PICES Annual Meeting in Qingdao

The development of high resolution global ocean surface wave-tide-circulation coupled model

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Oct 20, 2015, Qingdao, China

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Outline

1. Why surface wave in OGCM
2. Why tidal system in OGCM
3. High resolution coupled model
4. Summary

1. Why surface wave in OGCM

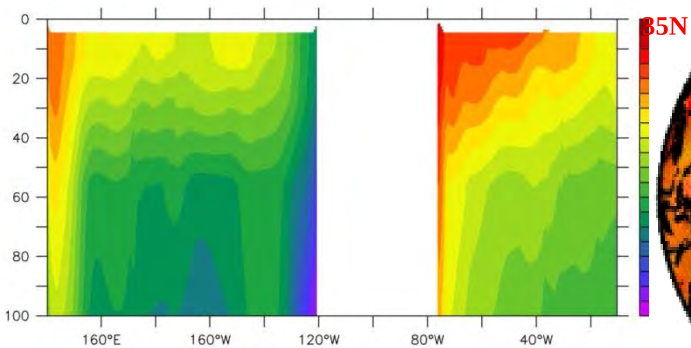
Motivations

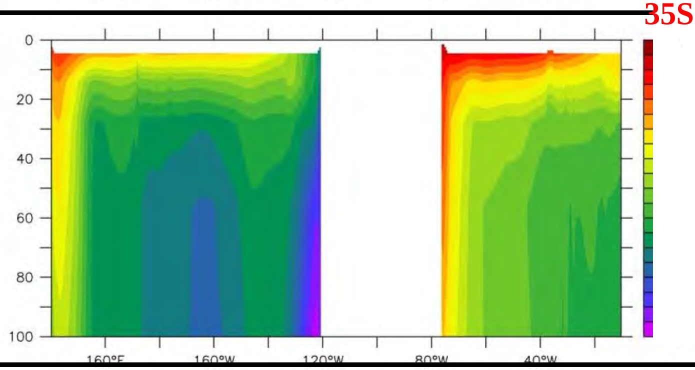
The common problems nearly all OGCMs faced: Simulated SST is overheating in summertime, and mixed layer depth is too shallow while the thermocline is too weak (Martin 1985, Kantha 1994, Ezer 2000, Mellor 2003).

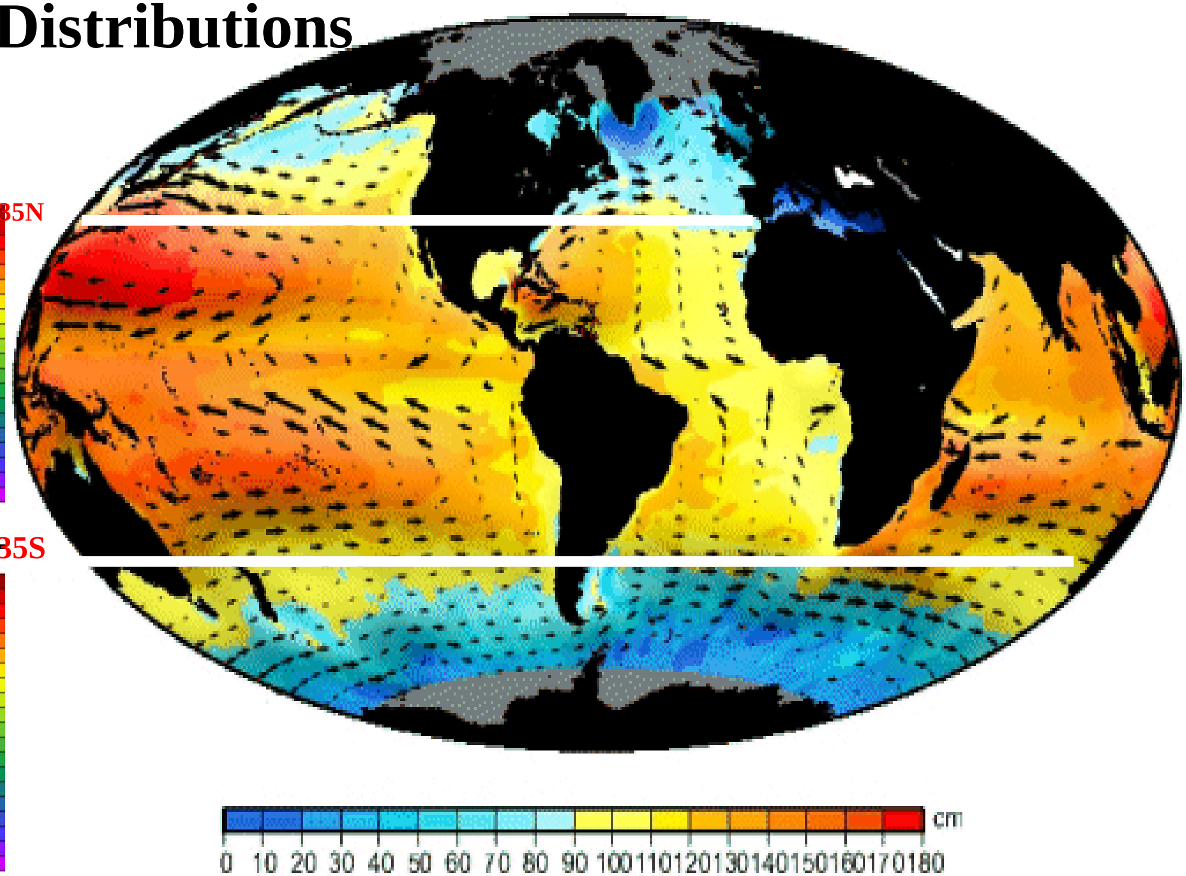
Is the surface wave a low-lying fruit?

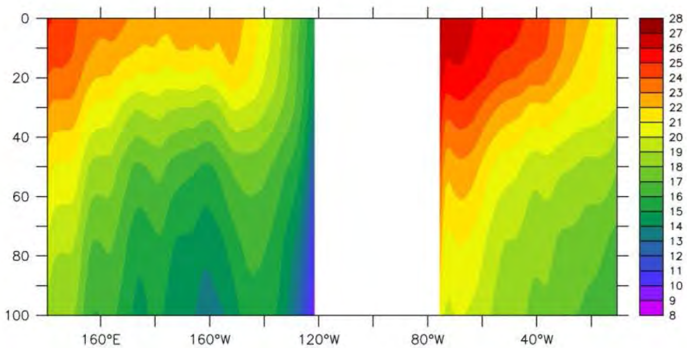
Vertical Temperature Distributions

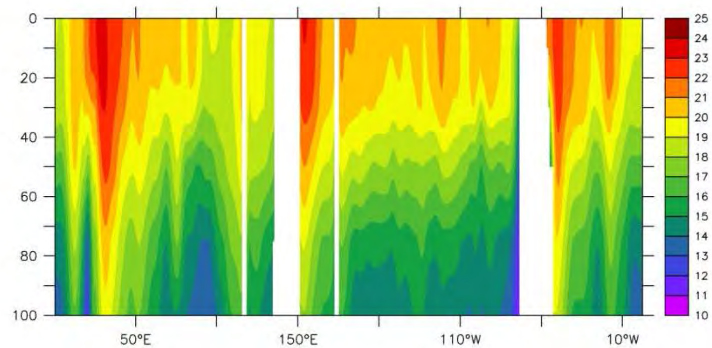
Pacific **Atlantic**











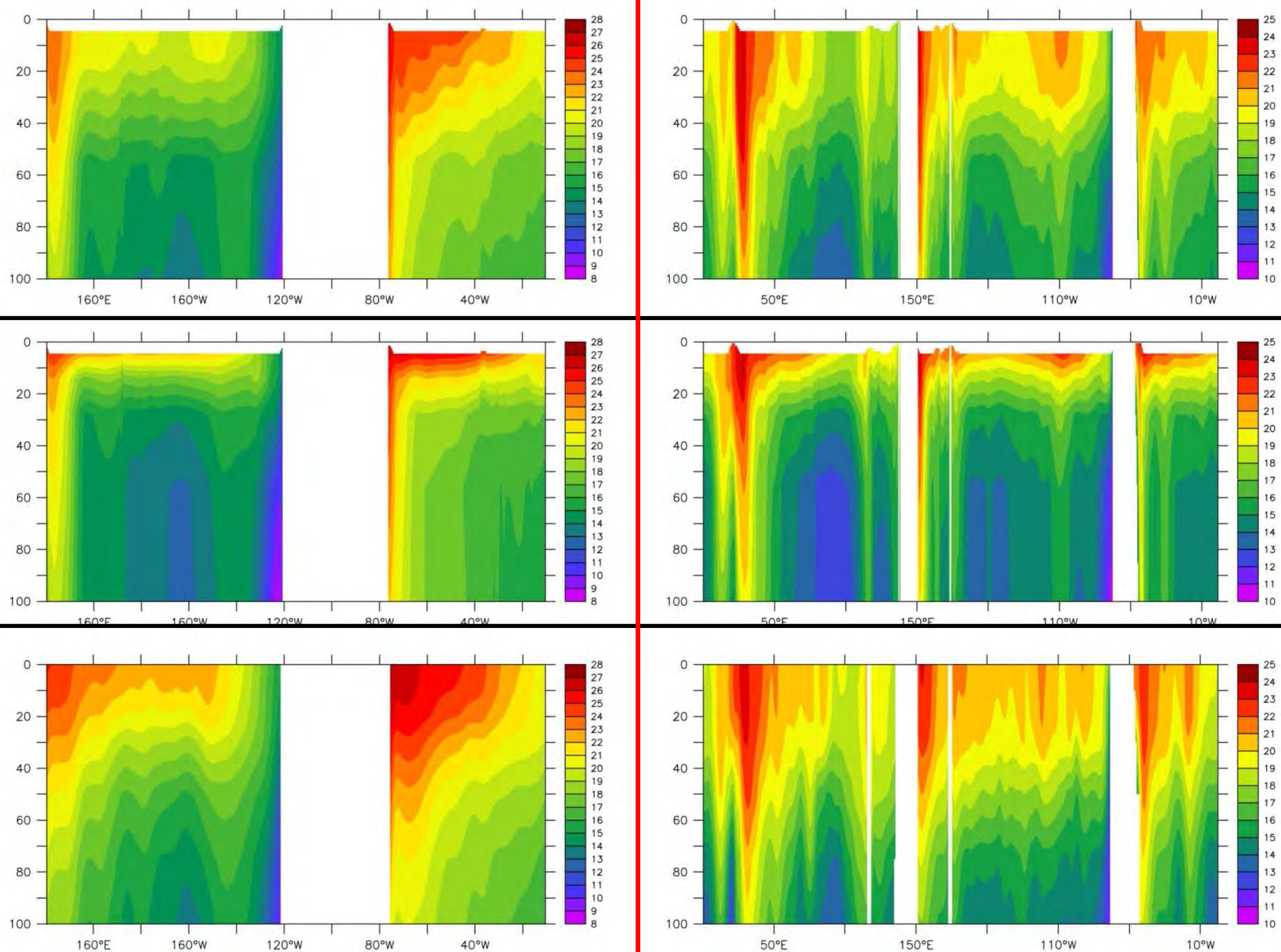
World Ocean Atlas

Along 35N transect in Aug.

Along 35S transect in Feb.

Vertical Temperature Distributions

Pacific Atlantic | Indian Pacific Atlantic



With wave-induce mixing

Without wave-induce mixing

World Ocean Atlas

Along 35N transect in Aug.

Along 35S transect in Feb.

$$B_V = \alpha \iint_{\vec{k}} E\left(\vec{k}\right) \exp\left\{2kz\right\} d\vec{k} \frac{\partial}{\partial z}\left(\iint_{\vec{k}} \omega^2 E\left(\vec{k}\right) \exp\left\{2kz\right\} d\vec{k}\right)^{1/2}$$

E(K) is the wave number spectrum which can be calculated from a wave numerical model. It will change with (x, y, t), so Bv is the function of (x, y, z, t).

Yuan et al, 1999; Qiao et al, GRL, 2004; OD, 2010

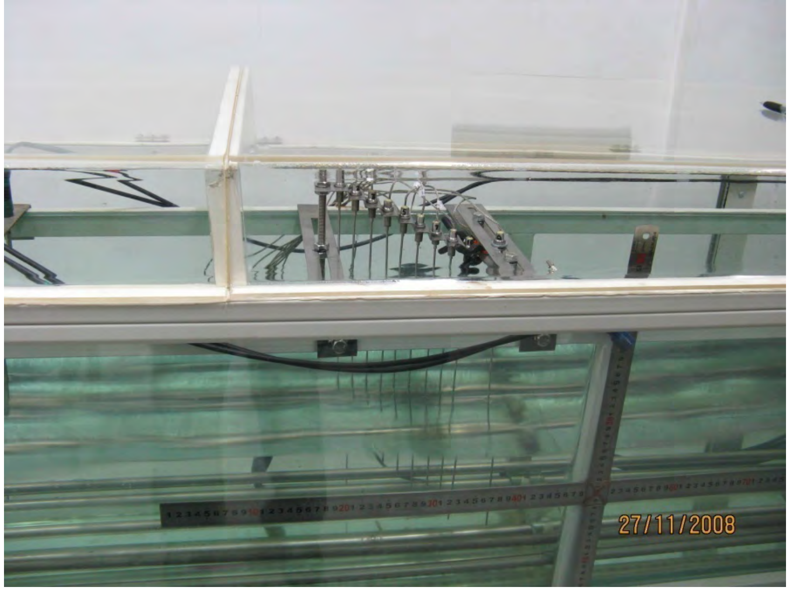
If we regard surface wave as a monochramatic wave,

$$B_v = \alpha A^3 k \omega e^{(-3kz)} = \alpha A u_s e^{(-3kz)} ,$$

Stokes Drift

Bv is wave motion related vertical mixing instead of wave breaking.

Although the horizontal scale of surface wave, 100m, is much smaller than that of circulation, however, the wave-induced vertical velocity in the upper ocean could be stronger than vertical current turbulence velocity.

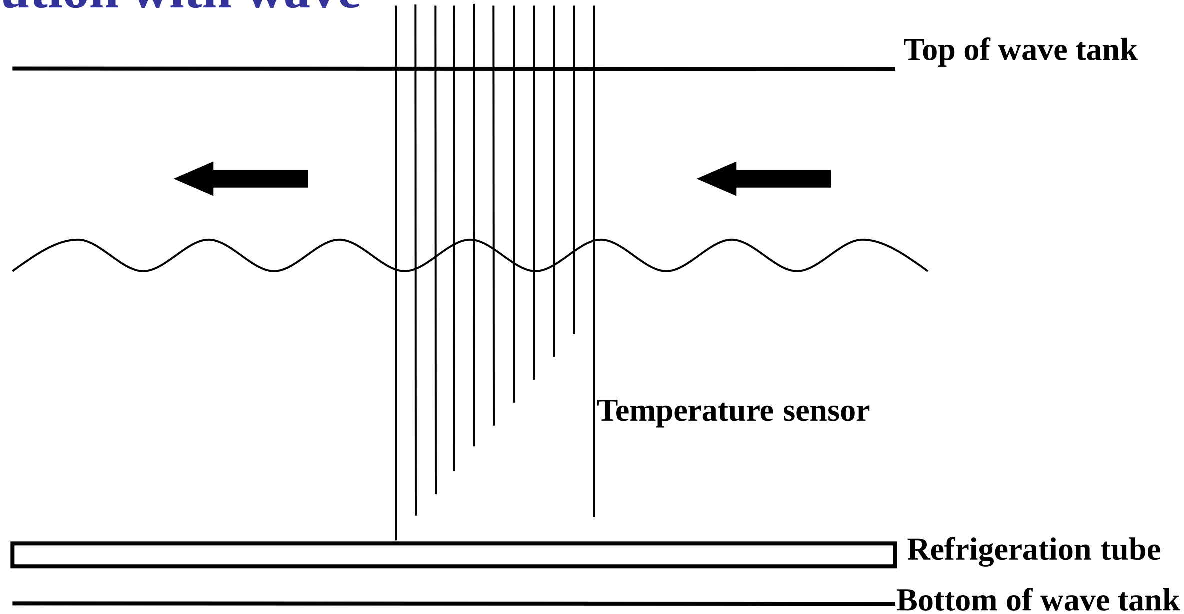


Laboratory experiments:

Wave tank: 5m in length with height of 0.4m and width of 0.2m. To generate temperature gradient through bottom cooling of refrigeration tubes, and temperature sensors are self-recorded with sampling frequency of 1Hz.

(1) Temperature evolution in natural condition

(2) Temperature evolution with wave

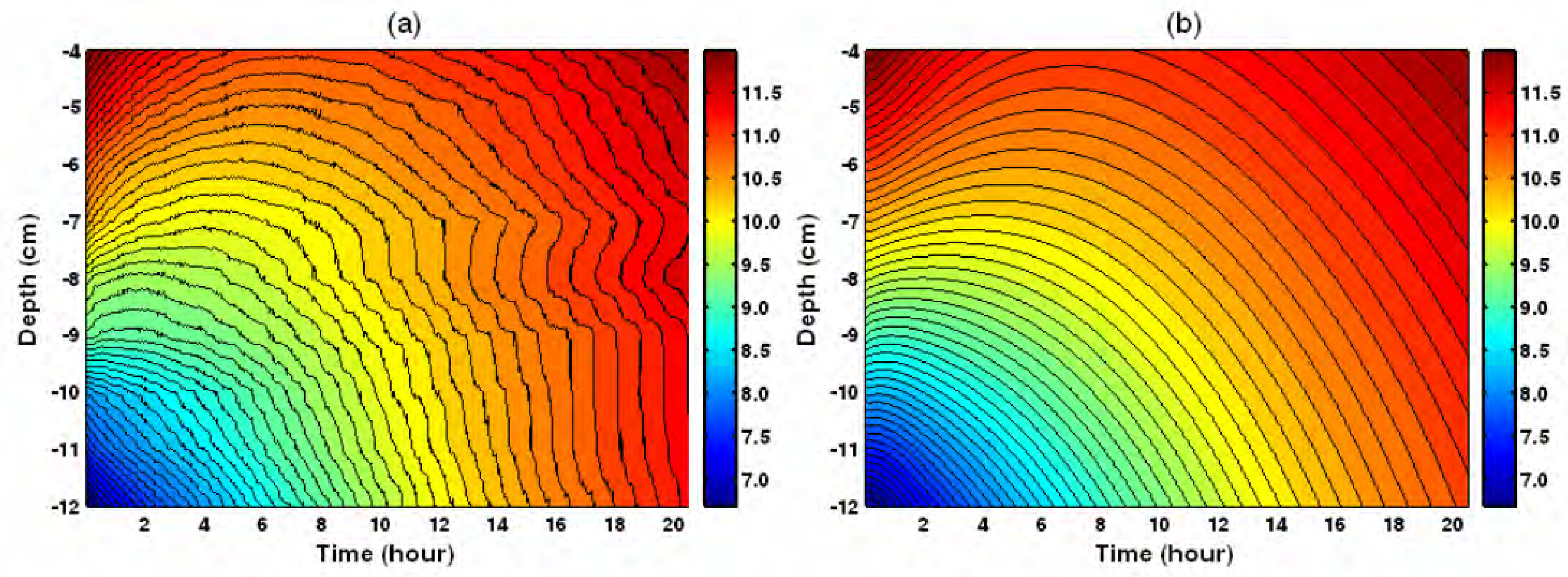


Dai and Qiao et al, JPO, 2010

Experiment results without and with waves

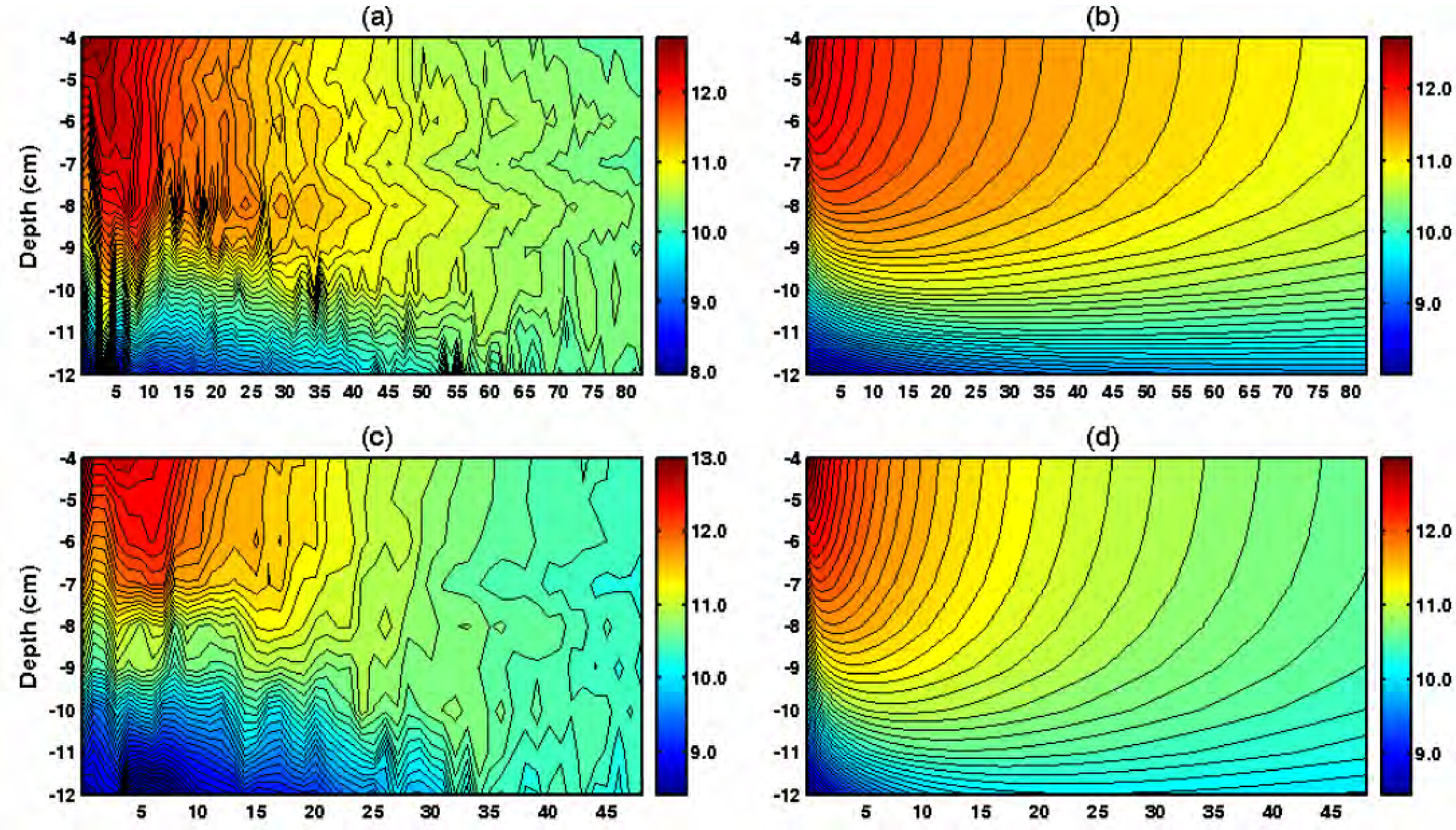
$$\frac{\partial T}{\partial t} = \frac{\partial}{\partial z}\left(k_z \frac{\partial T}{\partial z}\right)$$

kz=k0+Bv



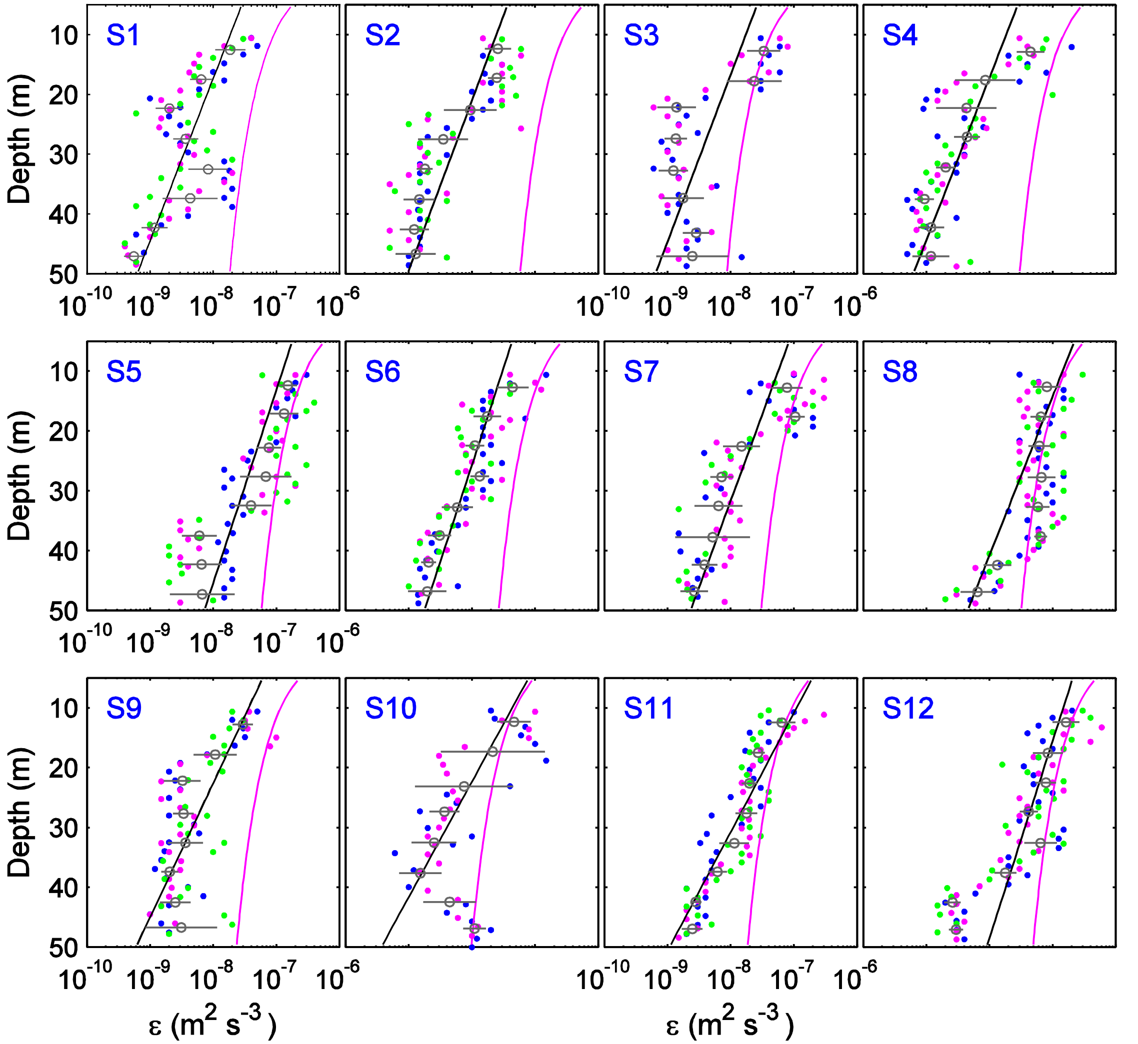
Evolution of water temperature without waves.
(a) Observation; (b) simulation.

Simulation results with waves

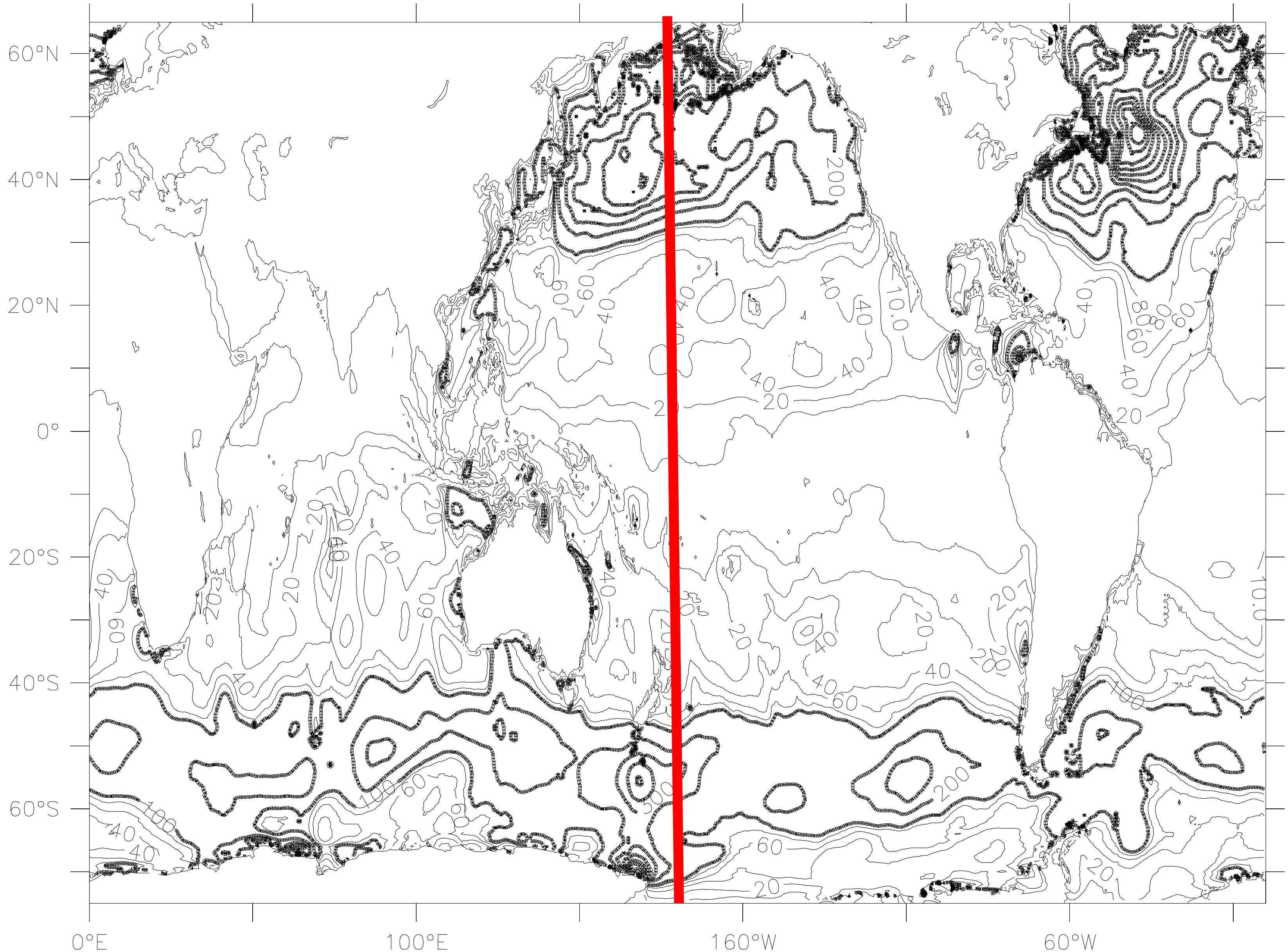


Evolution of water temperature with waves. Left: observation; right: simulation; (a,b) 1.0cm, 30cm; (c,d) 1.0cm, 52cm;

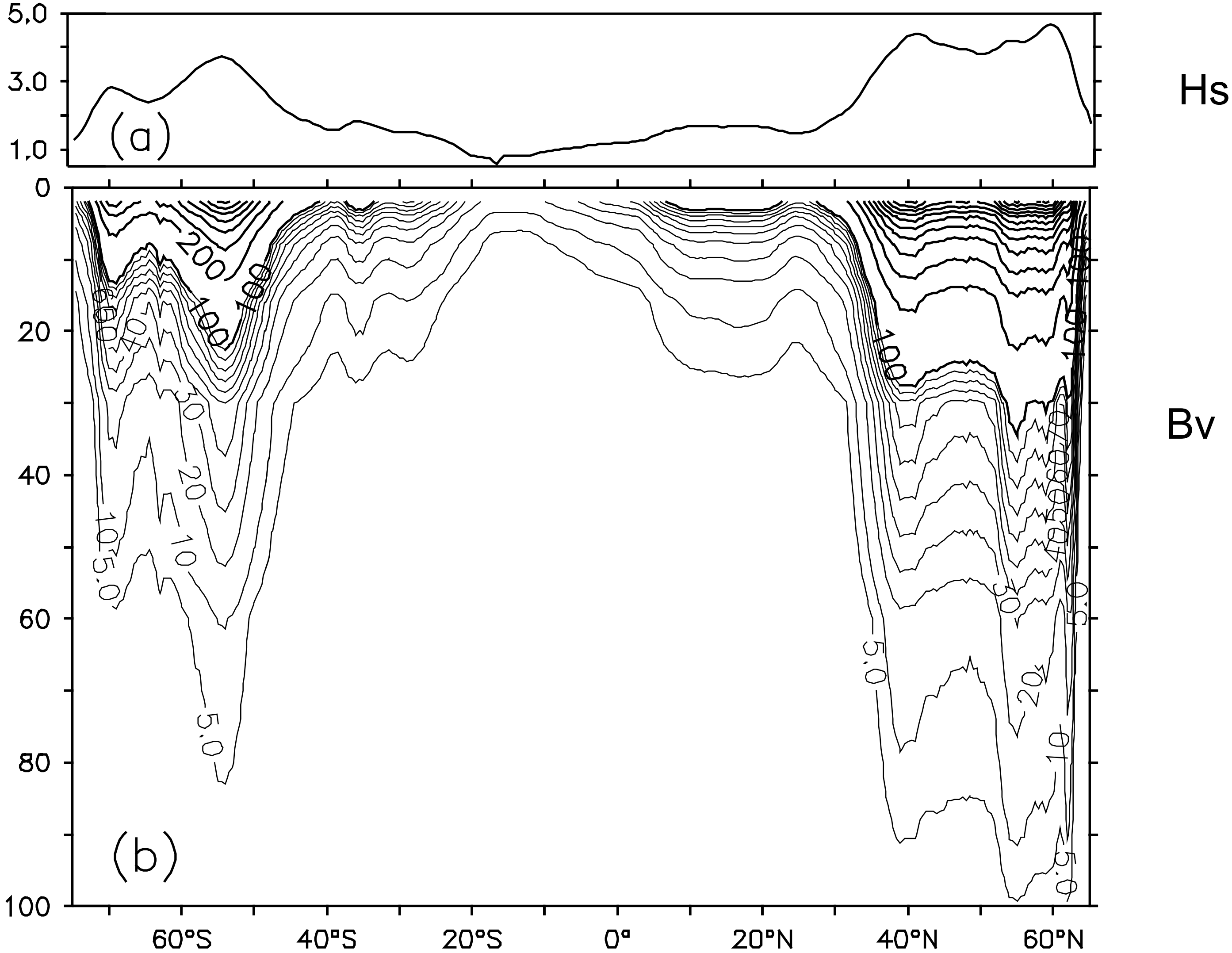
Observation evidences



Vertical profiles of the measured dissipation rates ε_m (dots), and those predicted by wave ε_{wave} (black lines) and the law of the wall ε_{wall} (pink lines) at Station S1~S12 (in $m^2\ s^{-3}$). Observation is conducted in SCS during October 29 to November 10, 2010. Huang and Qiao et al, 2012, JGR



The distribution of the 20m-averaged Bv (cm^2/s) in Feb.



The vertical distribution of the Bv (cm^2/s) along dateline in Feb.

(In fact, 0.1 cm^2/s means a lot for circulation processes)

Wave-circulation coupled model: How to use Bv

(1) To include current effects into a wave model is another story, but not so important.

(2) To include wave effects into a circulation model is so simple, just add Bv

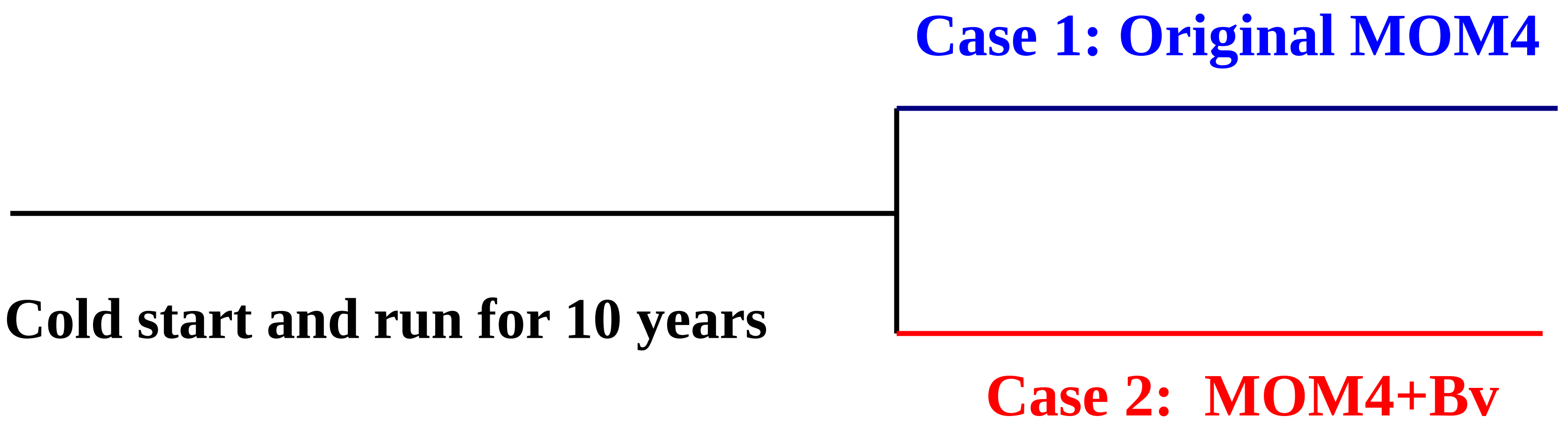
$$\frac{\partial}{\partial z}(K_M \frac{\partial U}{\partial z}) \Rightarrow \frac{\partial}{\partial z}[(K_M + B_V)\frac{\partial U}{\partial z}]$$

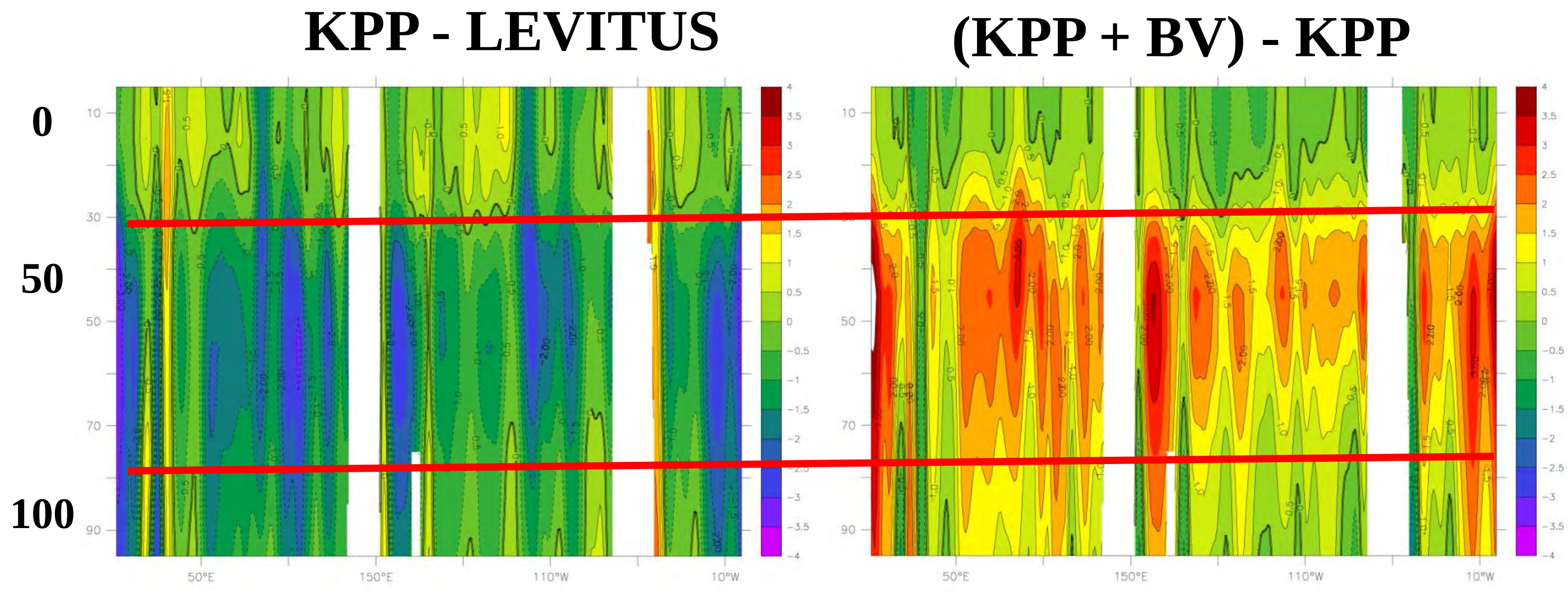
$$\frac{\partial}{\partial z}(K_M \frac{\partial V}{\partial z}) \Rightarrow \frac{\partial}{\partial z}[(K_M + B_V)\frac{\partial V}{\partial z}]$$

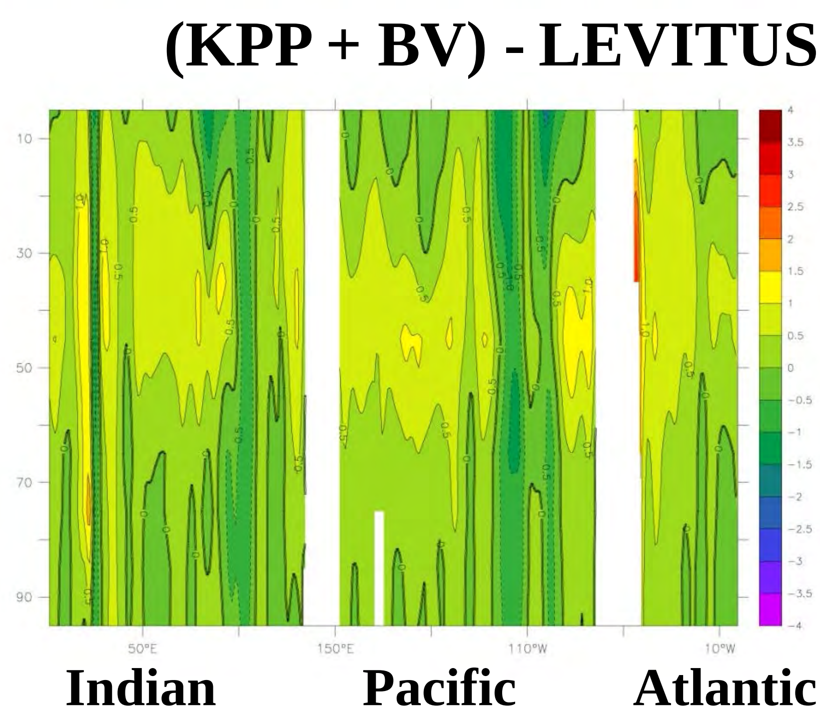
$$\frac{\partial}{\partial z}(K_H \frac{\partial T}{\partial z}) \Rightarrow \frac{\partial}{\partial z}[(K_H + B_V)\frac{\partial T}{\partial z}]$$

$$\frac{\partial}{\partial z}(K_H \frac{\partial S}{\partial z}) \Rightarrow \frac{\partial}{\partial z}[(K_H + B_V)\frac{\partial S}{\partial z}]$$

Model Linkage of MOM4p0
Topography: ETOPO5
Horizontal resolution: 0.5X0.5
Vertical resolution: 50 layers (5-225: DZ=10m)
Wind forcing: NCEP monthly mean climatology
Vertical mixing scheme: KPP
Heat flux: calculated based on the simulation of SST



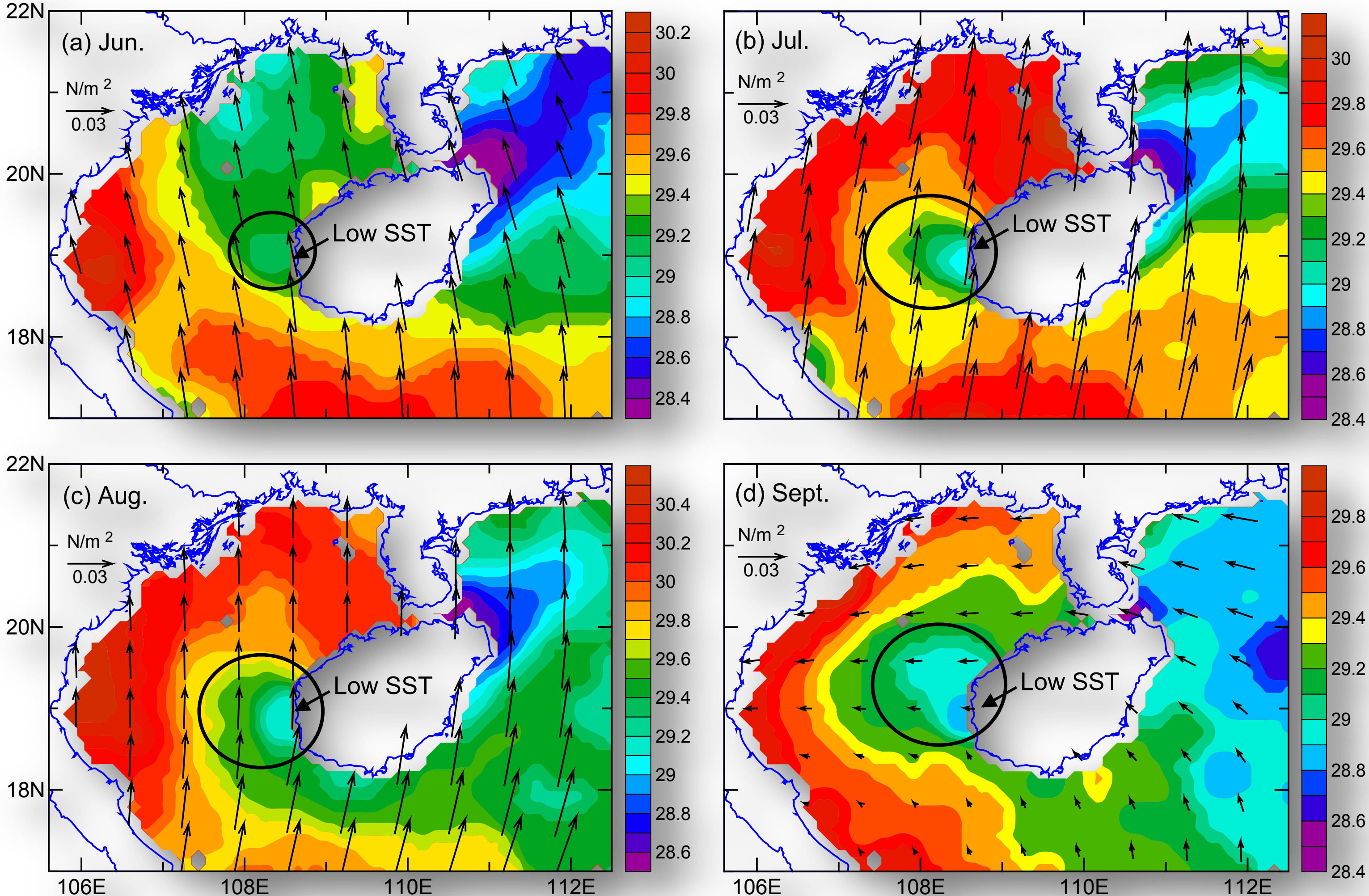




Temperature deviation distributions along transect of 35S in Feb

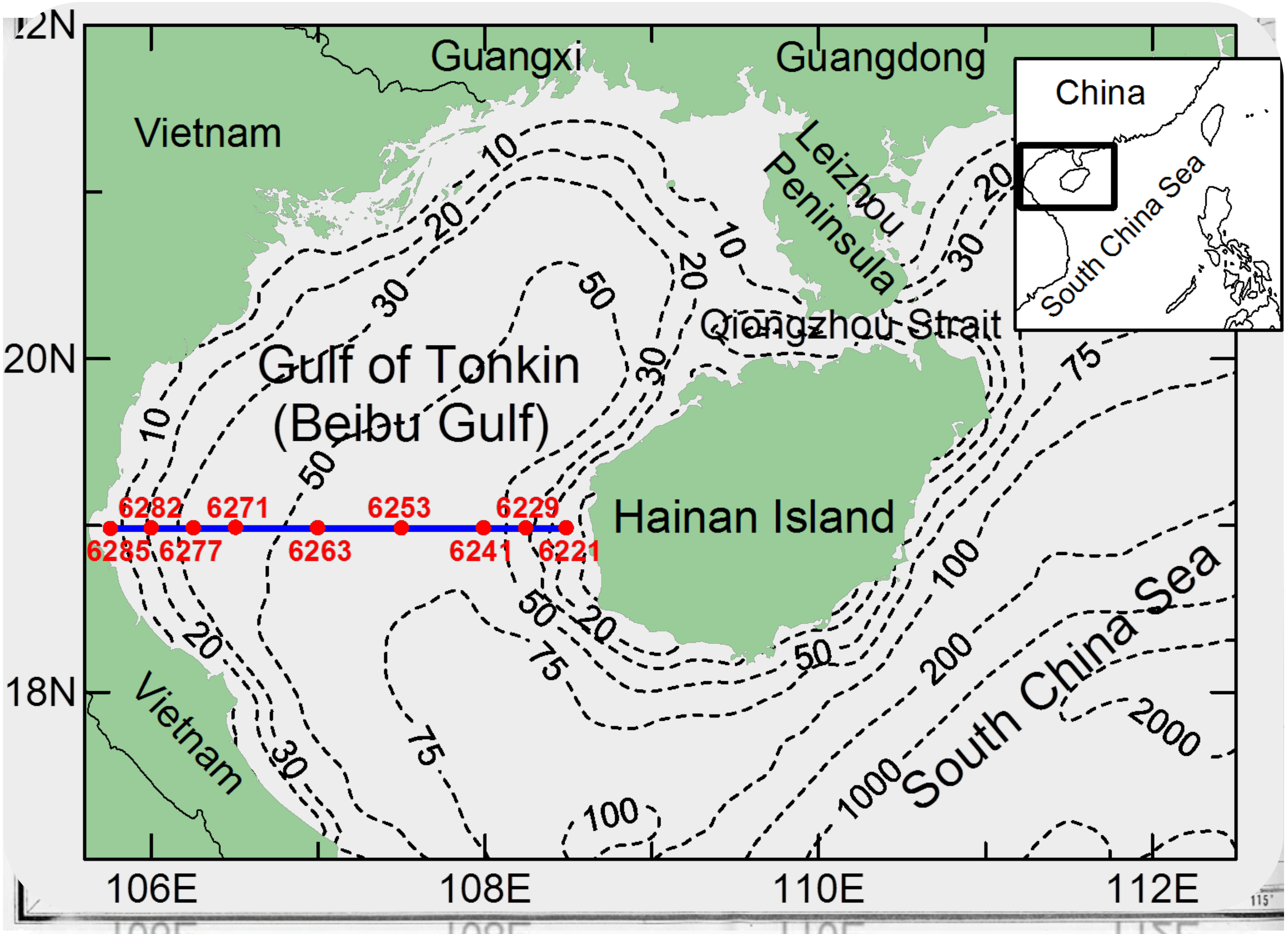
2. Why tidal system in OGCM

●AVHRR SST Climatology

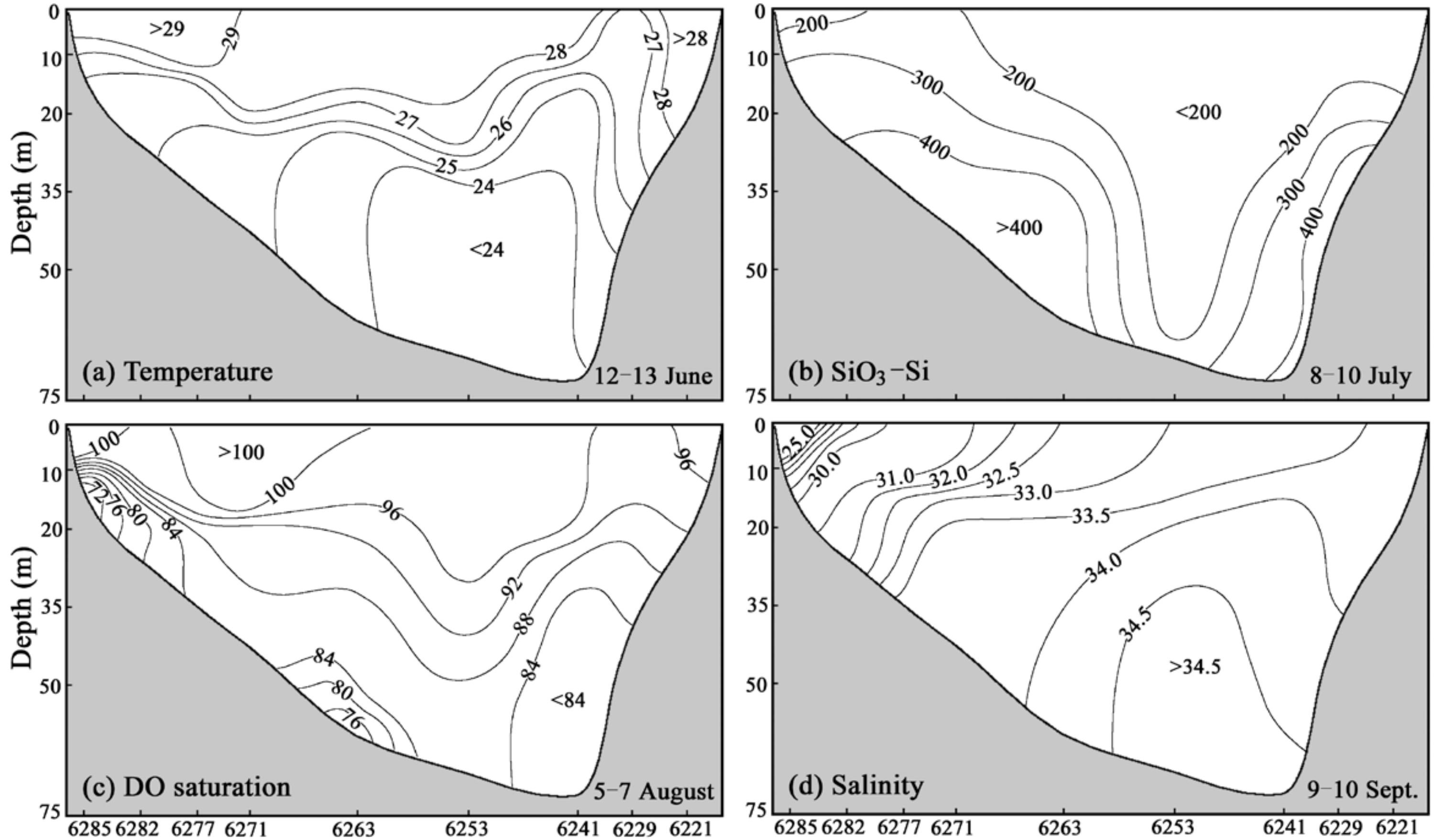


AVHRR Pathfinder SST monthly climatology over 13 years
[*Casey and Cornillon*, 1999, JC]

- **1964 field survey**

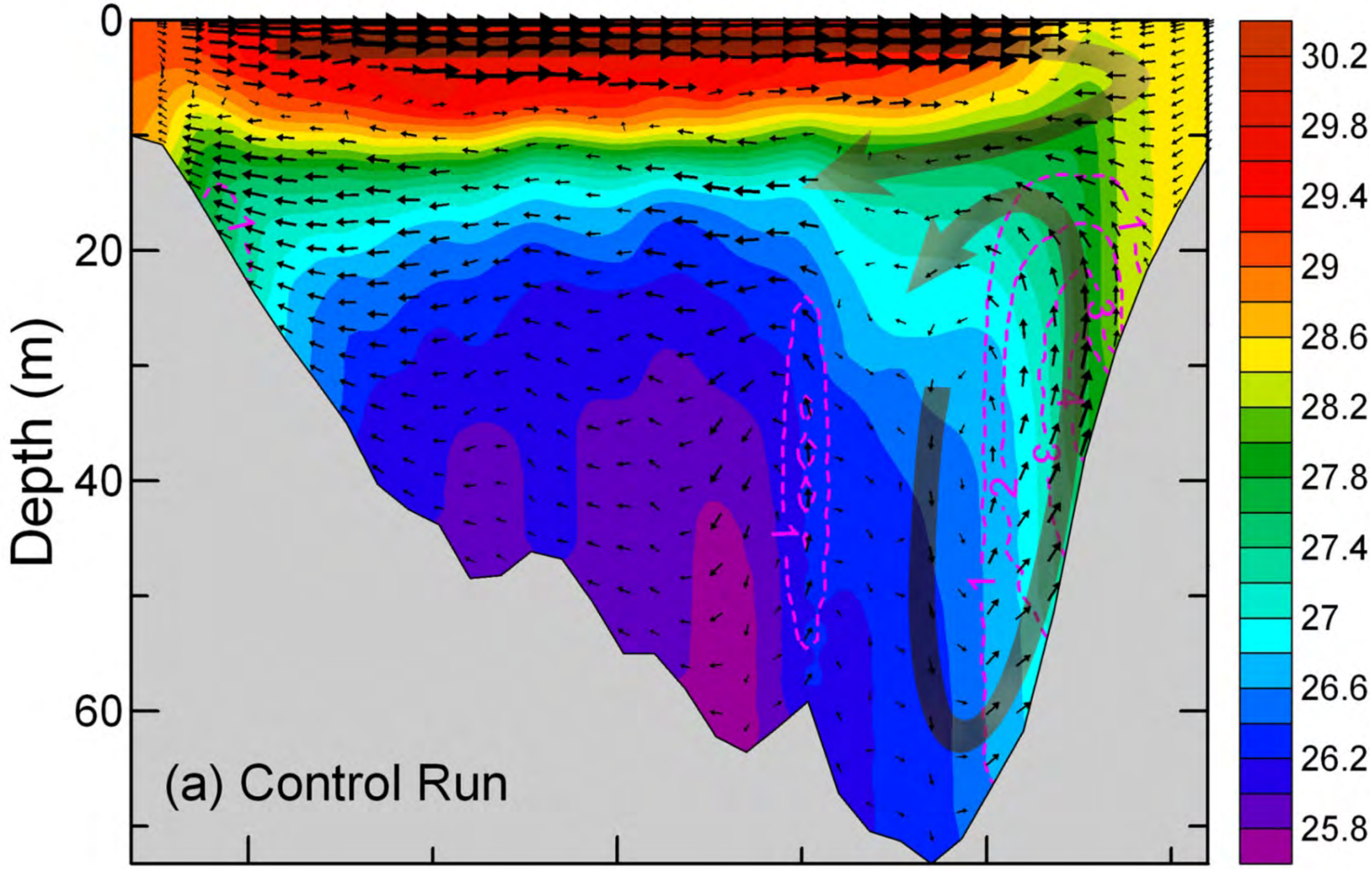


● **1964 field survey**



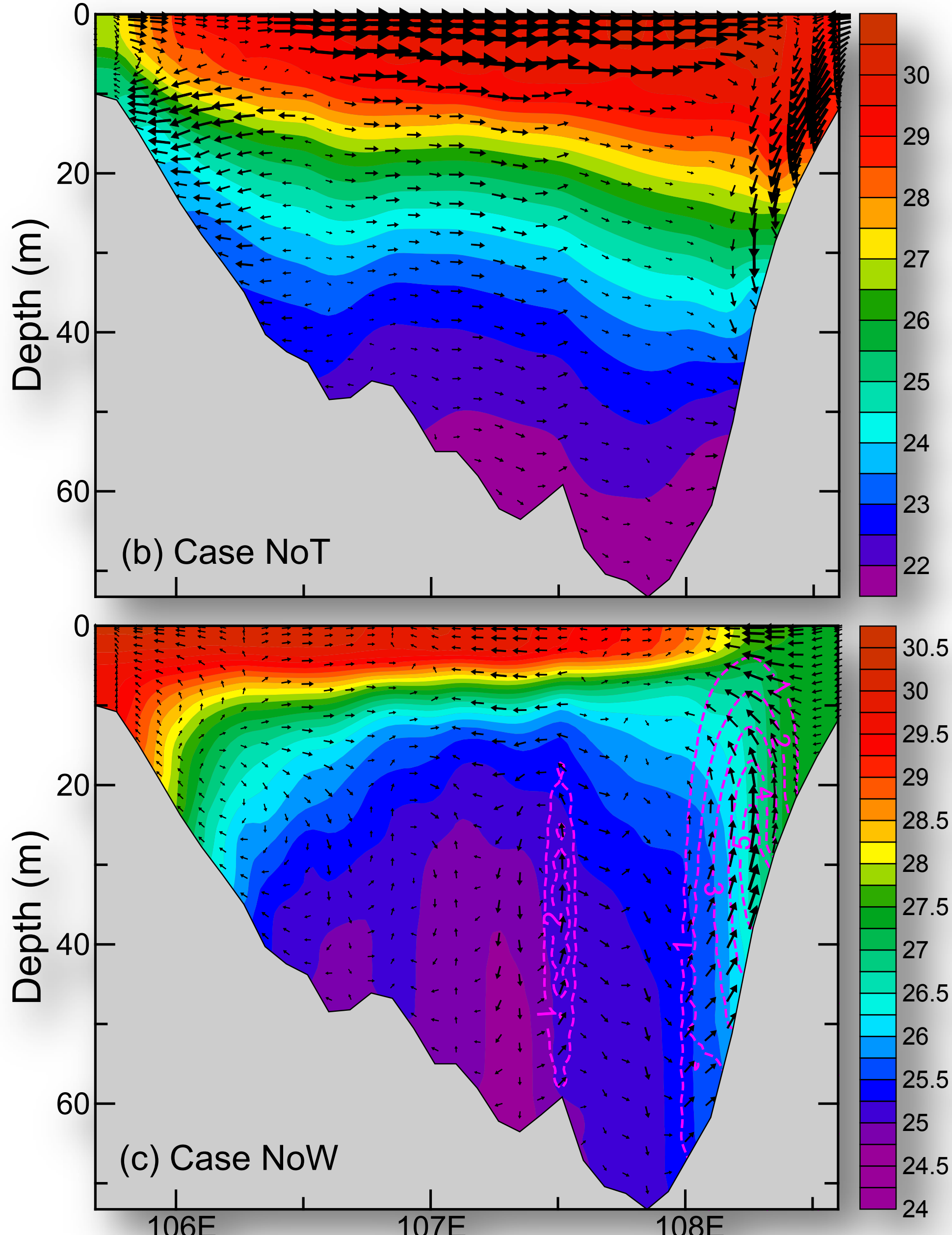
Cross sections of T, SiO3-Si, DO, Salinity along 19^{o}N

Numerical model results



Cross sections of temperature and *u*-*w* vectors along 19°N. **(The vertical velocity has been amplified 1000 times to sharply plot the vectors)**

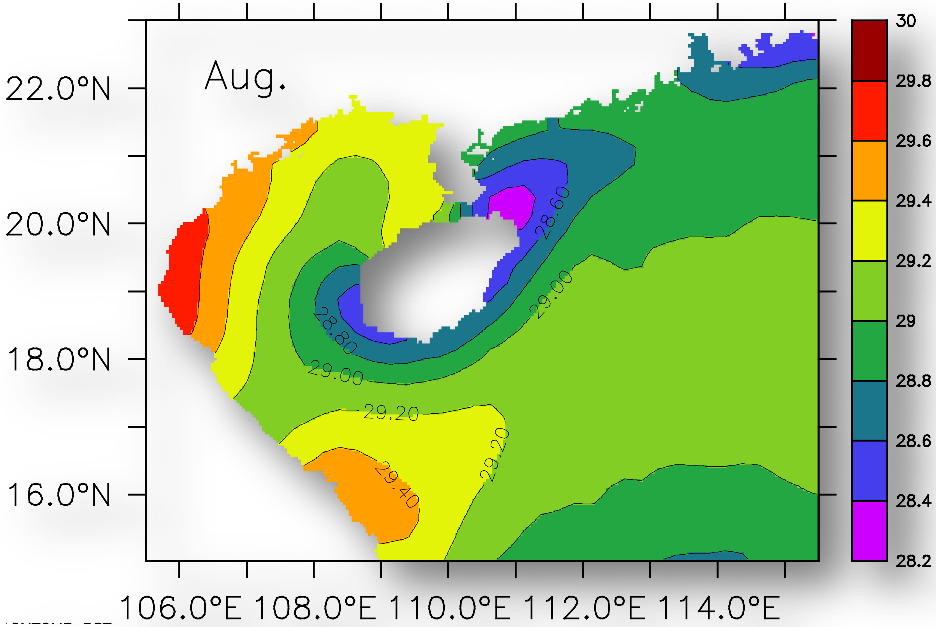
Numerical experiments



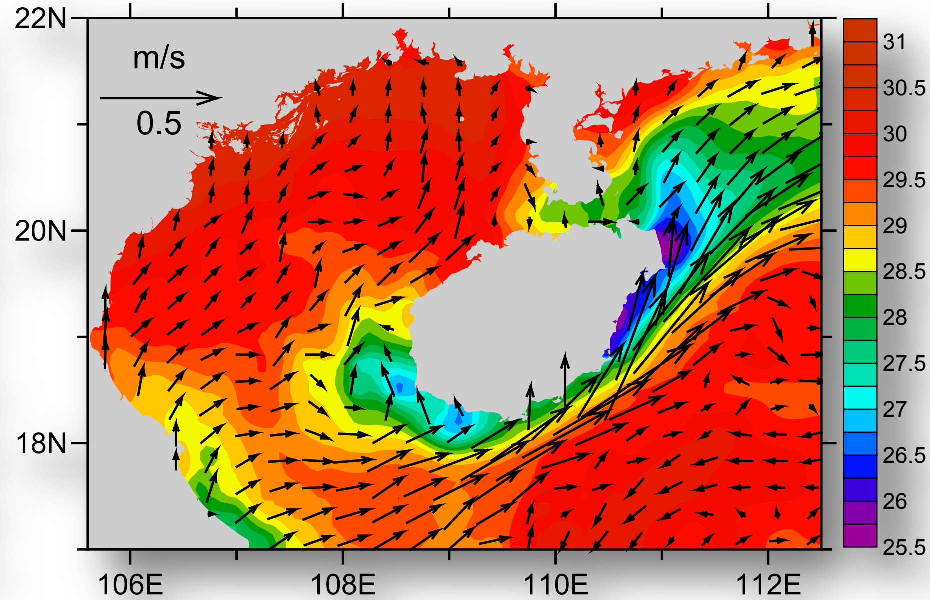
Without tide

Without wind

Numerical model results



Satellite SST

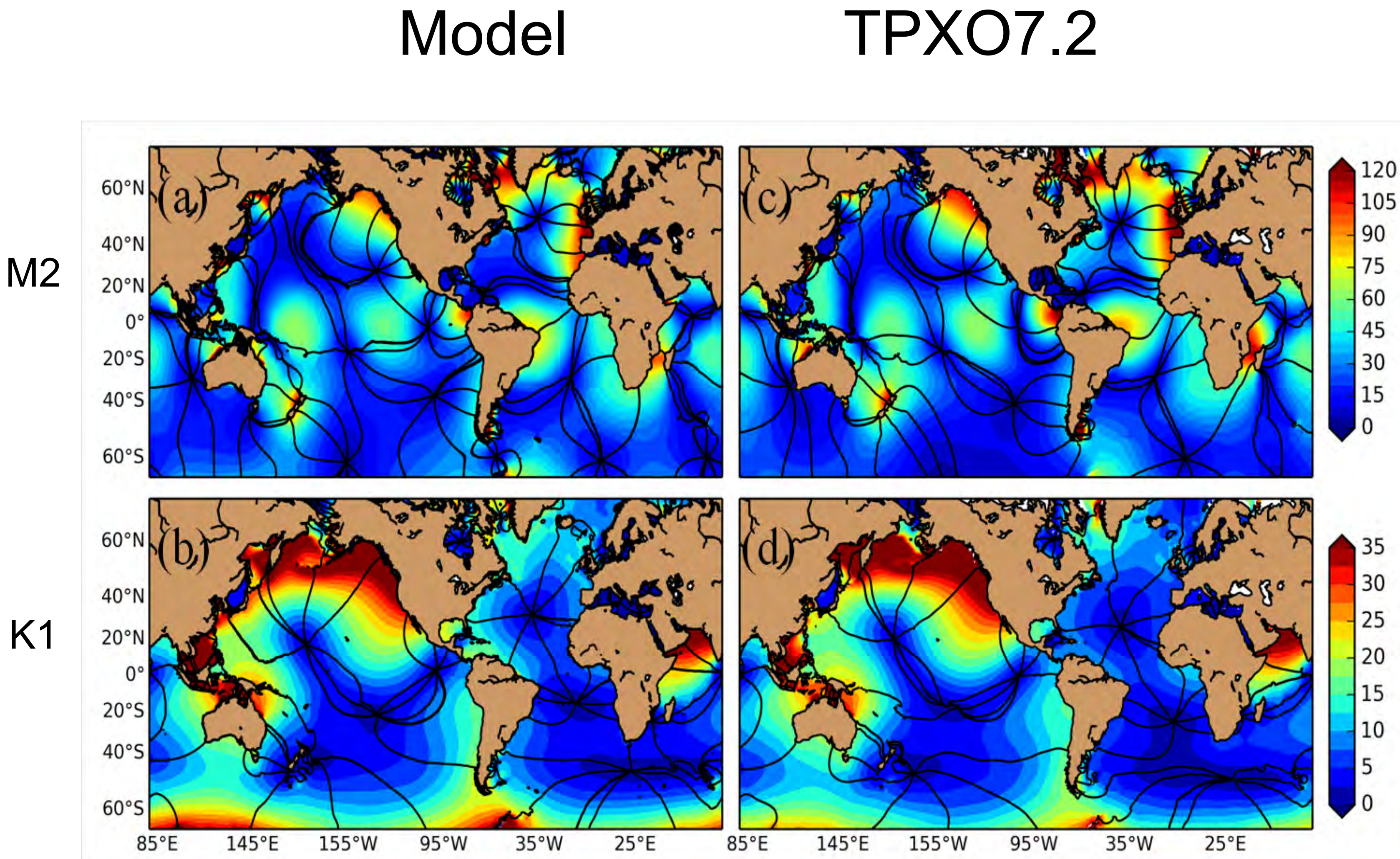


Numerical modeling of SST in August, superimposed by surface currents

3. High resolution coupled model

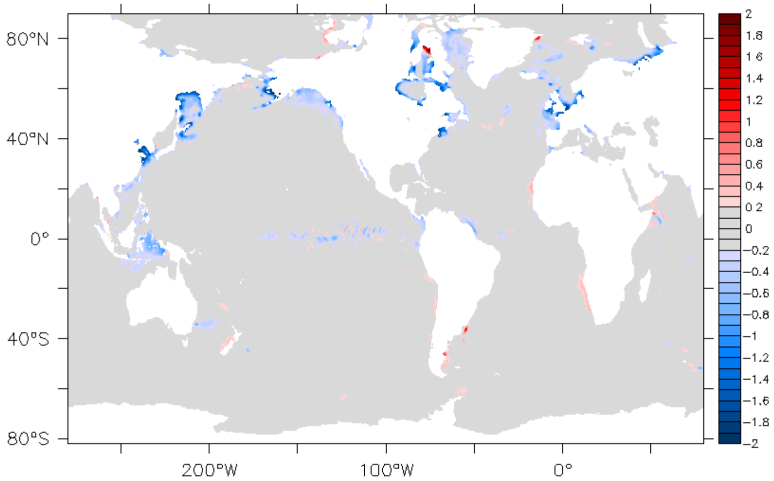
Model Linkage

- **Circulation model : MOM5**
- **Sea ice model: SIS**
- **Surface wave model: MASNUM (FIO)**
- **Tide: 8 components**
- **Resolution: 0.1° X 0.1°, 54 layers**
- **Data assimilation: Ensemble Adjustment Kalman Filter (EAKF) ; Data: SST, SLA, Argo T/S profiles; Period: 2014.01~2015.08**

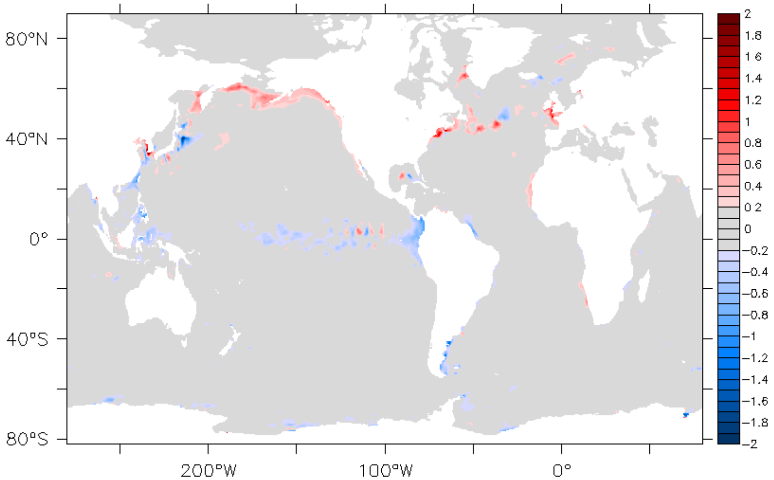


Model
TPXO7.2
M2
K1
(a)
(b)
(c)
(d)
60°N
40°N
20°N
0°
20°S
40°S
60°S
85°E
145°E
155°W
95°W
35°W
25°E
120
105
90
75
60
45
30
15
0
35
30
25
20
15
10
5
0

The contribution of tidal current on SST

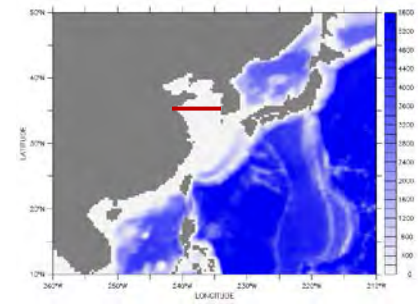


(JJA)

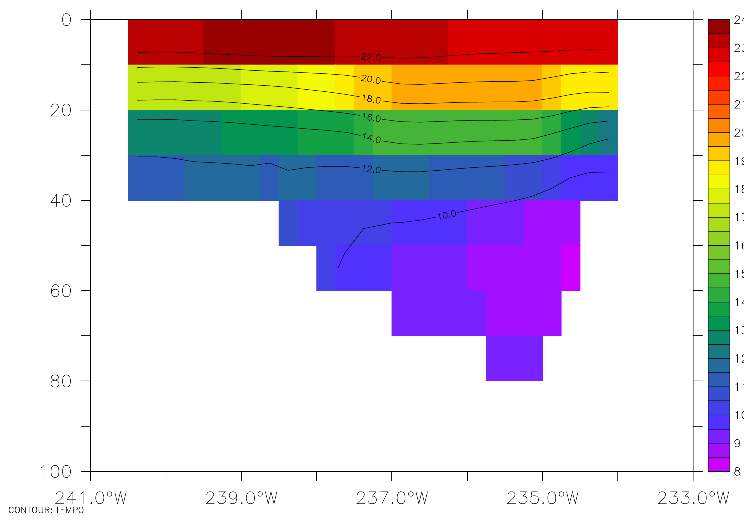


(JFM)

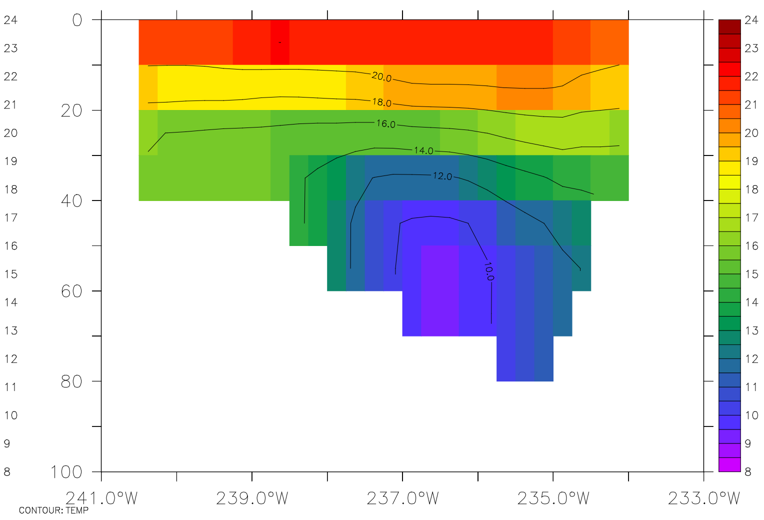
The effects of tidal current on temperature in coastal area are much stronger.



35° N， July

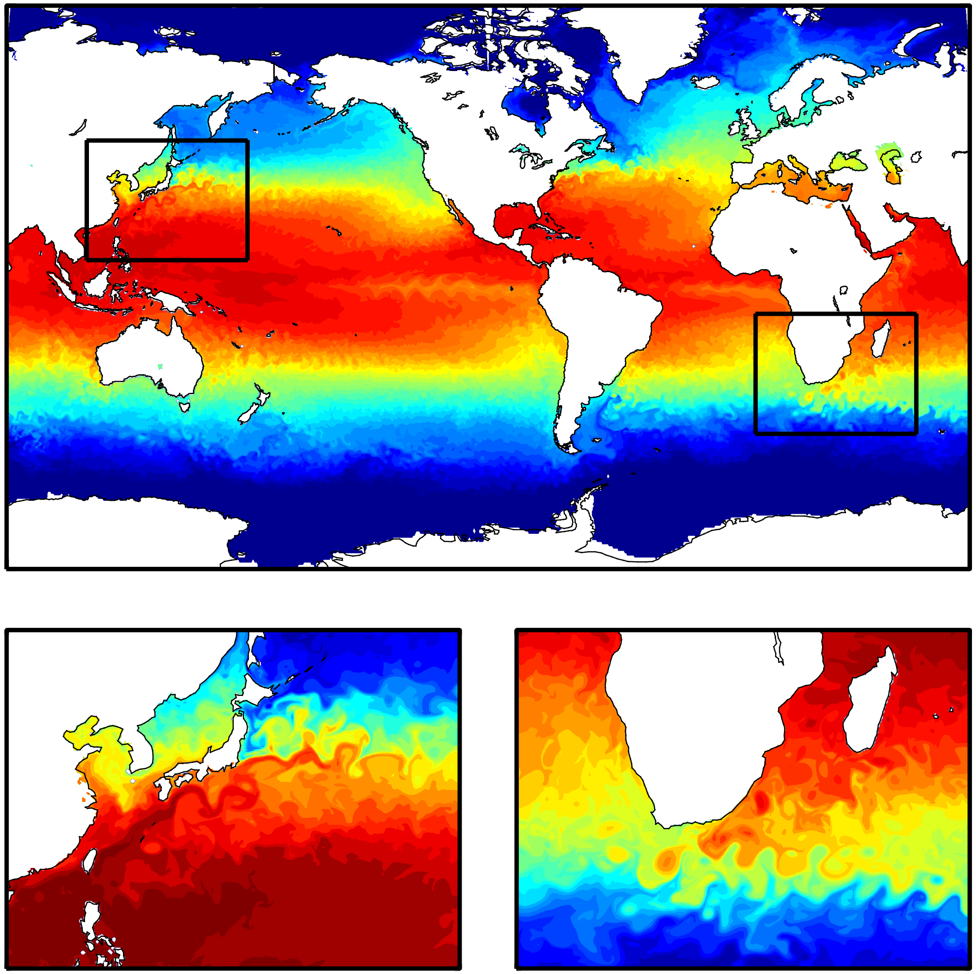


No tide

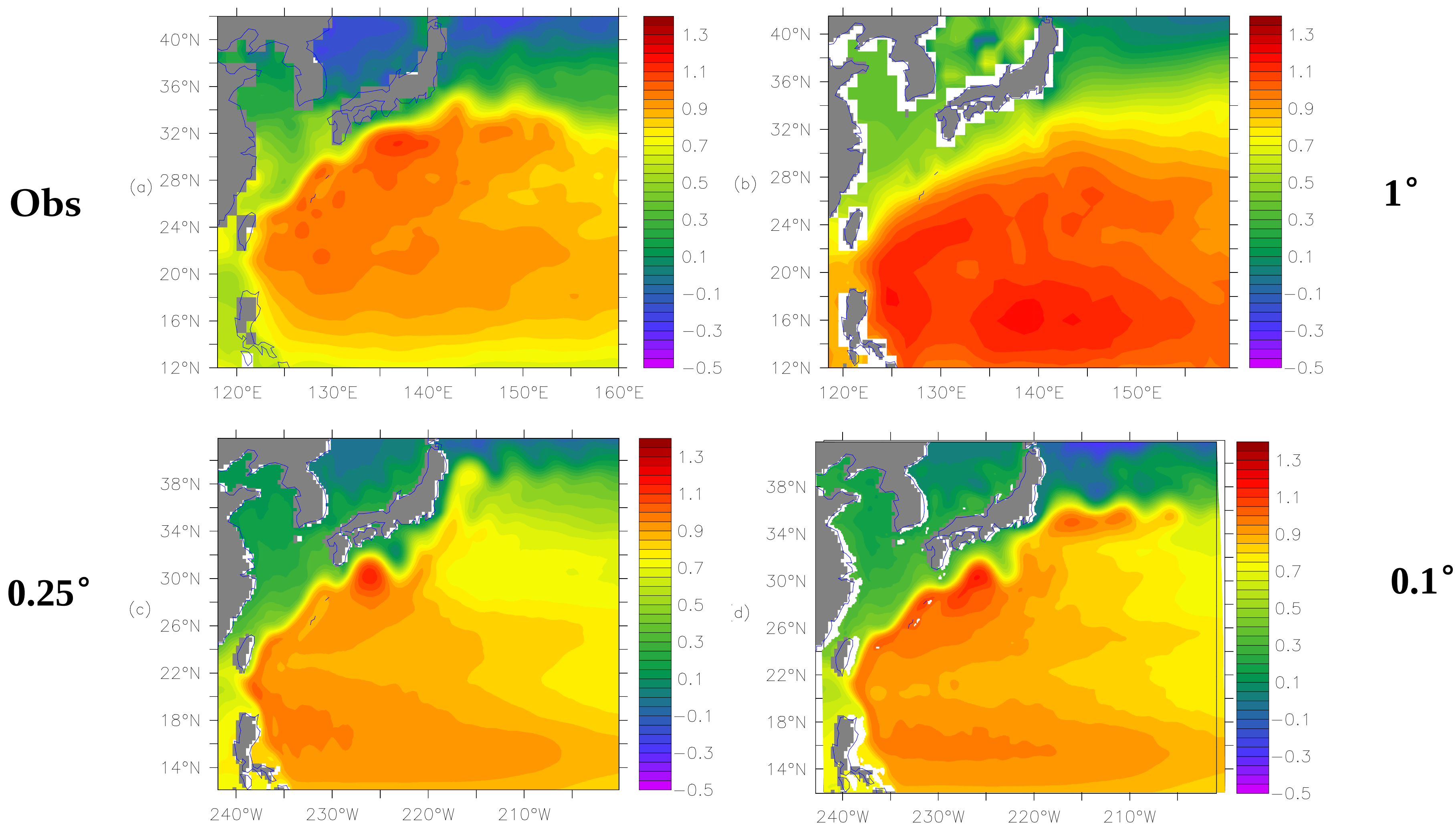


Tide

Coupled model results



Comparison of different resolutions

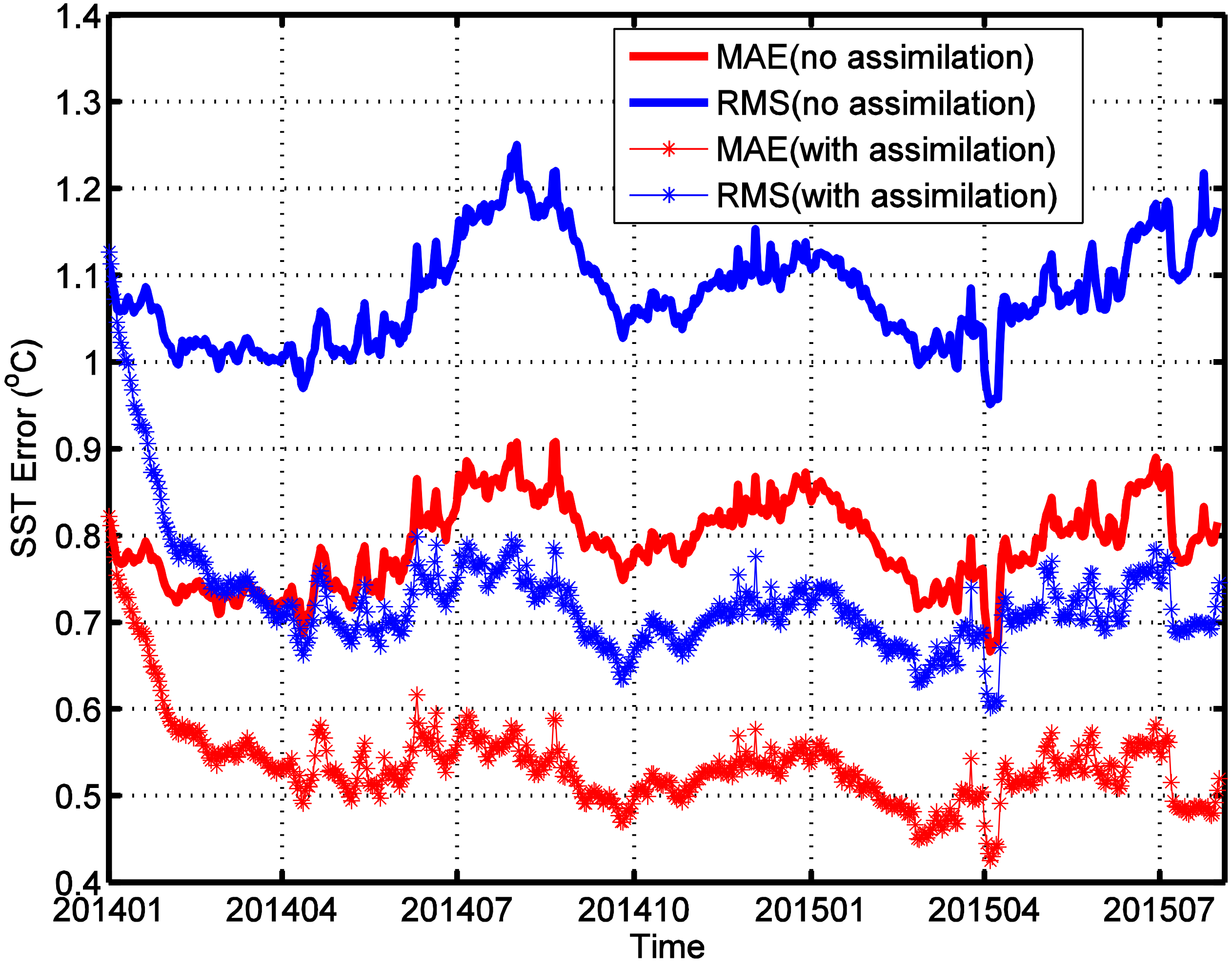


DA

SST, SLA, Argo

RMS

AME

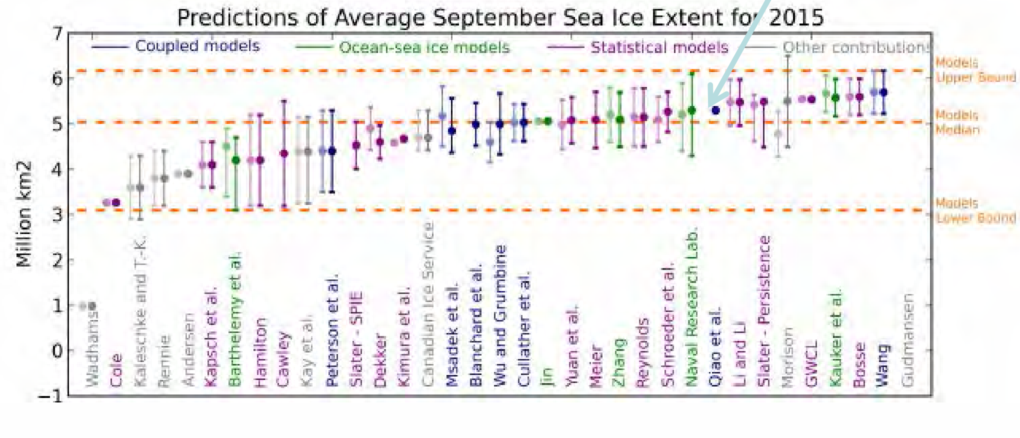


Conclusions

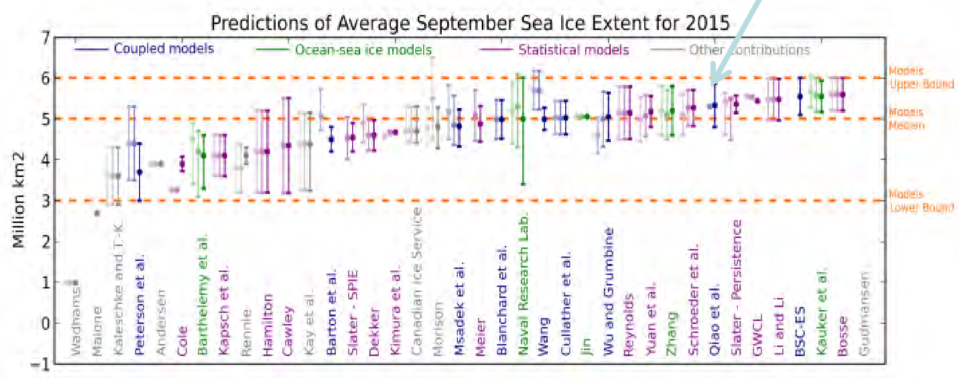
1. **Based on MOM5, a surface wave-tide-circulation-sea ice coupled model with resolution of 0.1X0.1 was successfully developed.**
2. **AEKF data assimilation is developed.**
3. **What could we contribute to FUTURE of PICES?**

- ☐ **Short-time forecast of north of 30N**
- ☐ **Seasonal to inter-annual prediction (Arctic sea ice prediction)**
- ☐ **Long term projection (CMIP5)**

Seasonal prediction of Arctic Sea ice



SIPN (2 months ahead)



SIPN 1 month ahead


Thanks for your attentio