The influences of seasonal winds and Kuroshio intrusion on the South China Sea circulation

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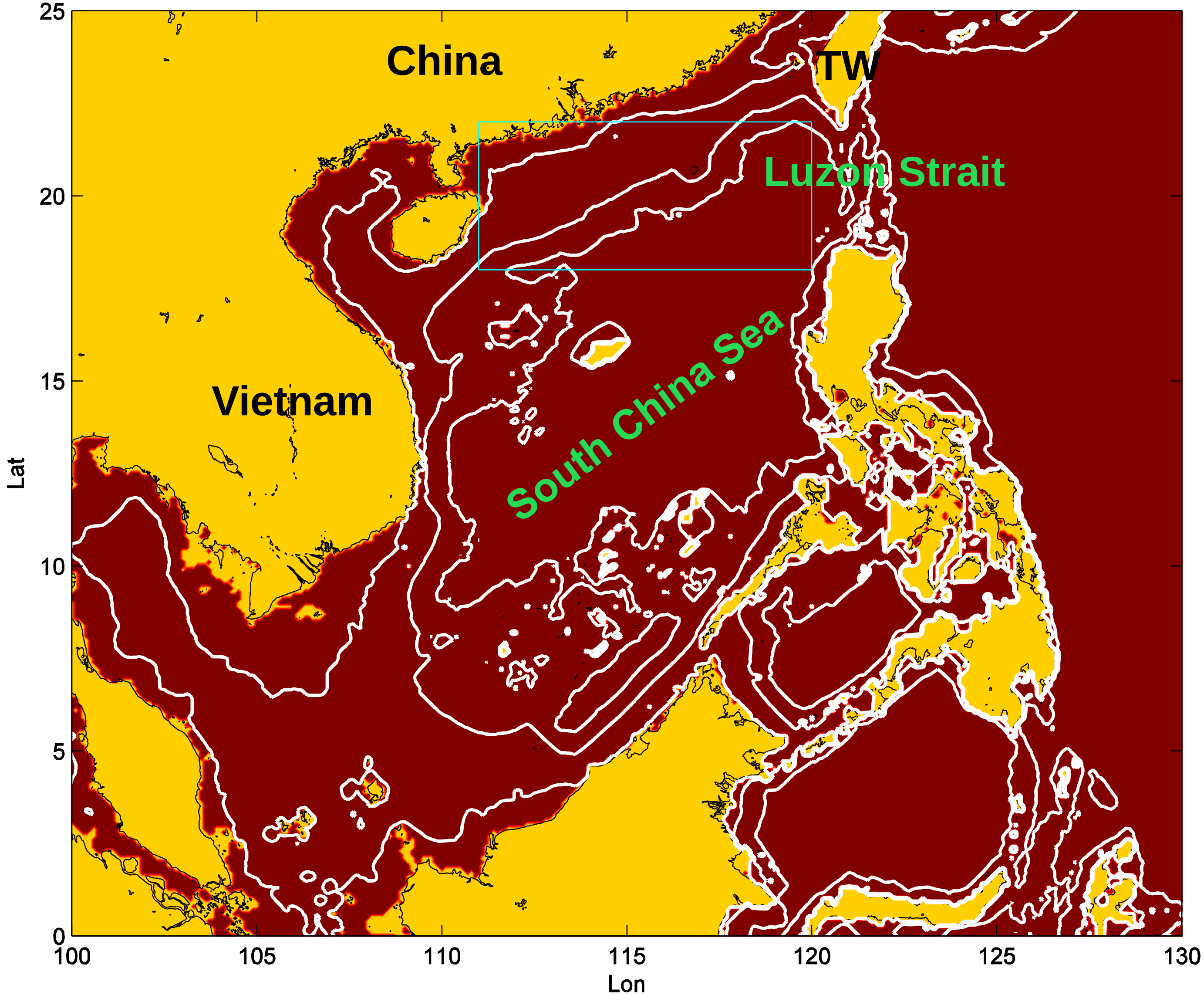
IHOS, NCU, Taiwan, 2014-01-17

SCS



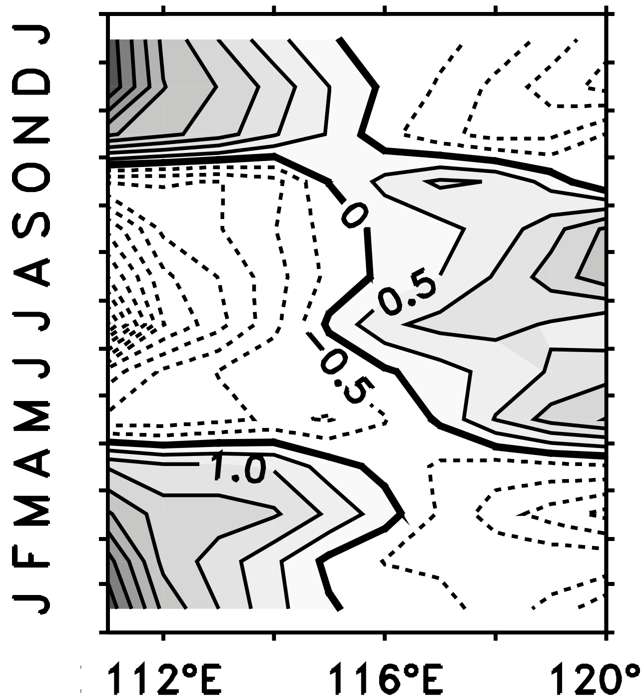
China
TW
Luzon Strait
Vietnam
South China Sea
25
20
15
10
5
0
Lat
100
105
110
115
120
125
130
Lon

(1)How does the Monsoon influence the NSCS directly?

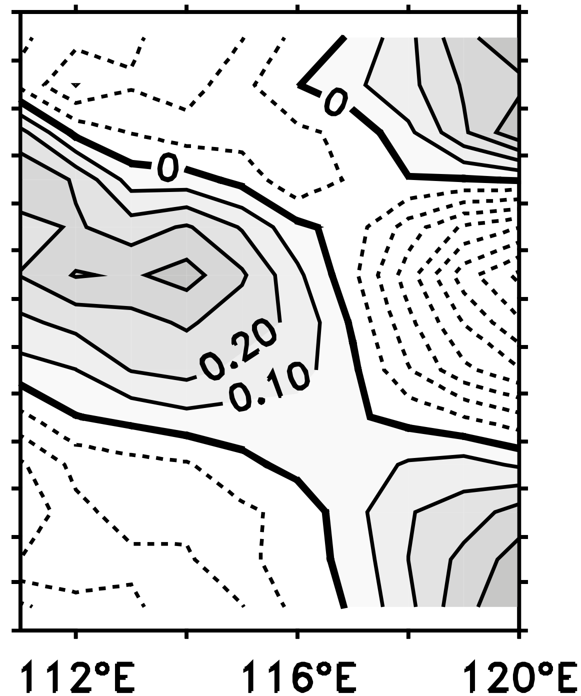
Motivation

Yang and Liu, *DSR I*, (2003)

SSHA

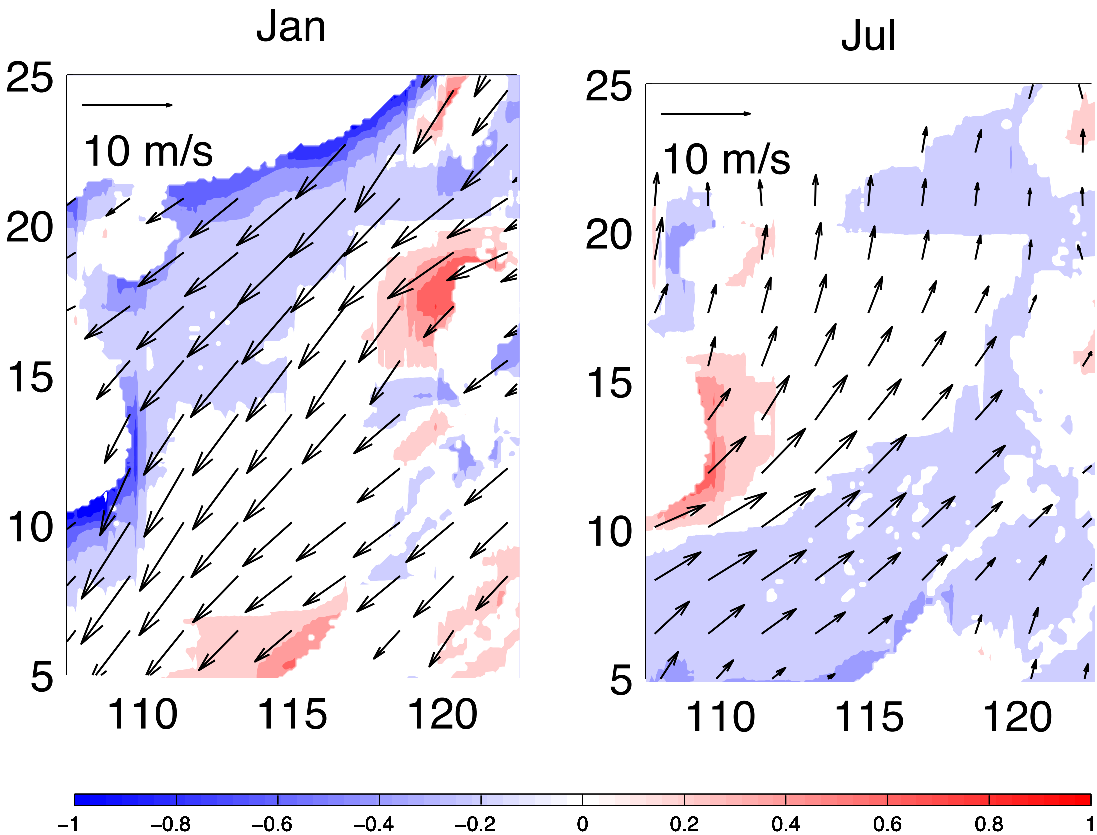


WSC



Rossby Wave? Ekman pumping?

Cross Calibrated Multi-Platform Wind (CCMP) 1987/07-2009/12



In winter, northeastly

In summer, southwestly

$$\frac{\partial h}{\partial t} + C\frac{\partial h}{\partial x} = -w_e$$

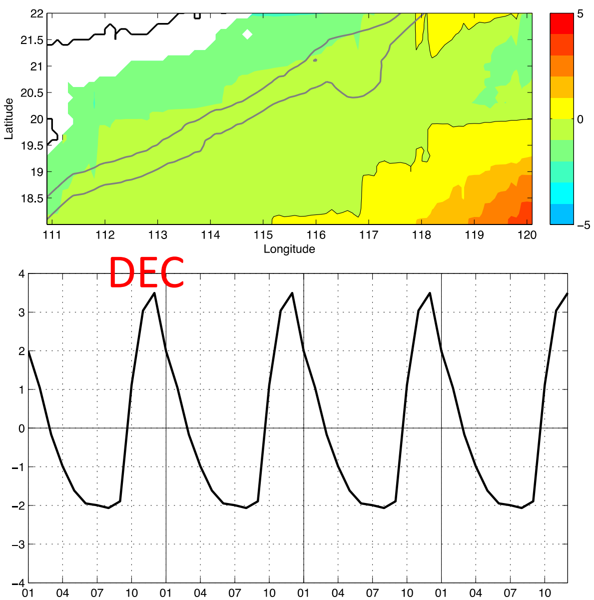
$$C = -\beta R_o^2 ; R_o^2 = \frac{g' H}{f^2}$$

$$w_e = curl\left(\frac{\tau}{\rho_0 f}\right)$$

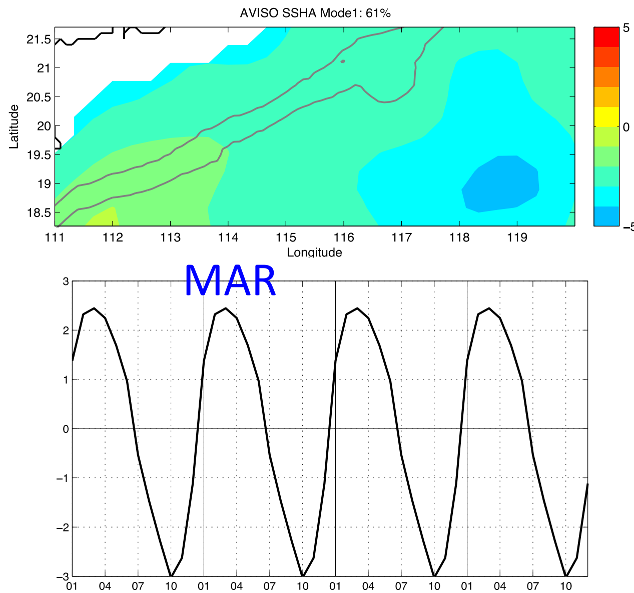
Monthly CCMP winds (vectors) and the wind curl (shaded).

EOF of monthly WSC anomaly and AVISO SSHA(18^o-22^{o}N, 111^o-120^{o}E)

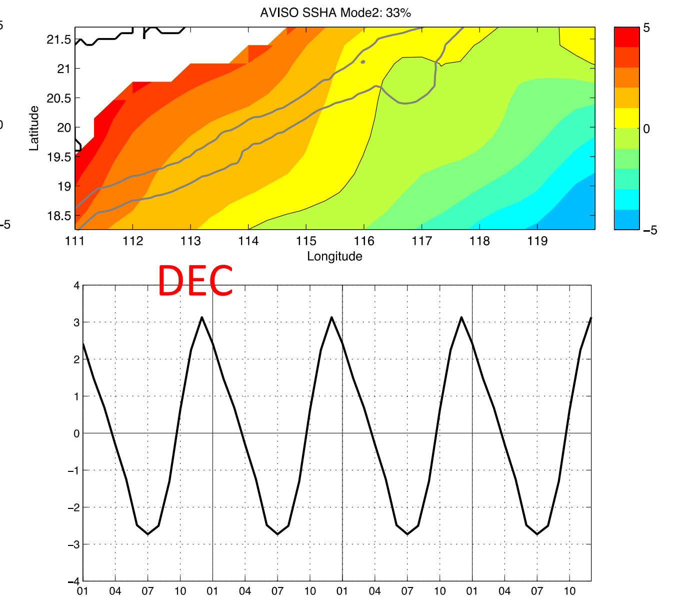
WSC mode 1 (95%)



SSHA mode 1 (61%)



SSHA mode 2 (33%)

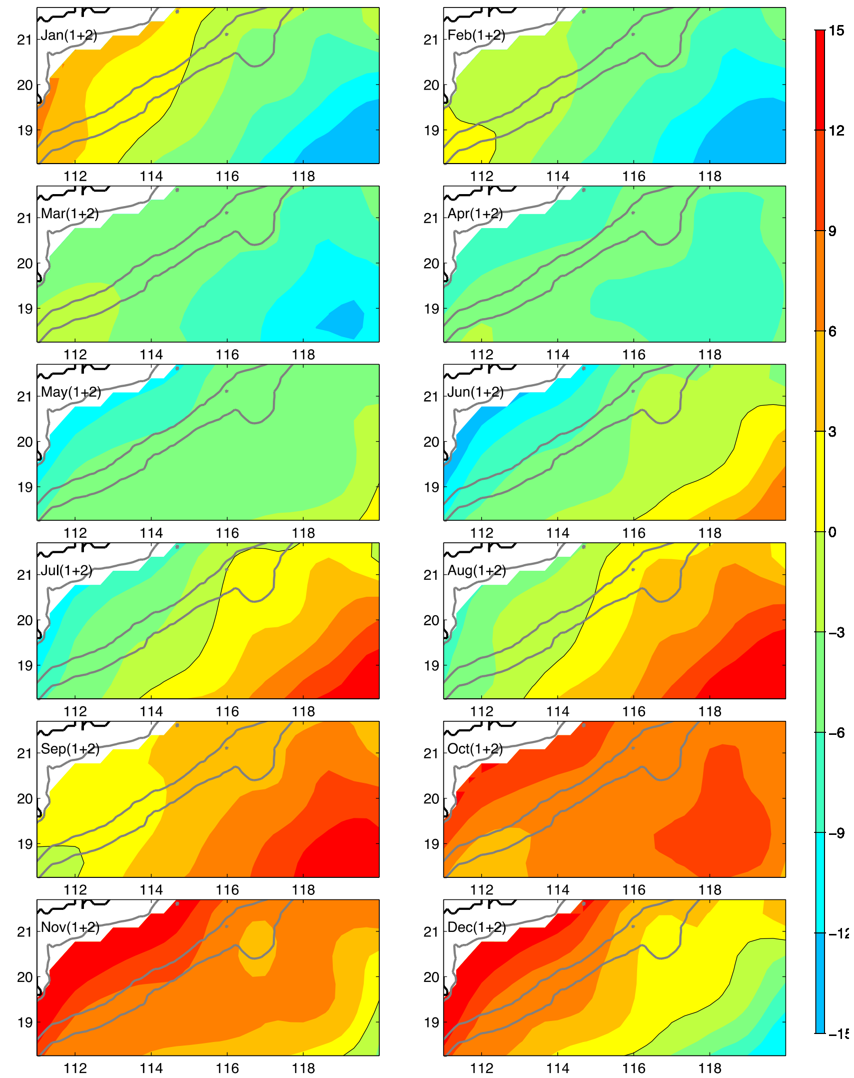


R(WSC PC1, AVISO PC1)@3months=0.92

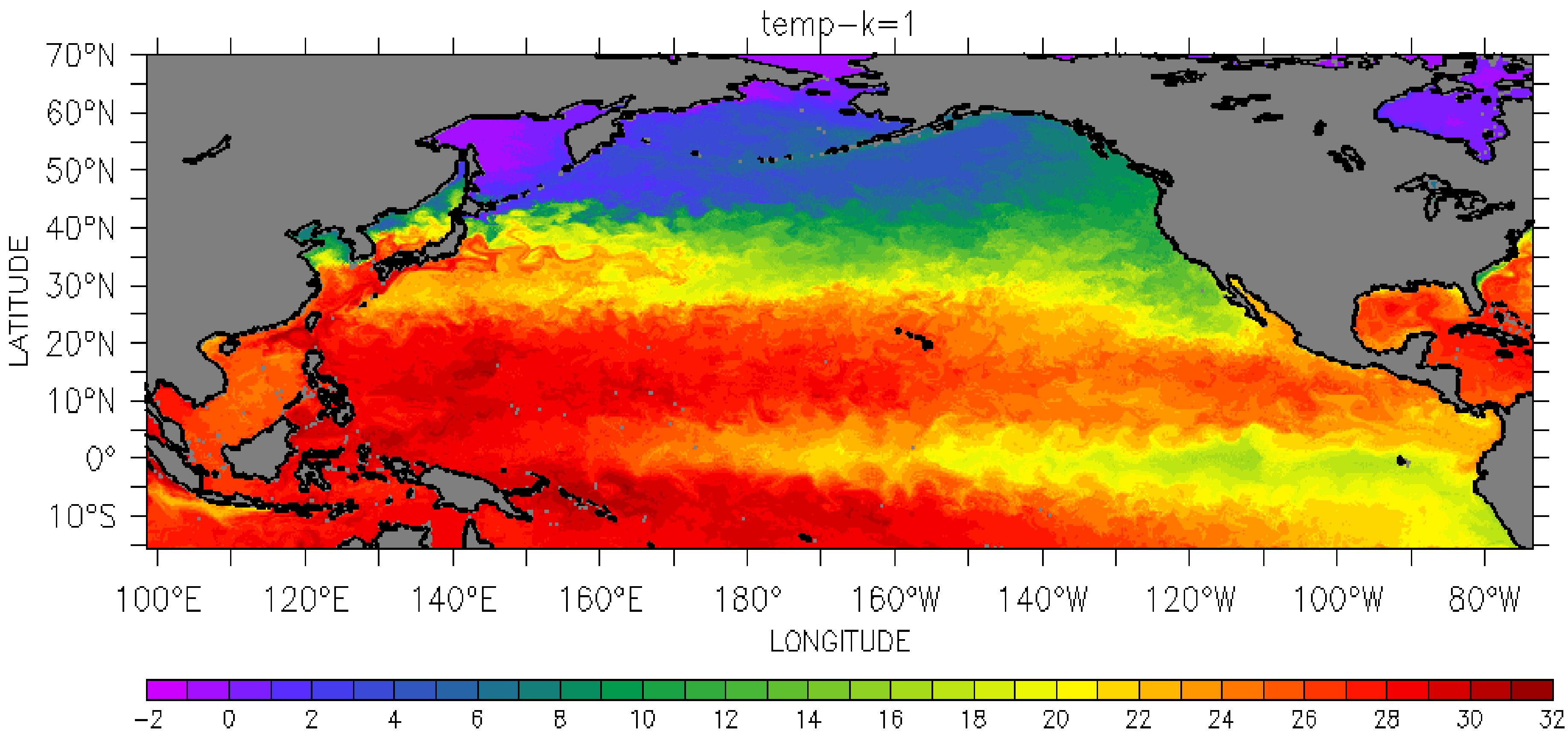
R(WSC PC1, AVISO PC2)=0.96

Reconstructed SSHA EOF1+2

- The SSHA negative southwest of LZS in winter, and positive in summer.
- It seems to propagate towards the China coastlines.
- How much can Ekman dynamics alone (f-effect) contribute to the SSHA variability over the NSCS?



Advanced Taiwan Ocean Prediction (ATOP)

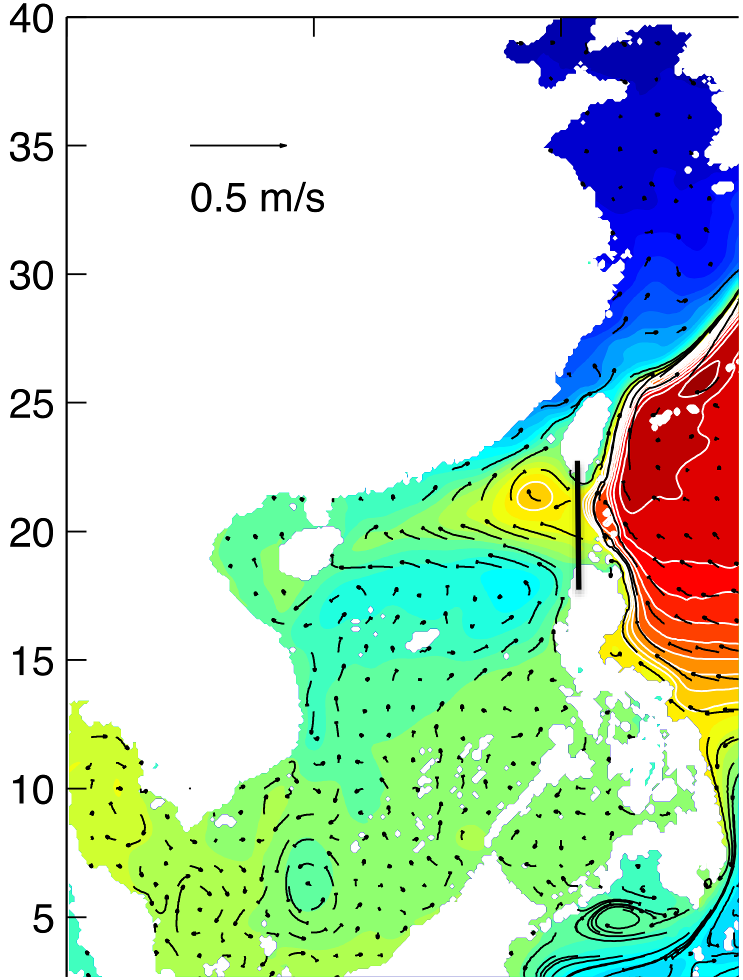


* http://mpipom.ihs.ncu.edu.tw/index.php

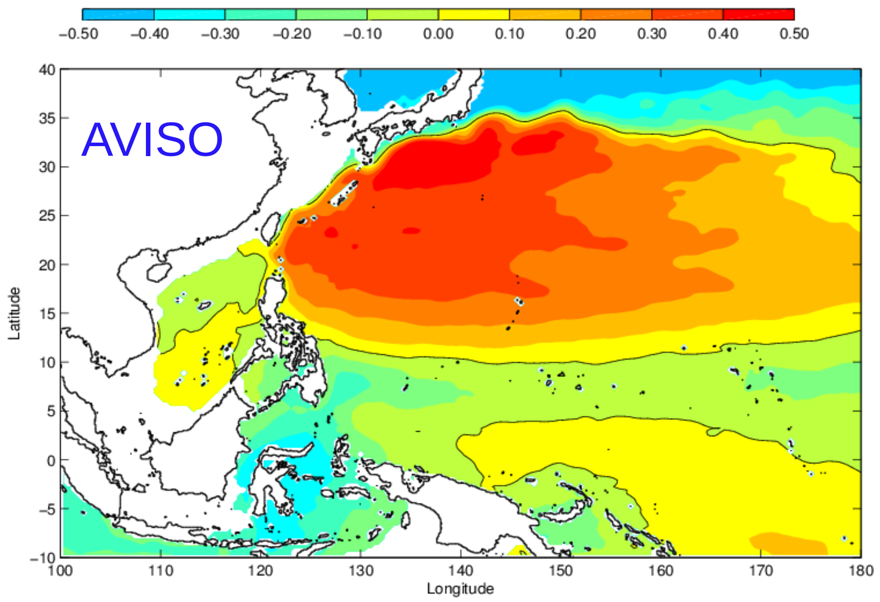
Oey et al. 2013: ATOP – Advanced Taiwan Ocean Prediction System based on the mpiPOM. Part 1: model descriptions, analyses and results. Terr. Atmos. Ocean. Sci., Vol. 24, No. 1, 137-158, doi: 10.3319/TAO.2012.09.12.01(Oc). (http://tao.cgu.org.tw/pdf/v241p137.pdf)

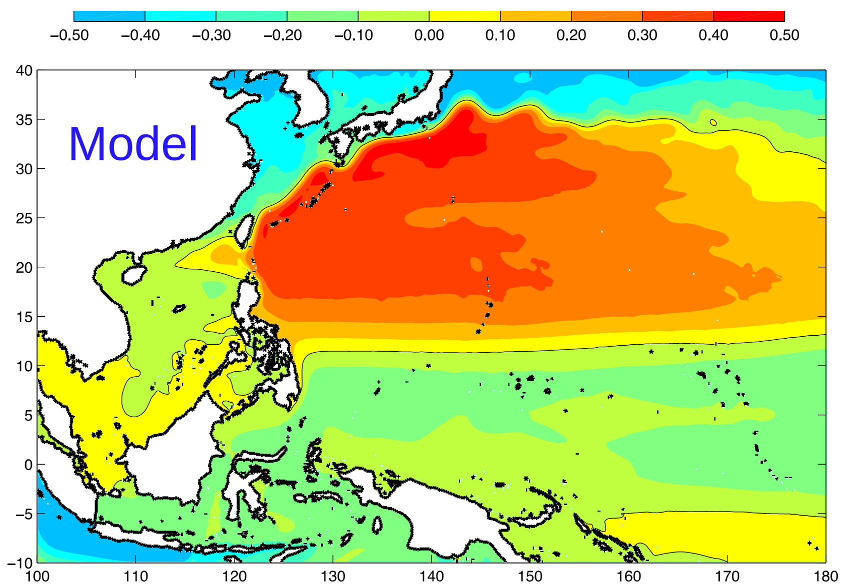
Three Numerical Experiments

Name	Luzon Strait
β-plane (control run)	Open
f-plane, clz	Closed
β-plane, clz	Closed



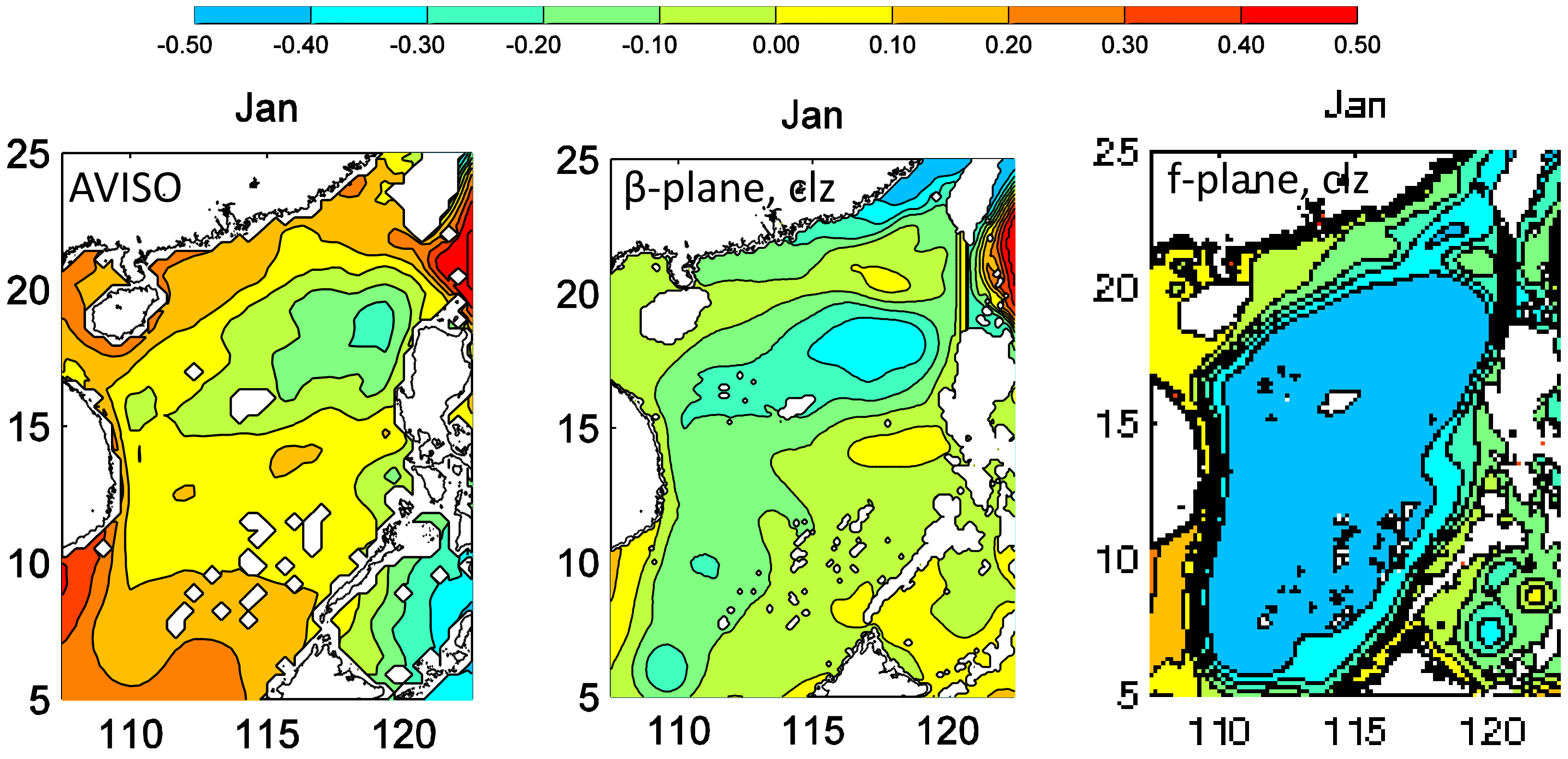
Comparison of
Model & AVISO SSH





AVISO Maps of Absolute Dynamic Topography (MADT) data: averaged over 1993-2011 (H>500m)

Comparison of monthly SSHA

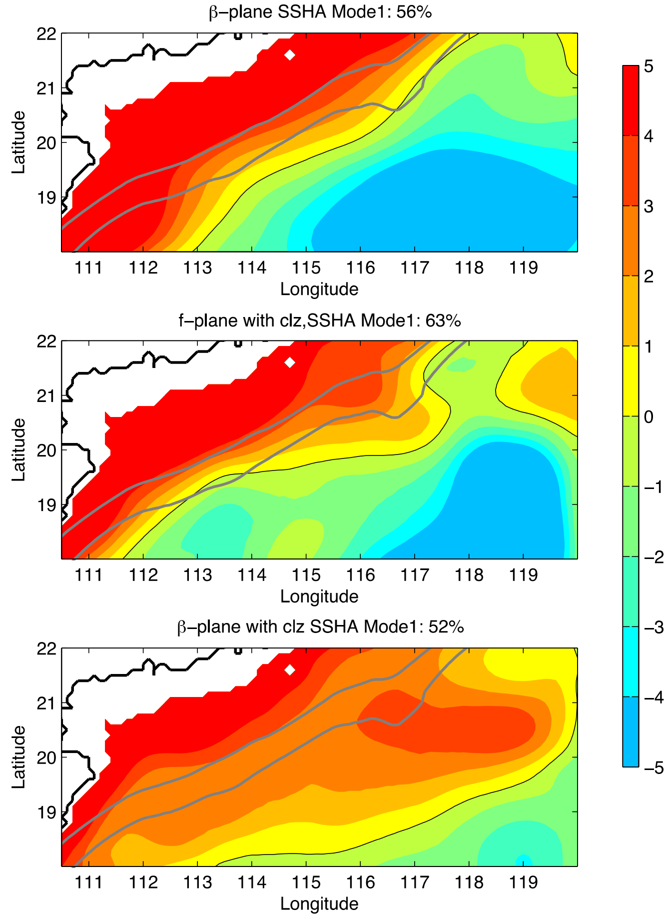


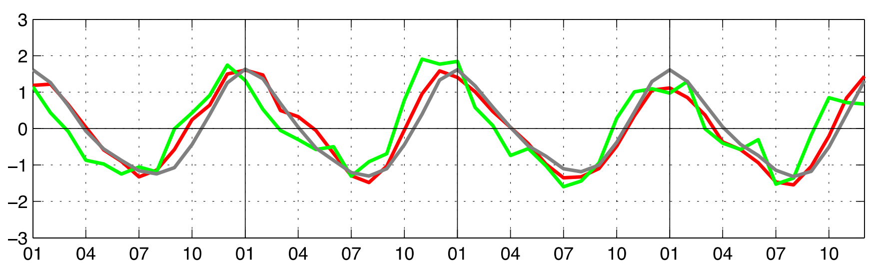
EOF mode 1 of the modeled SSHA

β-plane,
control run

f-plane,
close Luzon

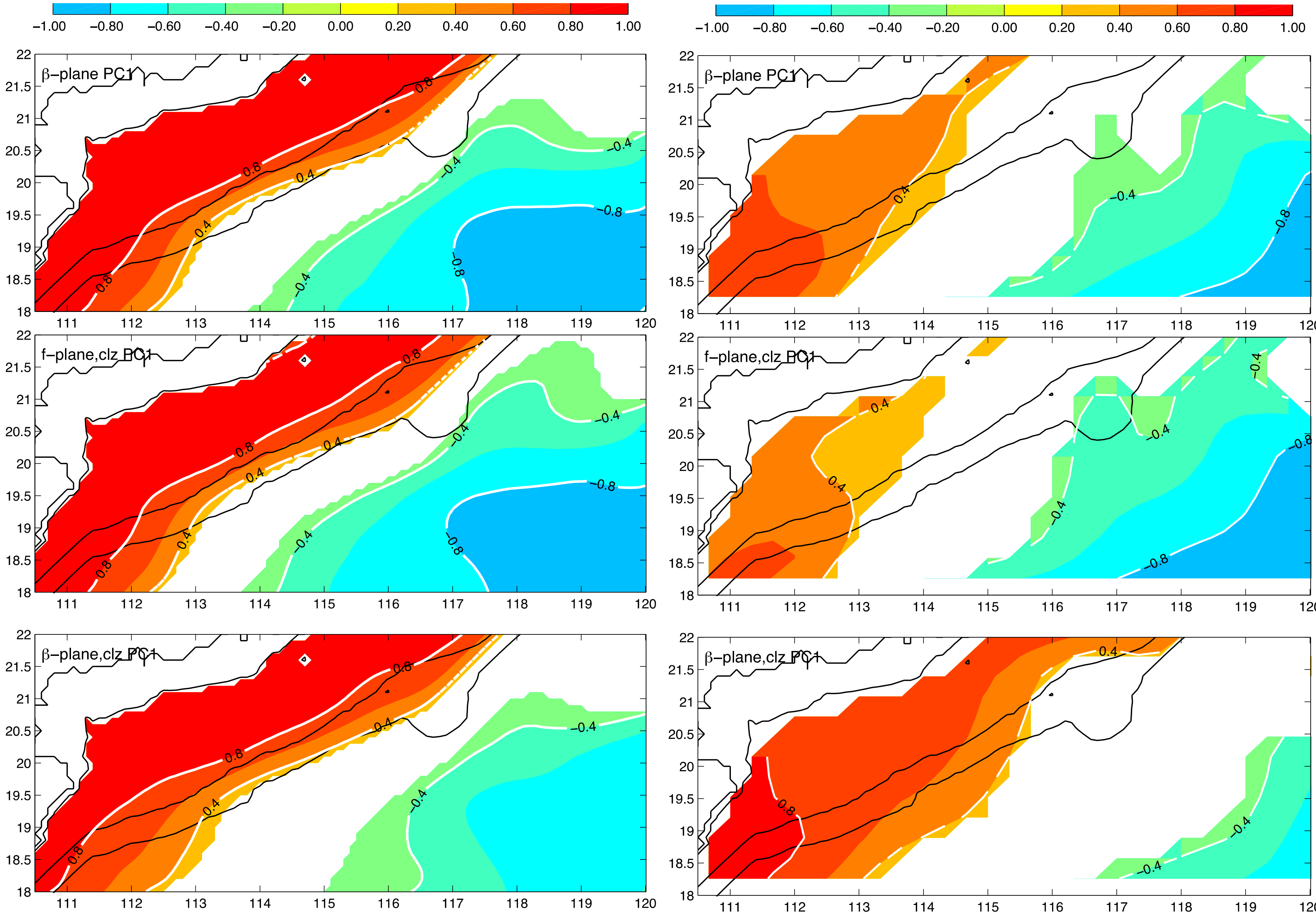
β-plane,
Close Luzon





- The f-plane explain a lot of the SLA change in the NSCS.
- The β-plane with close Luzon cannot explain well the SLA
- Kuroshio intrusion?

Correlation with β-plane (Control Run) SSHA | Correlation with AVISO SSHA



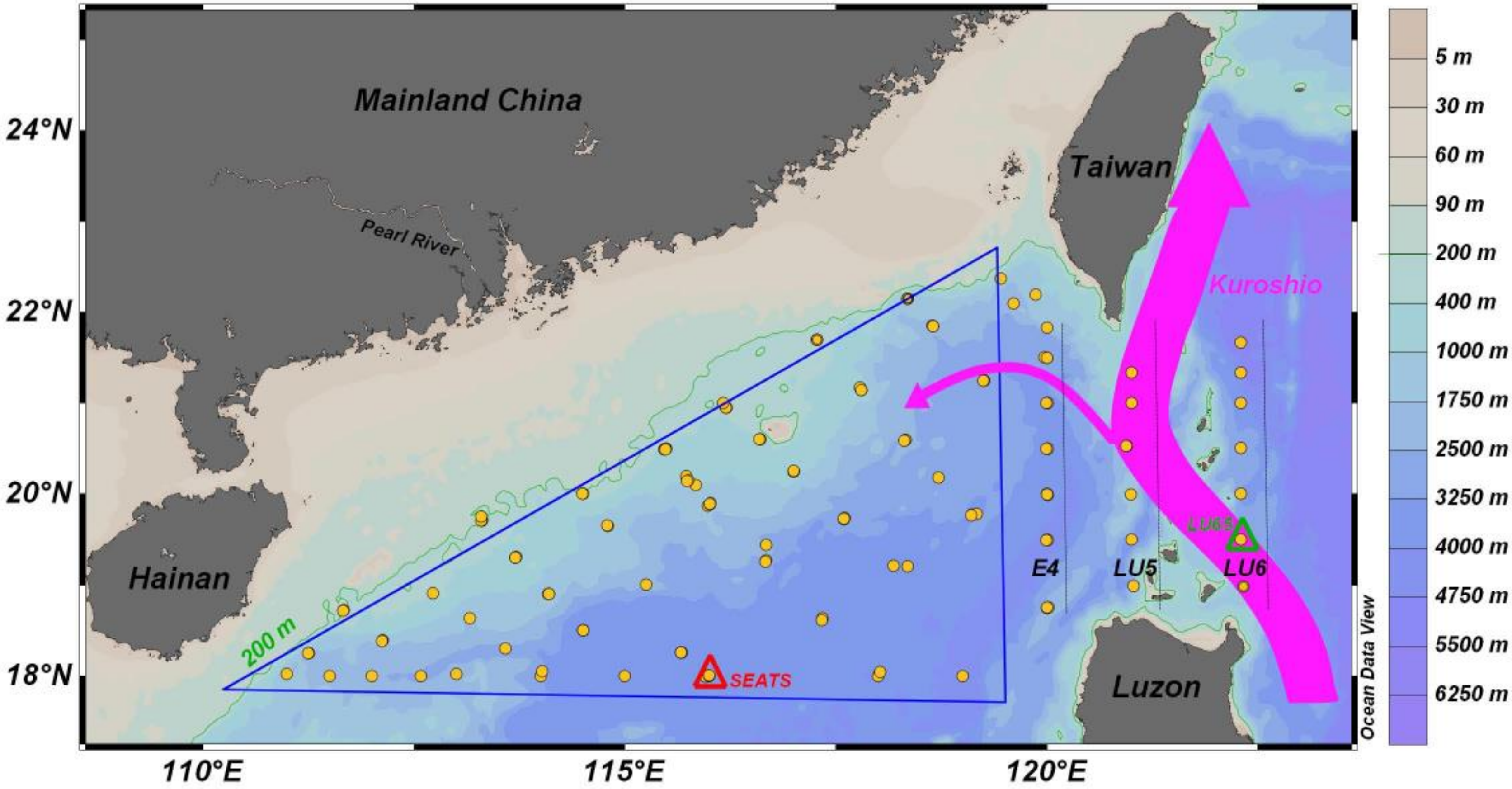
Summary 1

In northern SCS, on seasonal time scale, wind stress curl shows a westward-propagating pattern that is highly correlated with the observed SSHA from AVISO.

The f-plane model can explain a large percentage of the variance of SSHA, while β-plane with Luzon Strait closed can not produce the coherent structure seen in the Control Run with open Luzon Strait.

(2) How does the Kuroshio intrusion (via Luzon Strait Transport (LST)) influence SCS Circulation?

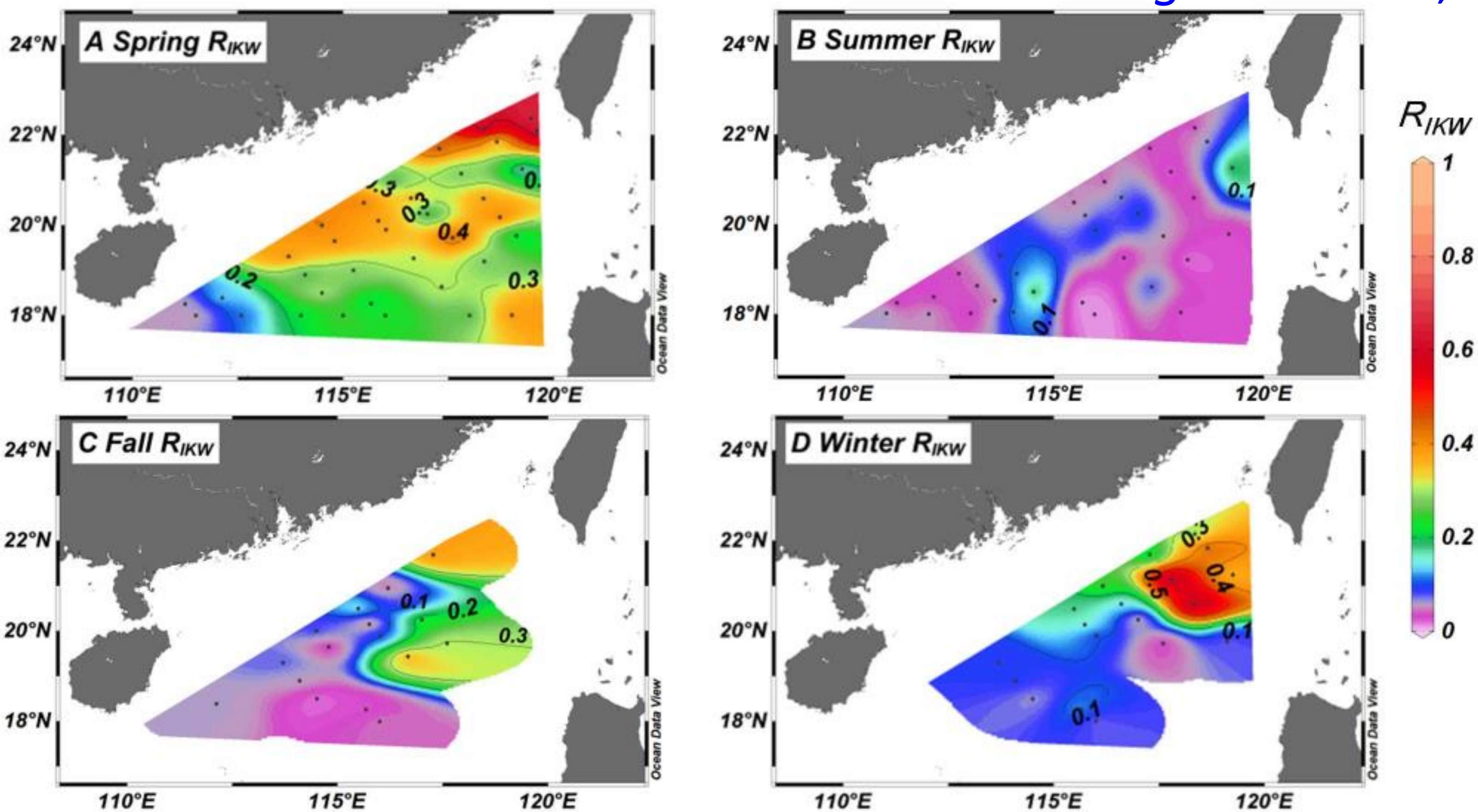
Observation of the Kuroshio Intrusion



From Du et al. *Biogeosciences*, 2013

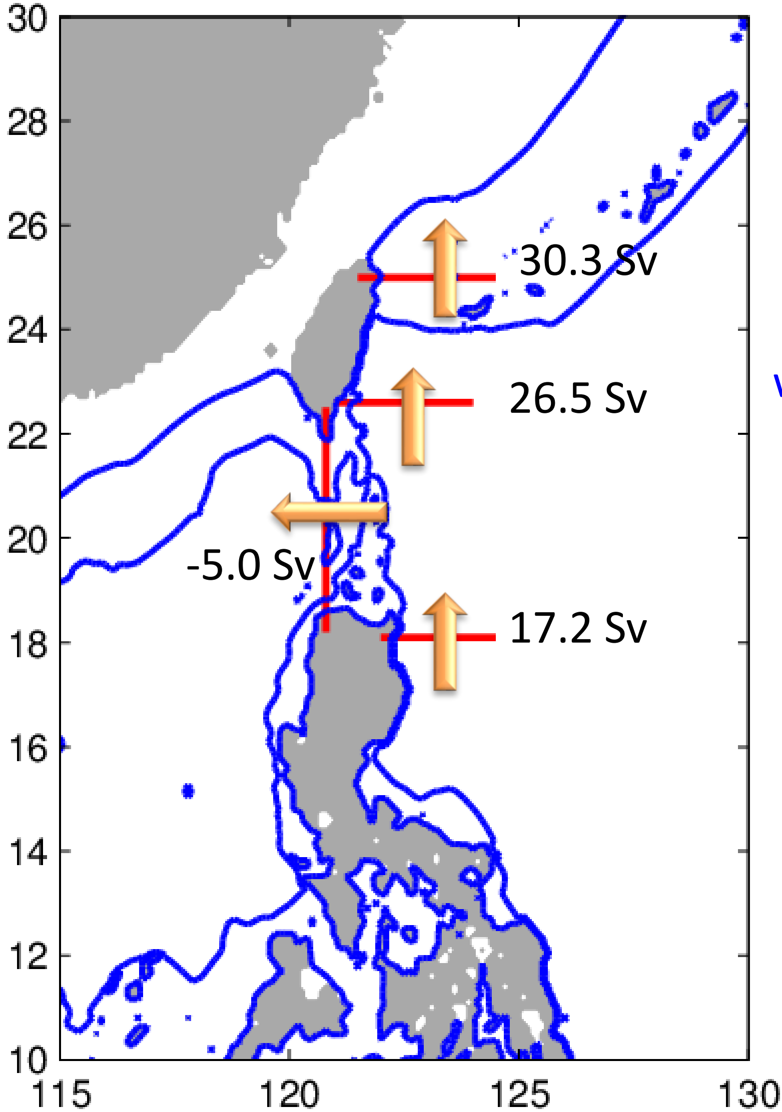
Station-integrated Kuroshio Water Fraction

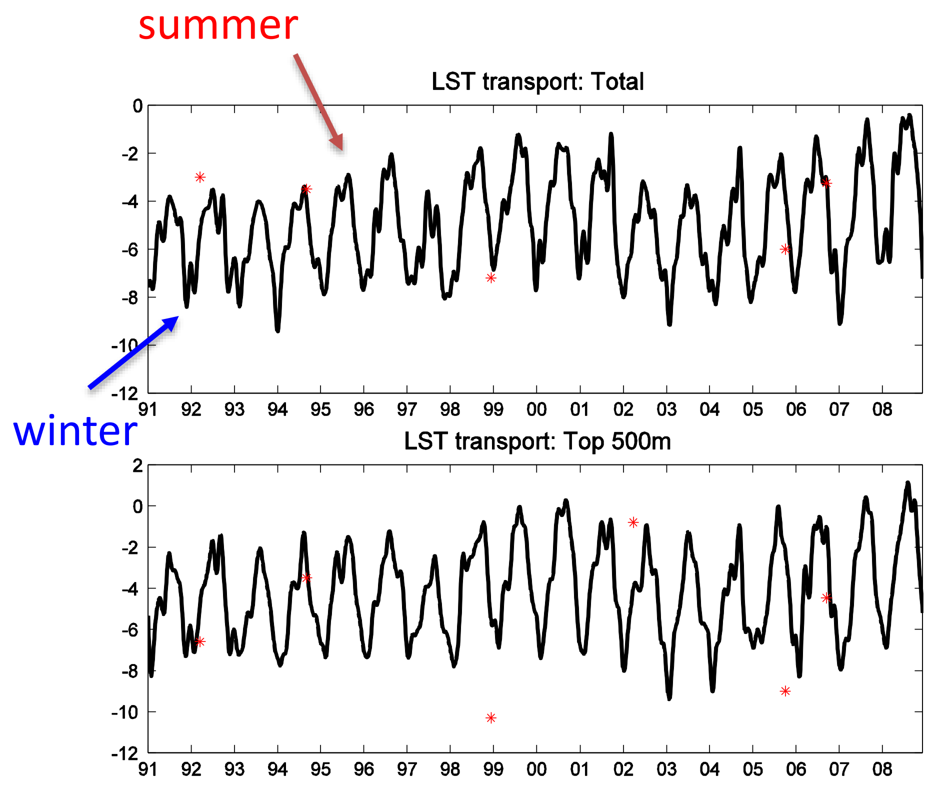
From Du et al. *Biogeosciences*, 2013



- Kuroshio intrusion is confined near (west of) Luzon Strait.
- Can it influence further downstream? And how?

LST estimated from the control run





- 30-day low pass transport across Luzon Strait
- Observed transport (red star) from Hsin et al. JGR (2012)

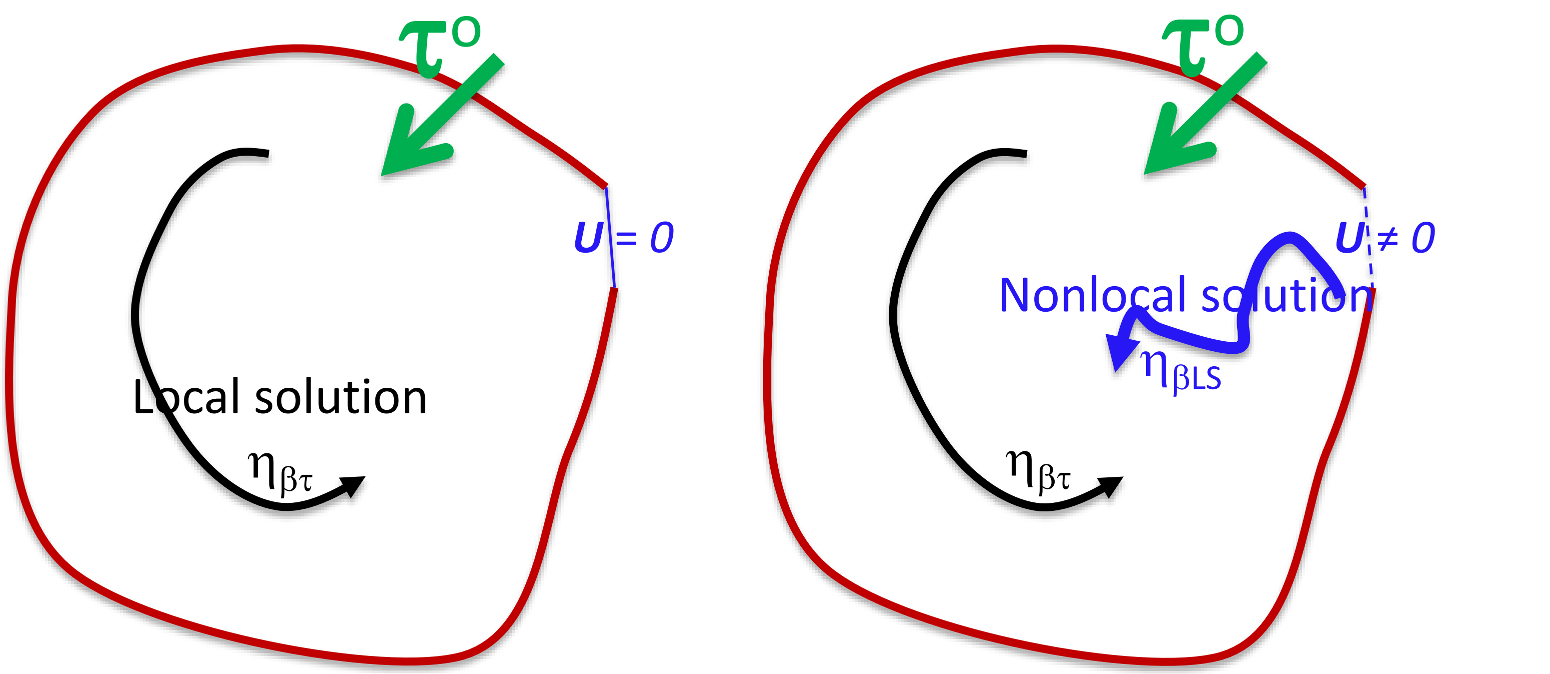
SCS response due to Luzon Strait Transport (LST): $\eta_{\beta LS}$

$$\eta_{\beta LS} = \eta_{Con} - \eta_{\beta\tau}$$

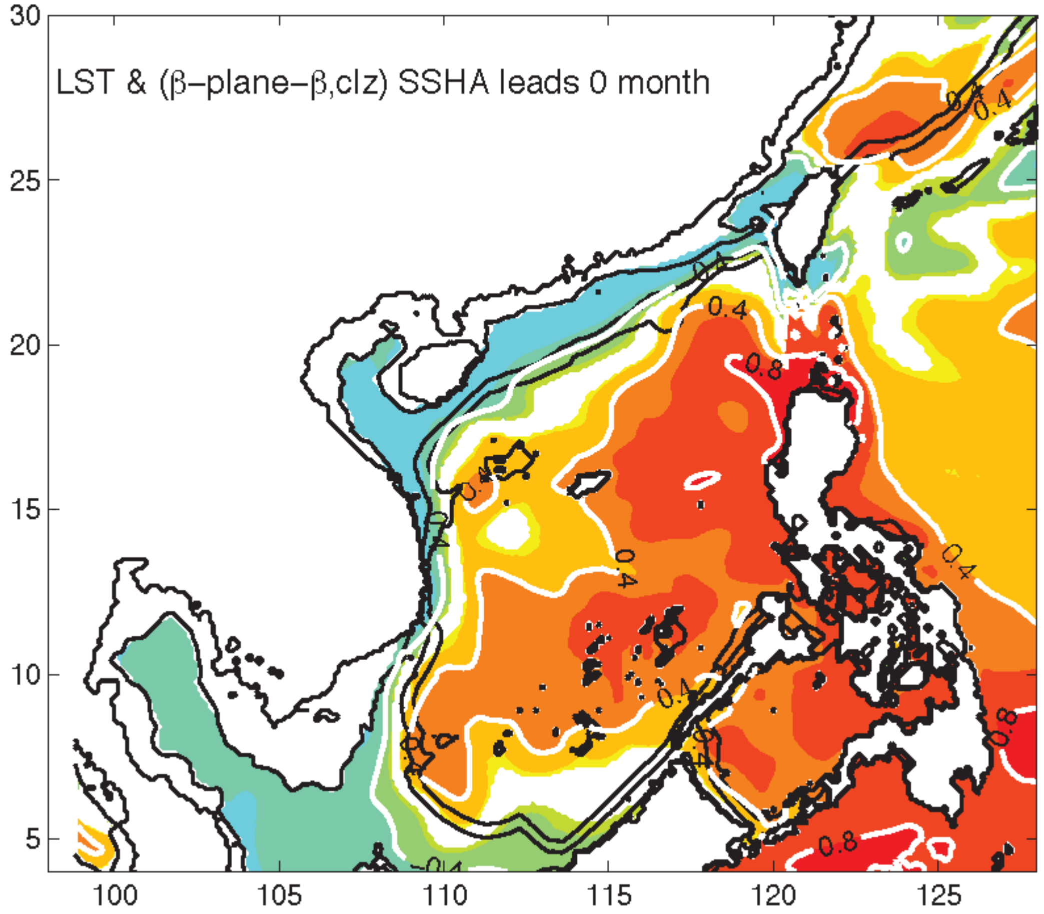
where η = SSHA

Con = Control run with opened Luzon Strait (LS) & wind τ^o

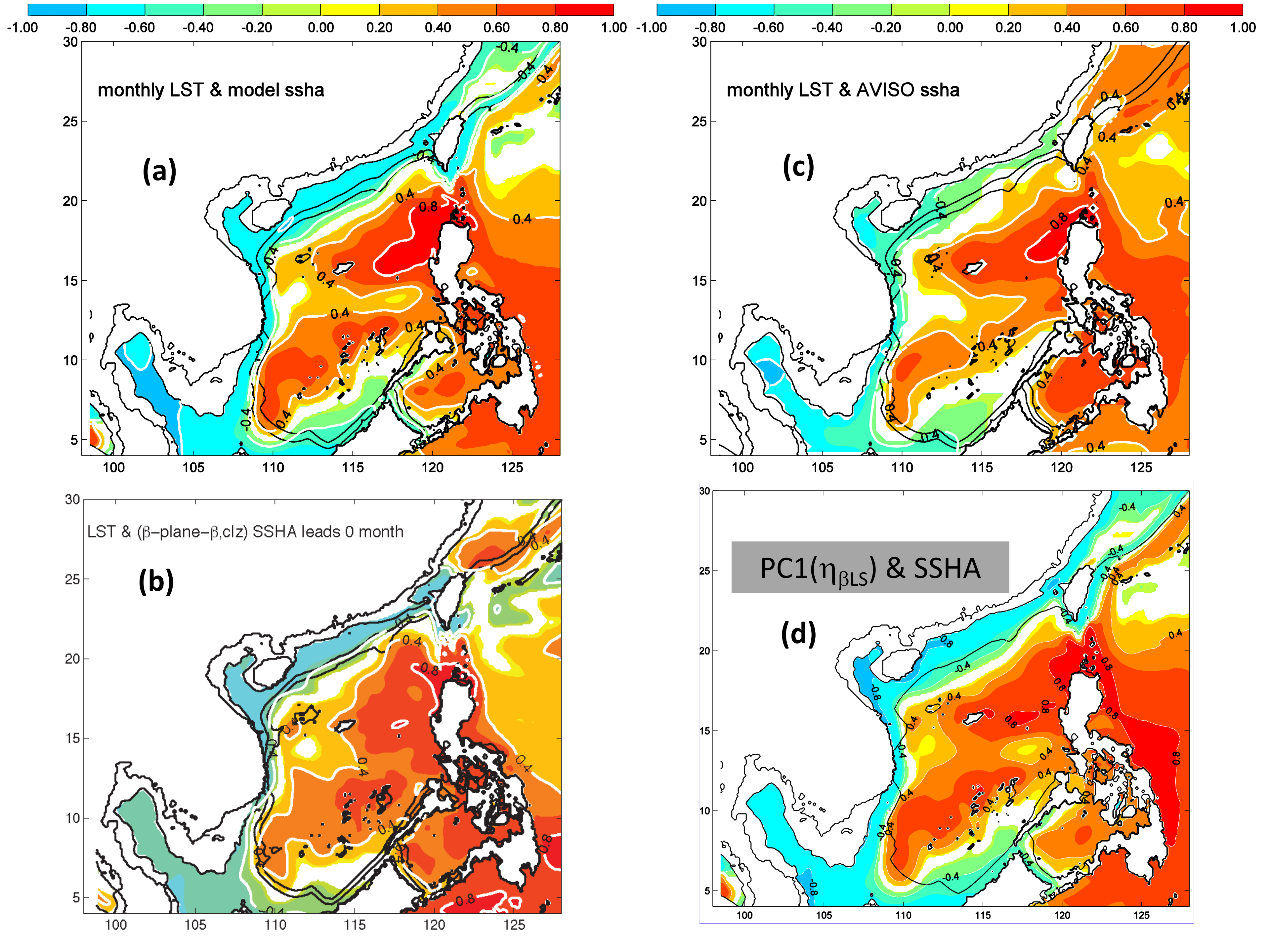
$\beta\tau$ = β-clz run w/same τ^o but closed LS.



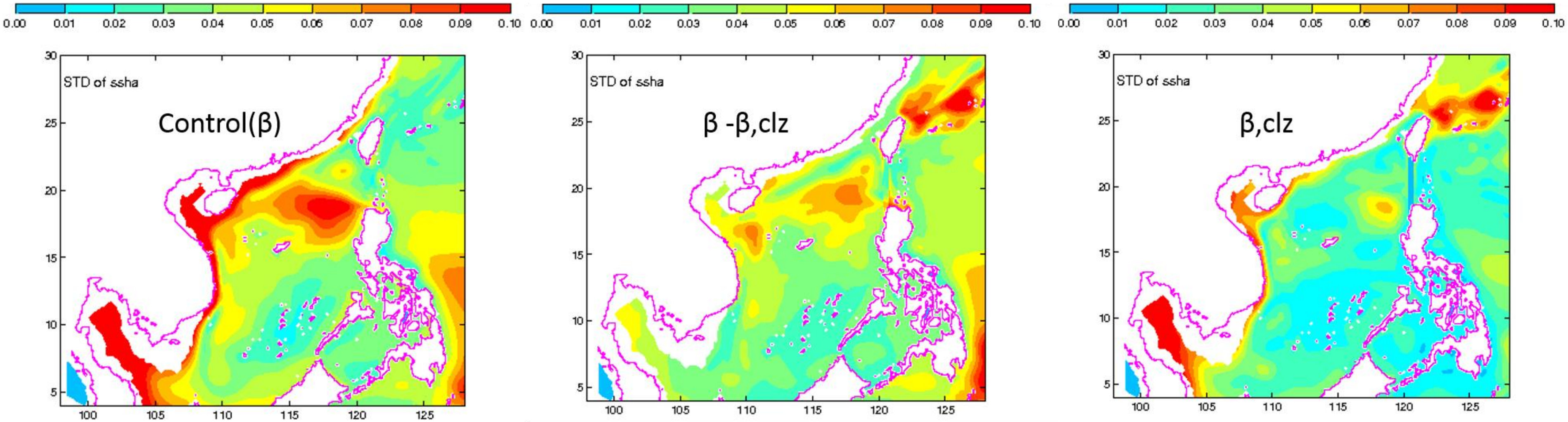
Correlation of LST and $\eta_{\beta LS}$



This confirms that $\eta_{\beta LS}$ is produced by LST.


monthly LST & model ssha
(a)
LST & (β-plane-β,clz) SSHA leads 0 month
(b)
monthly LST & AVISO ssha
(c)
PC1(η βLS) & SSHA
(d)
-1.00 -0.80 -0.60 -0.40 -0.20 0.00 0.20 0.40 0.60 0.80 1.00

STD of η_{Con}, $\eta_{\beta LS}$, and $\eta_{\beta\tau}$

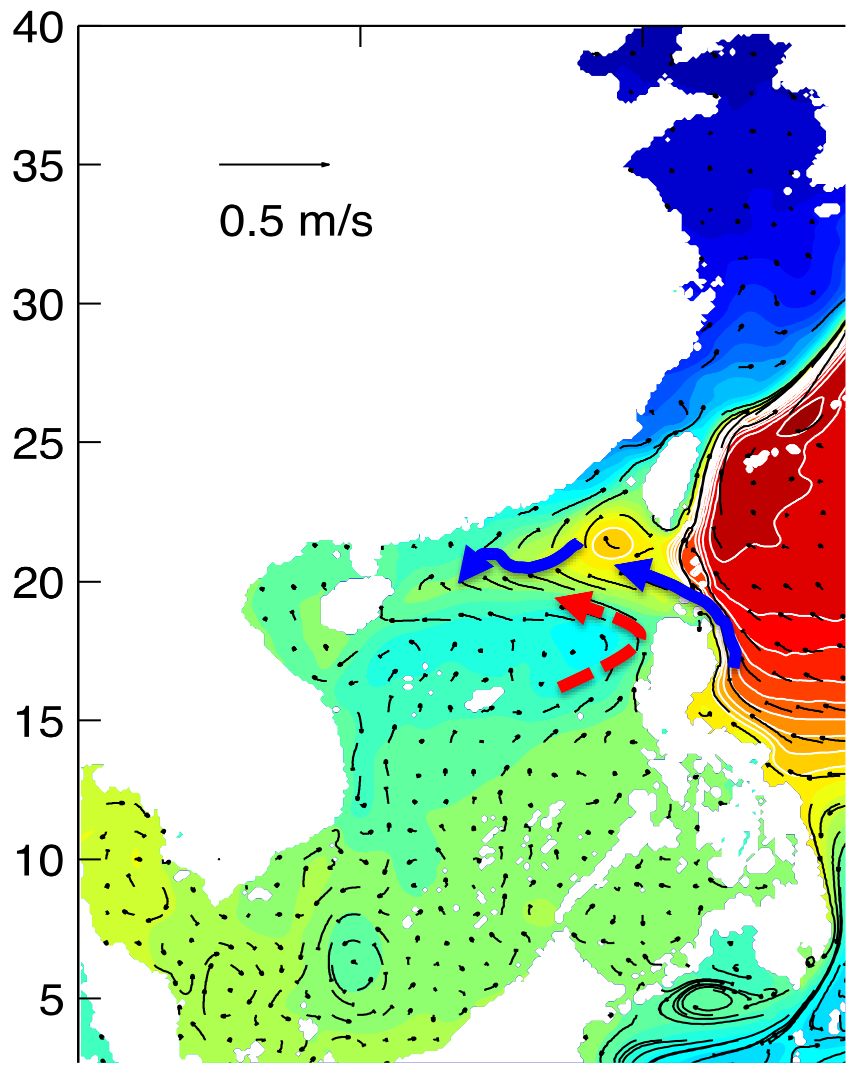


LST has a stronger influence on η_{Con} than the wind.

Summary 2

- Kuroshio intrusion is examined. Its variation at seasonal cycle is: strong in winter, but weak in summer.

- The intrusion shows a cyclonic type of circulation and tend to intrude SCS water west of Luzon Island into the NSCS, consistent also w/β-plume, and then propagating west-southwestward along the shelf break.

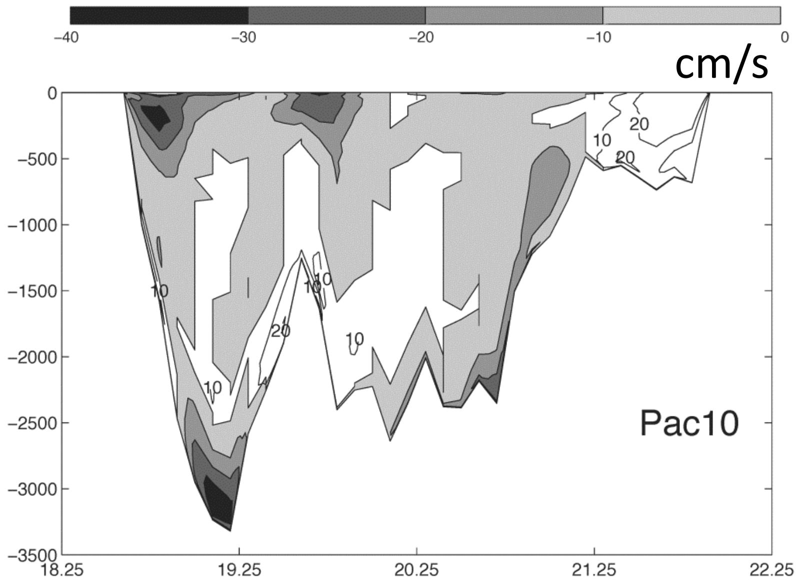


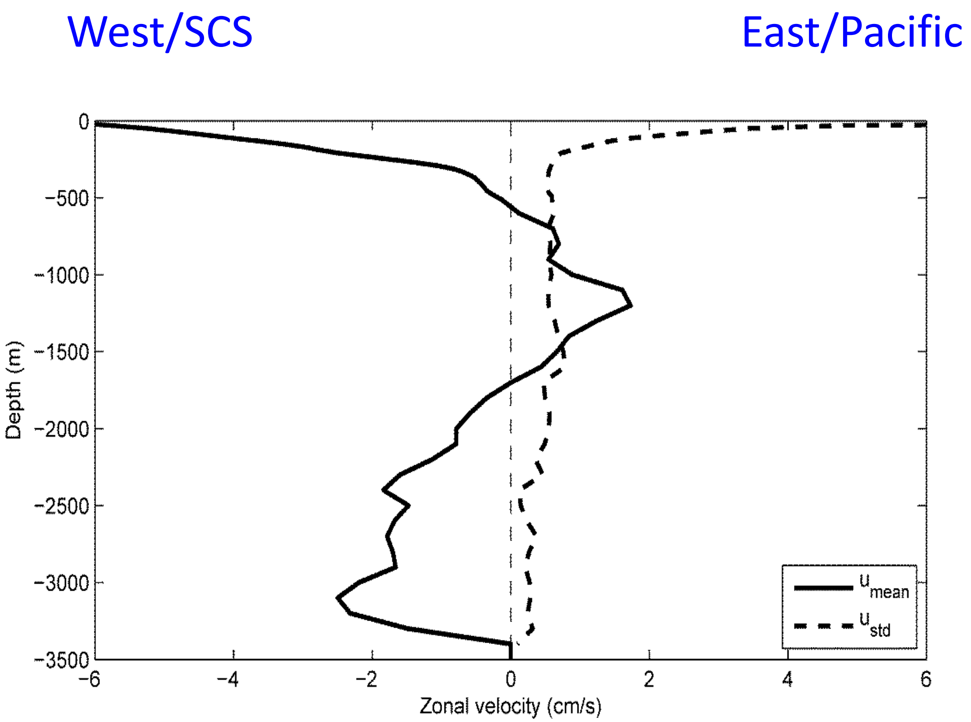
(3) How does the 3-layer transport of the Luzon Strait influence the 3-layer circulation in the SCS?

Luzon Strait Transport

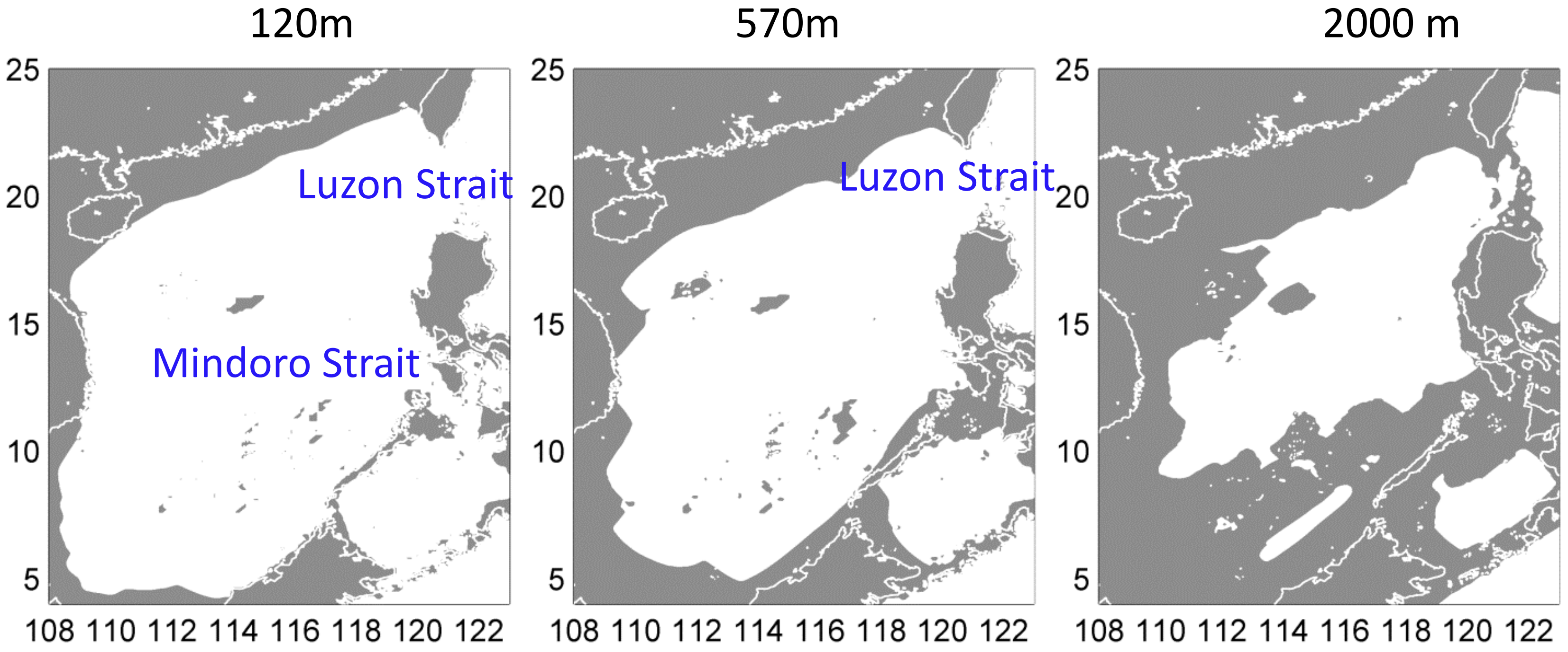
Transport (Sv) → Authors ↓	Total (BI) 0-bottom	Upper 0-500m	Middle 500-1500m	Lower 1500-bottom	Time ↓
1. Tian et al. (2006)	-6 (10.5)	-9	5	-2	10/04-06 2005
2. Liao et al. (2008)	-7.2 0-2000m	-10.3 0-400m	3.1 400-2000m		11/28-12/27 1998
3. Yuan et al (2008a)	-3.5 (2.1)	-3.5 0-400m	0.22 400-1200m	-0.22 1200-bottom	08/28-09/10 1994
4. Yuan et al (2008b)		-0.8 0-400m	2.4 500-1200m		03/17-04/15 2002
5. Yuan et al (2009)	-3 (7.1)	-6.6 0-400m	3.7 400-2000m	-0.1 2000-bottom	03/08-27 1992
6. Zhou et al (2009)	-3.25 0-1500m	-4.37	1.12		09/18-20 2006
7. Yang et al. (2010)	5.5 (1.0)	5	2.5	-2	07/05-14 2007
8. Exp.OI	-0.4 (8.2)	-3.7	5.6	-1.5	01/20-04/03 2012
9. Exp.LETKF	-2.4 (8.4)	-5.5	4.8	-1.7	
10. Pac10: Mean → JFM AMJ JAS OND	-5.0 (6.6) -6.7 (7.4) -4.0 (5.9) -3.1 (5.5) -6.1 (7.3)	-4.3 -6.7 -3.5 -1.8 -5.1	2.7 2.7 2.6 2.6 2.8	-3.4 -2.7 -3.1 -3.9 -3.8	1991-2008 Winter Spring Summer Fall
11. Zhang et al (2010) Global HYCOM	-1.9 (4.6)	-4.4 0-300m	-2.2 300-1200m	4.7 1200-bottom	2005-2006

The width-averaged zonal currents across the LS

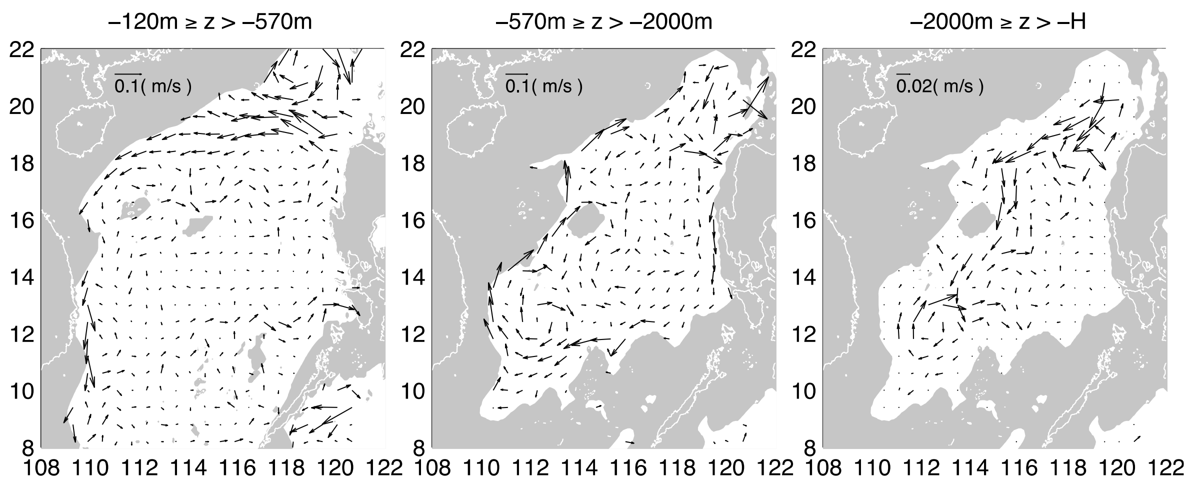




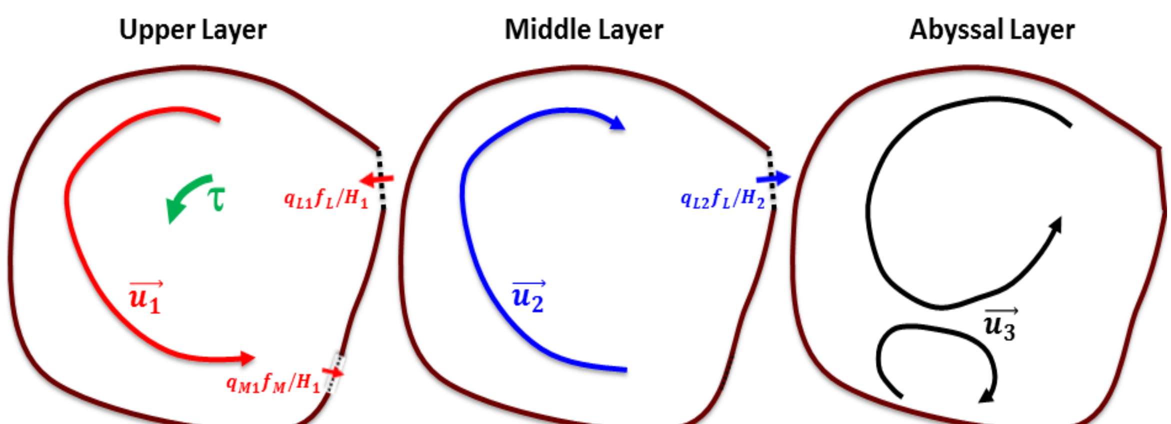
Topography of the SCS in Pac10



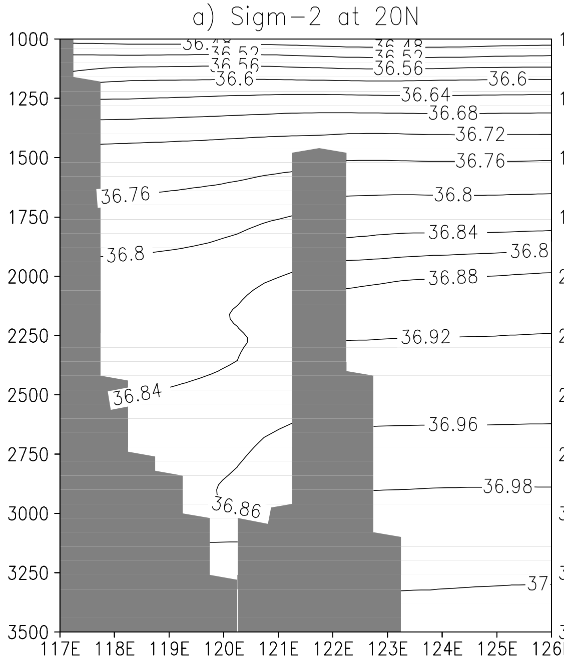
The mean 3-layer circulation from Pac10 (1991-2008)

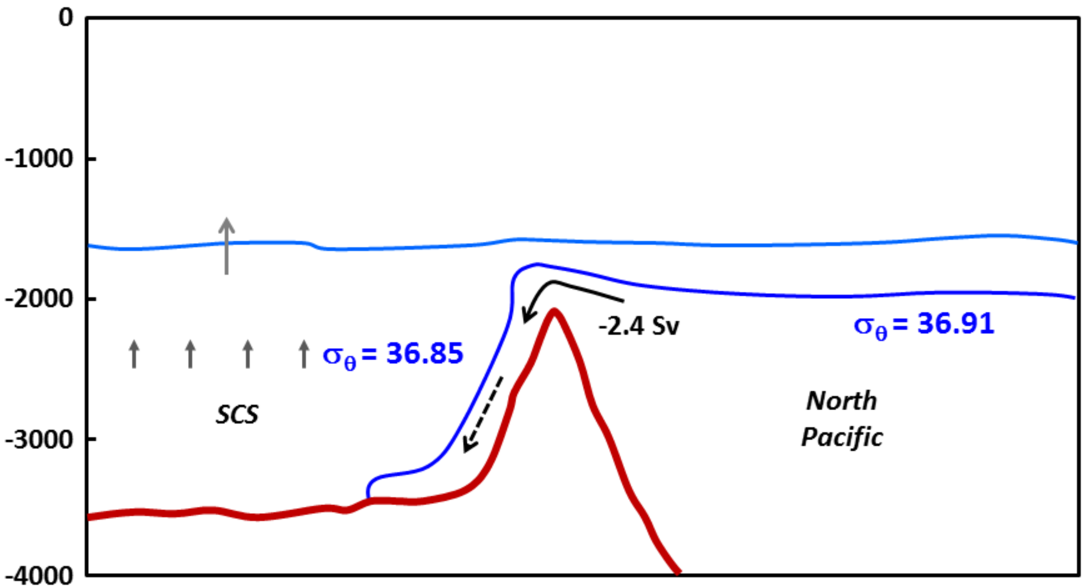


$$\oint \boldsymbol{u} \cdot d\boldsymbol{l} \approx \oint \boldsymbol{\tau} \cdot d\boldsymbol{l} - Q_{\text{strait}}$$



Dense water over flow from the North Pacific to the SCS (Qu et al. 2006)





Summary 3

- By conservations of mass and potential vorticity, the mean circulations in the SCS consist of three layers, similar to the Luzon Strait transport.
- The upper layer (z>-570m) circulation is cyclonic driven by Ekman pumping by the wind stress curl and by inflow through the Luzon Strait.
- The middle layer (-570m ~ -2000m) is anti-cyclonic due to outflow transport through the Luzon Strait.
- The abyssal basin (<-2000m) is driven by deep overflow from the Luzon Strait; its circulation is cyclonic in the northern portion of the SCS, but is anti-cyclonic in the southern portion.

Conclusions

- On seasonal time scale, the Ekman responses induced by the wind stress curl are important for the sea level change over the northern SCS.
- The Kuroshio intrusion shows a cyclonic type of circulation and tend to intrude SCS water west of Luzon Island into the NSCS, consistent also w/β-plume, and then propagating west-southwestward along the shelf break.
- Potential-vorticity and mass conservations suggest a basin-wide cyclonic circulation in the upper layer of the SCS ($z > -570$ m), an anti-cyclonic circulation in the middle layer ($-570 \text{ m} \geq z > -2000$ m), and in the abyssal basin (-2000m) the circulation is cyclonic in the north and anti-cyclonic in the south.

Thank you!