A Numerical Study of the Sediment Transport Process from the Yellow River to the Bohai Sea and the Yellow Sea

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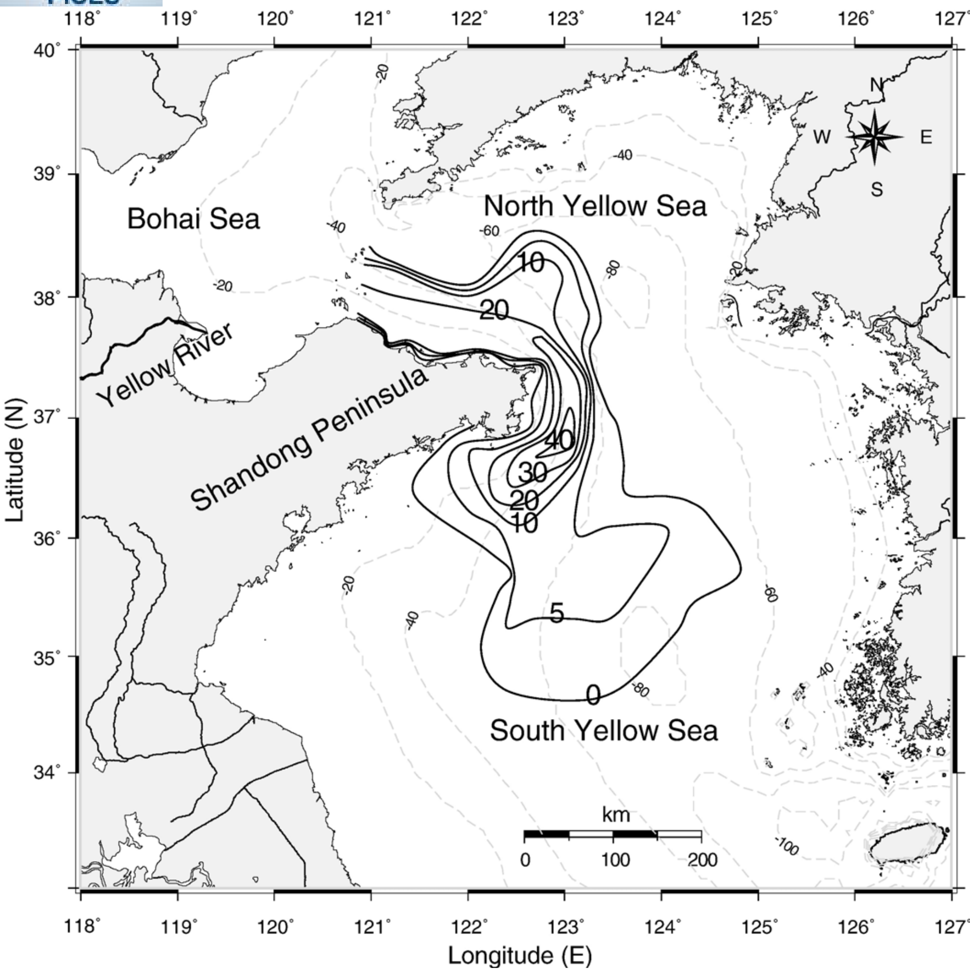
Content

- based on Ecomsed, a 3D baroclinic and wave-tide-circulation coupled numerical model was established to simulate the sediment transport, diffusion, deposition and resuspension processes of the Yellow River-derived sediment.
- considering wave-induced mixing (bv).
- considering wave-enhanced bottom friction.
- radiation boundary condition of sediment concentration.
- spatial variation of critical bottom shear stress.

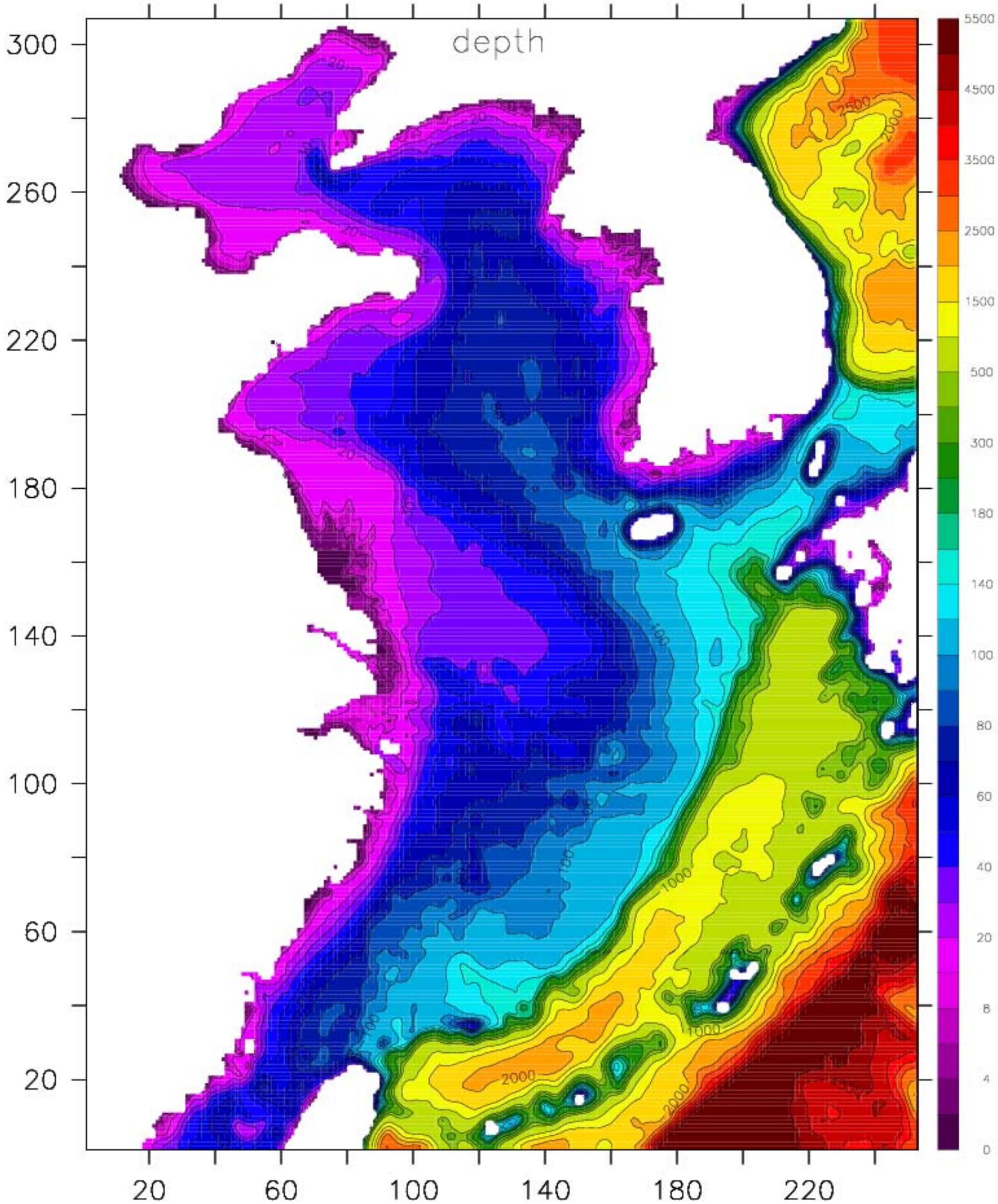
Background



Z.S. Yang, J P Liu(2007)

- High-resolution Chirp sonar profiles reveal a unique Yellow River-derived, subaqueous deltaic lobe deposited around the eastern tip of the Shandong Peninsula in the Yellow Sea.
- This clinoform deposit directly overlies the postglacial transgressive surface, up to 40 m thick locally.
- over the past 7000 years, nearly 30% of the Yellow River-derived sediment has been resuspended and transported into the Yellow Sea.
- the Yellow River-derived sediment could reach the −80m water depth in the central South Yellow Sea

Model setup



Region:	24～41°N 117～130.1°E
Horizontal Resolution:	1/18°×1/18°
Vertical Resolution:	20 equal σ layers
Grid number:	247×307
Topography:	ETOP5
Surface condition:	COADS
T,S initial &boundary :	GDEM
U,V boundary:	OCCAM

MASNUM wave number spectral model can compute wave-induced vertical mixing coefficient-Bv (Qiao et al,GRL,2004)

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

Where $E(\vec{k})$ represents the wave number spectrum

- Sediment transport Governing Equation

$$\frac{\partial C}{\partial t} + \frac{\partial UC}{\partial x} + \frac{\partial VC}{\partial y} + \frac{\partial (W - W_s)C}{\partial z} = \frac{\partial}{\partial x}\left(A_H \frac{\partial C}{\partial x} \right) + \frac{\partial}{\partial y}\left(A_H \frac{\partial C}{\partial y} \right)$$

$$+ \frac{\partial}{\partial z}\left(K_H \frac{\partial C}{\partial z} \right)$$

$$K_H = K_H + bv$$

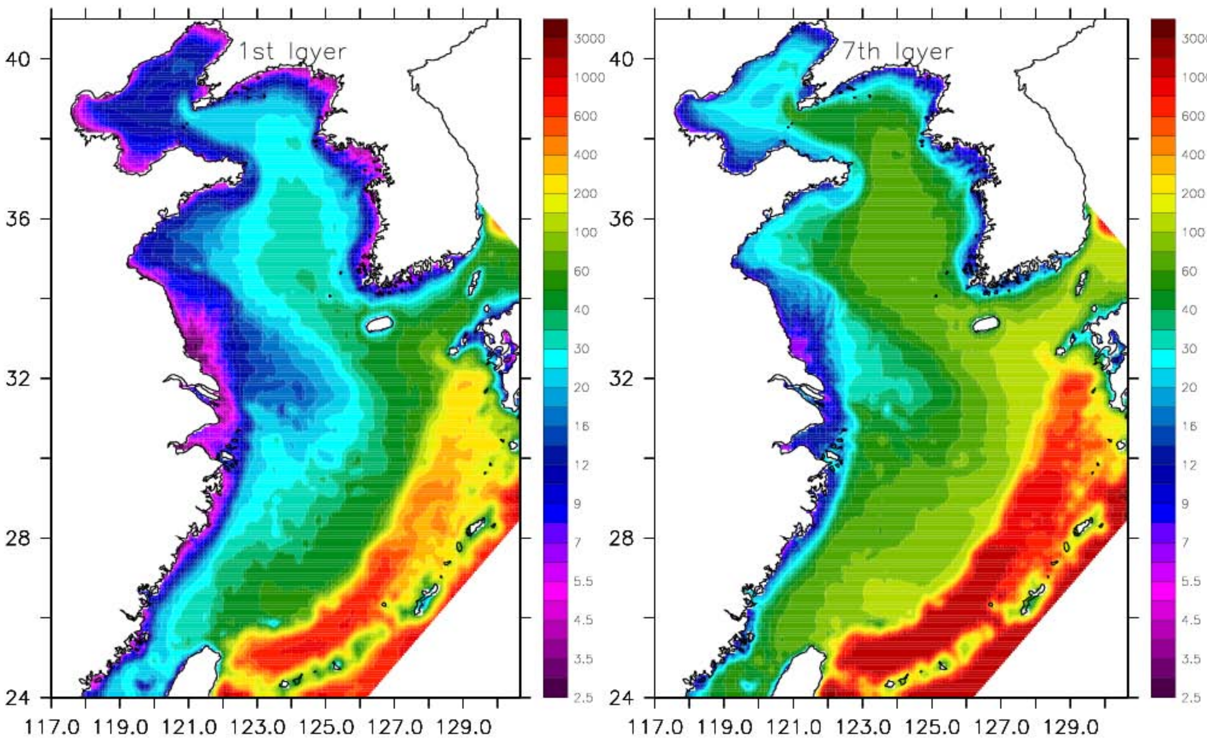
Wave-induced mixing coefficient

Critical shear stress

- Dou G R(1999):

$$\tau_C = k^2 \rho \left(\frac{d'}{d_*} \right)^{\frac{1}{3}} \left[3.6 \frac{\rho_S - \rho}{\rho} g d_{50} + \left(\frac{\gamma_0}{\gamma_{0*}} \right)^{\frac{5}{2}} \left(\frac{\varepsilon_0 + g h \delta \sqrt{\delta / d_{50}}}{d_{50}} \right) \right]$$

- The grain size of sediment from the Yellow River is considered as19μm.
- This particle diameter is used to compute the critical shear stress, which deposits on regions of different water depth.



1. corresponding to the water depth. small where the water depth is small.
2. no resuspension when deeper than 120m, because the critical shear stress is higher than 200 dynes/cm^2

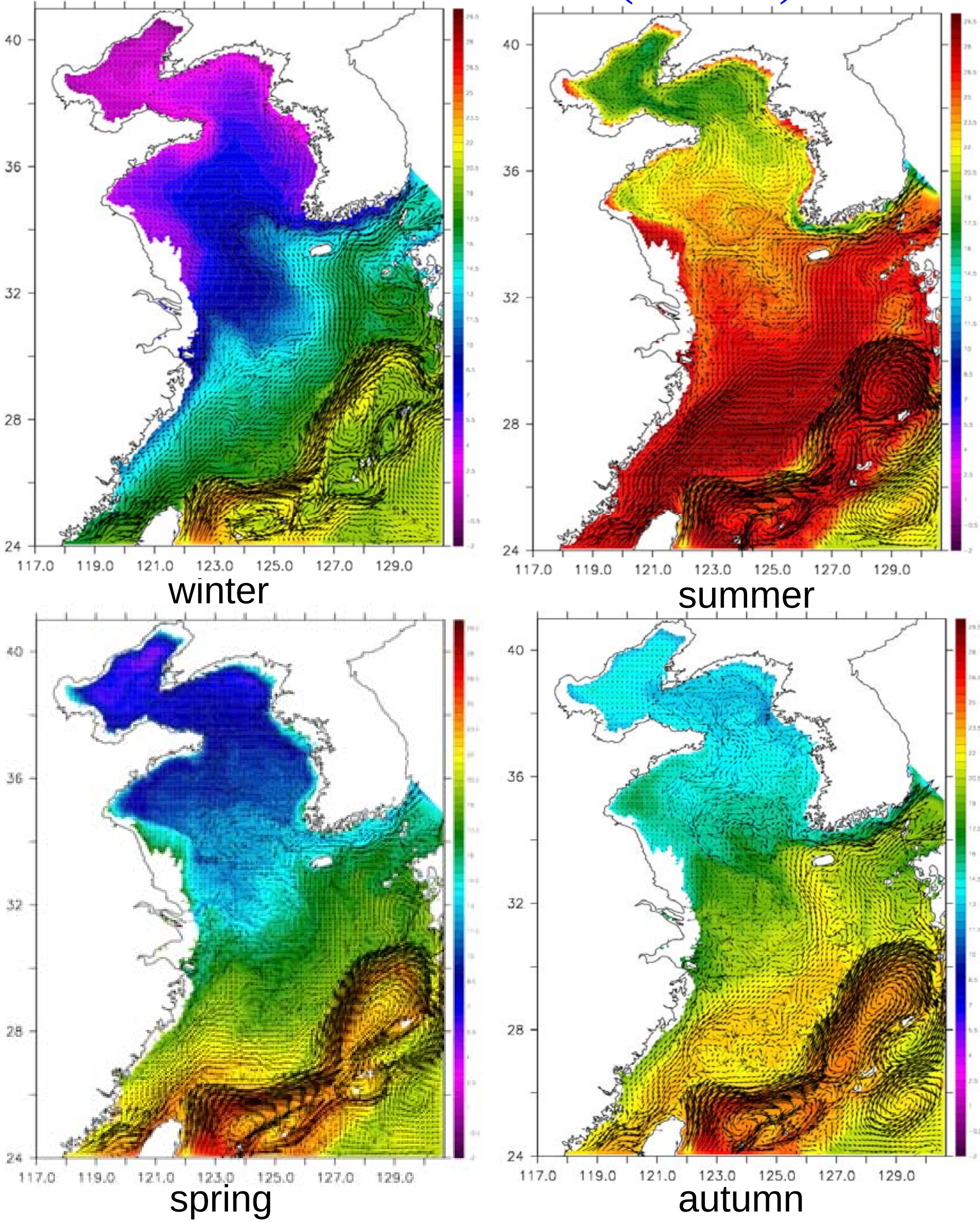
radiation boundary condition of sediment concentration

- take the South boundary as an example:

U1=2.*V(IC,JC,K)*DTI/(H2(IE,JE)+H2(IC,JC))

- 1. U1>=0. ! water flow in
- UF(IE,JE,K)=csed1(IE,JE,K)-U1*(csed1(IE,JE,K)-CBDRY(KS,N,K)) ! Use boundary concentration
- Here, the boundary concentration=0,because the yellow river derived sediment is only considered .
- 2.U1<0. ! water flow out
- UF(IE,JE,K)=csed1(IE,JE,K)-U1*(csed1(IC,JC,K)-csed1(IE,JE,K)) ! Use connecting grid concentration

simulated results (z=10m)

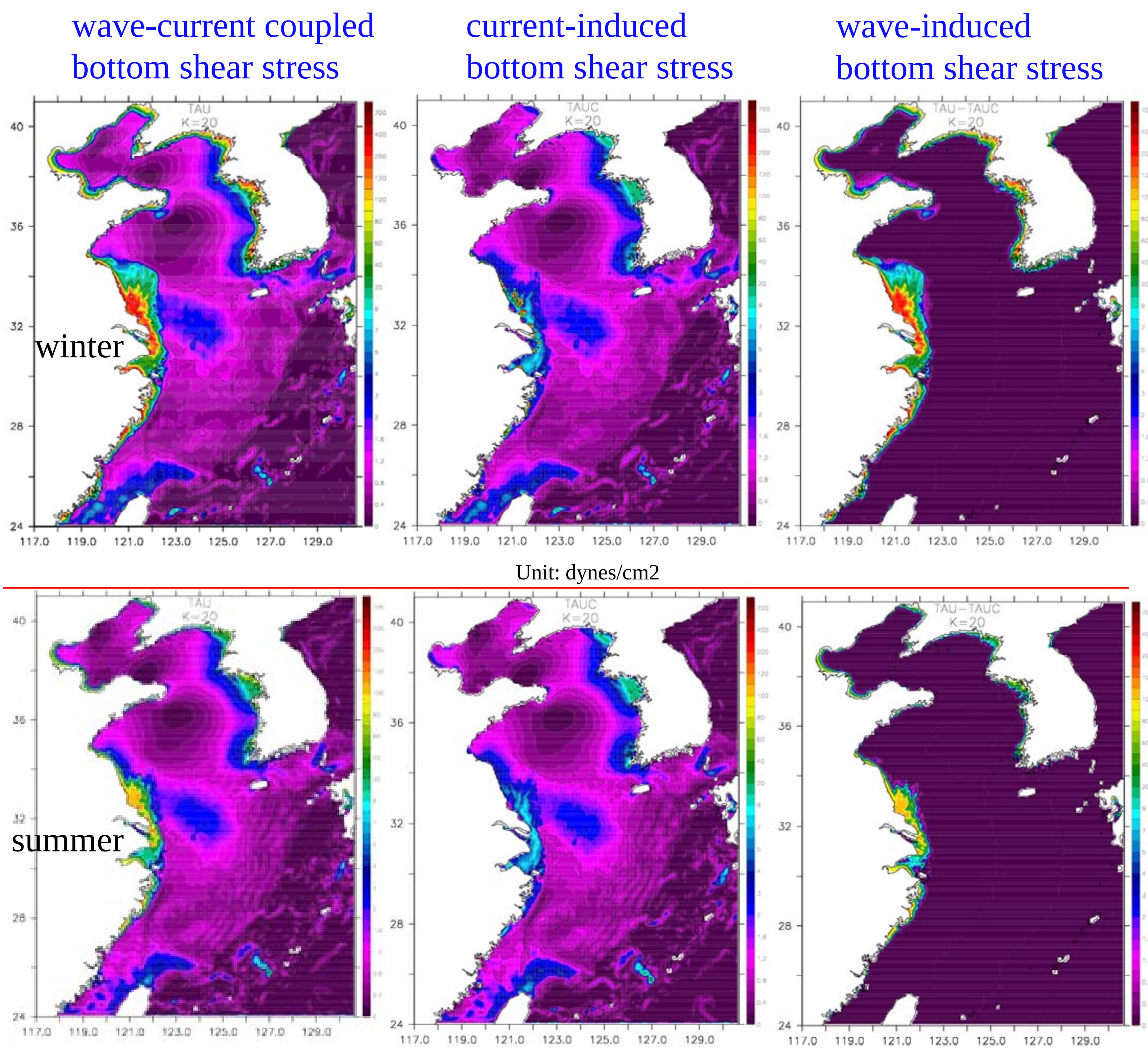


permanent coastal current: eastward: Northern Shandong coastal current. southward: Western Yellow Sea coastal current, and Northern Jiangsu coastal current.

winter:the most obvious feature is the southward coastal current driven by strong north wind. For example: the southward Zhejia and Fujian coastal current, and the southward Western Korea coastal current.

summer:the wind-driven coastal current is weak, because the south wind is less strong than the north wind in winter. A basin-scale Cyclonic gyre induced by tide mixing appears in the Yellow Sea.

Spring&autum:the circulation is a transition pattern between winter and summer.

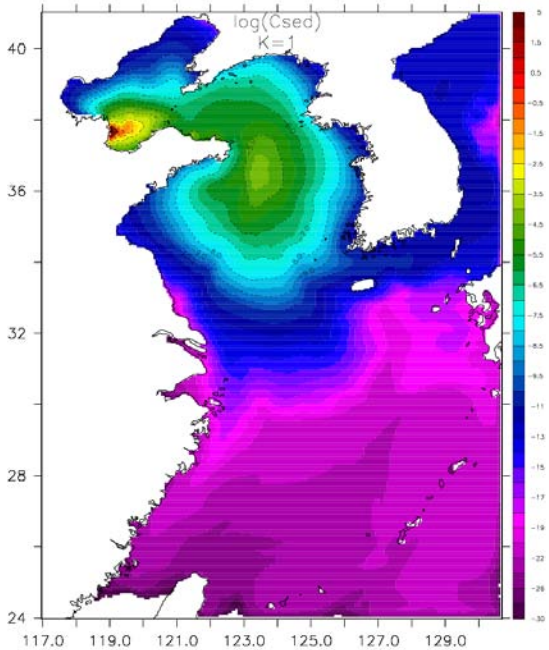


wave-current coupled BSS: in winter>in summer, especially in coastal area.

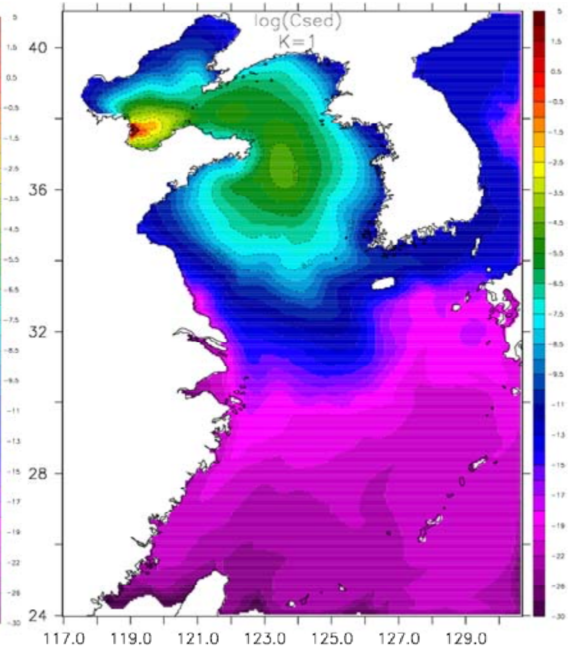
current-induced BSS: is mainly determined by bottom velocity. Generally, it's larger where the water depth is smaller.

wave-induced BSS: is determined by wave height, wave period, and water depth. In winter it's very large where the water depth is less than 20m, and almost 0 where water depth is deeper. In summer, the wave-induced BSS is amost 0 where water depth is deeper than 10m.

sc in winter(order of magnitude)

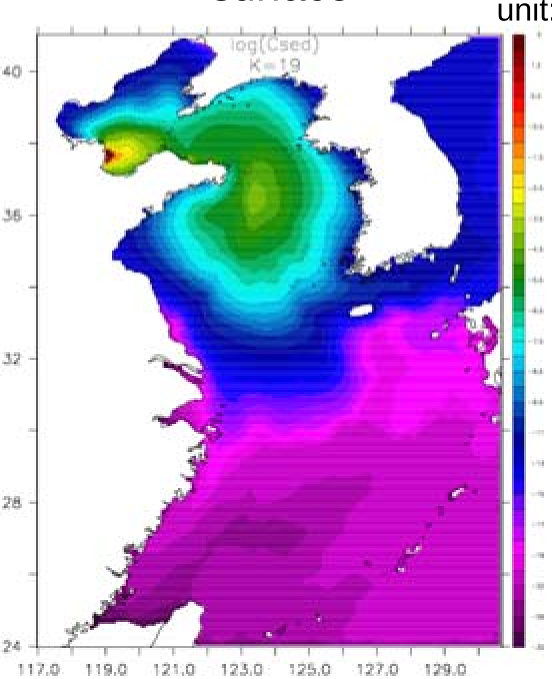


surface

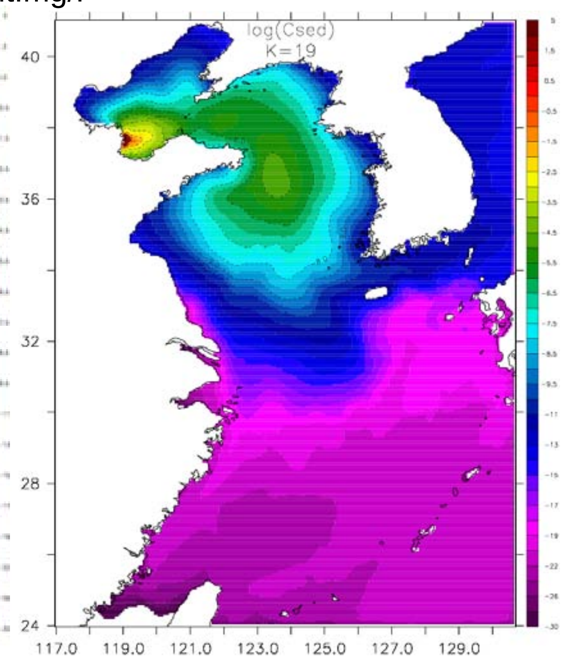


surface(no wave)

unit:mg/l

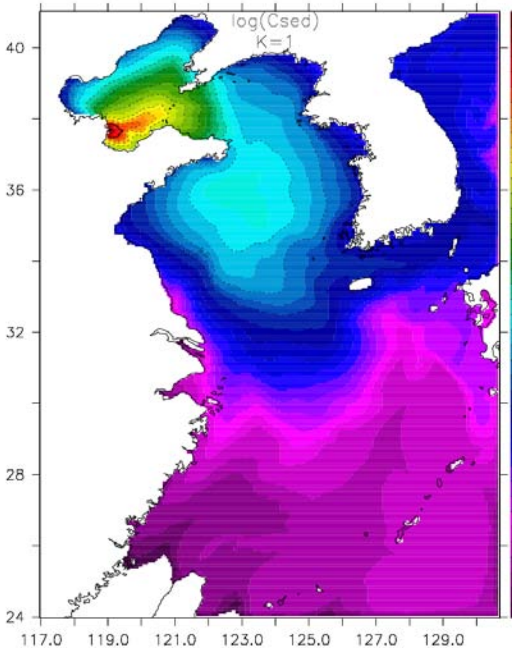


bottom

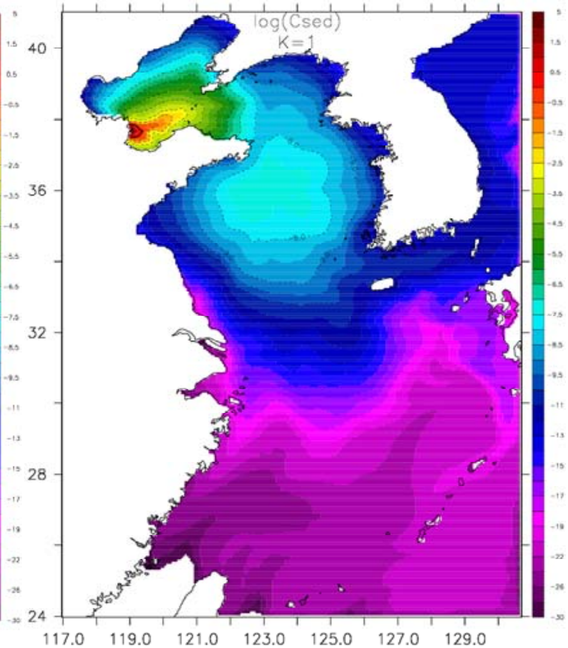


bottom(no wave)

high concentration region	•1.Laizhou Bay •2.South Yellow Sea
maximum &minimum in the 4 seasons	•maximum sc: South Yellow Sea(resuspension) •minimum sc: Bohai Sea(river discharge)
surface/ bottom	•Surface>bottom •Difference very little, vertically homogeneous
wave/ no wave	•wave>no wave

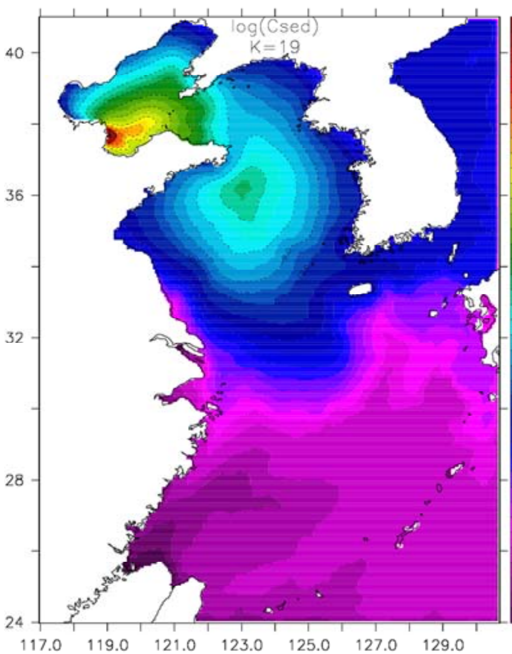


surface

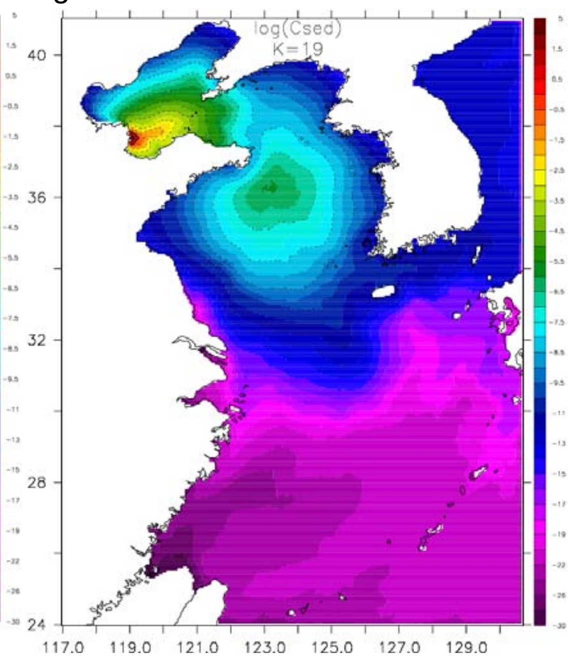


surface(no wave)

unit:mg/l



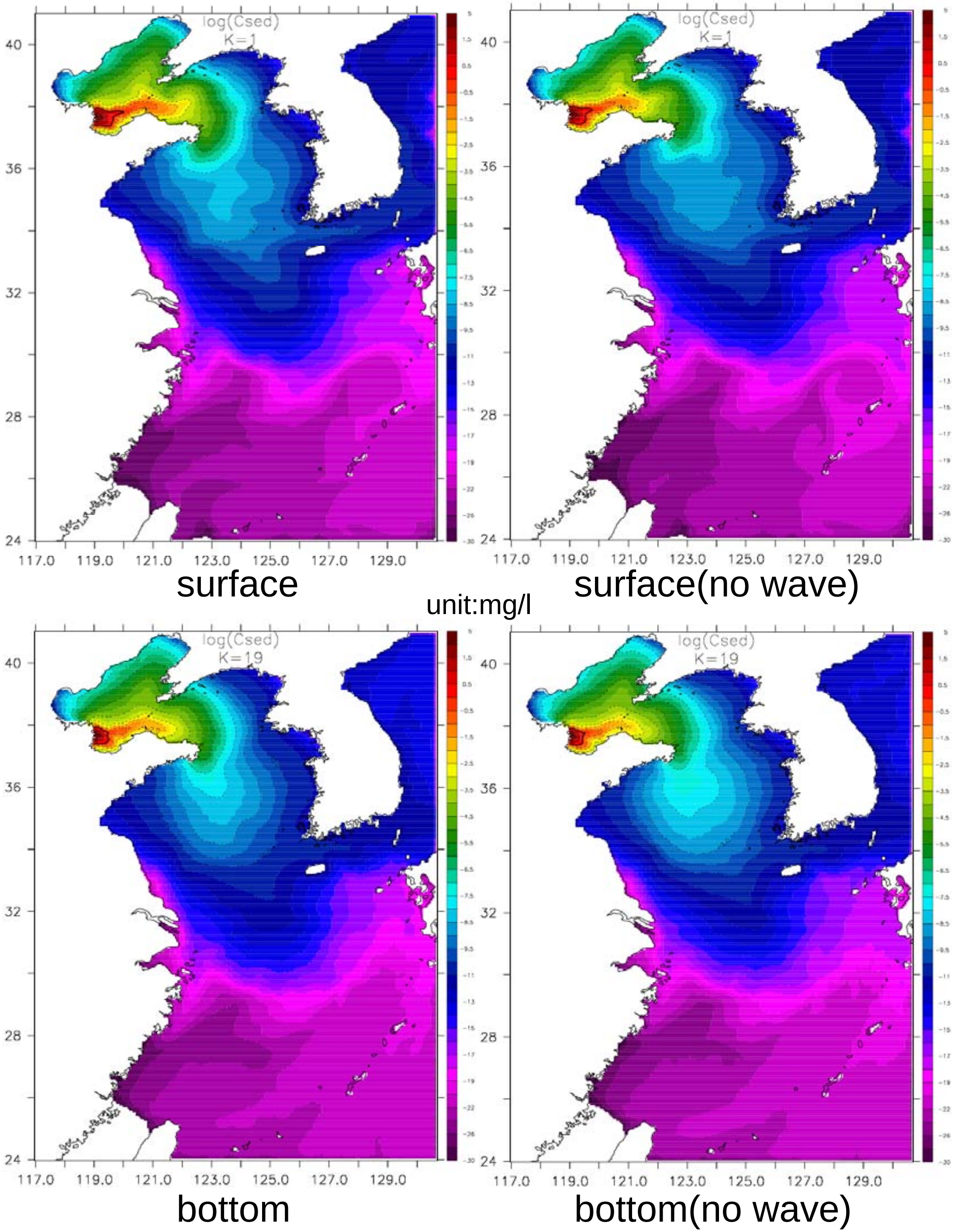
bottom



bottom(no wave)

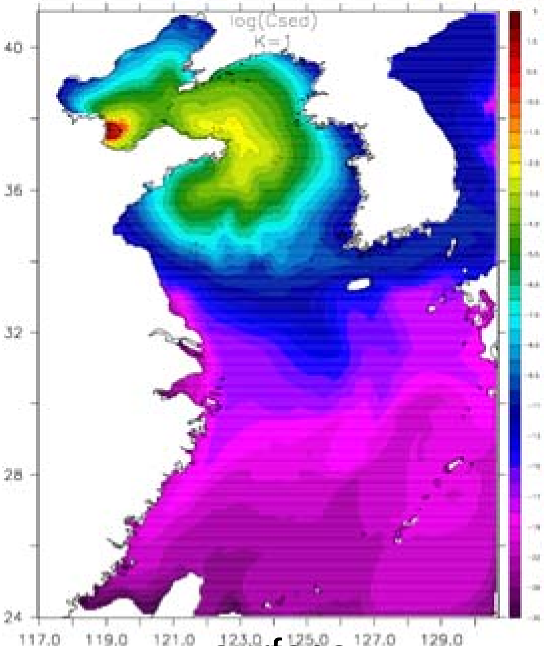
sc in spring(order of magnitude)

high concentration region	•1.Laizhou Bay •2.South Yellow Sea
surface/ bottom	•1.Bohai &N.Y.: Surface>bottom •2.S.Y.: Surface<bottom
wave/ no wave	•1.Bohai &N.Y.: wave>no wave •2.S.Y.: •wave<no wave

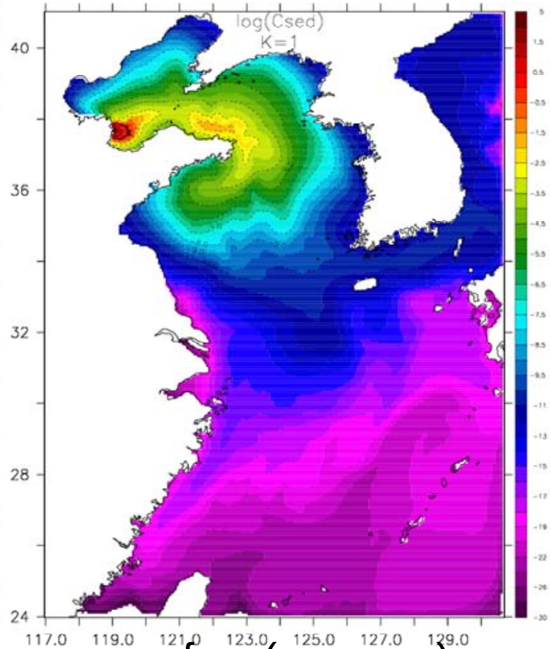


sc in summer(order of magnitude)

high concentration region	•1.Laizhou Bay
maximum &minimum in the 4 seasons	•maximum sc: Bohai Sea Sea(river discharge) •minimum sc: South Yellow Sea(resuspension)
surface/ bottom	•1.Bohai &N.Y.: Surface>bottom •2.S.Y.: ①. wave: Surface>bottom ②. no wave: Surface<bottom
wave/ no wave	•1.Bohai &N.Y.: •wave>no wave •2.S.Y.: ①. surface: wave>no wave ②. bottom: wave<no wave

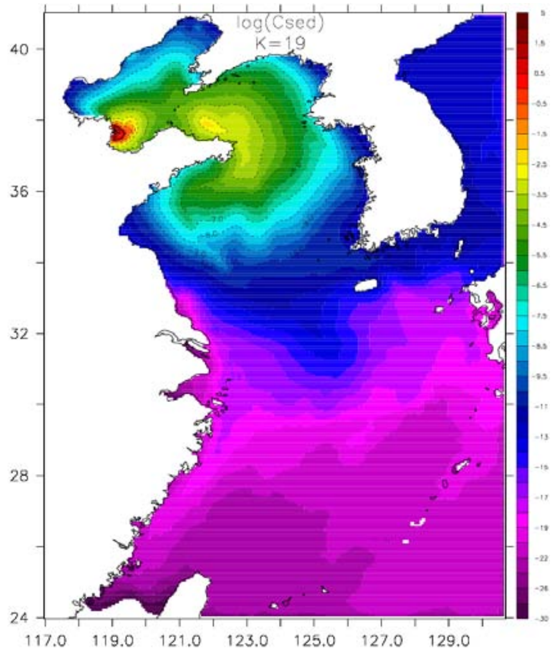


surface

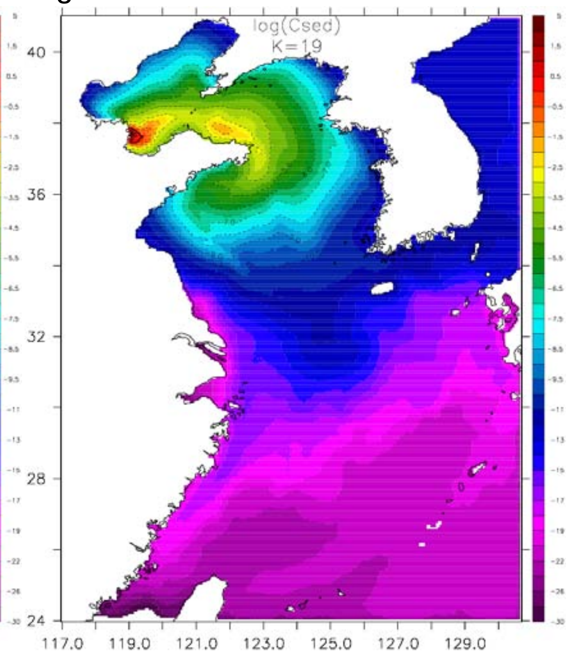


surface(no wave)

unit:mg/l



bottom



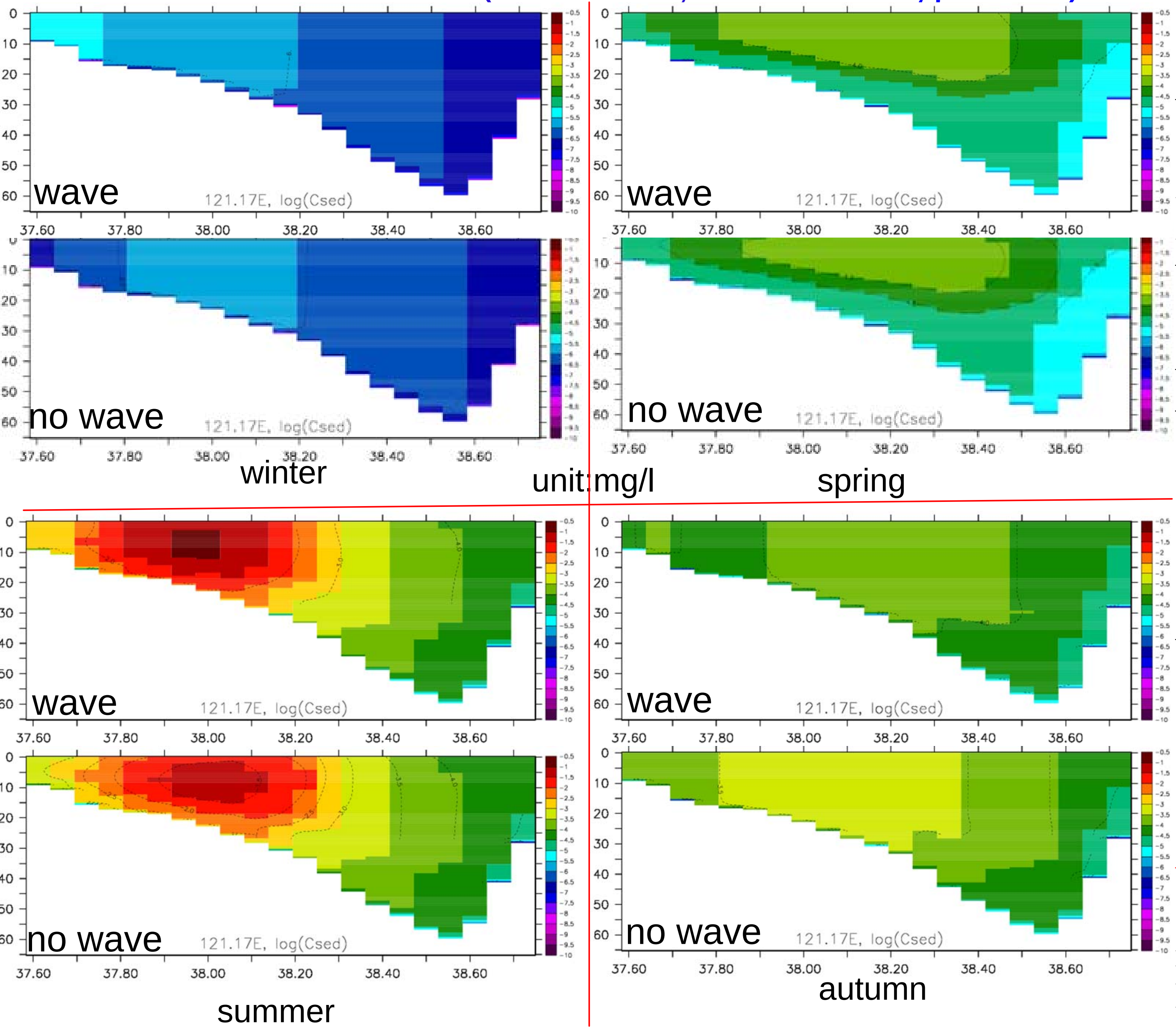
bottom(no wave)

sc in autumn(order of magnitude)

high concentration region	•1.Laizhou Bay •2.NorthYellow Sea
maximum &minimum in the 4 seasons	•North Yellow Sea
surface/ bottom	•Surface>bottom
wave/ no wave	•1.Bohai &N.Y.: wave<no wave •2.S.Y.: difference very little

The wave-induced vertical mixing plays an important role

SC of the Bohai Strait(121.17ºE,order of magnitude)



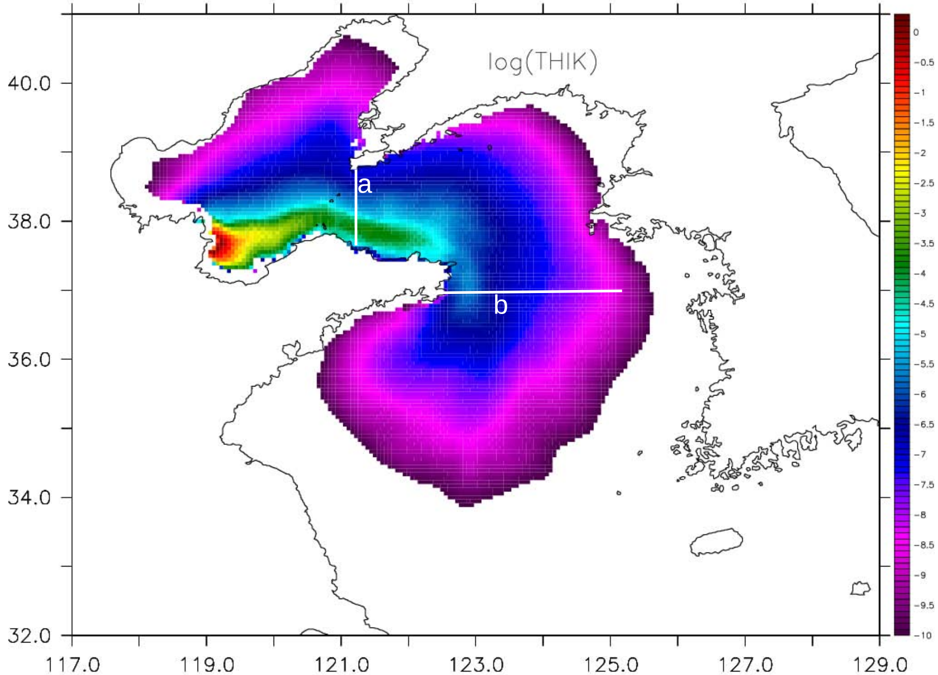
winter: minimum SC, vertically the same. HCR with wave is in the south coast, for wave-induced bss is large in winter. HCR no wave is round 38ºN.

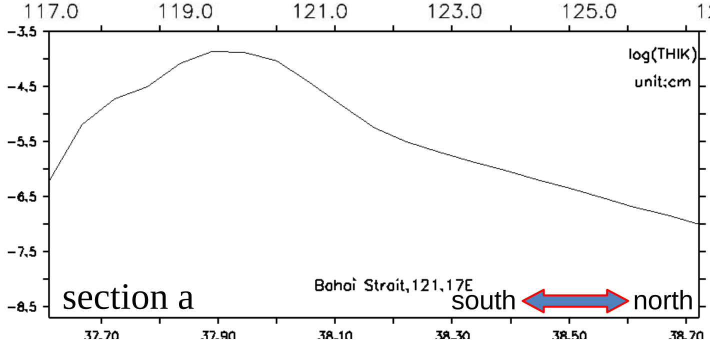
spring: wave>no wave, difference is very little. surface>bottom

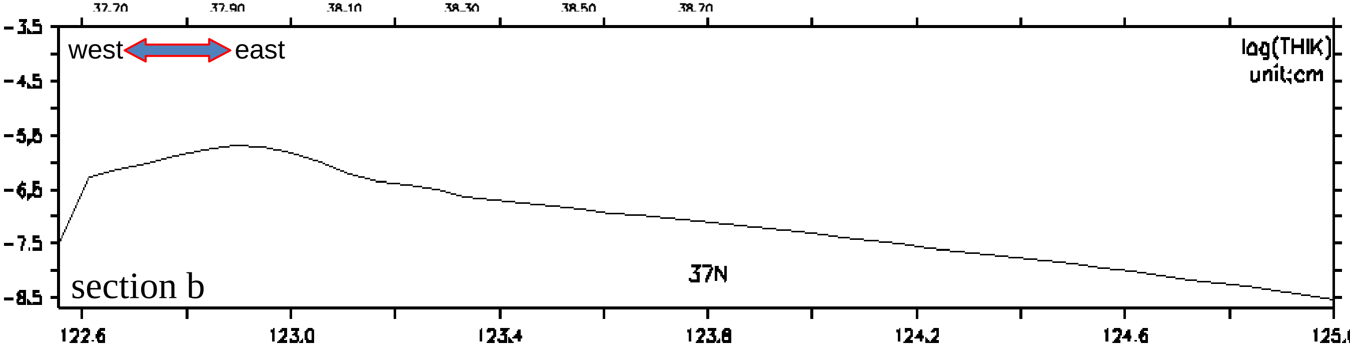
summer: maximum SC in the 4 seasons, $10^{-0.5}$mg/l. wave>no wave in 0~30m depth. surface>bottom.

autumn: vertically similar, wave<no wave. wave:2 HCR, 1small, 1large region. no wave:1 large HCR

Annual bed rise thickness (order of magnitude, unit: cm)







1. deposits along the Shandong Peninsula in 3 main areas: northwest of the Laizhou Bay, southwest of the North Yellow Sea, and northwest of the South Yellow Sea.
2. The annual bed rise thickness in the Bohai Strait(121.17ºE):the highest value is $10^{-3.9}$cm, in 37.9 ºN.
3. the annual bed rise thickness in 37ºN: the highest value is $10^{-5.6}$cm, in 122.9ºE.
4. The bed rise thickness in coastal area is small, because the wave-induced bottom shear stress is high in coastal areas.

conclusion

- 1.Under the eastward Northern Shandong coastal current and southward Western Yellow Sea coastal current, the Yellow River-derived suspended sediment is transported first eastward along the northern coast of Shandong Peninsula, and then southward into the South Yellow Sea. This diffusion direction remains the same all the year round.
- 2.The Yellow River-derived fine sediment deposits along the Shandong Peninsula in three main areas:
- a. northwest of the Laizhou Gulf,
- b. northwest of the North Yellow Sea,
- c. north of the South Yellow Sea.

sediment concentration

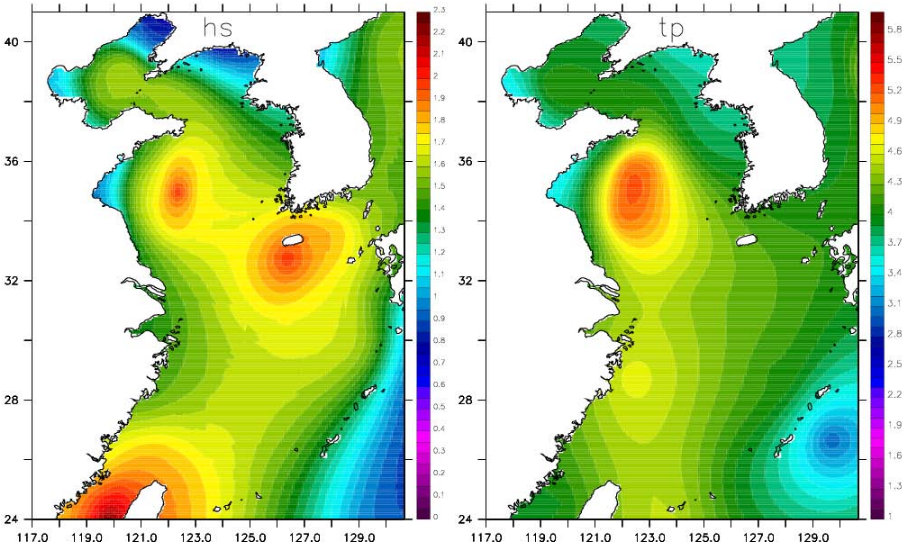
Sediment concentration	winter	spring	Summer	autumn
high concentration region	•1.Laizhou Bay •2.South Yellow Sea	•1.Laizhou Bay •2.South Yellow Sea	•1.Laizhou Bay	•1.Laizhou Bay •2.NorthYellow Sea
maximum &minimum in the 4 seasons	•maximum: South Yellow Sea •minimum: Bohai Sea		•maximum: Bohai Sea •minimum: South Yellow Sea	•North Yellow Sea
surface/ bottom	•Surface>bottom •Difference very little, vertically homogeneous	•1.Bohai &N.Y.: Surface>bottom •2.S.Y.: Surface<bottom	•1.Bohai &N.Y.: Surface>bottom •2.S.Y.: ①. wave: Surface>bottom ②. no wave: Surface<bottom	•Surface>bottom
wave/ no wave	•wave>no wave	•1.Bohai &N.Y.: wave>no wave •2.S.Y.: •wave<no wave	•1.Bohai &N.Y.: •wave>no wave •2.S.Y.: ①. surface: wave>no wave ②. bottom: wave<no wave	•1.Bohai &N.Y.: wave<no wave •2.S.Y.: difference very little

PICES

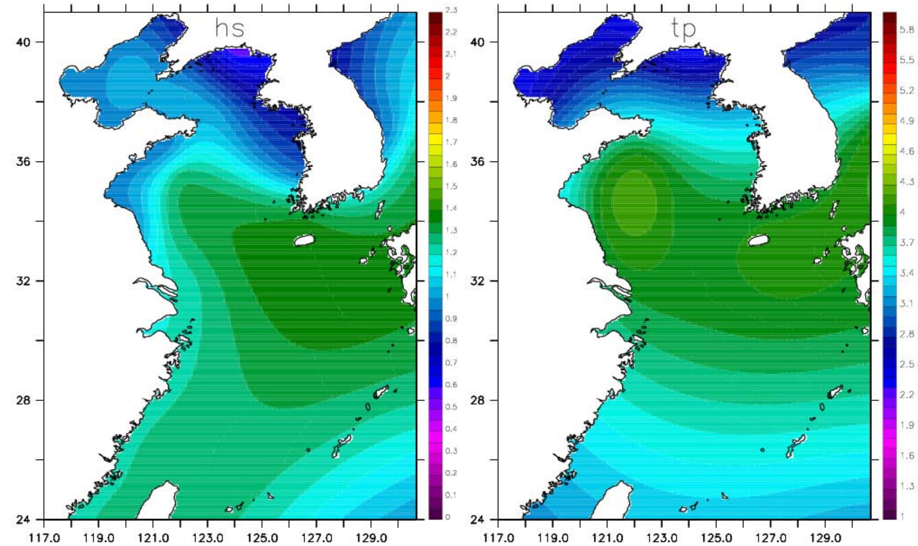
The end

Thank you!

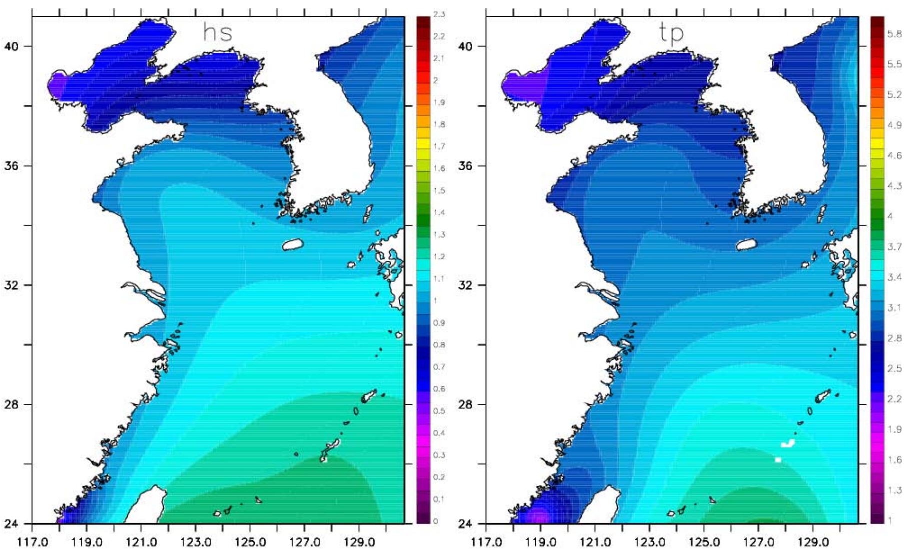
Wave height & wave period



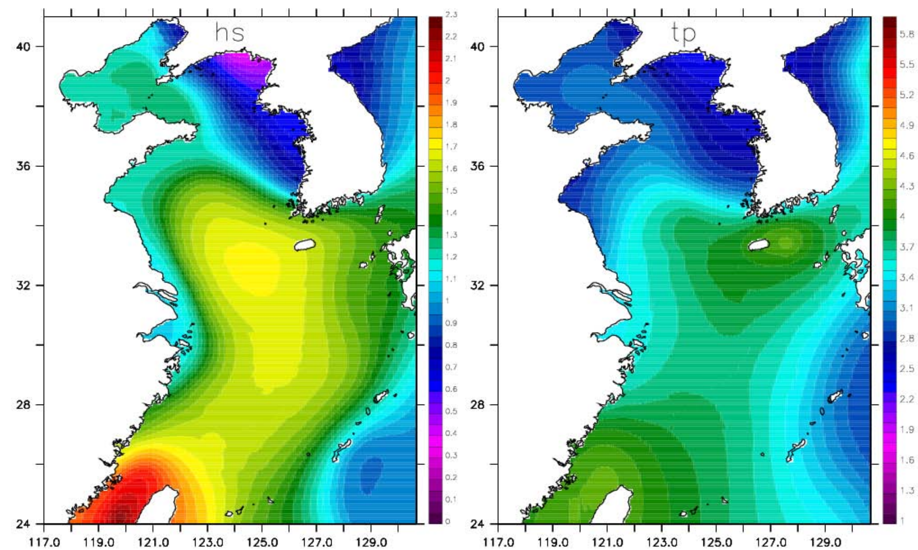
winter



spring

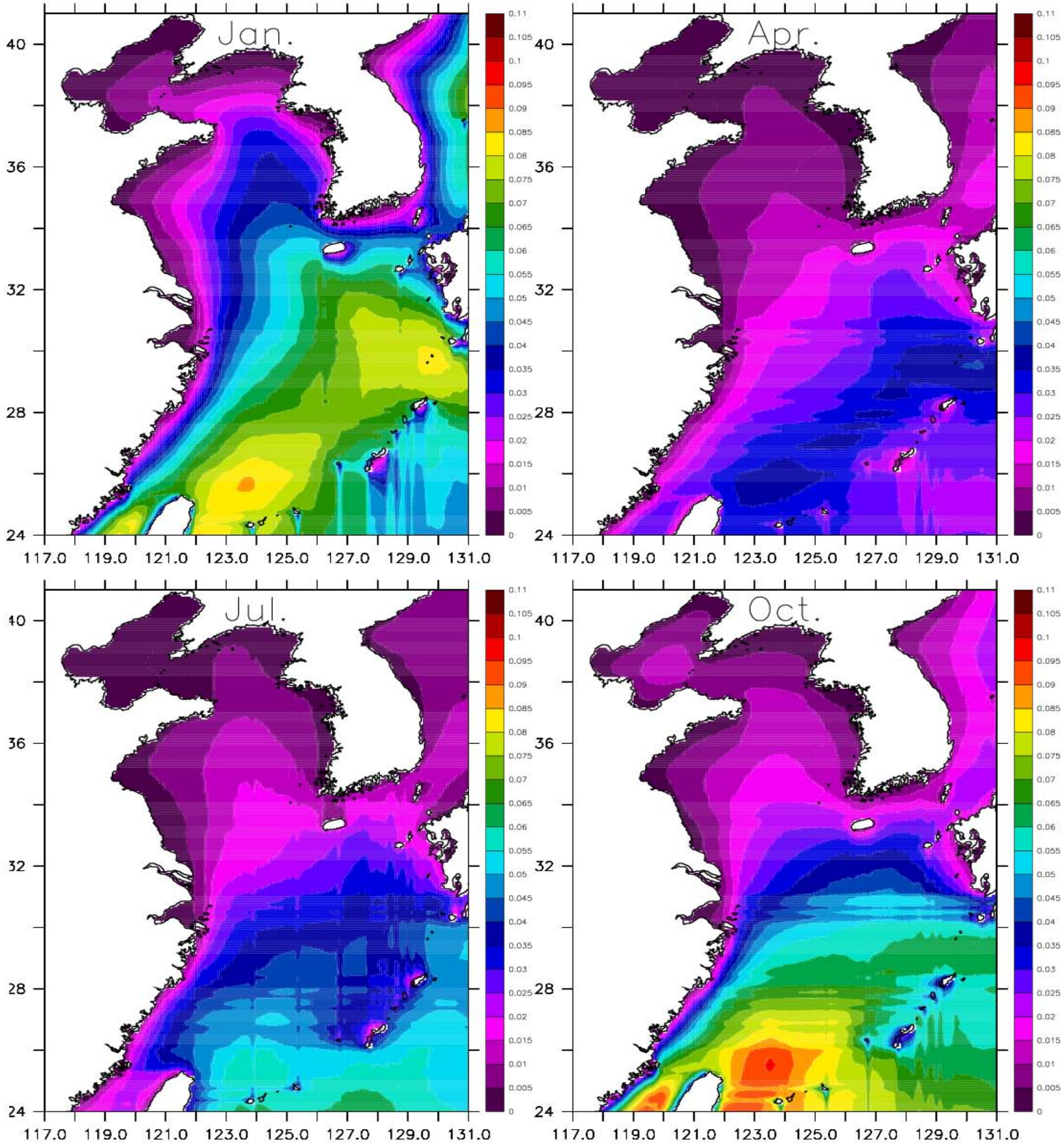


summer



autumn

Distribution of bv computed by MASNUM wave model



surface layer

unit: m^2/s

Mellor and Yamada turbulence closure scheme

- Vertical mixing coefficients use 2nd order turbulence closure scheme (1974)：

$$\frac{\partial q^2}{\partial t}+\bar{V}\cdot\nabla q^2+W\frac{\partial q^2}{\partial z}=\frac{\partial}{\partial z}\left(K_q\frac{\partial q^2}{\partial z}\right)+2K_M\left[\left(\frac{\partial U}{\partial z}\right)^2+\left(\frac{\partial V}{\partial z}\right)^2\right]$$

$$+\frac{2g}{\rho_0}K_H\frac{\partial\rho}{\partial z}-\frac{2q^3}{B_1 l}+F_q$$

$$\frac{\partial\left(q^2 l\right)}{\partial t}+\bar{V}\cdot\nabla\left(q^2 l\right)+W\frac{\partial\left(q^2 l\right)}{\partial z}=\frac{\partial}{\partial z}\left[K_q\frac{\partial}{\partial z}\left(q^2 l\right)\right]+$$

$$lE_1K_M\left[\left(\frac{\partial U}{\partial z}\right)^2+\left(\frac{\partial V}{\partial z}\right)^2\right]+\frac{lE_1 g}{\rho_0}K_H\frac{\partial\rho}{\partial z}-\frac{q^3}{B_1}\tilde{W}+F_l$$

Signell et al. [1990]'s model of Wave-current coupled bottom boundary layer model

- The combined friction velocity :

$$u_{*cw} = \sqrt{u_{*w}^2 + u_{*c}^2}$$

- Wave-current induced bottom shear stess:

$$\tau_{cw} = \rho u_{*cw}^2 = \rho(u_{*w}^2 + u_{*c}^2)$$

wave friction factor f_w

- Empirical expression, Grant and Madsen ,1982

$$f_w = \begin{cases} 0.13\left(k_b / A_b\right)^{0.40} & k_b / A_b < 0.08 \\ 0.23\left(k_b / A_b\right)^{0.62} & 0.08 < k_b / A_b < 1.00 \\ 0.23 & k_b / A_b > 1.00 \end{cases}$$

$A_b = u_w / \omega$, Where u_w is wave obital velocity

$k_b = 30 z_0$, Where z_0 is roughness length, 0.001 here

Current induced shear stress τ_c

$$\tau_c = \rho u_{*c}^2 = \rho C_d u_c^2 = \frac{1}{2}\rho f_c u_c^2$$

$$u_{*c} = \left(\frac{\tau_c}{\rho}\right)^{1/2}$$

$$f_c = \frac{1}{2} C_{de} = \left[\frac{\kappa}{\ln\left(30 z_r / k_{bc}\right)}\right]^2$$ current friction factor

$$u_{*c} = \sqrt{\frac{f_c}{2}} \cdot u_c$$ current friction velocity

- The combined friction velocity :

$$u_{*cw} = \sqrt{u_{*w}^2 + u_{*c}^2}$$

- Wave-current induced bottom shear stess:

$$\tau_{cw} = \rho u_{*cw}^2 = \rho(u_{*w}^2 + u_{*c}^2)$$

Cohesive Sediments

- Resuspension, Gailani et al. (1991)

$$\varepsilon = \frac{a_0}{T_d^m}\left(\frac{\tau_b - \tau_c}{\tau_c}\right)^n$$

- ε= resuspension potential (mg /cm^2);
- a_0= constant depending upon the bed properties;
- T_d = time after deposition (days);
- τ_b= bed shear stress (dynes/ cm^2);
- τ_c= critical shear stress for erosion (dynes / cm^2);
- m, n = constants dependent upon the depositional environment.

- Deposition, Krone (1962)

$$D_1 = -W_{s,1} C_1 P_1$$

- D_1 = depositional flux (g /cm^2/ s);
- $W_{s,1}$ = settling velocity of the cohesive sediment flocs (cm /s);
- C_1 = cohesive suspended sediment concentration (g /cm$^{3)}$
- P_1 = probability of deposition.

- Settling speeds of cohesive flocs:

$$W_{s,1} = \alpha \left(C_1 G \right)^{\beta}$$

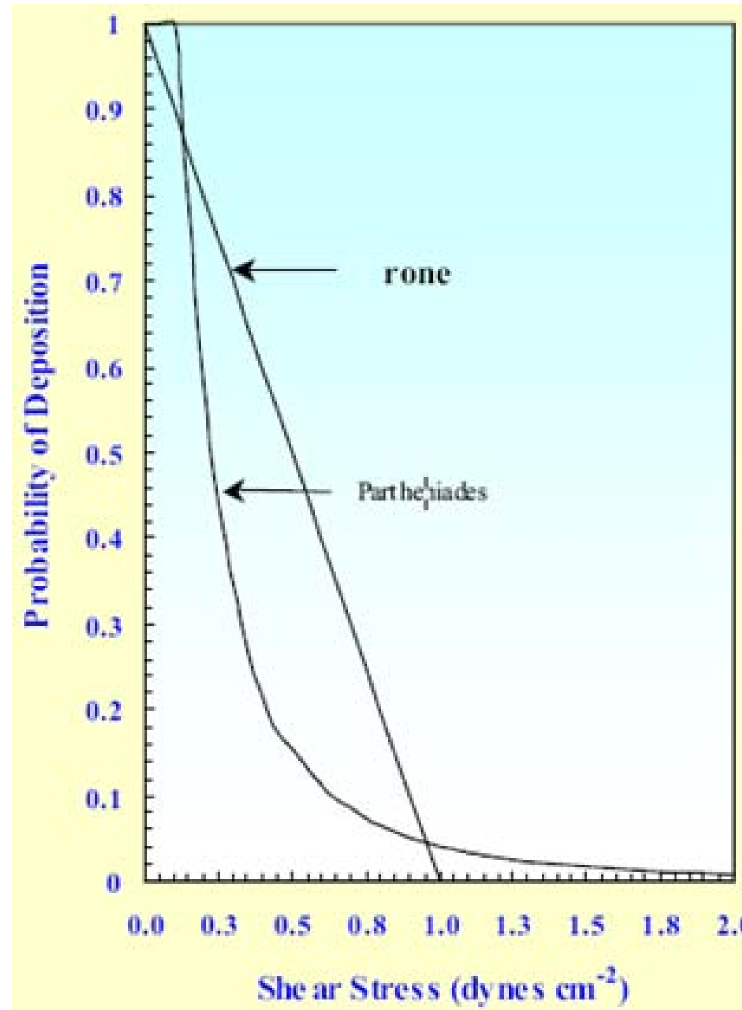
- water column shear stress:

$$G = \rho K_M \left[\left(\frac{\partial u}{\partial z} \right)^2 + \left(\frac{\partial v}{\partial z} \right)^2 \right]^{1/2}$$

- the probability of deposition:

$$P_1 = \begin{cases} 1 - \dfrac{\tau_b}{\tau_d}, & \tau_b \le \tau_d \\ 0, & \tau_b > \tau_d \end{cases}$$

(Krone (1962) formulations.)



Cohesive Sediment Bed Model

- the sediment bed is discretized into seven layers. Each layer of the bed is characterized by a dry density (D_d), a critical shear stress for erosion (τ_{cr}), and an initial thickness.
- The "time after deposition" for each layer increases linearly from one day at the surface, which is composed of freshly deposited material, to seven days in the bottom layer.