The Upwelling System in the East China Sea in summer and winter

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- Introduction
- Observation
- Numerical experiments
- Conclusions

Introduction 1. Summer **Existence** (Yes) and mechanism (wind-induced/ **Tide-induced**) 2. Winter **Existence** (?) and mechanism (??)



Mechanisms remain unclear

- Yangtze River Estuary (YRE) upwelling
 - Zhao [1993]: Taiwan Warm Current (TWC) intrusion on continental shelf; wind-driven
 - Zhu [2003]: baroclinic effect; TWC intrusion
- Zhejiang coastal upwelling
 - Hu et al. [1980]: TWC intrusion
 - Liu and Su [1991]: wind-driven; TWC intrusion
 - Luo et al. [1998]: barotropic tides

Summer observation



Satellite Image in Summer

SST satellite image



Composite SST satellite image on 8-12 August, 1998.

Winter Obs.

Temperature



DO

Nitrate



Model linkage

- Model domain: Northwest Pacific
- Resolution: 1°/6 × 1°/6, 16 sigma levels in vertical
- Physical processes: wind driving, Yangtze River runoff, heat flux input, open boundary inflows, M2 tide
- Open boundary velocity: interpolated from a global model results of 1°/2 × 1°/2.

MASNUM Coupled Model

Introducing wave mixing

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

into POM [*Qiao et al.*, 2004].

• *Bv* is obtained by running MASNUM wave model (used to be called "LAGFD-WAM").

• Control Test: the basic run of the model including complete physical processes.



The simulated current system of control run is consistent with schematic pattern: the main four factors are YRD, TWC, Tide and Wind

Numerical Experiments

Table. Summary of the Numerical Experiments Schemes

| Exp. | River Discharge | TWC | Wind | Tide |
|---------------------|--------------------|-----|------|------|
| Control Test | Y | Y | Y | Y |
| NoYRD | N | Y | Y | Y |
| NoTWC | Y | Ν | Y | Y |
| NoWind | Y | Y | Ν | Y |
| NoTide | Y | Y | Y | Ν |

Upwelling in Summer

Results — **Control Test**



Upwelling patterns (10⁻⁵ m s⁻¹) superimposed on the color image of temperature (°C).

Results — **Experiments**

• Exp. NoYRD, NoTWC, and NoWind

Despite variations, the basic upwelling patterns are retained.

• Exp. NoTide Upwelling decreases considerably.

Results — **Experiments**



Upwelling comparison between Control Test and Case NoTide

Results — A Key Process: Tidal Mixing



u-w vectors and density distribution along 32.5°N

Results — A Key Process: Tidal Mixing



u-w vectors and density distribution along 31.5°N

Results — How does tidal mixing induce upwelling?

tidal mixing tidal fronts high baroclinicity large pressure gradient near bottom frontal circulation upwelling branch



A schematic of the cross-frontal circulation induced by tidal mixing

Wind effect: downwelling favorable



19 20 21 22 23 24 25 26 27 28 29 30

Numerical results of Case NoW experiment. Left: Distributions of upwelling at 10 m depth, and bottom currents (red arrows, =-0.9). The bottom currents of Control Test are also shown in black arrows for comparison. Right: The longitudinal section along 123°E of *v*-*w* vectors (black arrows), temperature (color filled, °C) and the *u* component differences (*UNoW–Ucontrol*). The thick lines denote 0 and the dashed lines denote negative values. The vertical velocity in (c) is amplified 1000 times.

Wind effect

In the coastal waters near Zhoushan Islands, winds may exert a negative rather than positive influence on upwelling.

(1) Wind—Ekman pumping—Upwelling favorable (+)
(2)Wind—Taiwan Warm Current encroachment – Downwelling favorable (-)
Net: (-)



• Tidal mixing is the primary dynamic factor in inducing the upwelling, while other factors' effects are subsidiary.

- Wind effect is downwelling favorable.
- The above two pionts are totally different from the previous studies.

Upwelling in Winter



Comparison of SST in winter between the (a) model results of the Control Run and (b) historical observation



Comparison of SSS in winter between the (a) model results of the Control Run and (b) historical observation





Low Salinity of YRD plays a key role



Numerical Upwelling results of the Control Run (a) and Exp. EvenS. (b) at 10 m depth (c) Cross section of the density field (ρ -1000, kg m-3) and the *u*-*w* velocity vectors along 29°N of the Control Run.



No Wind: wind is upwelling favorable in winter UL:The surface wind stress **UR:** Simulated upwelling at 10 m depth for NoW DL: current and SSS at 10 m depth DR: *u*-*w* velocity vectors along 29°N 124E



126E

No Taiwan WC: no much difference

UL:The Simulated upwelling UR: current and SSS at 10 m depth DOWN: *u-w* velocity vectors along 29°N No Tide: No much difference

Left: The Simulated upwelling

Right: simulated salinity at 10 m depth



In winter,

- the upwelling off the ECS coast in winter is induced primarily by the strong density (or salinity) front
- wind serves as the main propeller for the southward movement of YRD. The low salinity water will not flow southward without the wind forcing, therefore the effect of wind is upwelling favorable.
- The above two pionts are totally different from the previous studies.

