Sino-Australian Research Centre for Coastal Management
中澳海岸带管理研究中心

Never Stand Still

Effects of wave-current interaction in suspended-sediment dynamics during strong wave events

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"If I have seen further than others, it is by standing upon the shoulders of giants." - Sir Isaac Newton

One on-going topic since 1st IWMO2009 - ***Waves, Currents and Turbulence***

with the keynote speaker by Prof George Mellor

1st IWMO2009 Taipei Taiwan:

The Depth Dependent Current and Wave Interaction Equations

2nd IWMO2010 Norfolk USA:

Wave Radiation Stress

4th IWMO2012 Yokohama Japan:

Waves Circulation and Vertical Dependence

5th IWMO2013 Bergen Norway:

Surface Boundary Layers and Gravity Waves

6th IWMO2014 Halifax Canada:

A combined derivation of the integral and differential, coupled wave-current equations

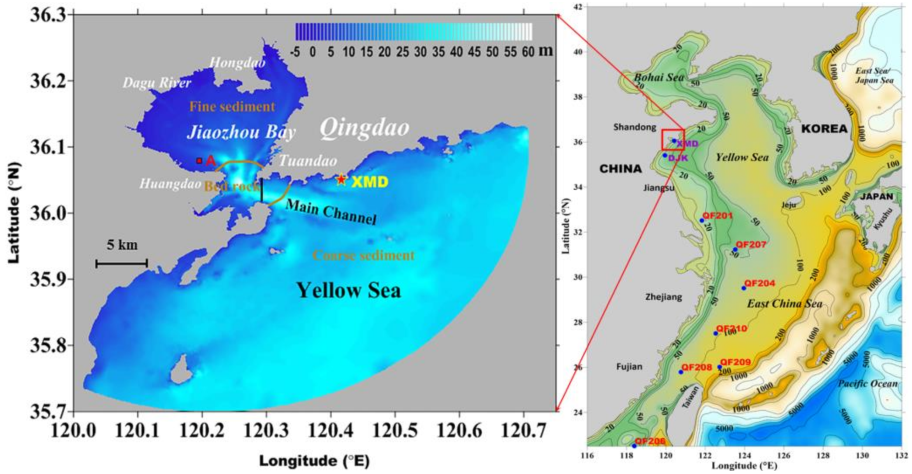
8th IWMO2016 Bologna Italy (Skype):

Waves Currents and Turbulence

10th IWMO2018 Santos Brazil:

On the two components of wind-driven ocean surface stress

Jiaozhou Bay, Qingdao, China



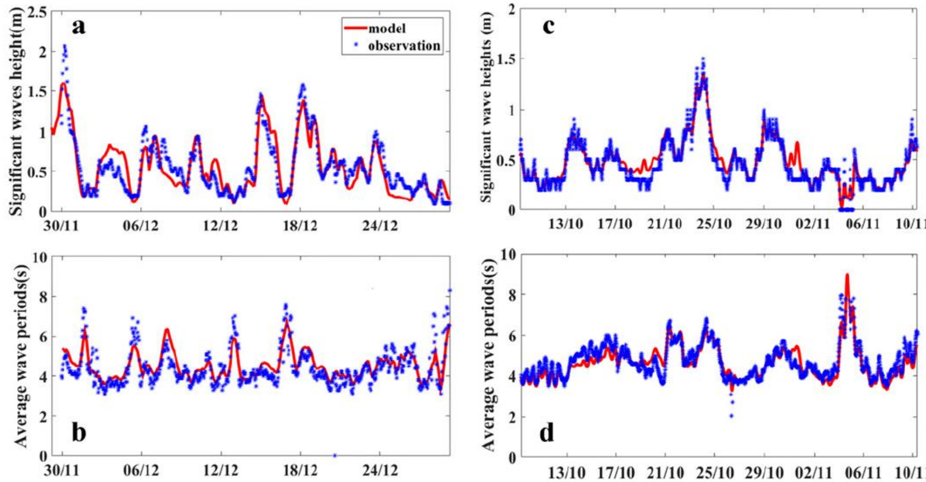


FIG. 7. Comparison of observed and modeled significant wave heights and averaged wave periods at stations (a),(b) DJK and (c),(d) XMD.

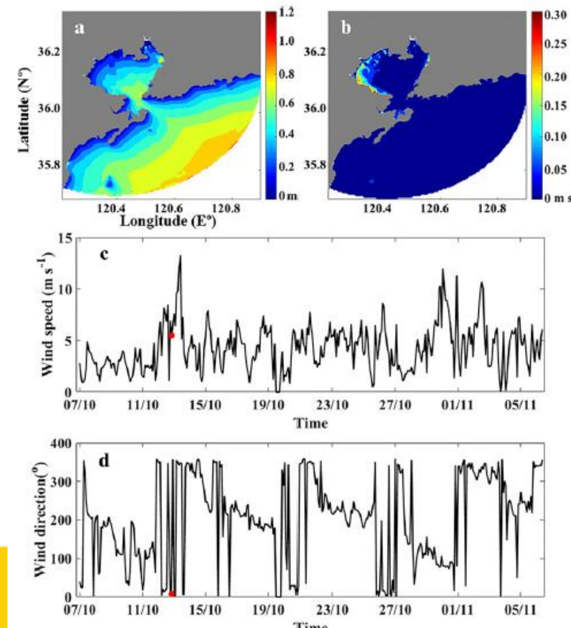
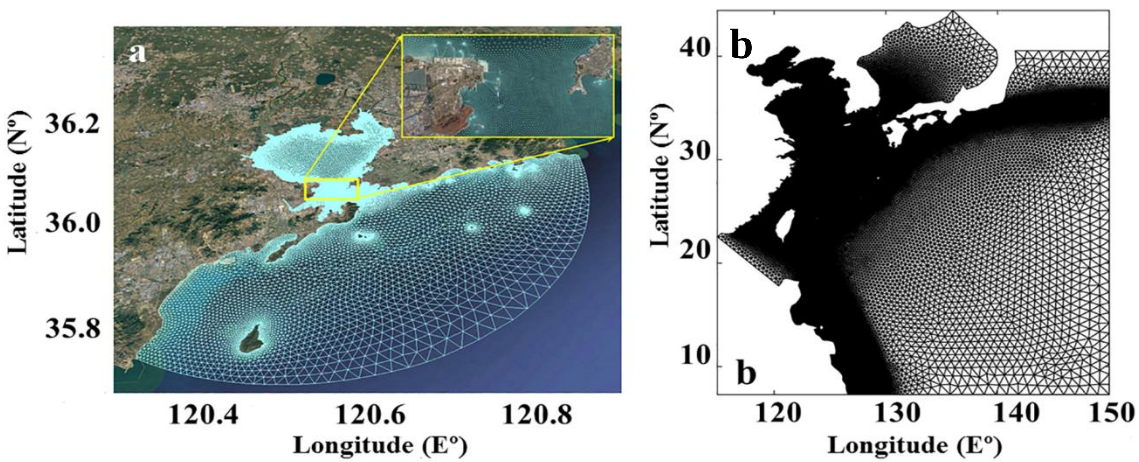


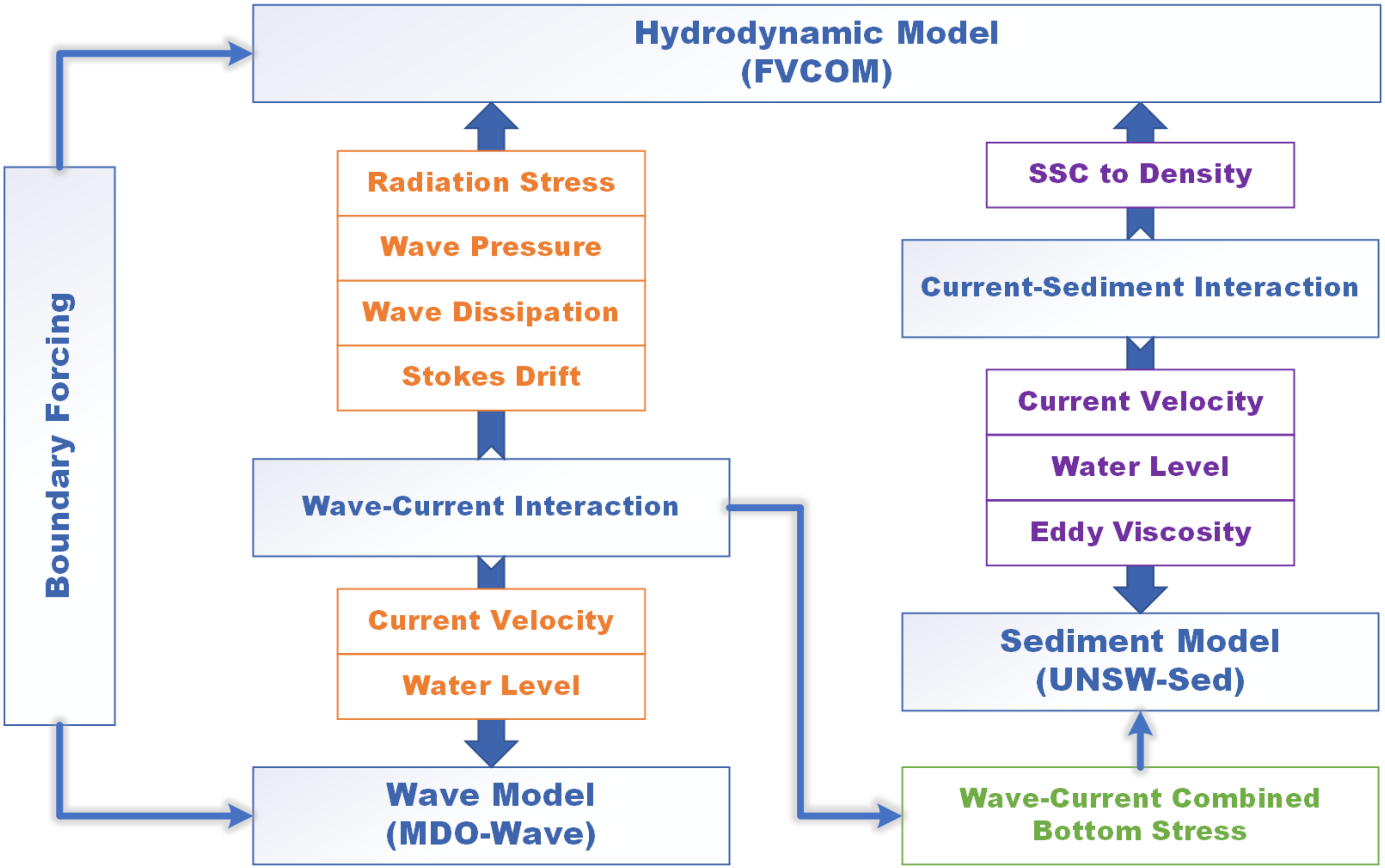
FIG. 2. Snapshot of (a) significant wave heights and (b) wave orbital velocities near the bottom in a cold-front wave event (0130 UTC 13 Oct 2014) in JZB. Time series of (c) wind speeds and (d) directions observed at station XMD. Red dots indicate the time of 0130 UTC 13 Oct 2014.



Mathematical expression of wave-current interaction terms

Term	Mathematical expression
Combined wave-current bottom stress	$\overrightarrow{\tau_{wc}} = \overrightarrow{\tau_c} + \overrightarrow{\tau_{wm}}$
Wave dissipation	$\dfrac{\partial q^2}{\partial z} = \dfrac{2\alpha_{CB} u_{\tau s}^3}{K_q}$; $l = \max(\kappa z_w, lz)$ at $z=\zeta(x,y,t)$
form drag	$(\tau_{px}, \tau_{py}) = (\dfrac{1}{2\pi}\int_0^{2\pi} P_{w0} \sin\phi \dfrac{\partial \eta}{\partial x_\alpha})\dfrac{\cosh 2kD(1+\gamma)}{\sinh 2kD}$
Wave radiation stress	$R_x = -D(\dfrac{\partial S_{xx}(\gamma)}{\partial x} + \dfrac{\partial S_{xy}(\gamma)}{\partial y}) + \Im(\dfrac{\partial D}{\partial x}\dfrac{\partial S_{xx}}{\partial \gamma} + \dfrac{\partial D}{\partial y}\dfrac{\partial S_{xy}}{\partial \gamma})$, $R_y = -D(\dfrac{\partial S_{yx}(\gamma)}{\partial x} + \dfrac{\partial S_{yy}(\gamma)}{\partial y}) + \Im(\dfrac{\partial D}{\partial x}\dfrac{\partial S_{yx}}{\partial \gamma} + \dfrac{\partial D}{\partial y}\dfrac{\partial S_{yy}}{\partial \gamma})$
Mean current advection and refraction of wave energy by currents	$\dfrac{\partial E_\theta}{\partial t} + \dfrac{\partial}{\partial x_\alpha}[(\overline{c_{g\alpha}} + \overline{u_{A\alpha}})E_\theta] + \dfrac{\partial}{\partial \theta}(\overline{c_\theta} E_\theta) + \int_{-1}^{0} \overline{S_{\alpha\beta}} \dfrac{\partial U_\alpha}{\partial x_\beta} D d\gamma = S_{\theta in} - S_{\theta Sdis} - S_{\theta Bdis}$ Note that currents are involved in the second to the third terms in the left hand side

Flow chart of the coupled wave-current-sediment model



Numerical experiments

Simulation	Description
1	Current only
2	Simulation 1 plus combined wave-current bottom stress
3	Simulation 1 plus wave dissipation
4	Simulation 1 plus form drag
5	Simulation 1 plus wave radiation stress
6	Simulation 1 with all wave-current interaction mechanisms. except mean current advection of wave energy
7	Simulation 1 with all wave-current interaction mechanisms. except mean current refraction of wave energy.
8	Simulation 1 with all wave-current interaction mechanisms.

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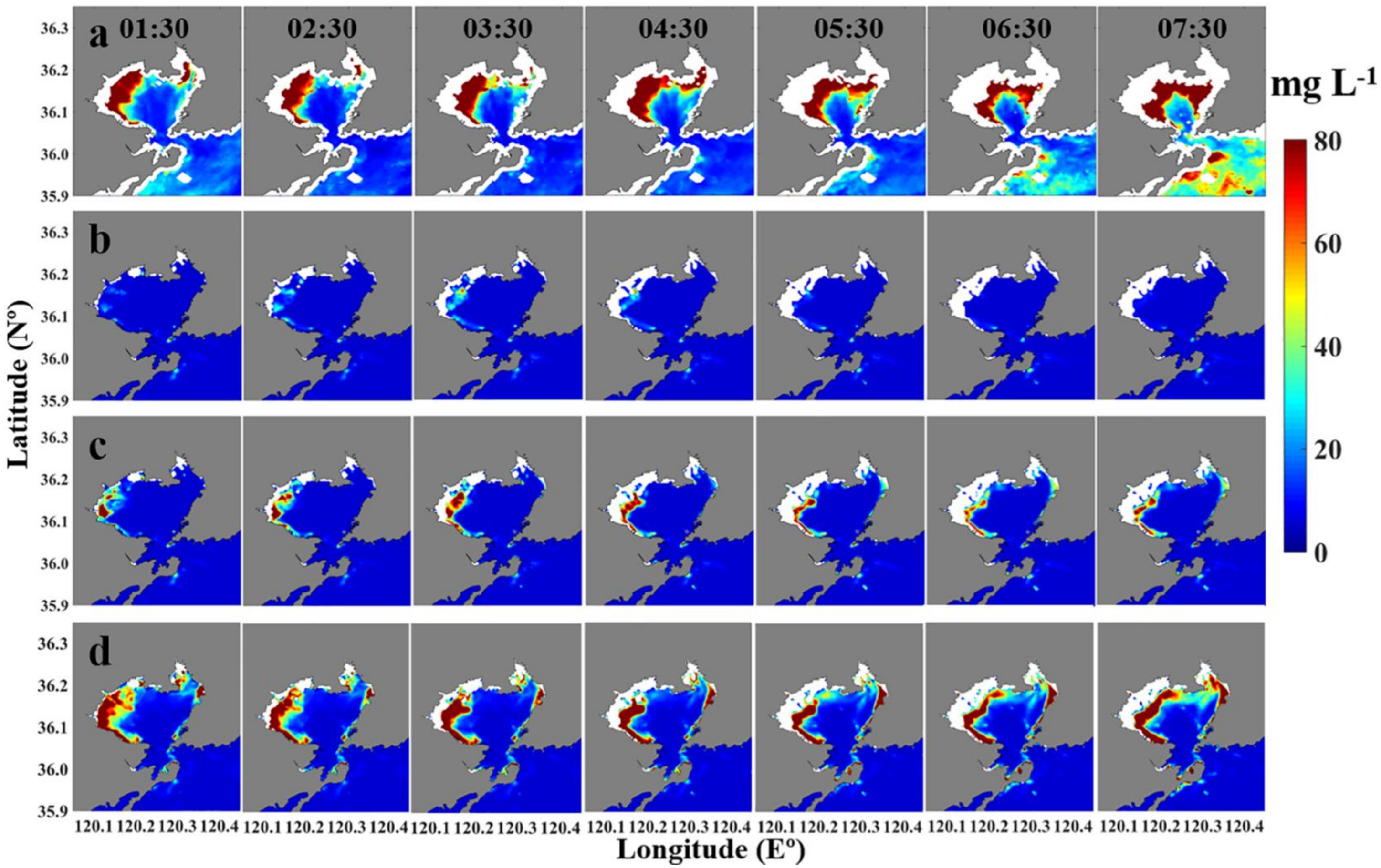
Surface suspended-sediment concentrations (SSC) from 01:30 to 07:30 on 13/10/2014 UTC



a GOCI-derived results
b Simulation 1 results; no waves
c Simulation 2 results; only combined wave-current bottom stress is considered
d Simulation 8 results; all the wave-current interaction mechanisms are considered

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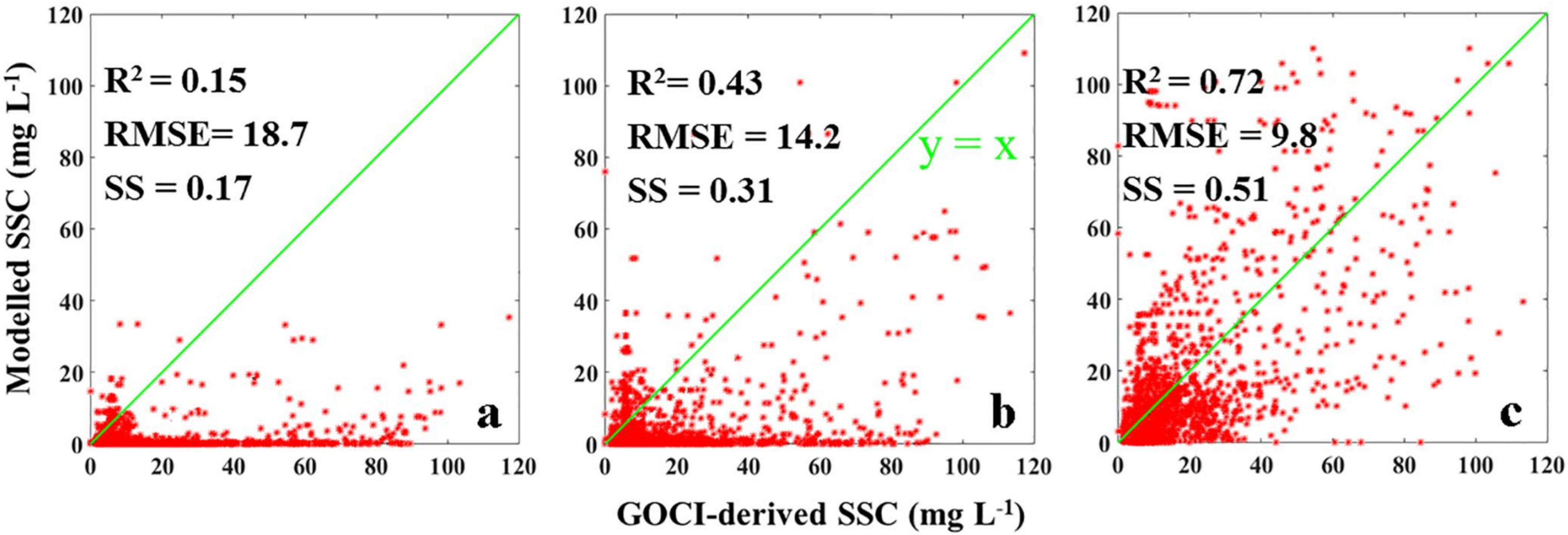
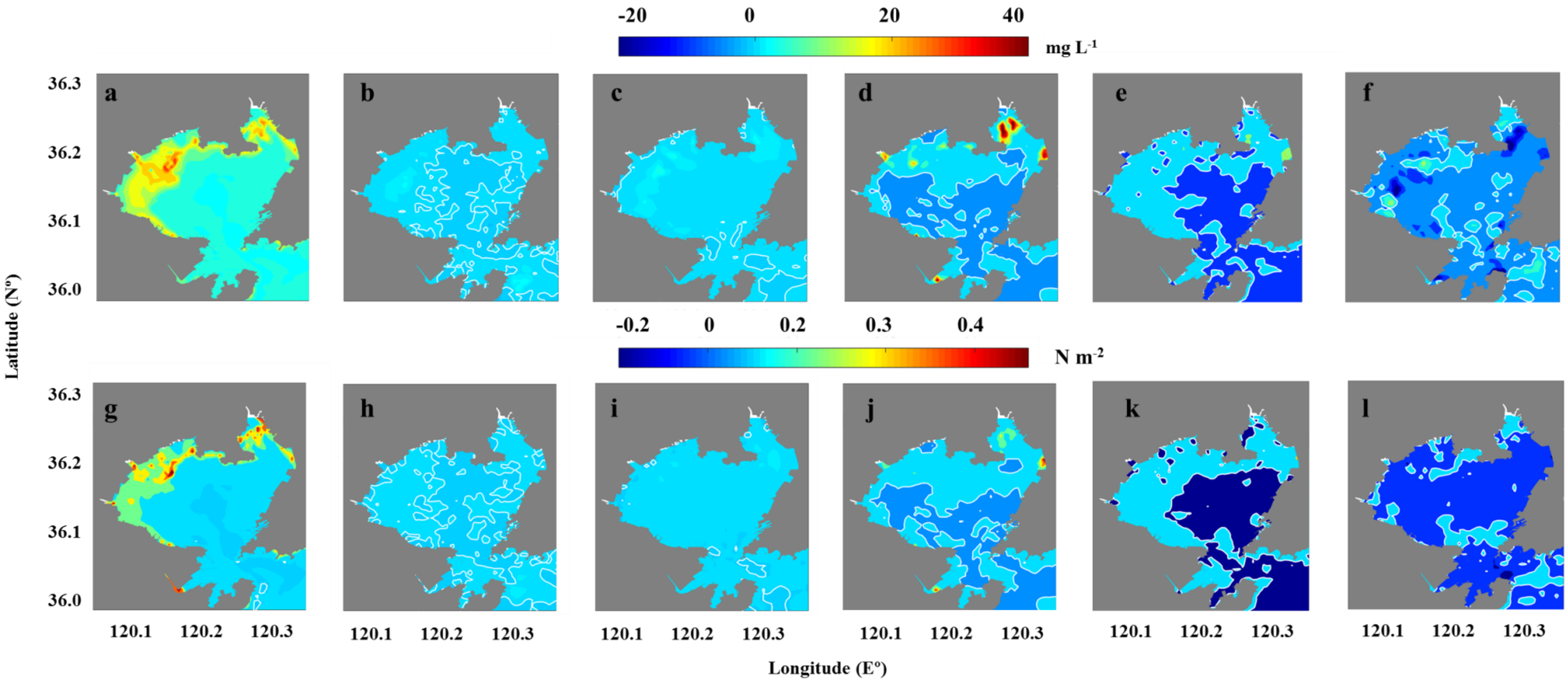
Scatterplots of the GOCI-derived SSC and the modelled SSC in (a) Simulation 1, (b) Simulation 2 and (c) Simulation 8, respectively.



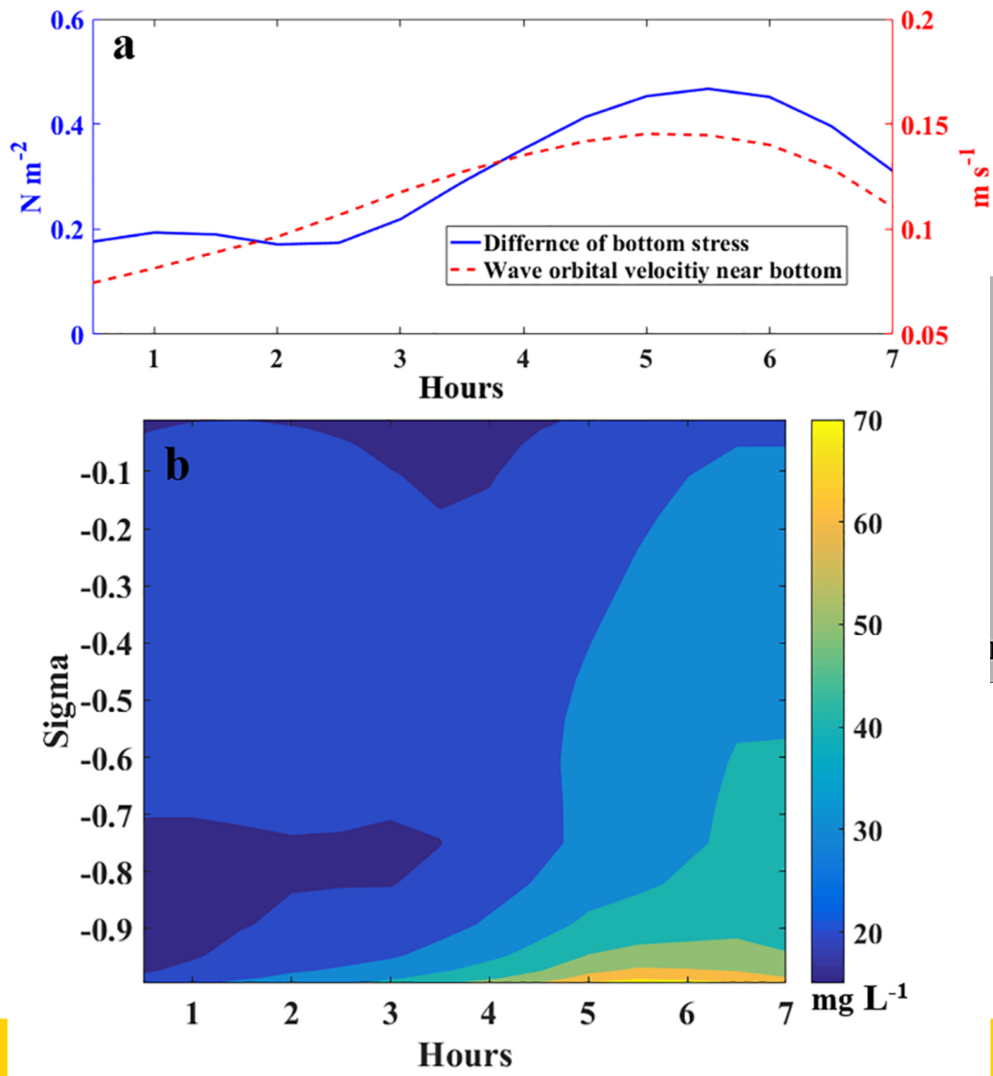
a Simulation 1 results; no waves
b Simulation 2 results; only combined wave-current bottom stress is considered
c Simulation 8 results; all the wave-current interaction mechanisms are considered

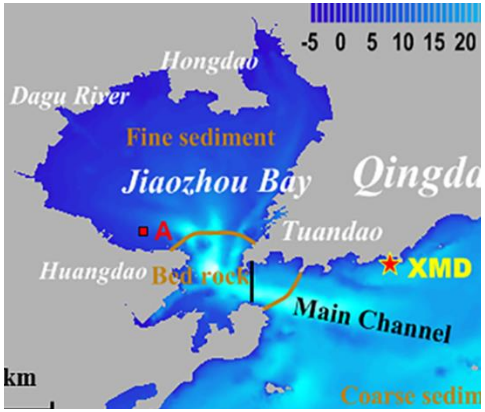
Differences in the monthly and depth-averaged SSC and in the monthly-averaged bottom stress caused by each wave-current interaction mechanism



a, g combined wave-current interaction bottom stress ; **b, h** wave dissipation
c, i form drag ; **d, j** wave radiation stress
e, k mean current advection of wave energy ; **f, i** mean current refraction of wave energy

Combined wave-current bottom stress





$$\overrightarrow{\tau_{wc}} = \overrightarrow{\tau_c} + \overrightarrow{\tau_{wm}}$$

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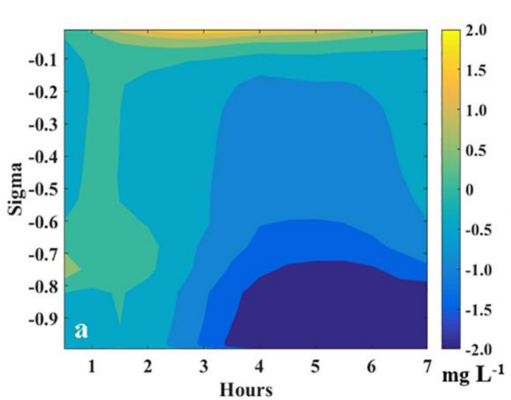
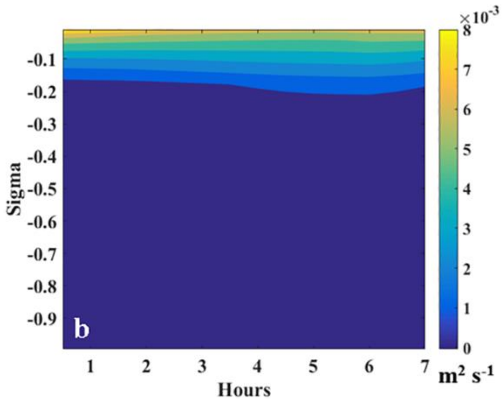
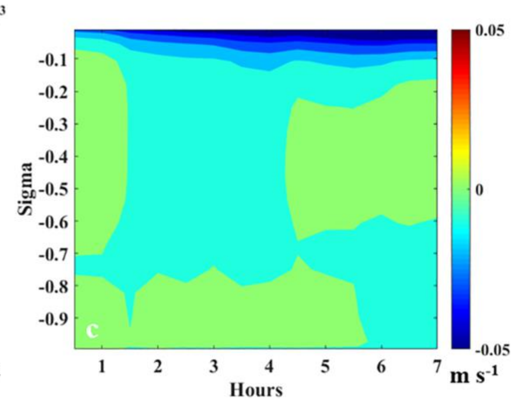
Wave dissipation



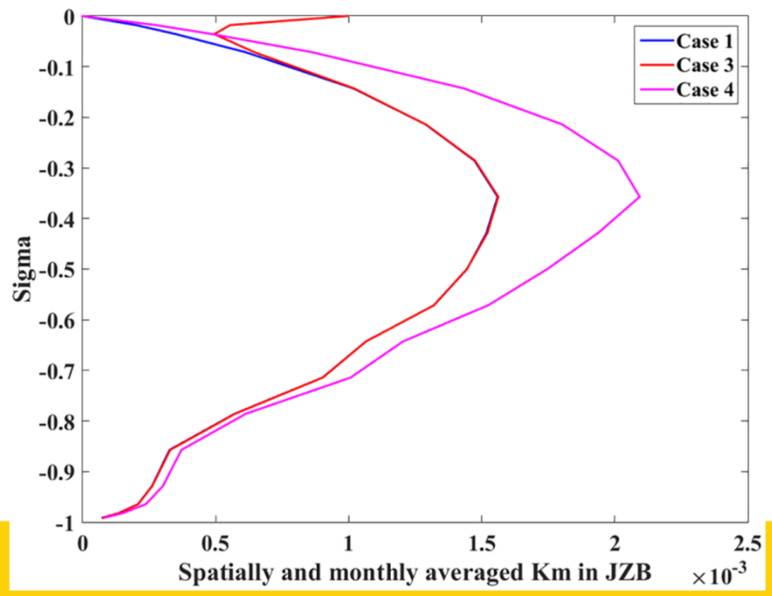
SSC



vertical eddy viscosity



current velocity



Case 1 no waves

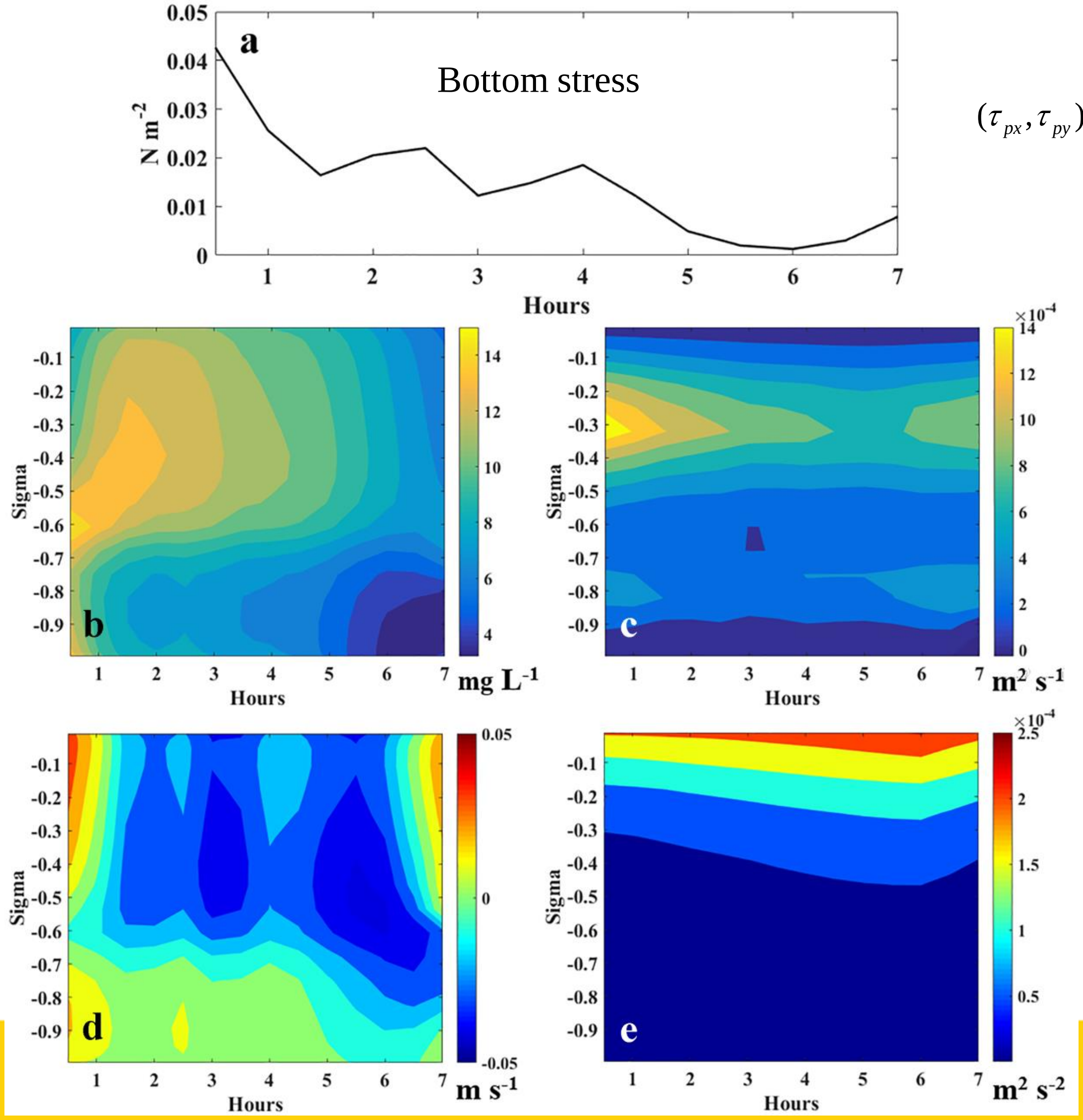
Case 3 wave dissipation added

Case 4 form drag added

$$\frac{\partial q^2}{\partial z} = \frac{2\alpha_{CB} u_{\tau s}^3}{K_q};\ l = \max(\kappa z_w, lz) \text{ at } z = \zeta(x, y, t)$$

Form drag (wave-generated pressure stress)

$$(\tau_{px},\tau_{py}) = \left(\frac{1}{2\pi}\int_0^{2\pi} P_{w0}\sin\phi\,\frac{\partial\eta}{\partial x_\alpha}\right)\frac{\cosh 2kD(1+\gamma)}{\sinh 2kD}$$



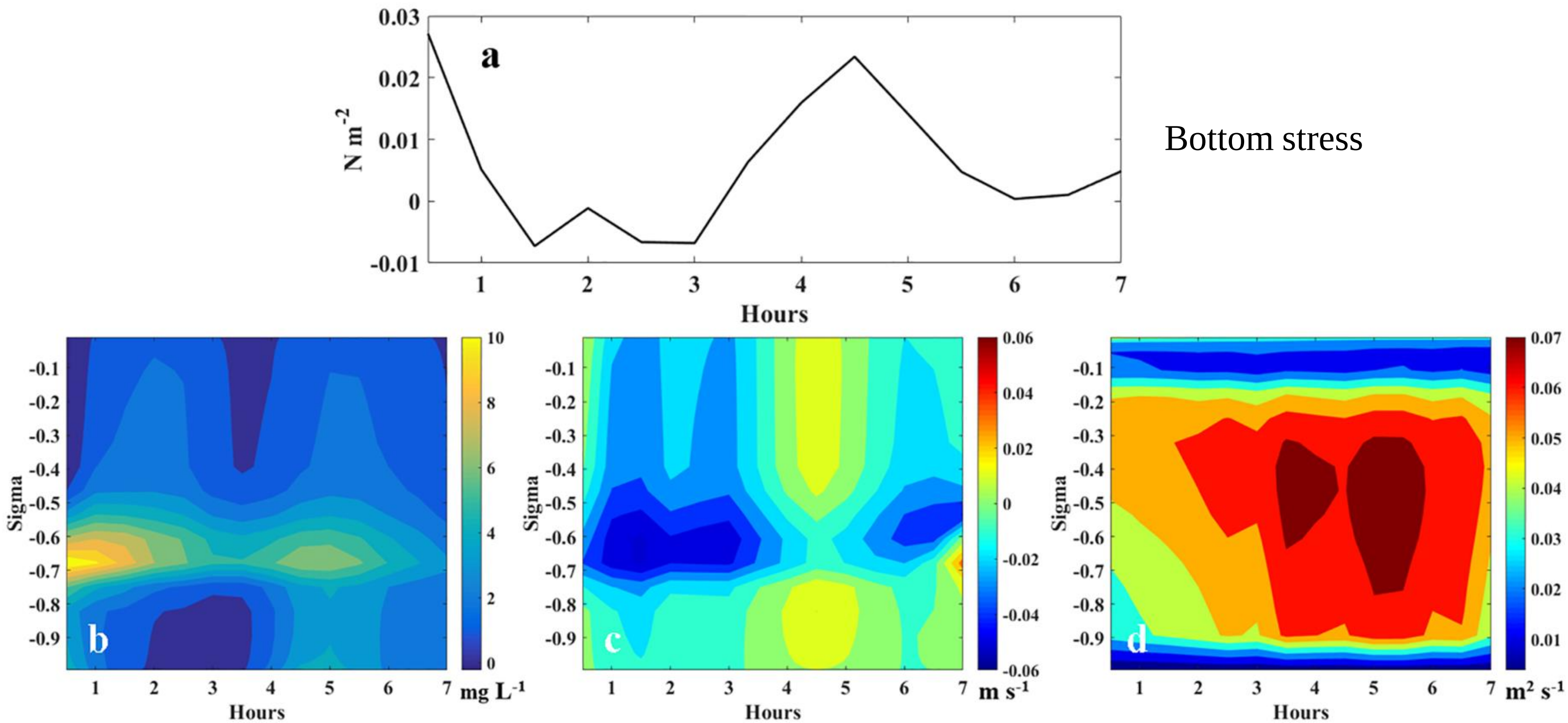
SSC

Vertical eddy viscosity

Current velocity

Magnitudes of form drag

Wave radiation stress



Bottom stress

SSC

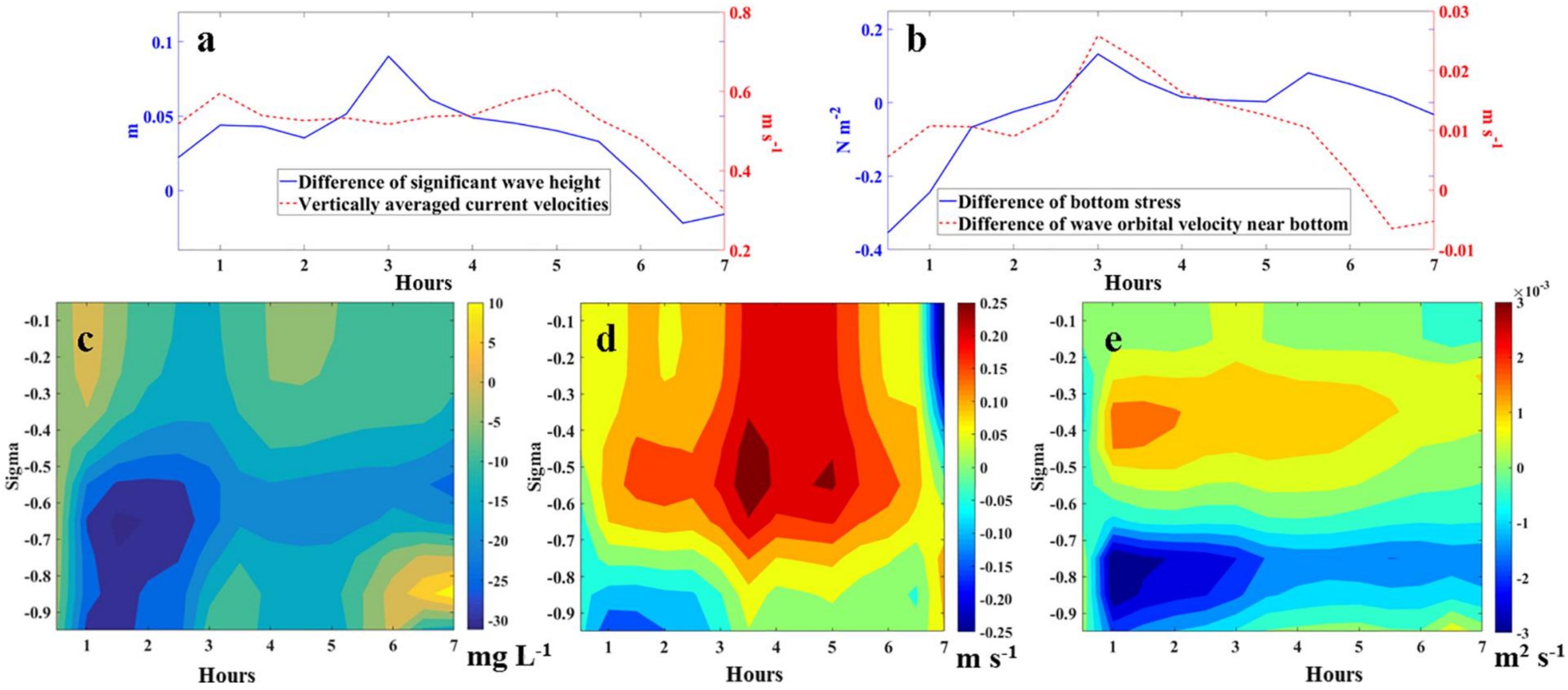
Current velocity

Magnitudes of wave radiation stress

$$R_x = -D\left(\frac{\partial S_{xx}(\gamma)}{\partial x} + \frac{\partial S_{xy}(\gamma)}{\partial y}\right) + \Im\left(\frac{\partial D}{\partial x}\frac{\partial S_{xx}}{\partial \gamma} + \frac{\partial D}{\partial y}\frac{\partial S_{xy}}{\partial \gamma}\right),$$

$$R_y = -D\left(\frac{\partial S_{yx}(\gamma)}{\partial x} + \frac{\partial S_{yy}(\gamma)}{\partial y}\right) + \Im\left(\frac{\partial D}{\partial x}\frac{\partial S_{yx}}{\partial \gamma} + \frac{\partial D}{\partial y}\frac{\partial S_{yy}}{\partial \gamma}\right)$$

Mean current advection of wave energy



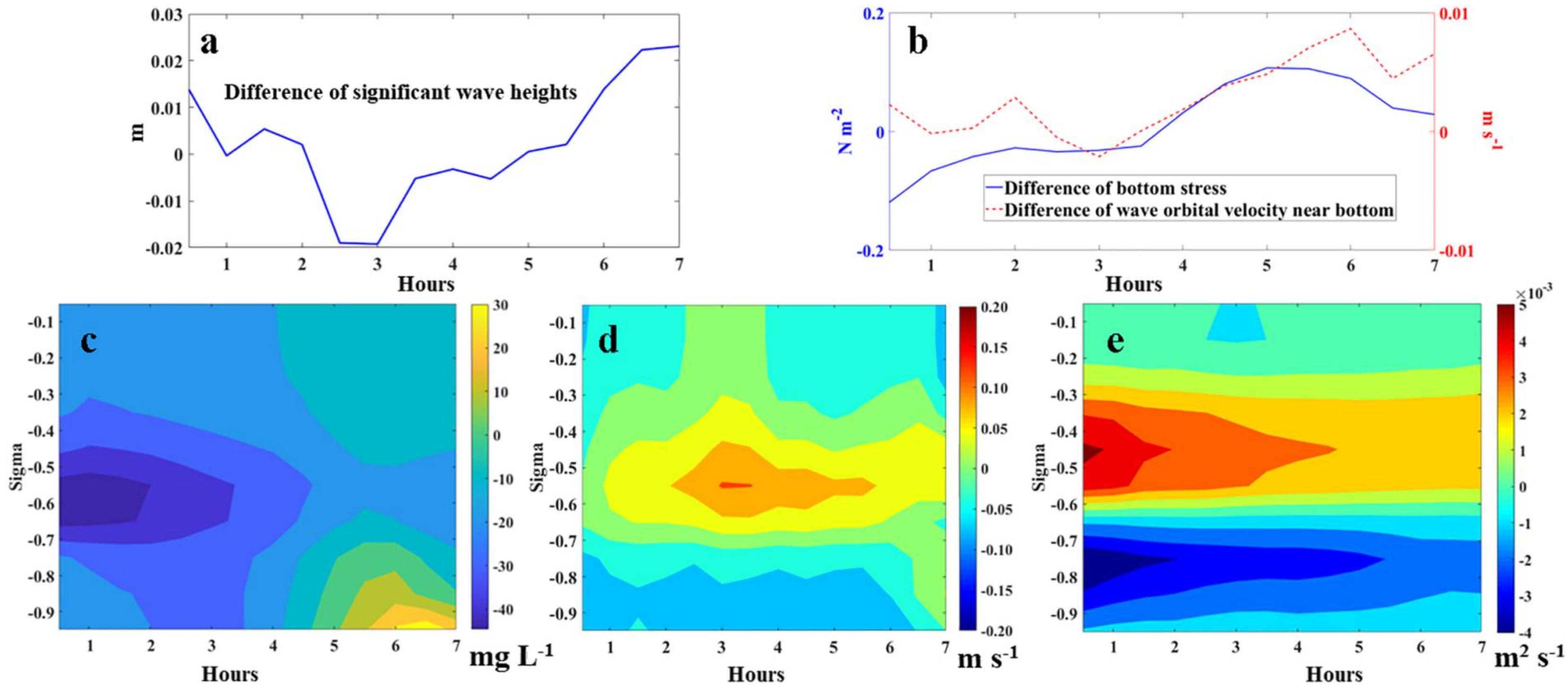
SSC

Current velocity

Vertical eddy viscosity

$$\frac{\partial E_\theta}{\partial t} + \frac{\partial}{\partial x_\alpha}[(\overline{c_{g\alpha}} + \overline{u_{A\alpha}})E_\theta] + \frac{\partial}{\partial \theta}(\overline{c_\theta} E_\theta) + \int_{-1}^{0} \overline{S_{\alpha\beta}} \frac{\partial U_\alpha}{\partial x_\beta} D d\gamma$$
$$= S_{\theta in} - S_{\theta Sdis} - S_{\theta Bdis}$$

Mean current refraction of wave energy



SSC

Current velocity

Vertical eddy viscosity

$$\frac{\partial E_\theta}{\partial t}+\frac{\partial}{\partial x_\alpha}[(\overline{c_{g\alpha}}+\overline{u_{A\alpha}})E_\theta]+\frac{\partial}{\partial \theta}(\overline{c}_\theta E_\theta)+\int_{-1}^{0}\overline{S_{\alpha\beta}}\frac{\partial U_\alpha}{\partial x_\beta}Dd\gamma$$

$$=S_{\theta in}-S_{\theta Sdis}-S_{\theta Bdis}$$

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Summary and conclusions

- **Sole addition of combined wave-current bottom stress into the model in the previous studies was far from realistic modelling**
- **The other wave-current interaction processes such as wave radiation stress, mean current advection and refraction of wave energy, form drag can also make equally significant contributions to the suspended-sediment dynamics**
- **Even though the combined wave–current bottom stress has the largest effect, the combined effect of the other wave–current interactions, mean current advection and refraction of wave energy, wave radiation stress, and form drag (from largest to smallest effect) are comparable**
- **All the wave-current interaction terms are affecting the bottom stress and consequently the SSC**

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