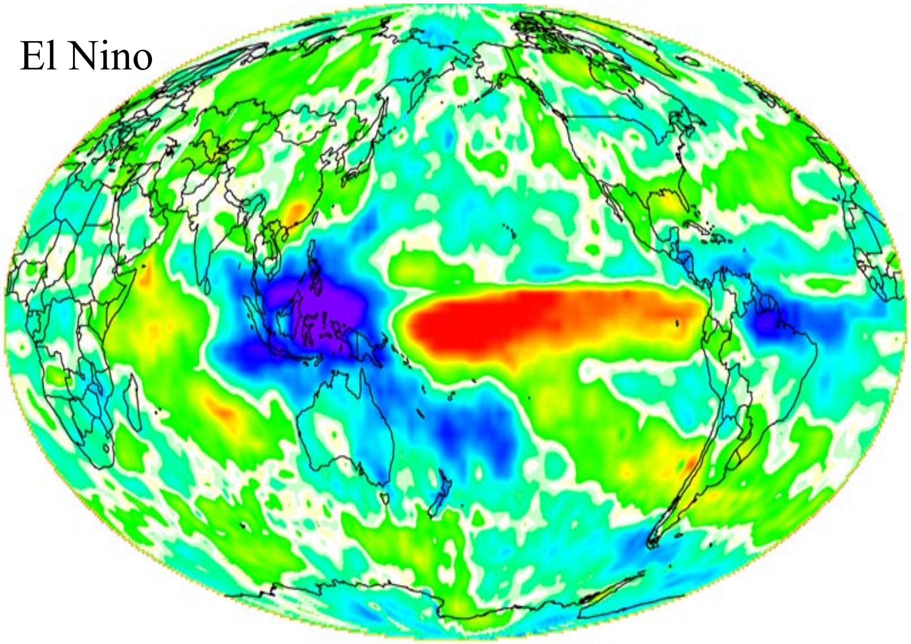


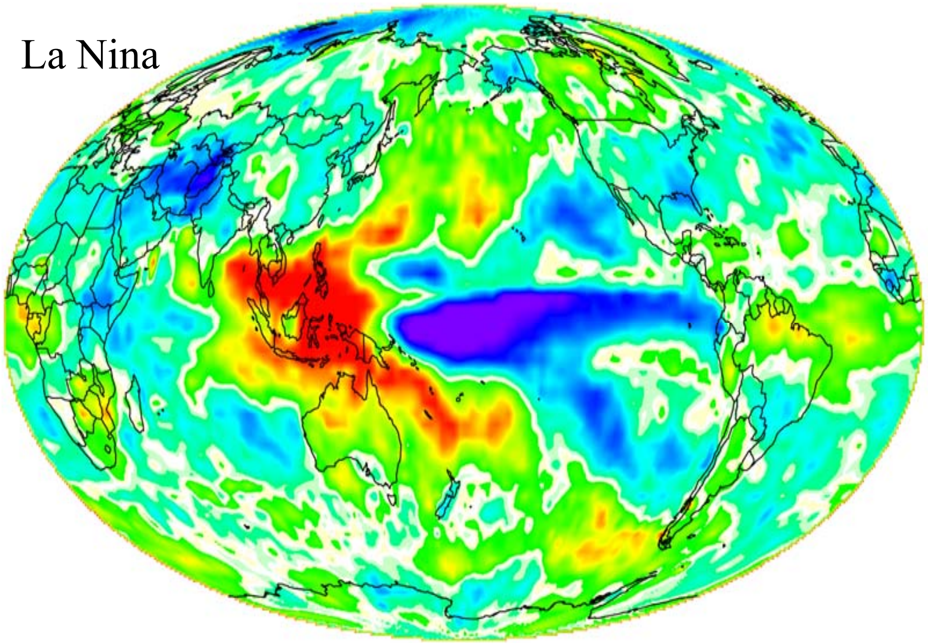
Processes involved in ENSO: Forcings & feedbacks



El Nino and La Nina Precipitation Anomaly Patterns

Warm Pacific *Cold Pacific*





Red: positive precipitation anomalies

Blue: negative precipitation anomalies

(normalized [by mean] anomalies, i.e., σ/μ)

From Dr. Robert Adler (NASA & UMD)

Roles of freshwater flux (*FWF*) forcing & related salinity effect in the Tropical Pacific Ocean

- ***Climate***
  - ✓ **One atmos forcing component;**
  - ✓ **Large FWF anomalies induced by ENSO;**
  - ✓ **Some unique FWF/salinity related phenomena;**
  - ✓ **Significant modulating effects;**
  - ✓ **Positive feedback**

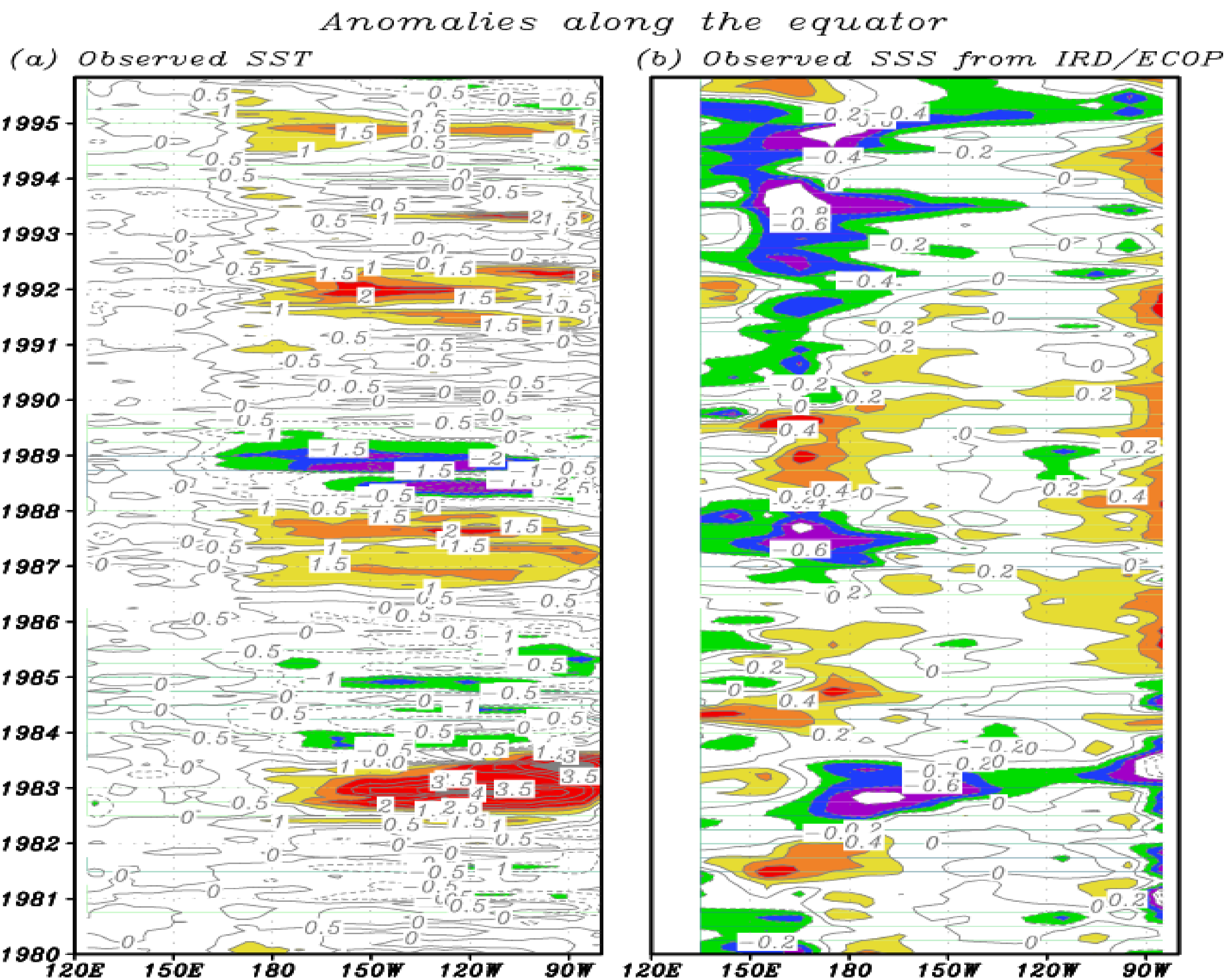
  ….
- ***Water/hydrological cycles*** **….**
- ***Data assimilation*** **….**
- ***Global warming*** **….**

Challenge in freshwater forcing & ocean salinity issues

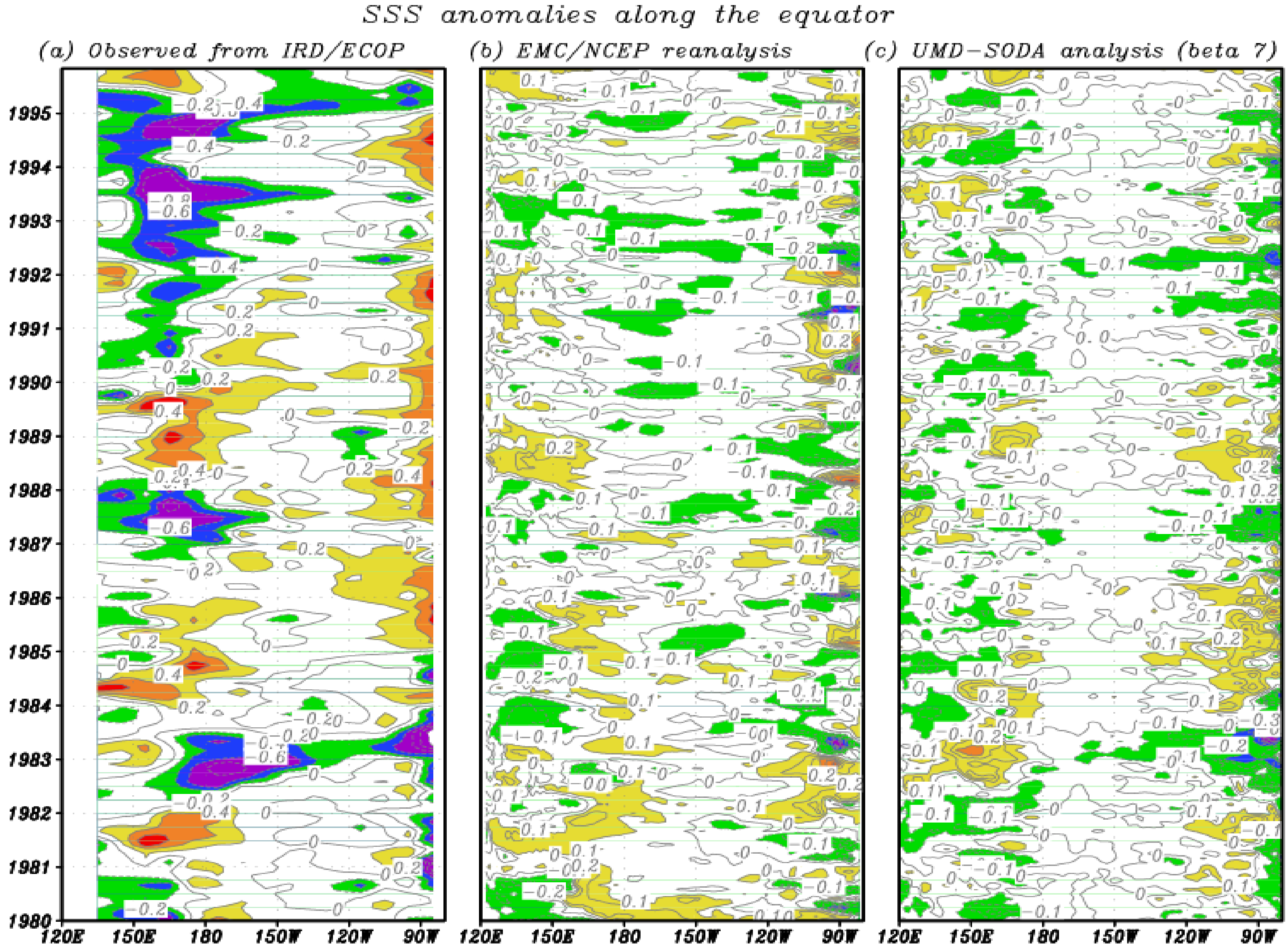
- **Studies mostly on *wind/heat flux*, less on FWF;**
- **Studies mostly on *ocean* modeling, less on coupled ocean-atmos modeling;**

- **FWF forcing not adequately represented in models;**
- **Uncertainty in observations & data products;**
- **Intermodel differences**
  - **Intermediate ocean models**
  - **level OGCMs**
  - **layer OGCMs**

- **Systematic biases & errors in SSS simulations:**
  - ***Ocean models:***
  - ***Coupled models:***



Anomalies along the equator
(a) Observed SST
(b) Observed SSS from IRD/ECOP
1995
1994
1993
1992
1991
1990
1989
1988
1987
1986
1985
1984
1983
1982
1981
1980
120E
150E
180
150W
120W
90W



SSS anomalies along the equator
(a) Observed from IRD/ECOP
(b) EMC/NCEP reanalysis
(c) UMD-SODA analysis (beta 7)
1980
1981
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
120E
150E
180
150W
120W
90W

Some approaches to improving SSS & SST simulations & predictions

1. Continue to improve parameterizations:

Great focus on We & Kv, *(but Te & Se equally important !!)*

2. Different ocean & coupled models:

Intermediate ocean model:

Layer models: *isopycnal coordinate*, …

Level models: *z-coordinate* (e.g., GFDL MOM)

(Te & Se depiction in different models !!)

3. Flux/bias corrections in ocean & coupled models

(better mean climatology!!)

4. MOS (model output statistics) corrections

(get SSTAs first and then try to correct them regardless of reasons!!)

5. Ocean data assimilation

This work

Taking into account freshwater flux (FWF) forcing

- Identify bias sources for SSS simulation;
- Understanding basic processes involved;
- Improving model simulations of salinity;
- Improving ENSO simulations & prediction;

- Support for satellite mission to measure SSS.

Outline

- **Introduction**
- **A hybrid coupled model (HCM$_{OGCM}$)**

  Ocean: **The Cane-Gent OGCM**

  Atmosphere: **Wind stress: SVD-based;**

  Heat flux: Seager et al.;

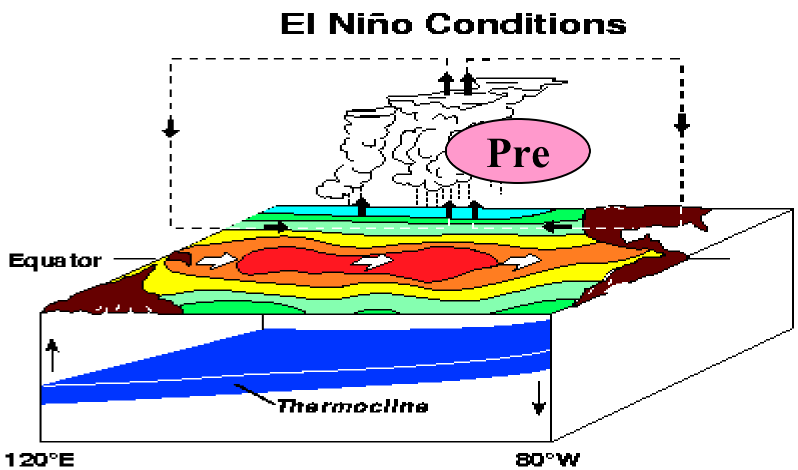
  FWF: SVD-based:

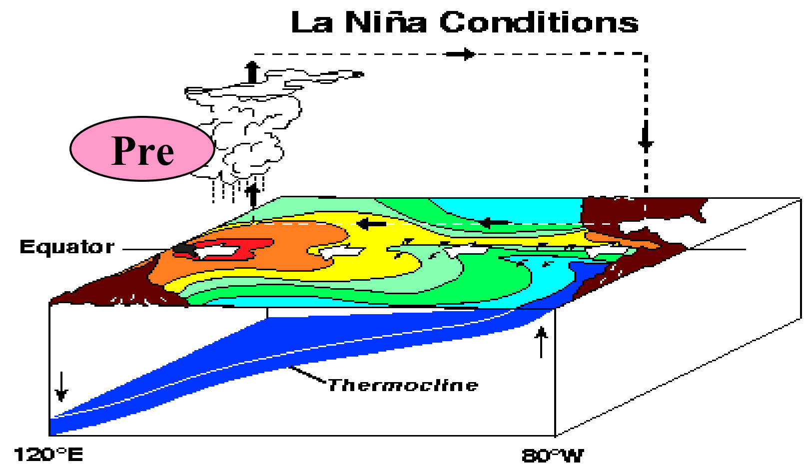
  $$\mathbf{FWF = (P\text{-}E)_{clim} + \alpha_{FWF} \bullet (P\text{-}E)_{inter}}$$

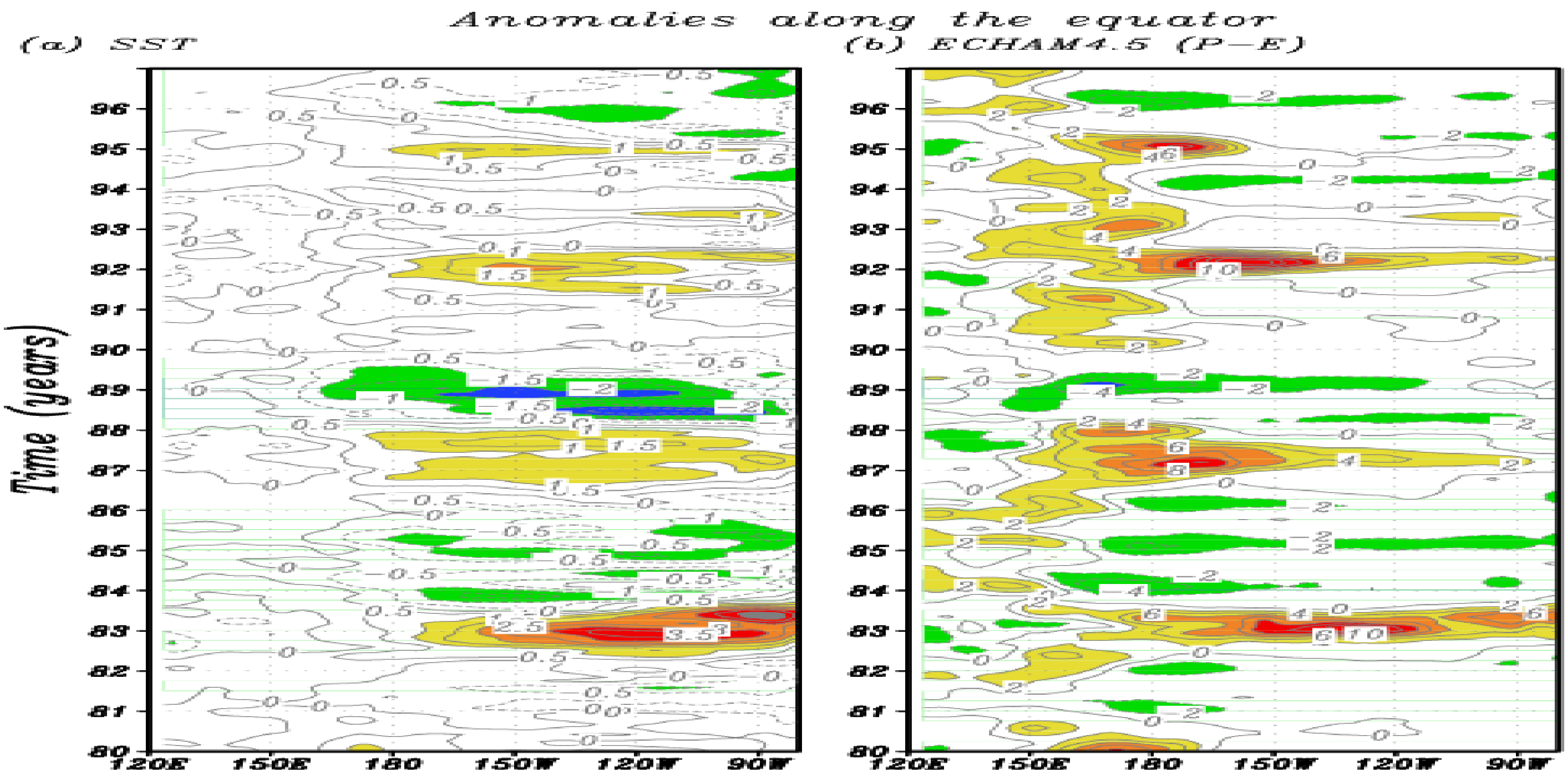
- **The standard HCM$_{OGCM}$ simulation** α_{FWF}**=1.0**
- **Sensitivity experiments:**

  α_{FWF}**=0.0** α_{FWF}**=2.0**

- **A FWF-induced positive feedback**
- **Summary**


El Niño Conditions
Pre
Equator
Thermocline
120°E
80°W

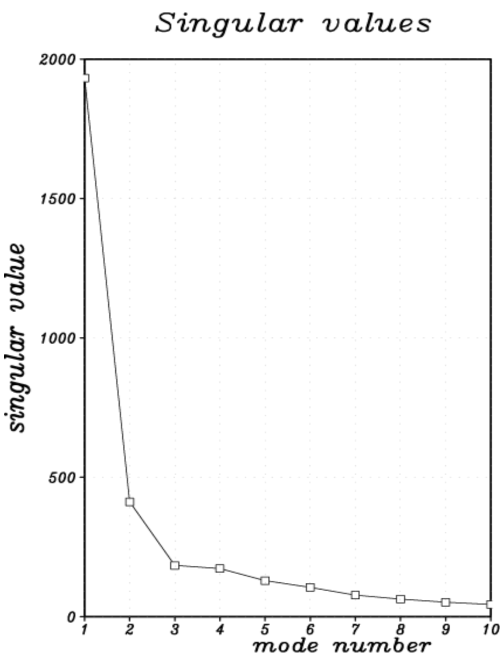

La Niña Conditions
Pre
Equator
Thermocline
120°E
80°W

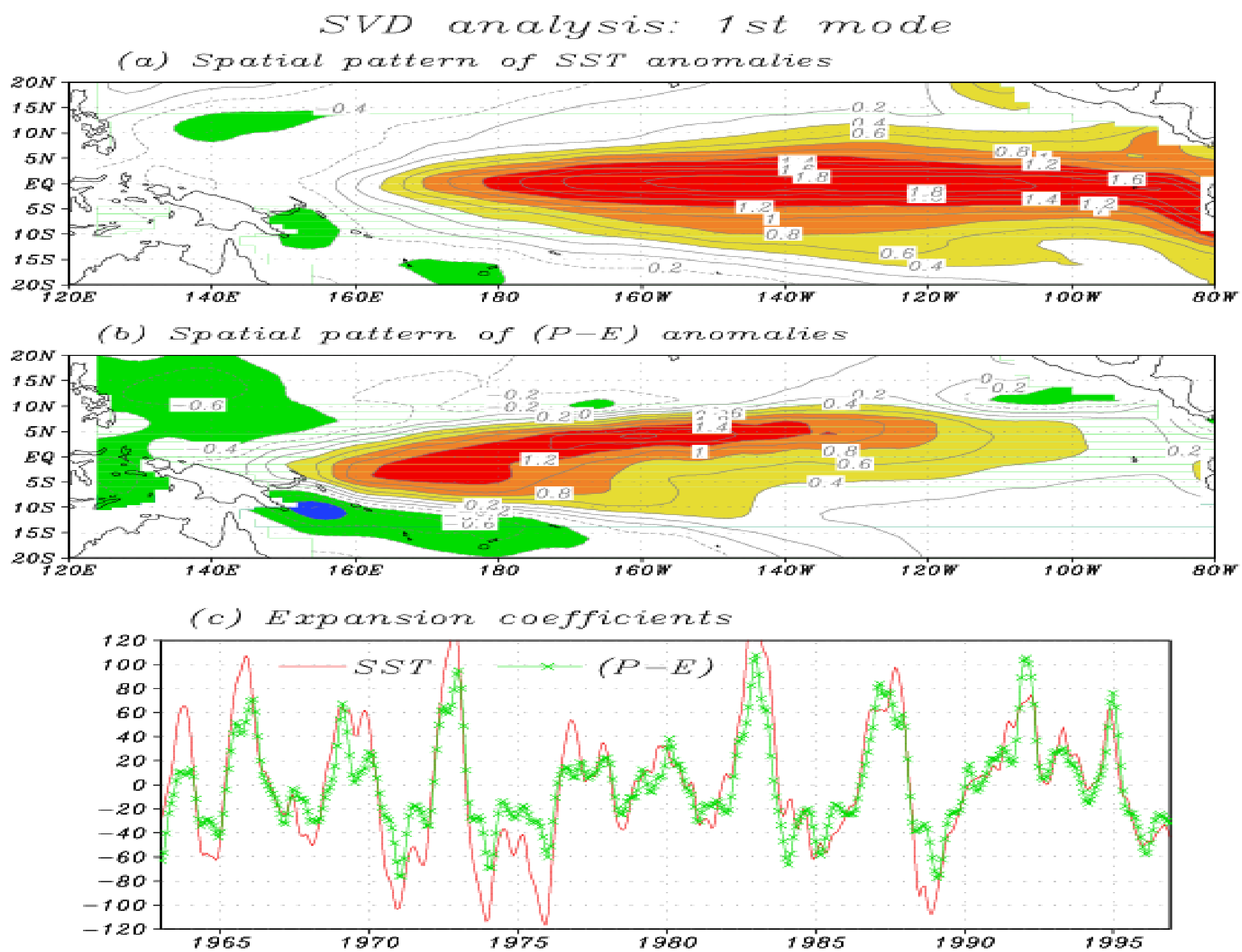

Anomalies along the equator
(a) SST
(b) ECHAM4.5 (P−E)
Time (years)
96
95
94
93
92
91
90
89
88
87
86
85
84
83
82
81
80
120E
150E
180
150W
120W
90W

A SVD-based Empirical Model for $(P\text{-}E)_{inter}$

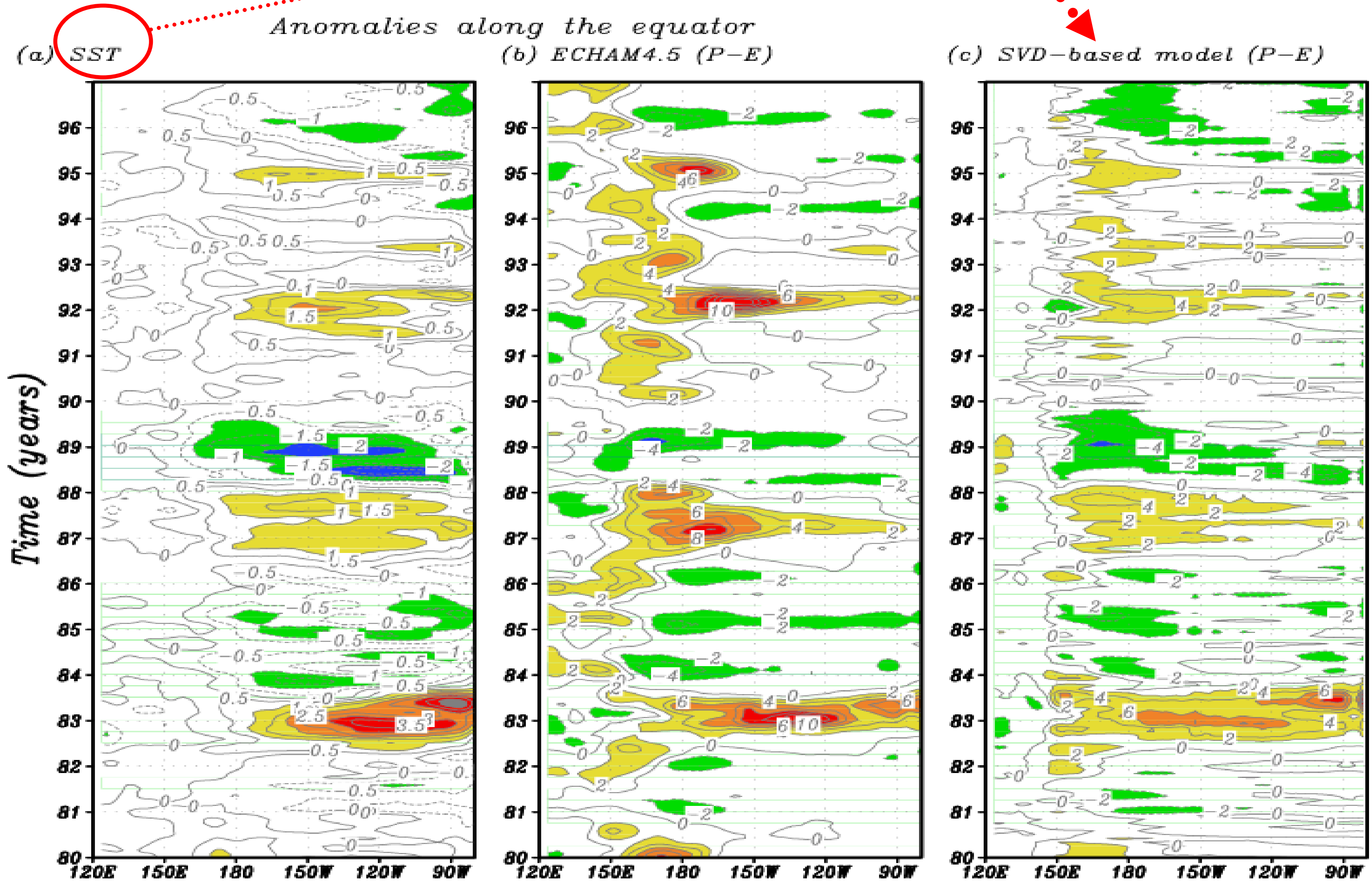
$$FWF = (P\text{-}E)_{clim} + \alpha_{FWF} \bullet S_{vd}(\ SST_{inter}\ )$$

- **P, E** : ECHAM 4.5 AMIP run
- **SST**: Reynolds & Smith





$$S_{vd}\left(SST_{inter} \right) = (P\text{-}E)_{inter}$$



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)

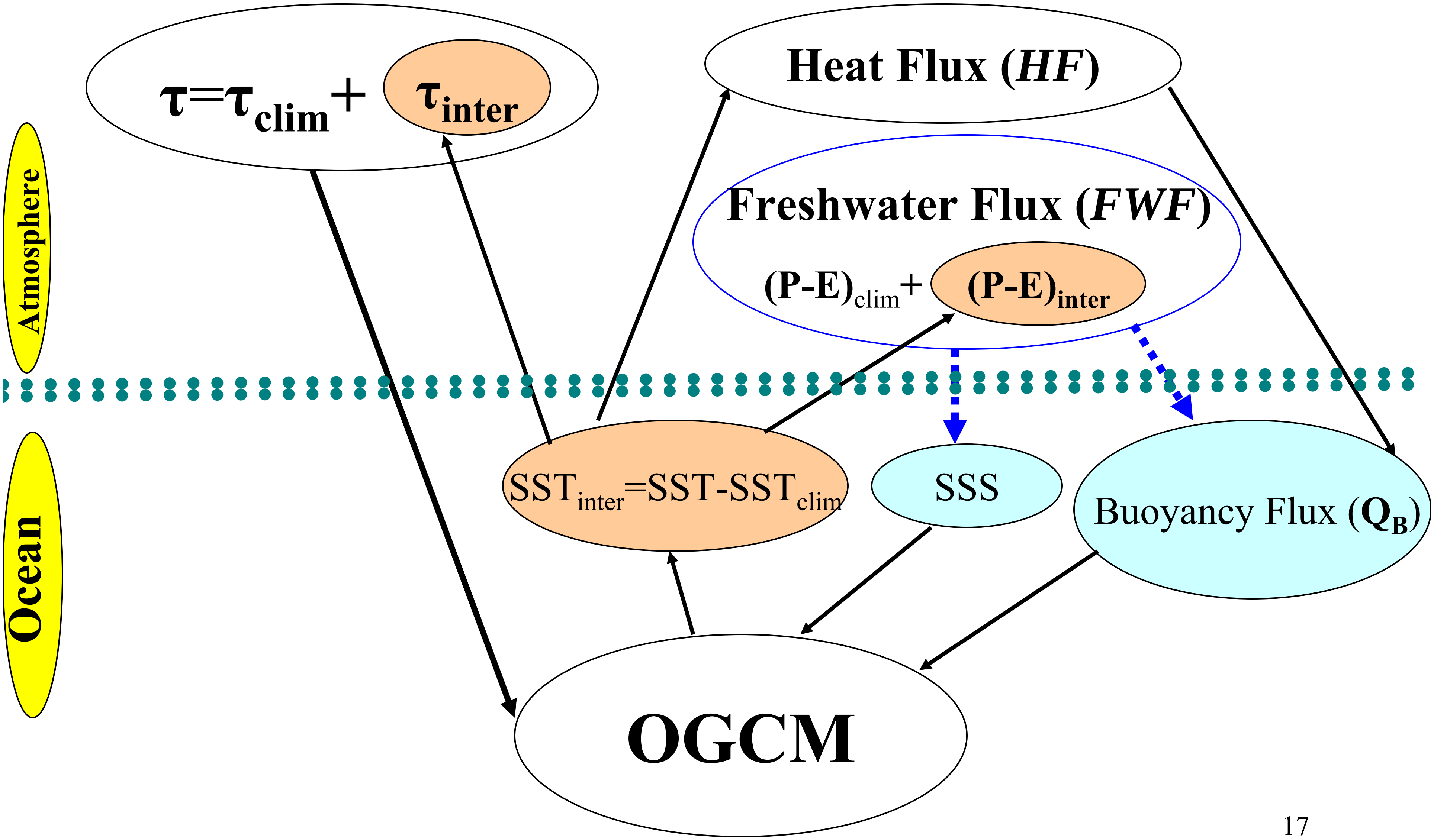
  (3) Model specifications:

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

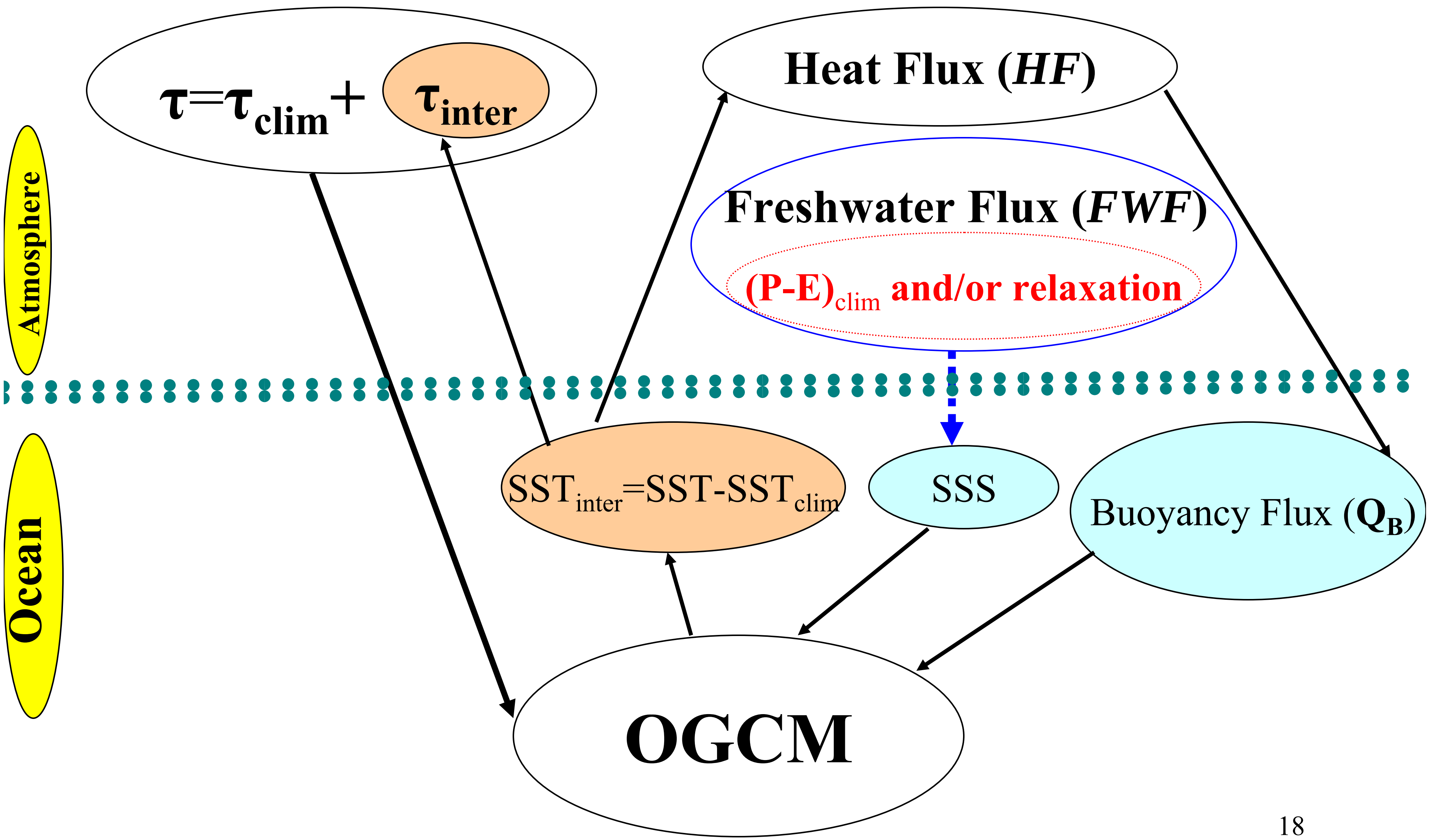
  Resolution: 1 deg in longitude and 0.5 deg in latitude

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

A hybrid coupled ocean-atmosphere model

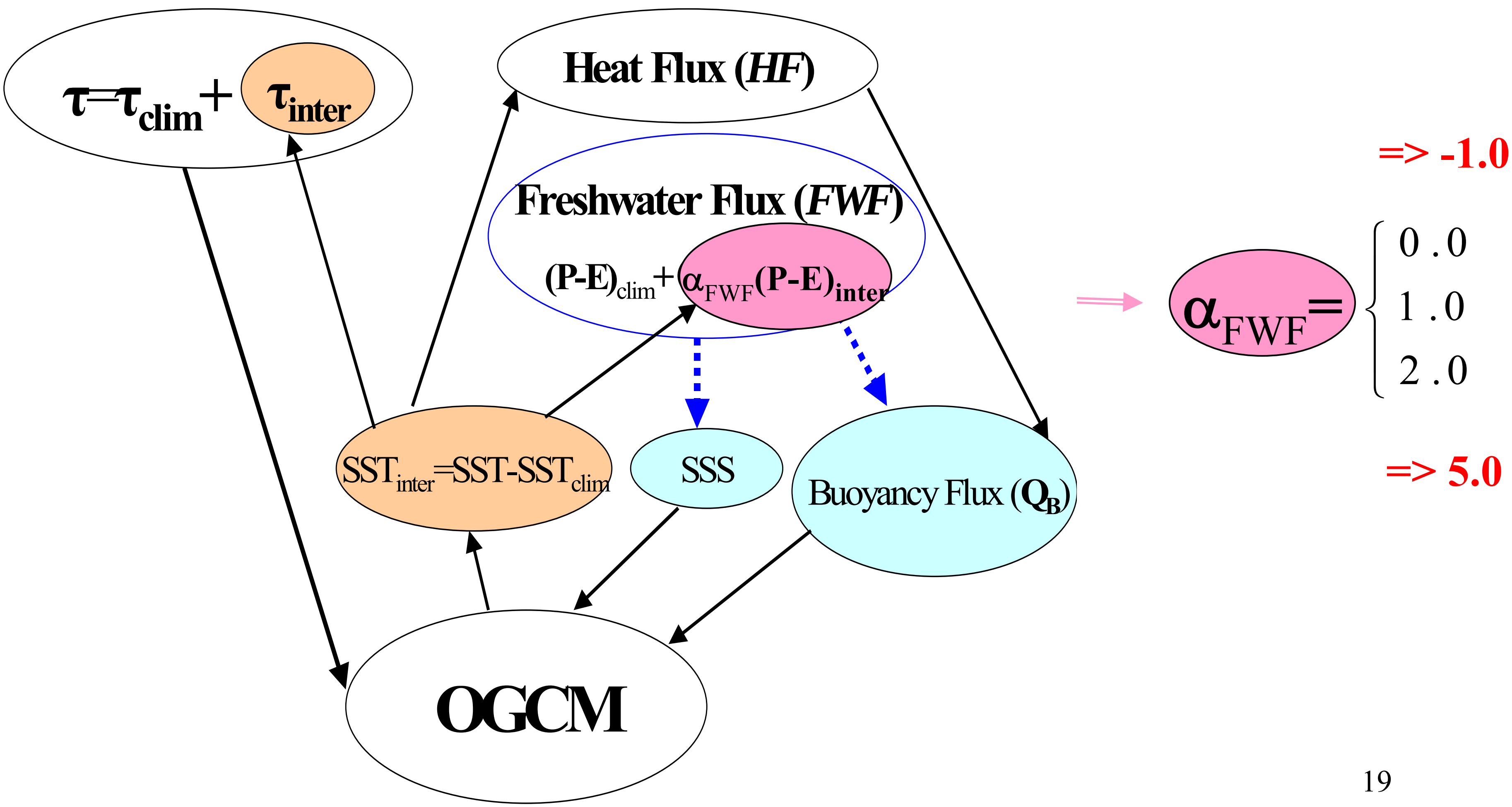


A hybrid coupled ocean-atmosphere model



Data & Model experiments

- **Wind stress, P, E** : ECHAM 4.5 AMIP run *1950-1997*
- **SST**: Reynolds & Smith



Effects of freshwater flux (*in general*):

$$FWF = (P\text{-}E)_{clim} + (P\text{-}E)_{inter}$$

Sea surface sailinty (SSS):

=> density => stratification & stability => mixing

Buoyancy flux (Q_B):

$$Q_B = \alpha \bullet \boldsymbol{HF}/(\rho C_p) + \beta \bullet S_0 \bullet \boldsymbol{FWF} = Q_T + Q_S$$

Gaining $\downarrow$ (+) => more bouyant (lighter) => stable => shallow mixed layer => less entrainment

Effects of anomalous FWF during ENSO:

$$SSS \ \& \ Q_B = \alpha \bullet \boldsymbol{HF}/(\rho C_p) + \beta \bullet S_0 \bullet \boldsymbol{FWF} = Q_T + Q_S$$

(as represented at Nino4 site)

	SST	Q_T	Q_S	*SSS*	Q_B	MLD	*SST*
El Nino	+	-	+	-	-	-	
La Nina	-	+	-	+	+	+	

Effects of anomalous FWF during ENSO:

$$\text{SSS \& } Q_B = \alpha \bullet \boldsymbol{HF}/(\rho C_p) + \beta \bullet S_0 \bullet \boldsymbol{FWF} = Q_T + Q_S$$

(as represented at Nino4 site)

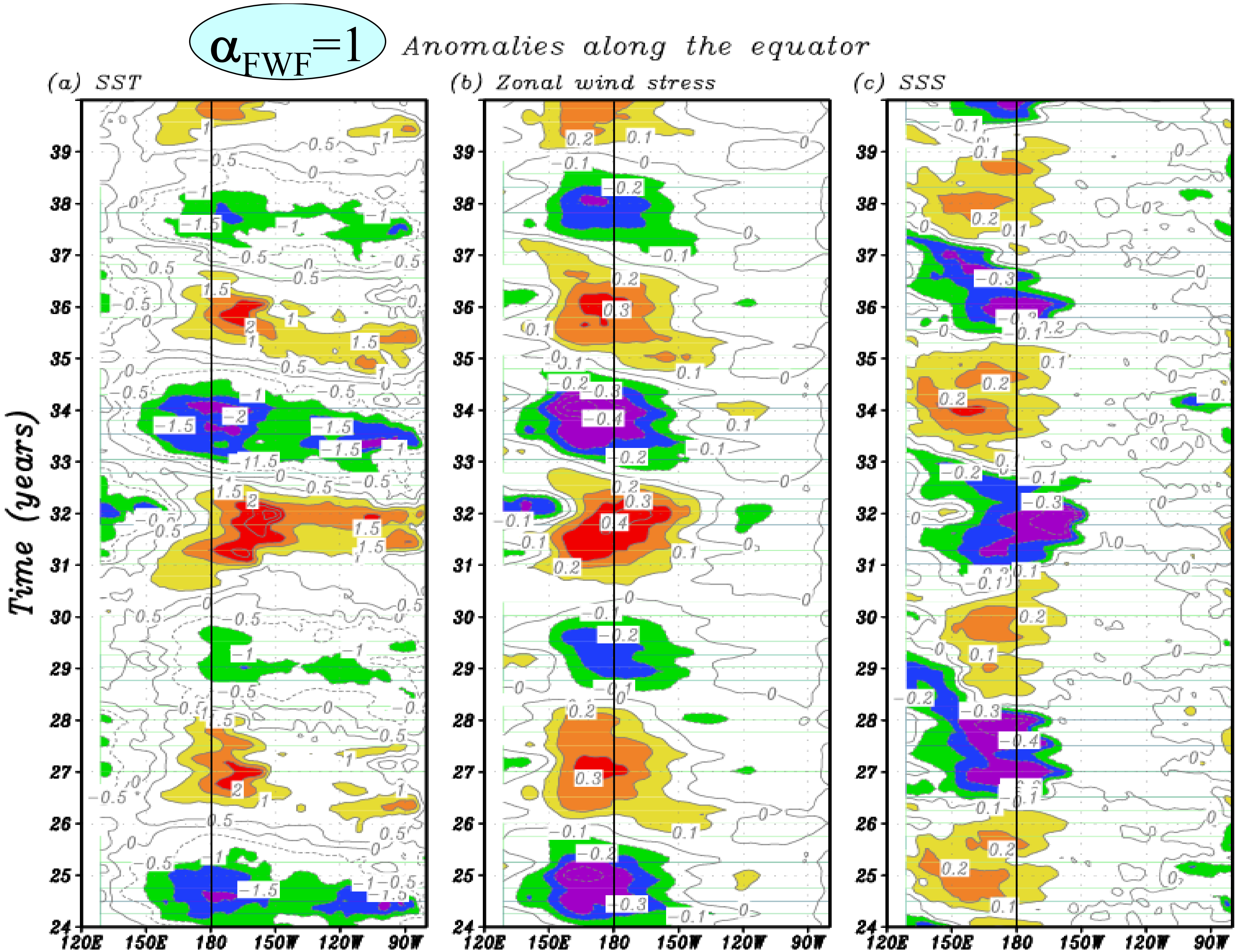
	SST	Q_T	Q_S	*SSS*	Q_B	MLD	*SST*
El Nino	+	-	+	-	-	-	?
La Nina	-	+	-	+	+	+	?

Effects of anomalous FWF during ENSO:

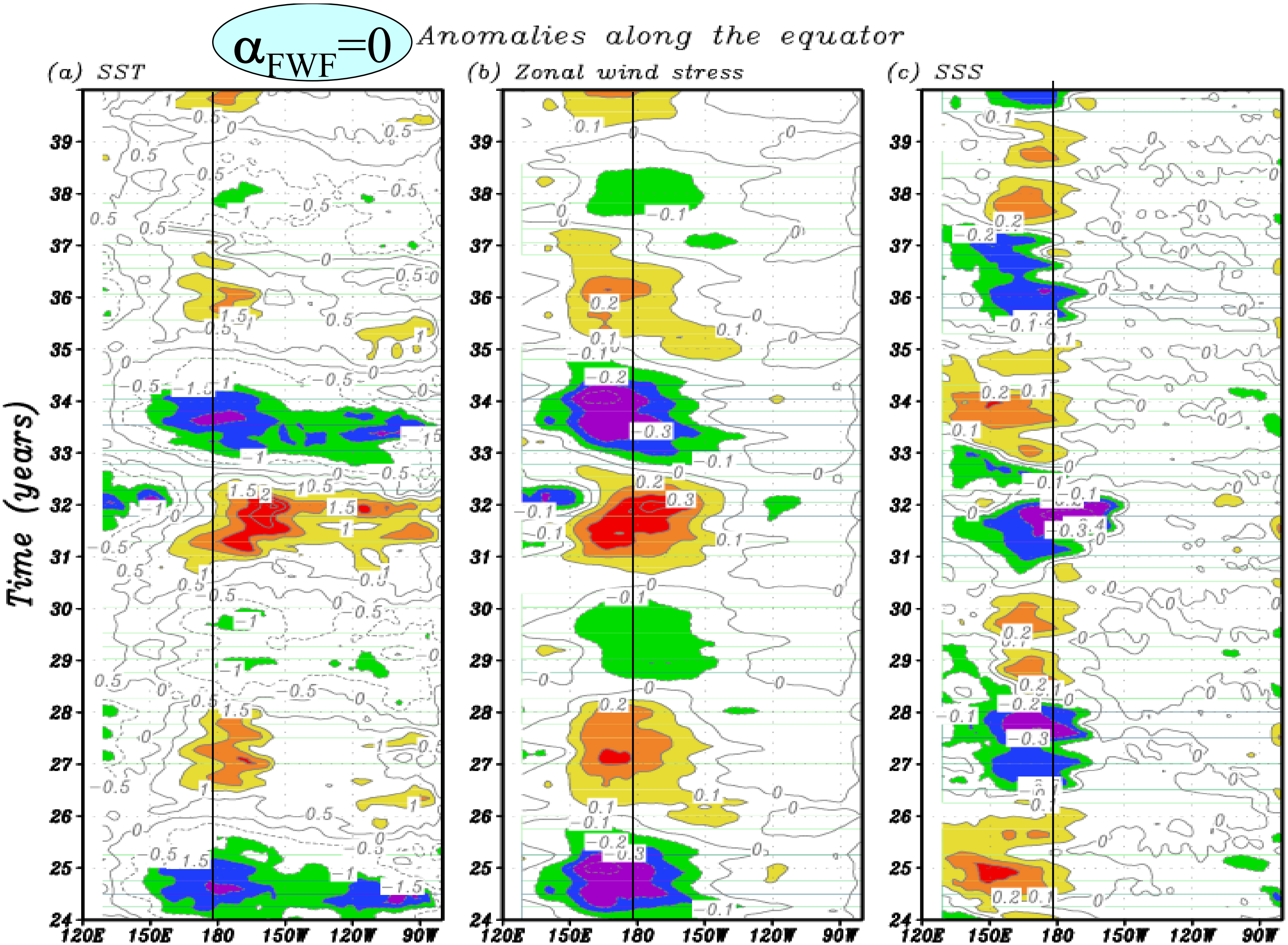
$$\text{SSS \& } Q_B = \alpha \bullet \boldsymbol{HF}/(\rho C_p) + \beta \bullet S_0 \bullet \boldsymbol{FWF} = Q_T + Q_S$$

(as represented at Nino4 site)

	SST	Q_T	Q_S	*SSS*	Q_B	MLD	*SST*
El Nino	+	-	+ More positive	- Freshening More stable	- Less negative	- shallow Less entrainment	More warming
La Nina	-	+	- More negative	+ more Salty Less stable	+ Less positive	+ deepening More entrainment	More cooling



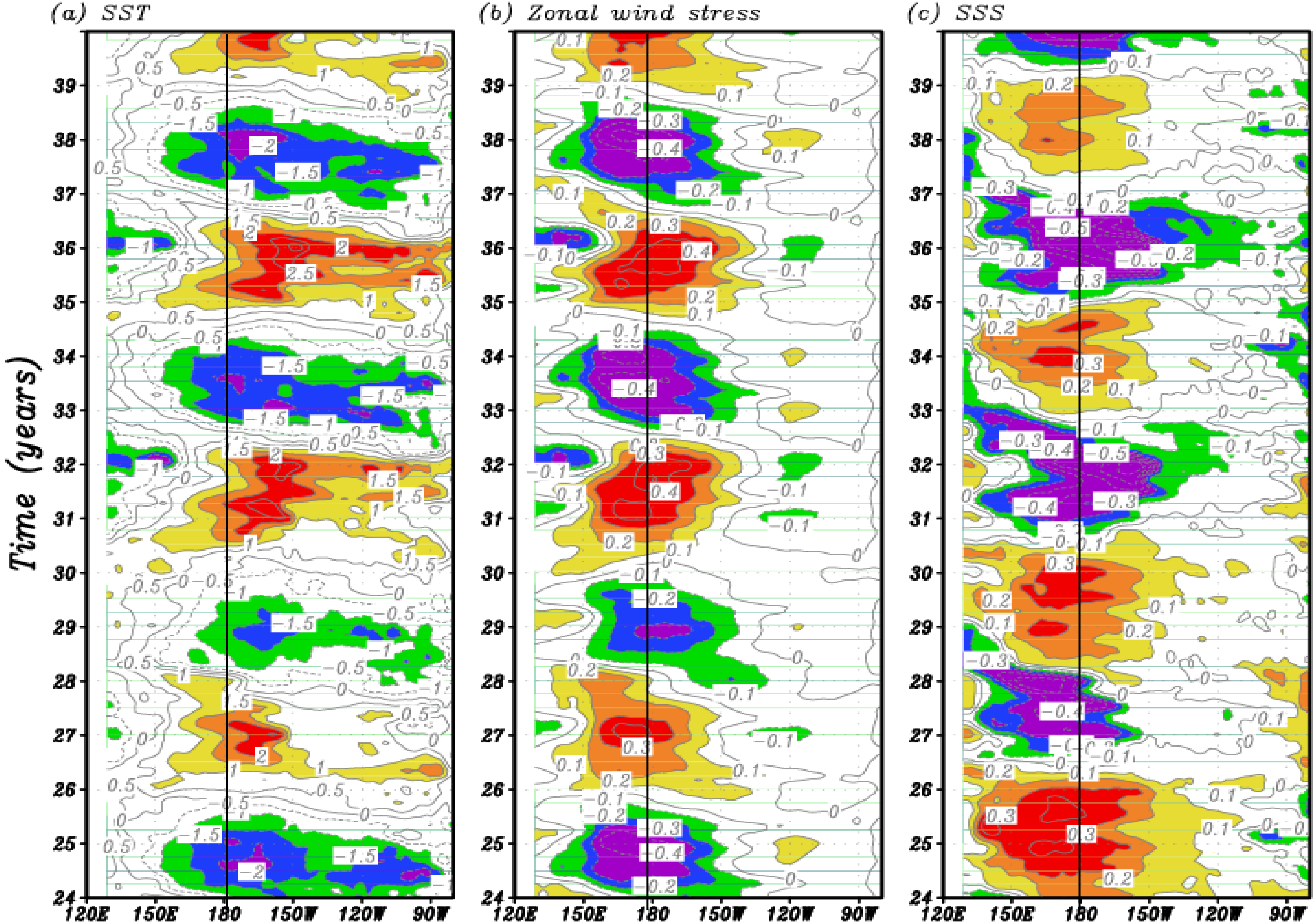
α_FWF=1
Anomalies along the equator
(a) SST
(b) Zonal wind stress
(c) SSS
Time (years)
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
120E
150E
180
150W
120W
90W

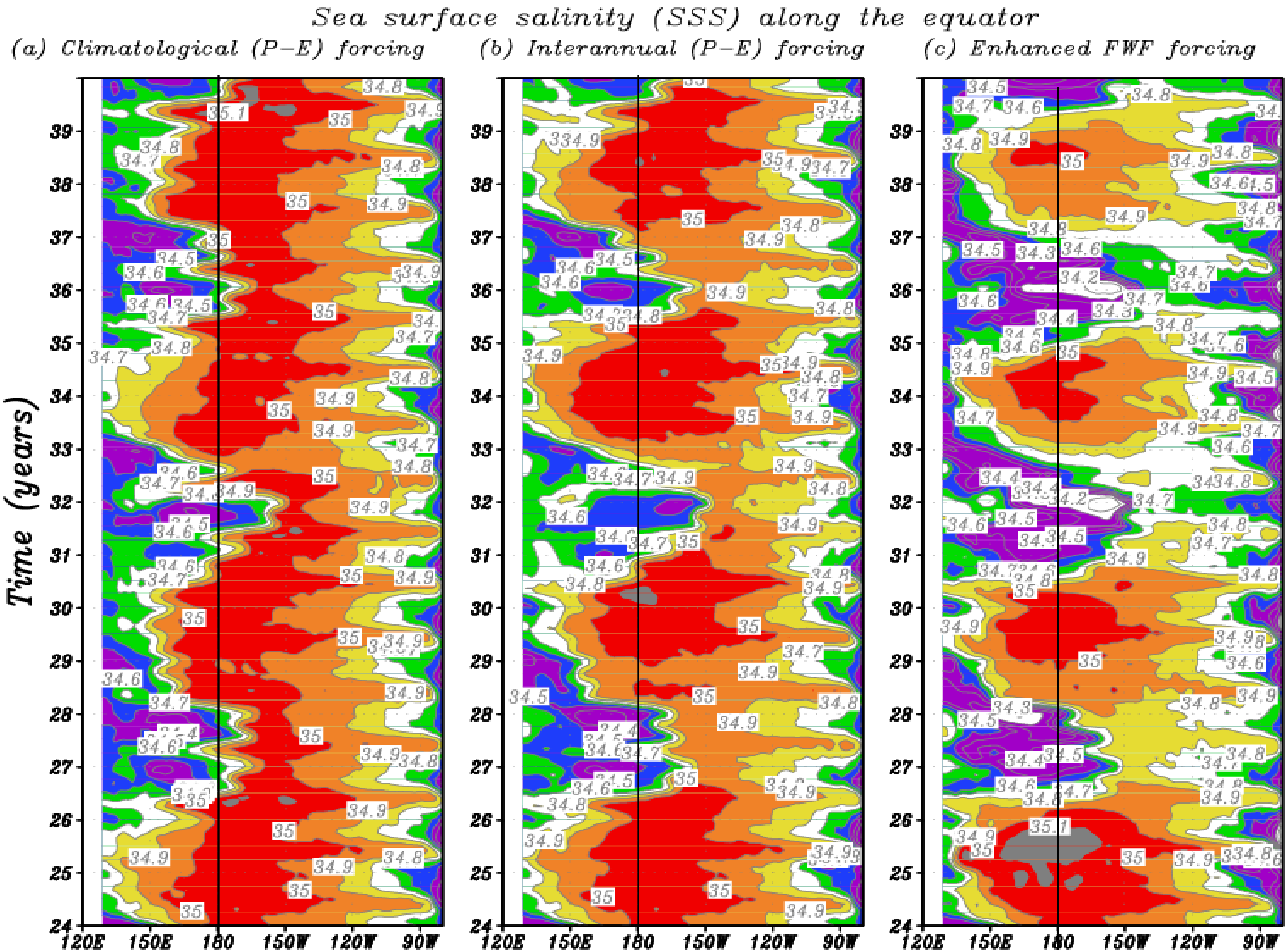


αFWF=0
Anomalies along the equator
(a) SST
(b) Zonal wind stress
(c) SSS
Time (years)
120E 150E 180 150W 120W 90W

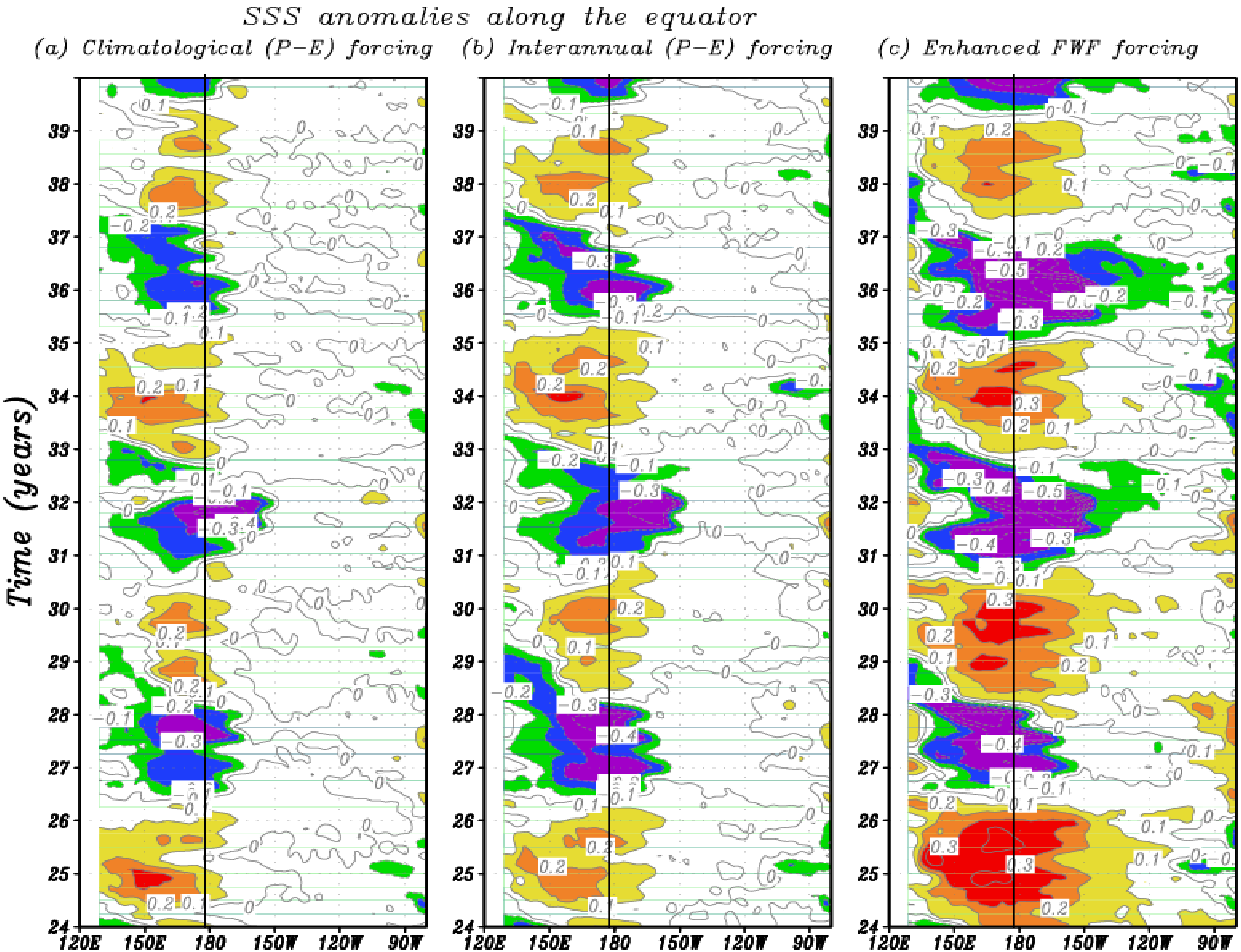
$\alpha_{FWF}=2$

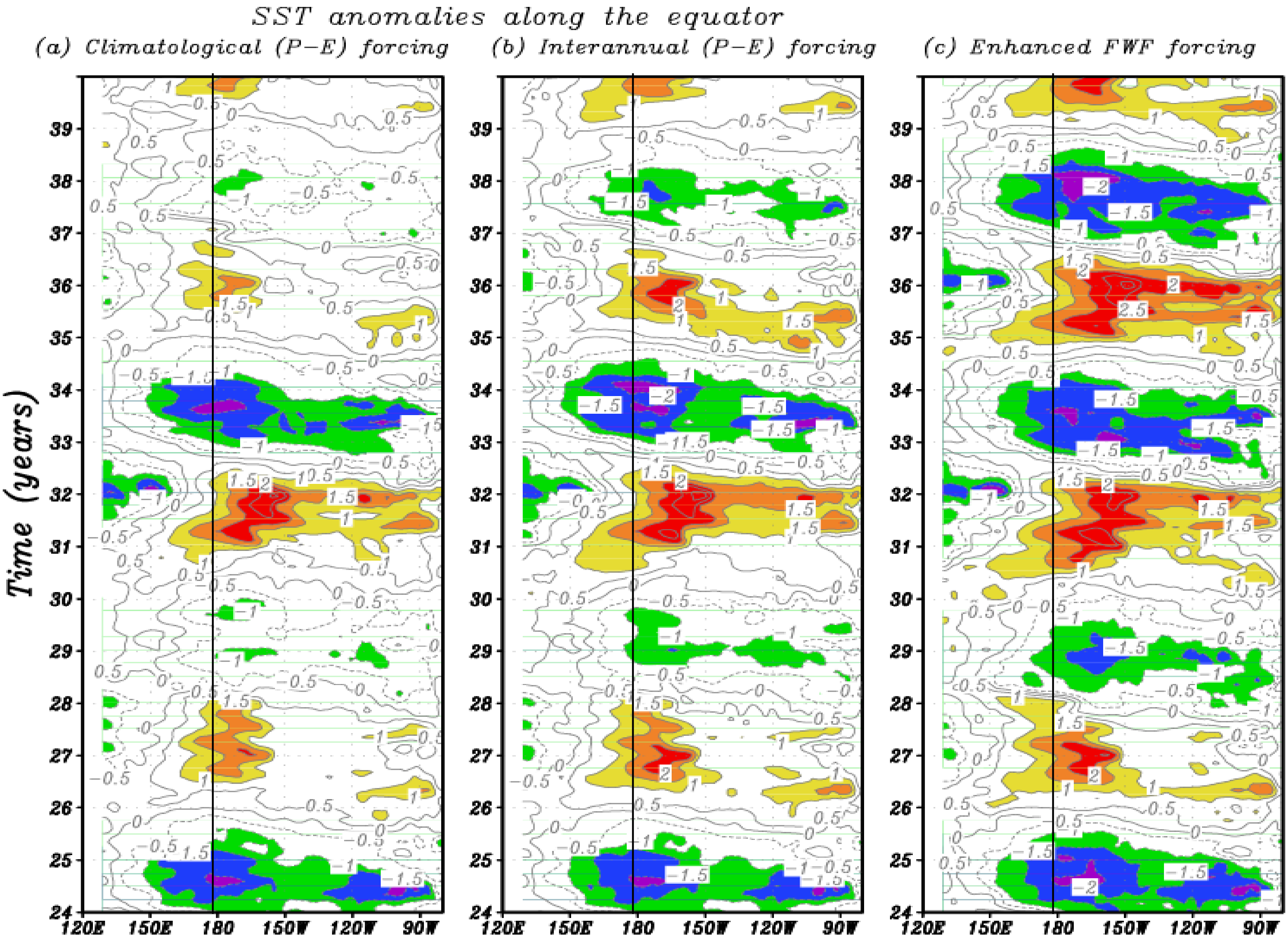
Anomalies along the equator





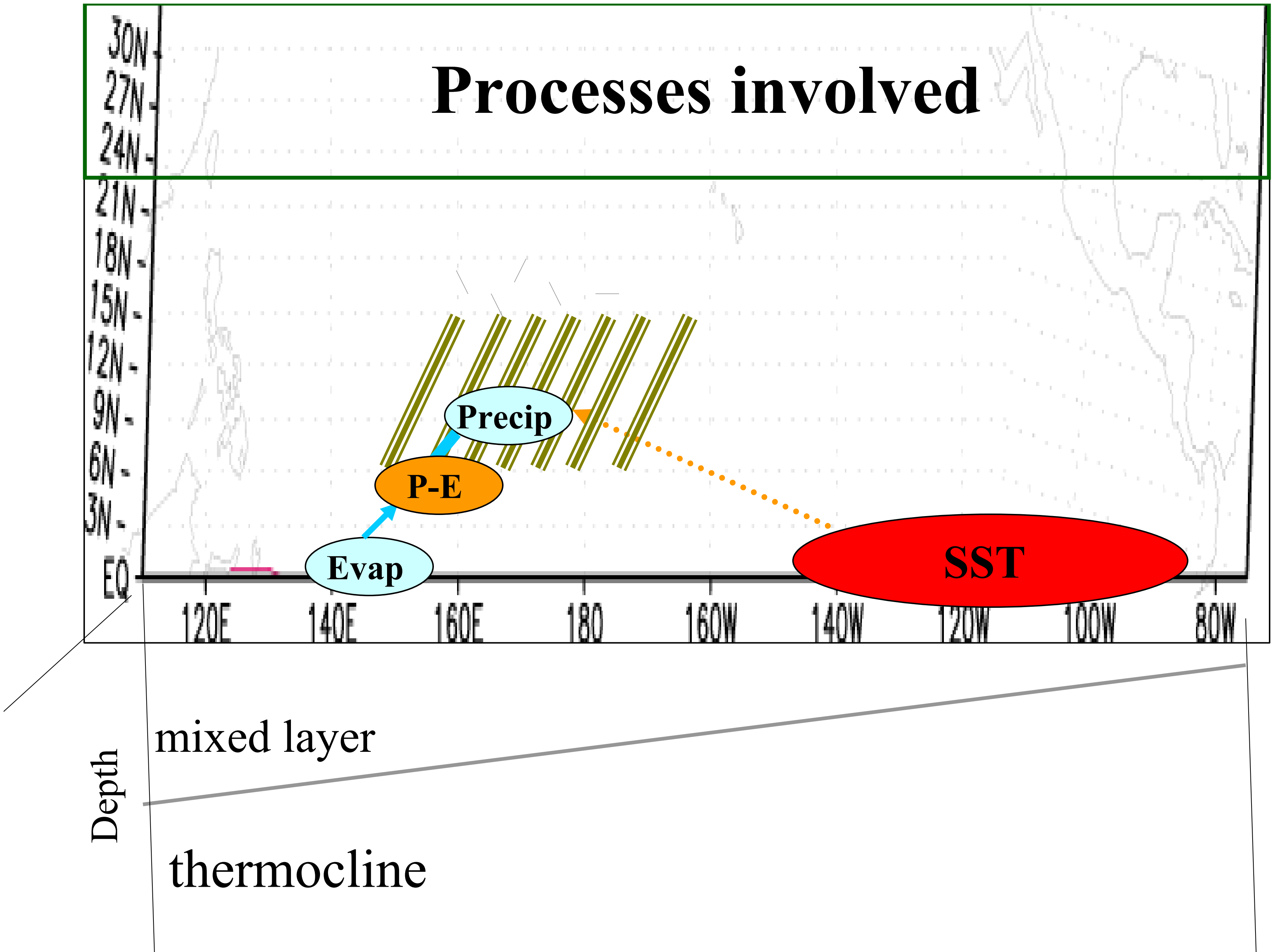
Sea surface salinity (SSS) along the equator
(a) Climatological (P-E) forcing
(b) Interannual (P-E) forcing
(c) Enhanced FWF forcing
Time (years)
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
120E
150E
180
150W
120W
90W


SSS anomalies along the equator
(a) Climatological (P−E) forcing
(b) Interannual (P−E) forcing
(c) Enhanced FWF forcing
Time (years)
120E
150E
180
150W
120W
90W

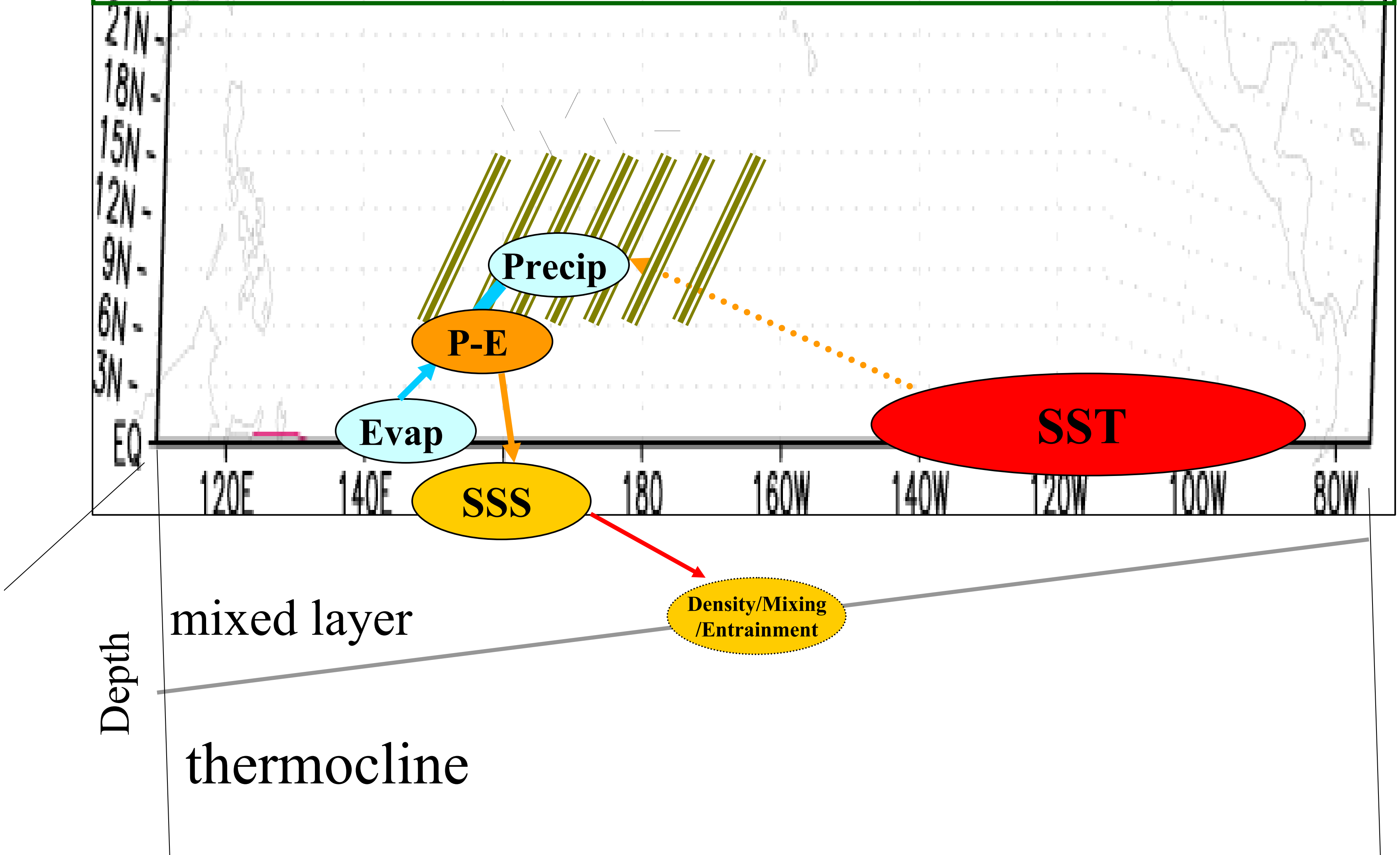


SST anomalies along the equator
(a) Climatological (P−E) forcing
(b) Interannual (P−E) forcing
(c) Enhanced FWF forcing
Time (years)
120E
150E
180
150W
120W
90W

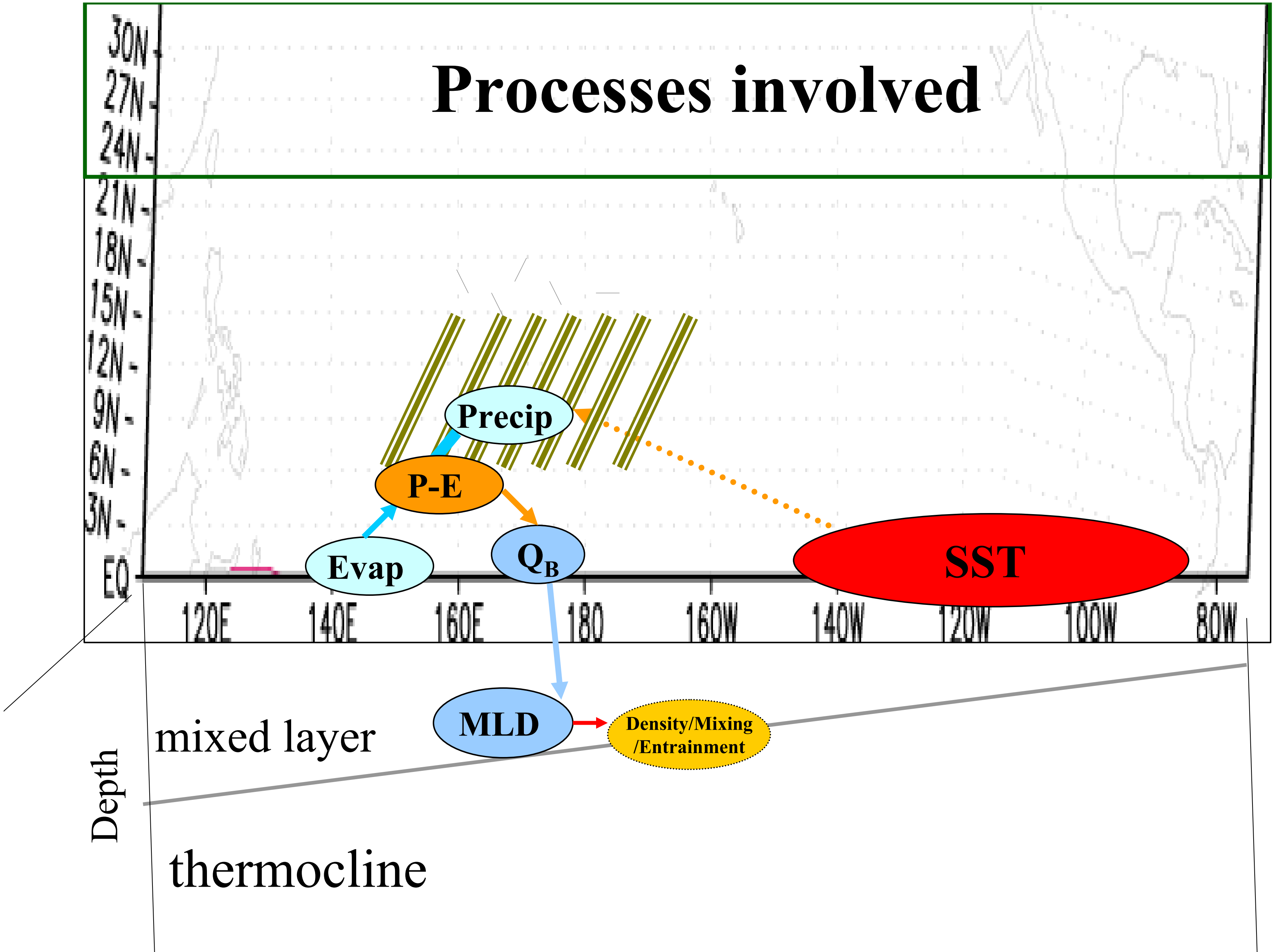
Processes involved



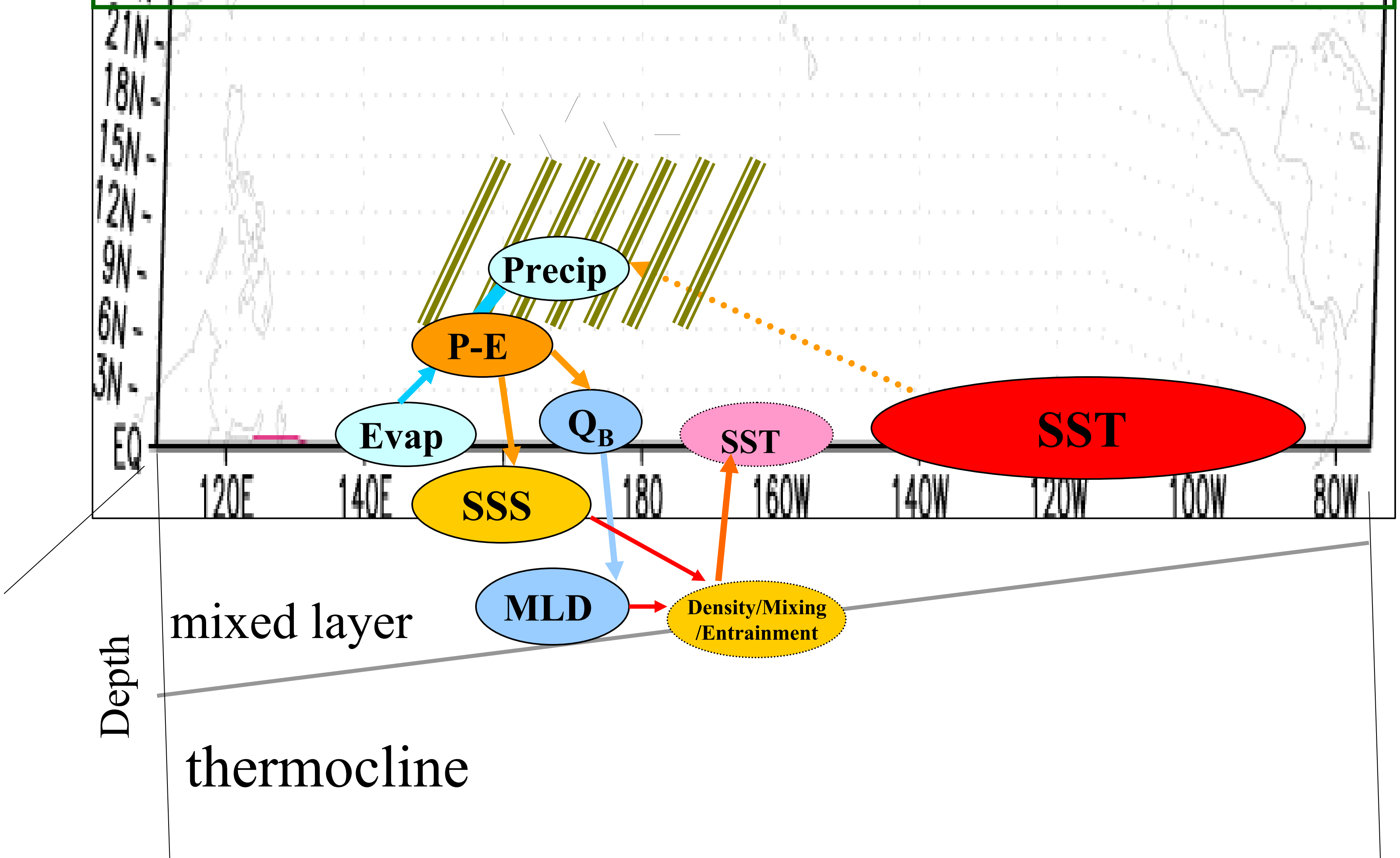
Processes involved

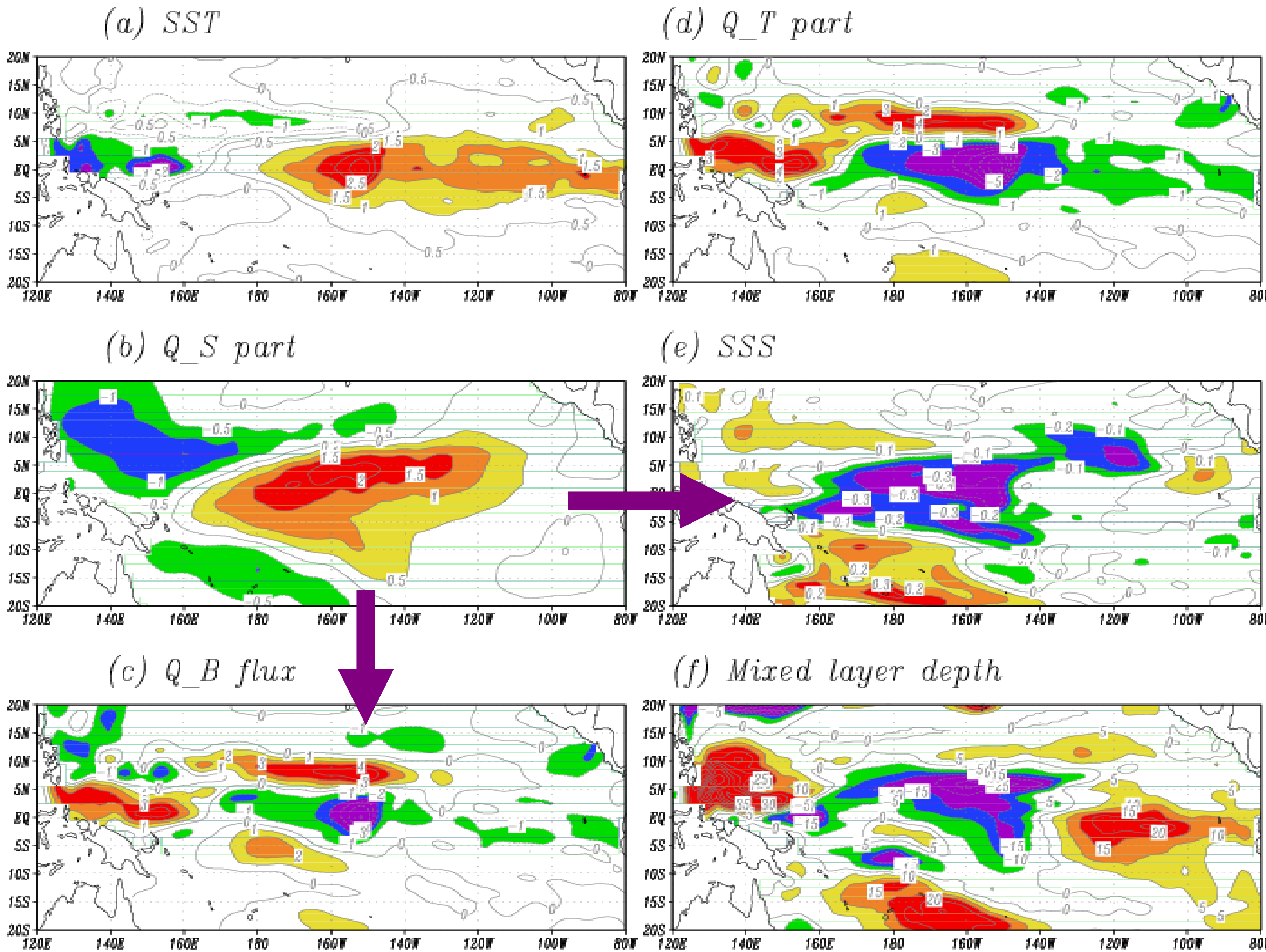


Processes involved



Processes involved

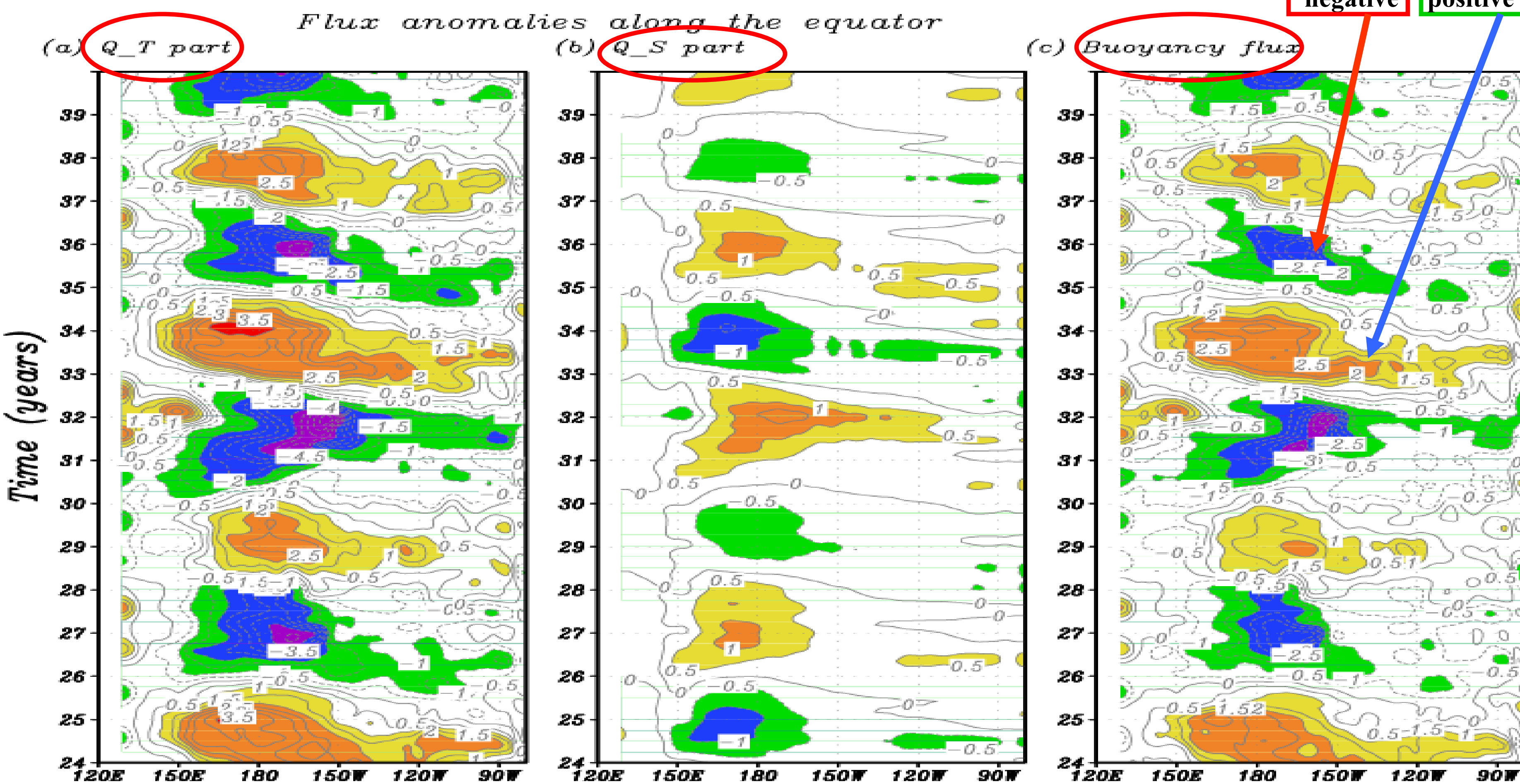



(a) SST
(b) Q_S part
(c) Q_B flux
(d) Q_T part
(e) SSS
(f) Mixed layer depth

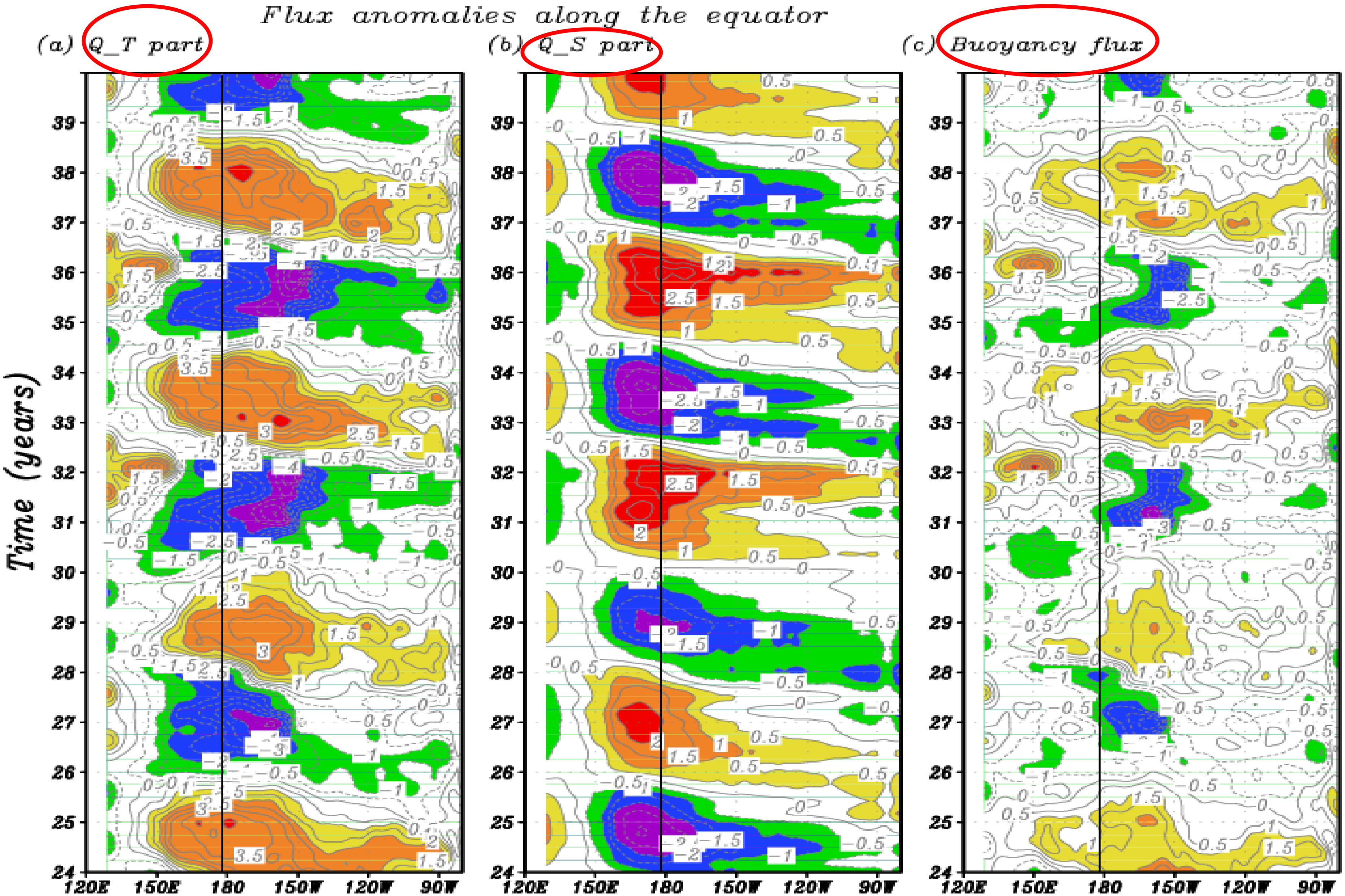
Buoyancy flux (Q_B) and its relation with Q_T & Q_S

$$\text{FWF} = (P-E)_{clim} + \alpha_{FWF} \bullet (P-E)_{inter}$$

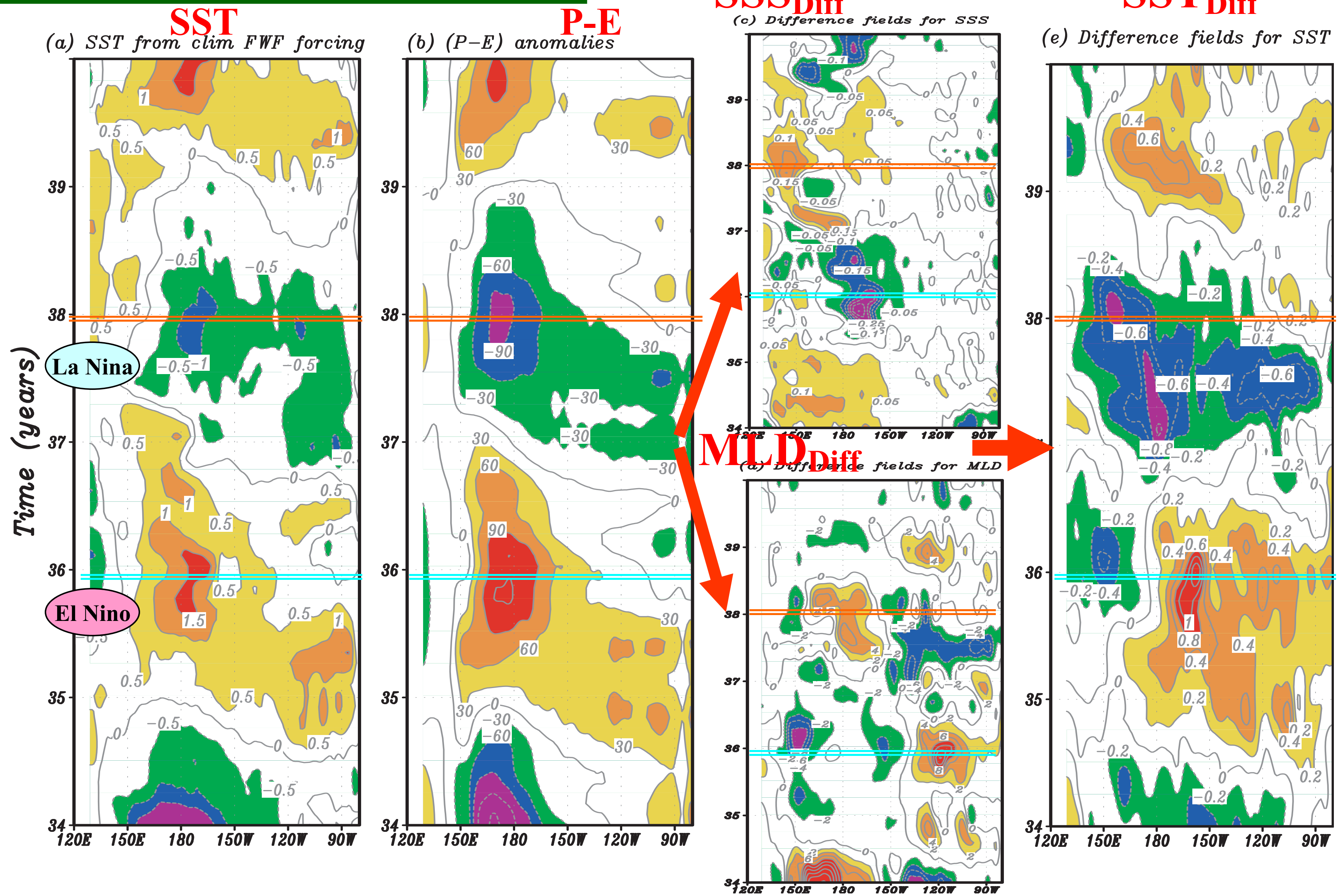
$$\alpha \bullet \boldsymbol{HF}/(\rho C_p) + \beta \bullet S_0 \bullet \boldsymbol{FWF} = Q_T + Q_S = Q_B$$



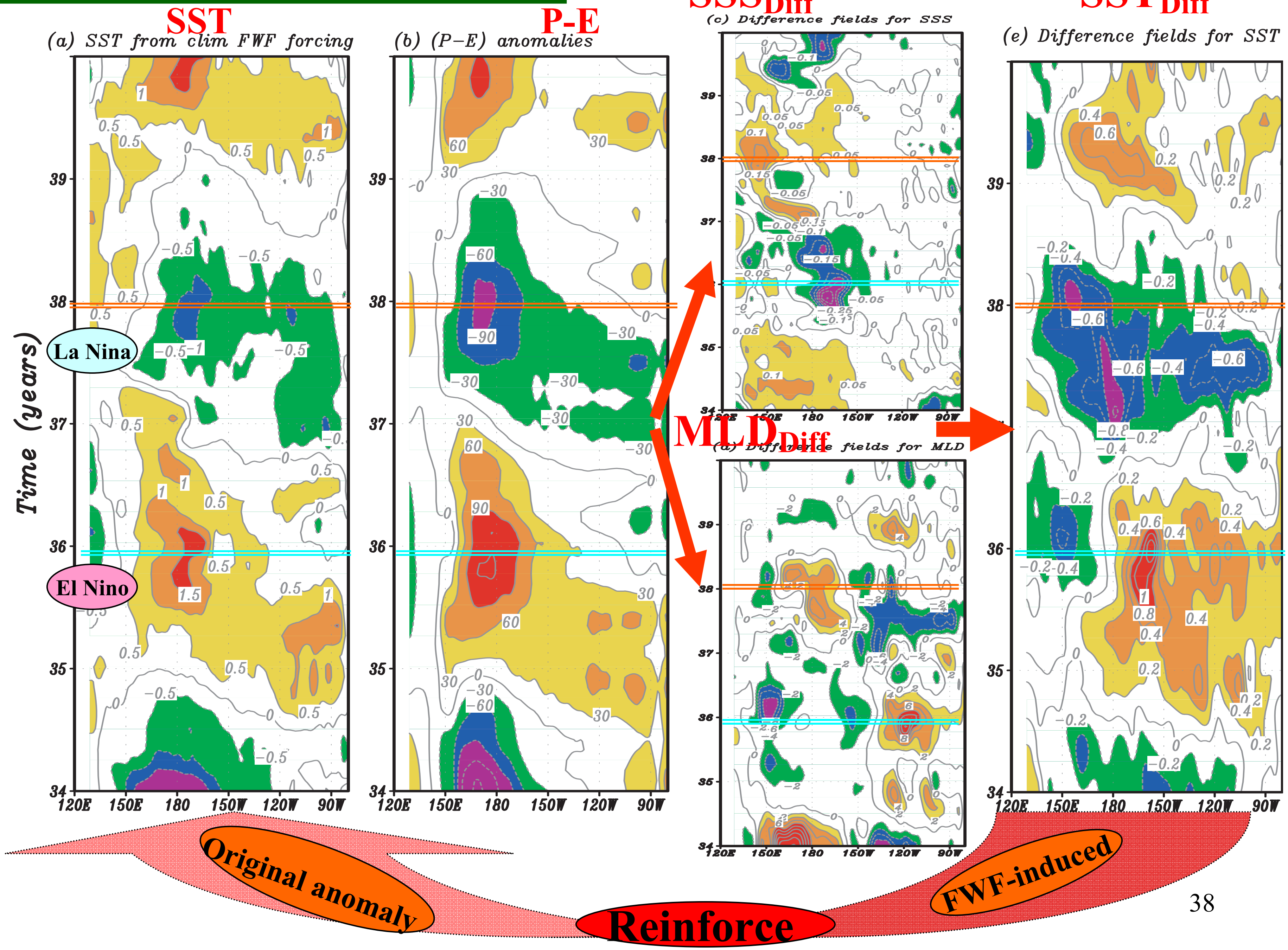
$\alpha_{FWF}=2$ $\qquad Q_T + Q_S = Q_B$

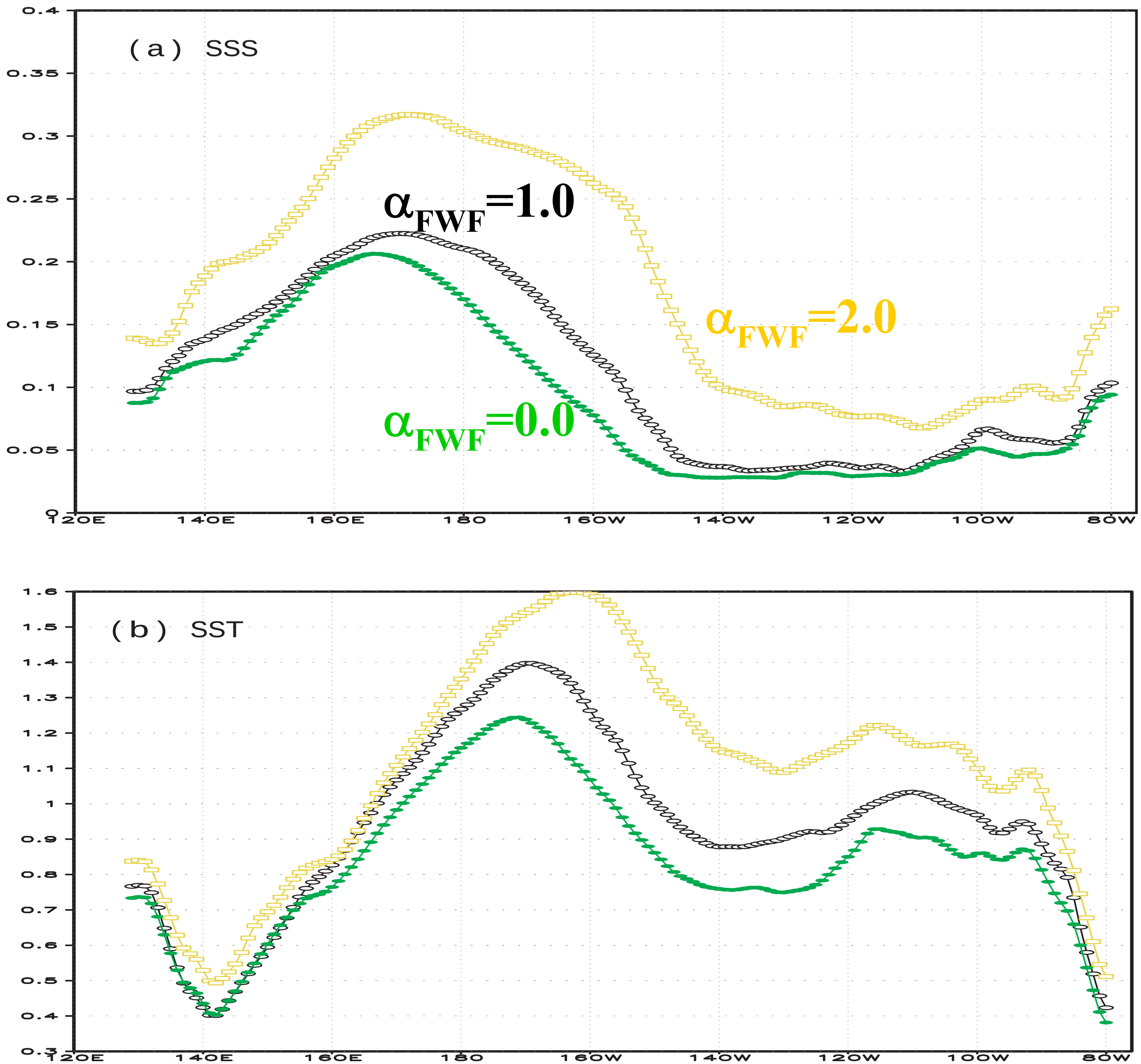


A FWF-induced positive feedback



A FWF-induced positive feedback





(a) SSS
α_{FWF}=1.0
α_{FWF}=2.0
α_{FWF}=0.0
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
120E
140E
160E
180
160W
140W
120W
100W
80W
(b) SST
1.6
1.5
1.4
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
120E
140E
160E
180
160W
140W
120W
100W
80W

The std of selected anomaly fields for α_{FWF} =0.0, α_{FWF} =1.0 and α_{FWF} =2.0.

***Niño4* region**	α_{FWF}= 0.0 (Clim run)	α_{FWF}= 1.0 (Standard run)	α_{FWF}= 2.0 (Enhanced run)
SSS	0.11	0.16	0.28
SST	0.76	0.85	0.97
MLD	5.6	6.7	9.0
τ_x	0.16	0.19	0.23
Q_T	1.49	1.72	1.95
Q_S	0.0	0.65	1.58
Q_B	1.49	1.24	1.08
Niño12 SST	0.53	0.57	0.64
Niño3 SST	0.67	0.76	0.92

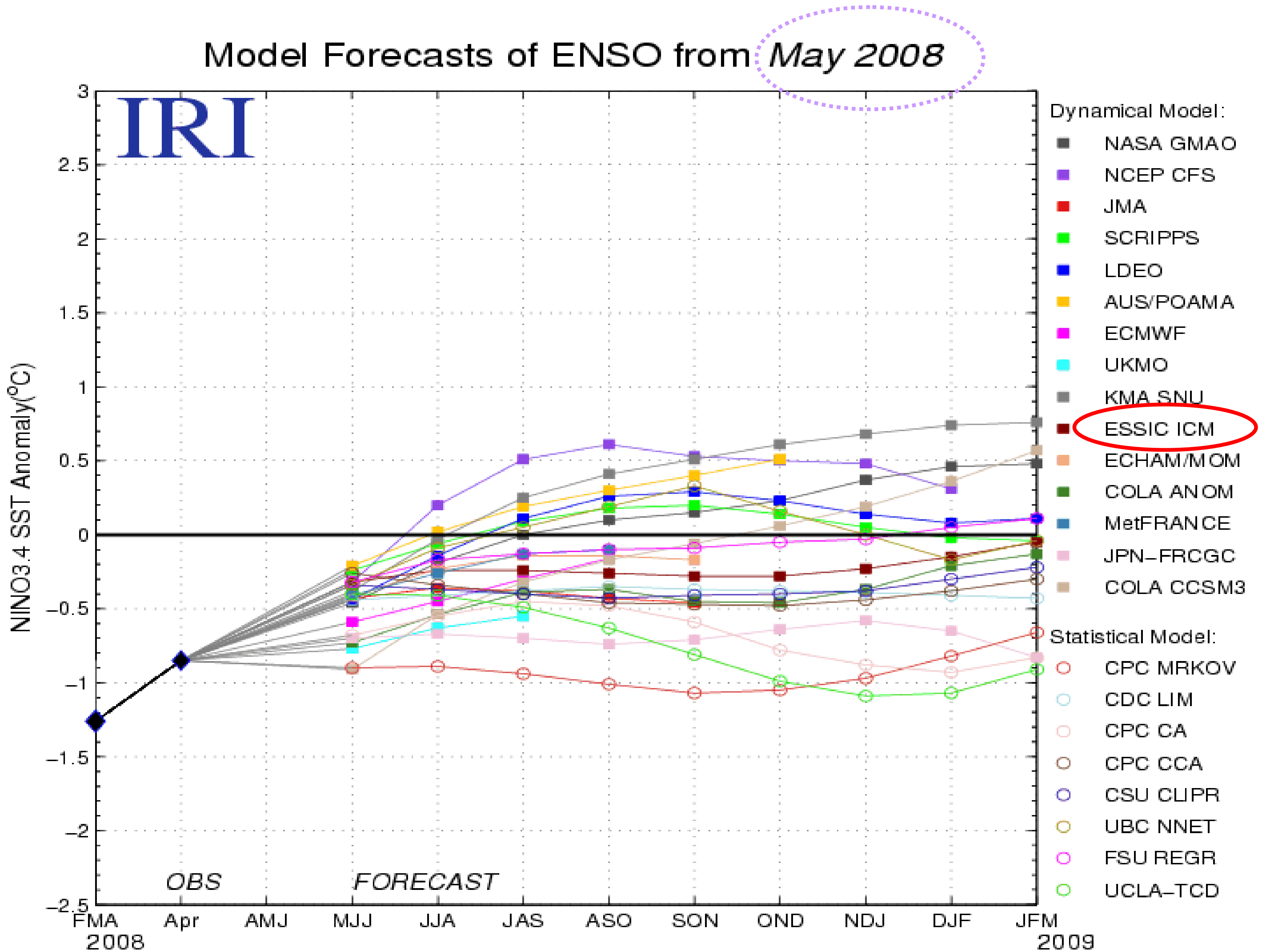
Summary

- **Demonstrate a *positive* feedback induced by FWF;**
- **FWF: compensating effect on Q_T for Q_B;**
- **Different role of FWF vs. heat flux;**
- **Significant effects on interannual variability**

  > 10% differences in SST

  > 20% differences in SSS

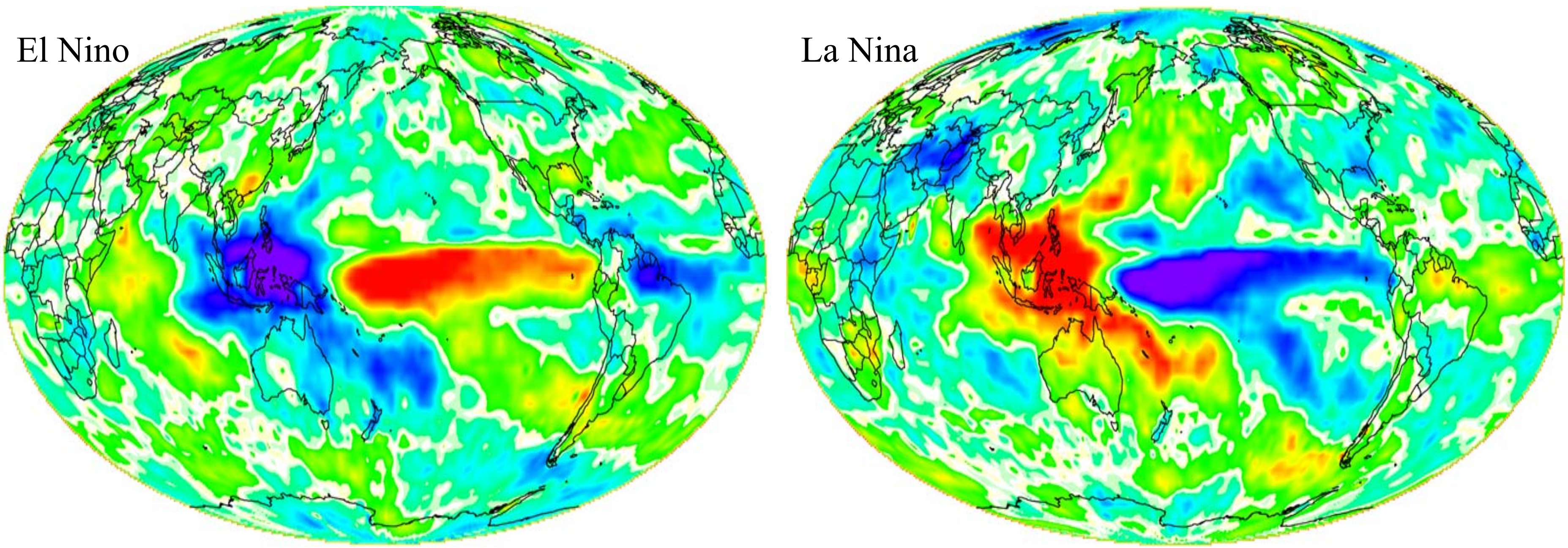
- **FWF is a clear source for model biases**
- **Taking into account this atmos forcing component for better ENSO simulation & prediction**
- **A link between ENSO & global water cycles**



Model Forecasts of ENSO from May 2008
IRI
NINO3.4 SST Anomaly(°C)
3
2.5
2
1.5
1
0.5
0
−0.5
−1
−1.5
−2
−2.5
OBS
FORECAST
FMA
2008
Apr
AMJ
MJJ
JJA
JAS
ASO
SON
OND
NDJ
DJF
JFM
2009
Dynamical Model:
NASA GMAO
NCEP CFS
JMA
SCRIPPS
LDEO
AUS/POAMA
ECMWF
UKMO
KMA SNU
ESSIC ICM
ECHAM/MOM
COLA ANOM
MetFRANCE
JPN−FRCGC
COLA CCSM3
Statistical Model:
CPC MRKOV
CDC LIM
CPC CA
CPC CCA
CSU CLIPR
UBC NNET
FSU REGR
UCLA−TCD

El Nino and La Nina Precipitation Anomaly Patterns

Warm Pacific *Cold Pacific*

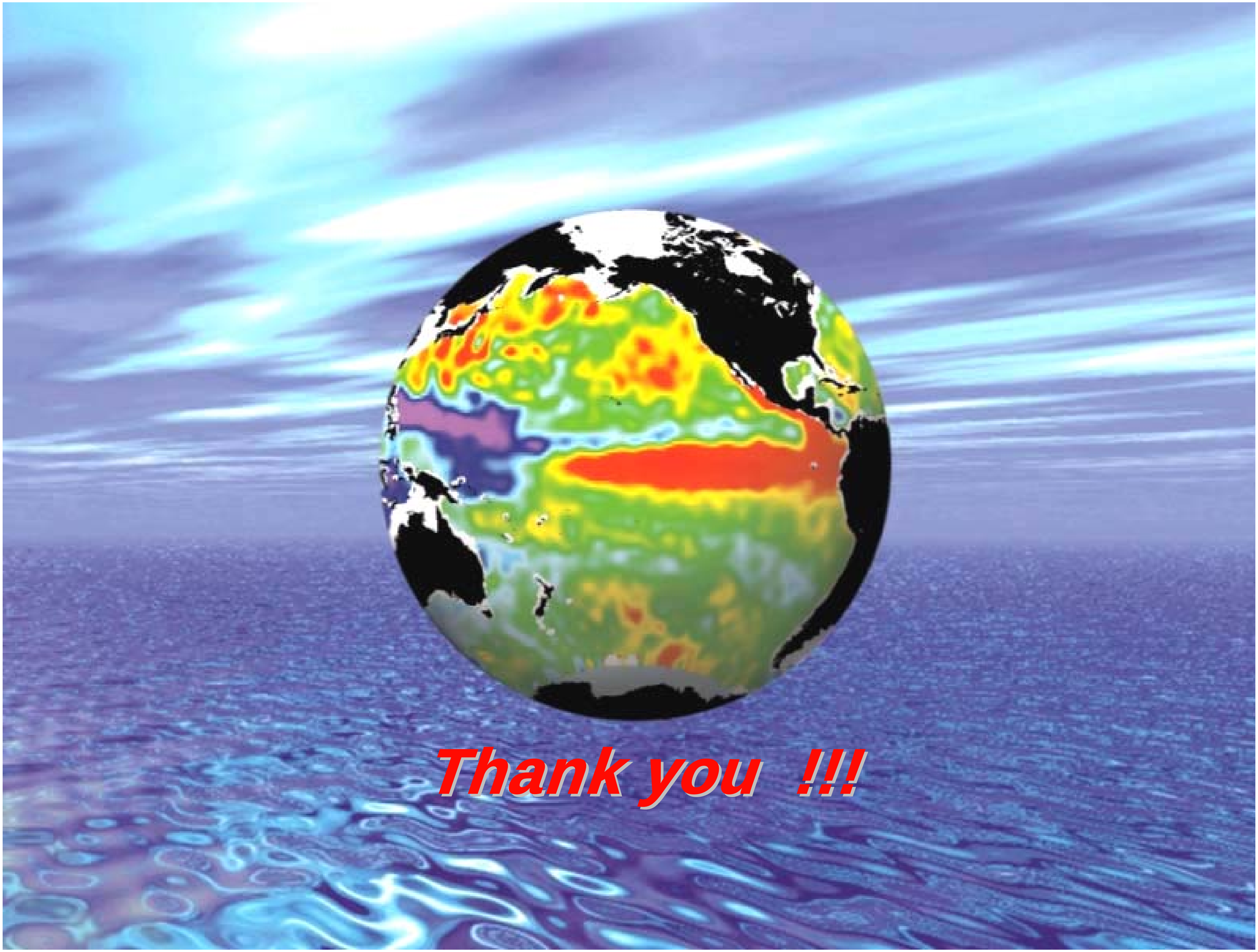


Red: positive precipitation anomalies

Blue: negative precipitation anomalies

(normalized [by mean] anomalies, i.e., σ/μ)

From Dr. Robert Adler (NASA & UMD)


Thank you !!!