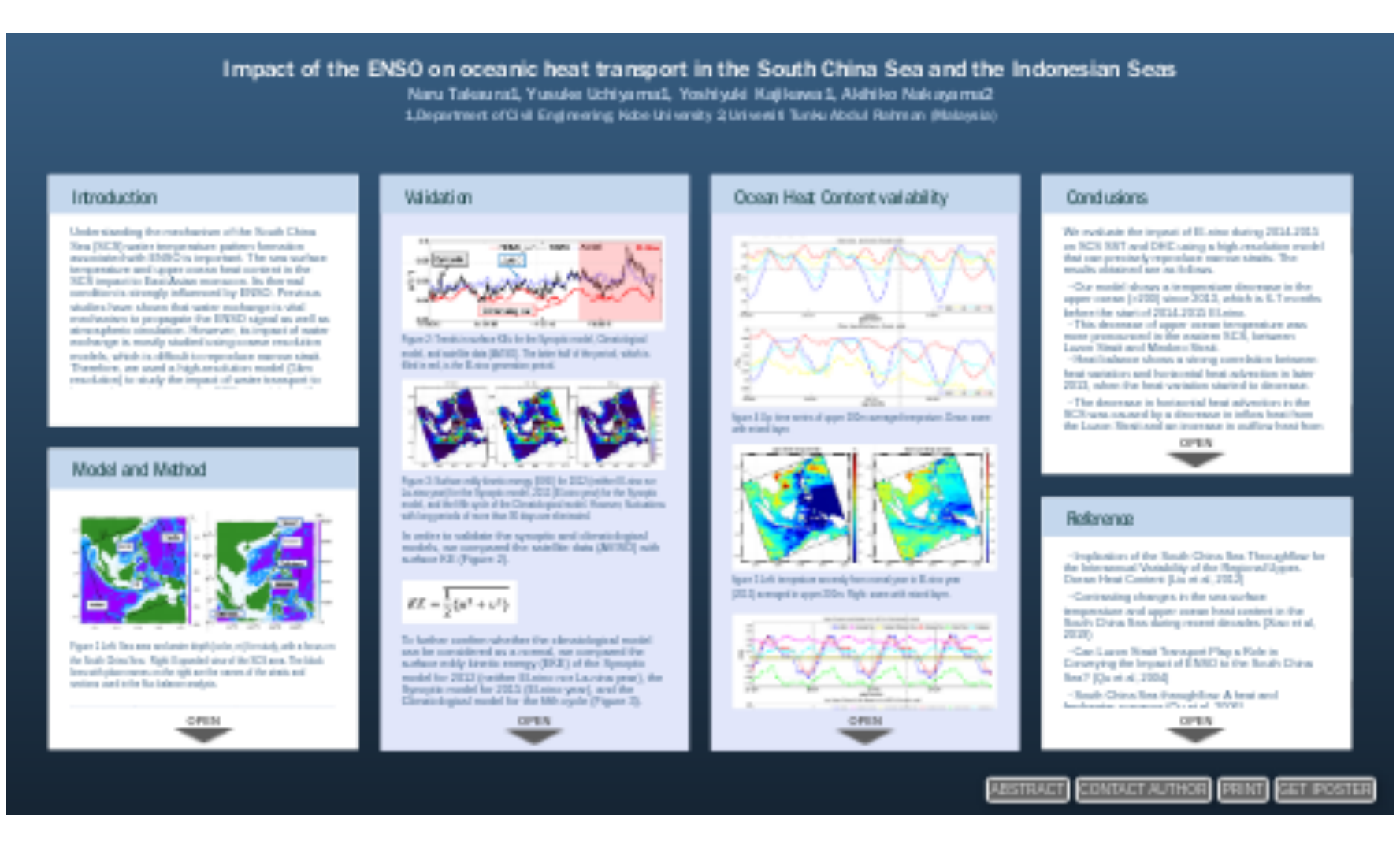
Impact of the ENSO on oceanic heat transport in the South China Sea and the Indonesian Seas


Impact of the ENSO on oceanic heat transport in the South China Sea and the Indonesian Seas
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INTRODUCTION

Understanding the mechanism of the South China Sea (SCS) water temperature pattern formation associated with ENSO is important. The sea surface temperature and upper ocean heat content in the SCS impact to East Asian monsoon. Its thermal condition is strongly influenced by ENSO. Previous studies have shown that water exchange is vital mechanism to propagate the ENSO signal as well as atmospheric circulation. However, its impact of water exchange is mostly studied using coarse resolution models, which is difficult to reproduce narrow strait. Therefore, we used a high-resolution model (5km resolution) to study the impact of water transport to temperature variations in the SCS associated with ENSO.

MODEL AND METHOD

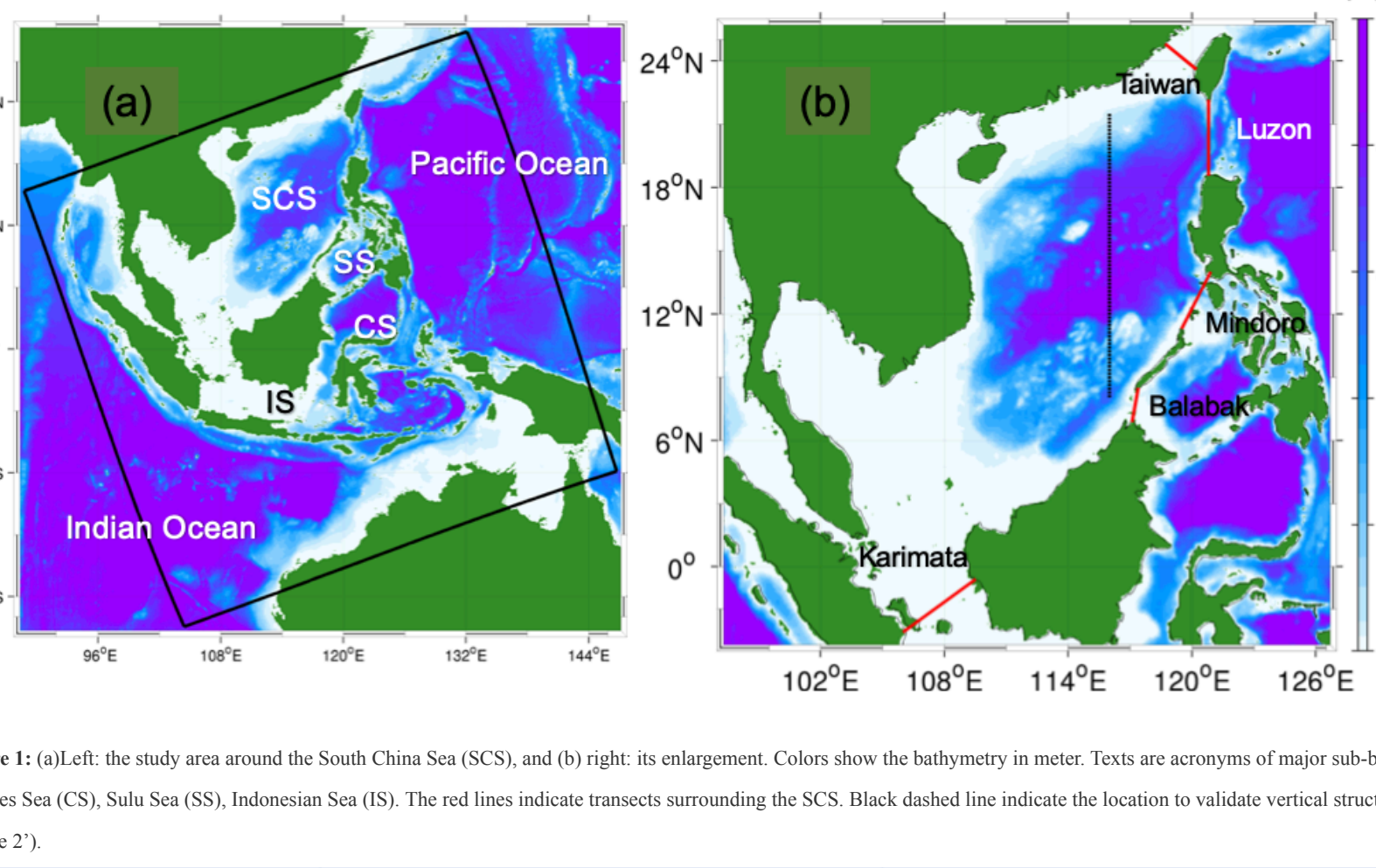

Figure 1: (a)Left: the study area around the South China Sea (SCS), and (b) right: its enlargement. Colors show the bathymetry in meter. Texts are acronyms of major sub-basins: Celebes Sea (CS), Sulu Sea (SS), Indonesian Sea (IS). The red lines indicate transects surrounding the SCS. Black dashed line indicate the location to validate vertical structure (figure 2').

	Synoptic Model	Climatological Model
Period	2012–2015	4 cycles
Resolution	5km × 5km	5km × 5km
Wind	GSM (synoptic)	GSM (climatology)
Surface flux	COADS(climatology)	COADS(climatology)
SSS,SST	HYCOM (synoptic)	HYCOM (climatology)
T-S nudging	HYCOM (synoptic)	HYCOM (climatology)
River	Dai and Trenberth (climatology)	Dai and Trenberth (climatology)
Tide	TPXO7.0	TPXO7.0
Boundary condition	HYCOM (synoptic)	HYCOM (climatology)
Initial condition	HYCOM (synoptic)	HYCOM (climatology)

Table 1: Model condition of synoptic and climatology

Model

The numerical model used in this study is based on the ROMS (Regional Oceanic Modeling System). It has horizontal resolution of 5km and has 40 layers in the vertical. Initial and boundary conditions are using HYCOM+NCODA (10 km horizontal resolution) and wind stress is using the GPV-GSM developed from the Japan Meteorological Agency (JMA), and other conditions are displayed in the Table 1. In the present study, we developed two types of models, the Climatological and the Synoptic model, in order to compare ENSO. Climatological model calculated using 7-year averaged initial conditions, boundary conditions and wind stress for each day or month.

Volume and heat transport analysis

In order to calculate the heat and volume transports through each passage around SCS, transects are set for the passages as shown in Figure 1.

Heat budget analysis

The heat budget for the upper 200m heat content is written

$$c_p\rho\int_V \frac{\partial T}{\partial t}\mathrm{d}V = Q_{net} + c_p\rho\int_A v_n T\mathrm{d}A + c_p\rho\int_A wT\mathrm{d}A + c_p\rho\int_A K_h\frac{\partial T}{\partial z}\mathrm{d}A + c_p\rho\int_A K_v\frac{\partial T}{\partial z}\mathrm{d}A + R$$

VALIDATION

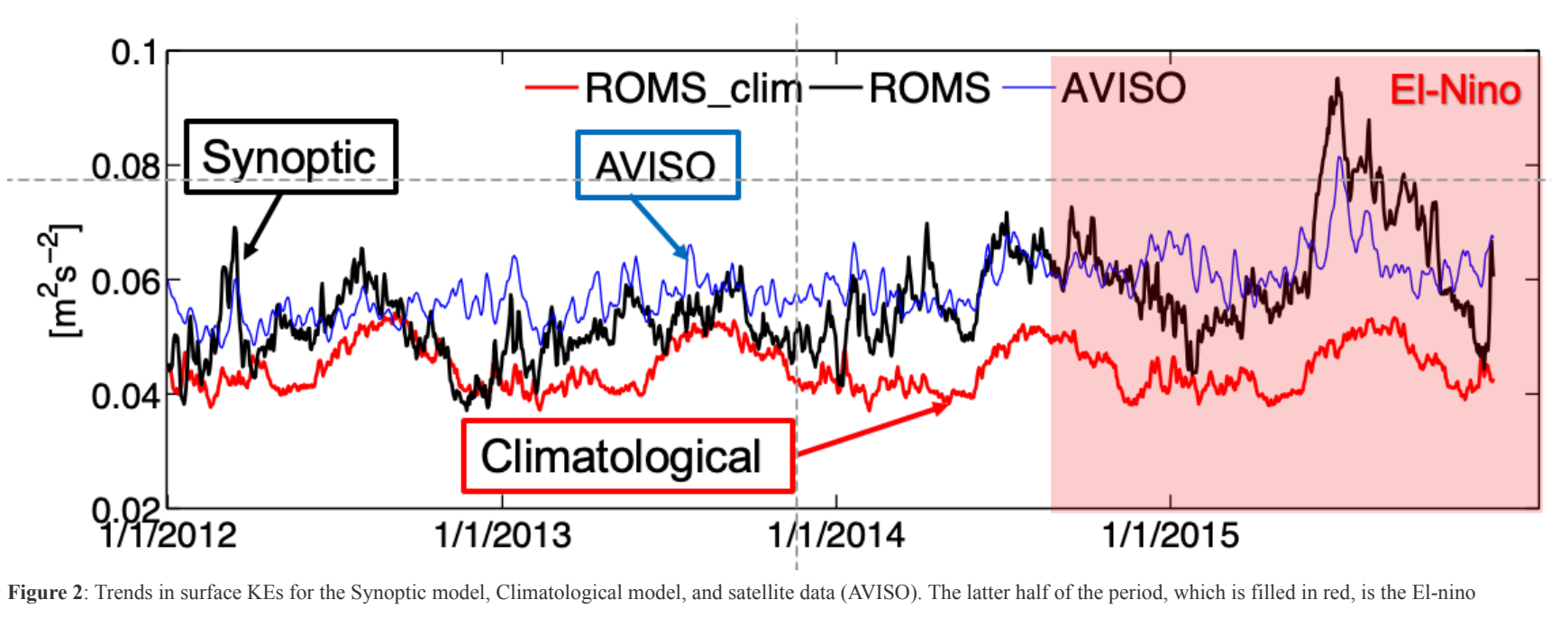

Figure 2: Trends in surface KEs for the Synoptic model, Climatological model, and satellite data (AVISO). The latter half of the period, which is filled in red, is the El-nino generation period.

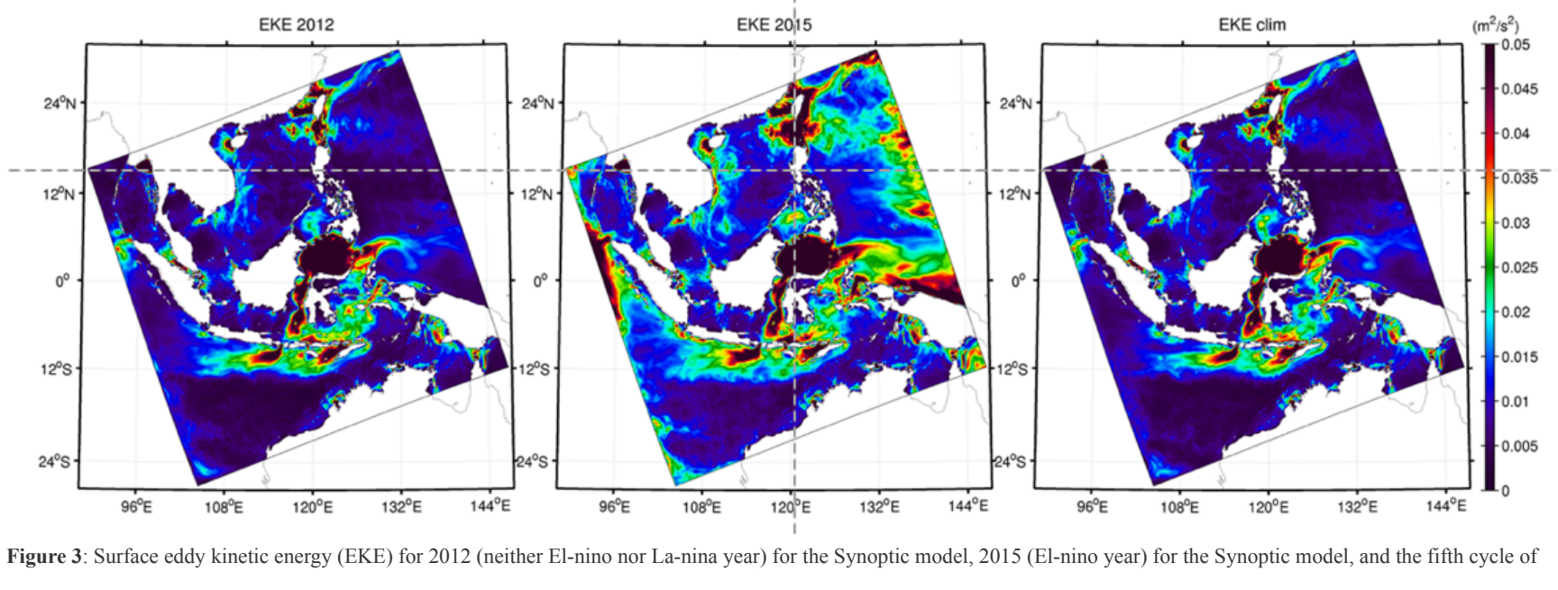

Figure 3: Surface eddy kinetic energy (EKE) for 2012 (neither El-nino nor La-nina year) for the Synoptic model, 2015 (El-nino year) for the Synoptic model, and the fifth cycle of the Climatological model. However, fluctuations with long periods of more than 90 days are eliminated.

In order to validate the synoptic and climatological models, we compared the satellite data (AVISO) with surface KE (Figure 2).

$$KE = \frac{1}{2}\overline{(u^2+v^2)}$$

To further confirm whether the climatological model can be considered as a normal, we compared the surface eddy kinetic energy (EKE) of the Synoptic model for 2012 (neither El-nino nor La-nina year), the Synoptic model for 2015 (El-nino year), and the Climatological model for the fifth cycle (Figure 3).

$$EKE = \frac{1}{2}\overline{(u'^2+v'^2)}$$

We can see that the Climatological model is almost identical to the 2012 model, whereas the values are larger in 2015. We can confirm that the Climatological model reproduces the climatological model well, and the synoptic model in 2015 reproduces the increase of the eddy kinetic energy due to the increase of the intra-annual variability by El-nino.

Appendix

Comparison of monthly mean SST and vertical cross sections of the Climatological model and the World Ocean Atlas 13 (WOA). Good reproducibility was confirmed.

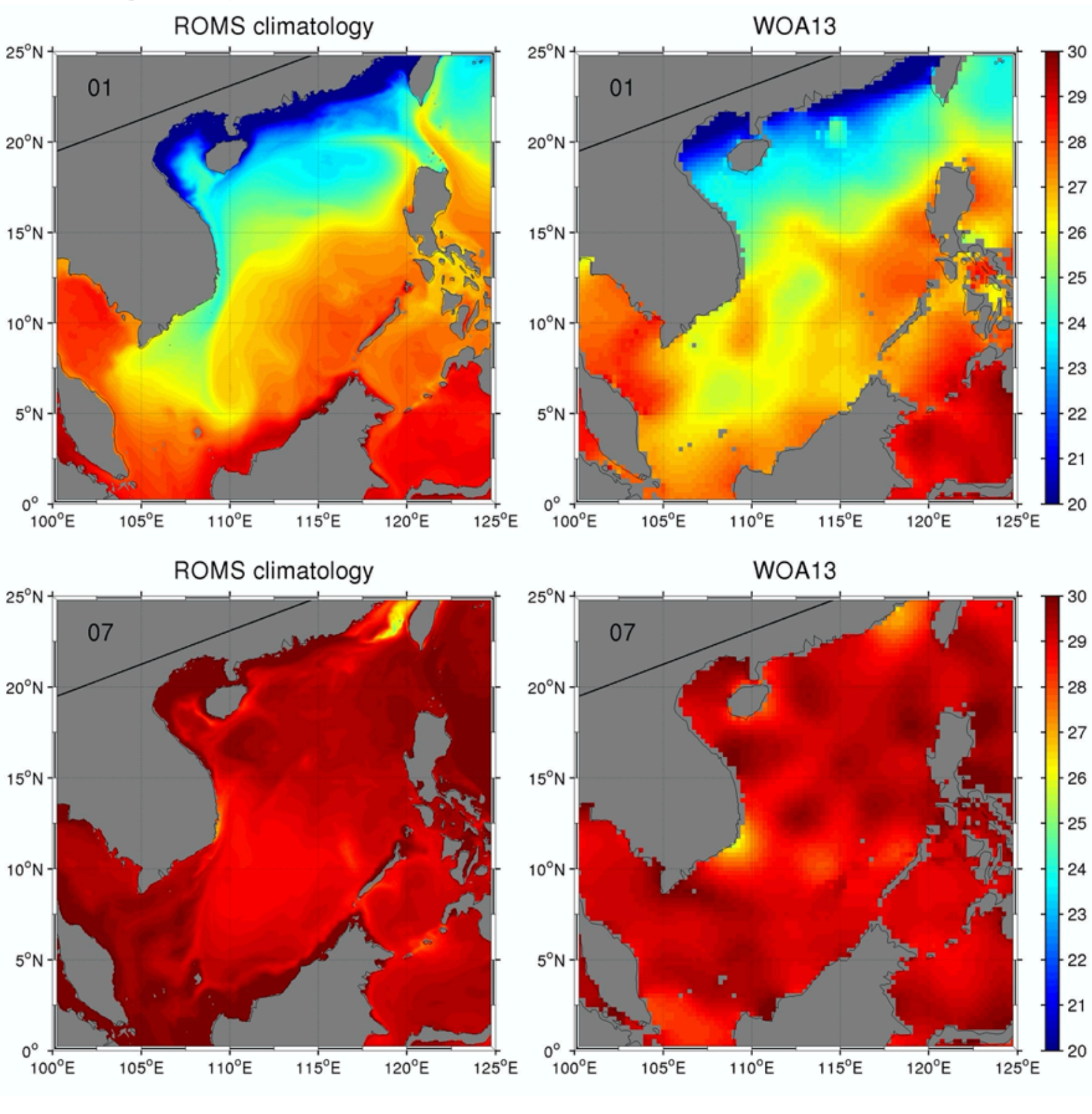

Figure 1': Monthly averaged spacial pattern of SST in Climatological model and WOA13.

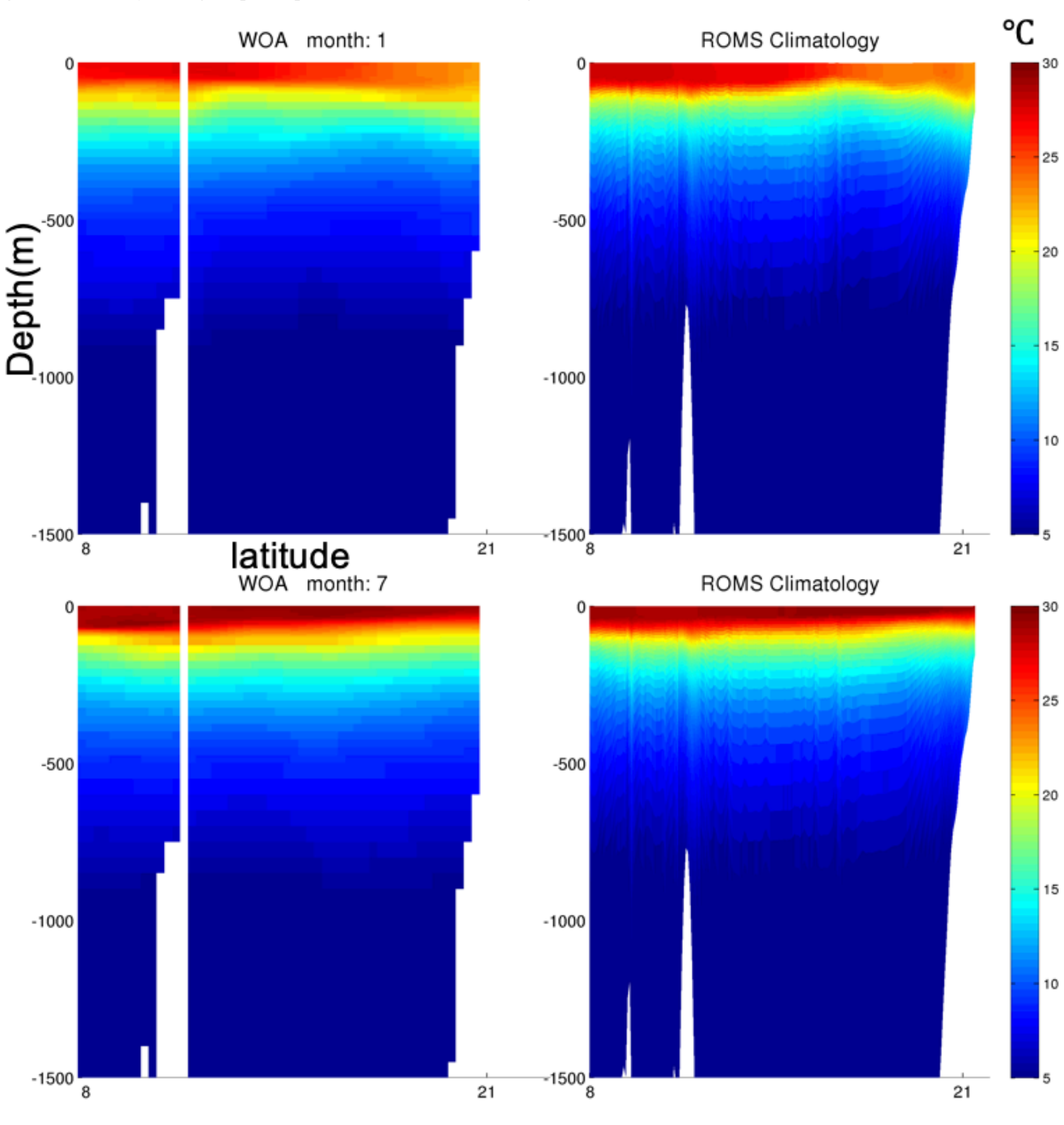

Figure 2': Mean zonal temperature at the cross-section at 120°.

UPPER OCEAN HEAT VARIABILITY

Temperature varaiability in SCS

Mixed layer temperature increases slightly in entire SCS, whereas upper layer temperature (>200) decreases significantly in the eastern SCS during El-nino phase (2014-2015). Time series of mixed layer temperature in SCS (Figure 4 Up) shows the increase in amplitude during El-nino and then anomaly from annual mean of Climatology to 2015 (Figure 5 Left) shows the slightly increase in entire SCS. The increase in mixed layer temperature is attributed to increase in surface net heat flux due to atmospheric circulation changes (The present model does not include the increase in surface heat flux associated with ENSO, but it is likely to be expressed by nudging with HYCOM assimilation model). In contrast, time series of upper layer temperature in SCS (Figure 4 Down) shows decrease during El-nino, and anomaly (Figure 5 Right) shows the increase off the coast of Vietnam and decreases significantly in the eastern SCS and tropical Pacific. This pattern seems to be attributed to weakened upwelling caused by a weakening summer monsoon and water exchange with the Pacific Ocean and Indian Ocean. To confirm this water exchange effect, a heat budget analysis in the SCS was performed.

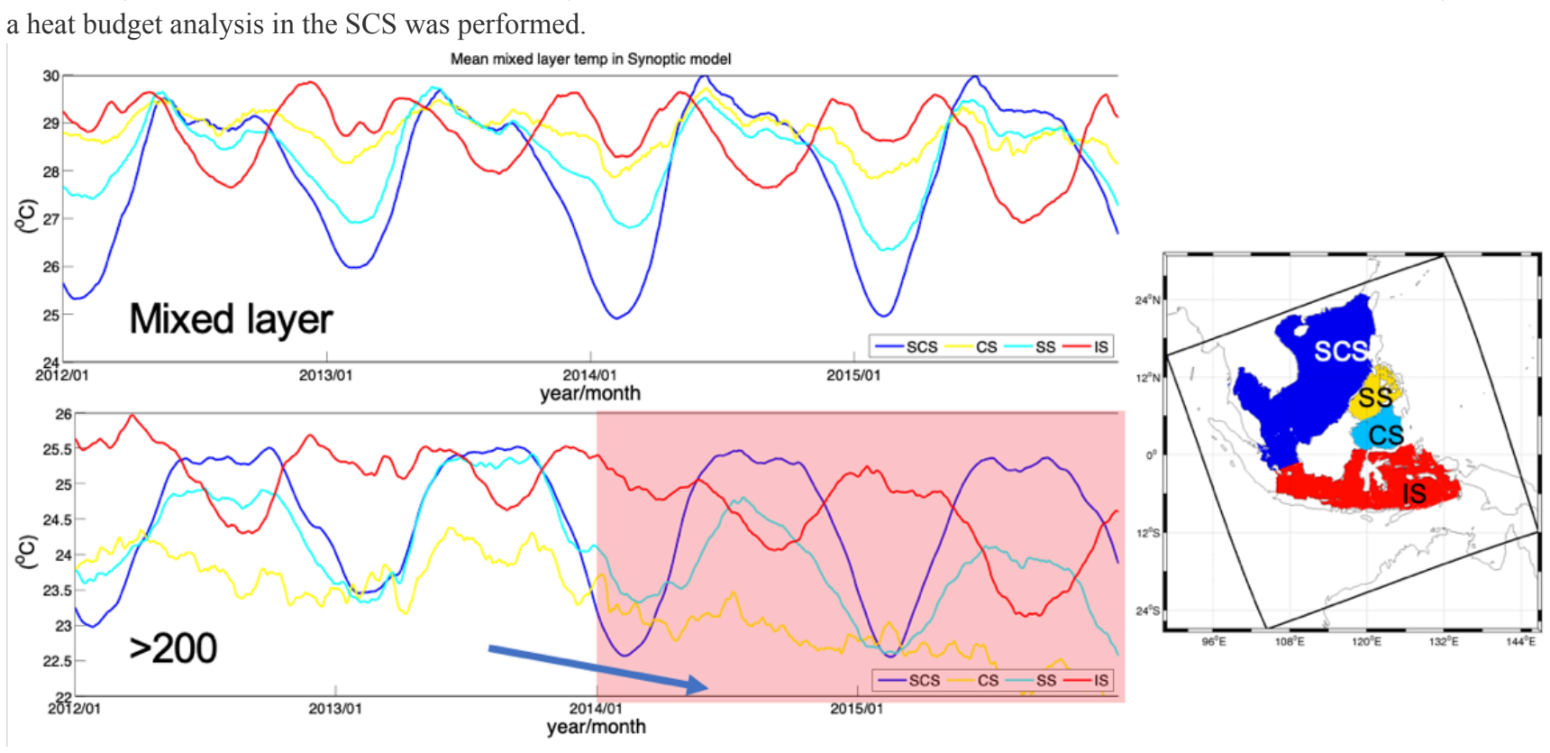

Figure 4 Up: time series of upper 200m averaged temprature. Down: same with mixed layer.

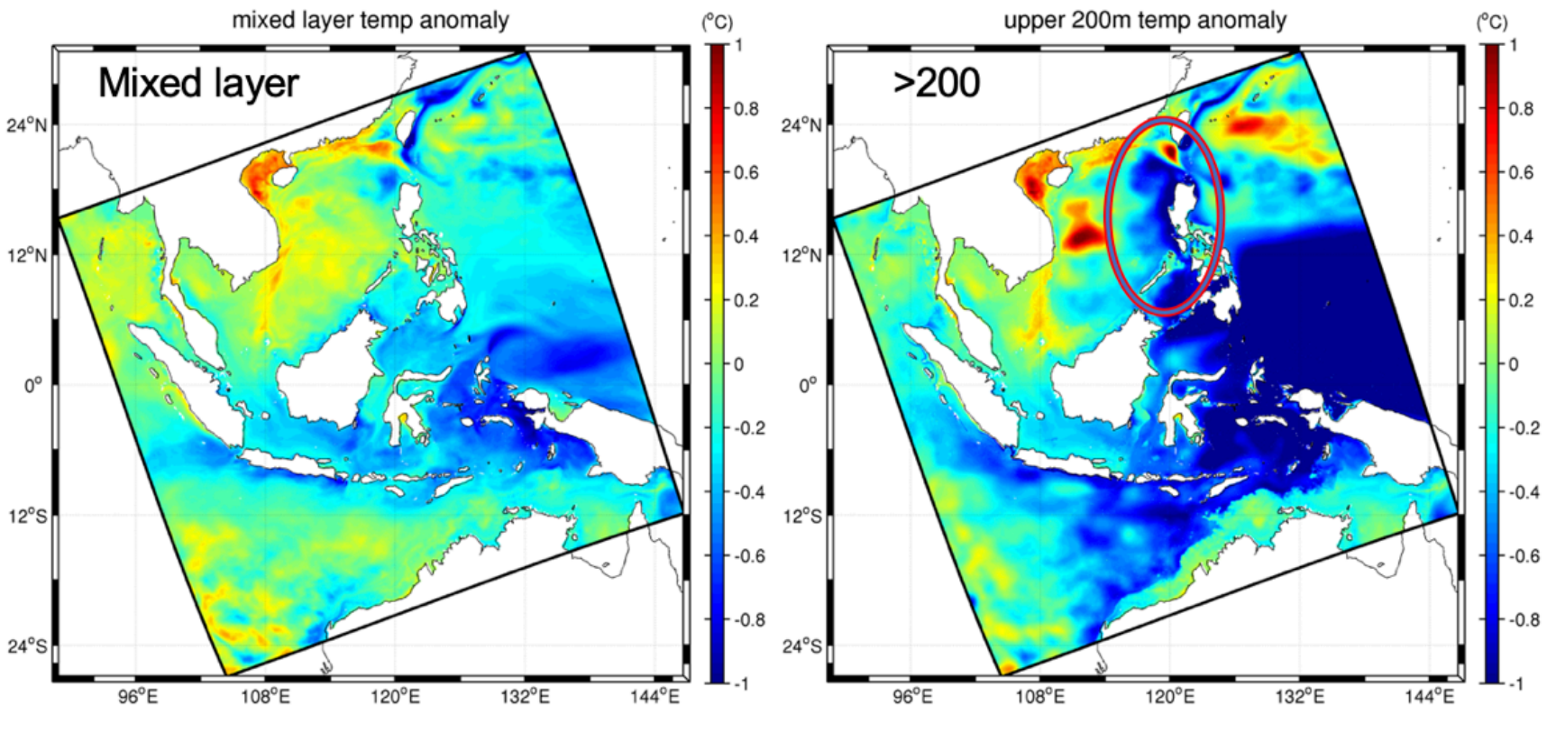

Figure 5 Left: temprature anomaly from nomal year to El-nino year (2015) averaged in mixed layer. Right: same with upper 200m.

Heat budget in upper SCS

The heat balance of the SCS is mainly balanced by the negative horizontal heat advection and positive surface heat fluxes and positive vertical heat advection(Figure 6). The vertical heat advection is out of phase to the horizontal heat advection and they compensate each other. The change in ocean heat is negative in late 2013. The 2014-2015 water temperature decrease is caused by the late 2013. Then we compared the variable components of each factor to ignore the effect of nudging. Ocean Heat decrease in 2013 is highly correlated with horizontal heat advection(correlation coefficient 0.97). Namely, horizontal heat advection cooled the SCS in late 2013 and decrease temperatures in 2014-2015. Next, we decompose horizontal heat advection into each strait, Luzon, Mindoro, Balabak, Taiwan and Karimata straits. Horizontal heat transport is determined by the inflow from Luzon Strait and outflow from Mindoro Strait. Therefore, the decrease in horizontal heat transport in 2013 is found to be due to a decrease in inflows from Luzon Strait and an increase in outflows from Mindoro Strait.

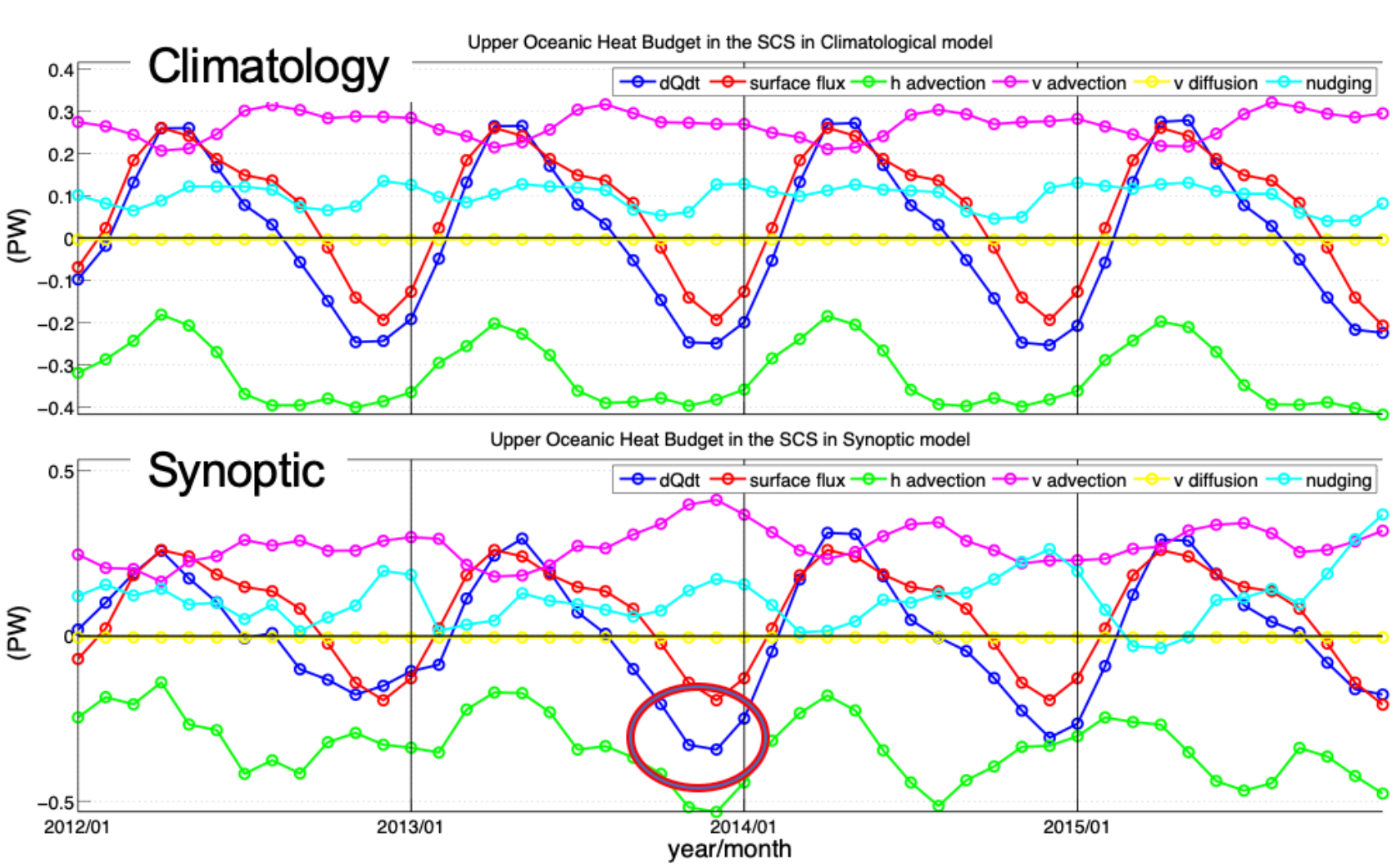

Figure 6 Up: Heat budget around SCS in synoptic model. Down: same with climatological model.

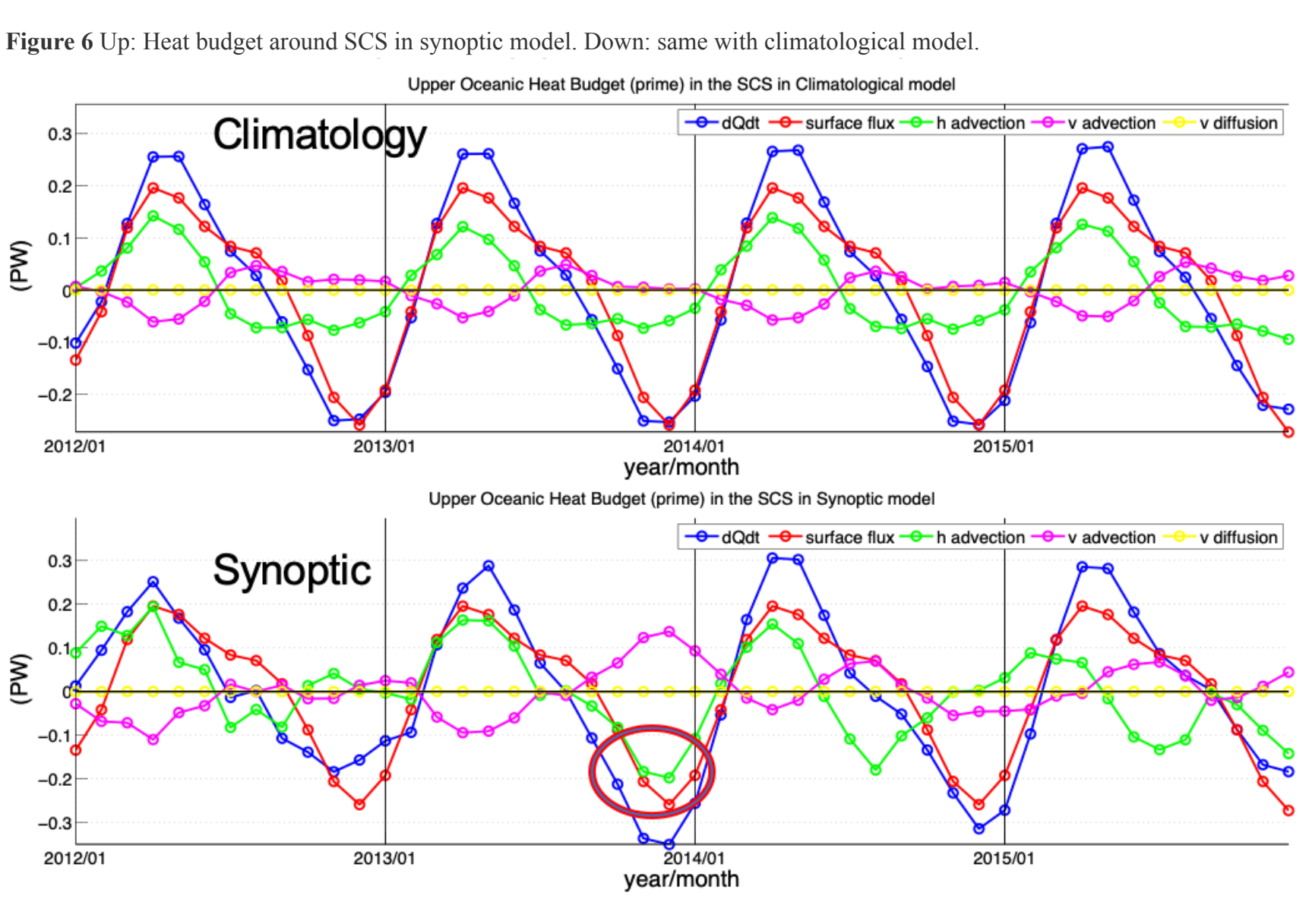

Figure 7 Up Same with figure 6, but anomaly

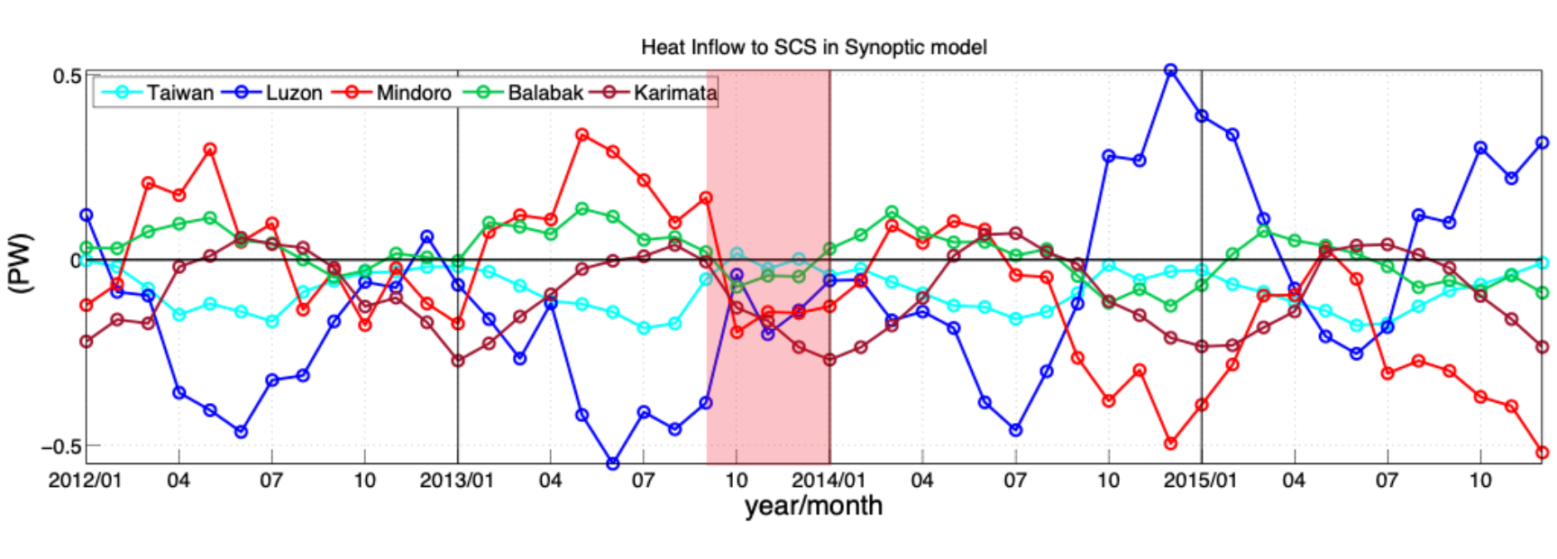

Figure 8: Heat transport in upper 200m through each passage

CONCLUSIONS

We evaluate the impact of El-nino during 2014-2015 on SCS SST and OHC using a high-resolution model that can precisely reproduce narrow straits. The results obtained are as follows.

・Our model shows a temperature decrease in the upper ocean (>200) since 2013, which is 6-7 months before the start of 2014-2015 El-nino.
・This decrease of upper ocean temperature was more pronounced in the eastern SCS, between Luzon Strait and Mindoro Strait.
・Heat balance shows a strong correlation between heat variation and horizontal heat advection in later 2013, when the heat variation started to decrease.

・The decrease in horizontal heat advection in the SCS was caused by a decrease in inflow heat from the Luzon Strait and an increase in outflow heat from the Mindoro Strait.

REFERENCE

・Implication of the South China Sea Throughflow for the Interannual Variability of the Regional Upper-Ocean Heat Content (Liu et al, 2012)

・Contrasting changes in the sea surface temperature and upper ocean heat content in the South China Sea during recent decades (Xiao et al, 2019)

・Can Luzon Strait Transport Play a Role in Conveying the Impact of ENSO to the South China Sea? (Qu et al, 2004)

・South China Sea throughflow: A heat and freshwater conveyor (Qu et al, 2006)

・An introduction to the South China Sea throughflow: Its dynamics, variability, and application for climate (Qu et al, 2009)

・Interannual variability of the South China Sea associated with El Nino (Wang et al, 2006)

・Interocean circulation and heat and freshwater budgets of the South China Sea based on a numerical model (Fang et al, 2009)

ABSTRACT

The South China Sea (SCS) and the Indonesian Seas play an important role in development of the Walker circulation by increased sea surface temperature (SST) that promotes transport of water mass and heat from the Pacific to the Indian Ocean through the Indonesian Throughflow. These areas are connected to the Pacific at the Luzon strait and the Celebes Sea by intrusions of the Kuroshio and the Mindanao Current. However, little has been known about how significantly the SCS and the Indonesian Seas are affected by the tropical western Pacific through these two Western Boundary Currents (WBCs). Here we examine interannual variability of regional circulations formed in these areas with a particular attention to the influences of the Pacific ENSO due to heat transport.
We developed a 3-D downscaling ocean circulation model based on the Regional Oceanic Modeling System (ROMS) at a lateral resolution of 5 km with tides, initialized and forced by the Hybrid Coordinate Ocean Model (HYCOM) non-tidal global reanalysis product. A twin numerical experiment was conducted with the HYCOM-ROMS model in synoptic and climatological modes, which enables us to explicitly extract interannual variability including the ENSO.
A comparison of the synoptic and the climatological models exhibits that during an El Niño, the incoming heat flux through the Luzon Strait is enhanced to increase SST in the southern SCS by 1°C and the heat flux to the Celebes Sea is reduced to decrease SST in the Indonesian Seas also by 1°C. We found it through a heat budget analysis that the interannual SST variability in the SCS and the Indonesian Seas are strongly influenced not only by the monsoon, but also pronouncedly by the WBCs due to the meridional shift of the bifurcation latitude of the WBCs associated with the ENSO. Therefore, the alteration of the oceanic structure of the subtropical and tropical western Pacific is important for the interannual variability of advective heat transport into the SCS and the Indonesian Seas, which is influential to the Walker circulation that could feed back again to the ENSO.