The performance of a Z-level coordinate model in modeling global tide

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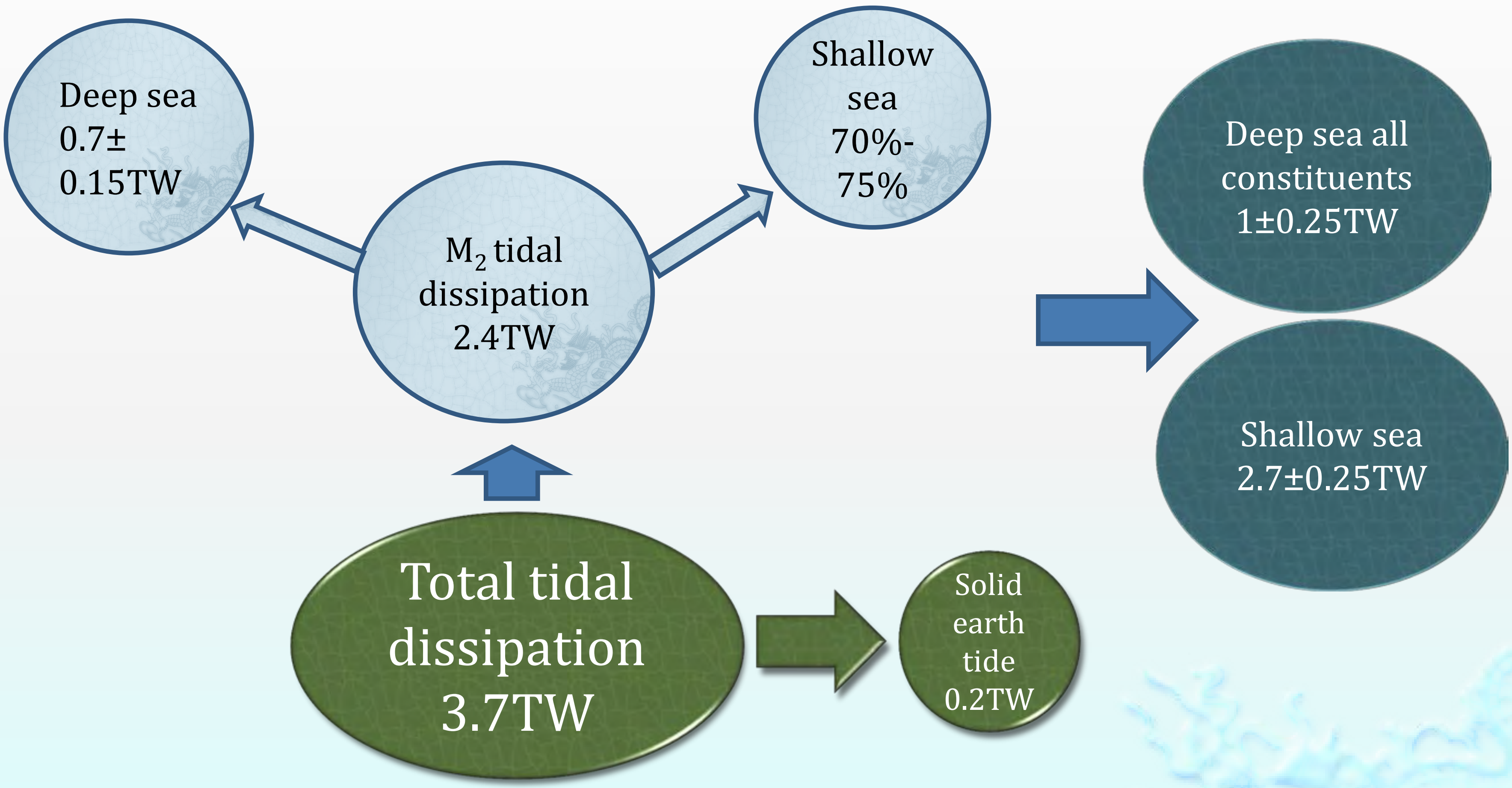
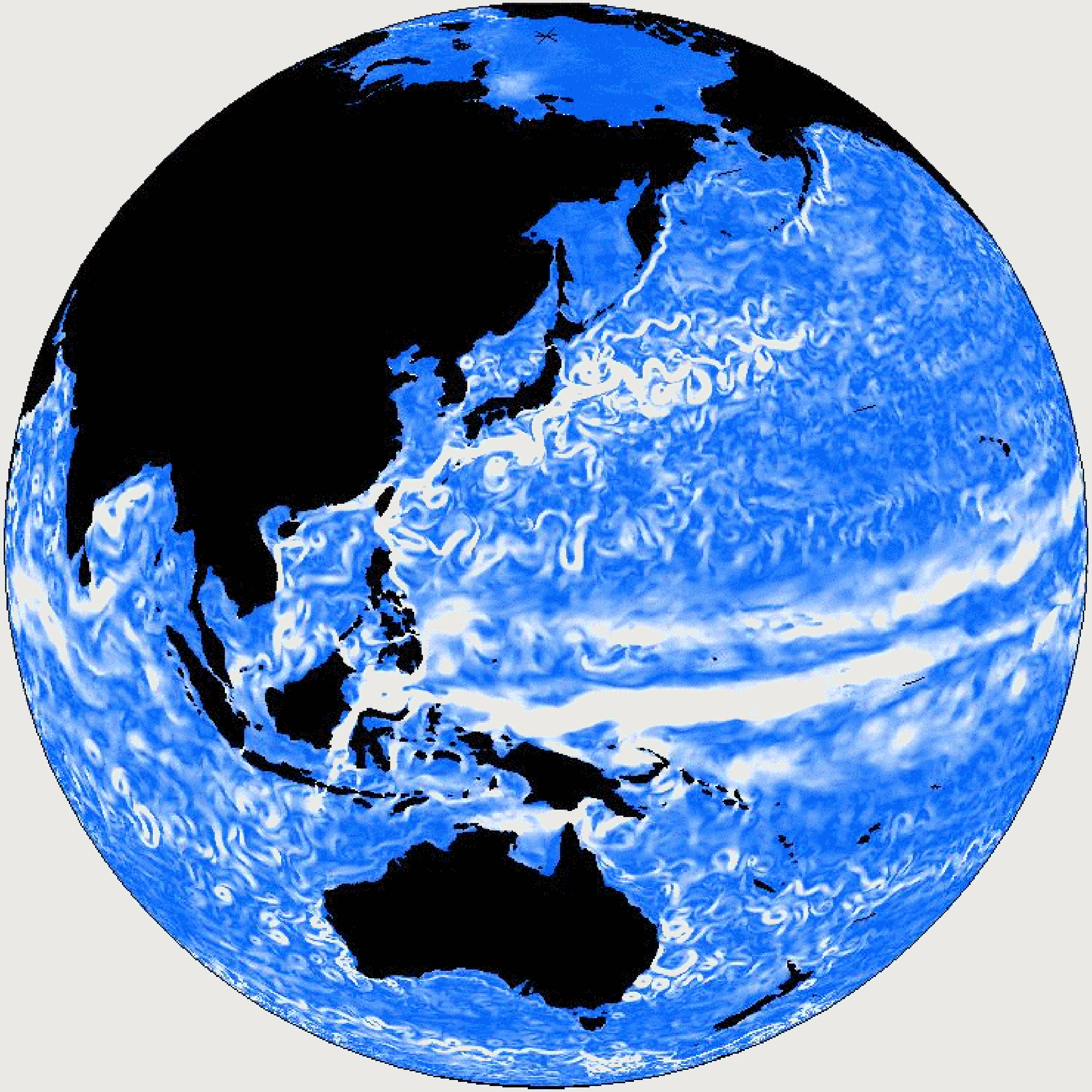
CONTENTS

1. Motivation and research background



(Egbert and Ray, 2000)



Could we set up high-resolution wave-tide-circulation coupled model?

1. Motivation and research background

First type global tide model is based on barotropic laplacian tidal equation

- JS model: Barotropic global tide model, internal tide drag parameterization ;

  （Jayne and St. Laurent， 2001）

- ERB model ： Barotropic global tide model, internal tide drag parameterization, complete self-attraction and loading (SAL) treatment;

  （Egbert et al. 2004）

Second type puts the equilibrium tidal potential into the OGCM(baroclinic)

- SHA model: HIM, 10 vertical layers, horizontal resolution: 1/8°, Self-Attraction and Loading effect(SAL) is scalar approximation;

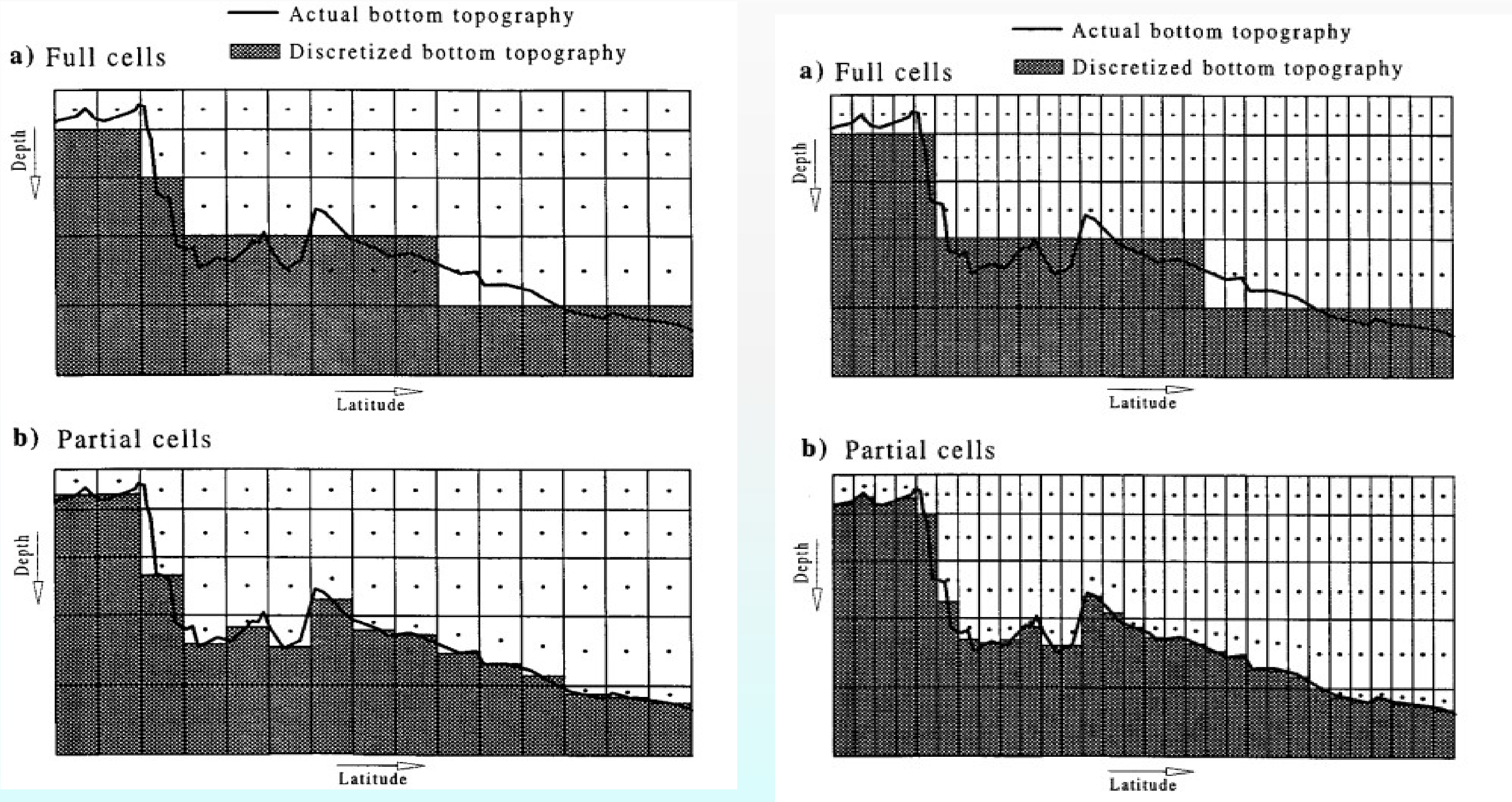
  （Simmons et al. 2004）

- AGHS model ： HIM, HYCOM, internal tide drag parameterization, horizontal resolution: 1/2°to 1/12.5°, SAL is scalar approximation.

  （Arbic et al. 2004, 2010）

1.1 Modular Ocean Model (MOM4)

Bottom partial cells



Comparison between Full cells and Partial cells under the same vertical resolution and different horizontal resolutions （Pacanowski and Gnanadesikan, 1998）

1.2 Inclusion of tidal forcing in MOM4 (Marchuk and Kagan, 1989)

- Equilibrium tidal potential：

$$\eta_n(t) = H_n \sin 2\phi \cos(\omega_n t + \chi_n + \lambda)$$

and

$$\eta_n(t) = H_n \cos^2 \phi \cos(\omega_n t + \chi_n + 2\lambda)$$

$$\eta_{eq} = \Sigma_{n=1}^{4}[\beta_n \alpha_n \cos^2 \phi[\cos(\omega_n t)\cos 2\lambda - \sin(\omega_n t)\sin 2\lambda] +$$
$$\beta_{n+4}\alpha_{n+4} \sin 2\phi[\cos(\omega_{n+4} t)\cos 2\lambda - \sin(\omega_{n+4} t)\sin 2\lambda]]$$

$$\partial \mathbf{U} / \partial t = - f\mathbf{k} \times \mathbf{U} - D\nabla_h[\alpha p_s / \rho_0 + \beta g \eta_{eq}] + G - \tau_{tides} / \rho_0$$

Beta represents LOVE number, accounting for the reduction of the ocean tide because of the deformation of the solid earth by tidal forces.

$$\tau_{tides} = \rho_0 c_d |u| \mathbf{u}$$

$$c_d \approx 0.0025$$

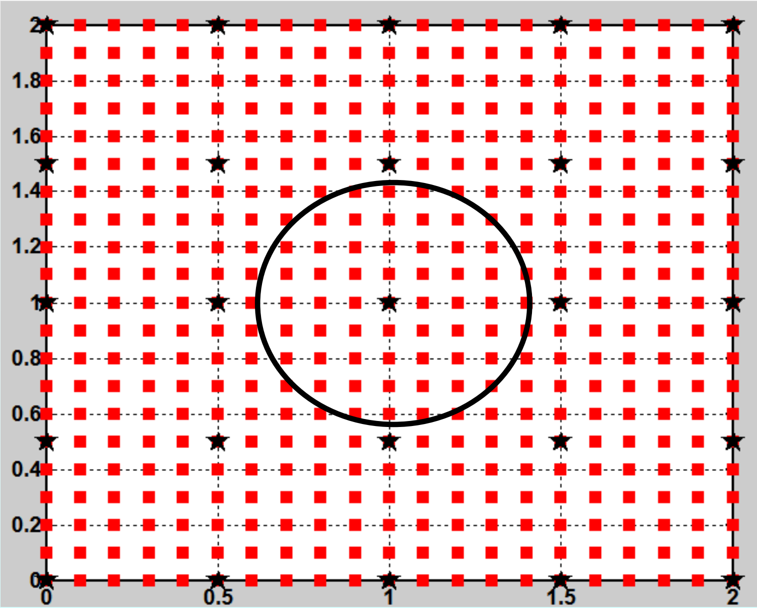
2. Influence of model topography on global tide

2.1 Preparation of model topography

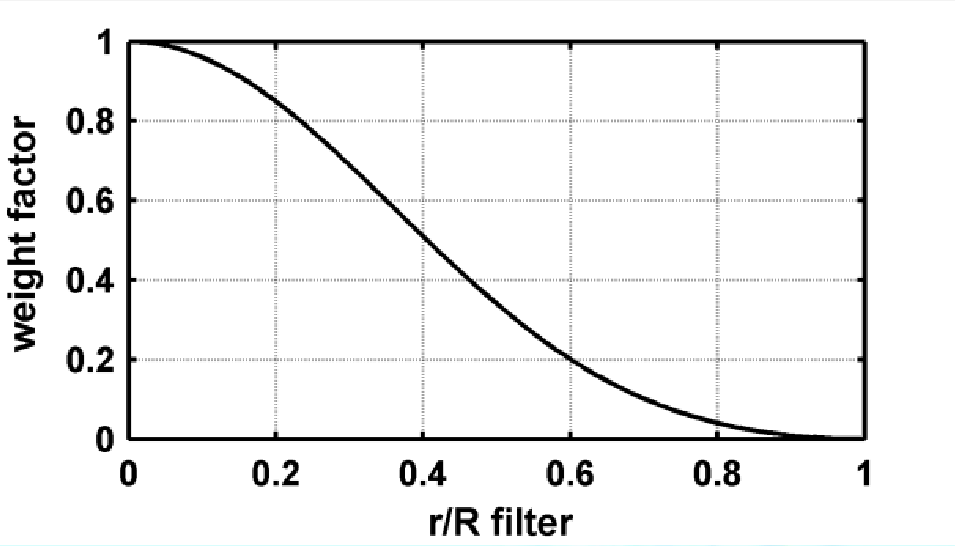
- Blackman radial filter (Arbic et al. 2004) :

$$\mathrm{Filted}(x,y)=\frac{\iint src_{fine\_grid}(x',y')F(x,y,x',y')dA}{\iint F(x,y,x',y')dA}$$

$$F(x,y,x',y')=0.42+0.5\cos(\pi r_{field}/r_{filter})+0.08\cos(2\pi r_{field}/r_{filter})$$

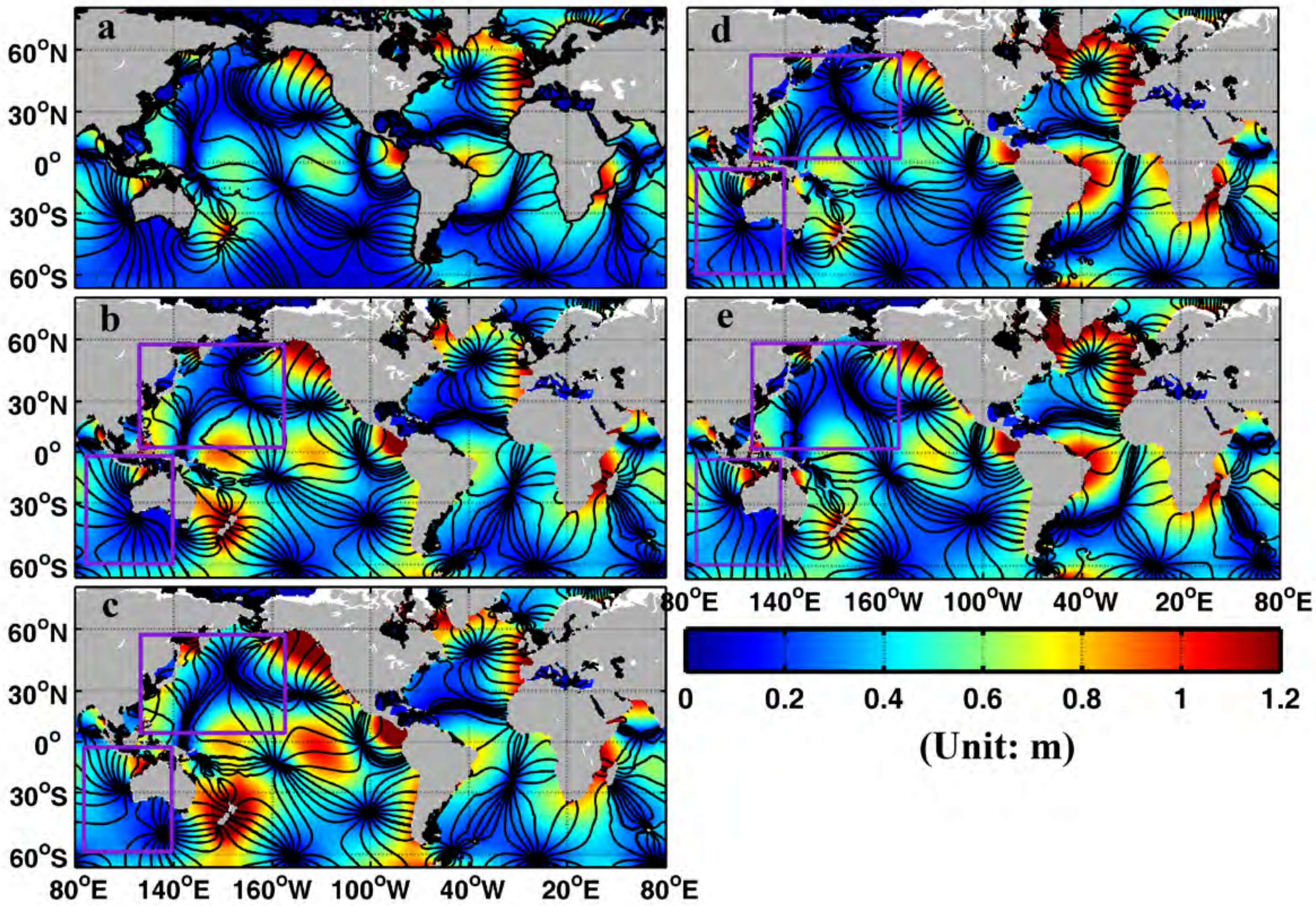


Schematic diagram of radial filter



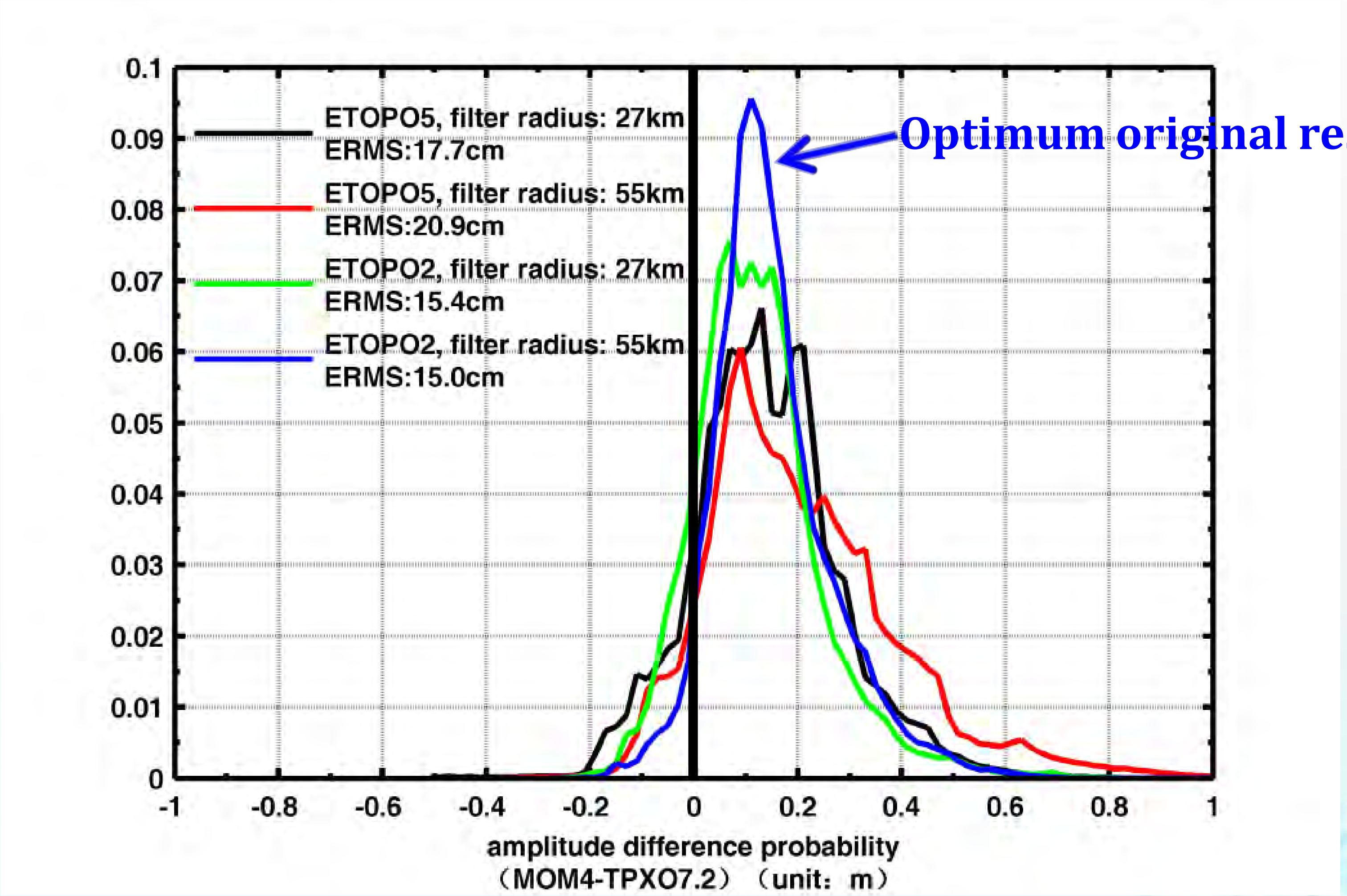
Weight factor of Blackman radial filter

2.2 Model topography sensitive experiments



Amplitude and phase (contour interval: 20°) of , (a) is from TPXO7.2, (b) is result of MOM4 (1/4°) and model topography is built from ETOPO5 with filter radius 27km. (c) (d) (e) are identical to (b) except that the model topography of (c) is built from ETOPO5 with filter radius 54km, (d) is built from ETOPO2 with filter radius 27km, (e) is built from ETOPO2 with filter radius 54km.

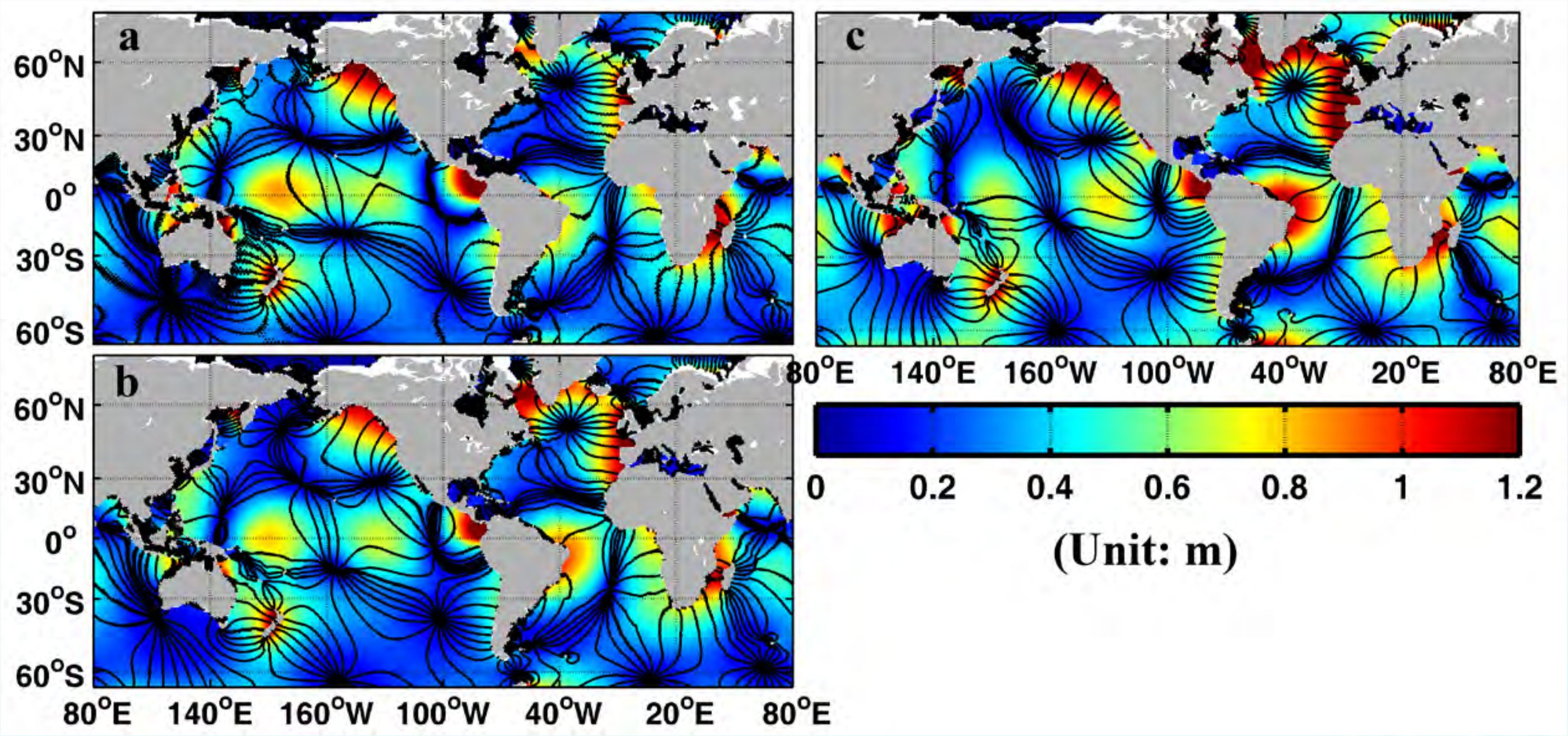
2.2 Model topography sensitive experiments



M_2 amplitude difference probability distribution between MOM4 and TPXO7.2 in corresponding to the 4 sensitive experiments.

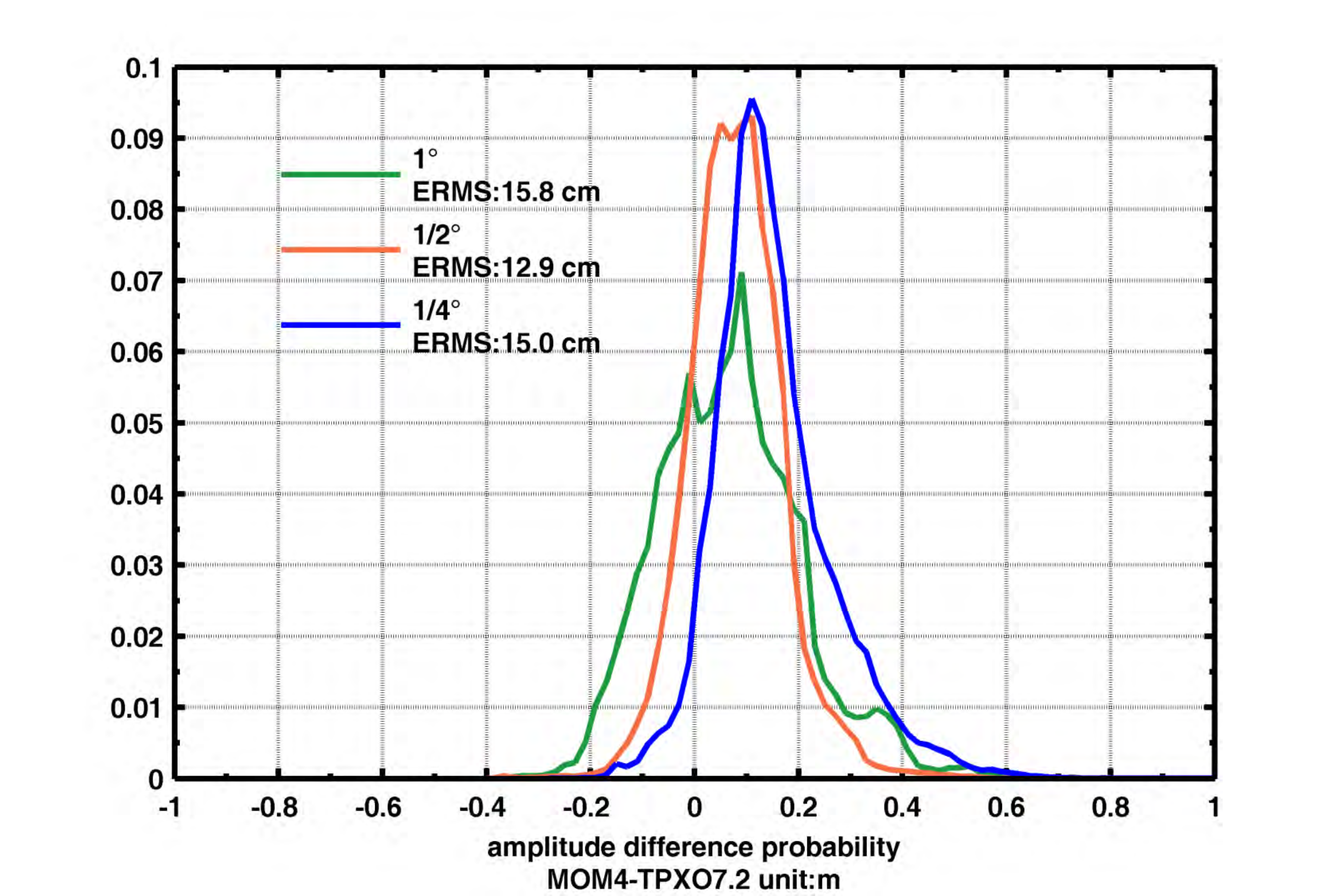
3, Critical model resolution

3.1 Horizontal resolution



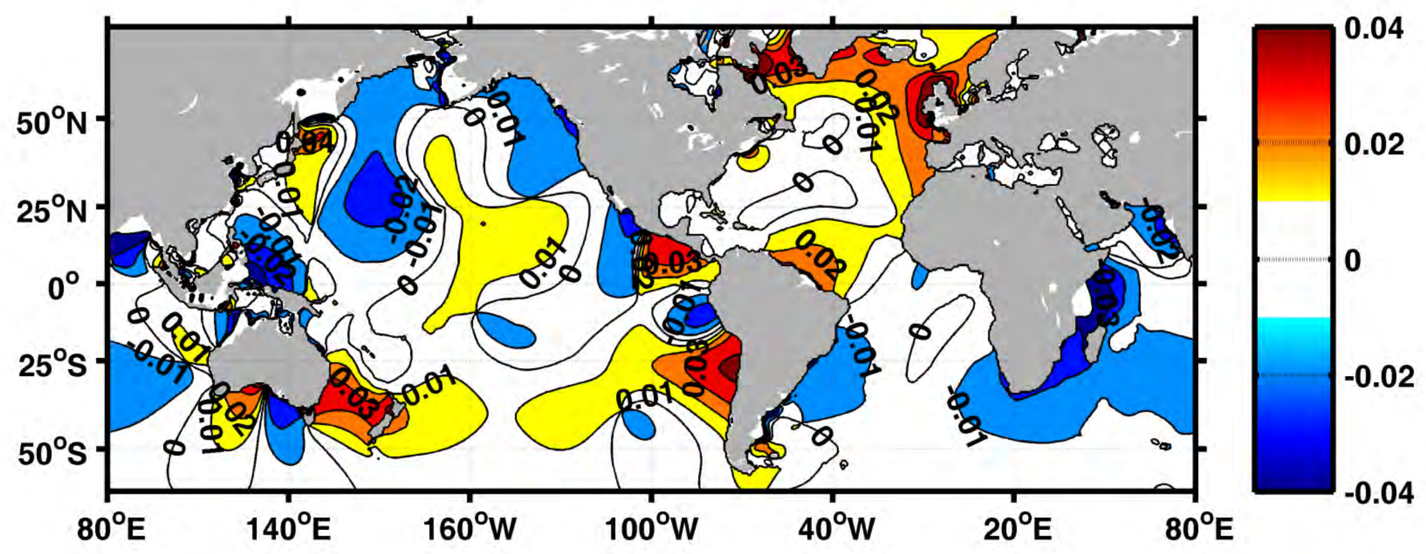
(a) 1°model results, (b) 1/2°model results, (c) 1/4°model results

3.1 Horizontal resolution



M_2 amplitude difference probability distribution between MOM4 and TPXO7.2 in corresponding to the 3 sensitive experiments.

3.2 Vertical resolution



M_2 amplitude difference between 11 levels model and 34 levels model (horizontal resolution 1/4°, 11 levels minus 34 levels model).

RMS difference is 1.2cm

4. Inclusion of internal tide dissipation parameterization

4.1 Parameterize the internal tide dissipation

- Bell (1975) proposed a theory on energy conversion between barotropic and baroclinic tide based on the assumption of small amplitude sinusoidal topography：

$$E_f = \frac{(\omega^2 - f^2)^{1/2}}{2\omega} \rho_0 \kappa h^2 N u^2$$

- Jayne and St. Laurent (2001) simplified Bell’s theory by ignoring the tidal frequency related terms and by replacing the h with topography roughness and come up with：

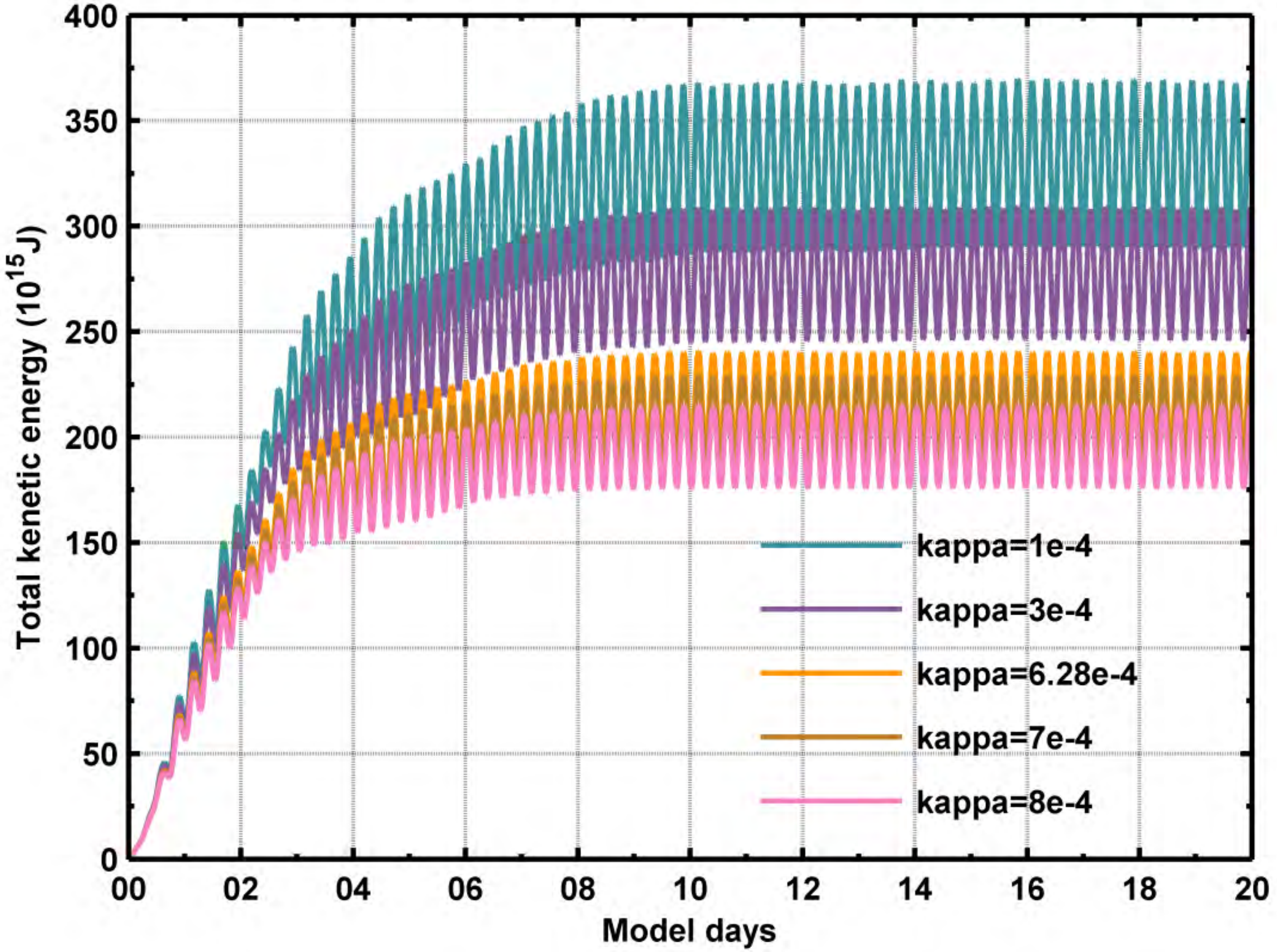
$$E_f = \frac{1}{2} \rho_0 \kappa h^2 N u^2$$

- We add the above parameterization (IT drag) into the barotropic momentum equation：

$$\partial \mathbf{U} / \partial t = -f\mathbf{k} \times \mathbf{U} - D\nabla_h [\alpha p_s / \rho_0 - \beta g \eta_0] + G - \tau_{tides} / \rho_0 - \frac{1}{2} \kappa h^2 N \mathbf{u}$$

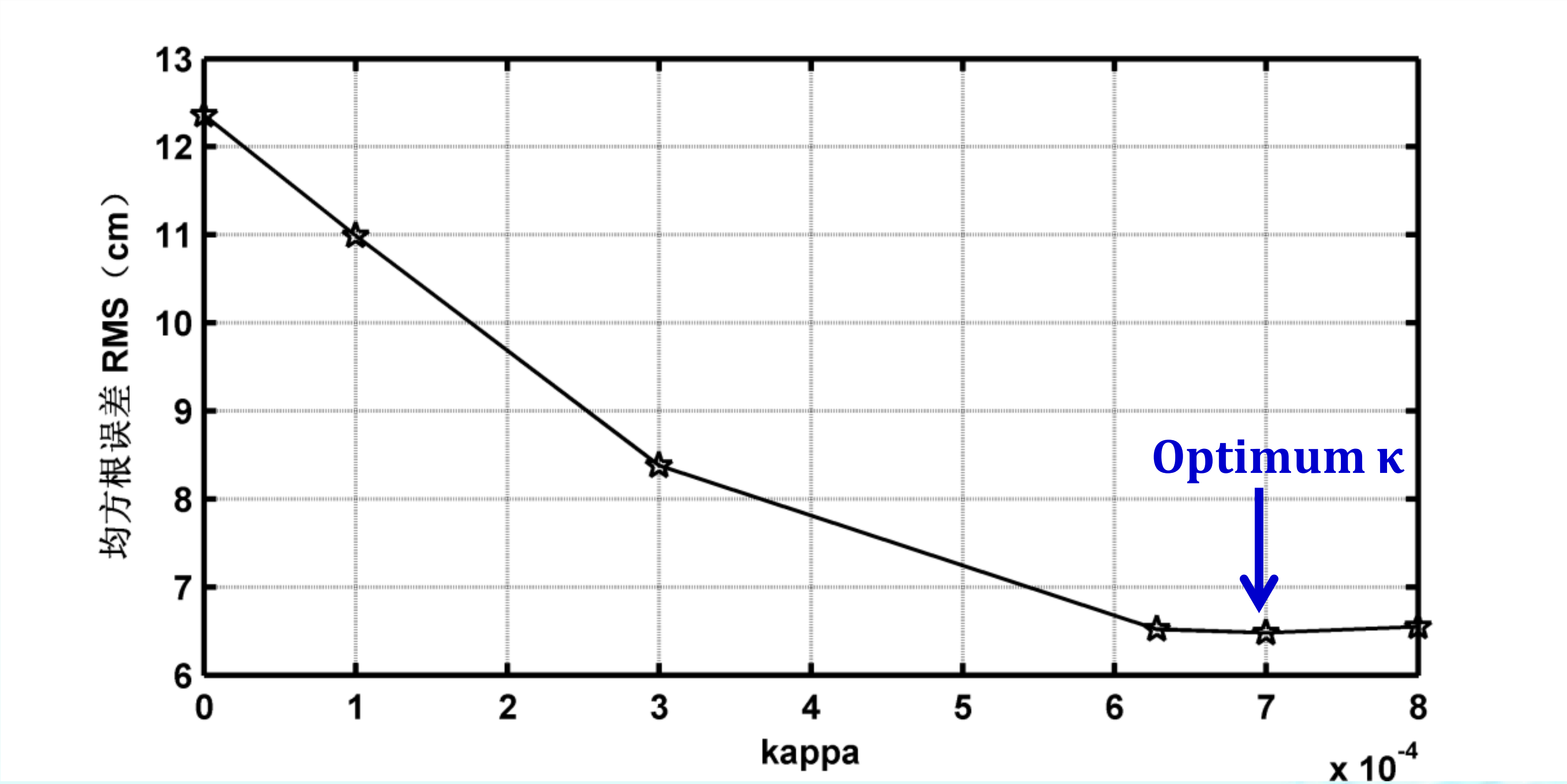
4.2 Model results with inclusion of internal tide drag parameterization

$\kappa = 1\times10^{-4} \rightarrow 8\times10^{-4}$

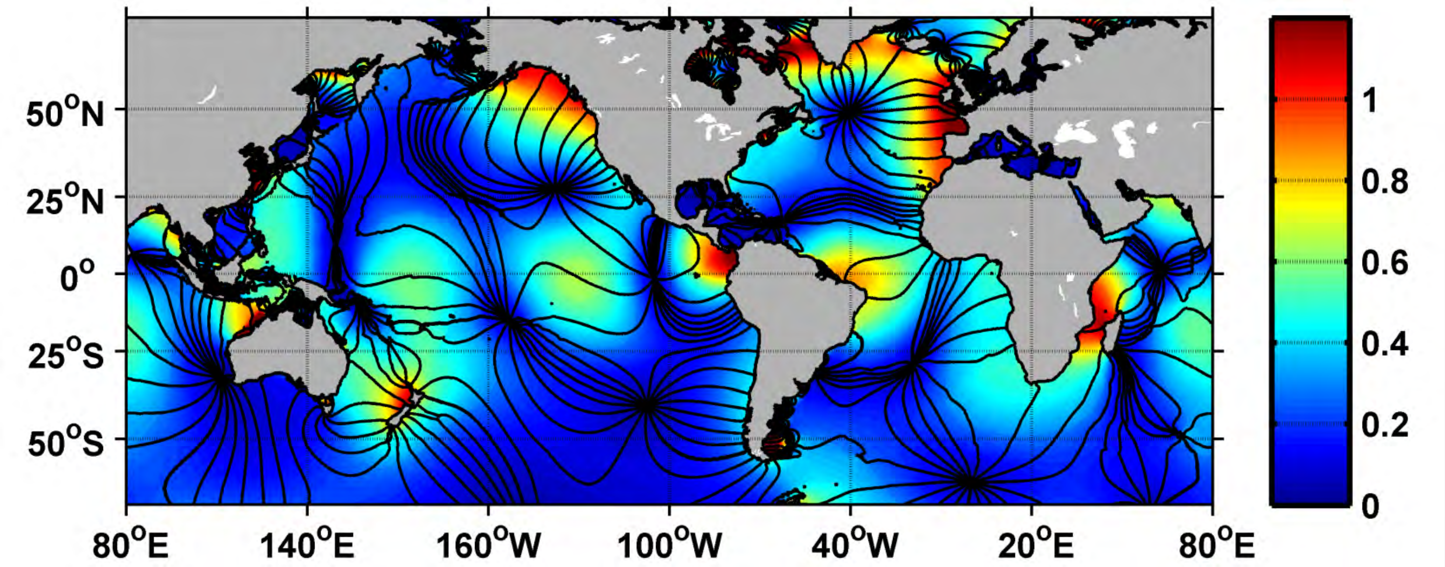


Total kenetic energy under different κ (M_2 only runs)

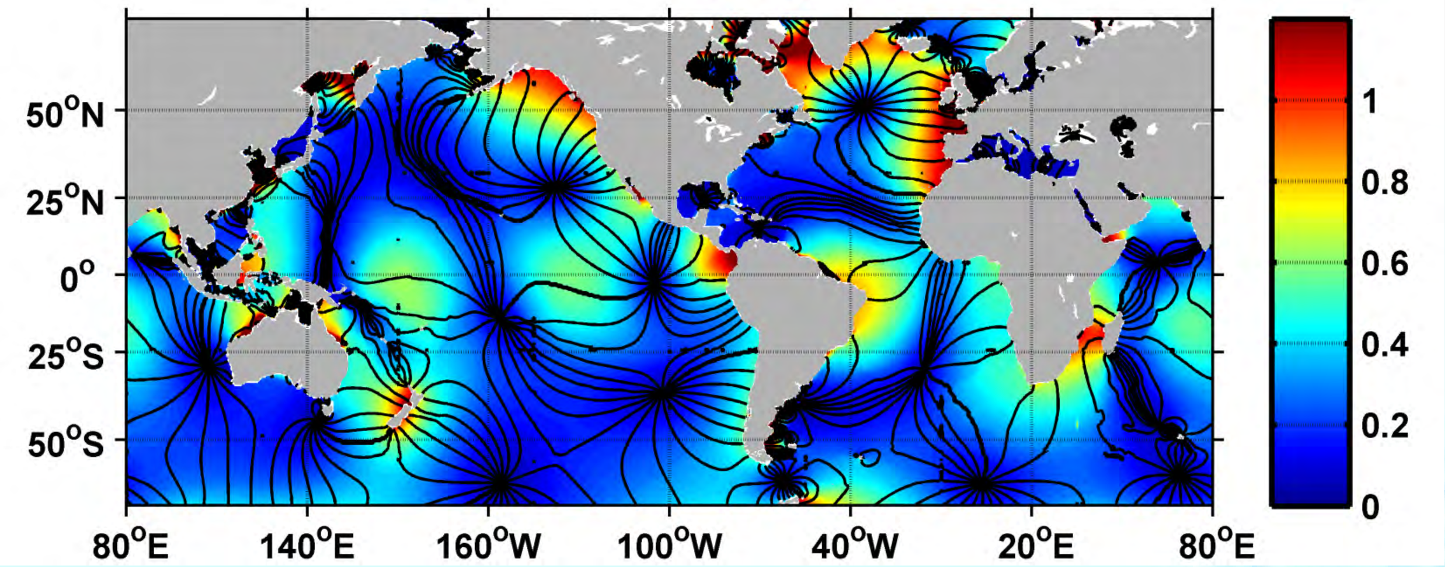
4.2 Model results with inclusion of internal tide drag parameterization



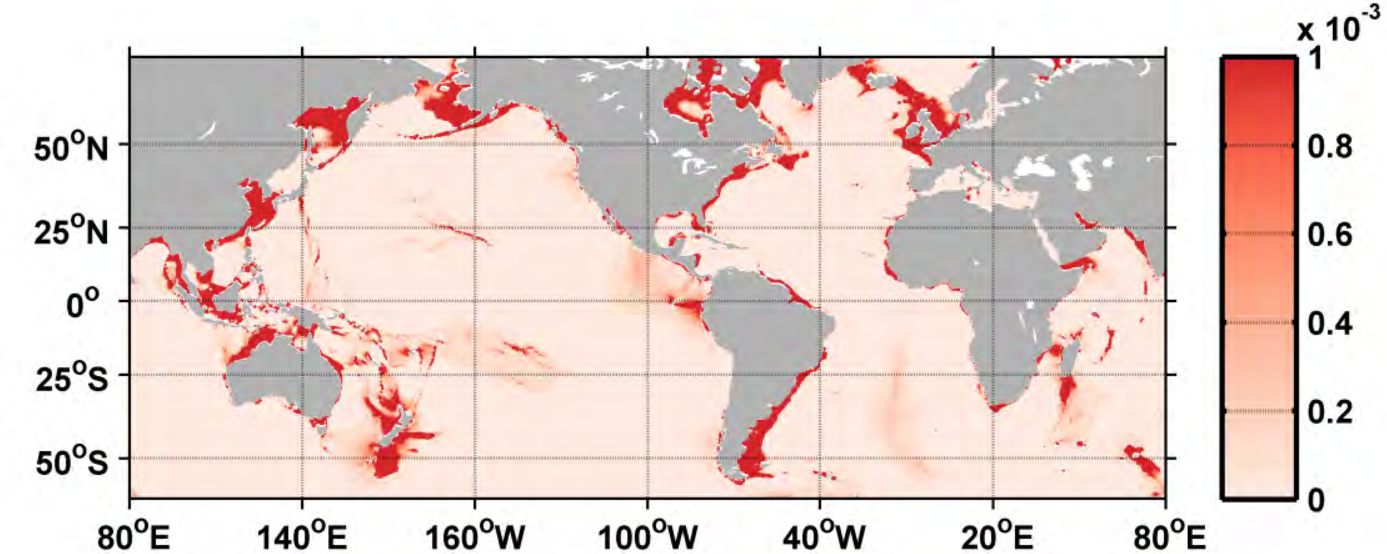
Modeled M_2 amplitude RMS(ARMS) errors compared with TPXO7.2 under different κ.



M_2 co-tidal charts of TPXO7.2

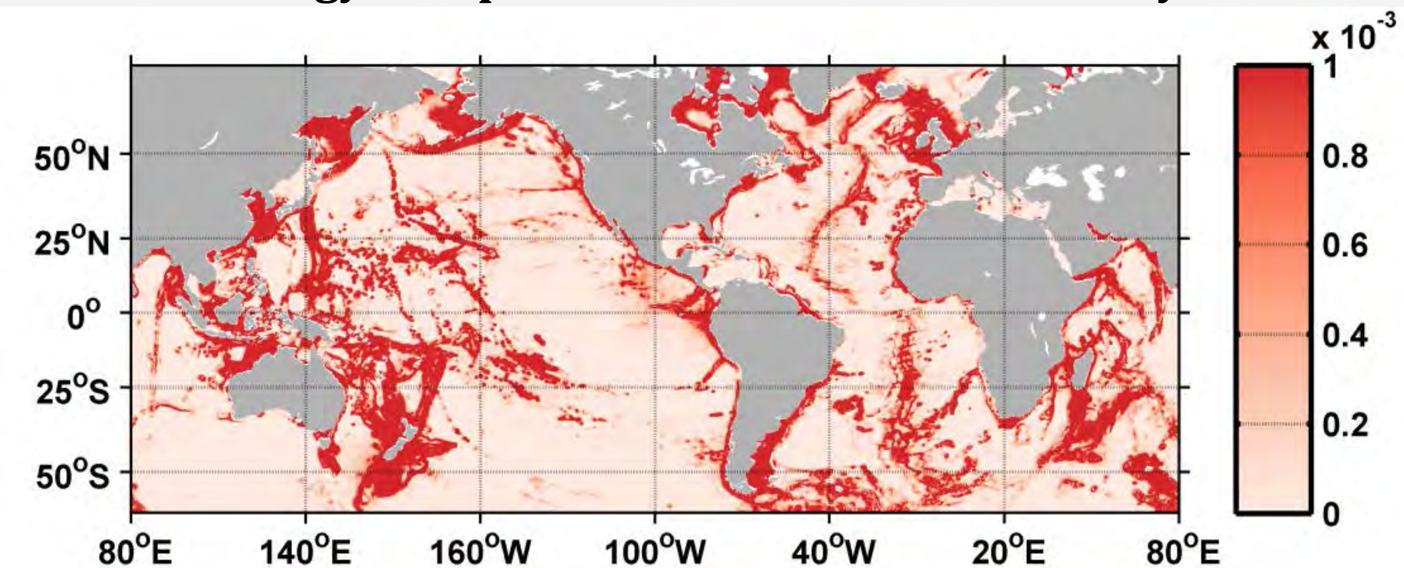


Modeled M_2 co-tidal charts $\kappa = 7.0e-4$



Tidal energy dissipation with bottom friction only w/m^2

$$c_d \rho_0 \left\langle \left|\vec{u}\right|^3 \right\rangle$$

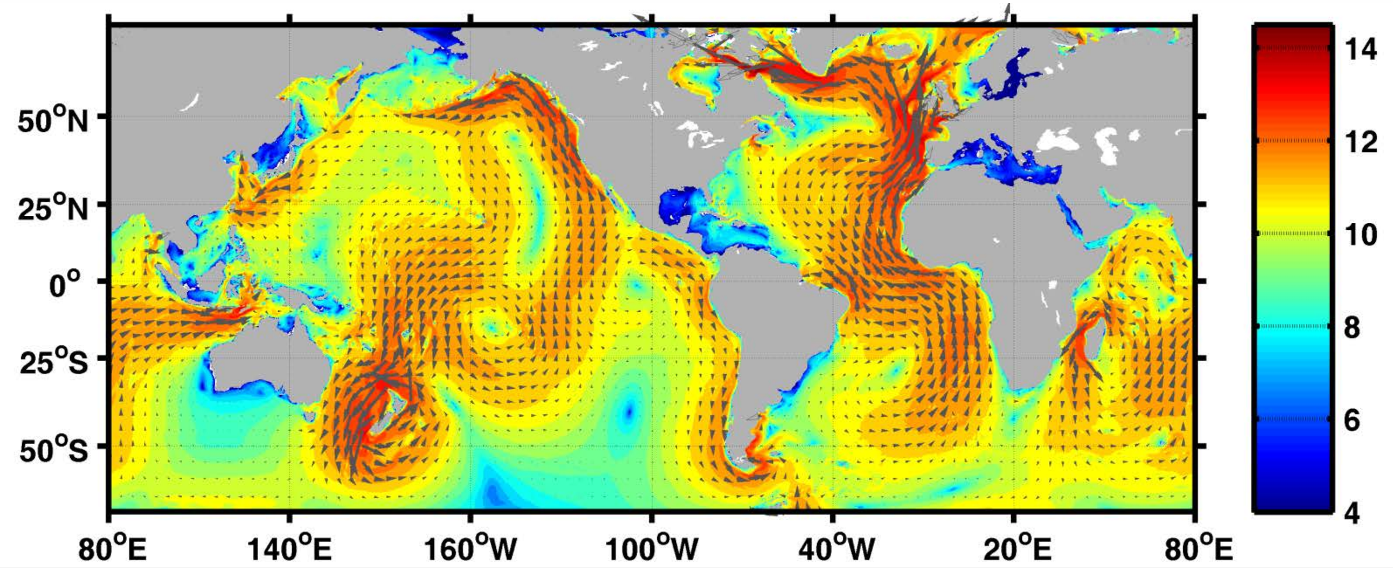


Tidal energy dissipation with inclusion of IT drag term w/m^2

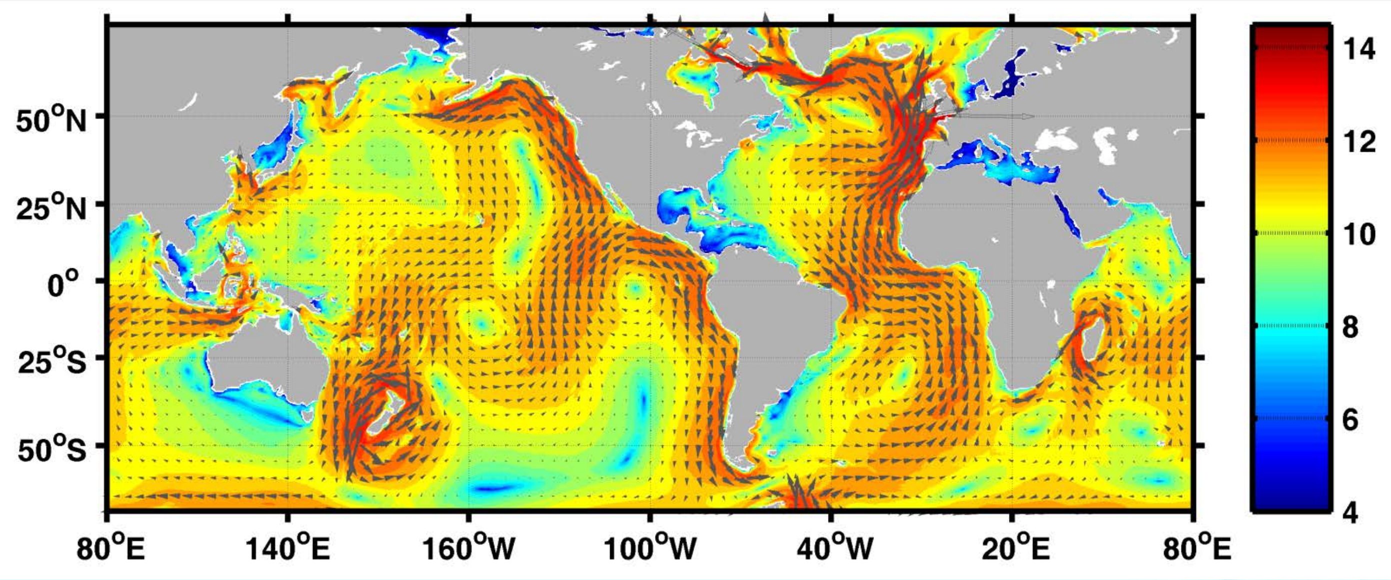
$$c_d \rho_0 \left\langle \left|\vec{u}\right|^3 \right\rangle + \frac{1}{2} \rho_0 \kappa h^2 N \left\langle \left|\vec{u}\right|^2 \right\rangle$$

	Jayne, St. Laurent (2001)	Egbert et al. (2004)	Arbic et al. (2004)	Arbic et al. (2012)	Müller et al. (2010)	MOM4
Comparison Datasets	UT-CSR	TPXO.5	ST102	ST102	ST102	TPXO7.2
Comparison Area	72°S-72°N, water depth > 1000m	66°S-66°N, water depth > 1000m	77°S-63°N	77°S-63°N	77°S-63°N	66°S-66°N, water depth>1000m
M_2 RMS: cm	ERMS: 6.7	ERMS: ~5.0	ERMS: 9.3	ERMS: 8.3	ARMS: 12.	ERMS/ARMS: 8.5/6.5
S_2 RMS: cm	ERMS:3.6	N.	ERMS:4.4	N.	N.	ERMS:4.3
K_1 RMS: cm	ERMS:5.5	N.	ERMS:2.9	N.	N.	ERMS: 3.7
O_1 RMS: cm	ERMS:2.9	N.	ERMS:1.8	N.	N.	ERMS: 3.5

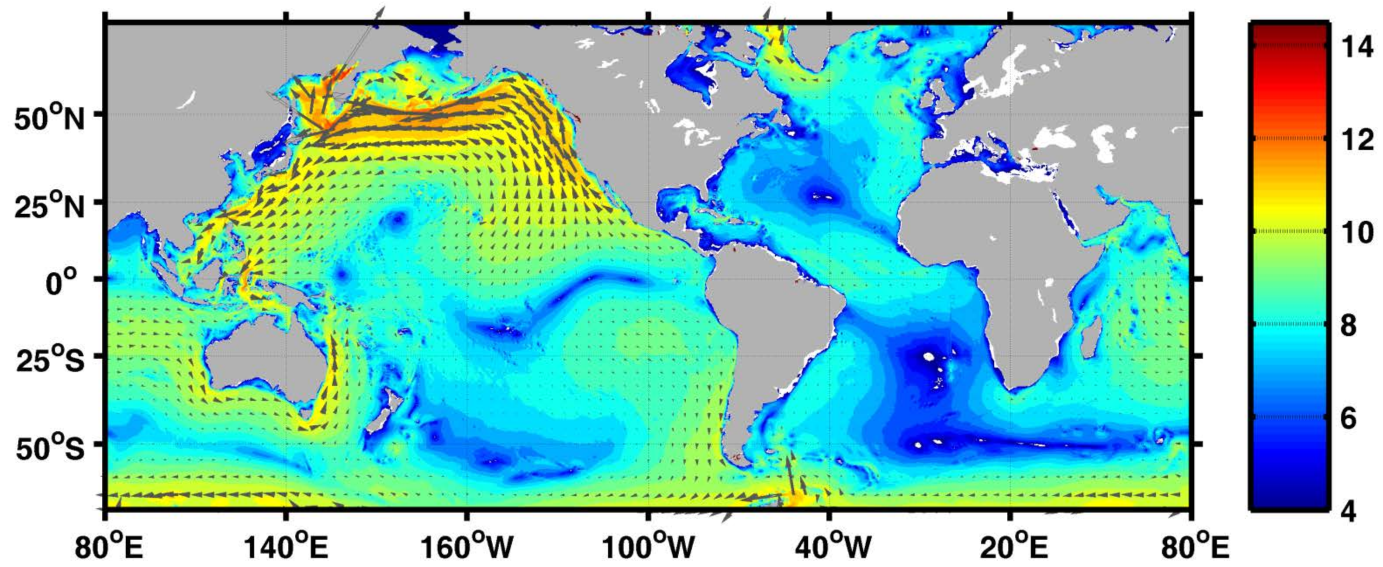
ARMS: amplitude RMS; ERMS: elevation RMS



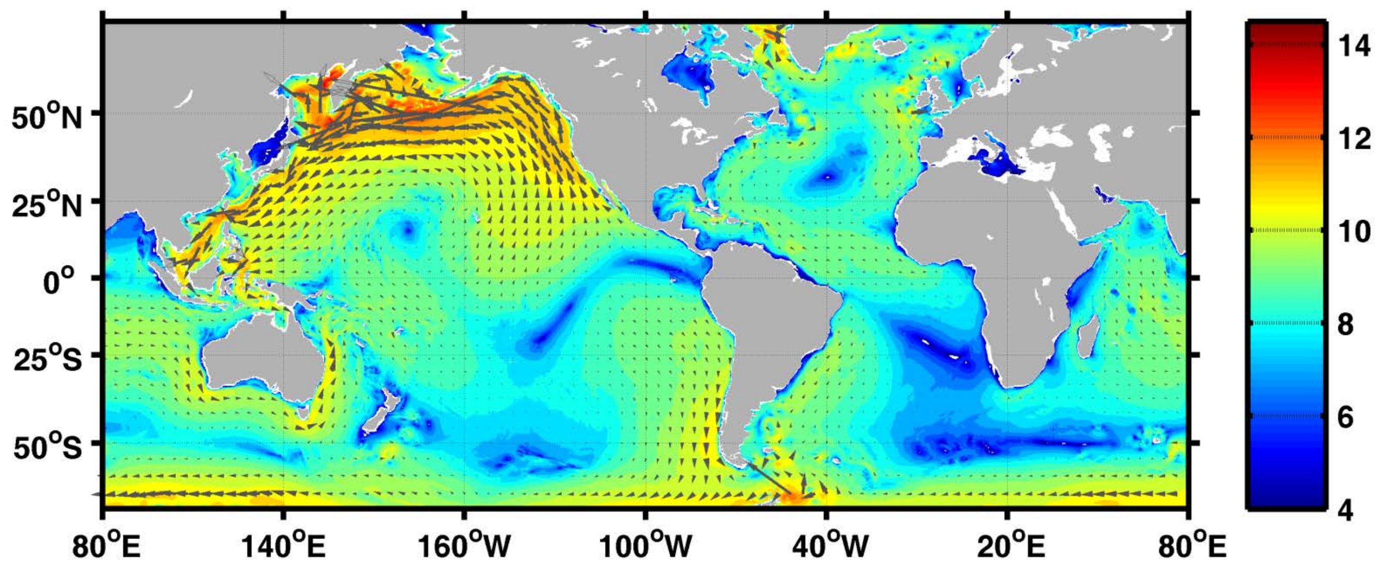
M_2 energy flux in TPXO7.2, vectors represent the direction, color is the natural logarithm of the energy flux amplitude



Same with above figure but for MOM4

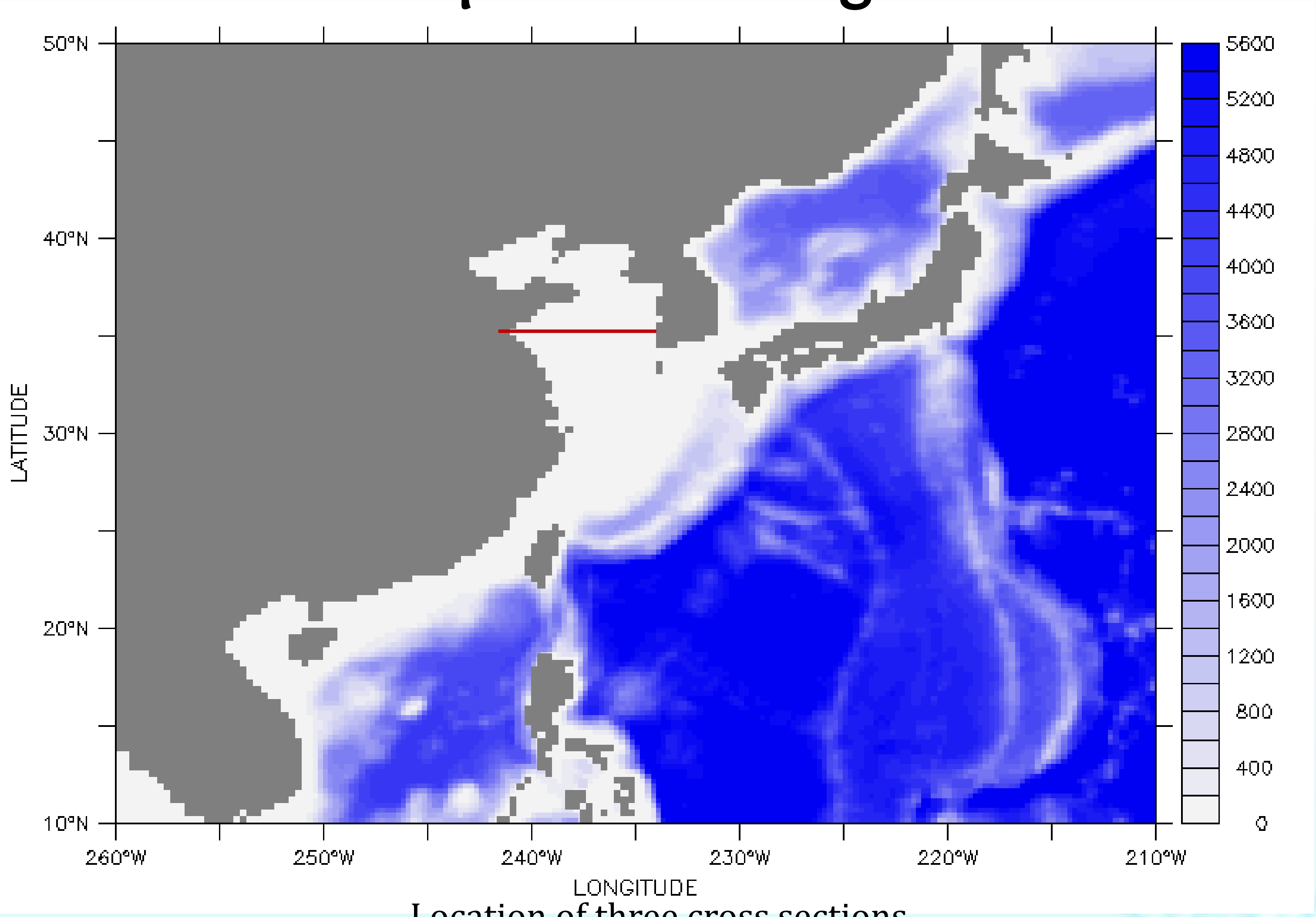


K_1 energy flux in TPXO7.2, vectors represent the direction, color is the natural logarithm of the energy flux amplitude



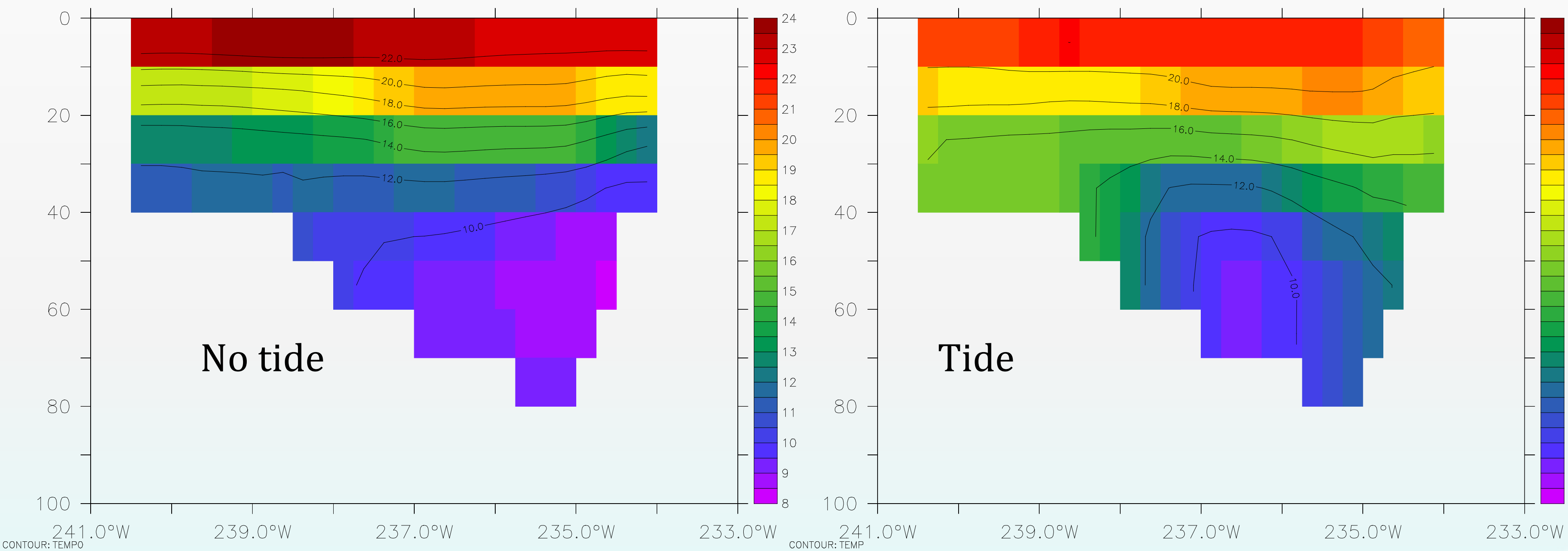
Same with above figure but for MOM4

5. Temperature at a glance



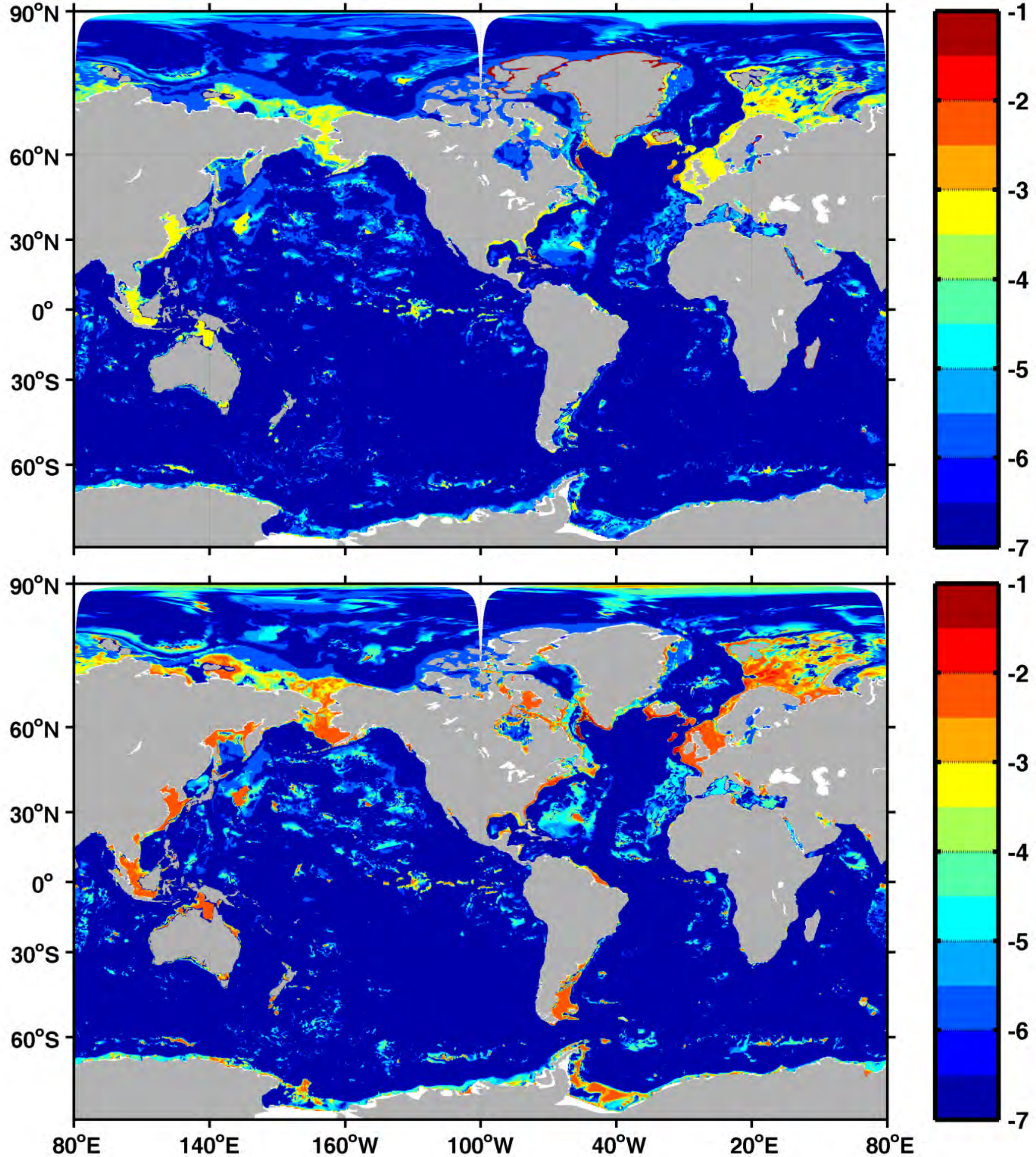
Location of three cross sections

35°N cross section in the Yellow Sea, July monthly mean of 15th model year.



This results should be consistent with our previous regional model results, implying that tide is crucial for the formation of Yellow Sea cold water mass.

Tidal influence on vertical diffusivity



Bottom diffusivity in the experiments without tide

Bottom diffusivity in the experiments with tide

6. Conclusions

(1) With model topography constructed properly, sufficient horizontal resolution and inclusion of internal tide drag parameterization the Z-level ocean model is able to reproduce reasonably accurate global barotropic tide, the optimum ERMS errors of our model is 8.5cm.

(2) The preliminary result of the global tide-circulation coupled model show improved simulation in coastal region.

Thank s for your attention