Mesoscale air-sea interaction and feedback in the western Arabian Sea

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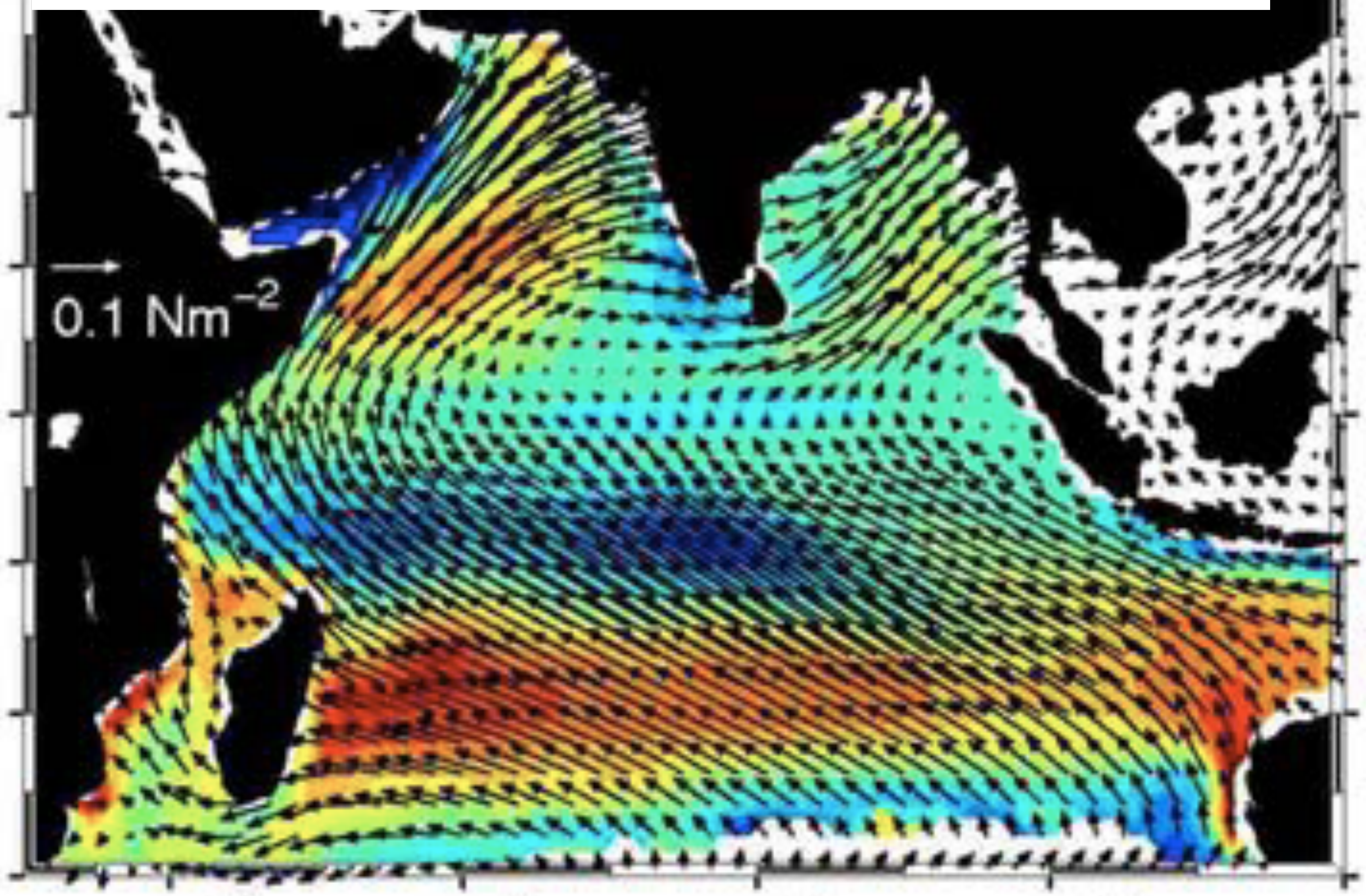
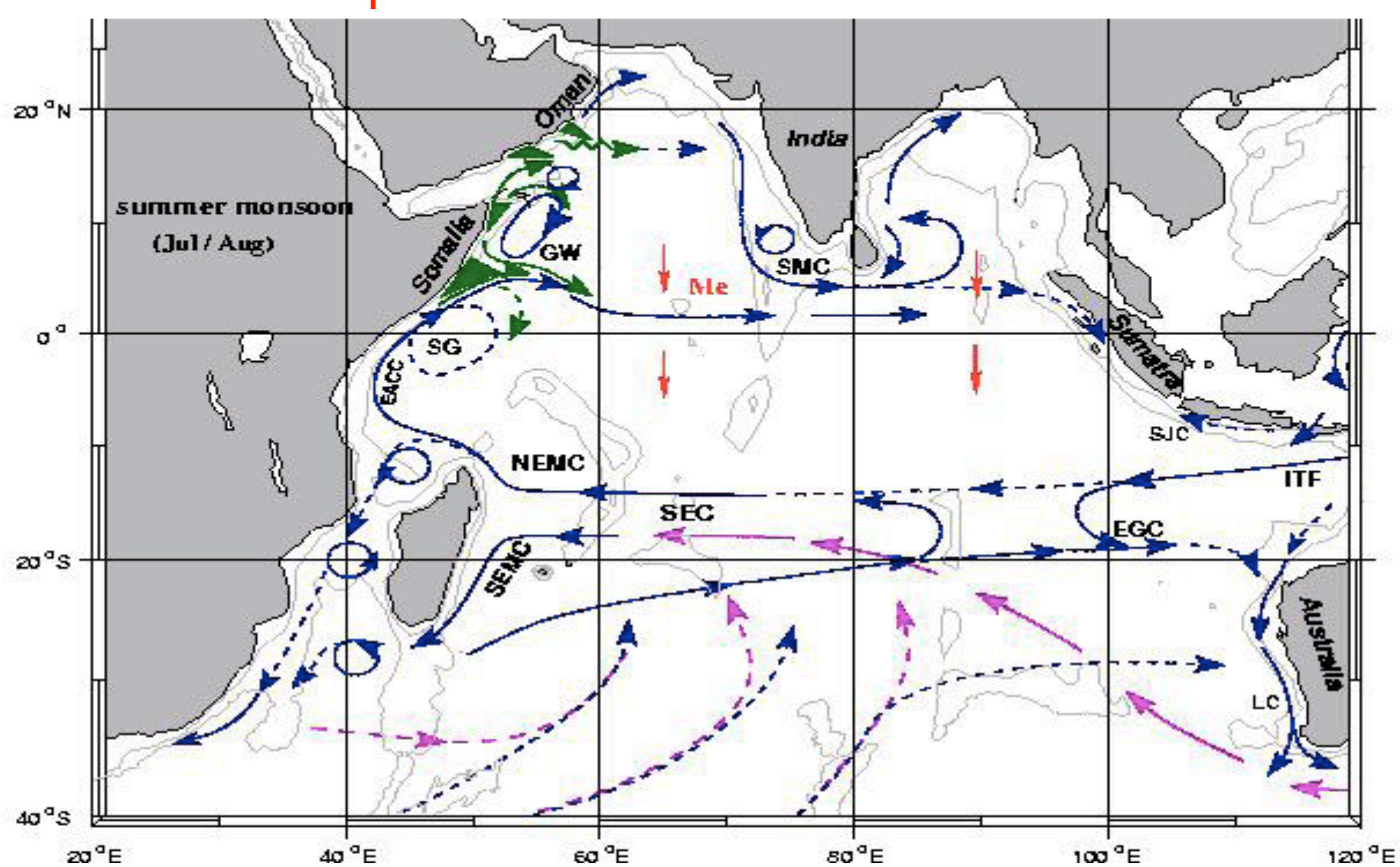
August NCEP Wind stress / SODA Z20 (40-200m)



Schematic representation of ocean current in SW monsoon

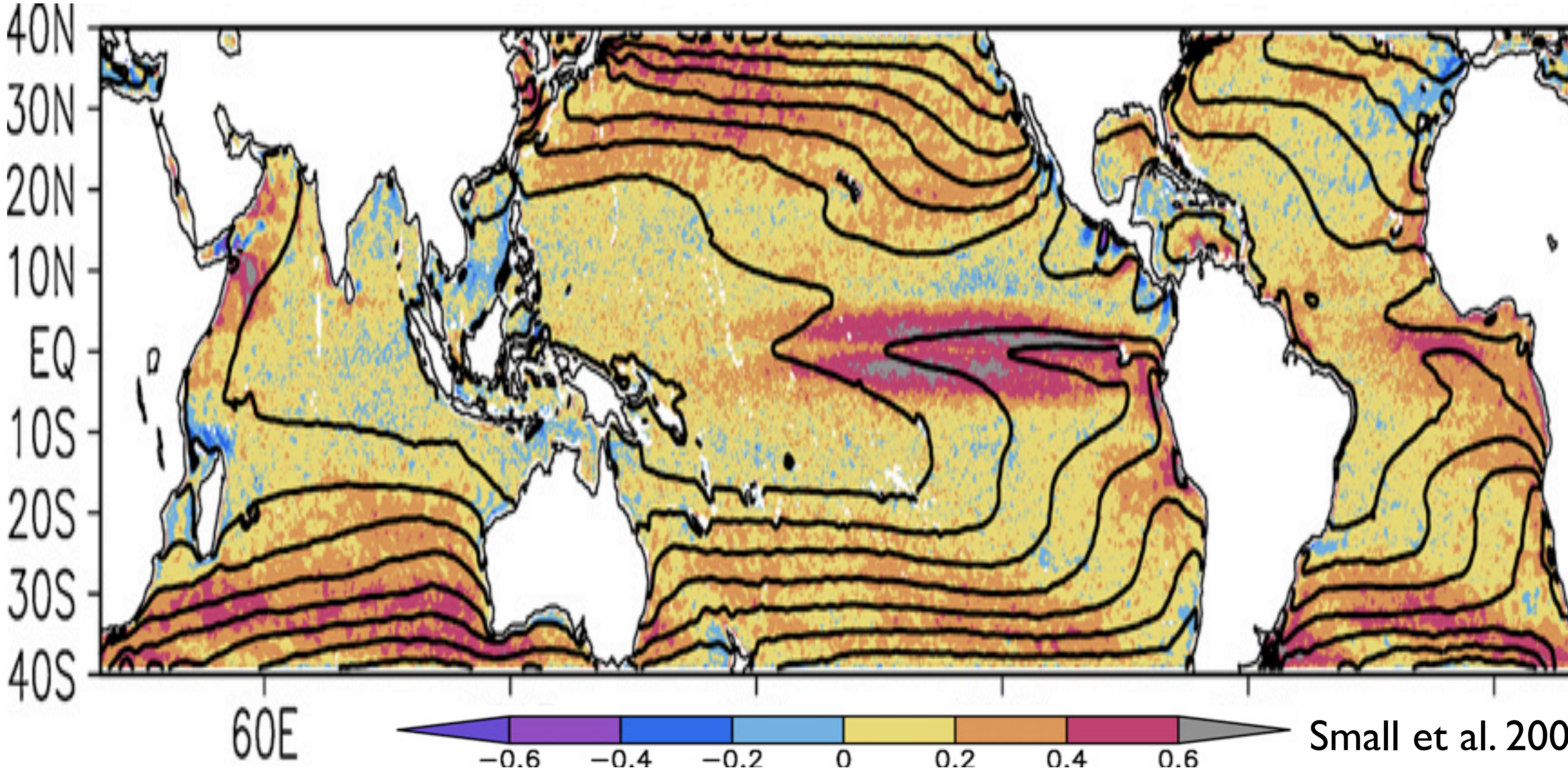


Wind and current in the Indian Ocean during summer monsoon

- Summer monsoon ➔ Somali Jet (>13 m/s)
- Somali Current (~2 m/s), anticyclonic Great Whirl.
- Costal upwelling, cold filaments and cold wedges.

Schott, McCreary, Xie 2009

Correlation of high-passed SST and wind speed



Small et al. 2008

- Large positive correlations are found in the western Arabian Sea and the eastern equatorial Pacific

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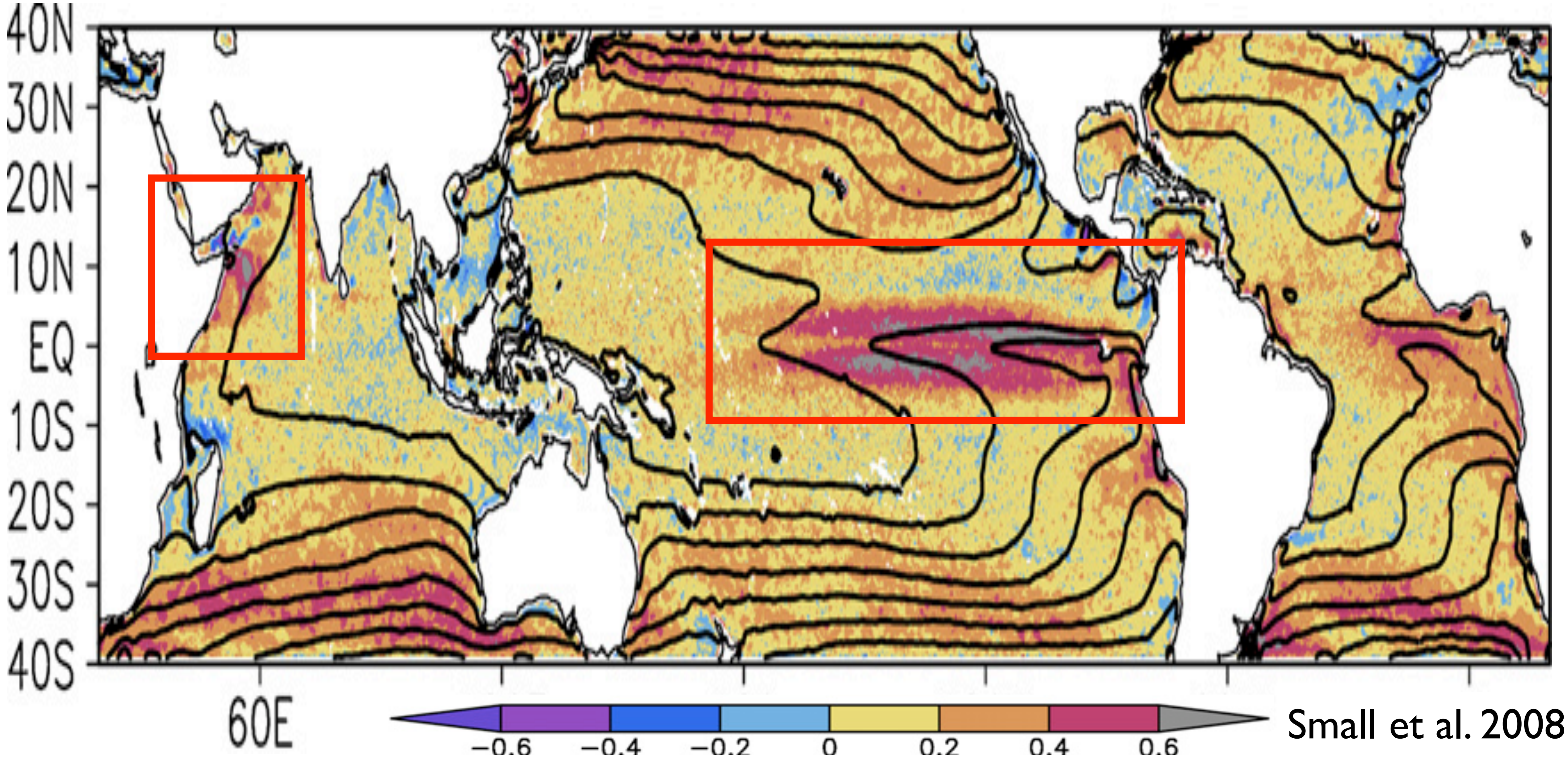

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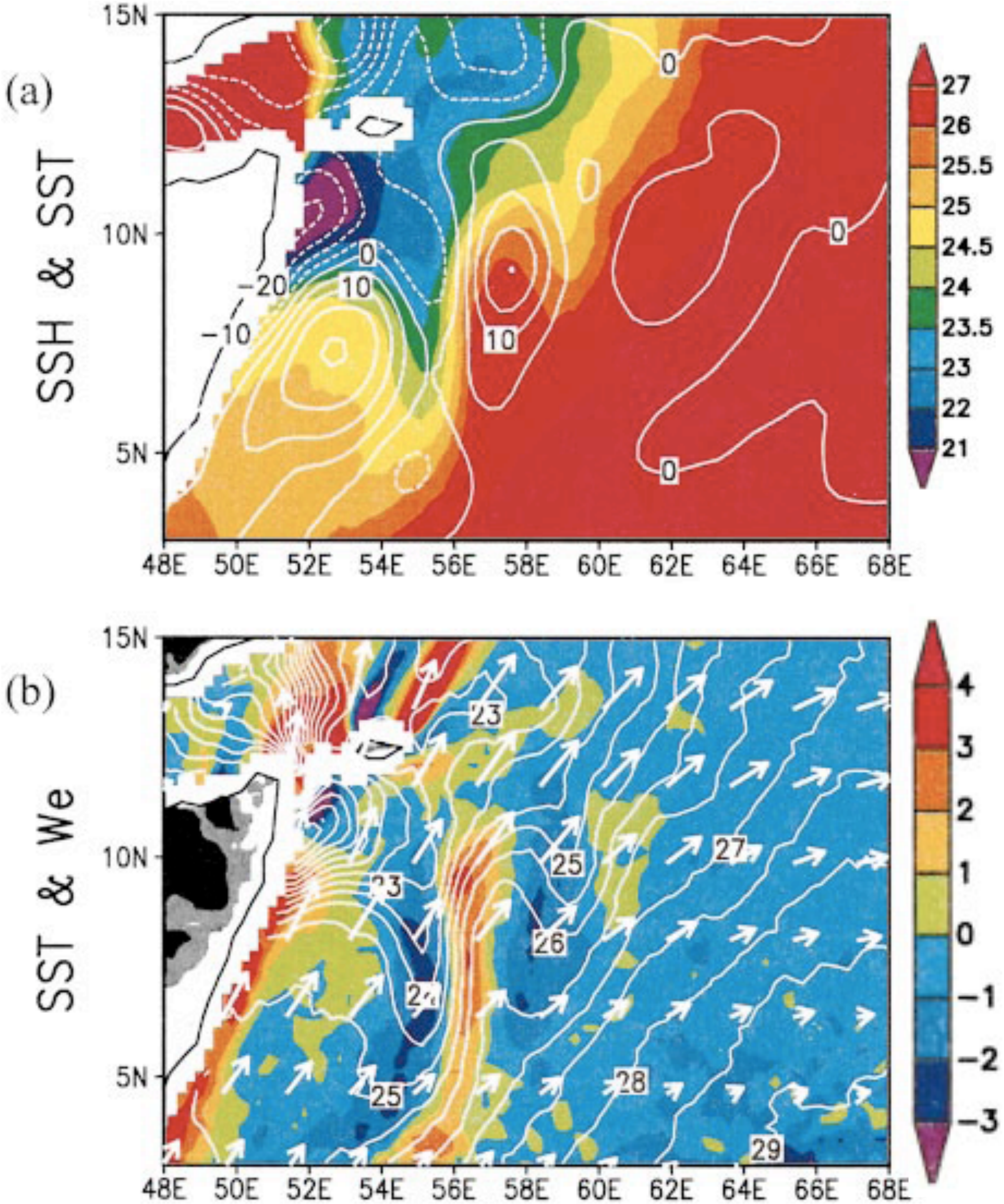
Observations of ocean-atmosphere interaction over cold filaments during summer monsoon (Vecchi et al. 2004)



15 Jul–15 Aug,1999–2002

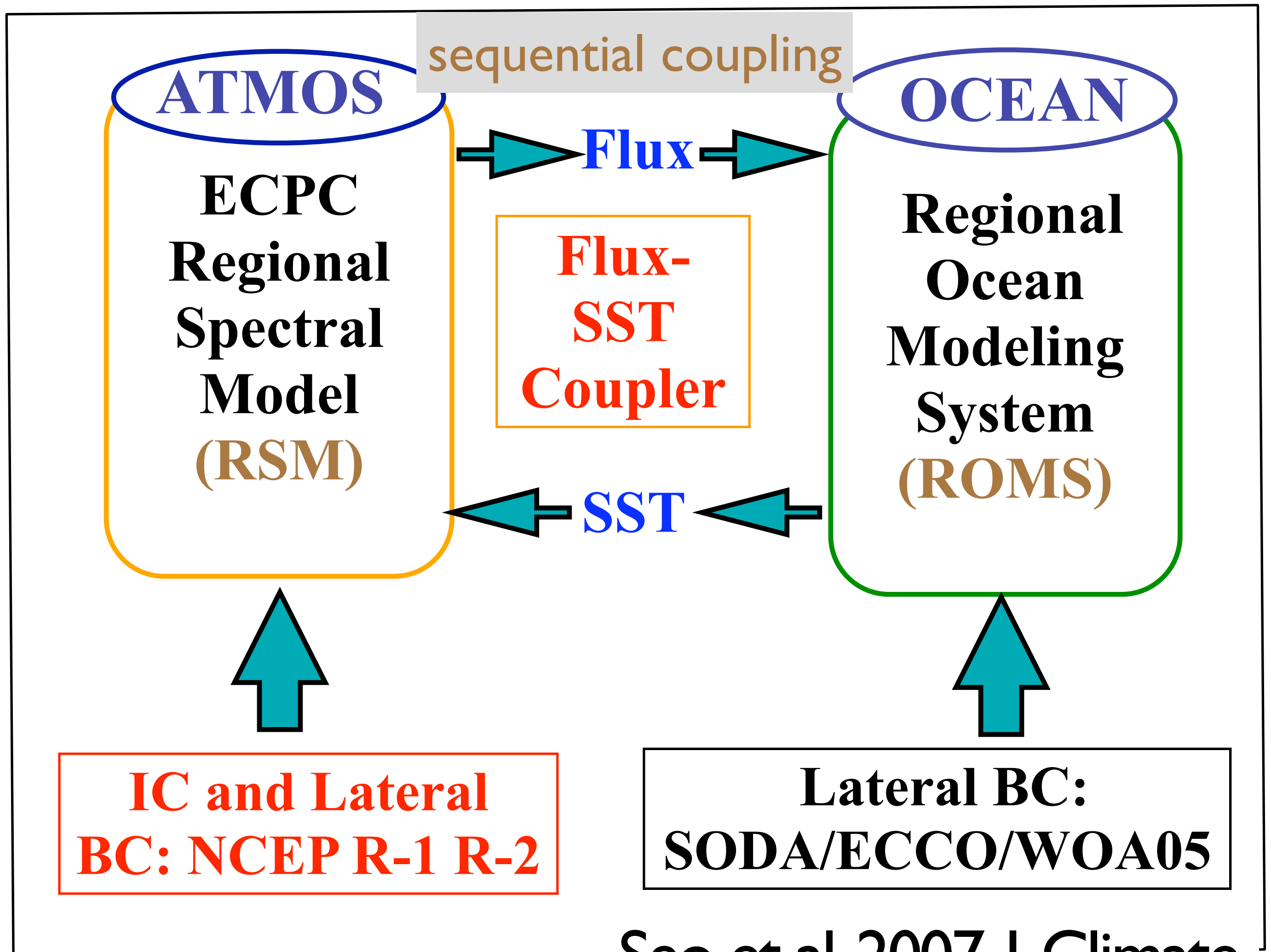
- Images from TRMM and QuikSCAT
- Generation of Ekman velocities of 2-3 m/day at the cold filaments
- This Wek is additional to the large-scale Ekman pumping.
- Main question: how important is Wek for the oceanic vertical structure and velocity?
- We need a high-resolution (*both ocean and the atmosphere*) coupled model to give detailed structure of the coupled system

Outline

- SCOAR Model: Fully-coupled high-resolution coupled climate model
- Wind and heat flux response to the cold filaments
- Ekman pumping velocity and the total vertical velocity
- Summary

Seo, Murtugudde, Jochum, and Miller, 2008:
Modeling of Mesoscale Coupled Ocean-Atmosphere Interaction and its Feedback to Ocean in the Western Arabian Sea. *Ocean Modelling*, **25,** 120-131

Scripps Coupled Ocean-Atmosphere Regional (SCOAR) Model: Indian Ocean



Seo et al. 2007, J. Climate

1. Study mesoscale coupled ocean-atmosphere interaction:
2. relation with the regional climate:

- 0.26° res. ocean and atmosphere
- daily coupling
- 1993-2006

- Higher model resolution; Identical resolution (0.26°) of ocean and atmosphere.
- Dynamical consistency with the NCEP Reanalysis forcing
- Greater portability

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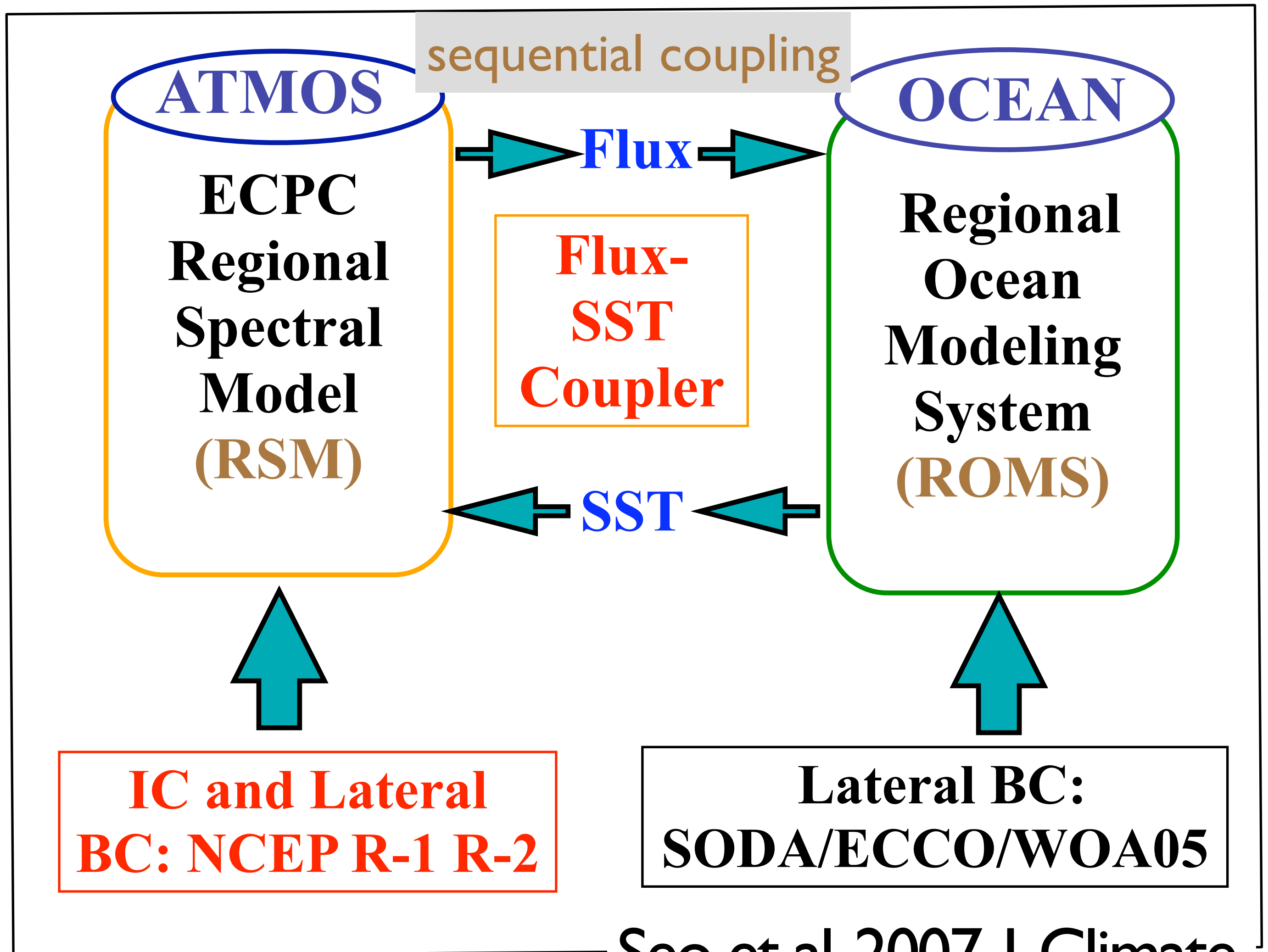

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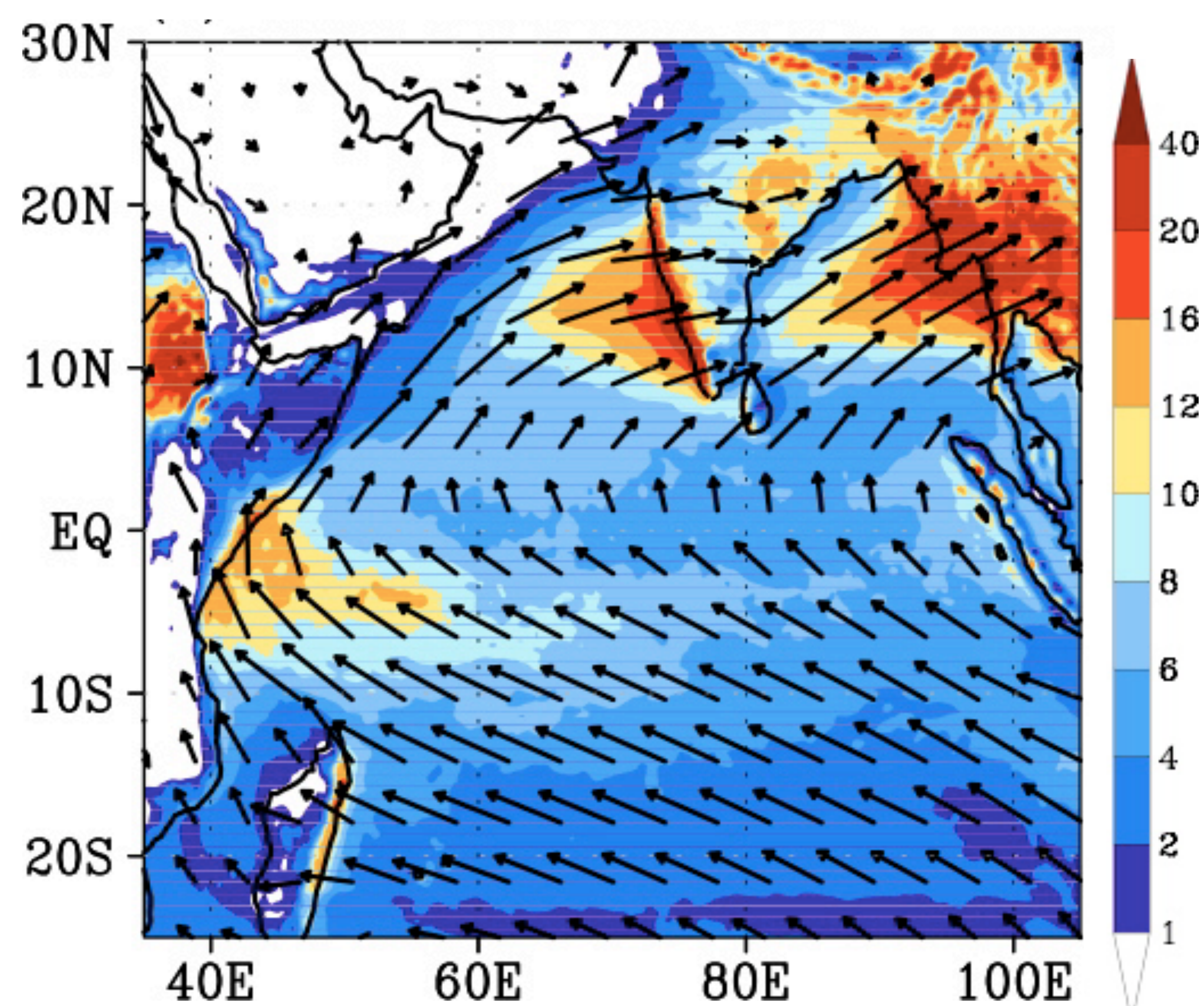
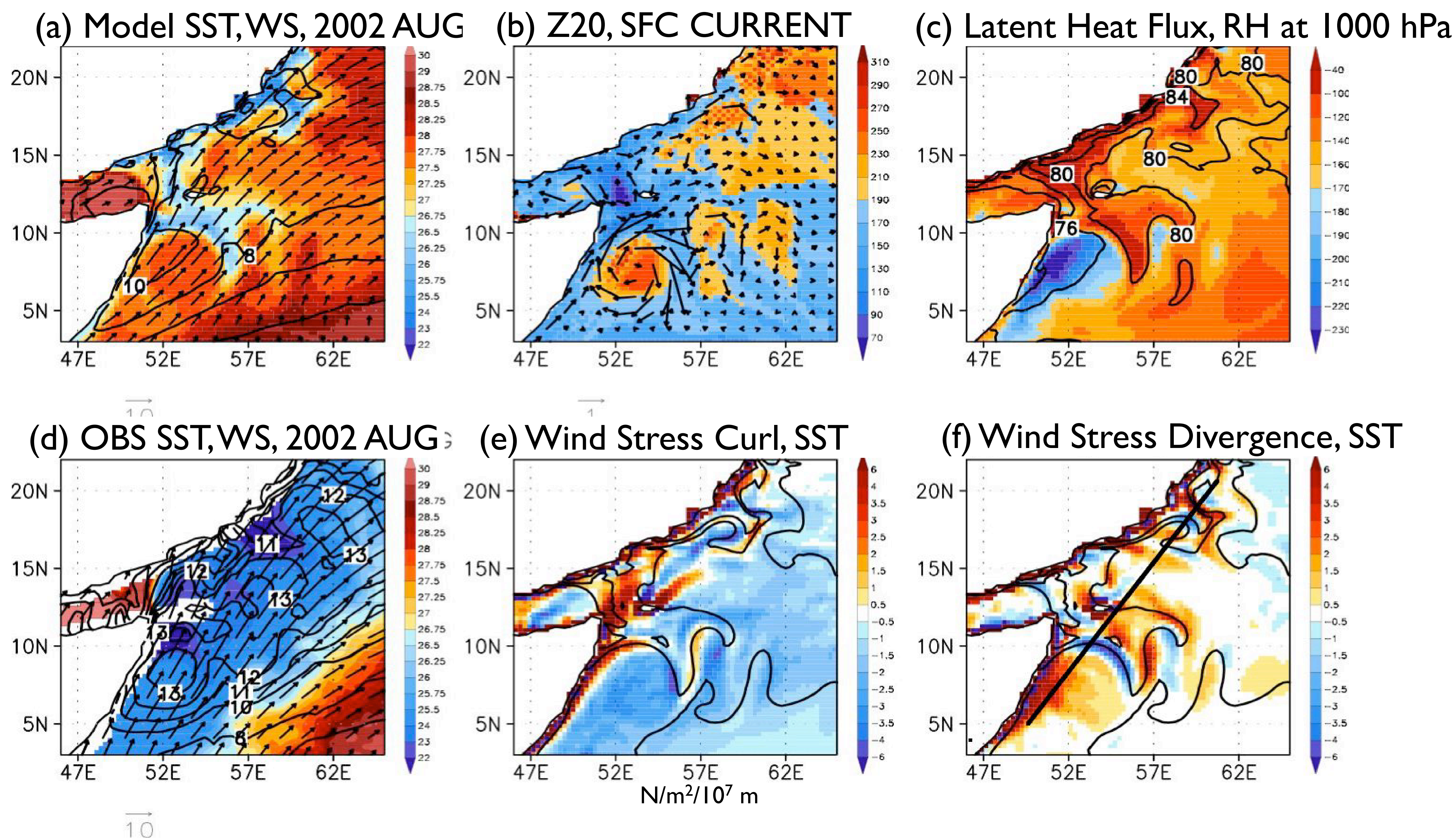


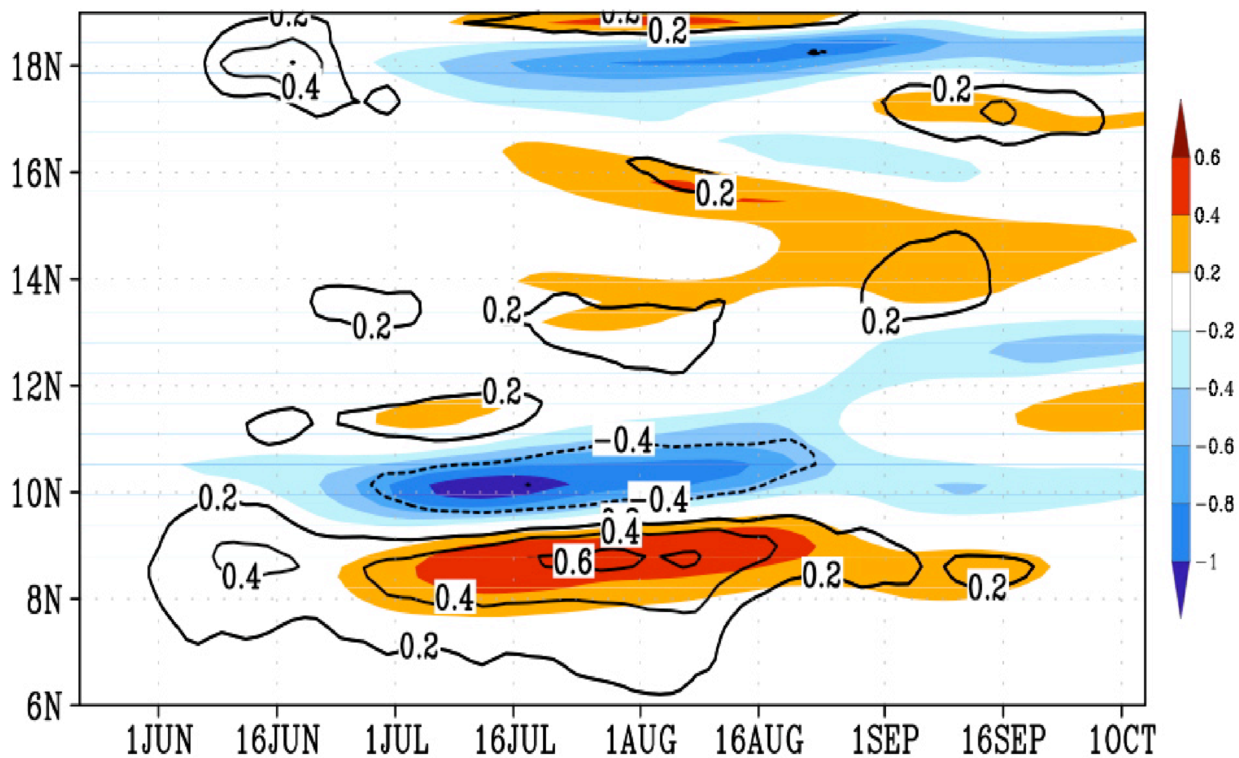
Simulated mean properties of the western Arabian sea



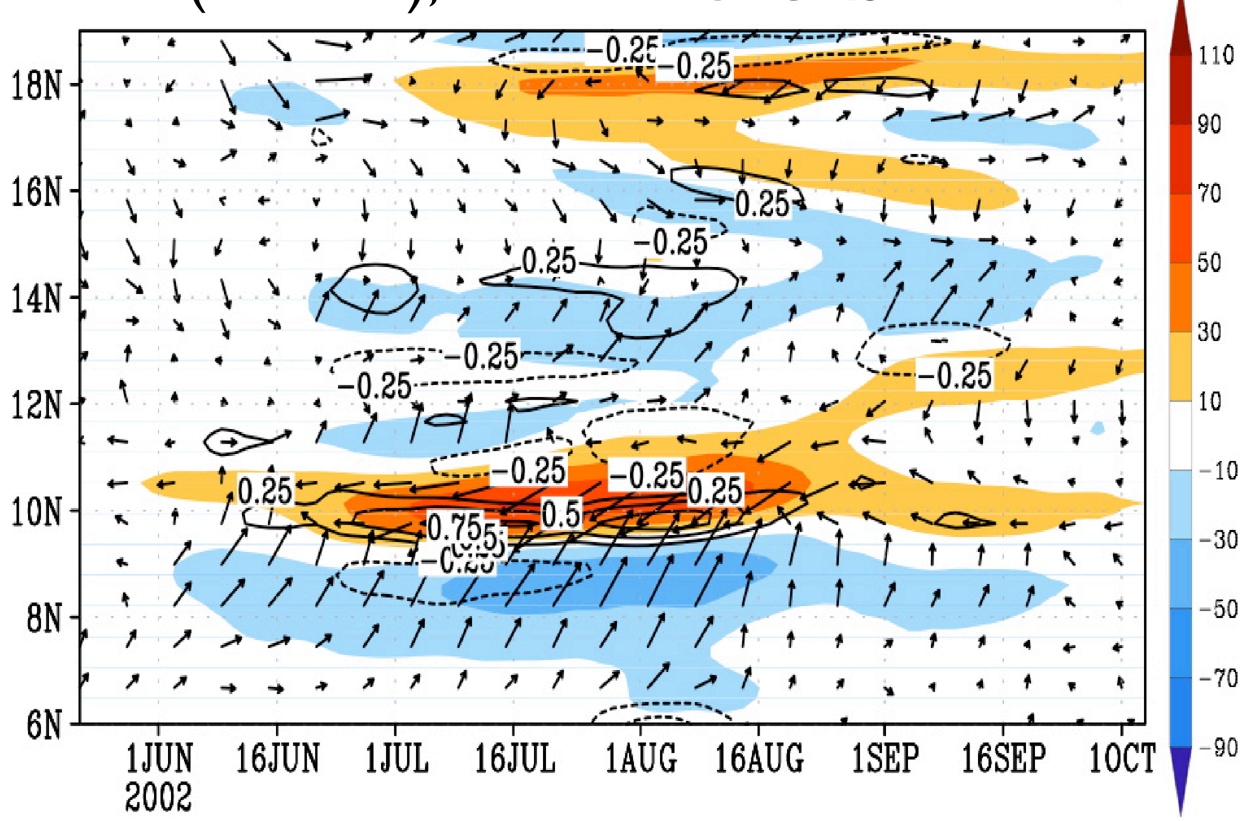
- Warm bias and weak Somali Jet in the model, but key features are reasonably well captured:
  - Large wind speed over the Great Whirl
  - Wind stress derivatives and SST gradients
  - Surface heat flux and the SST

August 2002 mean quantities
0.26° resolution RSM/ROMS daily coupled

SST (color), WIND SPEED (contour)



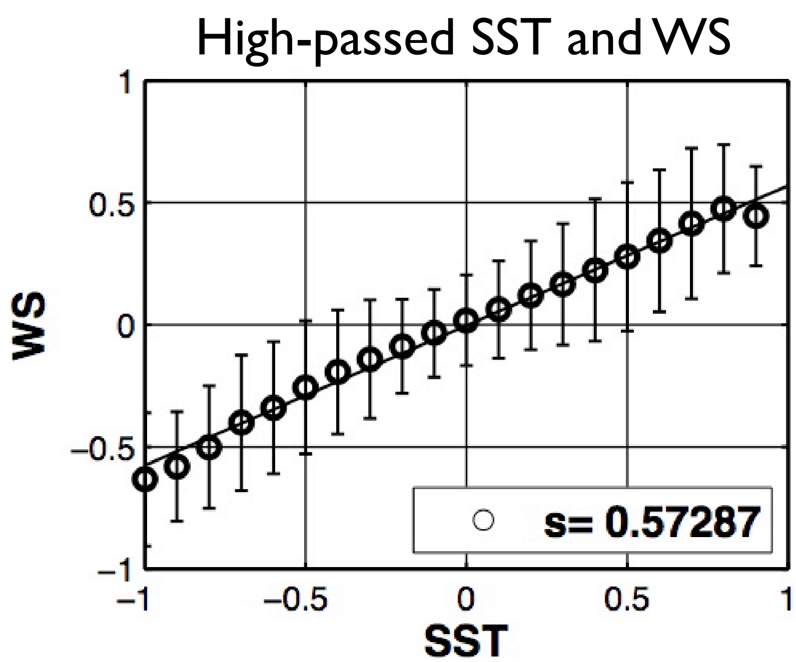
LATENT HEAT FLUX (color), Wek (contour), WIND VECTORS

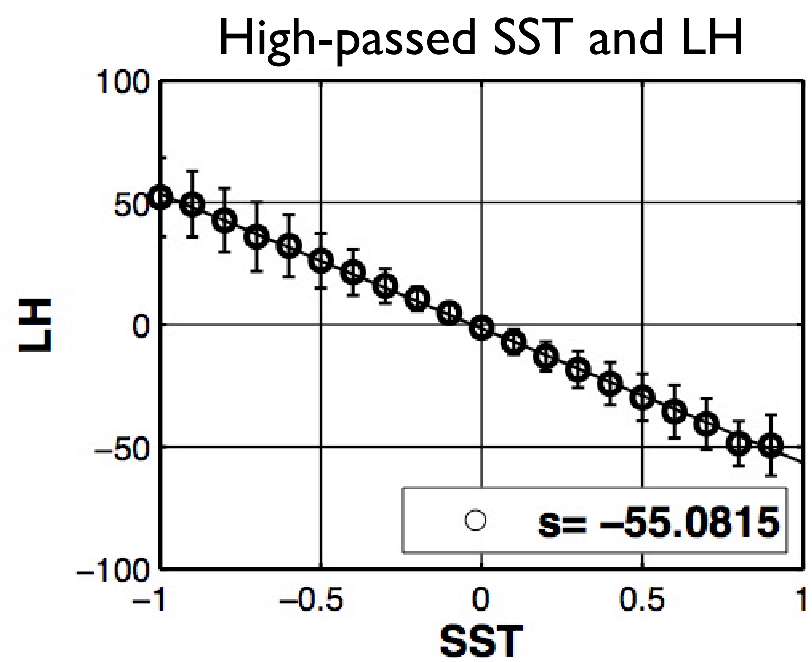


Model spatio-temporal covariability of ocean and atmosphere

- Cold filament develops in the beginning of June and reaches its maximum (<1° C) in July.
- In-phase response of surface wind to SST: southwesterly over warm water and northeasterly over cold water.
- Out-of-phase response from the latent heat flux: a damping effect.
- Large Ekman pumping velocity along the max. SST gradient (~ 1m/day)

Linear relationship between mesoscale SSTs vs wind speed (WS) and surface fluxes





- When spatially highpass filtered, SST and WS (SST and LH) exhibit a linear positive (negative) relationship.
- Wind-SST relationship is not obvious in background fields.
- Eddies reduce the latent heat flux out of the ocean by twice in the model.

JJAS 1995-2006

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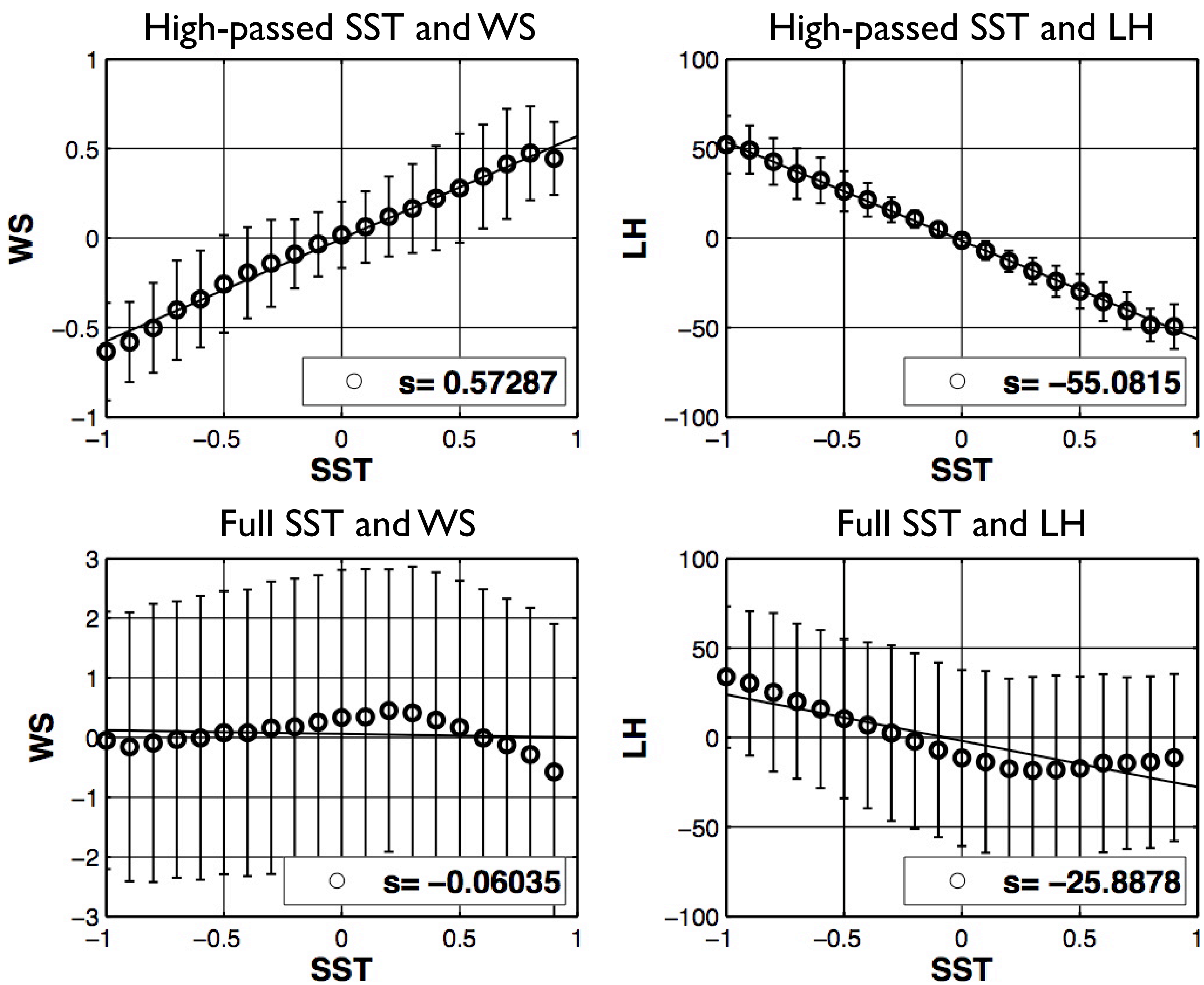

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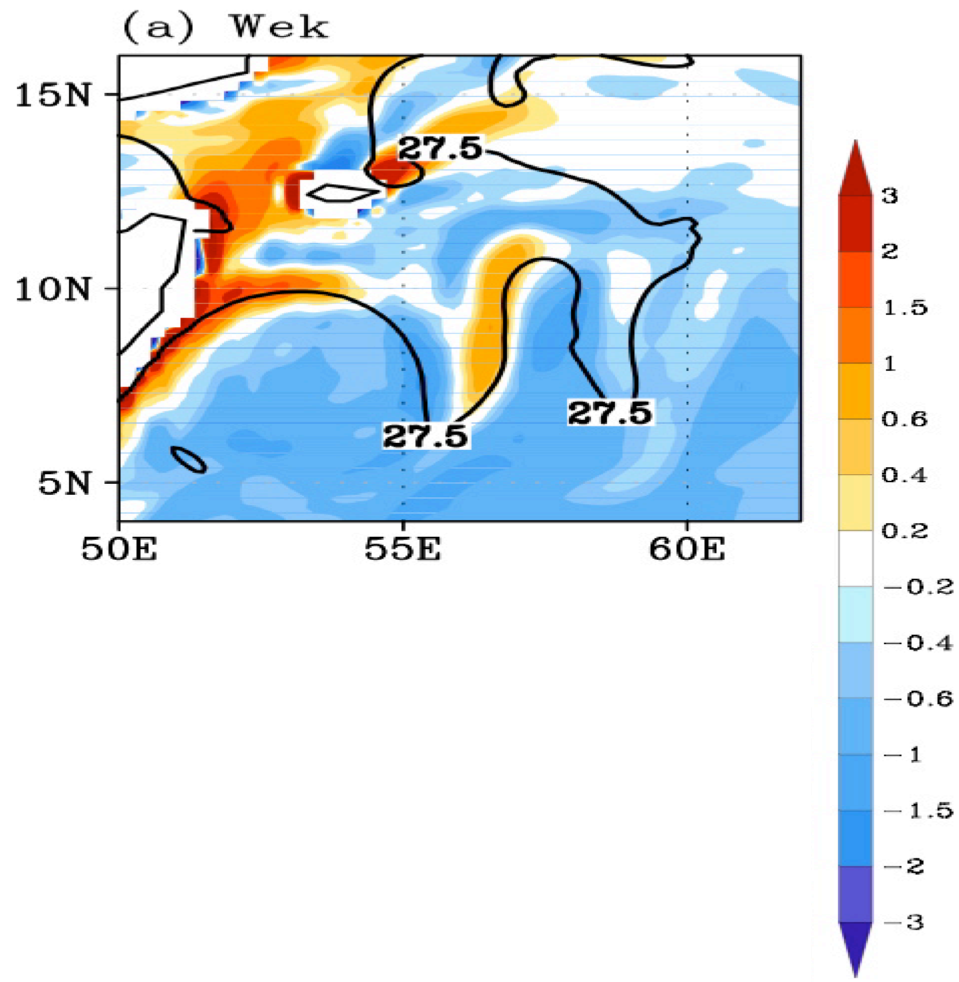
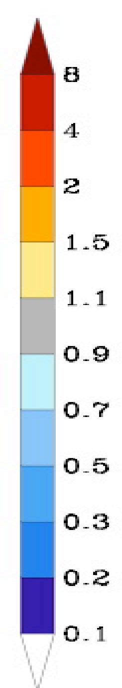
Ekman pumping and oceanic vertical velocity

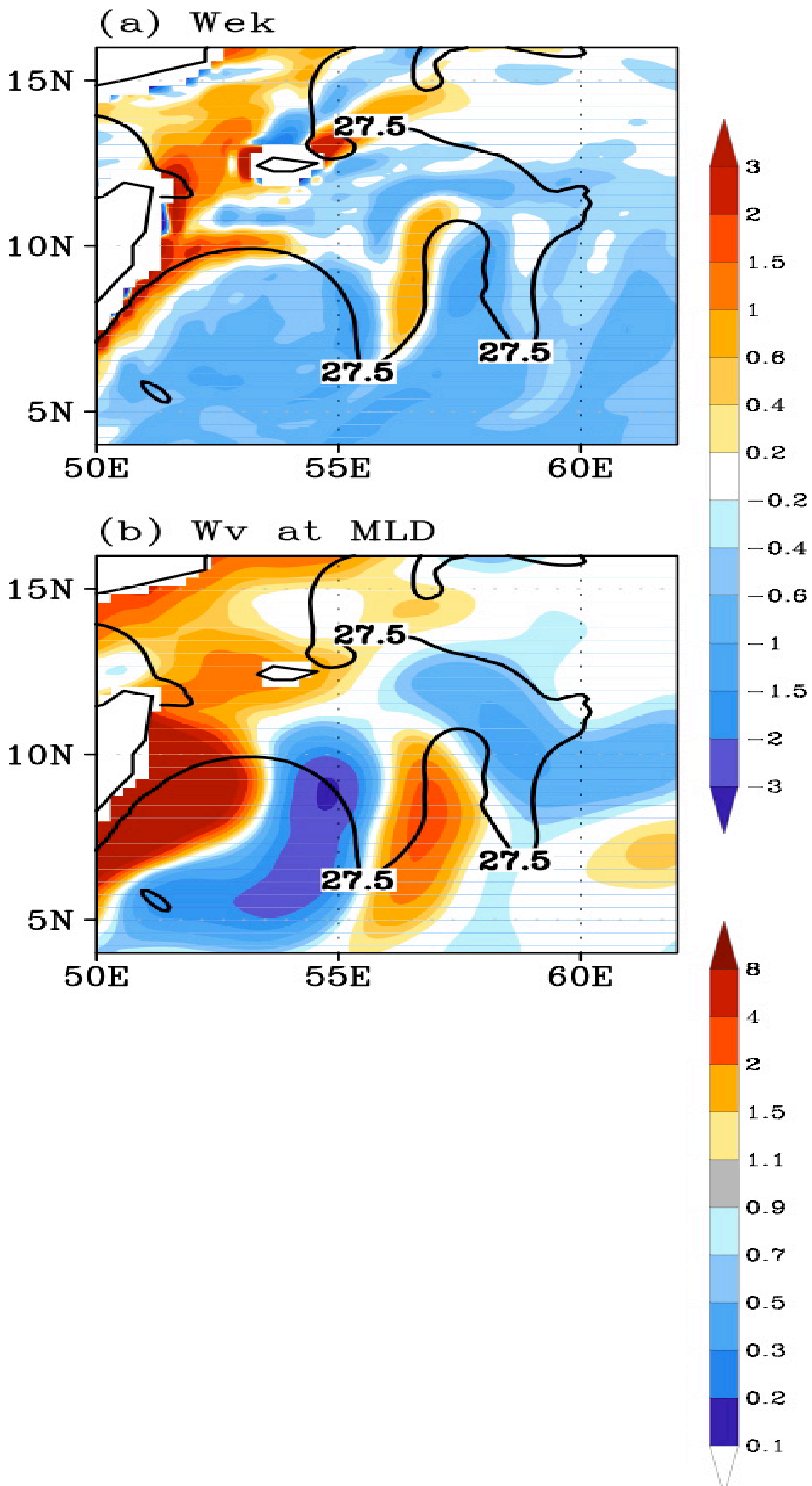




Direct comparison of *Wek* with the oceanic vertical velocity (*W* at the base of mixed layer)

- The narrow band of Wek reaches >1 m/day, concentrated along the cold wedge.
- W is ~±2-3 m/day in the vicinity of cold filaments
- The ratio is ~O(1) over the region of maximum Wek along the cold filaments
- This will affect the evolution of cold filament and other oceanic mesoscale eddies (Vecchi et al . 2004)

August 2002



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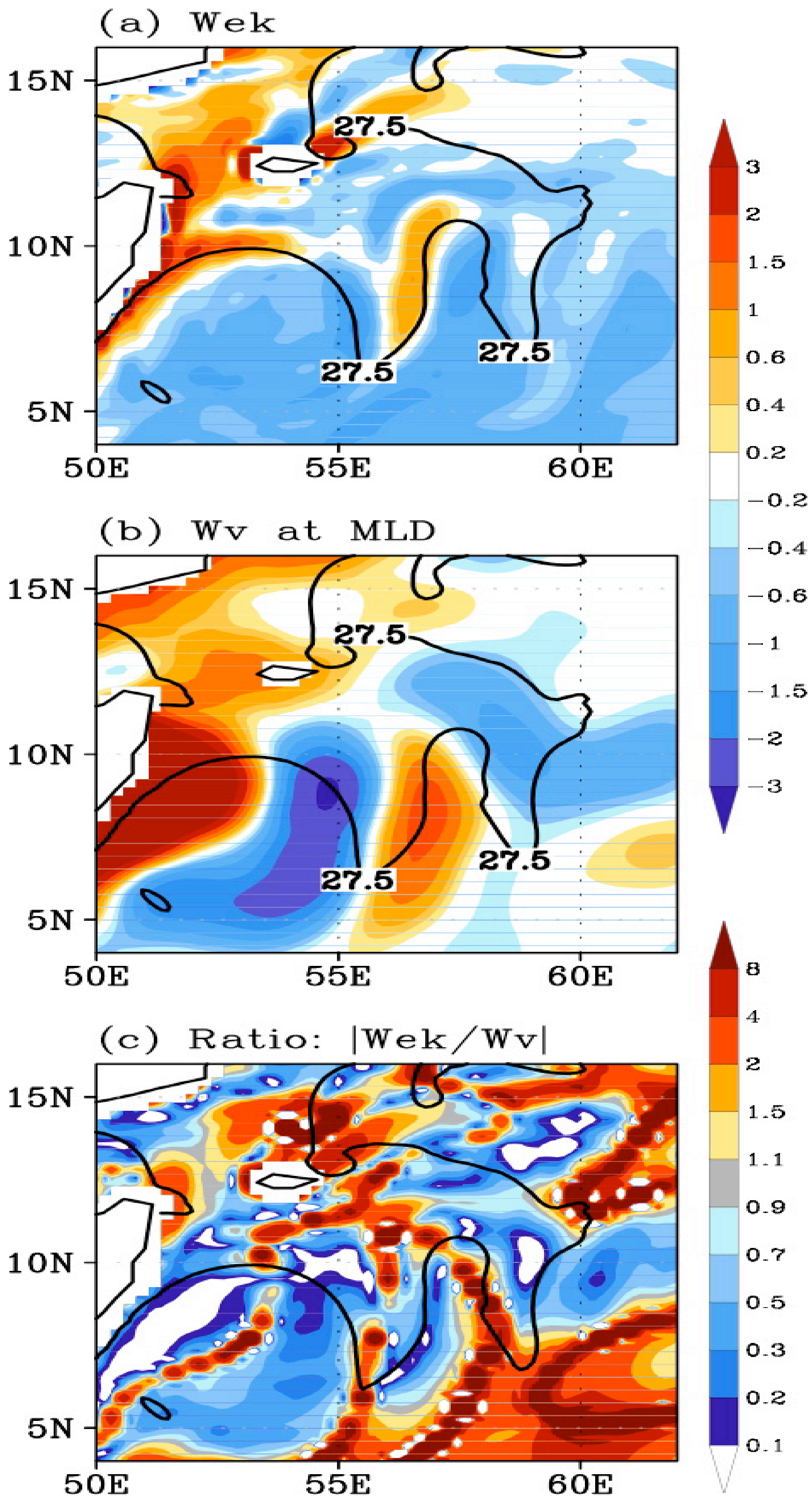

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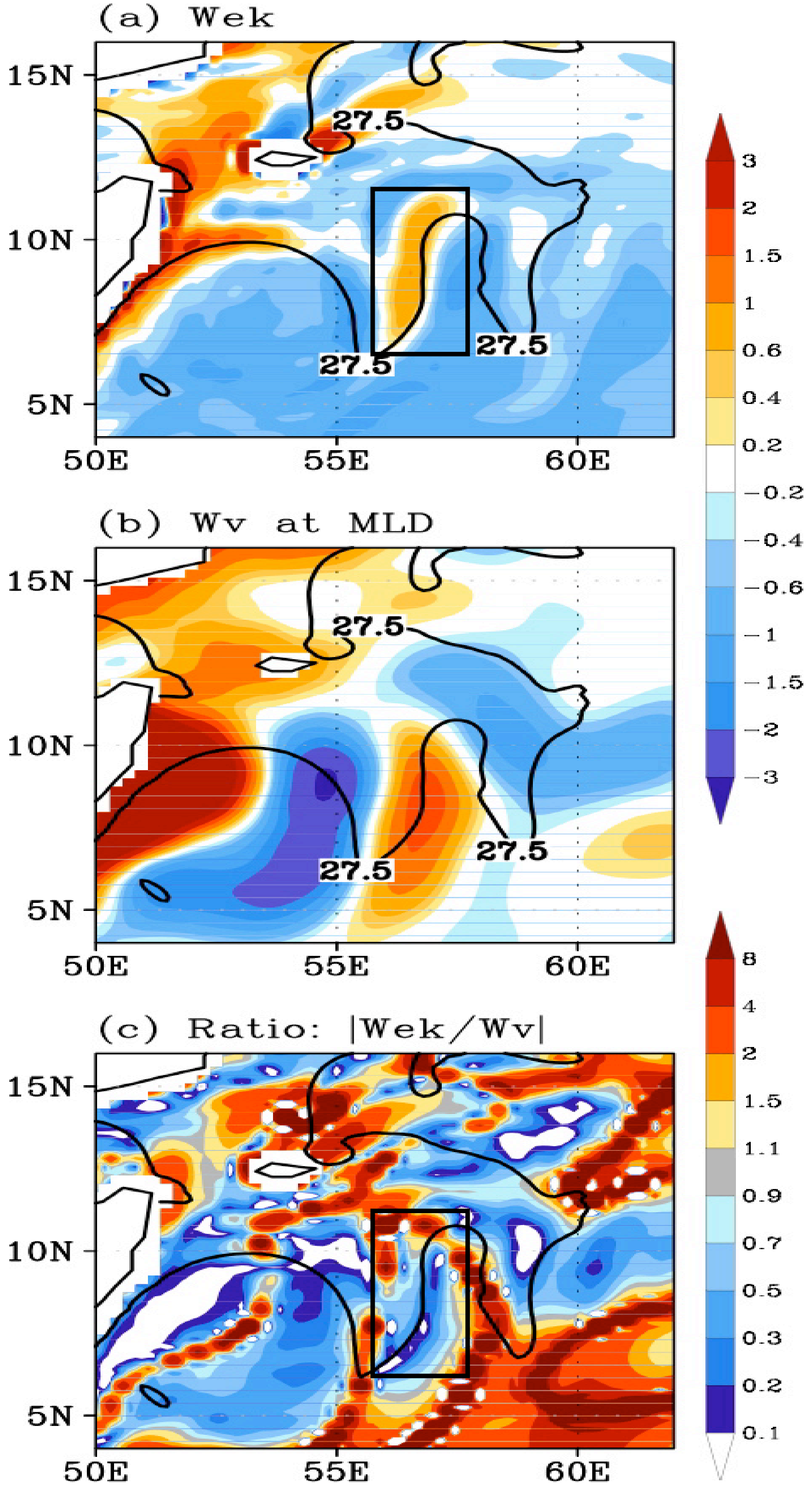

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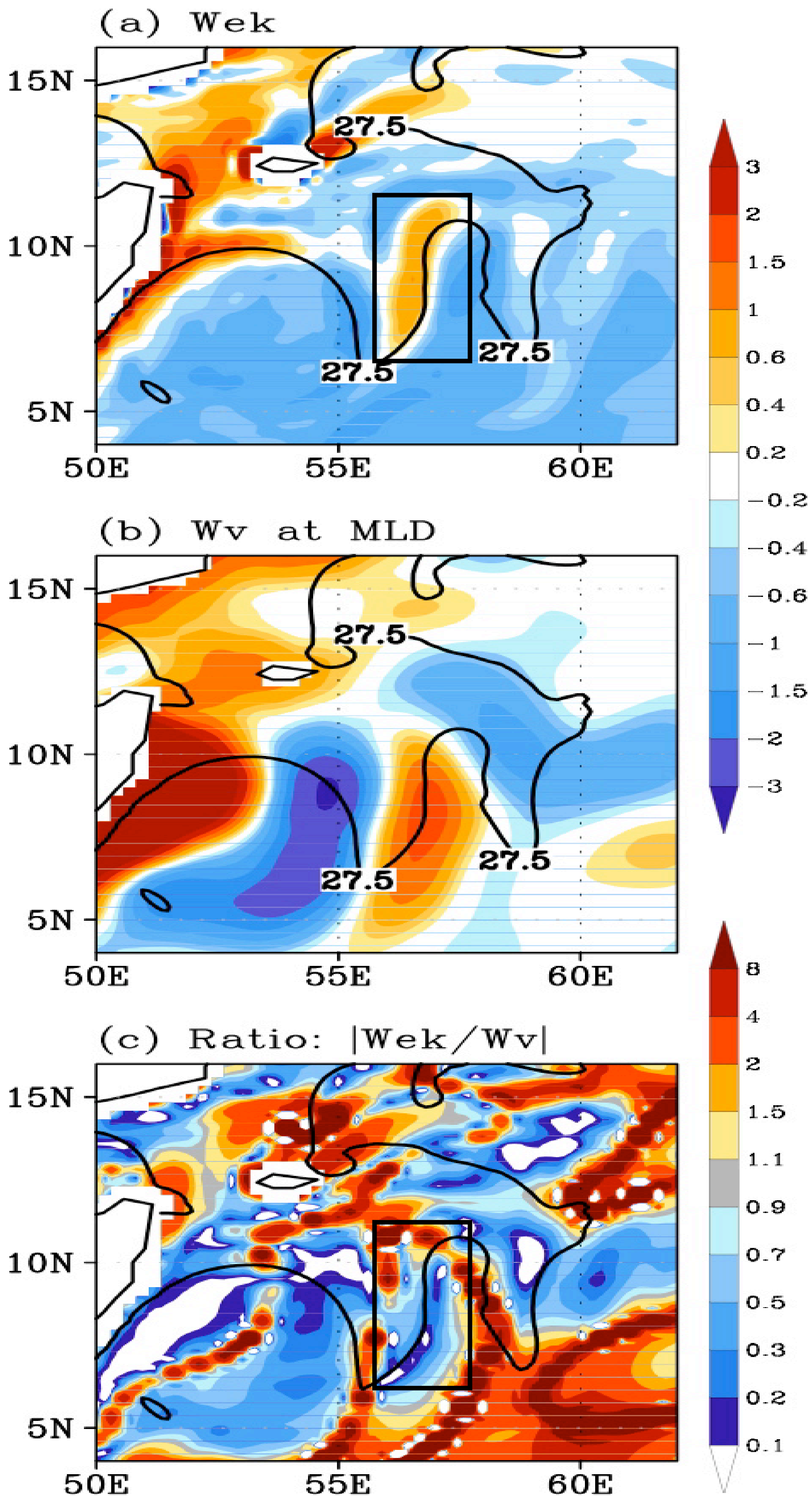

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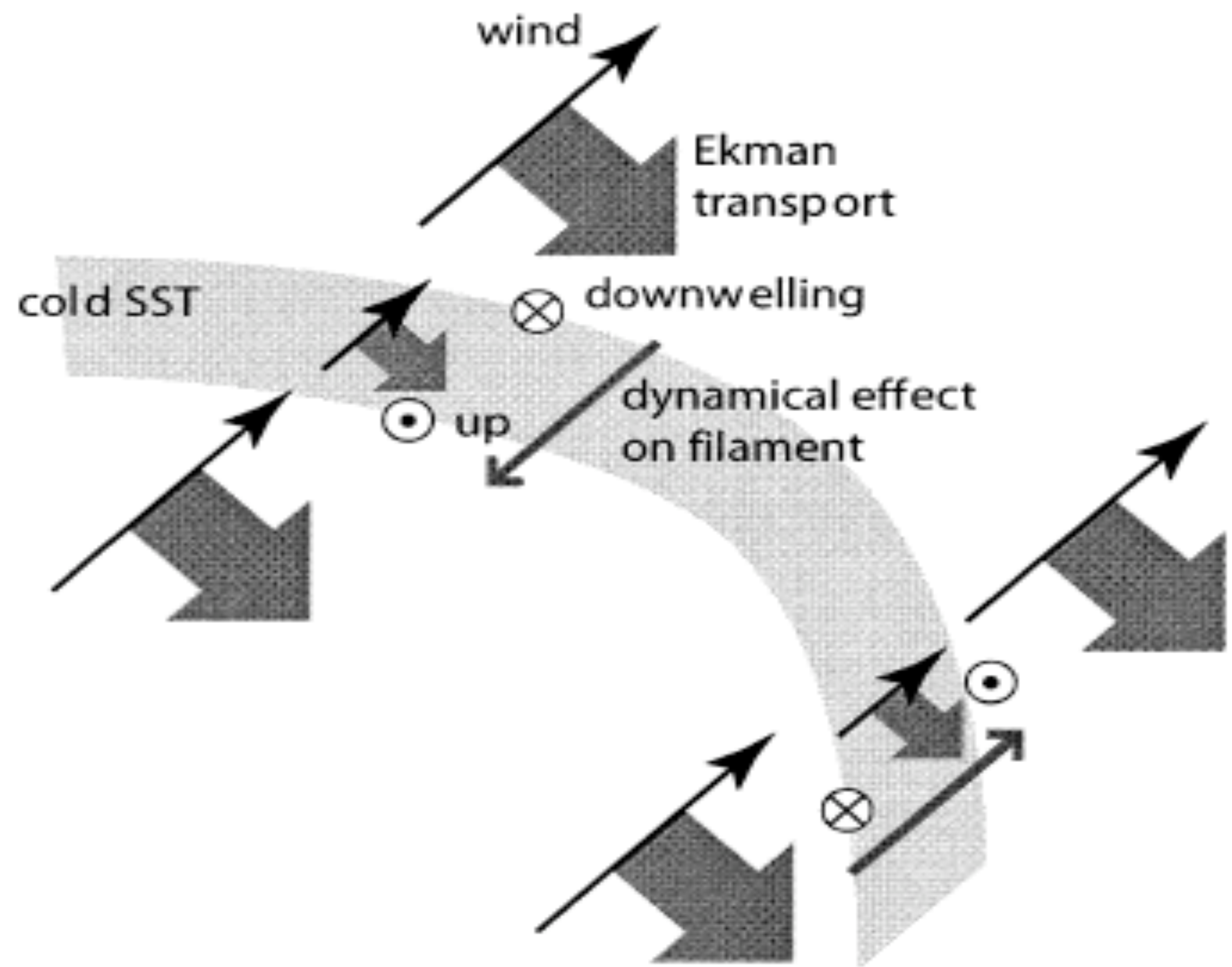

FIG. 9. Schematic of cold filaments and wind curl. Upwelling and downwelling Ekman pumping anomalies are dependent on the orientation of the filament to the mean wind direction.

- This will affect the evolution of cold filament and other oceanic mesoscale eddies (Vecchi et al . 2004)

Summary

- 0.26° SCOAR model has been used to study the mesoscale air-sea interaction and feedback effect in the western Arabian Sea (Seo et al. 2008, *Ocean Modelling*, **25,** 120-131)

- ***Dynamic feedback***: In agreement with the satellite observations, additional Ekman velocity (~1m/day) is induced in the vicinity of the cold wedges. The model results suggest that this additional Wek is comparable in magnitude to the total vertical velocity of the cold filaments.

  ➔ The observed mesoscale air-sea interaction could affect the vertical structure and the dynamic property of mesoscale eddy

- There is also ***thermodynamic impact*** due to the altered turbulent heat flux that impacts long-term heat budget of the ocean.

  ➔ Results imply that coupled feedback affects the local SST and thus the variability of Indian monsoon (Izumo et al. 2008)

Thanks!

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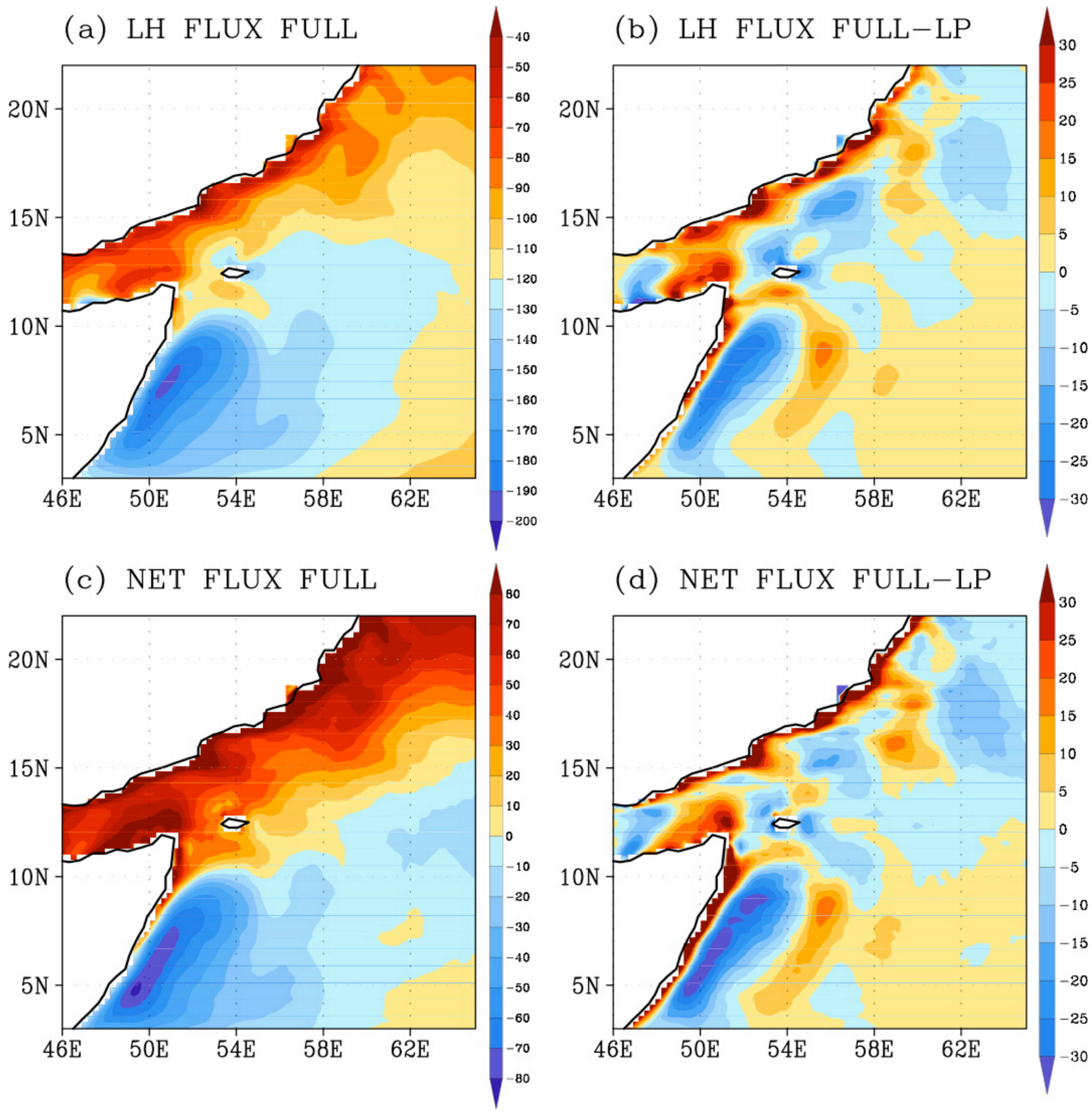
Email: hyodae@hawaii.edu

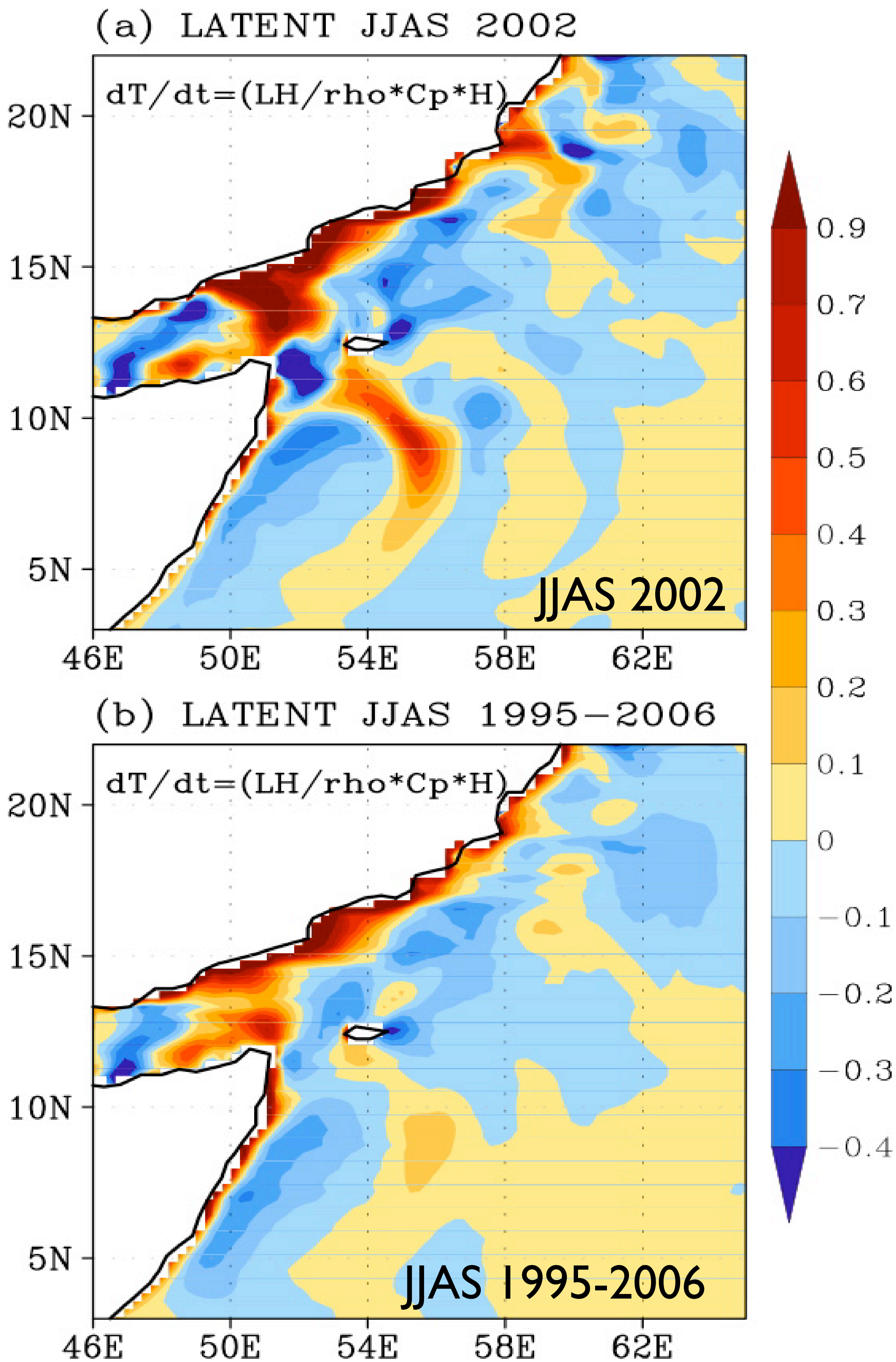
Any long-term effects of latent heat flux on the SST?

Latent heat flux induced by mesoscale eddies



JJAS 1995-2006

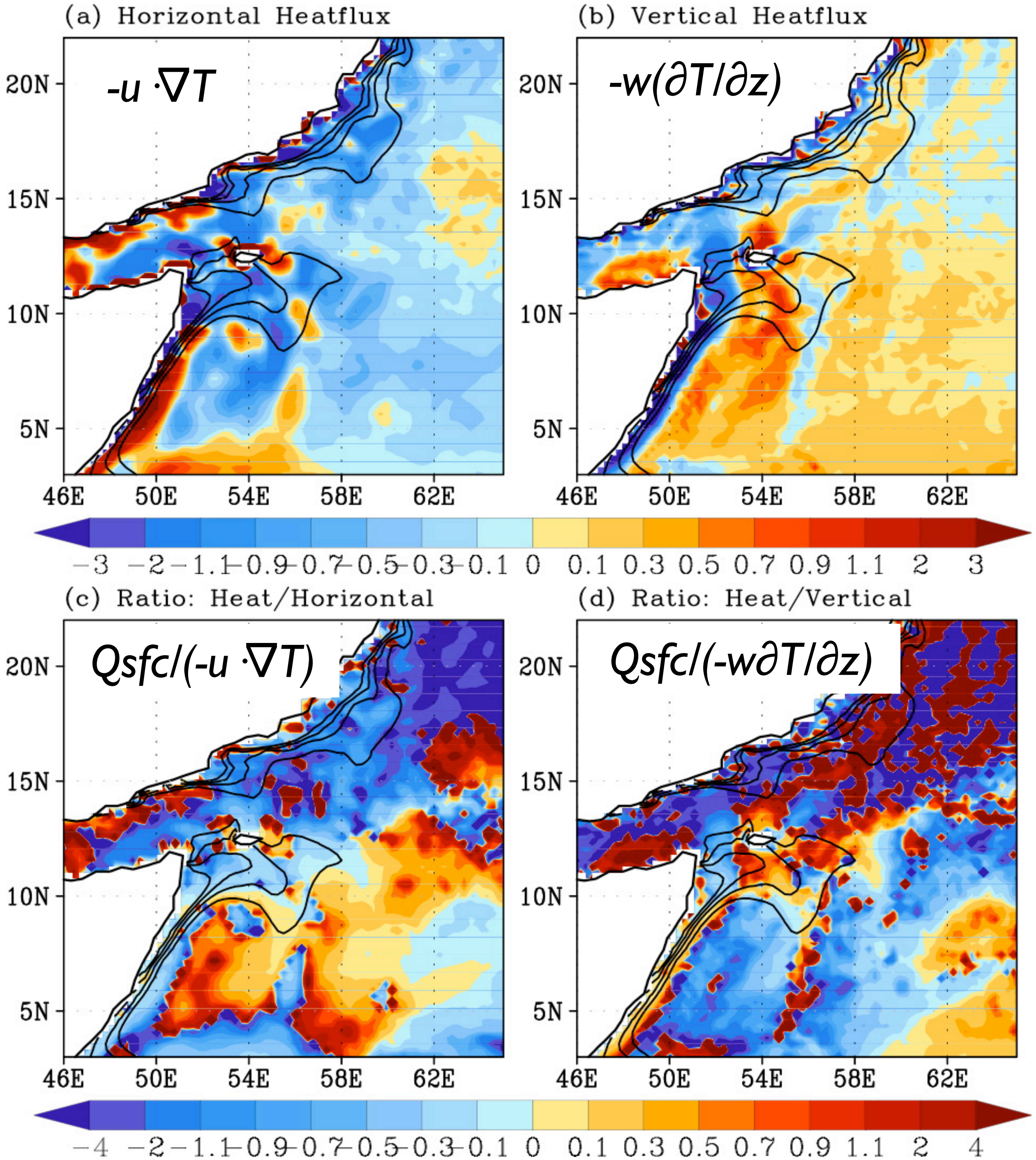
- $LH=\rho LC_HU(q_a-q_s)$
- Difference map (full field minus spatially averaged field) represents the additional LH flux input to the ocean: 10-15W/m^2 for a 12-yr mean.
- Difference map of total heat flux fields is similar to that of LH ➔ LH flux variability is the dominant factor in the net heat flux fields.



1-D heat budget: latent heat flux and mixeld layer depth

- $\partial T/\partial t = \Delta LH/\rho C_p H$ (Full-Lowpassed)
- With the shoaled mixed layer (H), the additional heat flux can warm mixed layer > 0.4°C/month for a single year of strong eddy activity (JJAS 2002). (The RMS of SST this season was 0.4-0.8°C.)
- For a 12-yr mean, warming effect is roughly 0.1-0.2°C/month. (RMS of SST was approximately 0.4-0.5°C.)
- Low-frequency modulation of SST by additional heat flux is possible.

Comparison with horizontal and vertical heat flux of the ocean



JJAS 1995-2006

Each term is averaged over the mixed layer depth

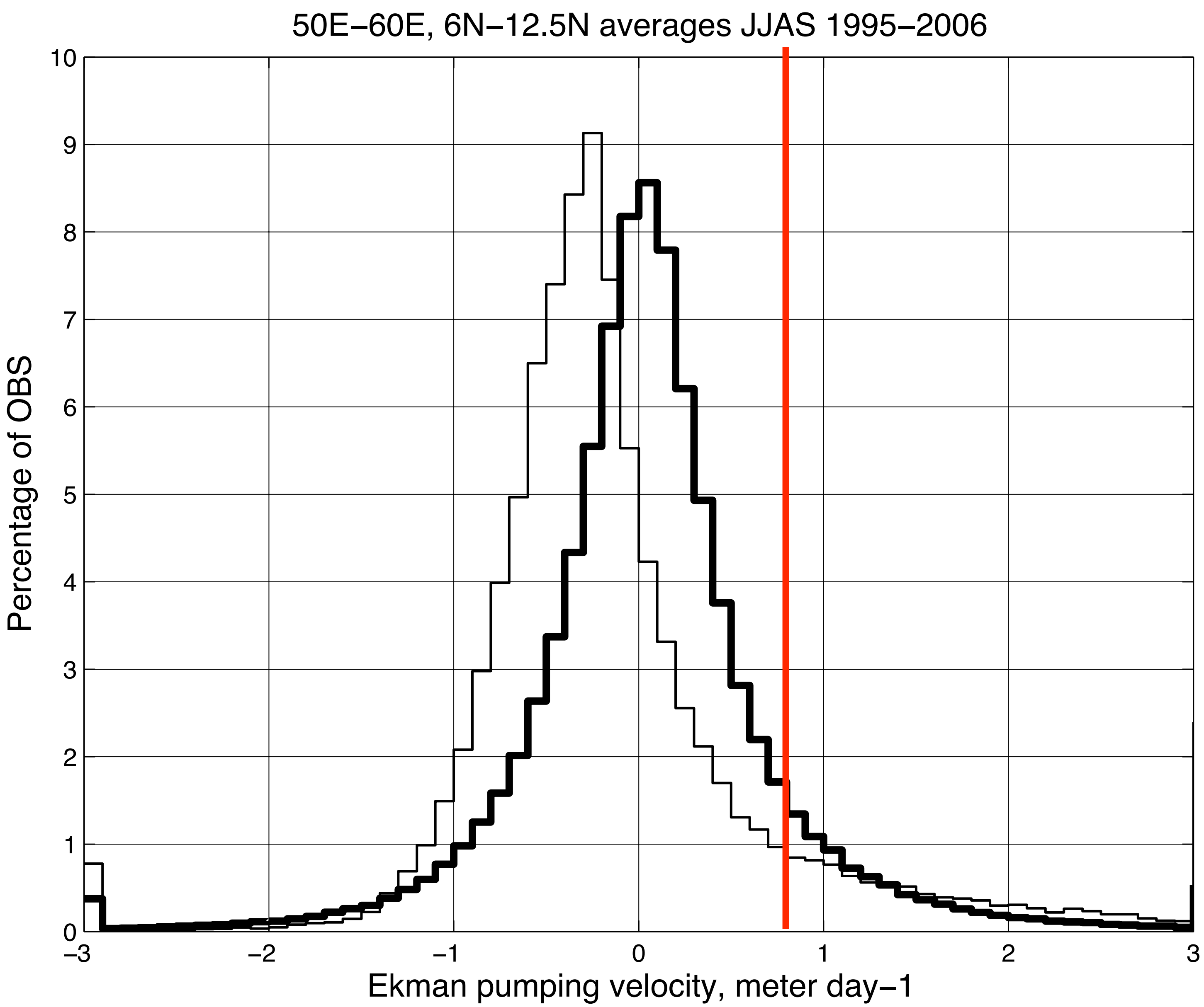
- Mean $-u \cdot \nabla T$ is a strong cooling effect over most of the coastal region (2-3°C/month).
- $-w\partial T/\partial z$ is a warming effect underneath the Great Whirl and cooling the filament.
- Dominance of lateral heat flux is well documented and the ratio of $Qsfc/(-u \cdot \nabla T)$ is generally small.
- Surface heating $(Q/\rho C_p H)$ can be comparable to $-w\partial T/\partial z$ in the region of the GW and cold filaments (localized large ratio).

Conclusion (2)

- ***<u>Thermodynamic feedback</u>***: mesoscale eddies create additional latent heat into/out of the ocean (10-15 W/m^2). This additional surface heat flux warms (cools) the cold filament (warm eddy) at the rate of 0.3-0.4°C/month for a single season with strong eddy activity, and 0.1-0.2°C/month in a 12-yr mean.

  ➔ How this long-term oceanic heat gain by eddies rectify the low-frequency variability of the SST and the monsoon requires further investigation (Izumo et al. 2008).

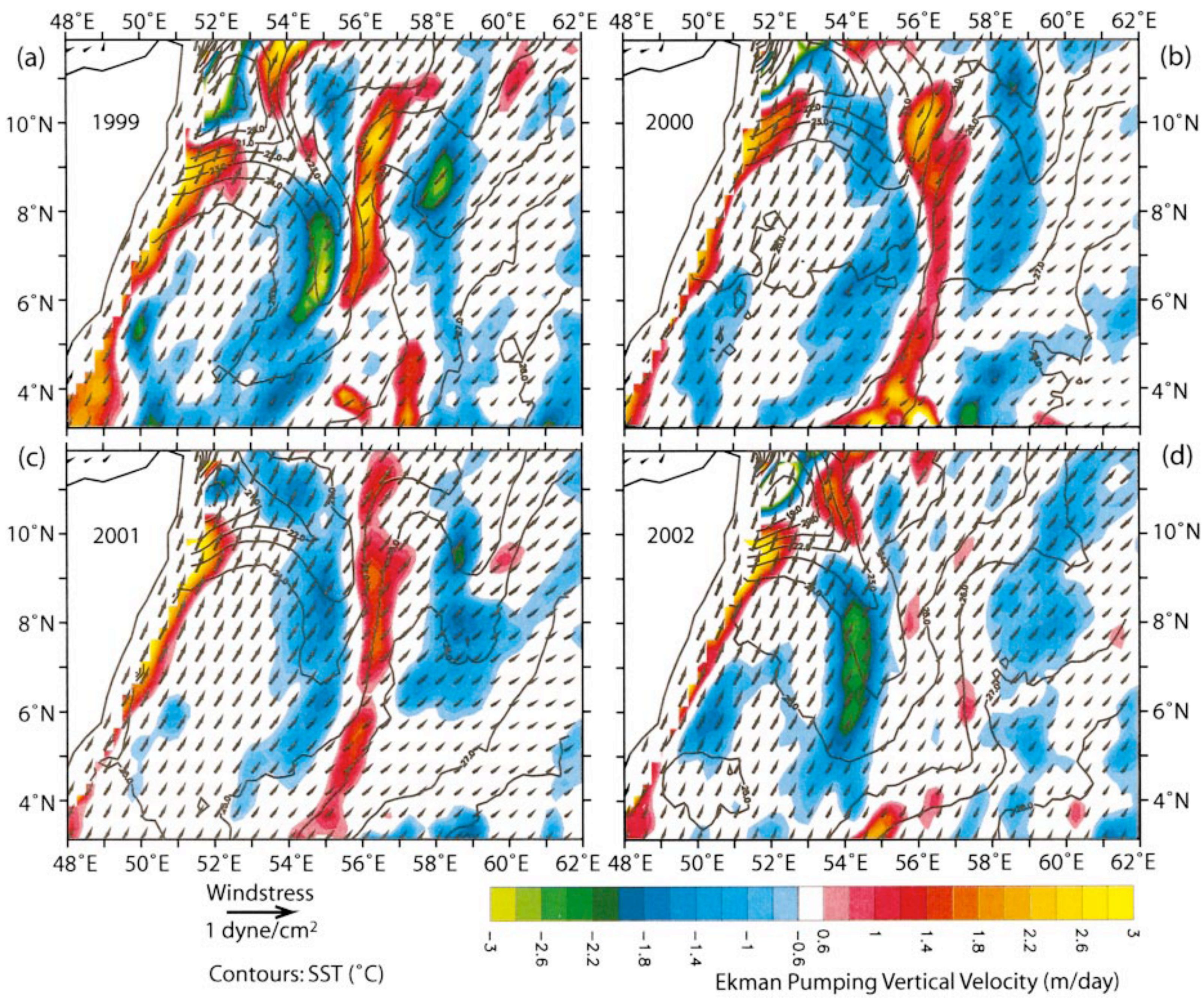
How does Ekman pumping velocity due to the mesoscale eddy compare with that due to the large-scale mean wind?



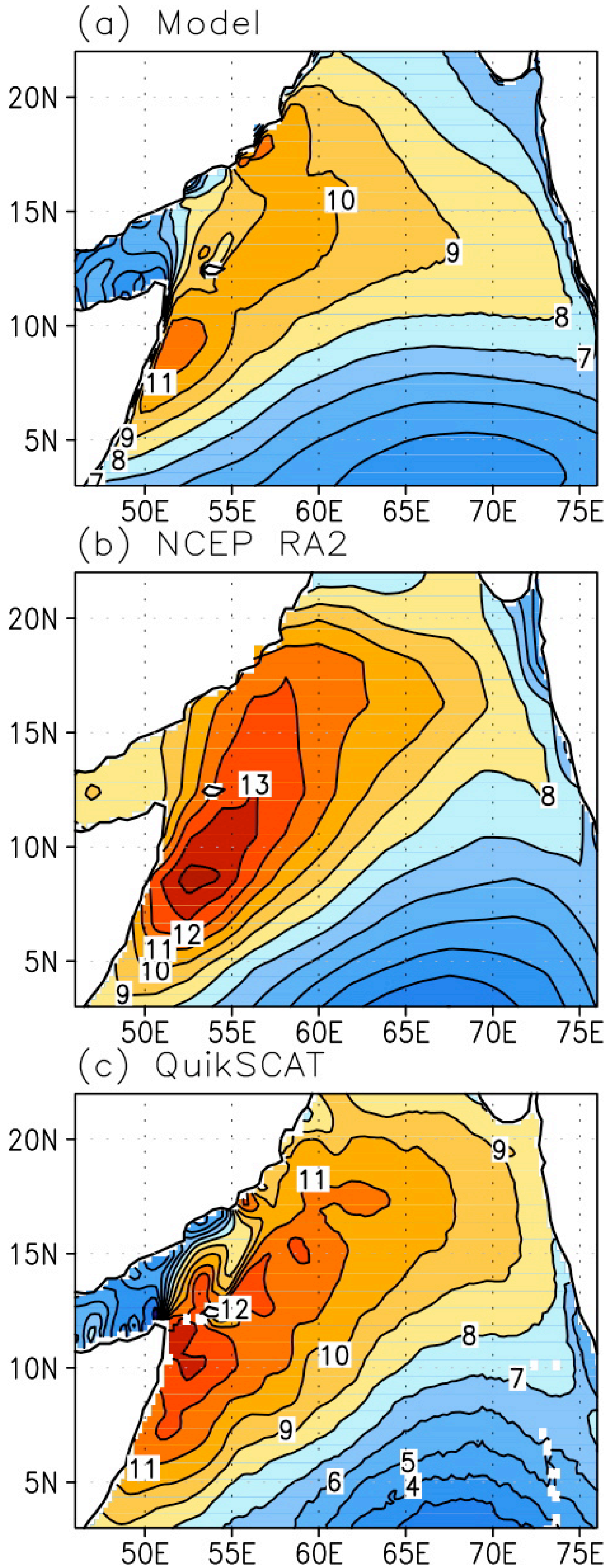
- PDFs of we (thin line) computed from summertime mean wind stresses, and (thick line) computed from anomalous wind stresses exhibit a comparable dynamic ranges.
- The RMS value of *we'* is 0.8 m/day. Approximately 10% of the mean we exceeds this RMS value
- Greater than 18% of the *we'* (both positive and negative) is larger than this RMS value.
- *we'* could be as important as mean we.

JJAS 1995-2006
Similar analysis by O'Neill et al. (2003) and Chelton et al. (2005).

Generation of Ekman pumping velocity due to oceanic influence on the wind



- An important finding of their study: the generation of Ekman up/down-welling velocity of 2-3 m/day over cold filaments (through varying winds: Chelton et al. 2001).
- This *we* is *additional* to the large-scale Ekman pumping.
- This *we* persists over a month following SST.
- Main question: how important is this *we* for the oceanic vertical structure and velocity?



August 10-m wind speed climatology

- Despite RSM's spectral nudging (of waves longer than 1000 km, Kanamaru and Kanamitsu, 2007), SW monsoon flow is too weak in the model.
- ➔ Excessive warm bias in the Arabian sea