The improvement of MOM4 by adding wave-induced mixing

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Background

1. Qiao et al, suggested that the wave mixing effects in the upper ocean layer are too important to be ignored, and they derived three-dimensional wave-induced Reynolds stress, and obtained the model equation of wave-induced mixing .

2. MASNUM established the wave-current coupled theory, and with this theory, ocean coastal models, global ocean general circulation models and global ocean climate models are both improved significantly.

3. K-profile parameterization (KPP) vertical mixing scheme used in Modular Ocean Model (MOM4) does not include wave-induced mixing.

Can MOM4 be improved by adding wave-induced mixing?

Add wave-induced mixing into MOM4

MOM4's vertical mixing schemes

- **Const —— too simple; (Bryan and Lewis ,1979)**
- **PP —— effective in the tropical ocean; (Pacanowski and Philander ,1981)**
- **KPP —— the best choice for a global ocean simulation. (Large et al. ,1994)**

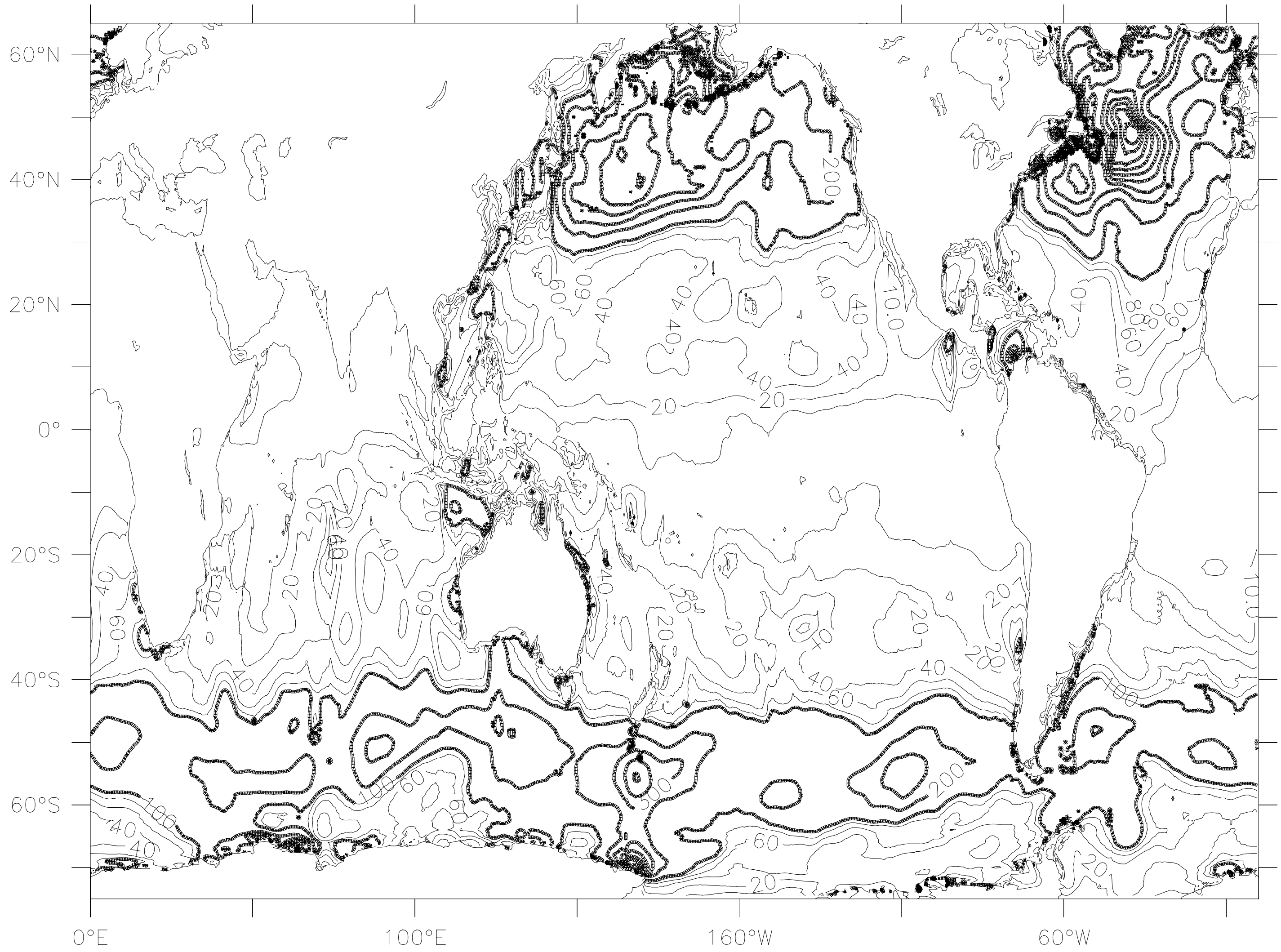
KPP is the best vertical mixing scheme for a global simulation. KPP scheme is chosen to study the impact of wave-induced mixing on MOM4 .

MASNUM wave number spectral model can compute wave-induced vertical mixing coefficient (Bv) ,

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

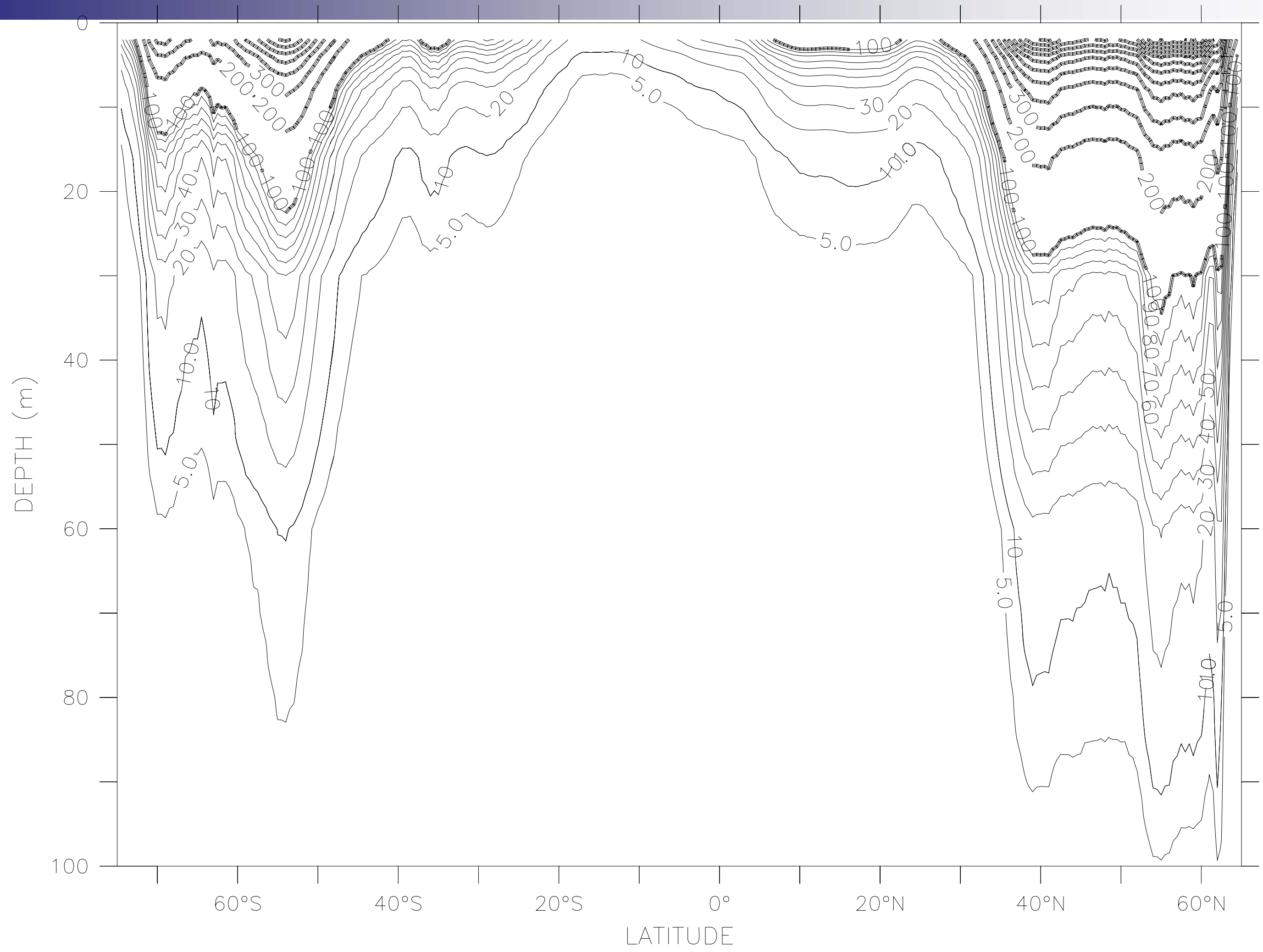
Where $E(\vec{k})$ represents the wave number spectrum, ω, the wave angular frequency, k , wave number, and z is the vertical coordinate axis downward positive with z=0 at the surface.

Bv is the function of (x, y, z, t). (Qiao et al, GRL, 2004)



The distribution of the 20m-averaged Bv (cm2/s) in Feb.

(Qiao et al, GRL, 2004)



The vertical distribution of the Bv (cm2/s) along dateline in Feb.

[Qiao et al, GRL, 2004]

In fact, 2-4 cm2/s mixing parameter is a threshold for a mixing process.

([Ledwell et al., 2000; Polzin et al., 1997])

**Based on the latest wave-induced mixing theory ,
We add Bv into KPP vertical-mixing scheme.**

$$\begin{cases} K_\theta = K_{\theta(KPP)} + B_v \\ K_s = K_{s(KPP)} + B_v \\ K_m = K_{m(KPP)} + B_v \end{cases}$$

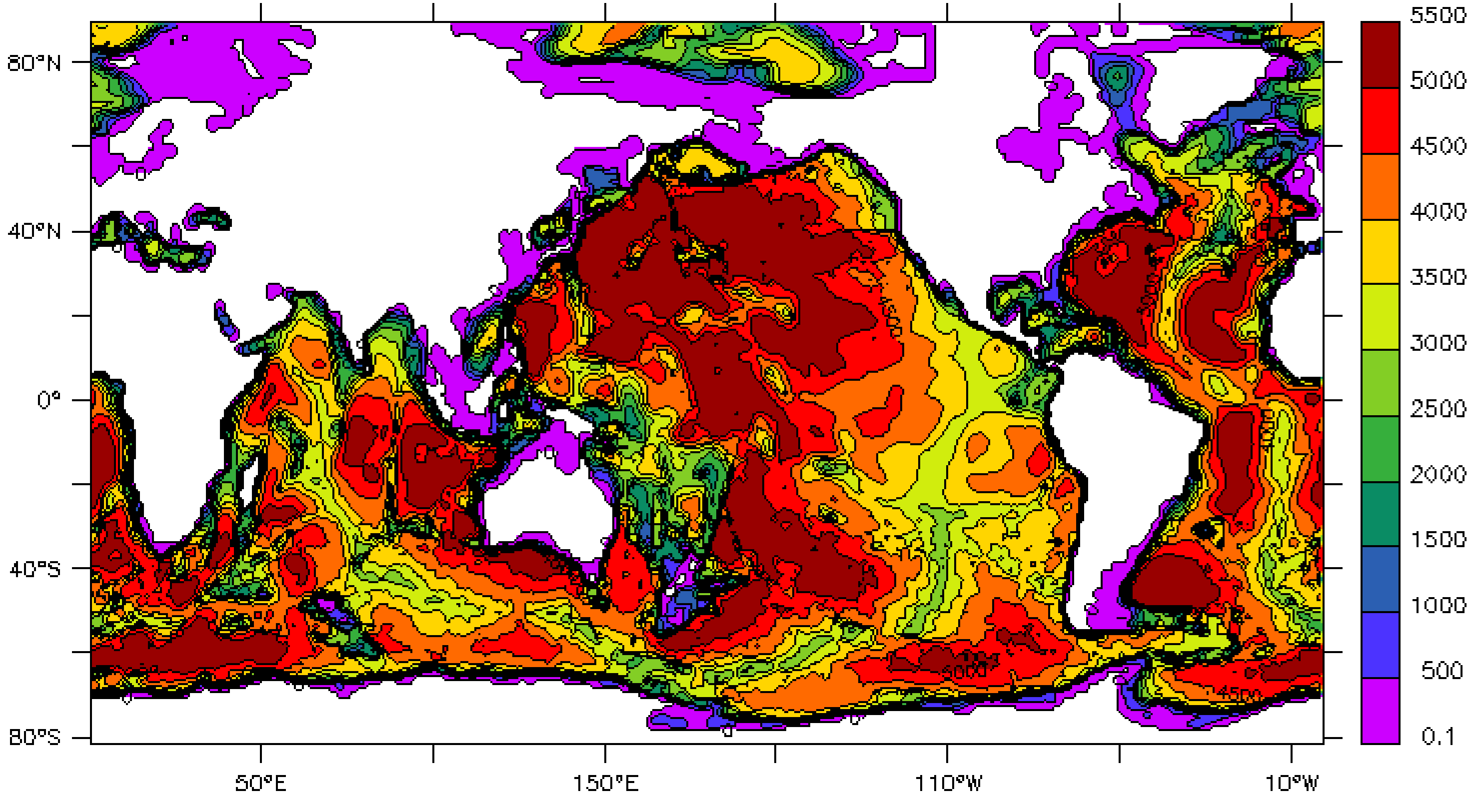
K_θ —— vertical temperature diffusivity

K_S —— vertical salinity diffusivity

K_m —— vertical momentum viscosity

KPP scheme can compute $K_{\theta(KPP)}$ **,** $K_{S(KPP)}$ **,** $K_{m(KPP)}$**.**

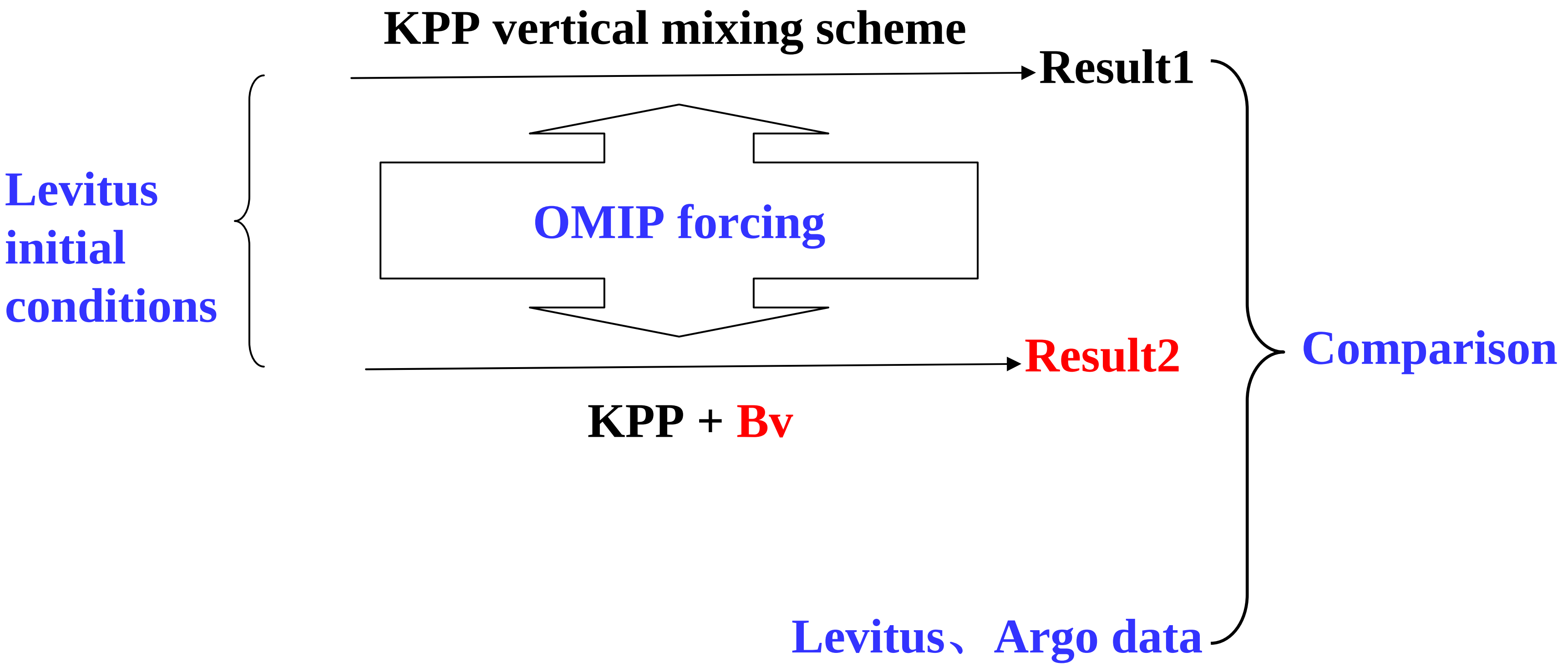
Experiments design



(1)Topography from ETOP05;
(2) 81.5° S-89.5° N, 0-360° ;
(3)Horizontal resolution is 1° by1° ;
(4) Z coordinate with 50 layers .

EXP1: The model is integrated for 11 years from initial conditions without Bv;

EXP2: The model is integrated for 11 years from initial conditions with Bv .



Result

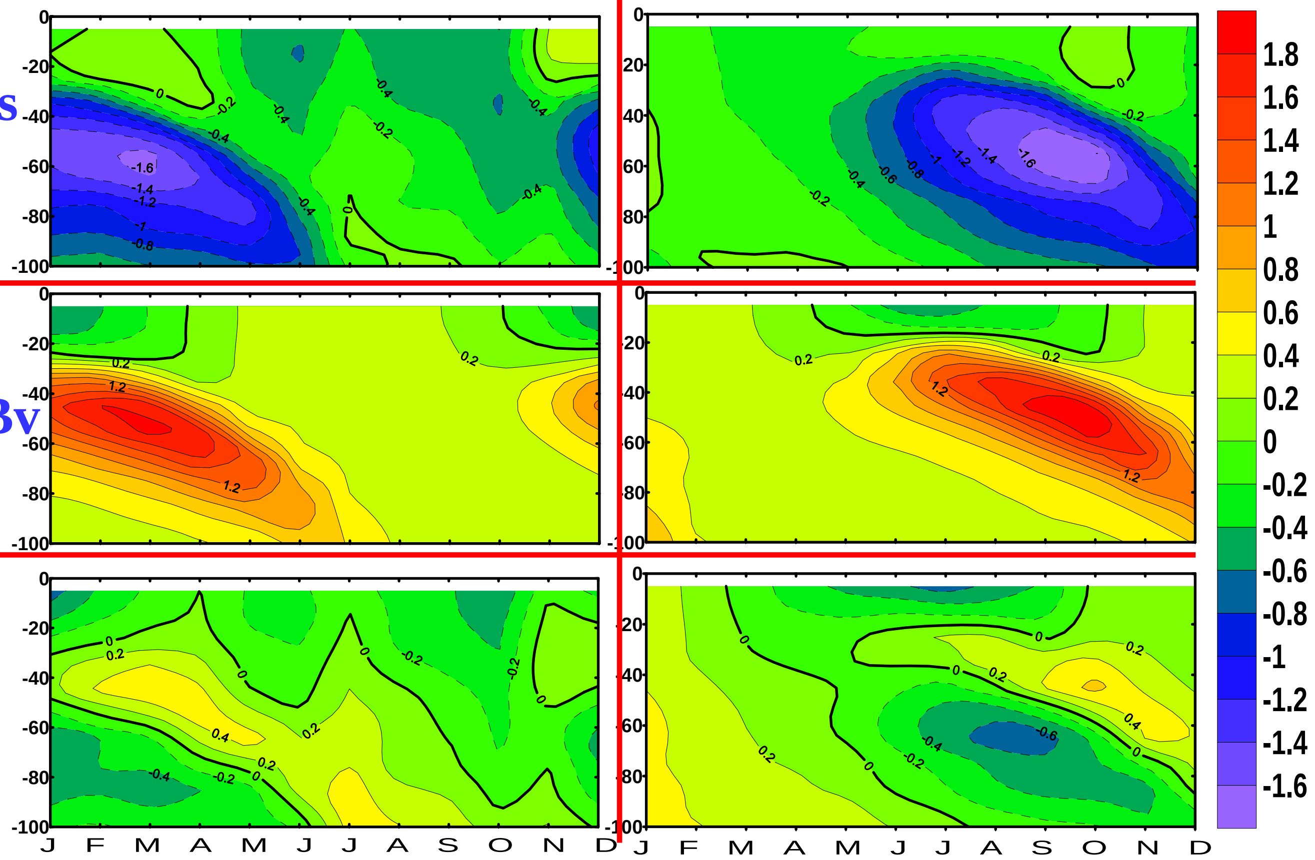
Zonally averaged temperature differences at 30° S and 30° N

30° S | 30° N

Without Bv-Levitus (KPP)

With Bv-Without Bv

With Bv-Levitus (KPP+Bv)



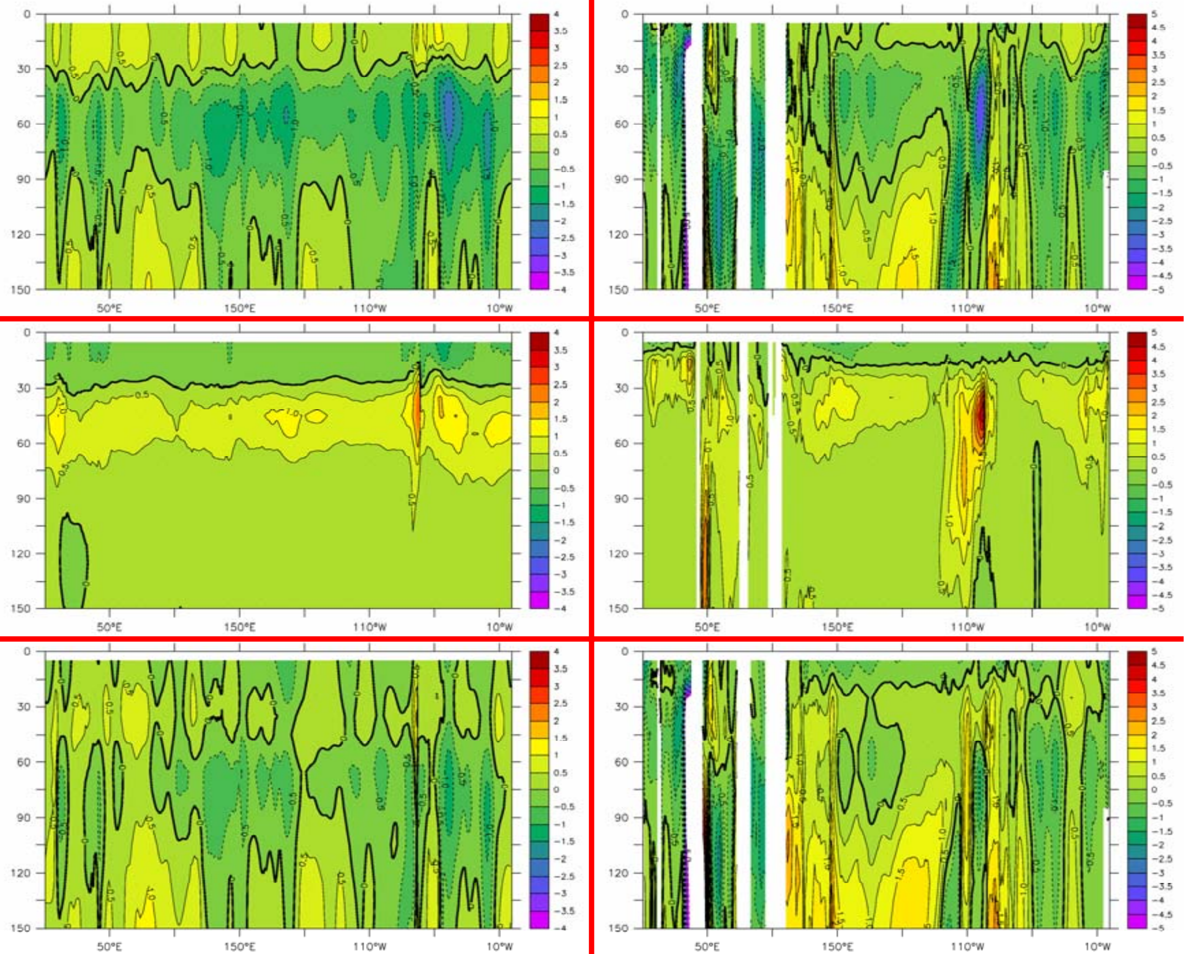
Without Bv, MOM4 have a problem.

The problem is the modeled subsurface(30-100 m) water is colder than Levitus data, especially in summer.

Wave-induced mixing can solve this problem partly.

Meridionally averaged temperature differences in summer

	Jan, 60° S~10° S ave	Jul, 60° N~10° N ave
Without Bv-Levitus (KPP)		
With Bv-Without Bv		
With Bv-Levitus (KPP+Bv)		



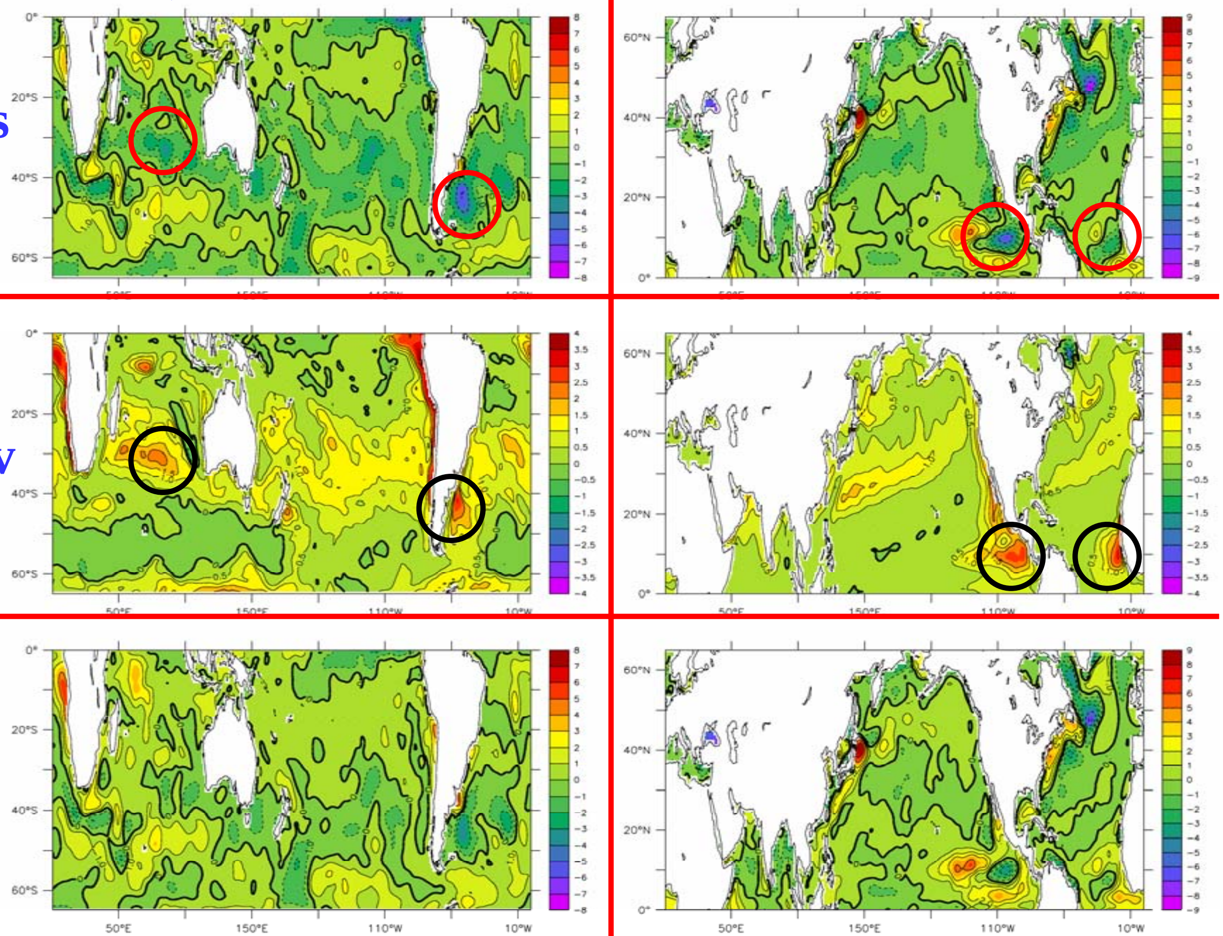
Vertically averaged temperature differences in summer

Jan, 20-100m ave | Jul, 20-100m ave

Without Bv-Levitus (KPP)

With Bv-Without Bv

With Bv-Levitus (KPP+Bv)



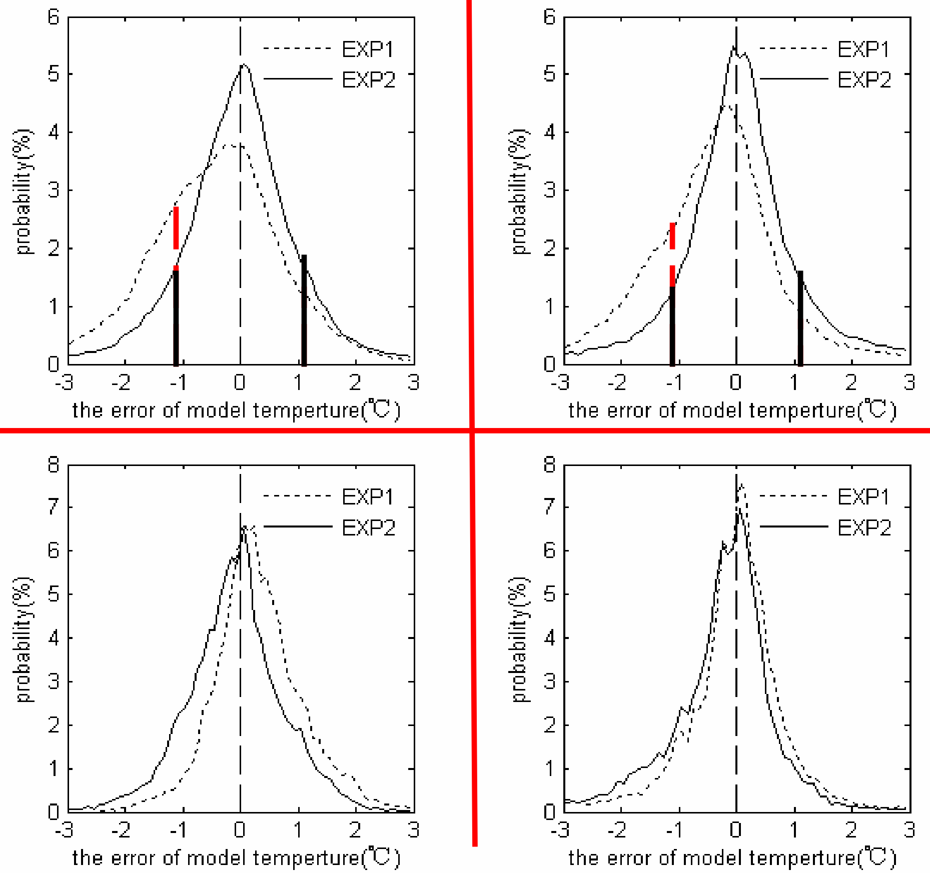
Southern hemisphere, Jan | Northern hemisphere , Jul

20-100m

64% → 76%

66% → 75%

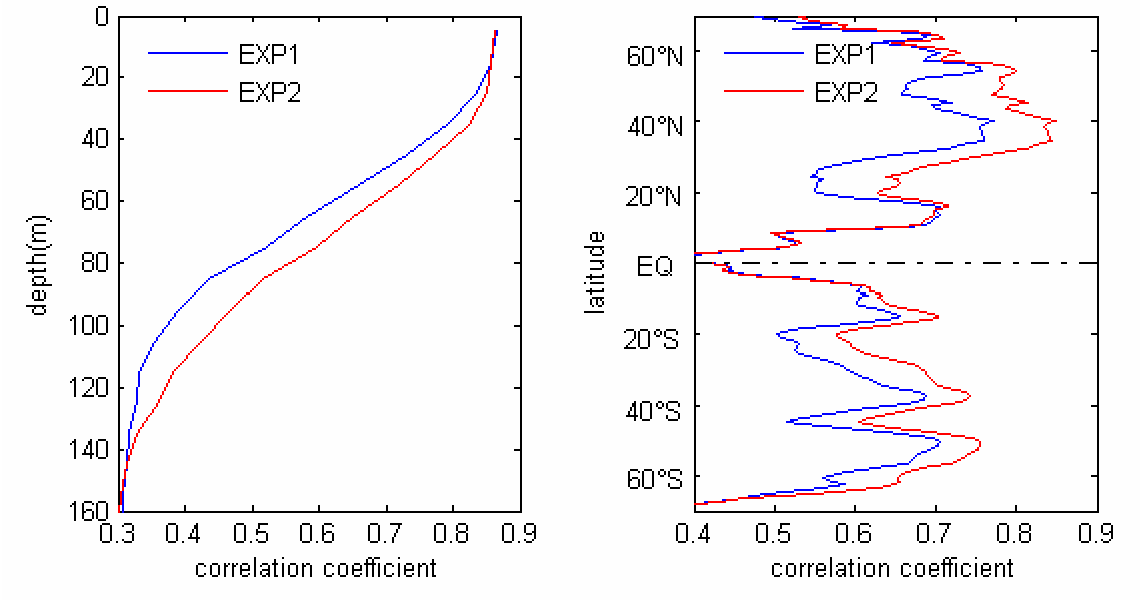
surface



Probability distribution of modeled temperature error

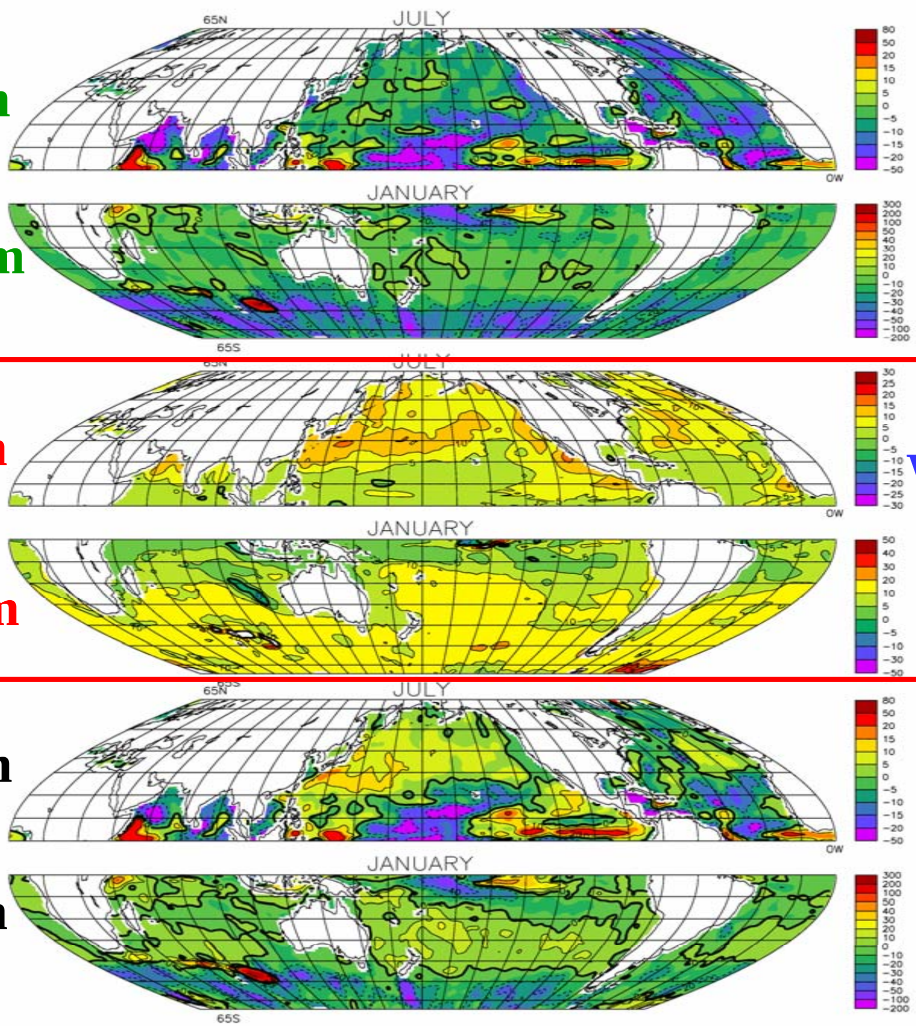
(error = EXP temperature - Levitus temperature)

The correlation coefficient between simulations and Levitus data



Upper 100m averaged correlation coefficient between EXP1 and Levitus is 0.60, and after adding wave-induced mixing, the correlation coefficient between EXP2 and Levitus reaches 0.67.

The MLD differences between simulation and Argo observation in summer



-7.2m

-14.4 m

Without Bv - Argo (KPP)

6.3m

12.4m

With Bv - Without Bv

-0.9 m

-2.0 m

With Bv - Argo (KPP+Bv)

Conclusions

●MOM4 has a problem : colder subsurface(30-100 m) temperature and warmer SST in summer.

●The problem can be solved partly by adding wave-induced mixing.

●After adding wave-induced mixing, the correlation coefficients between modeled temperature and observation have increased, and the modeled MLD has also deepened.

All the results suggest that incorporation of the process of wave-induced mixing can improve the performance of MOM4 significantly.

Thanks!