How to improve the forecasting ability ?
--One possible low-lying fruit

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Outline

1. Challenges faced
2. Surface wave in ocean models
3. Surface wave in climate models
4. Summary

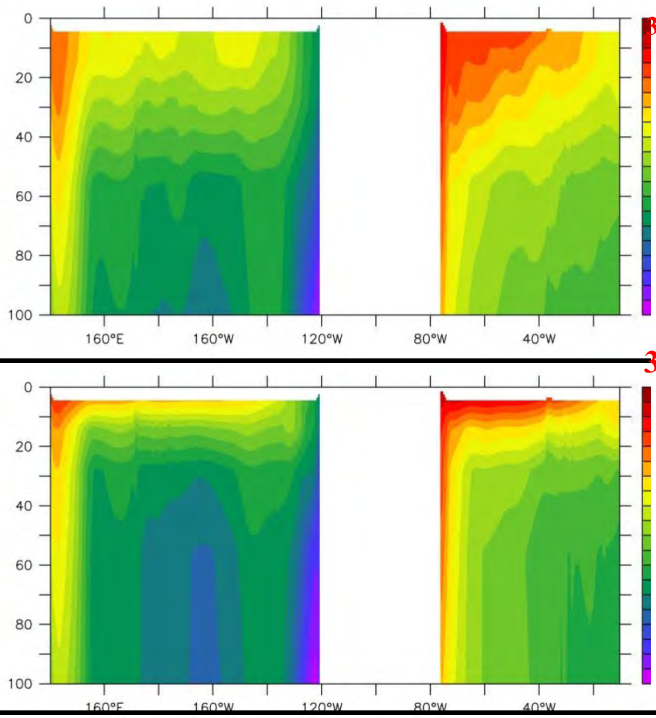
1. Challenges faced

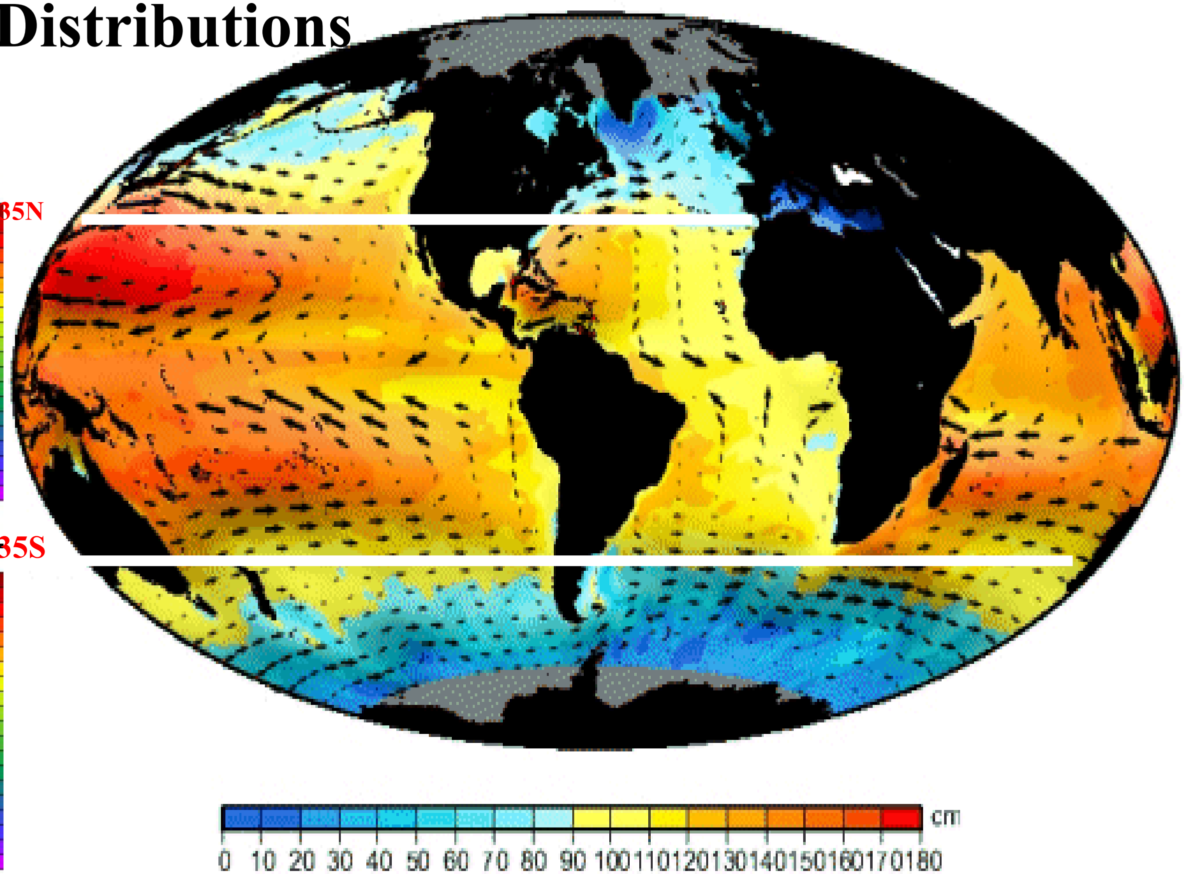
Challenge 1

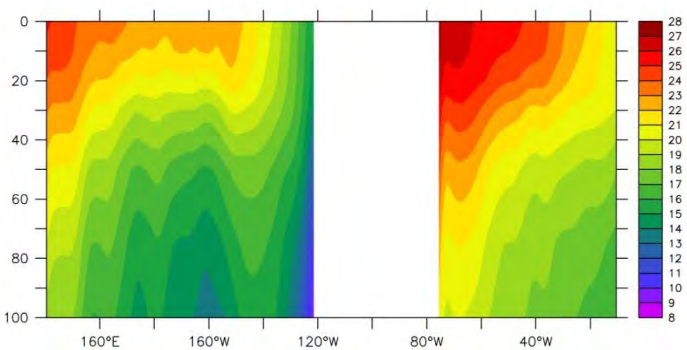
(1) OGCMs: Simulated SST is overheating in summertime, and mixed layer depth is too shallow while the thermocline is too weak (Martin 1985, Kantha 1994, Ezer 2000, Mellor 2003).

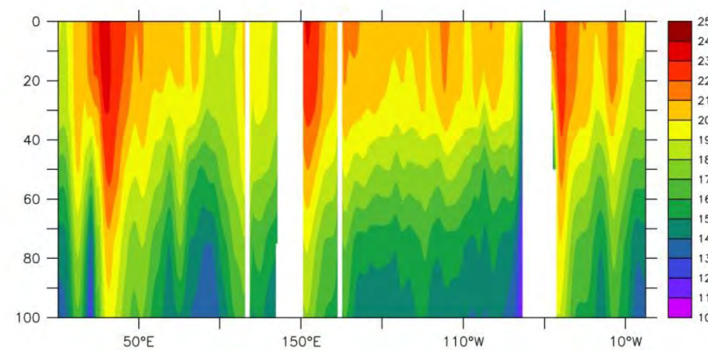
Vertical Temperature Distributions

Pacific **Atlantic**







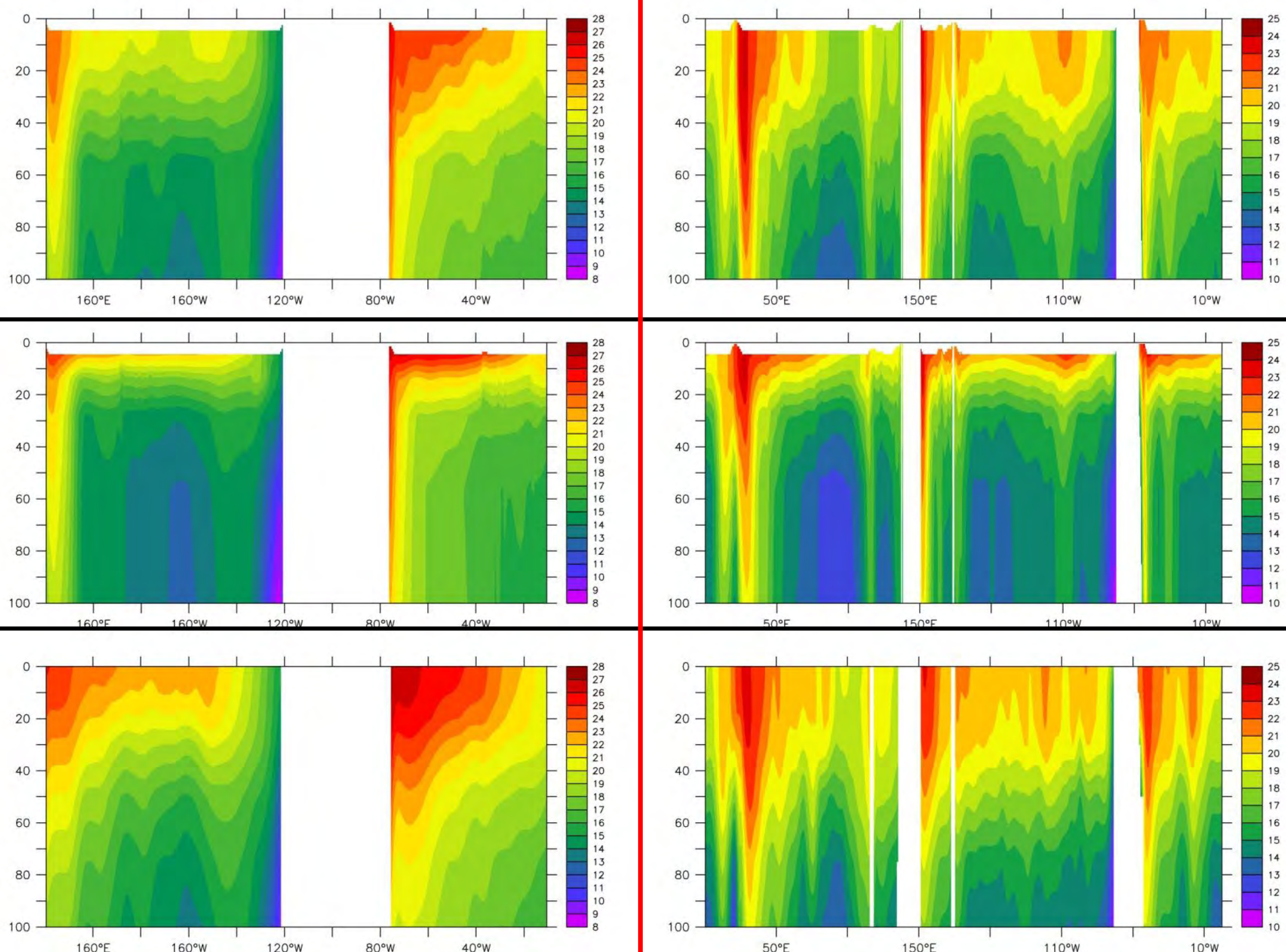


World Ocean Atlas

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

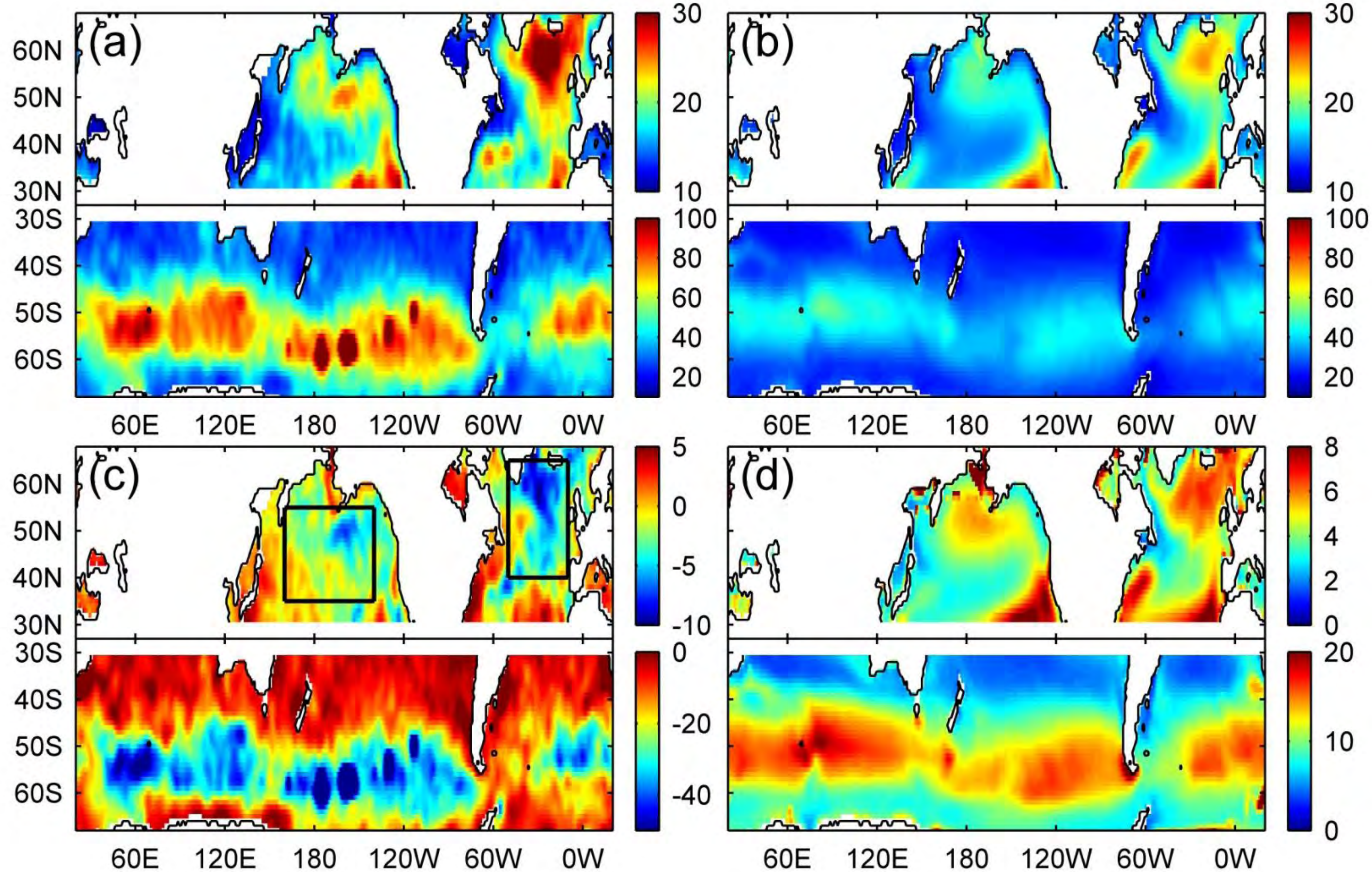
World Ocean Atlas

Along 35N transect in Aug.

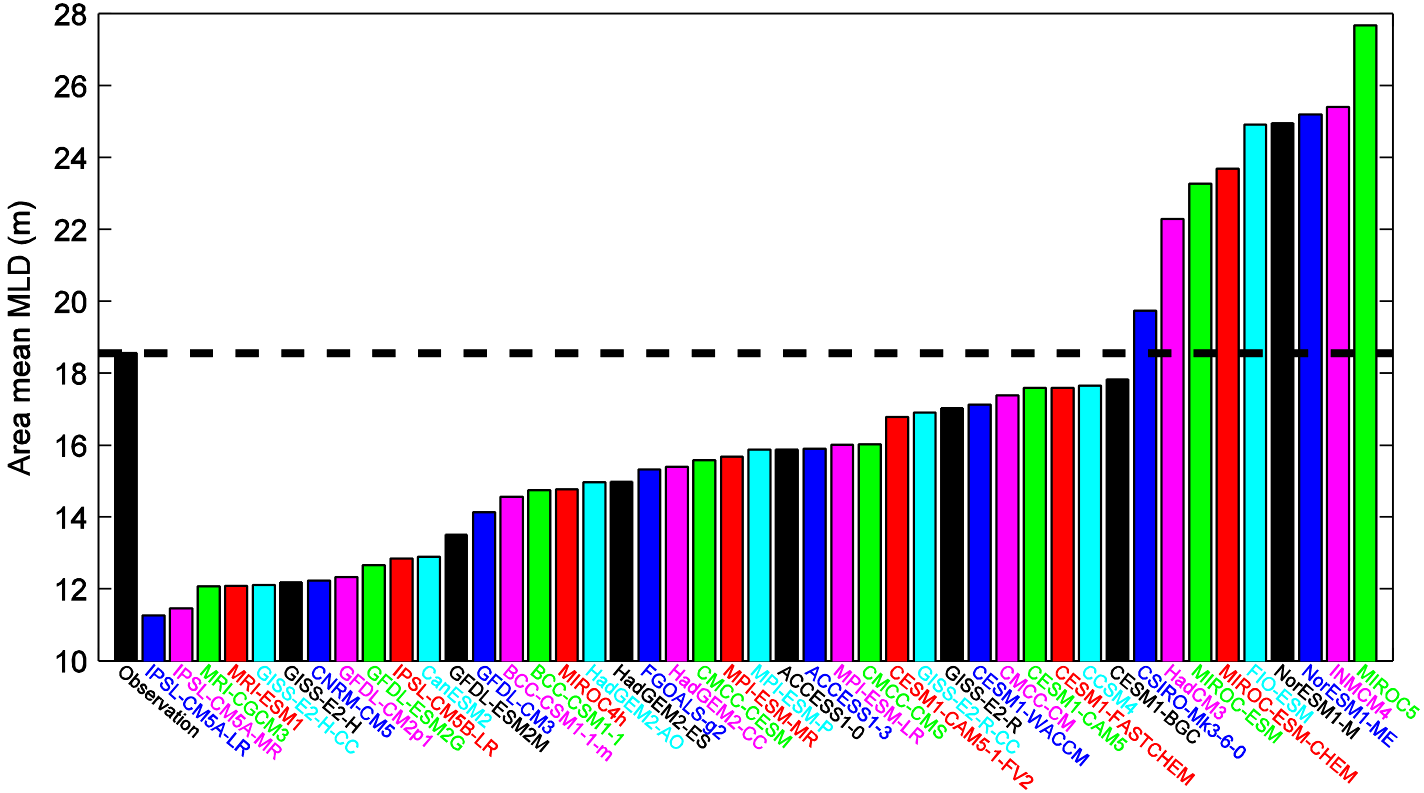
Along 35S transect in Feb.

Challenge 2

(2) Climate Models: The ML is too shallow in high latitudes; Tropical bias for all CGCMs.



Multi-model ensemble summer MLD compared with observations (Jul-Sep and Jan-Mar for the Northern and Southern hemispheres, respectively). (a) Observations , (b) mean of the 43 models (excluding NorESM1-M and NorESM1-ME), (c) multi-model ensemble minus observations, and (d) uncertainties represented by multi-model standard deviation.



Area-averaged MLD (in m) in the central North Pacific Ocean (35ºN-55ºN, and 160ºE-140ºW) during the boreal summer from the 45 CMIP5 models and the observation.

Huang and Qiao, 2014, JGR

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

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.

2. Surface wave in ocean models

2.1 MY (POM): Qiao et al, 2010, OD

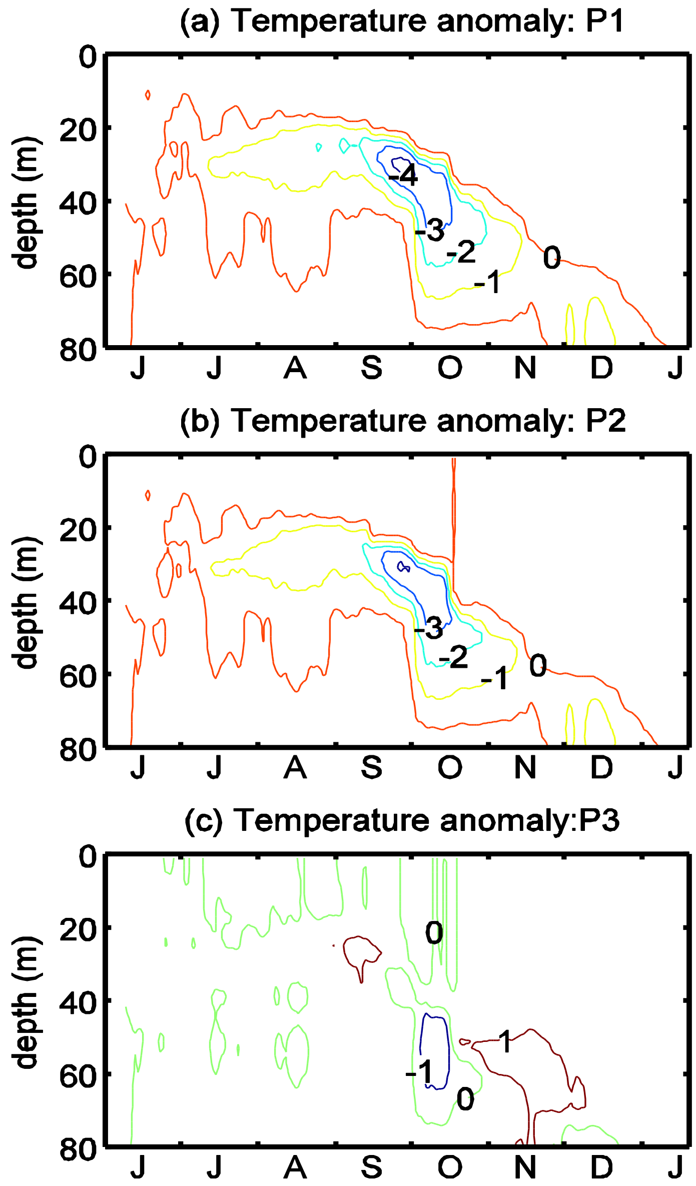
2.2 KPP (MOM4): Shu and Qiao et al, 2011, OM

KPP (ROMS): Wang and Qiao et al, 2010, JGR

KPP(POP): Huang and Qiao, 2012, JGR

2.3 TKE (NEMO): Shu et al, 2013

2.1 MY



Simulated daily mean temperature deviations from the observation (^oC)

MY

MY+ wave breaking by Mellor

MY+ Bv

Huang and Qiao, 2011, JGR

3-D coastal circulation model (Special Issue on JGR, 2006 at http://www.agu.org/journals/ ss/CHINASEAS1/)

We apply Bv into:

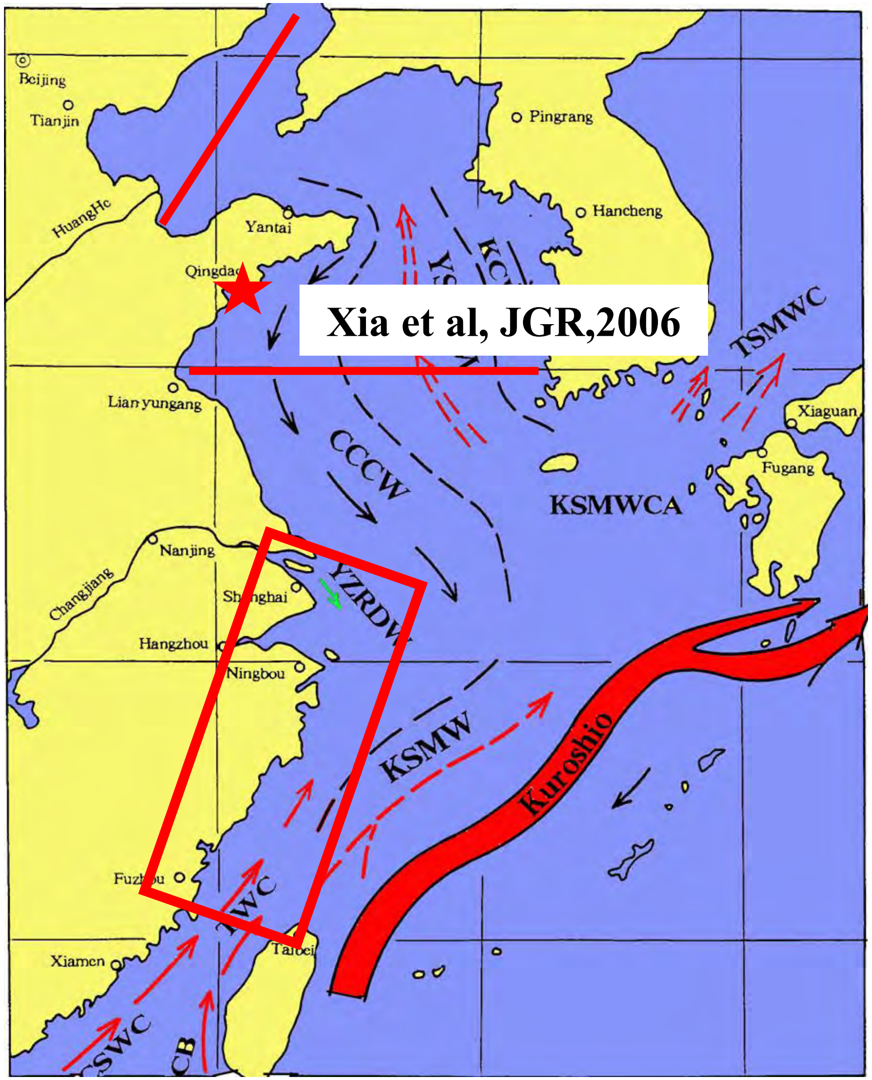
Bohai Sea

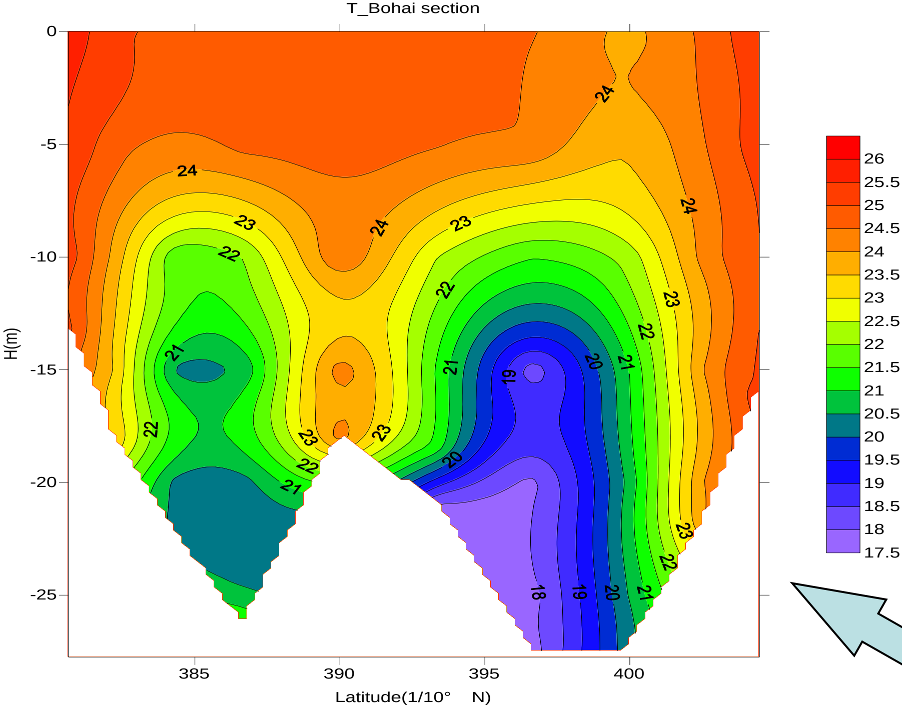
Yellow Sea

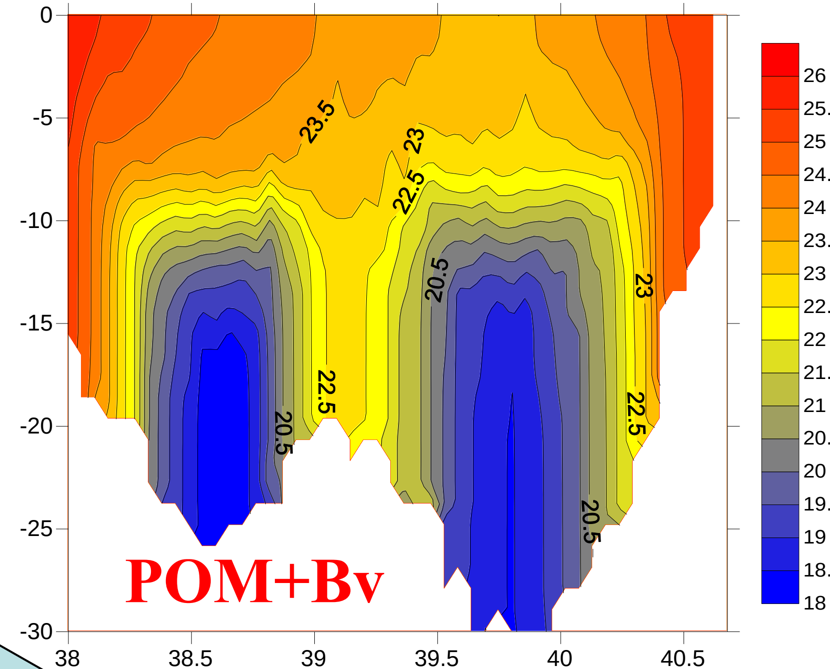
East China Sea

And

South China Sea

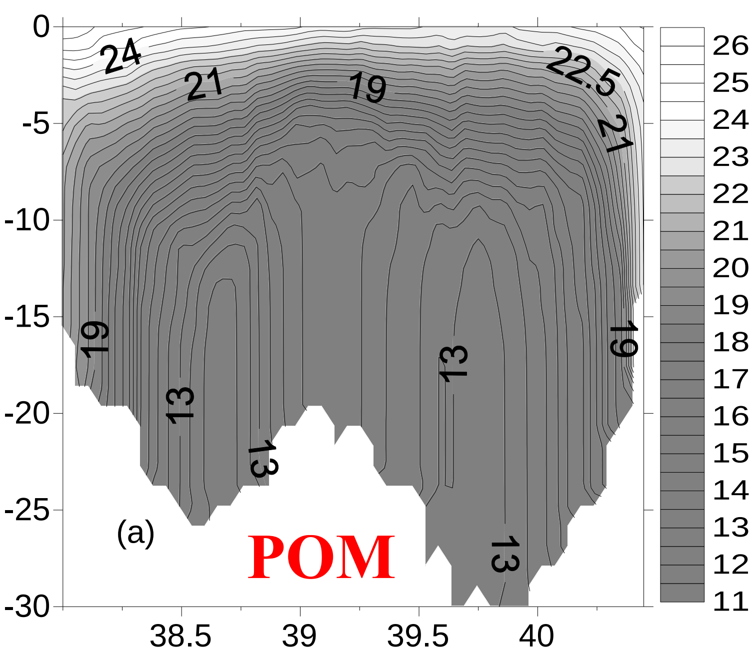


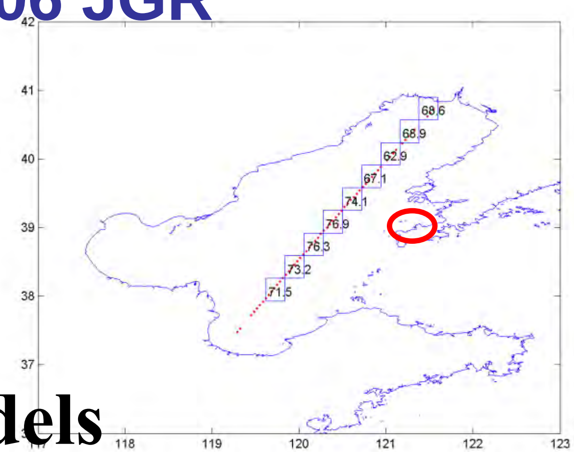




Observation in summer

Lin et al, 2006 JGR





3-D coastal models

Apply Bv into global ocean circulation models

POM: Mellor-Yamada turbulence closure model (1982)

and new scheme (2004, JPO)

Circulation model linkage:

(1) Topography from ETOPO5;

(2)78° S-65° N, 0-360° E, Solid Boundary along 65° N;

(3)Horizontal resolution of 0.5° by 0.5°

(4) 16 vertical sigma layers

(5) Wind stress and heat flux from COADS.

Case 1: Original POM

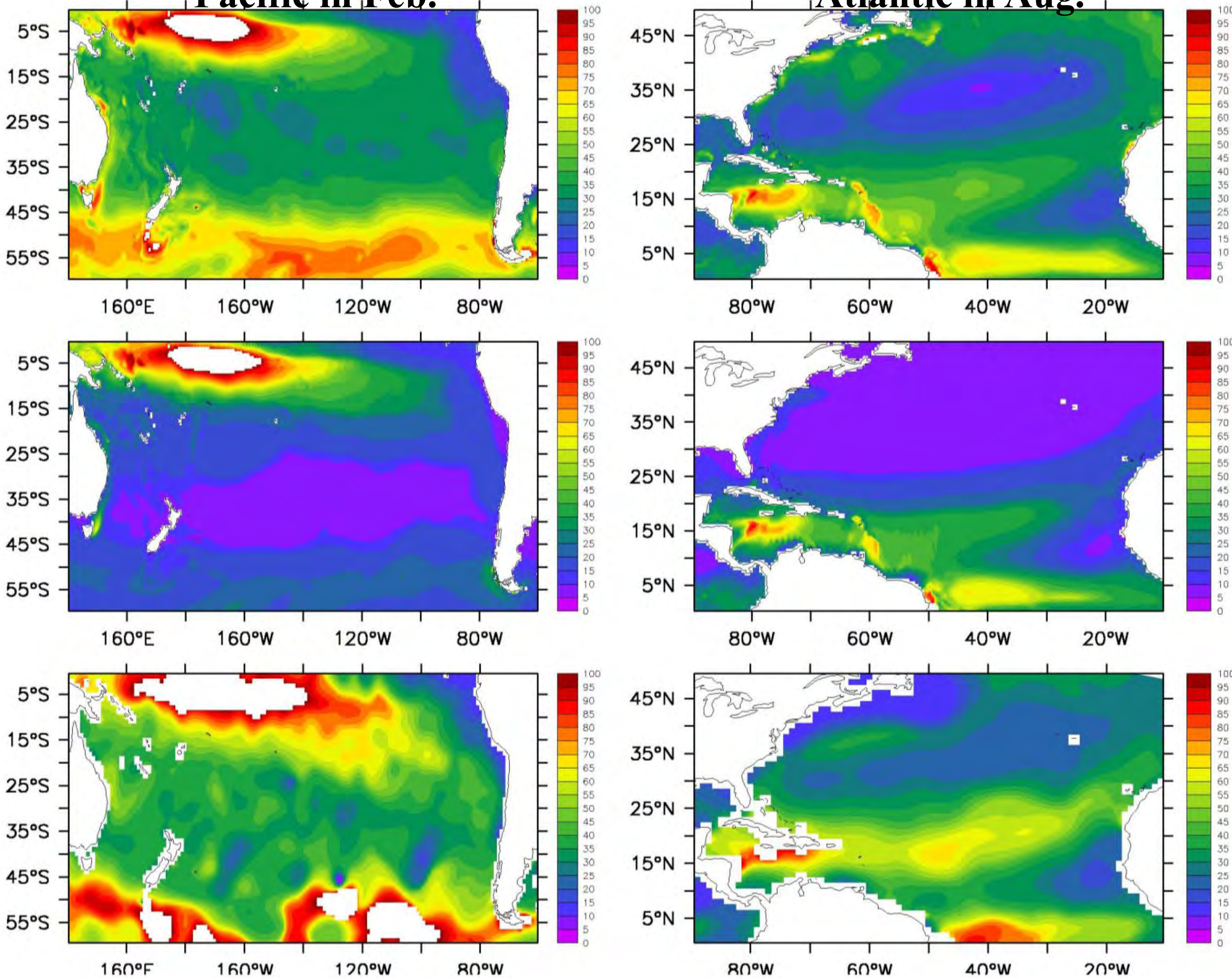
Cold start and run for 10 years

Case 2: POM+Bv

MLD in summer (Qiao et al, OD, 2010)

MLD of the Southern Pacific in Feb.

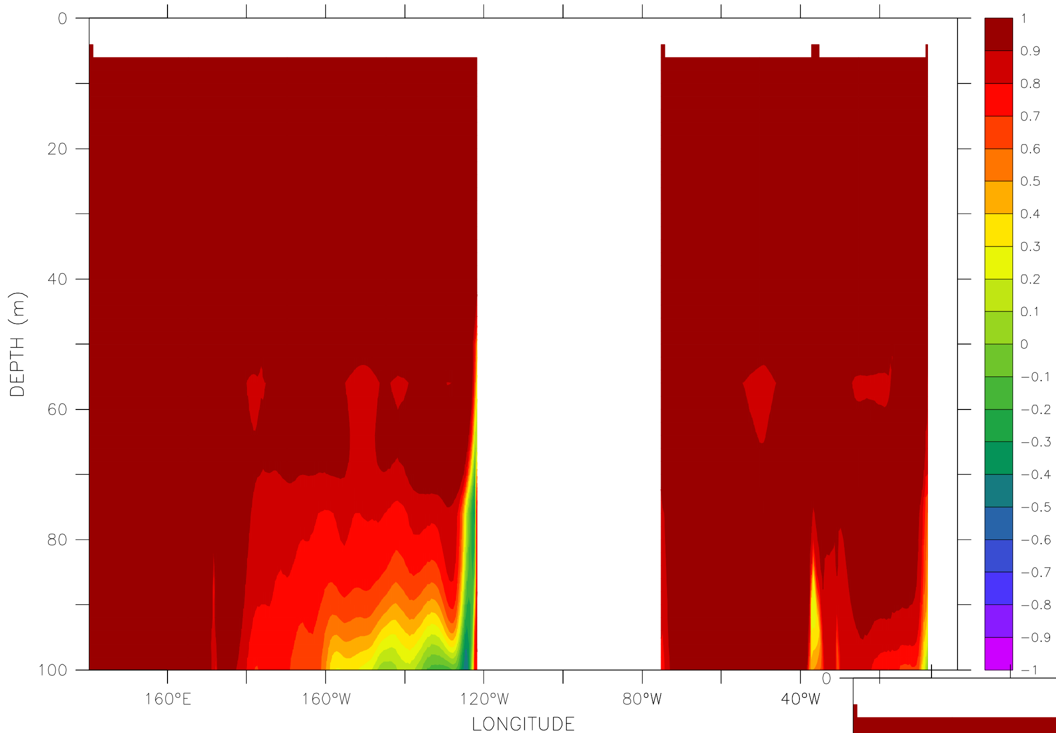
MLD of the Northern Atlantic in Aug.



With wave-induce mixing

Without wave-induce mixing

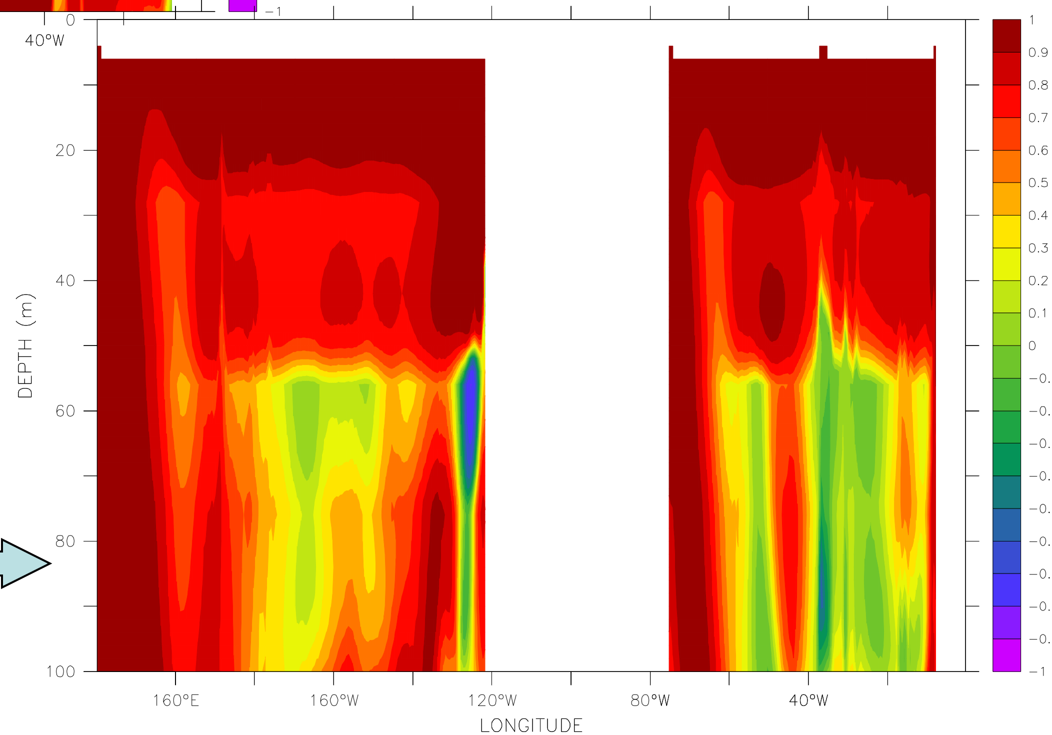
World Ocean Atlas



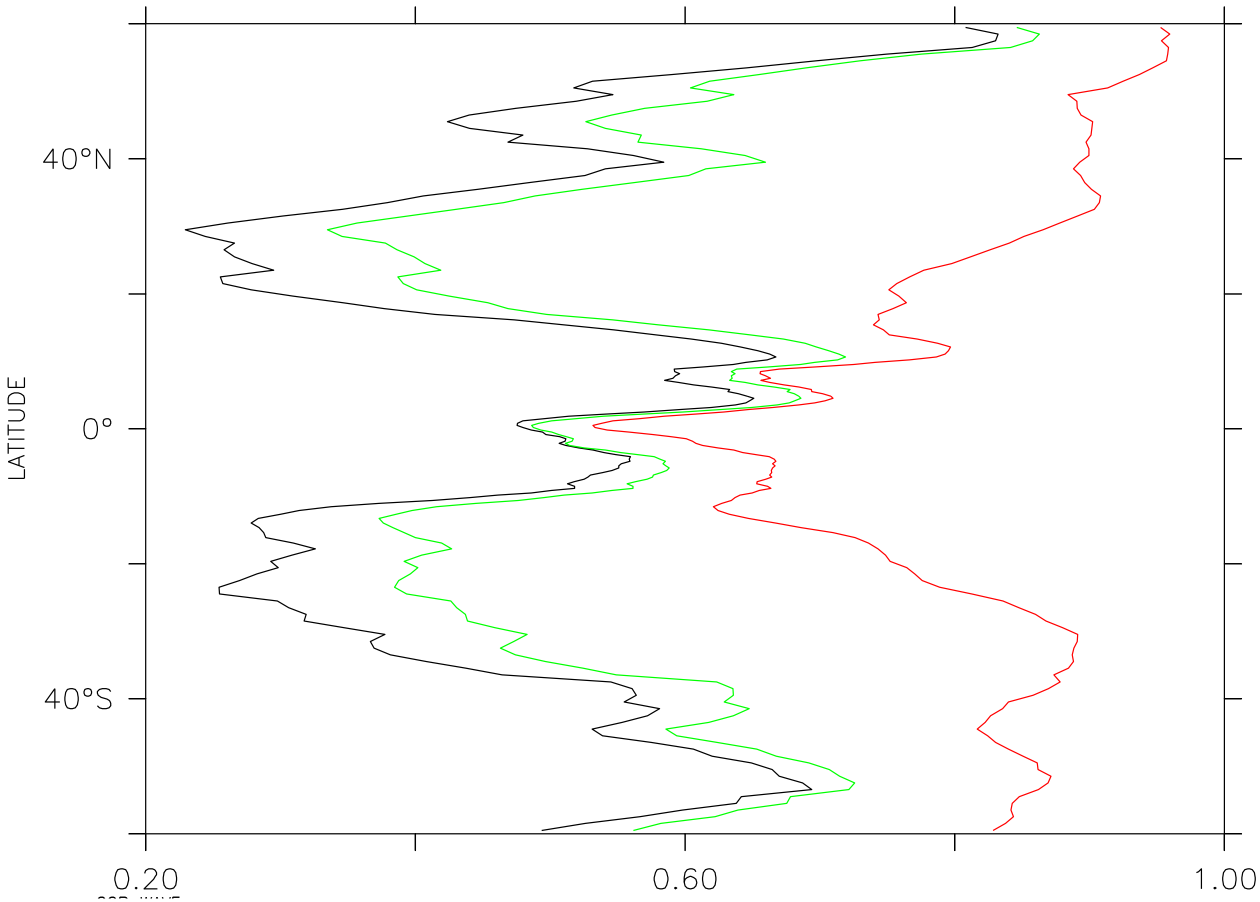
With Bv

Mean Correlation Coefficient:
0.68-0.93 (35N)

Without Bv



The two lines represent the whole upper ocean: Zonal (x-direction) and upper 100m (z-direction) averaged correlation coefficient (t).



Based on POM2008. Bleck, POM2008 without wave effects; Green: with wave breaking (and IW) suggested by Mellor (2004, JPO); Red: with Bv suggested by Qiao et al (2004)

2.2 Apply Bv into different ocean circulation models

ROMS: KPP scheme for vertical mixing (JGR, 2010)

Circulation model linkage:

(1) Topography from ETOPO5;

(2)78° S-65° N, 0-360° E, Solid Boundary along 65° N;

(3)Horizontal resolution of 0.5° by 0.5°

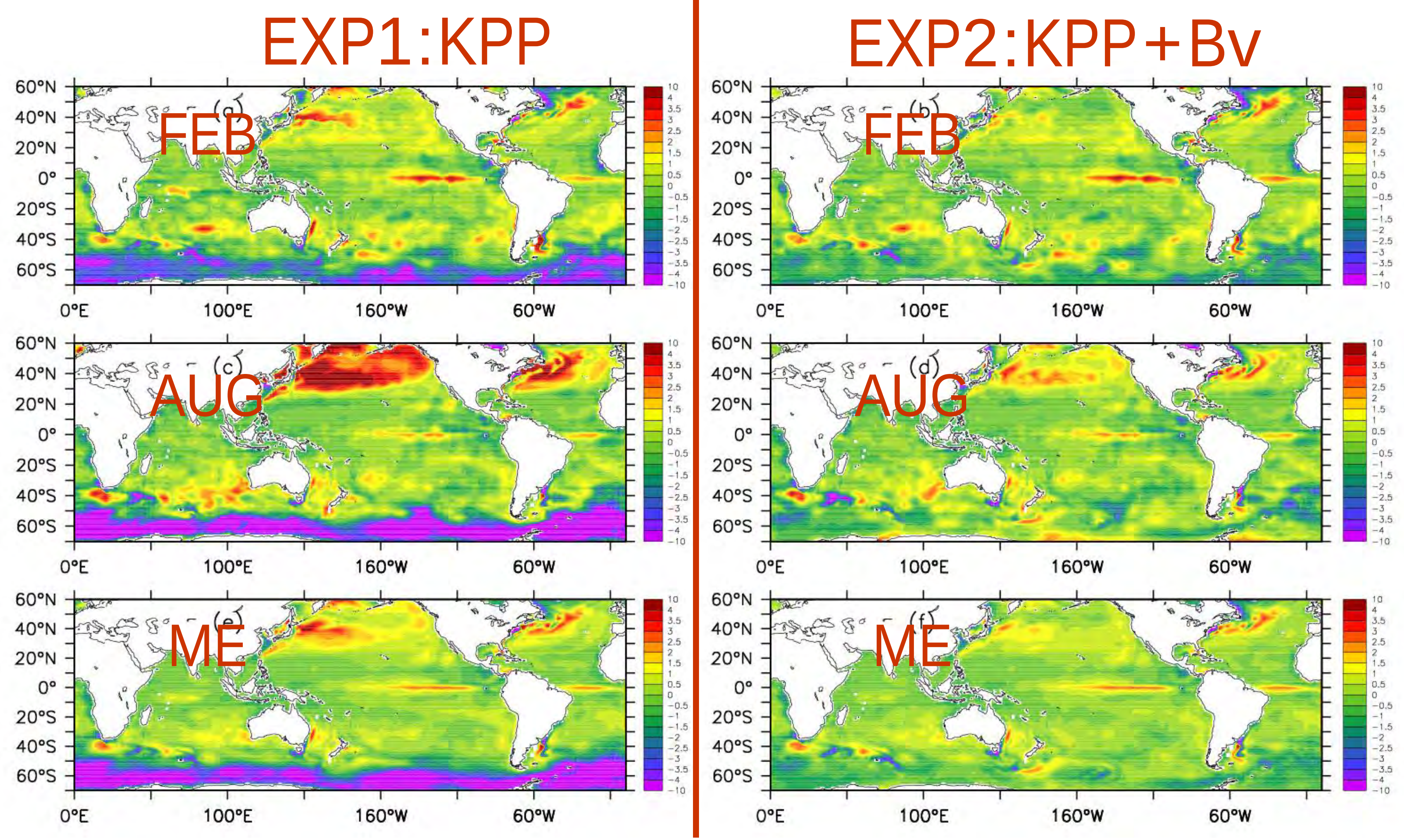
(4) Twenty terrain-following s-coordinate levels with θs = 7 and θb = 0.2 for ROMS

(5) Wind stress and heat flux from COADS.

Case 1: Original ROMS

Cold start and run for 6 years

Case 2: ROMS+Bv



The simulated temperature deviation (ROMS model-Levitus) at 20m.

2.3 TKE of NEMO: CORE numerical experiments on Bv

ORCA2_LIM: a coupled ocean / sea-ice configuration based on the ORCA tripolar grid at 2° horizontal resolution and 31 vertical levels. 182(x)×149(y)×31(z).
http://www.nemo-ocean.eu/Using-NEMO/Configurations/ORCA2_LIM

ORCA1: 362(x)×292(y)×75(z). http://www.noc.soton.ac.uk/nemo/

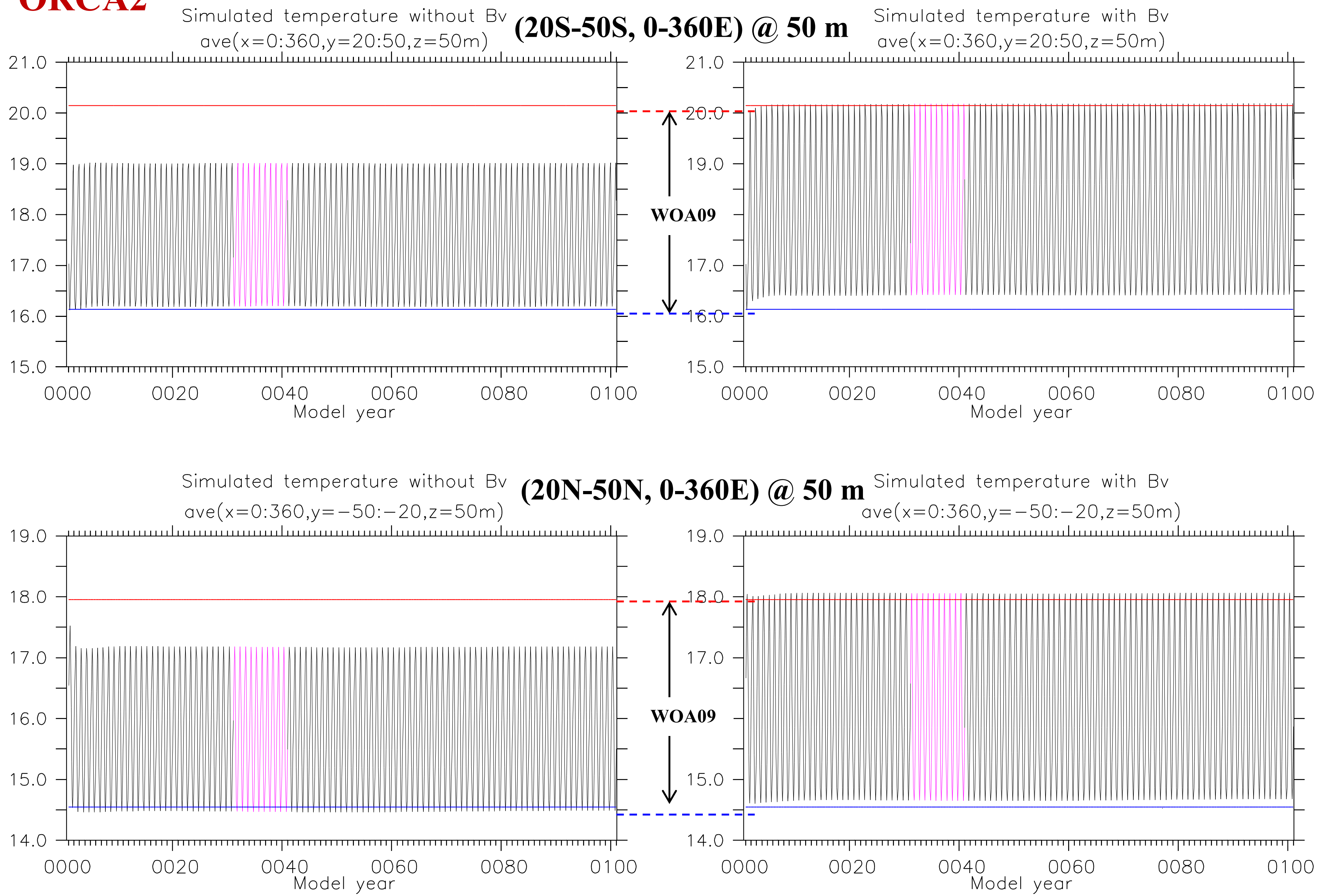
ORCA025: a coupled ocean / sea-ice configuration based on the ORCA tripolar grid at (1/4)° horizontal resolution and 75 vertical levels. 1442(x)×1021(y)×75(z).

Climatological ***Bv*** data are from a global wave model with 0.5 degree resolution in x/y direction and 32 levels in z direction.

$$\mathbf{avm = avm} + \boldsymbol{Bv}$$
$$\mathbf{avt = avt} + \boldsymbol{Bv}$$

Shu Q. et al, 2013

ORCA2



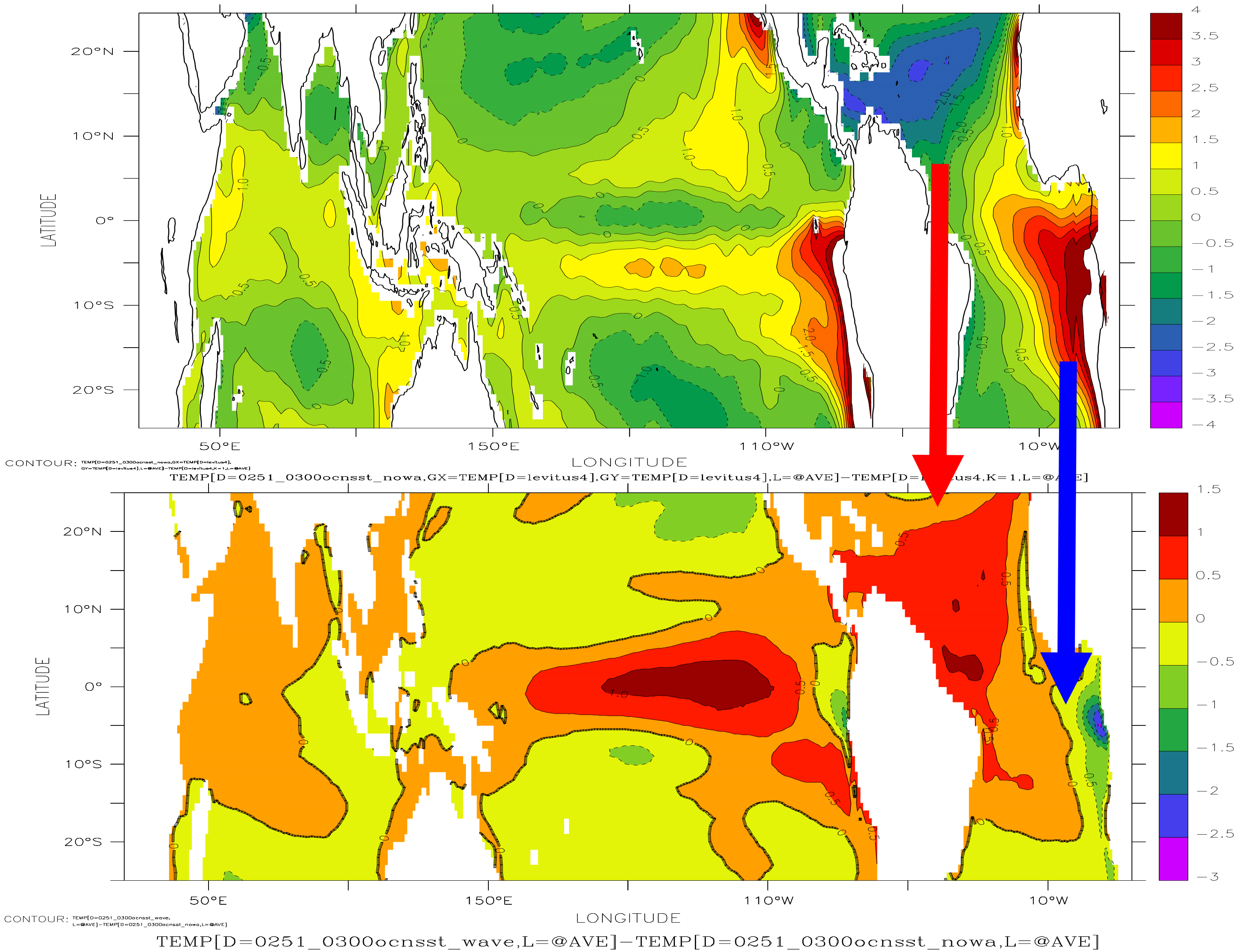
(20S-50S, 0-360E) @ 50 m
Simulated temperature without Bv
ave(x=0:360,y=20:50,z=50m)
Simulated temperature with Bv
ave(x=0:360,y=20:50,z=50m)
WOA09
21.0
20.0
19.0
18.0
17.0
16.0
15.0
0000
0020
0040
0060
0080
0100
Model year
(20N-50N, 0-360E) @ 50 m
Simulated temperature without Bv
ave(x=0:360,y=−50:−20,z=50m)
Simulated temperature with Bv
ave(x=0:360,y=−50:−20,z=50m)
WOA09
19.0
18.0
17.0
16.0
15.0
14.0
Model year

3. Surface wave in climate models

In tropical area, Bv has no much improvements for the ocean circulation model compared with mid- and high latitudes. For full coupled climate model, it is a different story because of the feedback and nonlinearity.

3.1 Tropical bias and summer MLD

3.2 FIO-ESM



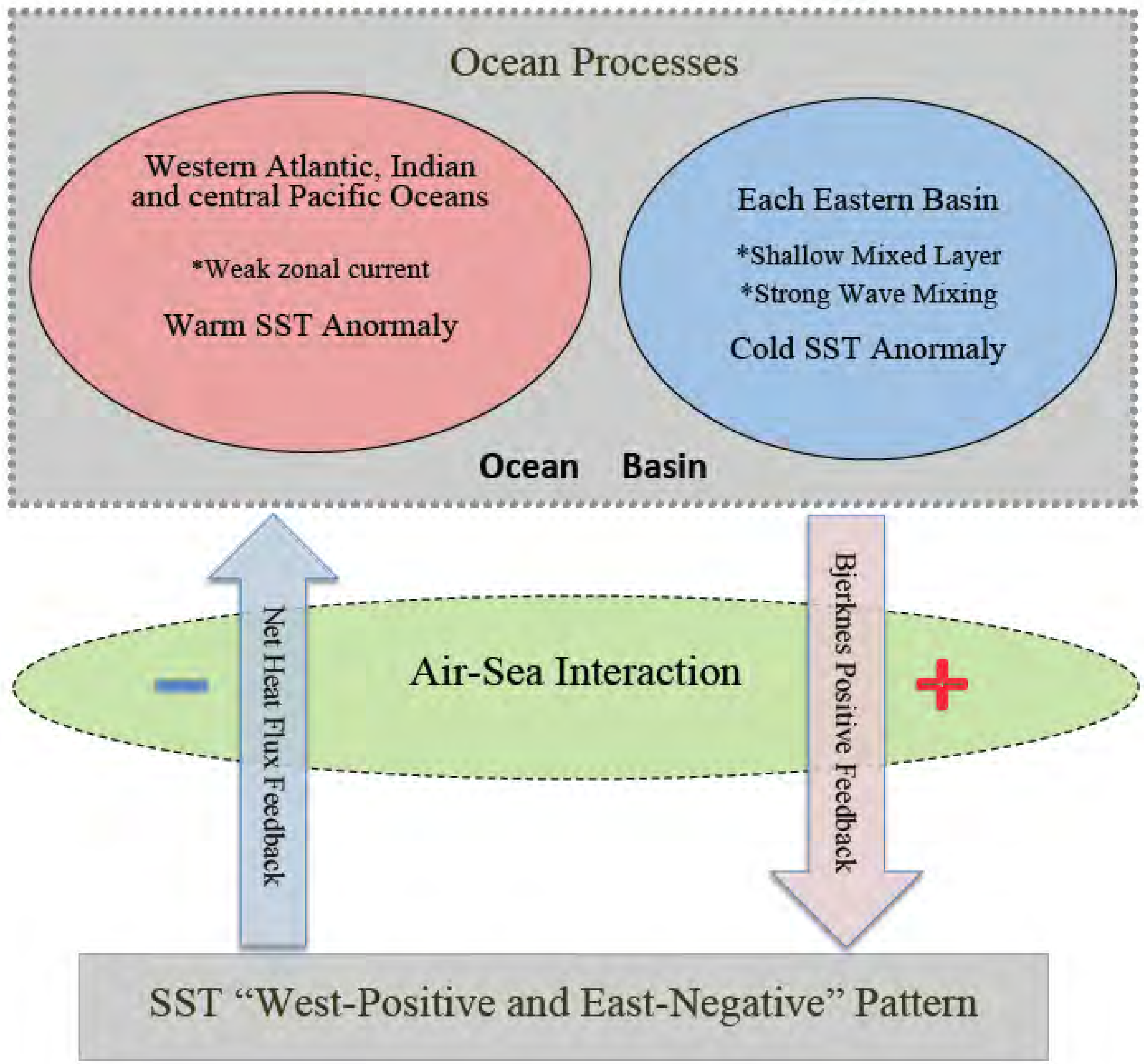
50a averaged SST (251-300a).

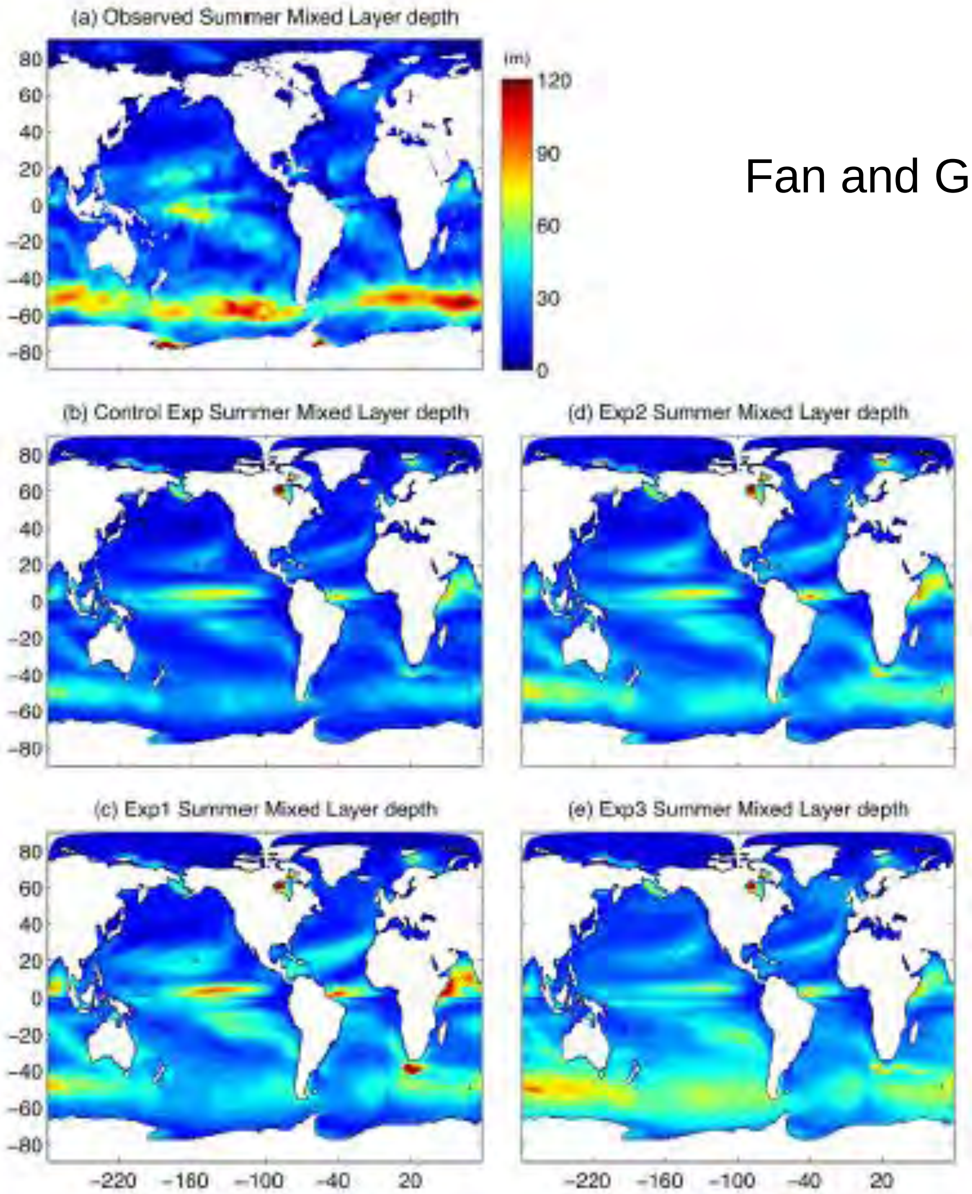
Up: Exp1-Levitus, Down: Exp2-Exp1

Exp1: CCSM3 without Bv

Exp2: with Bv

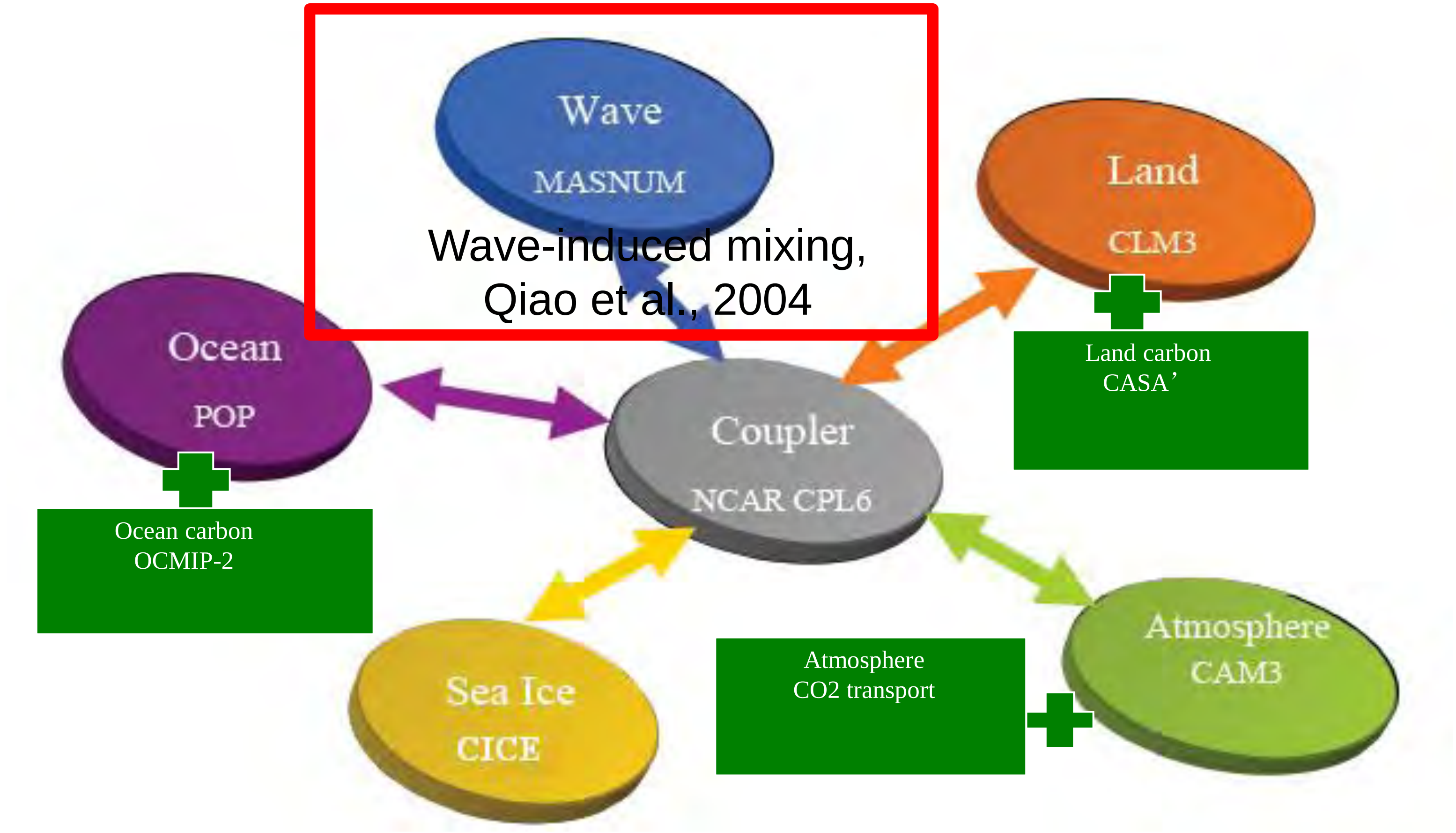
The mechanism (Song et al, 2012, JGR)





Fan and Griffies, 2014, JC [GFDL]

3.2 FIO-ESM for CMIP5



Framework of FIO-ESM version1.0

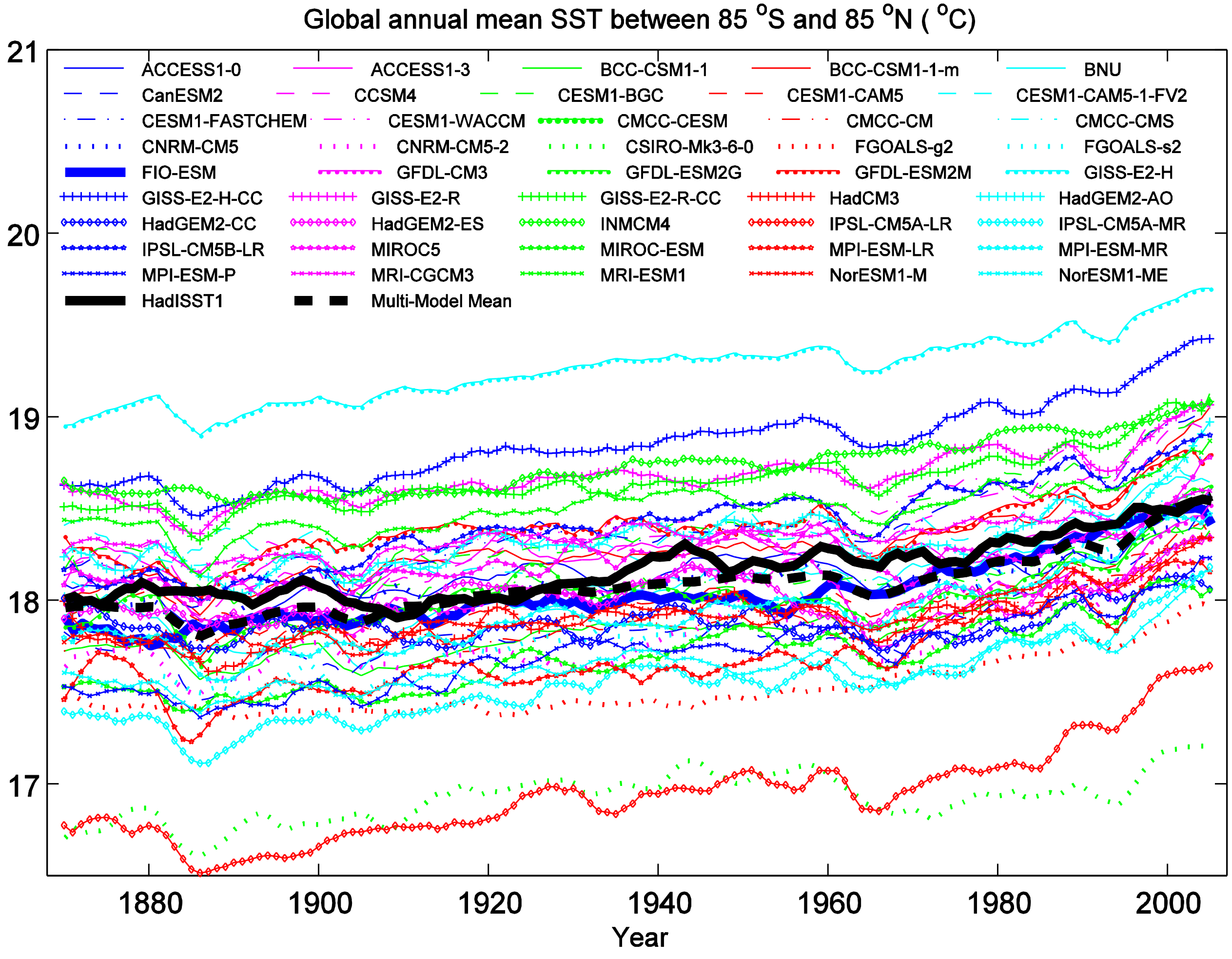
Descriptions of the FIO-ESM

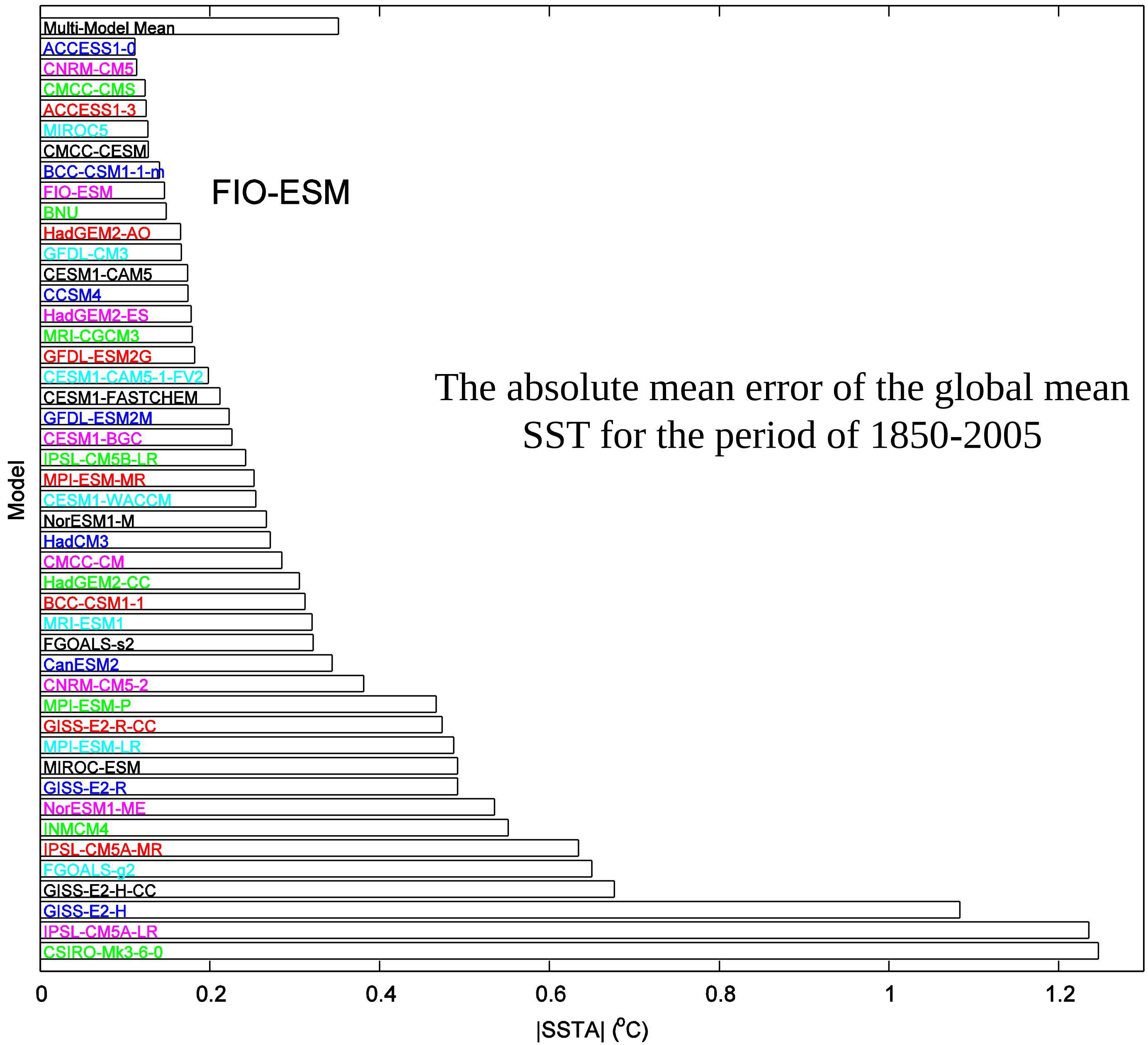
Physical models

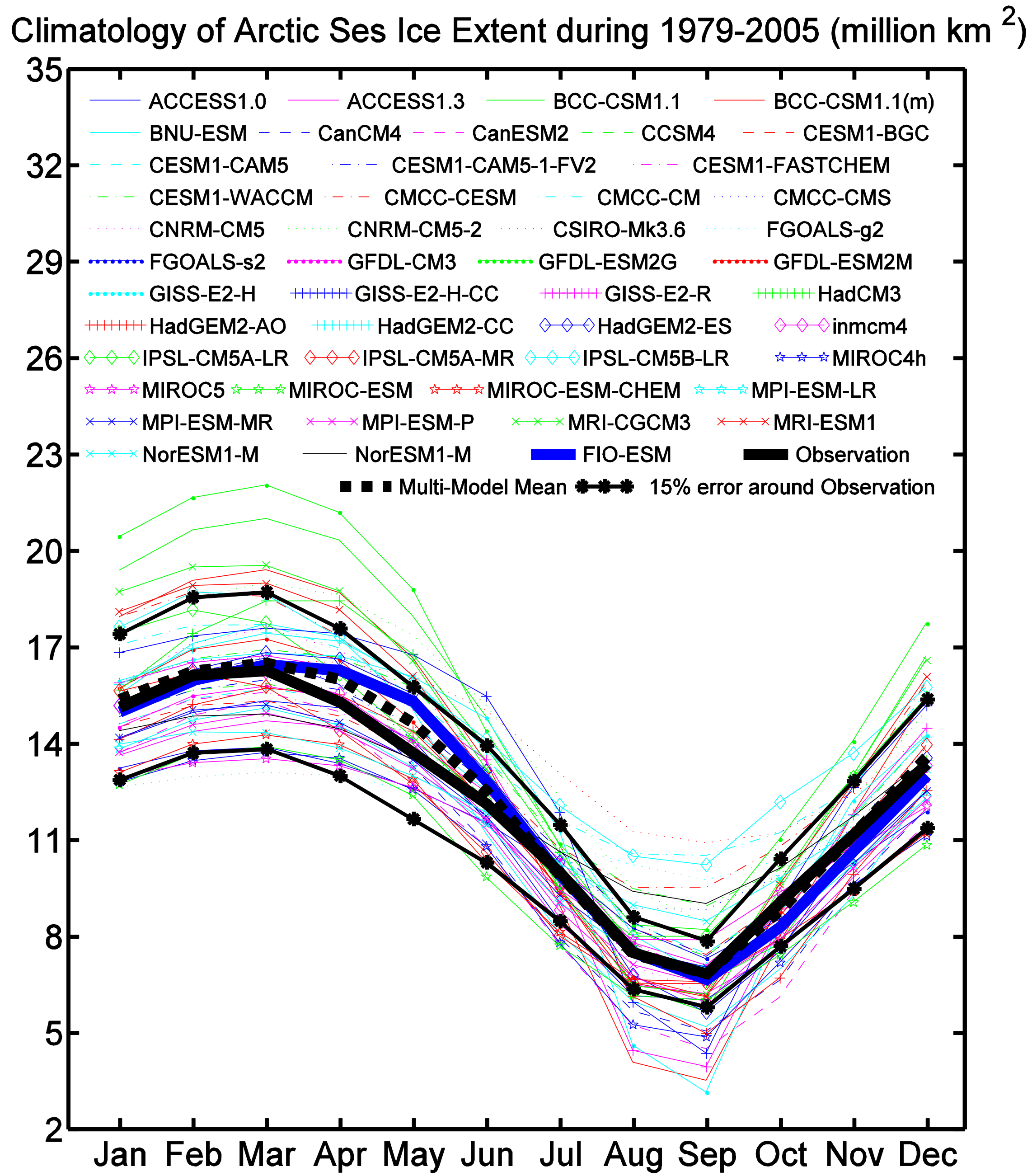
- ATM: CAM3.0, T42L26
- LND: CLM3, T42
- OCN: POP2, $1.1^o*0.3\sim0.5^o$, 40 vertical layers
- ICE: CICE4, $1.1^o*0.3\sim0.5^o$
- WAV: MASNUM wave model, 2^o*2^o
- Wave-circulation coupling: based on the wave-inducing mixing

Historical Experiment
1850-2005

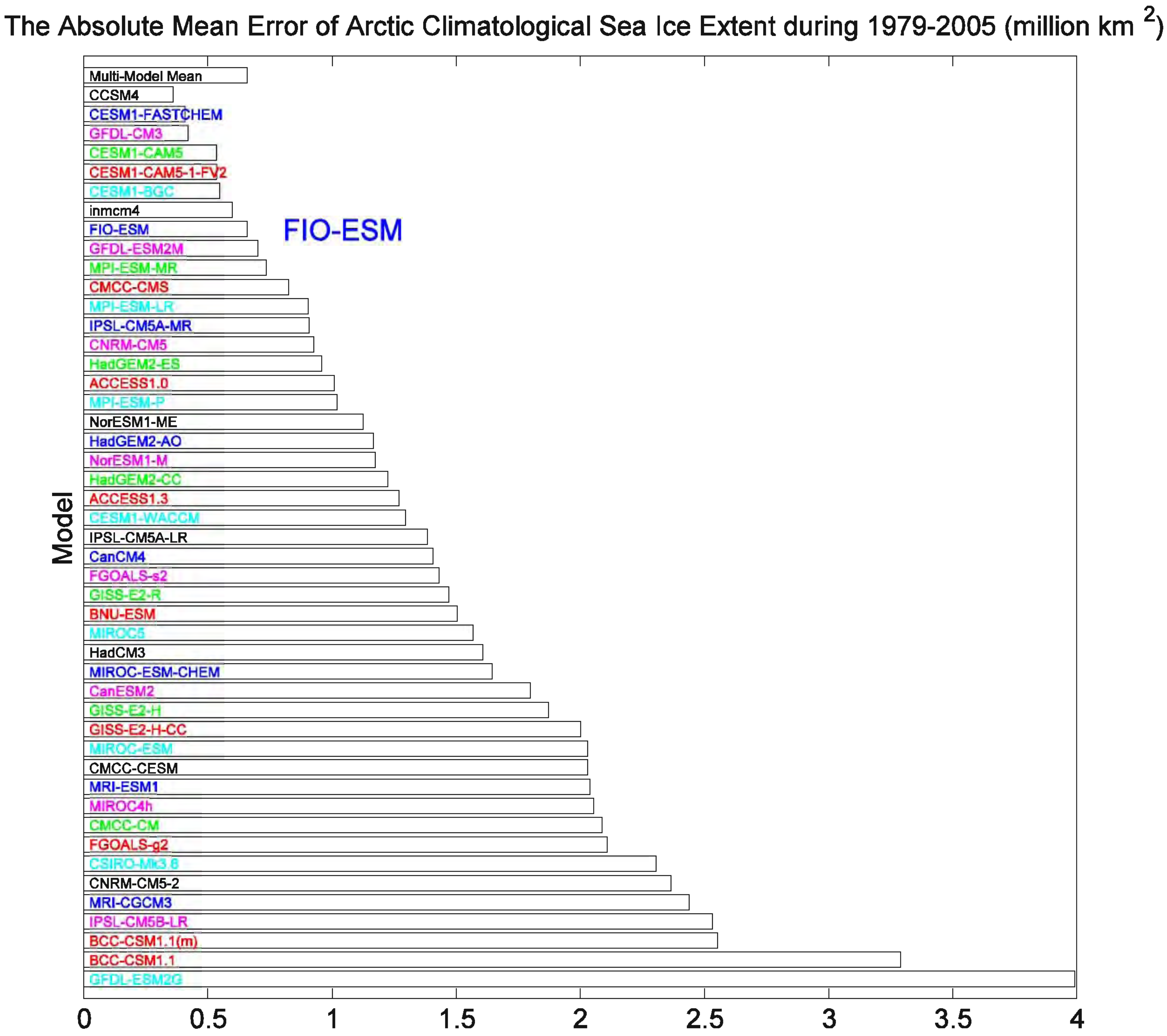
SST evolution in historical climate simulations. 45 models are downloaded and compared with HadSST, while other 4 models are not downloadable.




FIO-ESM
The absolute mean error of the global mean SST for the period of 1850-2005
Model
Multi-Model Mean
ACCESS1-0
CNRM-CM5
CMCC-CMS
ACCESS1-3
MIROC5
CMCC-CESM
BCC-CSM1-1-m
FIO-ESM
BNU
HadGEM2-AO
GFDL-CM3
CESM1-CAM5
CCSM4
HadGEM2-ES
MRI-CGCM3
GFDL-ESM2G
CESM1-CAM5-1-FV2
CESM1-FASTCHEM
GFDL-ESM2M
CESM1-BGC
IPSL-CM5B-LR
MPI-ESM-MR
CESM1-WACCM
NorESM1-M
HadCM3
CMCC-CM
HadGEM2-CC
BCC-CSM1-1
MRI-ESM1
FGOALS-s2
CanESM2
CNRM-CM5-2
MPI-ESM-P
GISS-E2-R-CC
MPI-ESM-LR
MIROC-ESM
GISS-E2-R
NorESM1-ME
INMCM4
IPSL-CM5A-MR
FGOALS-g2
GISS-E2-H-CC
GISS-E2-H
IPSL-CM5A-LR
CSIRO-Mk3-6-0
0
0.2
0.4
0.6
0.8
1
1.2
|SSTA| (°C)



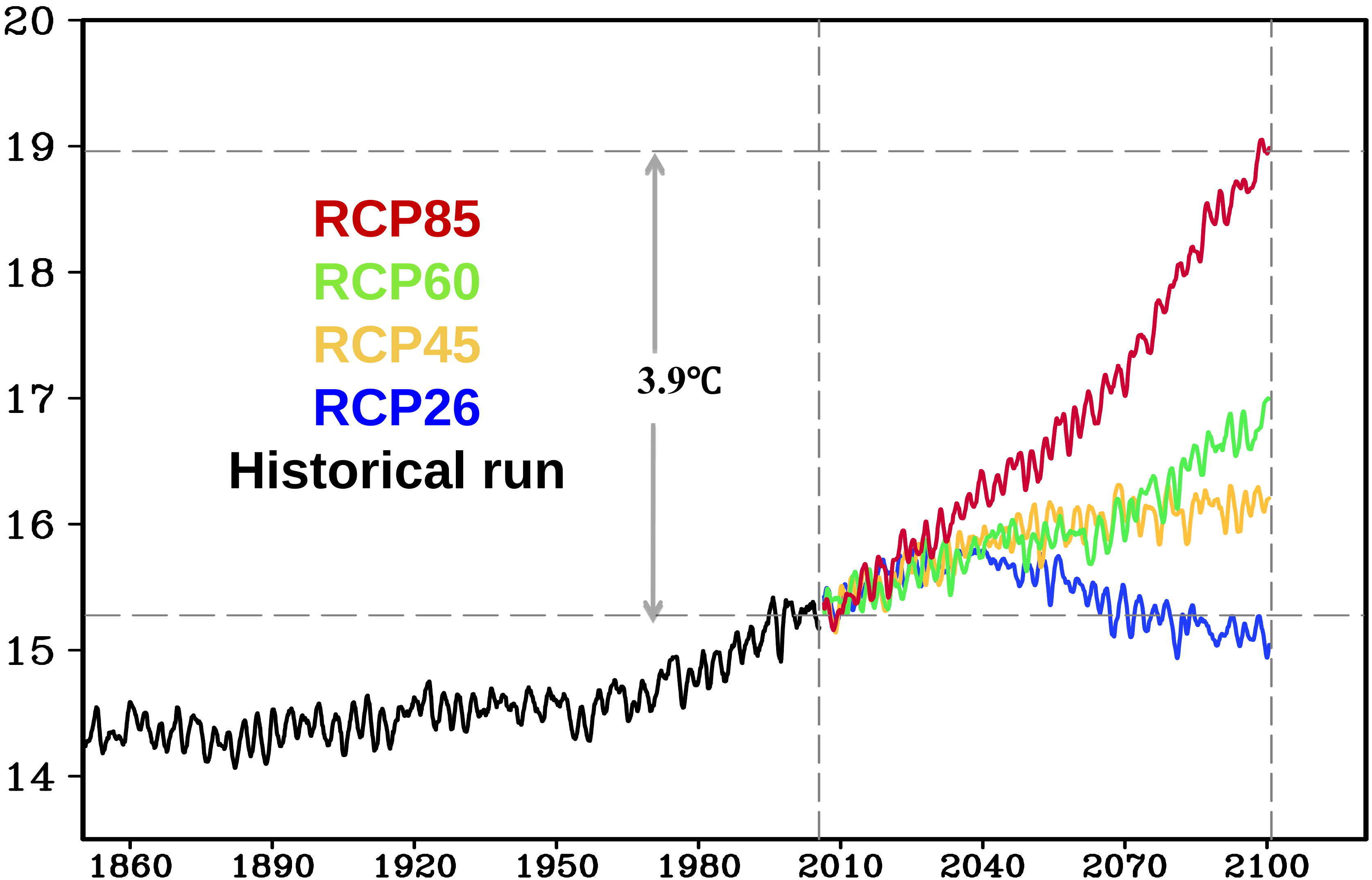
47 Models are downloaded and compared with Satellite observations, while other 2 models are not downloadable.

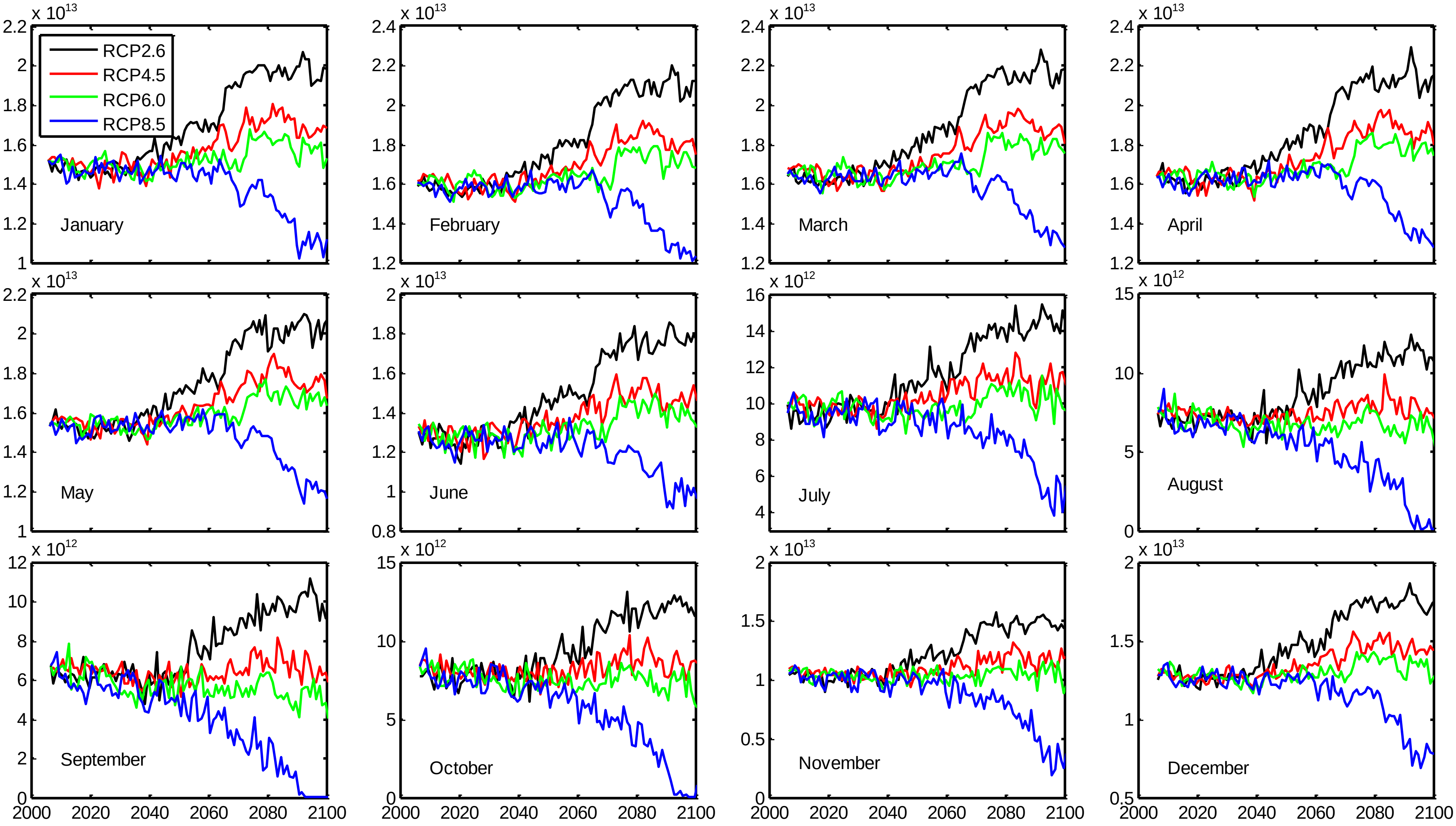


The Absolute Mean Error of Arctic Climatological Sea Ice Extent during 1979-2005 (million km 2)
Model
FIO-ESM
Multi-Model Mean
CCSM4
CESM1-FASTCHEM
GFDL-CM3
CESM1-CAM5
CESM1-CAM5-1-FV2
CESM1-BGC
inmcm4
FIO-ESM
GFDL-ESM2M
MPI-ESM-MR
CMCC-CMS
MPI-ESM-LR
IPSL-CM5A-MR
CNRM-CM5
HadGEM2-ES
ACCESS1.0
MPI-ESM-P
NorESM1-ME
HadGEM2-AO
NorESM1-M
HadGEM2-CC
ACCESS1.3
CESM1-WACCM
IPSL-CM5A-LR
CanCM4
FGOALS-s2
GISS-E2-R
BNU-ESM
MIROC5
HadCM3
MIROC-ESM-CHEM
CanESM2
GISS-E2-H
GISS-E2-H-CC
MIROC-ESM
CMCC-CESM
MRI-ESM1
MIROC4h
CMCC-CM
FGOALS-g2
CSIRO-Mk3.6
CNRM-CM5-2
MRI-CGCM3
IPSL-CM5B-LR
BCC-CSM1.1(m)
BCC-CSM1.1
GFDL-ESM2G
0
0.5
1
1.5
2
2.5
3
3.5
4

Future Experiment
2006-2100

Centurial Future Projections





Time series of Arctic sea ice extent from RCP run. **Unit: m^2**

Conclusions

1. We proposed a scheme on the non-breaking surface wave-induced vertical mixing (Bv), which can penetrate to the depth of the order of wave length. Bv can improve ocean models and climate models, and is nearly not model dependent. In the upper ocean, Bv plays much more important role than that of shear-induced mixing.

2. FIO-ESM is developed. Preliminary validations give us some confidence that surface wave should be important for climate system.

Accurate simulation and prediction is a key component of PICES-FUTURE , surface wave should be a low-lying fruit.


Thanks for your attenti