Regional Ocean-Atmosphere Feedback in the Eastern Pacific;

Gap Winds,TIWs, and Mesoscale Eddies

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Outline

- Background
- Regional Ocean-Atmosphere Coupled Model
- Research

1. Gap Winds and Air-Sea Interaction

- Wind-induced forcing → Thermocline doming → Suppression of atmospheric deep convection

2. TIWs and Air-Sea Interaction

2.1 Atmospheric Response to TIWs

- Stability adjustment of ABL → Thermal and dynamic response

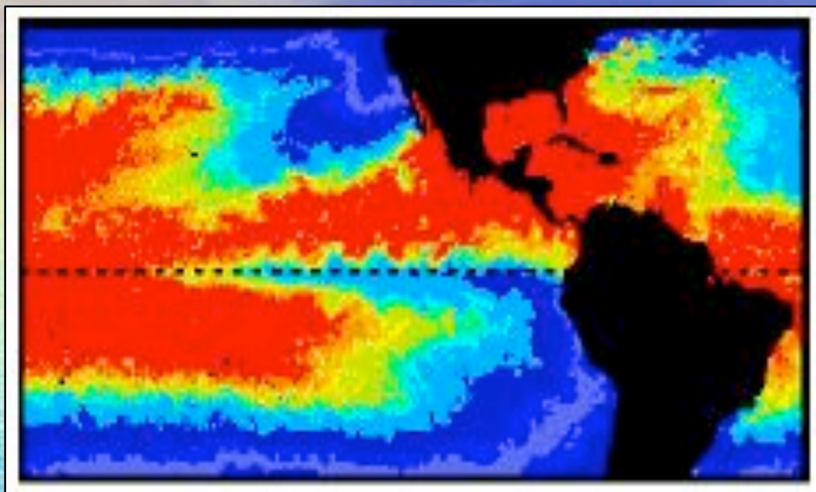
2.2. Effect of Atmospheric Feedback on TIWs

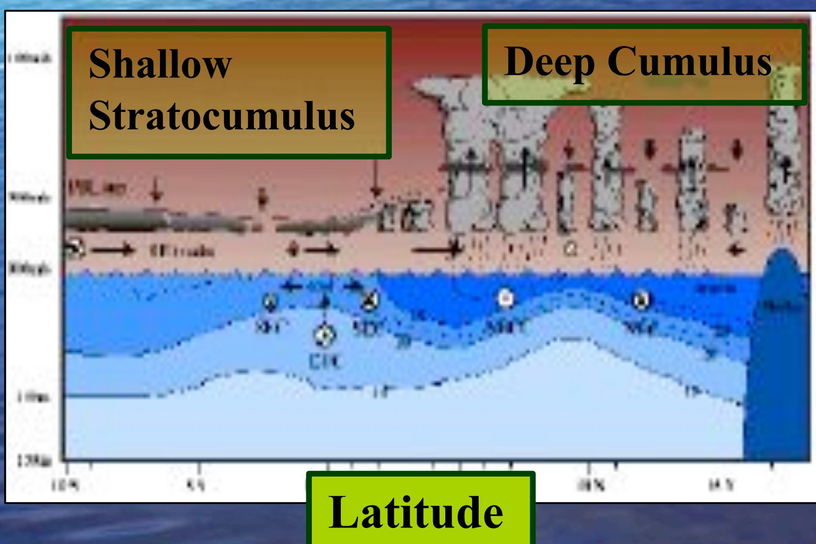
- Amplification (Suppression) of TIWs by dynamic (thermal) feedback;

- Summary

Background

• **Why is air-sea interaction important in the Eastern Pacific?**





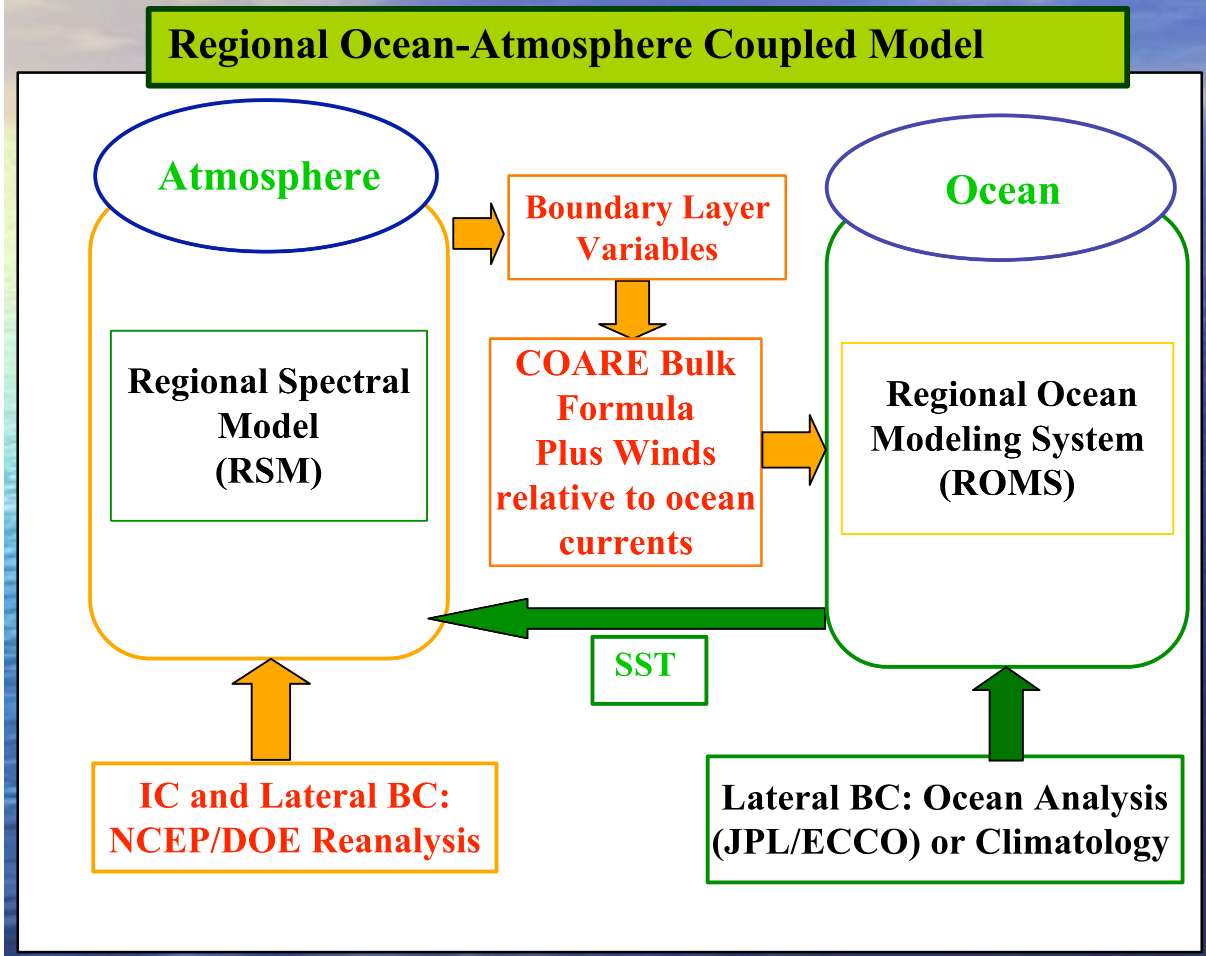
- Important component in large-scale atmospheric and oceanic circulations
- Atmospheric deep convection over the eastern Pacific *warm pool and* Equatorial Current system
- Costal upwelling and equatorial cold tongue
- Equatorial SST front and TIWs
- Influence by land and coastline
- Different cloud response to SSTs

➔ All involve interactions among air, sea and land. Therefore studying nature of such coupling is important for regional climate, and presumably for large-scale as well.

• **This will be perhaps one of only a few numerical studies in the Eastern Pacific using high-resolution coupled model!**

Regional Ocean-Atmosphere Coupled Model

Model and Coupler Descriptions



- Bulk Formula in ABL
- Winds Relative to Ocean

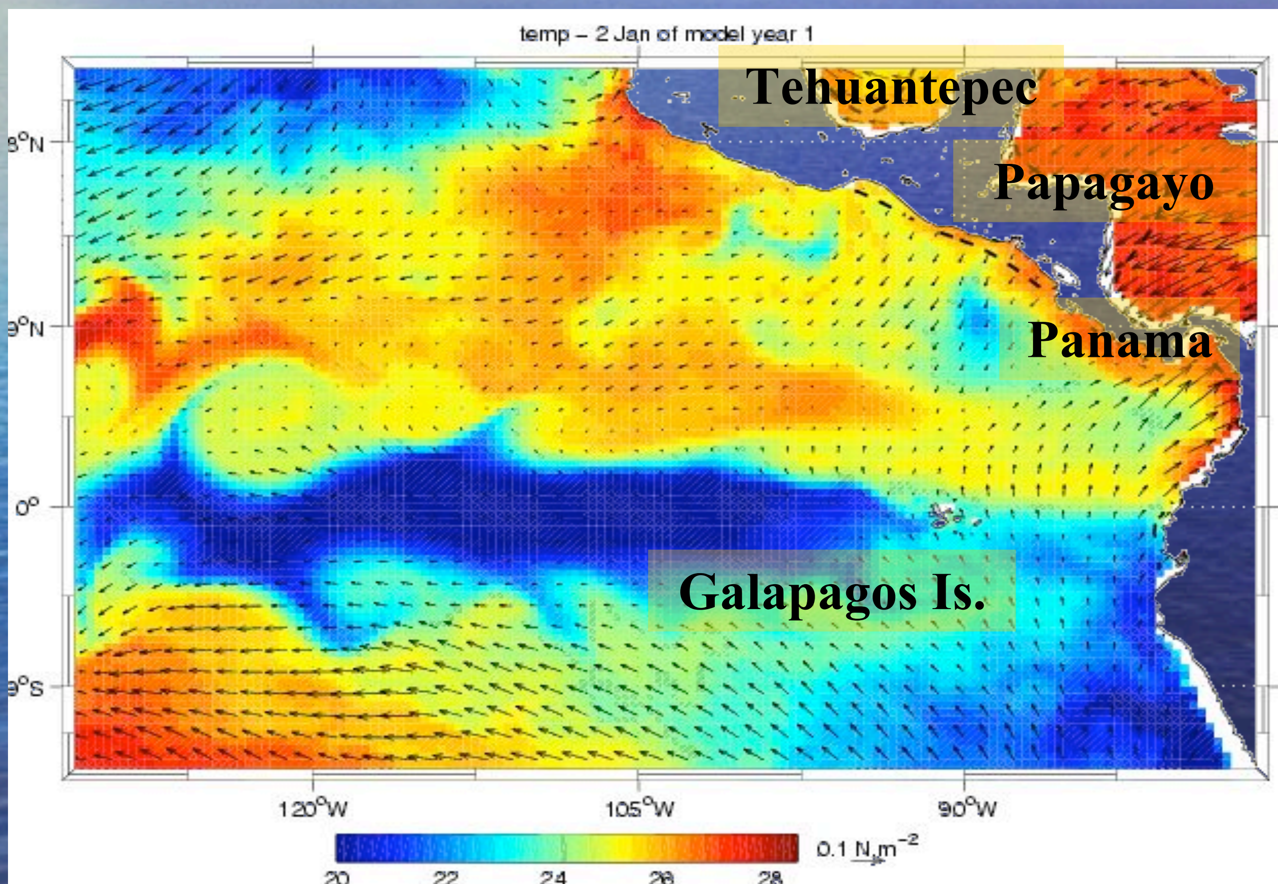
$$\tau = \rho C_d |U_a - U_o| (U_a - U_o)$$

- Sequential Coupling
- Coupling Frequency
  → 3 hourly coupling
  → Daily coupling

Model Domain in the Eastern Pacific

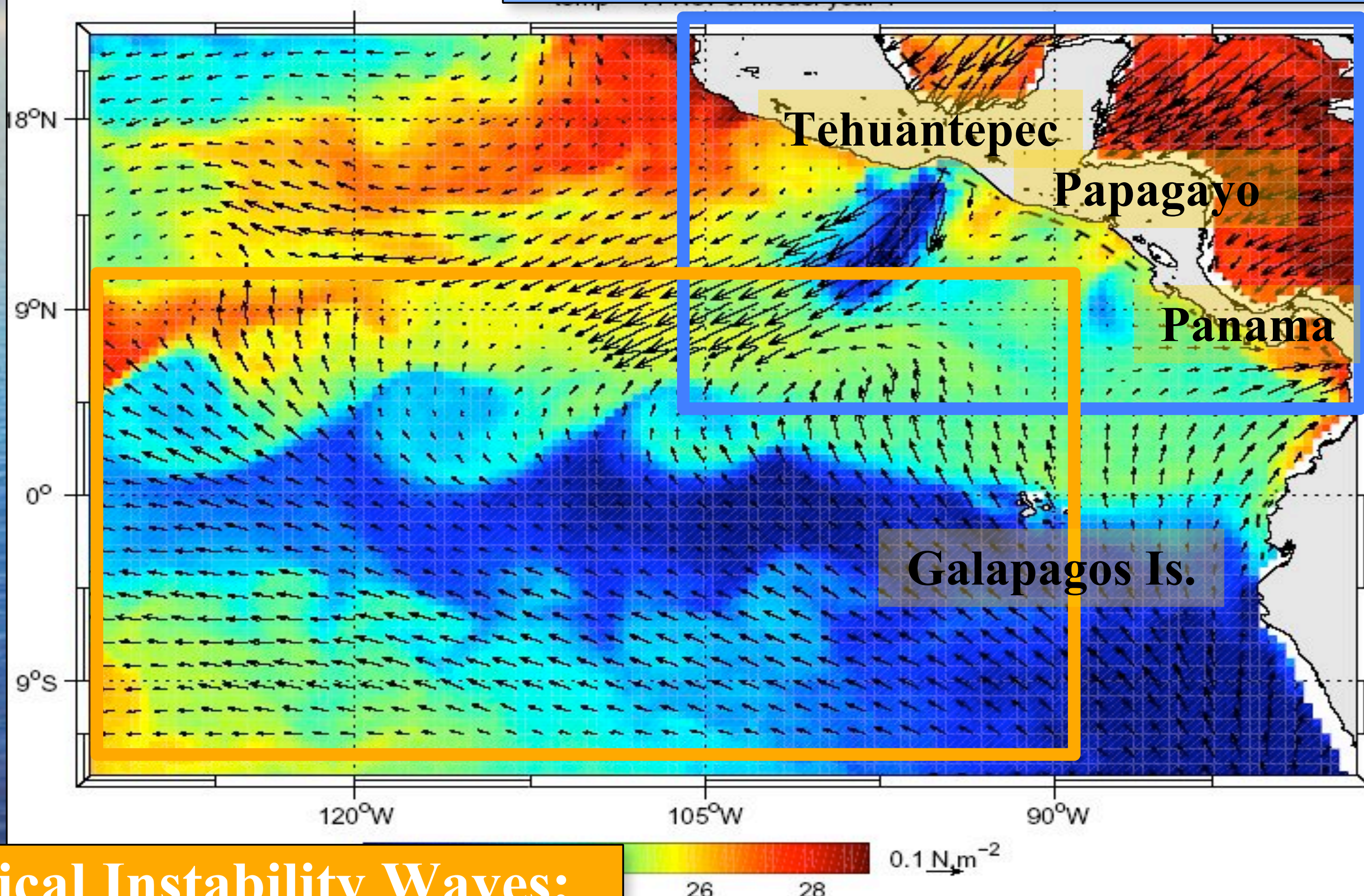
- Eastern Equatorial Pacific Ocean: 45km ROMS + 50km RSM

SST and Wind-stress vector in 1999



Model Domains in the Eastern Pacific (cont.)

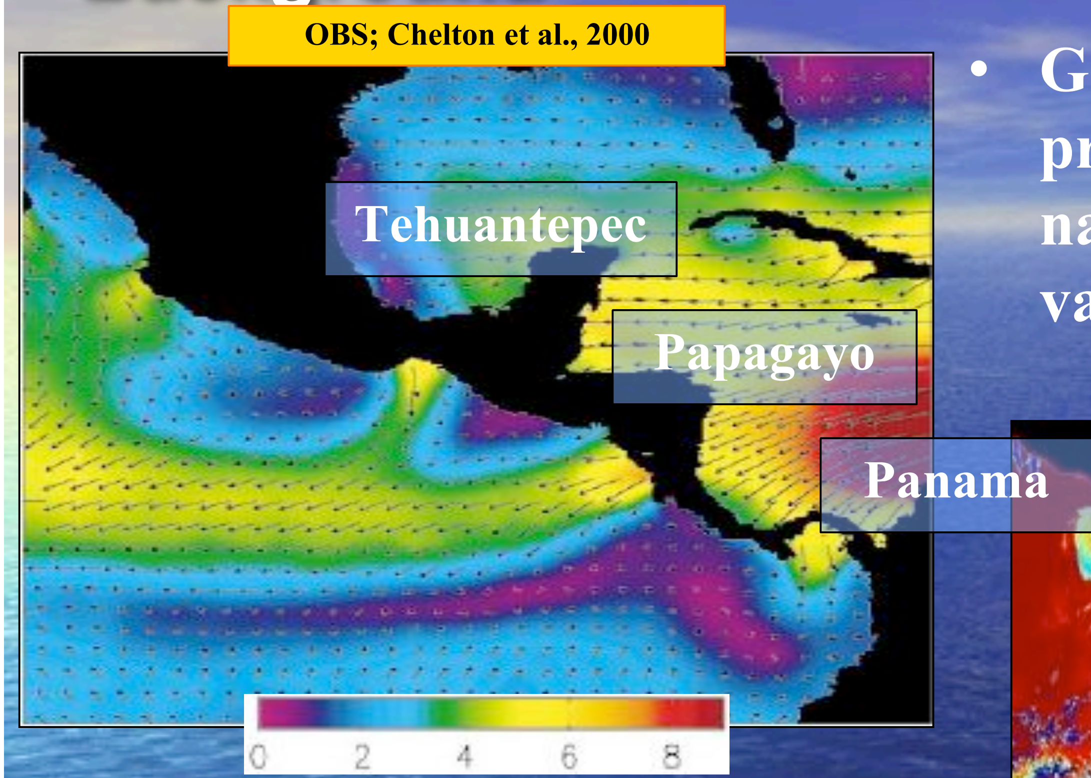
- Central America Gap Winds; 25km ROMS + 28km RSM



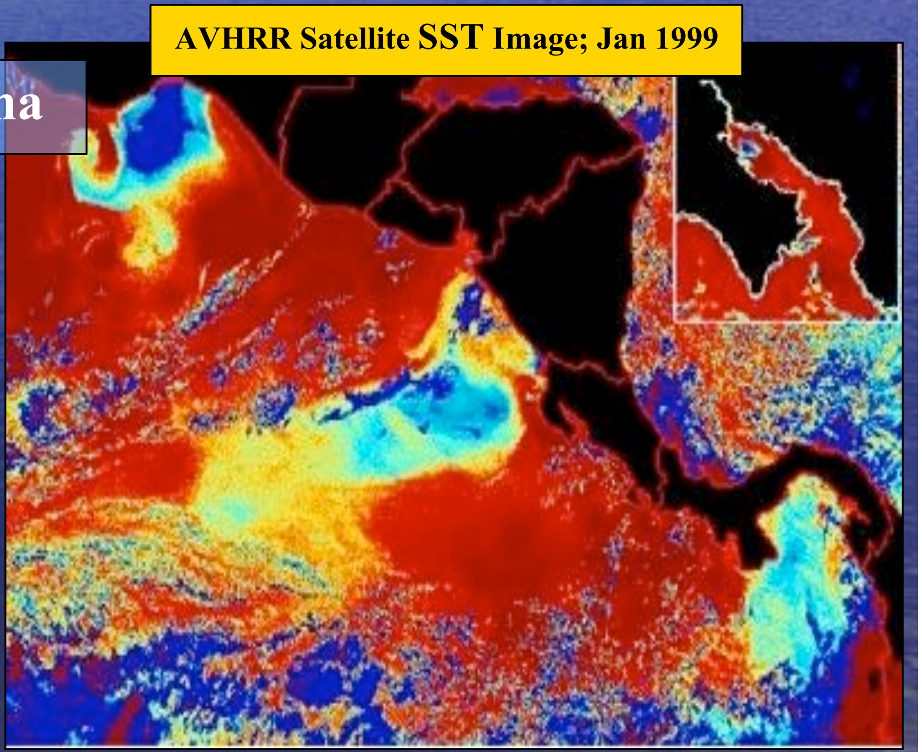
- Tropical Instability Waves; 20km ROMS + 30km RSM

1. Gap Winds and Air-Sea Interactions

Background



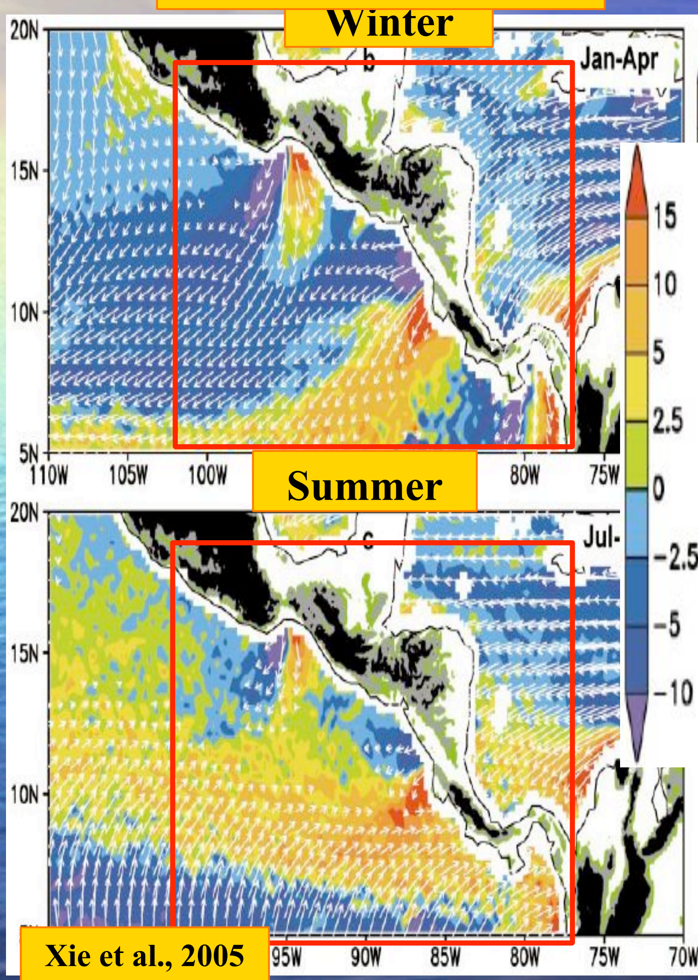
- Gap winds are driven by pressure gradient across narrow gaps or intrinsic variability of trades.



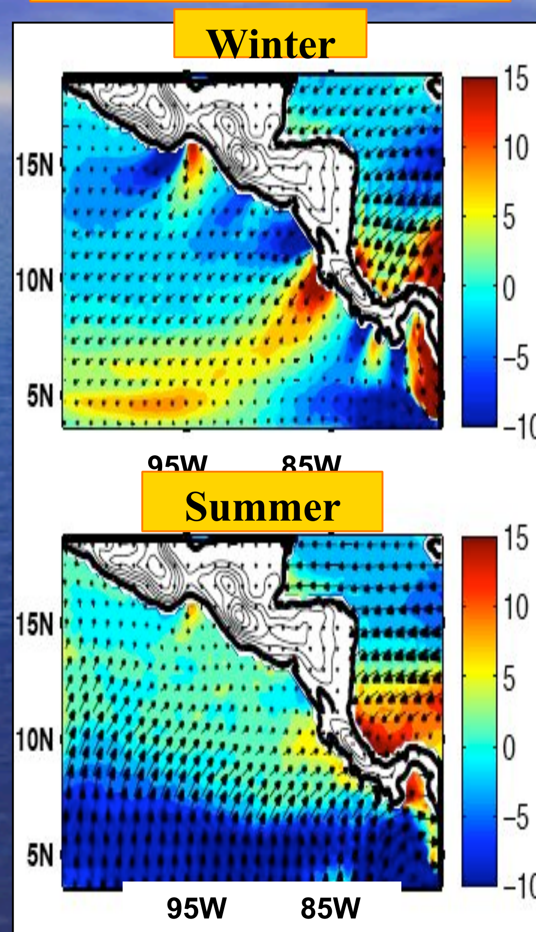
- Gap Winds produces cold tongues due to evaporative cooling and entrainment, plus windstress curl forcing.
- Affect the atmospheric deep convection and precipitation.

Wind Stress and Ekman Pumping Velocity

OBSERVATION



MODEL: 1999-2003



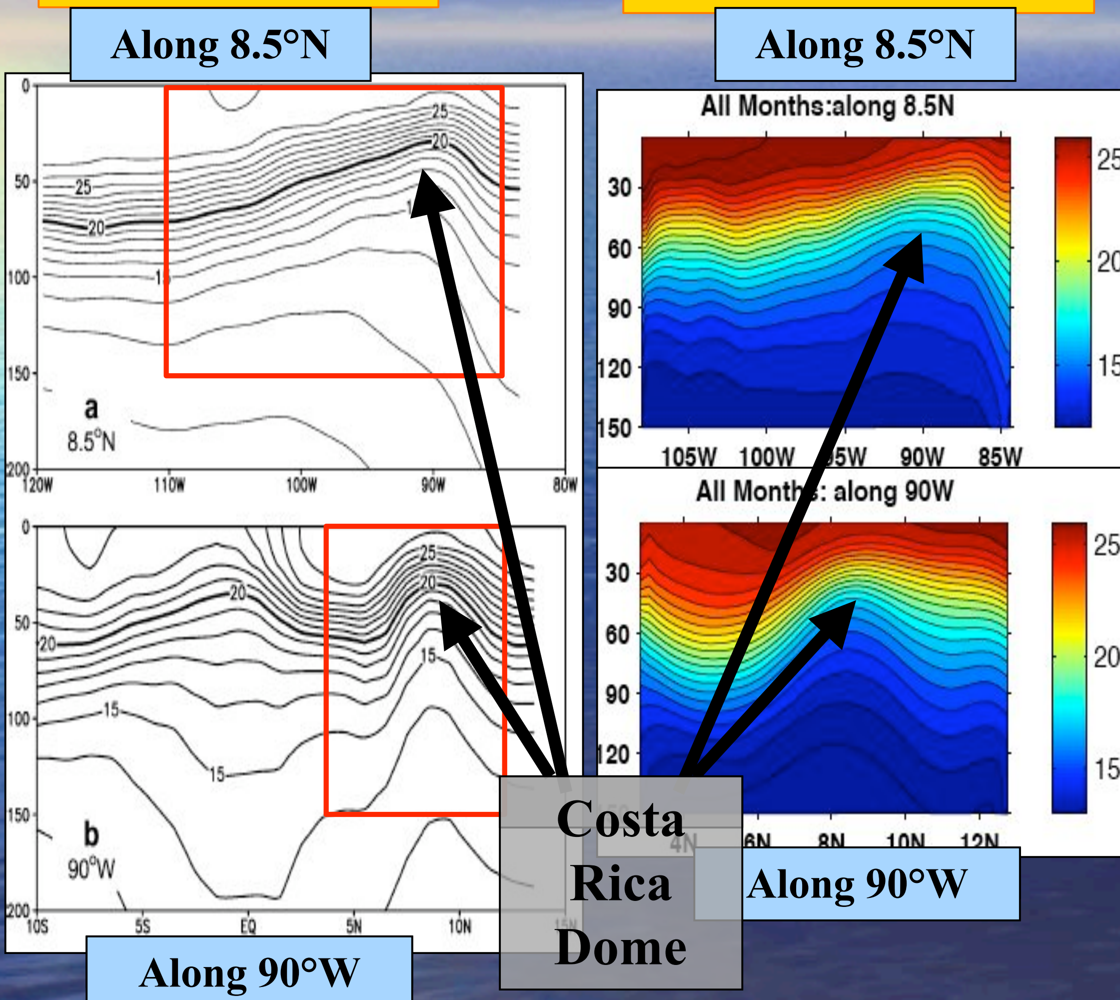
- **Ekman Pumping Velocity Unit : 10^{-6}m/s**
- **Low-level wind jets through mountain gaps**
- Wind-induced vorticity forcing may lead to dynamic response from the ocean thermocline.

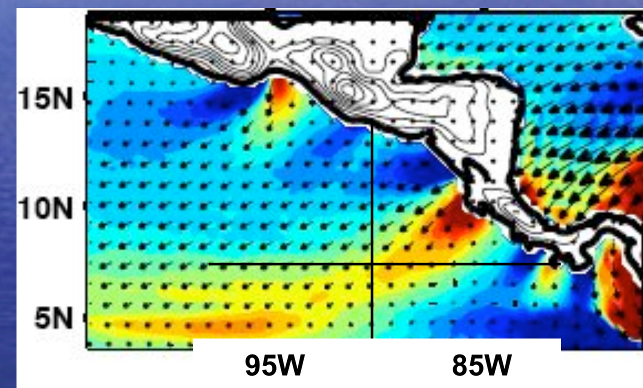
Thermocline Doming by Ekman Forcing; Costa Rica Dome

OBSERVATION

MODEL: 1999-2003

$$h - h_E = -\frac{f^2}{g'H\beta}\int_{x_E}^{x} w_e \, dx,$$

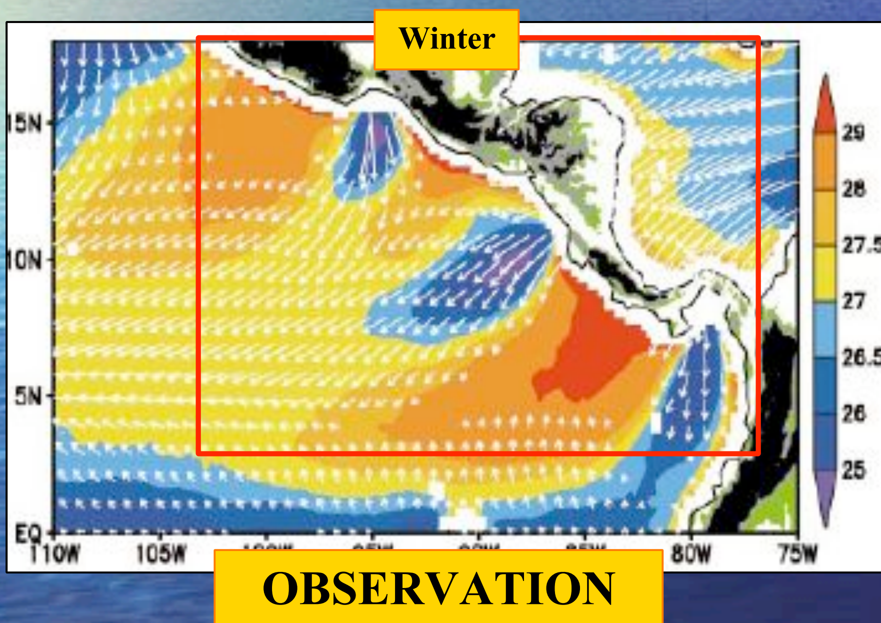


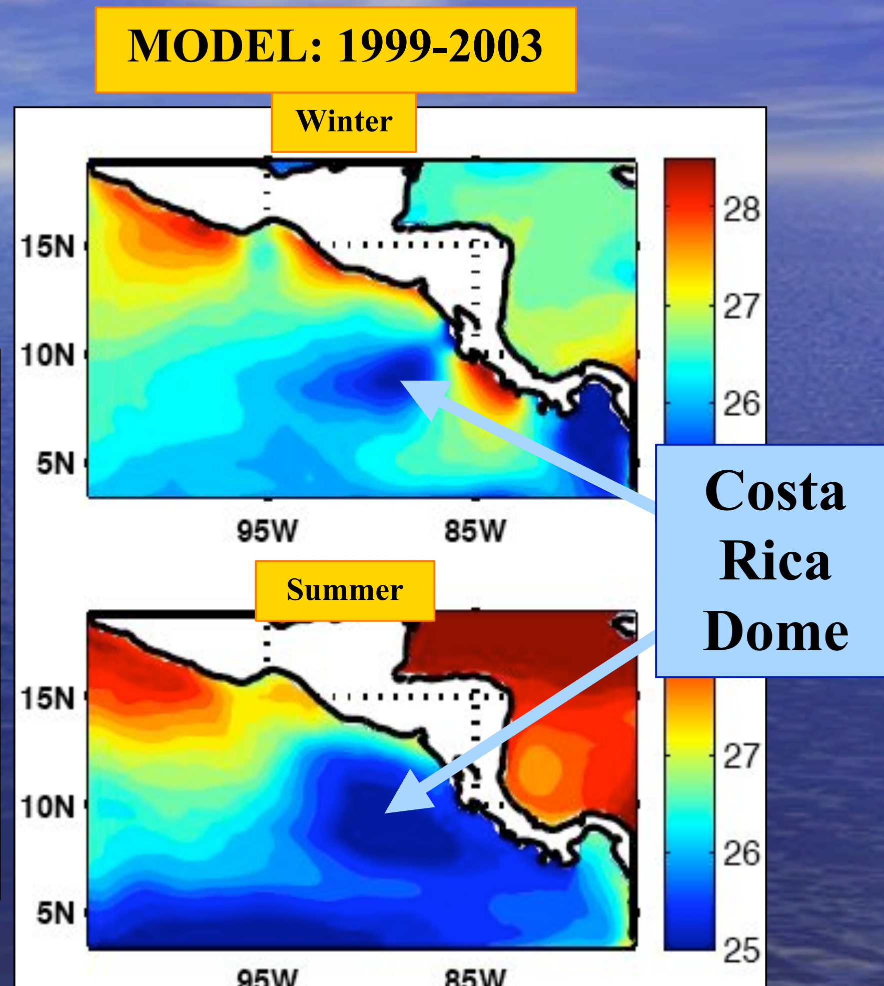


- Ekman upwelling causes shoaling of thermocline, which helps further cool SST by gap-winds and supports rich fishery.
- MLD is ~10 m and thermocline is ~30 m deep over Costa Rica Dome, both in the obs. and model.

SST: Response to Gap Winds

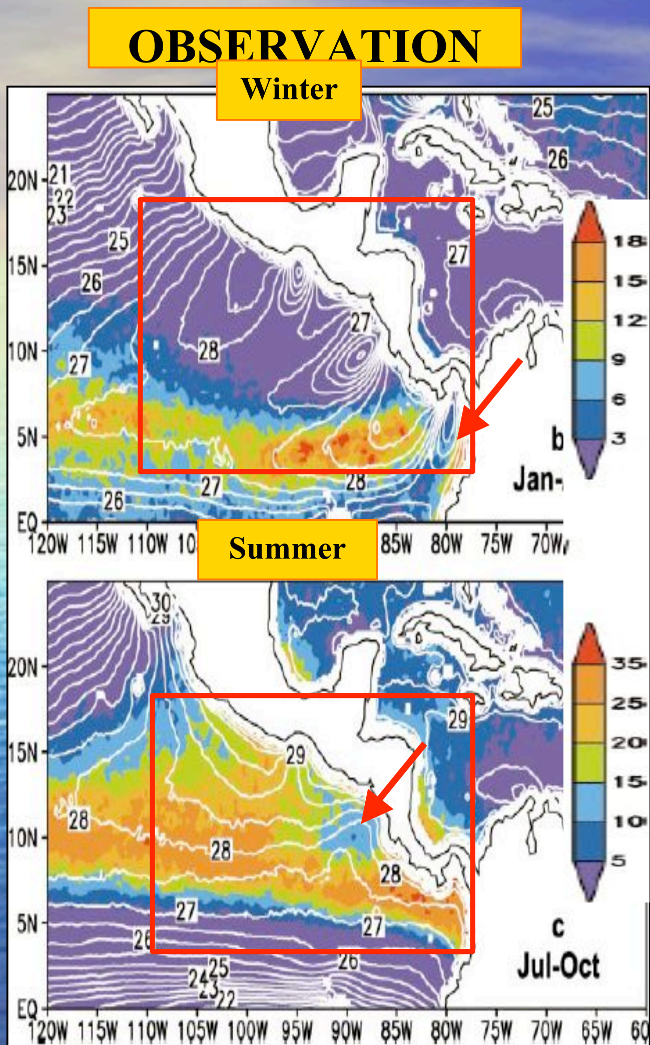
- Cold tongues off the major mountain gaps (due to wind-induced mixing, evaporative cooling, and Ekman dynamics)



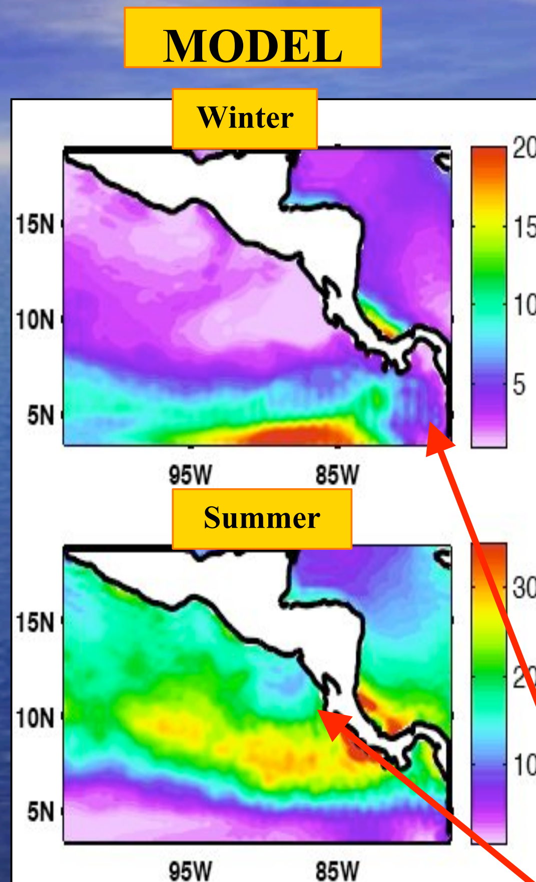


- Model's cold bias over the Costa Rica Dome

Rainfall: Suppression of Precipitation by Eddies



Xie et al., 2005



- Costa Rica Dome and cold tongue by gap winds suppress atmospheric deep convection and precipitation, and shifts ITCZ southward (Xu et al., 2005)

Region of rain deficit within ITCZ

Summary of Part 1

- Model reproduces observed mean structure and seasonal variability of gap winds and their influences on upper ocean topography as in Xie et al. (2005).

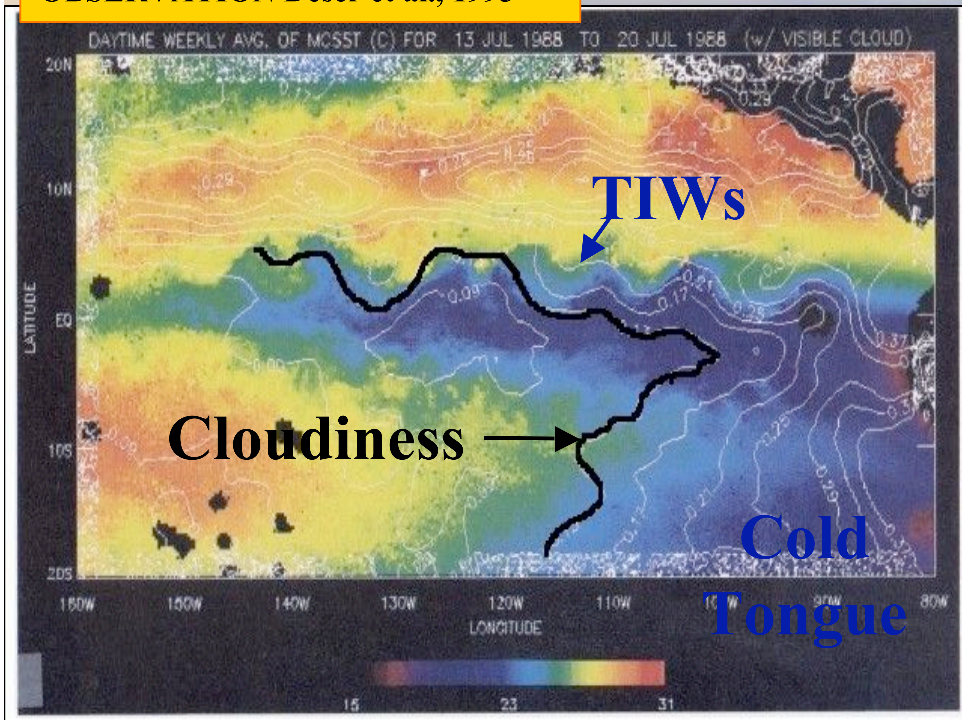
- Shoaling of thermocline and colder SST over Costa Rica Dome result in suppression and displacement of atmospheric deep convection and rainfall (Xie et al.(2005), Xu et al.(2005)).

- Questions;
- How important is this impact on ITCZ in regional climate?
- What is the influence on generation and migration of hurricanes?

2. Response and *Feedback* of ABL to SST by TIWs

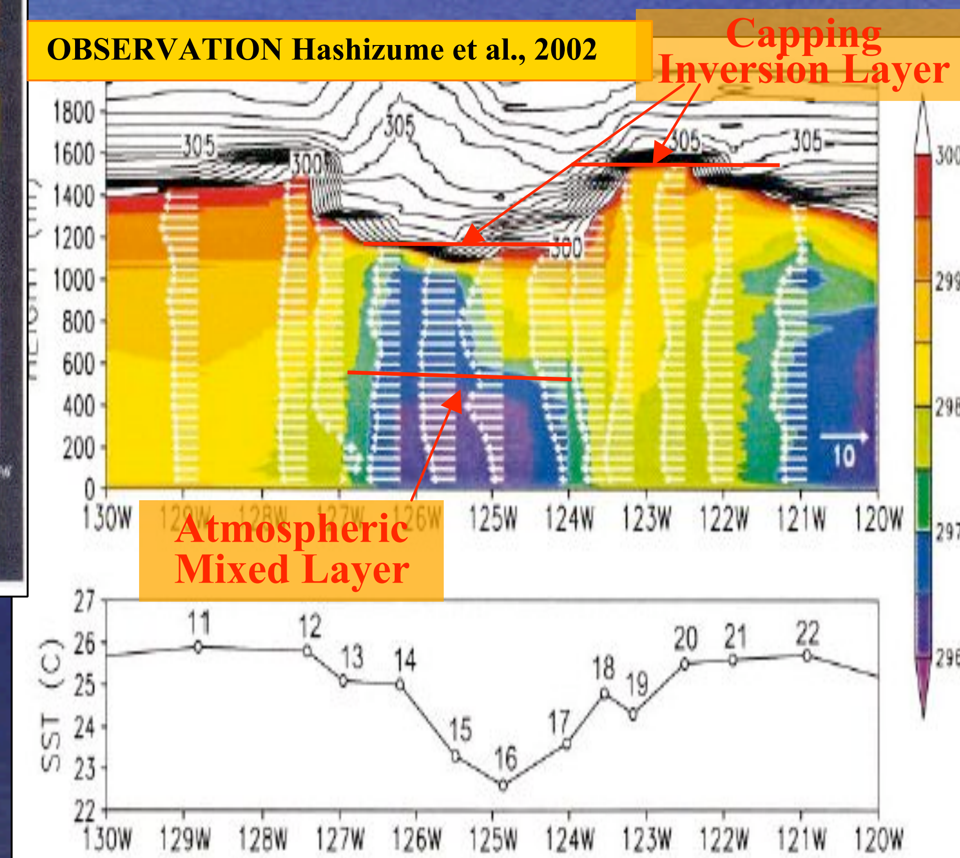
Response of ABL to SSTs
Background

OBSERVATION Deser et al., 1993



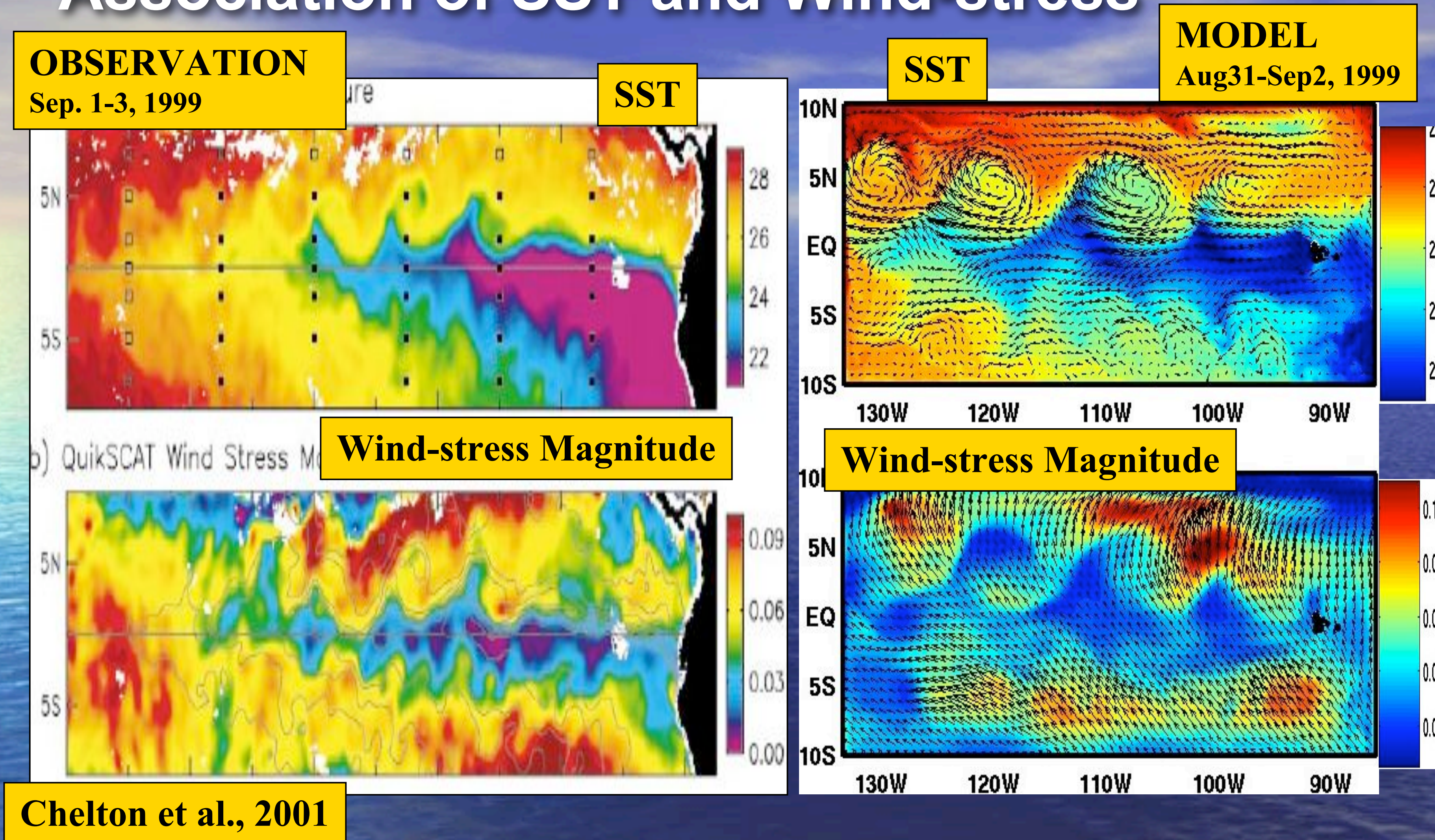
- Warm Water: Stronger Surface Winds
- Cold Water: Weaker Surface Winds

OBSERVATION Hashizume et al., 2002



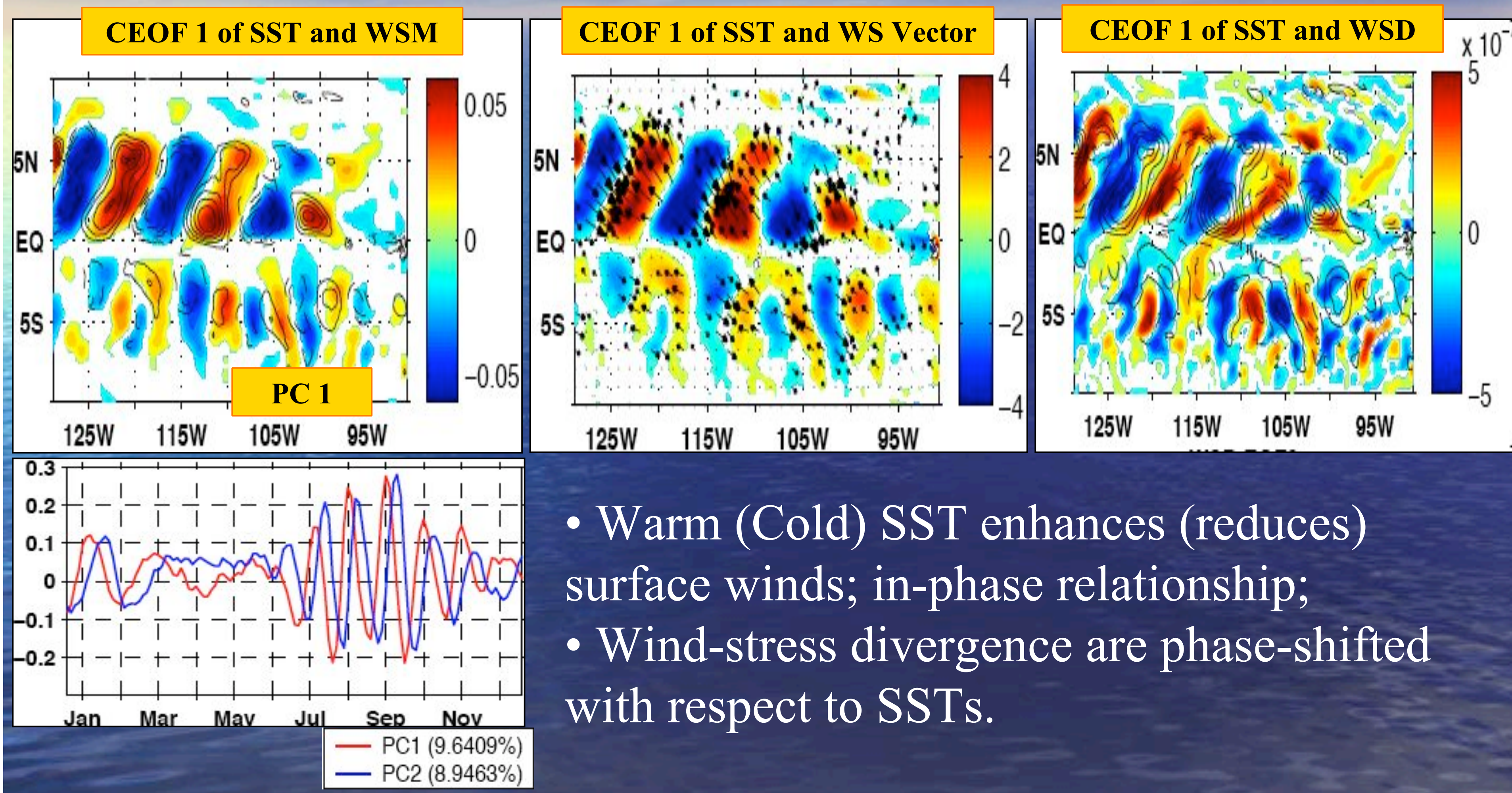
- Warm ridge ~ More Cloudiness
- Cold Trough ~ Less Cloudiness

Association of SST and Wind-stress



- Winds respond to SST by TIWs with similar spatial and temporal scales.

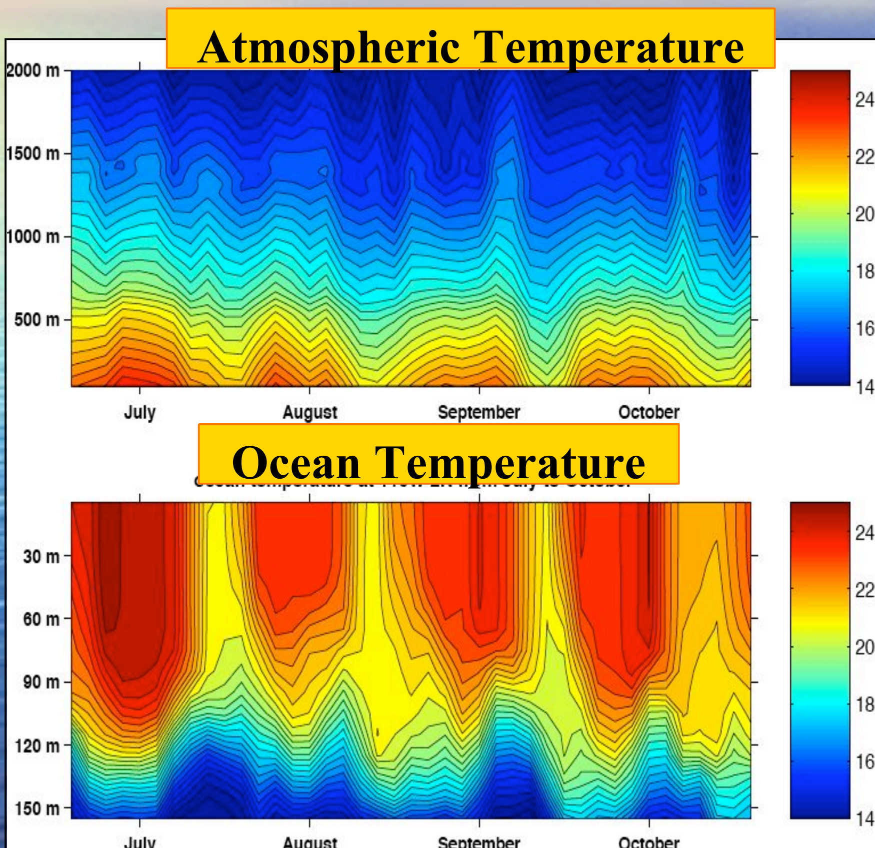
Temporal/Spatial Associations:
Combined EOFs of SST and ABL flux



- Warm (Cold) SST enhances (reduces) surface winds; in-phase relationship;
- Wind-stress divergence are phase-shifted with respect to SSTs.

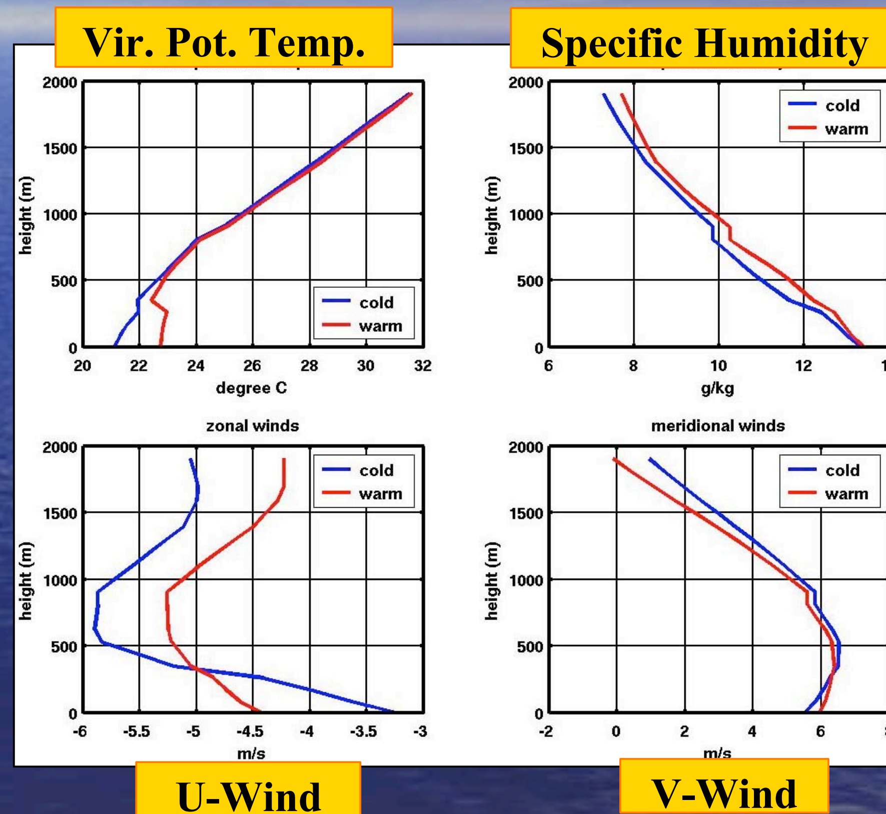
Stability Adjustment of ABL by TIWs

Temperature at 110°W, 2°N
July - October, 1999



• Stronger stratification of ABL over cold water

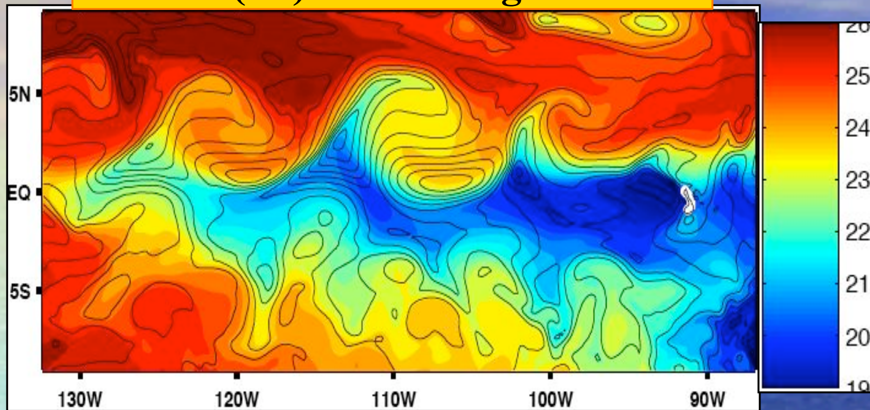
Composites from
September 2 - 18, 1999;
Warm Phase: 173, Cold Phase: 217



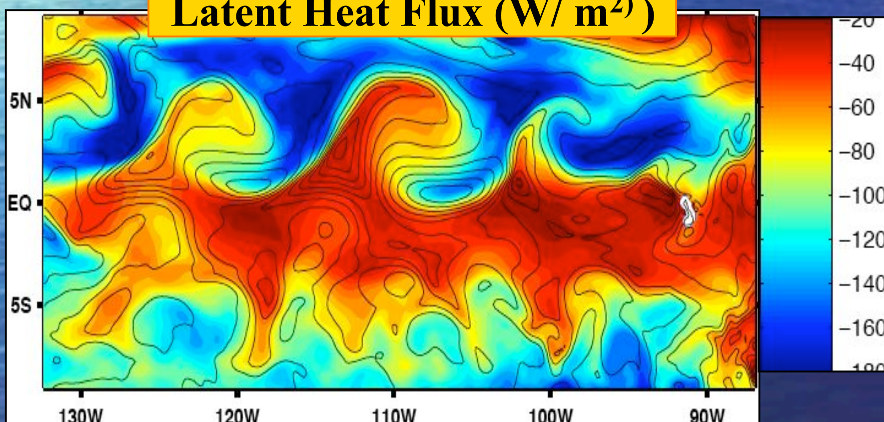
• Weaker stratification of ABL below 400m

Response from thermal state of ABL; Combined EOFs of SST and Latent Heat-flux

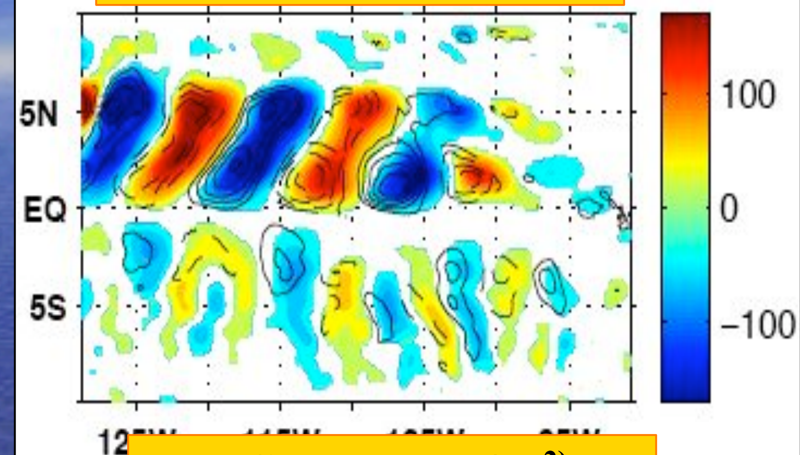
SST (°C): Jul31-Aug2 1999



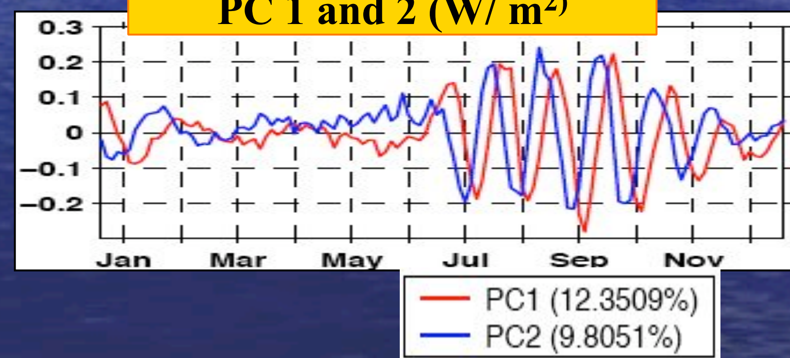
Latent Heat Flux (W/ m^{2}))



CEOF 1 of SST and LH

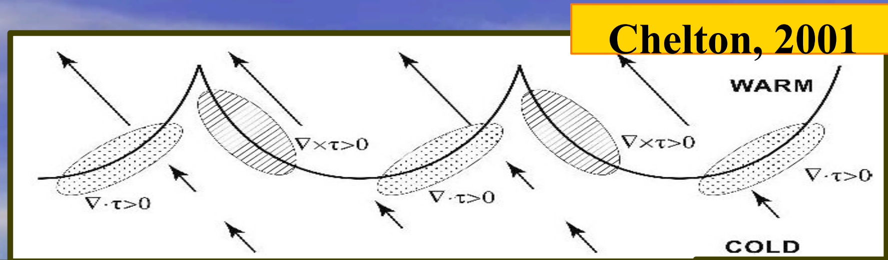


PC 1 and 2 (W/ m^{2})

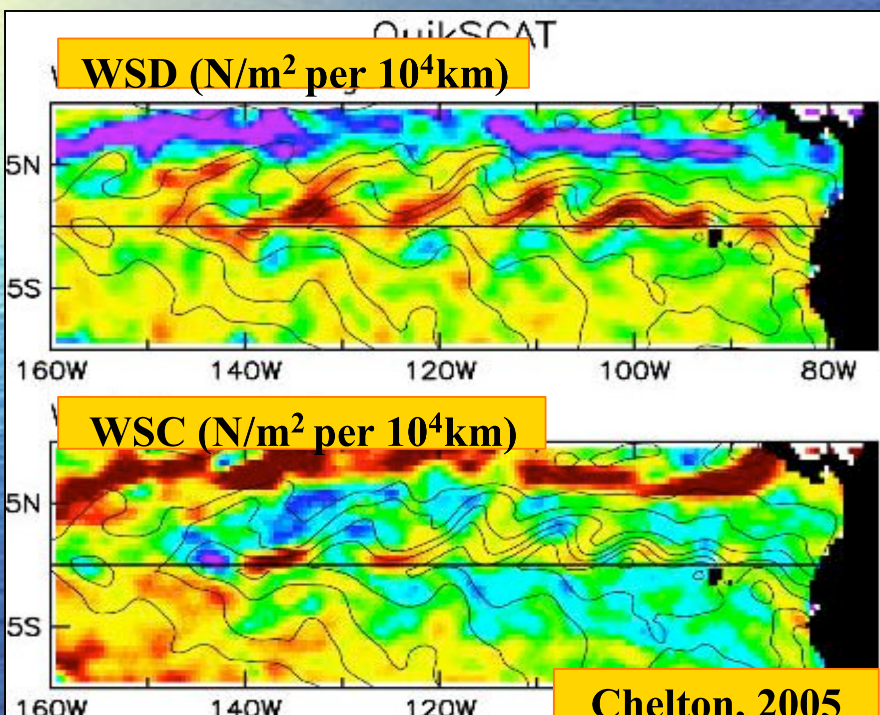


- Latent heating flux (and sensible heat flux) appear to dampen the growth of TIWs; **negative feedback** by heat-flux (Xie et al. 2004, Chelton et al., 2001, Liu et al., 2000).

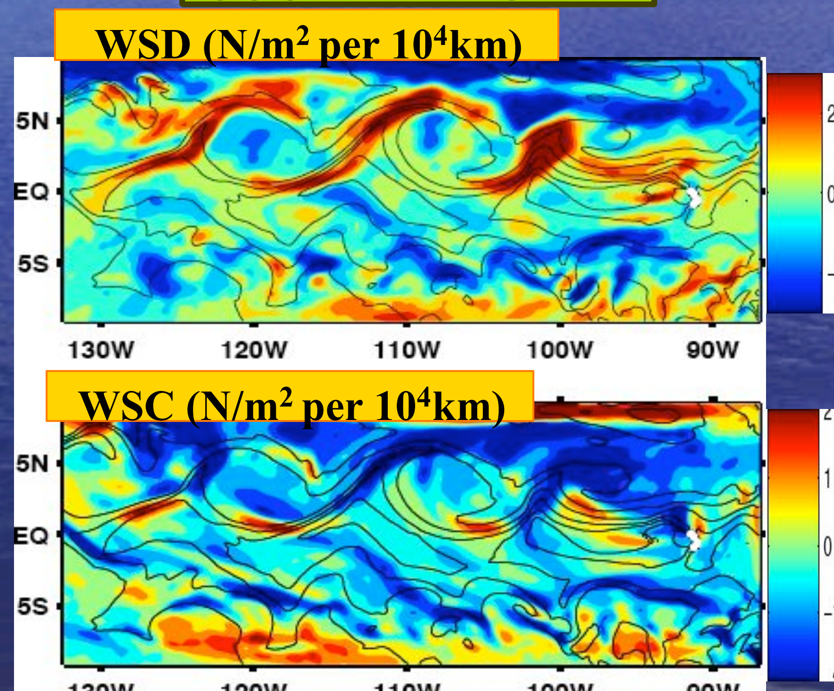
Dynamic Response of ABL to TIWs



OBSERVATION



COUPLED MODEL



- WSC/WSD according to the alignment of wind-vector and isotherm.
- What would be the **dynamic feedback** on to TIWs; positive? negative?

Atmospheric Feedback to Mesoscale Stability

- **Question still remains;**

What are the effects of atmospheric FEEDBACK on to TIWs?

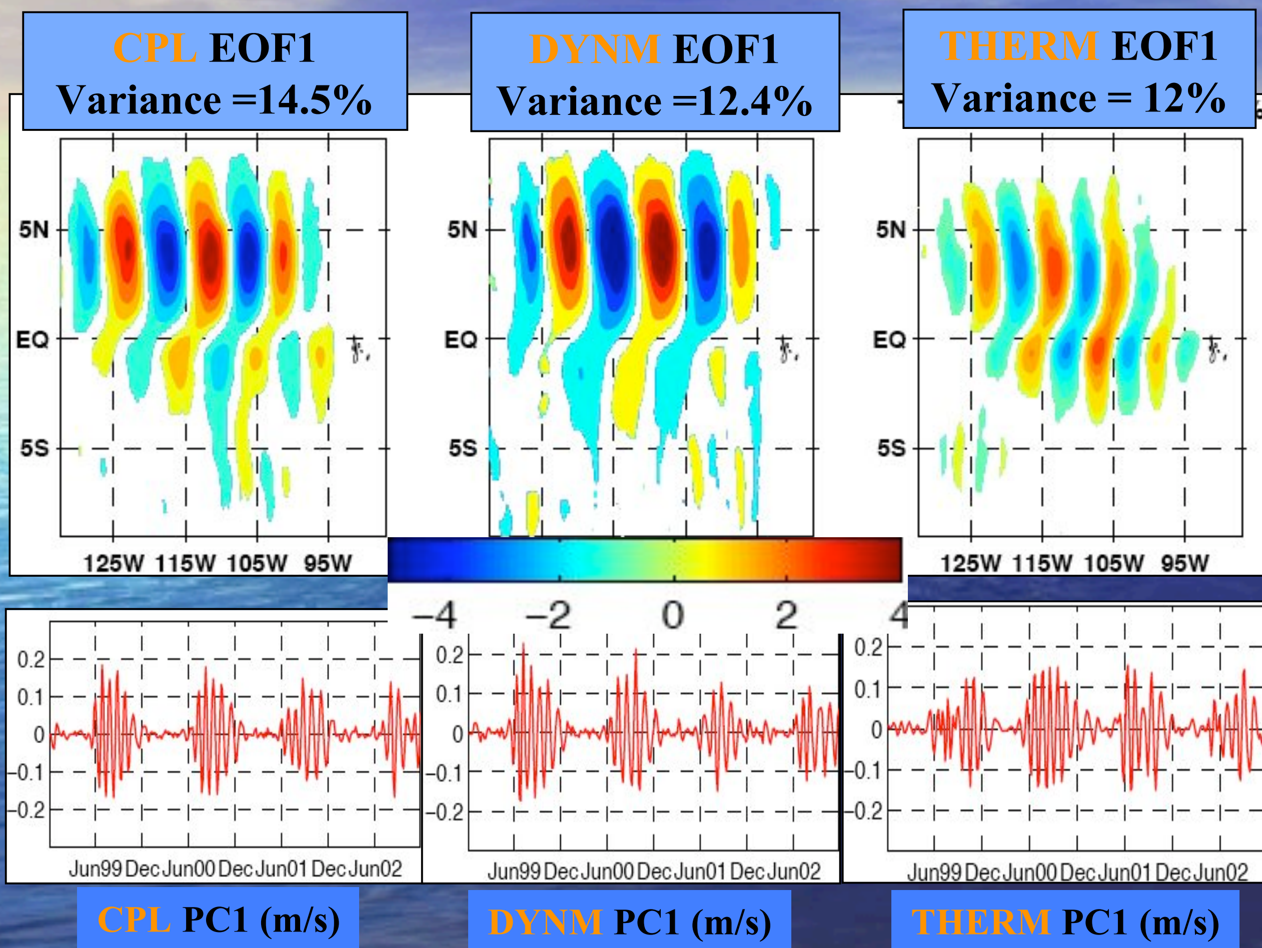
Additional Experiments: 1999-2003

1. **DYNM**: **Coupled Wind-stress** + Climatological heat-flux
2. **THERM**: Climatological Wind-stress + **Coupled Heat-flux**
3. **CPL**: **Coupled Wind-stress** + **Coupled Heat-flux**

- Climatological flux: Southampton Oceanography Centre (SOC) surface climatology based on ship data

Atmospheric Feedback to Mesoscale Stability;

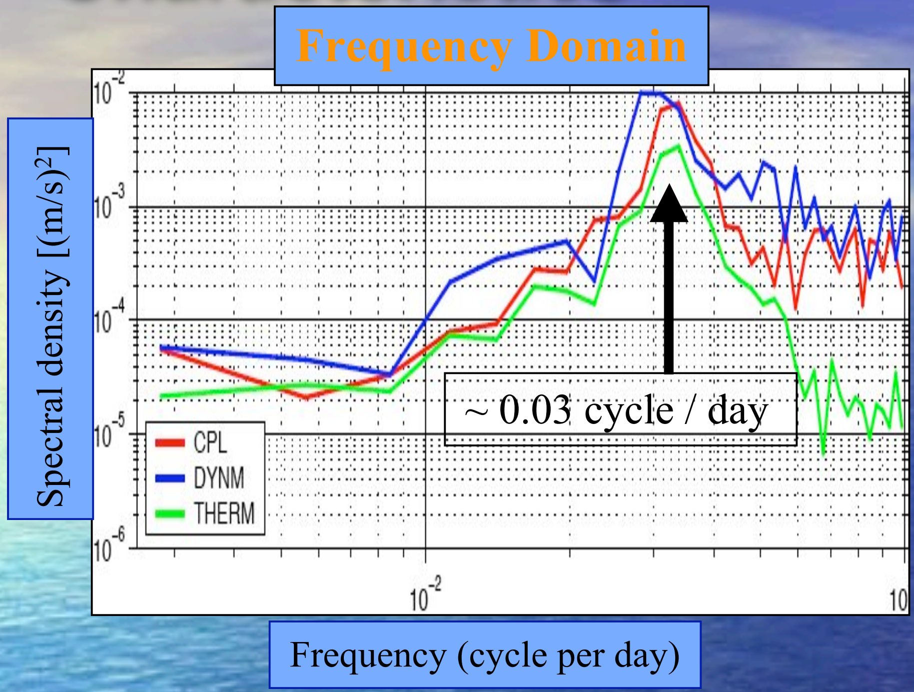
Meridional Surface Current (m/s)

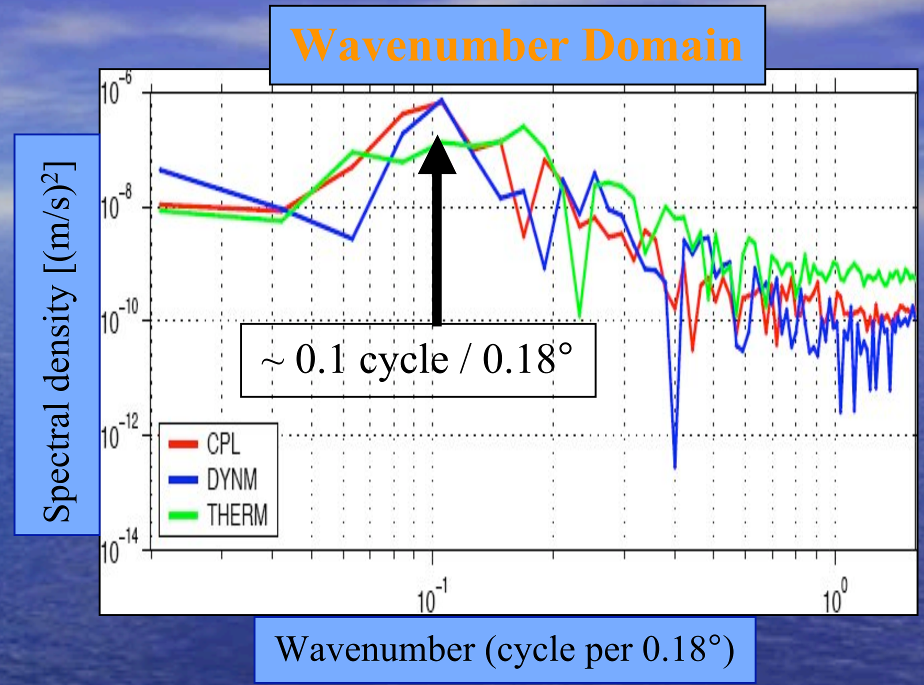


- Heat-flux dampens TIWs; Negative Feedback; weaker TIWs (30%) .
- Dynamic forcing amplifies TIWs; Positive Feedback; 40% stronger TIWs.

- Beside amplitudes, atmospheric feedback changes wavenumber-frequency characteristics of TIWs.

Changes in wavenumber-frequency Characteristics





- Wind-forcing ➔ Frequency (Period)
- Heat-flux ➔ Wavenumber (Wavelength)

	Period (day)	Wavelength (° Longitude)	Phase Speed (m/s)
CPL	30 (30)	11 (10)	0.5 (0.3)
DYNM	36 (32)	11 (11)	0.4 (0.4)
THERM	30 (29)	7 (9)	0.3 (0.3)

Summary of Part 2

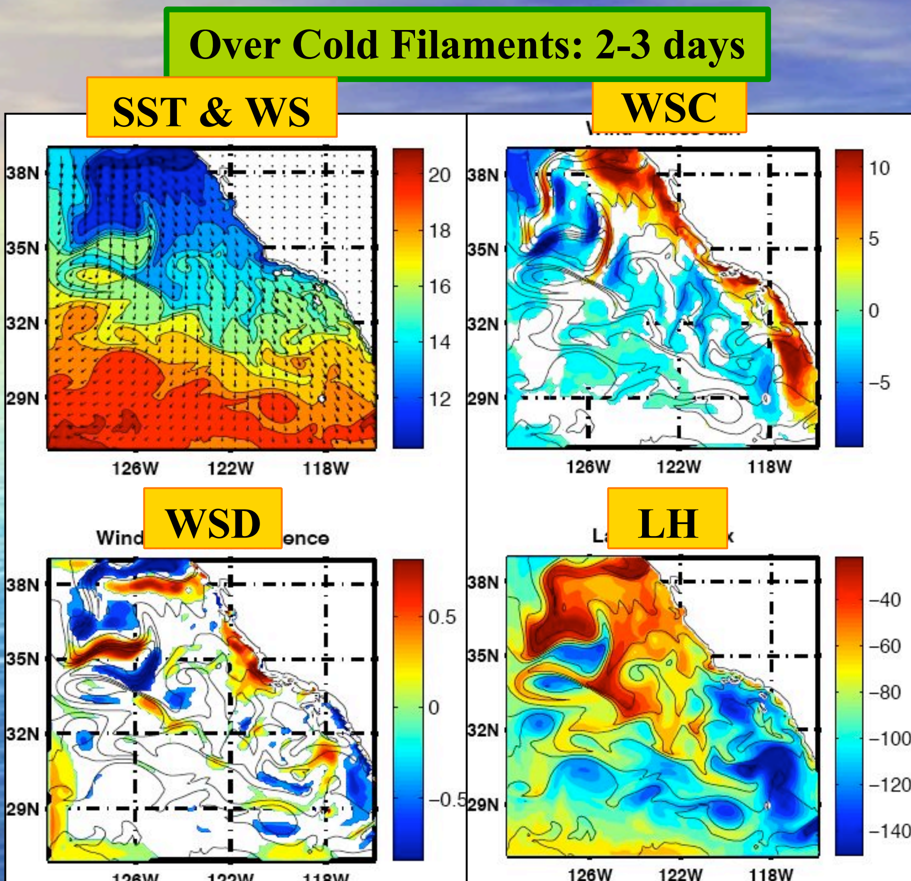
- **Coupled model captures an observed association between undulating SST by TIWs and ABL.**

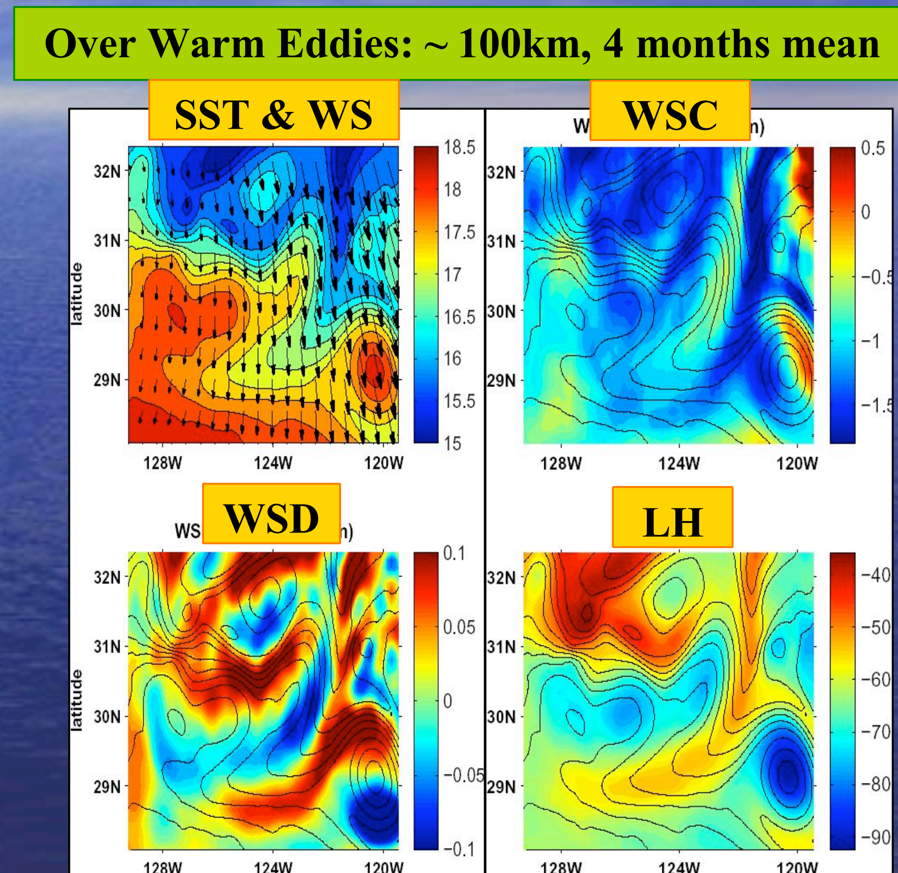
1. Warm SST produces weak stratification within the ABL, enhancing vertical turbulent mixing of momentum and moisture, and thus increase surface winds (Wallace et al.), Sc cloudiness (Deser et al.), and turbulent flux (Thum et al., Small et al, Liu et al); THERMAL FEEDBACK.

2. Effect of SST on wind-stress derivatives changes according to the alignment of isotherms and wind vectors. Winds-stress divergence (curl) is closely related to the downwind (crosswind) component of the SST gradient (Chelton et al., 2001); DYNAMIC FEEDBACK.

- **Questions;**
  - **How does thermal coupling due to TIWs contribute to heat budget in the equatorial Pacific? (Jochum et al., 2005)**
  - **Does the stability modification by SST extend above the ABL?**

Air-Sea Coupling in S. California Coastal Ocean





- Similar coupling of SST with dynamics and thermodynamics of ABL is also seen in CCS region over various spatial and temporal scales.

Summary of Part 2 (cont.)

- **Similar coupling patterns are observed wherever strong SST gradient is associated with oceanic front, meander of the currents and mesoscale eddy in both tropics and extra-tropics.**

- **Thermal Feedback**

  1. Heat-flux provides **negative feedback** to ocean; dampening TIWs.

- **Dynamic Feedback**

  1. In the absence of damping by heat-flux, wind-induced forcing results in amplification of TIWs; **positive feedback** (cf. Pezzi et al., 2004)

- Different modes of feedback by atmosphere leads to different wavenumber-frequency characteristics of TIWs.

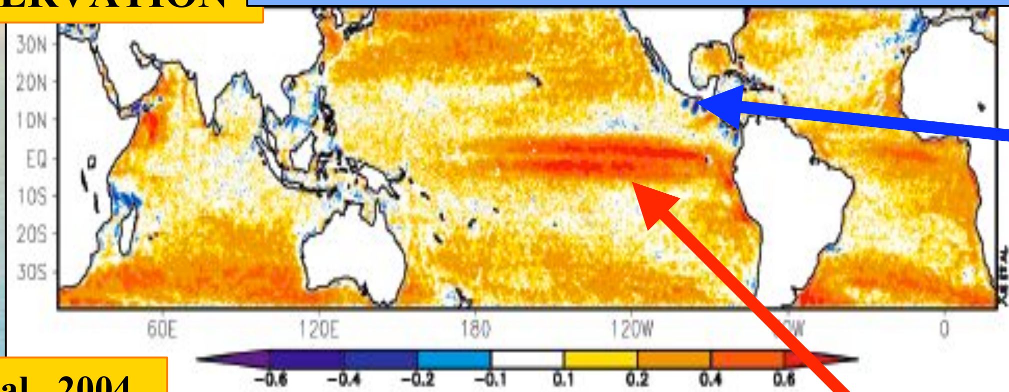
- Questions;
- 1. Why does wind-induced forcing amplify TIWs?
- 2. Can we use this feedback mechanism to understand stability of mesoscale oceanic eddy in the ocean?

Thanks!

Correlation between Wind and SST

TRMM microwave imager observations; high-pass filtered.

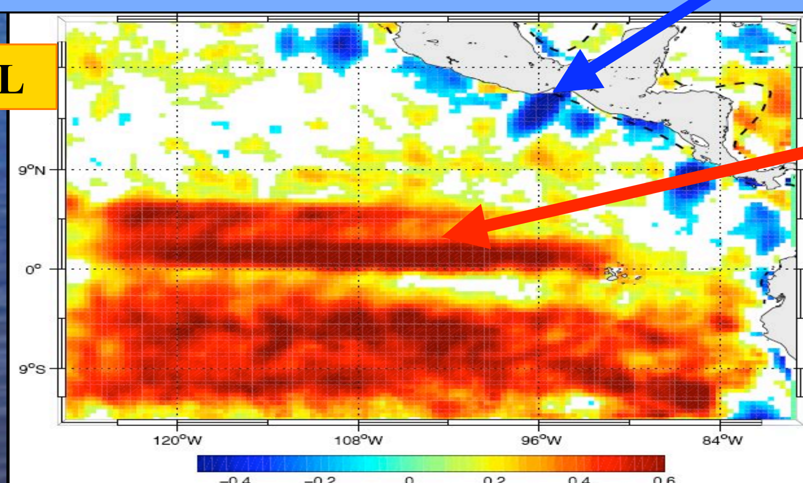
OBSERVATION



Xie et al., 2004

Correlation Coefficient between high-pass filtered 10 m wind and SST at 95%.

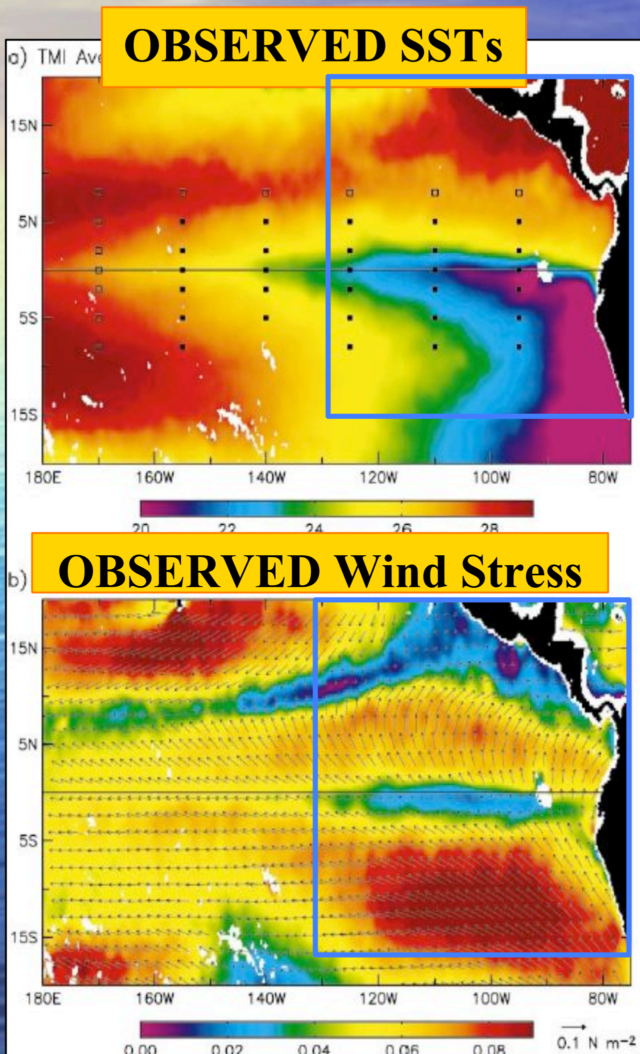
MODEL



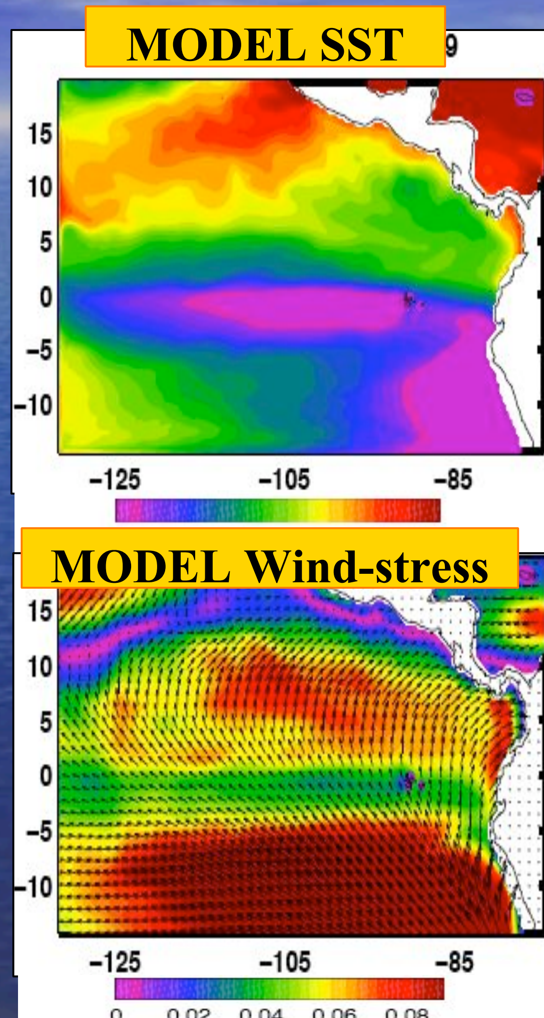
- Negative Correlation; Atmospheric forcing on upper ocean

- Positive Correlation; Oceanic forcing on atmospheric boundary layer

Mean SST and Wind-stress: Jun - Oct, 1999



Chelton et al., 2001



- 3-month average of wind-stress and SST
- Similar gross patterns of winds and SST during TIWs season