Respiration and enhanced water acidification in the hypoxic zone off the Changjiang estuary

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Highlights

- Hypoxia zone observed in the subsurface water off Changjiang estuary in August 2011.
- Estimate the roles of the aerobic respiration on hypoxia development.
- Evaluate the water acidification or pH drawdown enhanced by aerobic respiration

Outline

- **Introduction:**

  About coastal hypoxia

  The mechanisms cause hypoxia

  Hypoxia drawdown the pH

- **Study area and methods**
- **Results:**

  Hypoxia zone observed in the subsurface water off Changjiang estuary in August 2011.

  The restoration of the hypoxia in short time scale in summer was observed.

- **Discussions:**

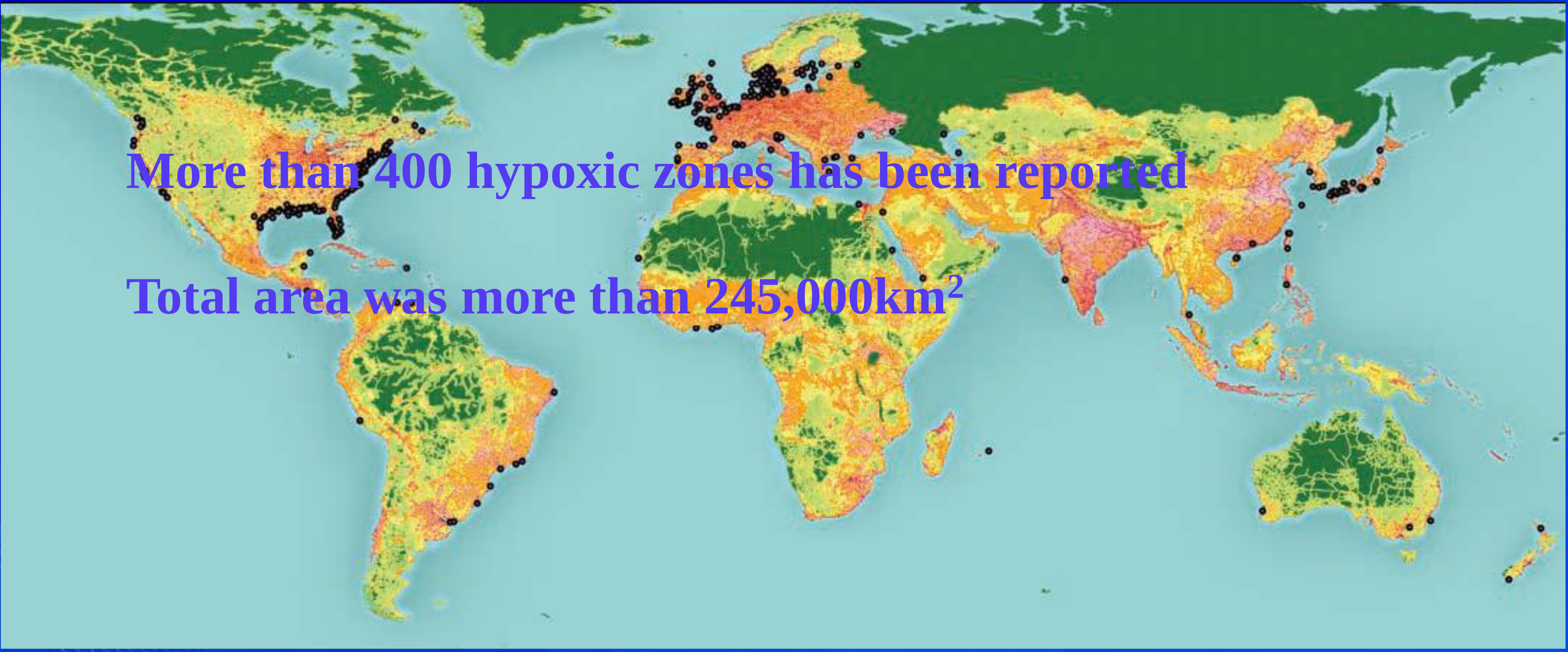
  Roles of aerobic respiration on hypoxia development.

  The role of Taiwan Warm Current on hypoxia formation.

  Aerobic respiration enhance the acidification

- **Conclusions**

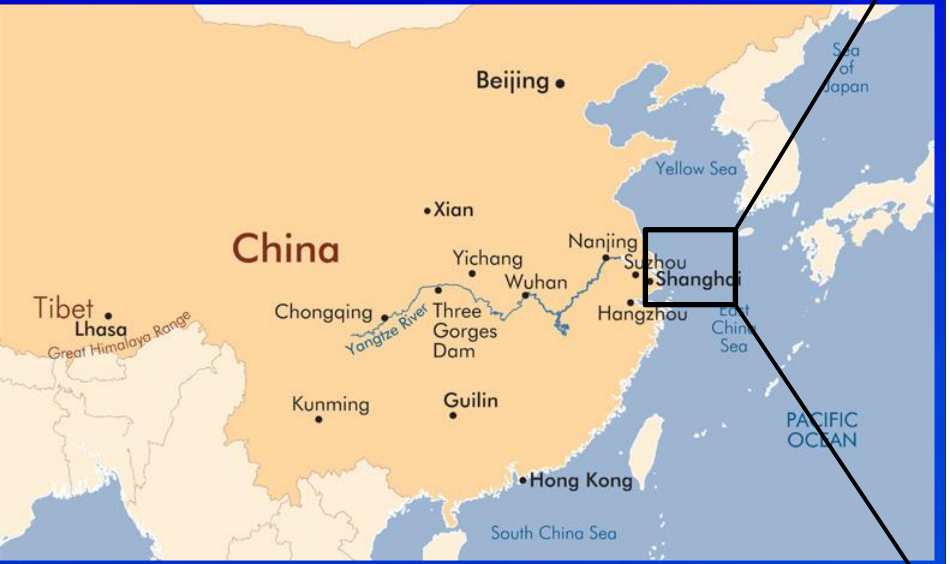
Spreading hypoxia in marine ecosystems

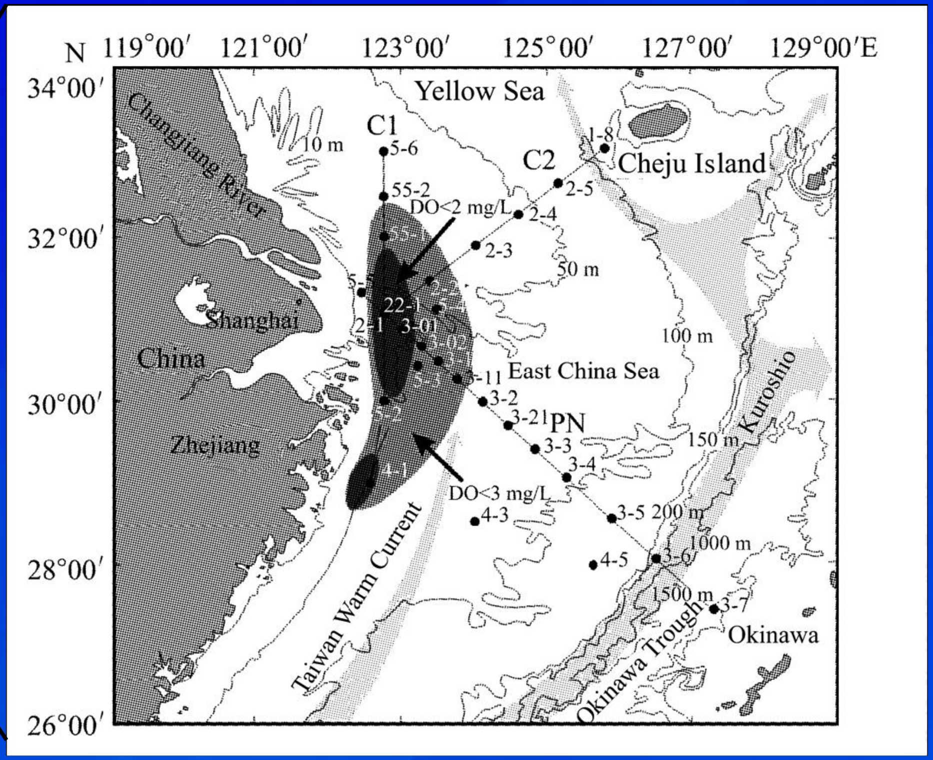


Global distribution of 400-plus systems that have scientifically reported accounts of being eutrophication-associated dead zones. (Díaz & Rosenberg, 2008)

Hypoxia has become a world-wide environmental problem in the global coastal ocean and got more and more attentions in recent decades.

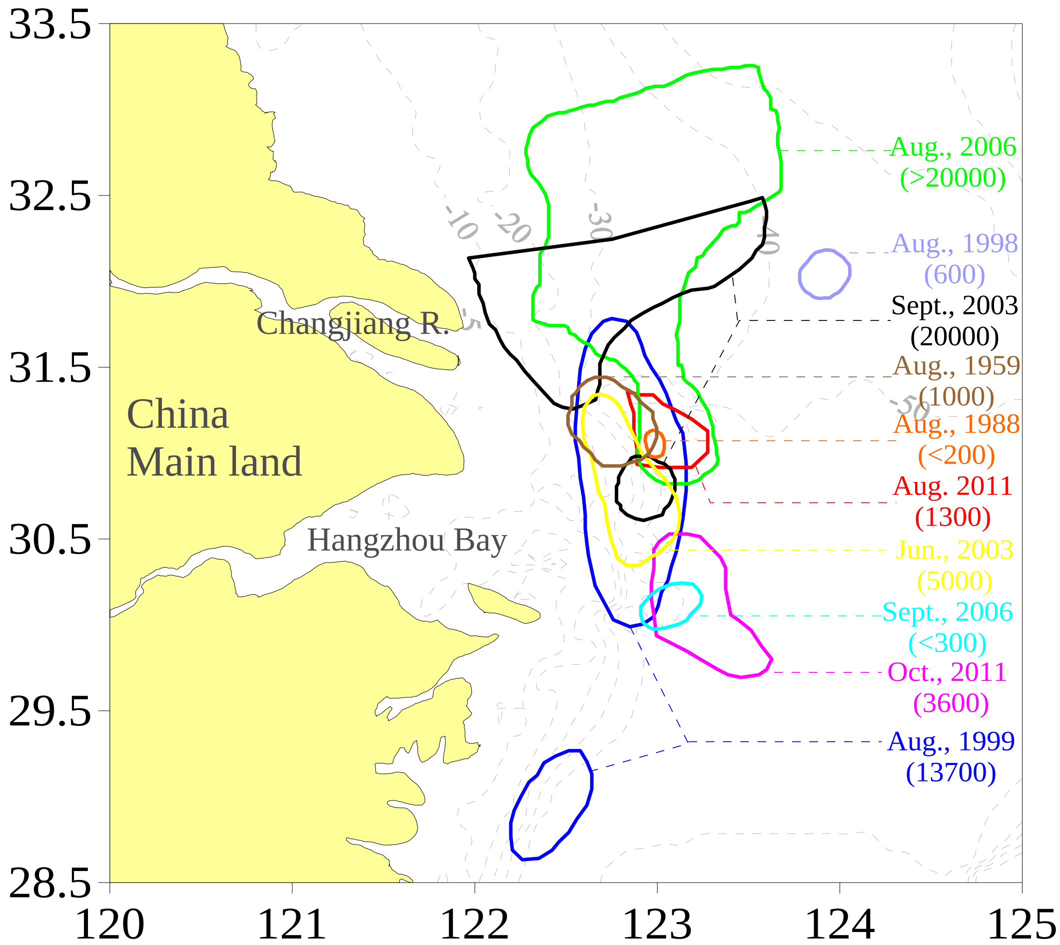
Summer bottom hypoxia off the Changjiang Estuary





The hypoxia area off the Changjiang estuary (Li et al., 2002), the area of hypoxia was more than 13700 km^2

Seasonal hypoxia off the Changjiang estuary!



Bottom hypoxic zones off Changjiang estuary from 1959 to 2011
(Office of Integrated Oceanographic Survey of China, 1961; Tian et al., 1993; Wang and Wang, 2007; Li et al., 2002; Xu, 2005; Wei et al., 2007; Wang, 2009 and this study)

The mechanisms cause hypoxia

DO replenishment $\xleftrightarrow{\text{equilibrium}}$ DO consumption

Two essential conditions for formation of hypoxia :

- Stratification of the water column
- DO consumption by respiration (Li et al., 2002; Chen et al., 2007; Wei et al., 2007; Rabouille et al., 2008; Wang, 2009; Zhu et al., 2011).

Others:

- Geomorphology and water circulation patterns (Wang, 2009)
- Bottom water residence time (Rabouille et al., 2008)
- Temperature (Chen et al., 2007)
- River discharge (Zhu et al., 2011)
- Sediment DO consumption (Cai et al., 2014)

The aerobic respiration mediated pH drawdown

$$(CH_2O)_{106}(NH_3)_{16}H_3PO_4 + 138O_2 \downarrow \rightarrow$$
$$106CO_2 \uparrow + 122H_2O + 16HNO_3 + H_3PO_4$$

$$\updownarrow \quad H_2CO_3$$

$$HCO_3^- + H^+$$

$$\updownarrow \qquad \longrightarrow \qquad pH \quad [CO_3^{2-}] \downarrow$$

$$CO_3^{2-} + H^+$$

The consumption of DO and decline in pH is associated!

Study area off the Changjiang estuary

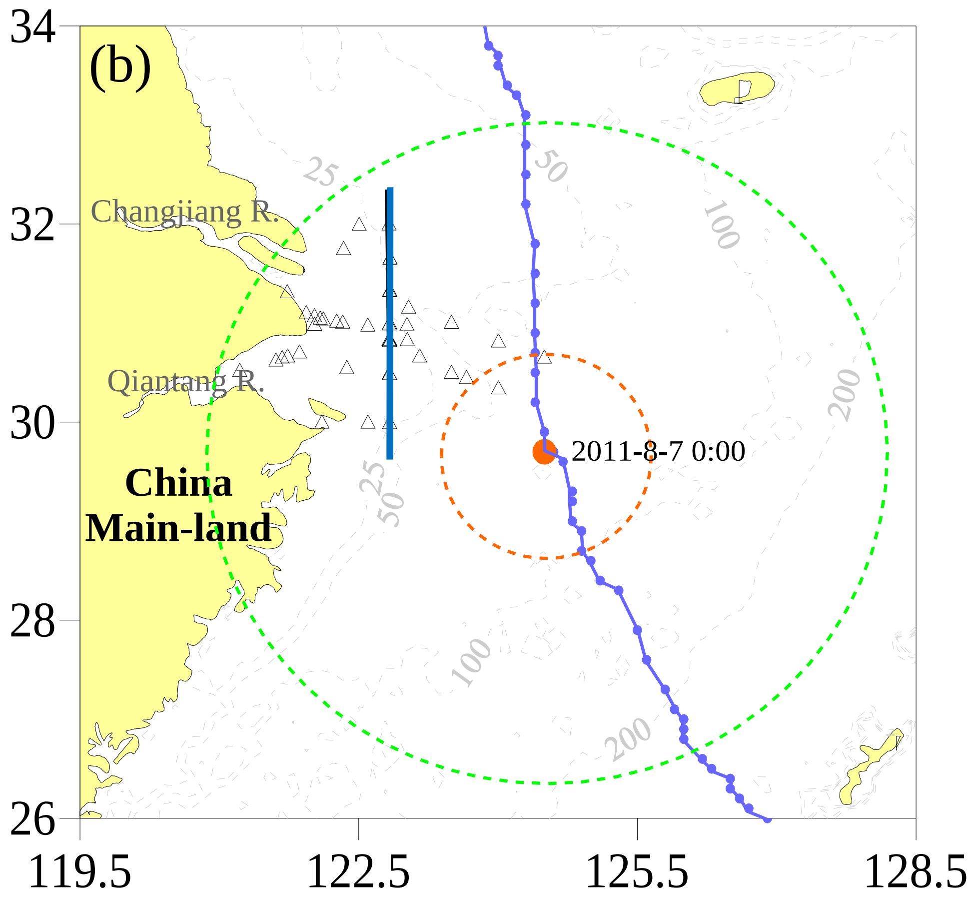
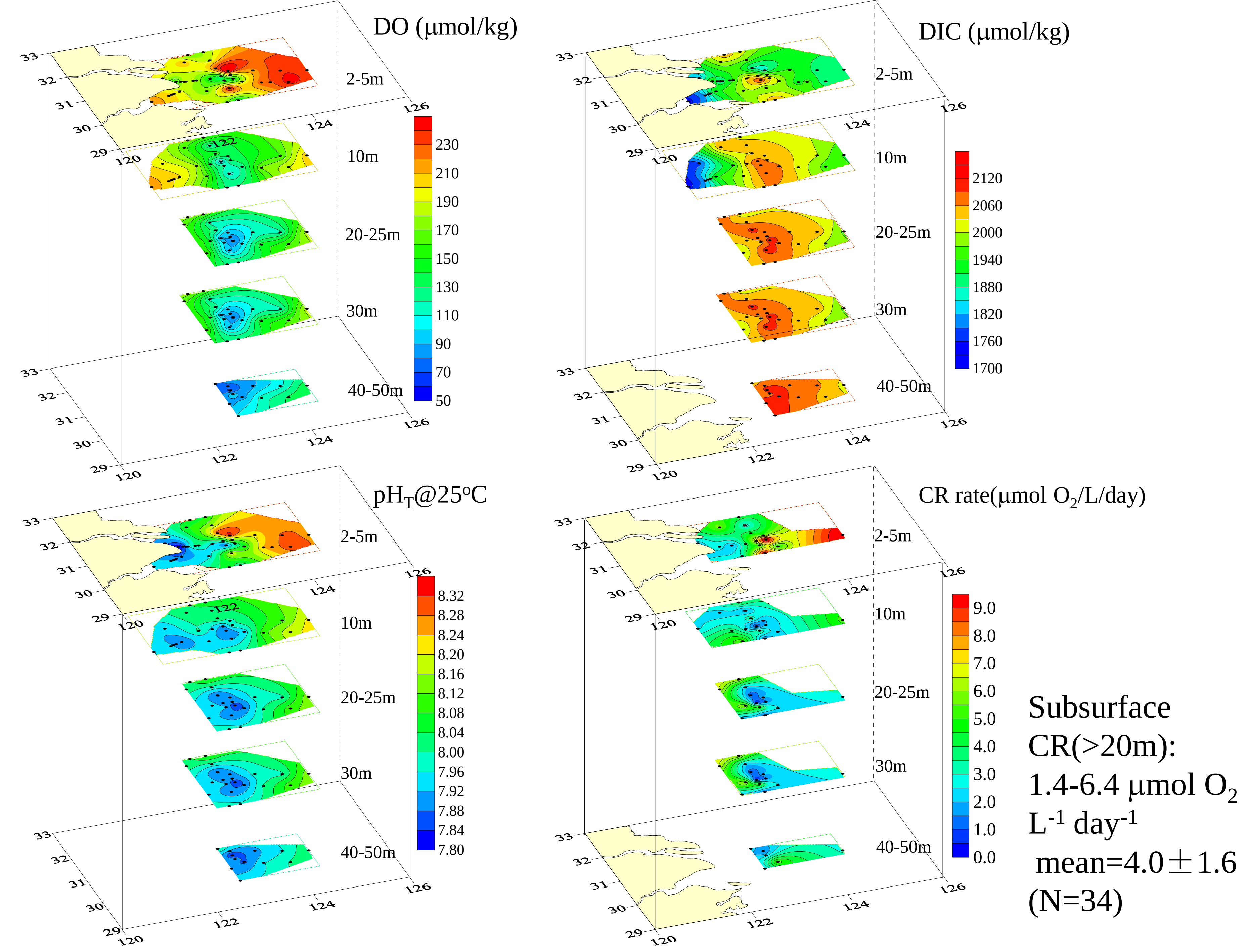
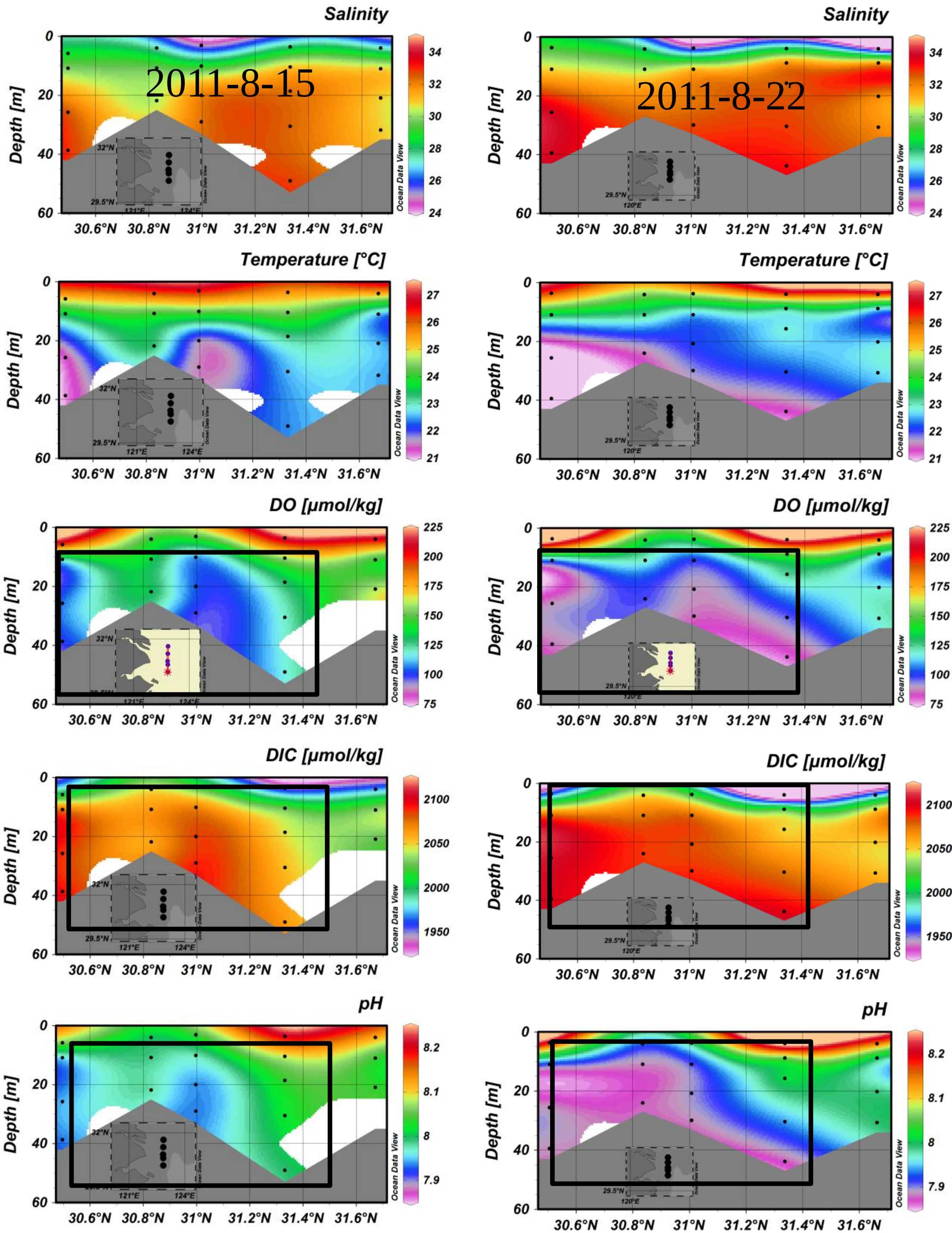


Fig.1 Map of the Changjiang estuary showing the sampling stations in Aug. 2011, The trajectory of the typhoon "Muifa" (light blue line) during 5-7th August 2011 and the sampling locations of the cruise carried out during 15-24th August 2011.

Results:


DO (μmol/kg)
DIC (μmol/kg)
pH$_T$@25°C
CR rate(μmol O$_2$/L/day)
2-5m
10m
20-25m
30m
40-50m
230
210
190
170
150
130
110
90
70
50
2120
2060
2000
1940
1880
1820
1760
1700
8.32
8.28
8.24
8.20
8.16
8.12
8.08
8.04
8.00
7.96
7.92
7.88
7.84
7.80
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
33
32
31
30
29
120
122
124
126
Subsurface
CR(>20m):
1.4-6.4 μmol O$_2$
L^{-1} day^{-1}
mean=4.0±1.6
(N=34)

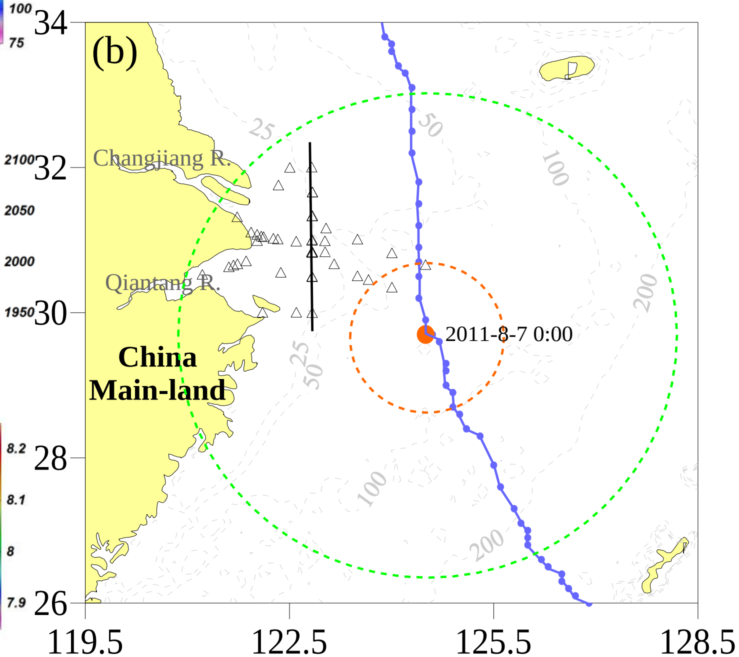


Significant and rapid drawdown in DO and addition in DIC were observed during two repeated surveys along the 123°E transect within a week's interval.

DO: 12.3-57.1 μmol kg^{-1}
(mean= 30.5±18.1, N=9)

DIC: 1.5-48.7 μmol kg^{-1}
(mean=22.6 ±17.3, N=9)

pH: 0-0.16
(mean=0.057±0.059, N=9)



Short summary 1

- Hypoxia zone observed in the subsurface water off Changjiang estuary in August 2011.

- The process of hypoxia formation were observed in August 2011.

- In short time scale, strong events such as typhoon have significant impact on the maintain of hypoxia

Discussions:

- **Roles of aerobic respiration on hypoxia development**

- **The role of Taiwan Warm Current on Hypoxia formation time.**

- **Aerobic respiration enhance the ocean acidification**

Three end member mixing model

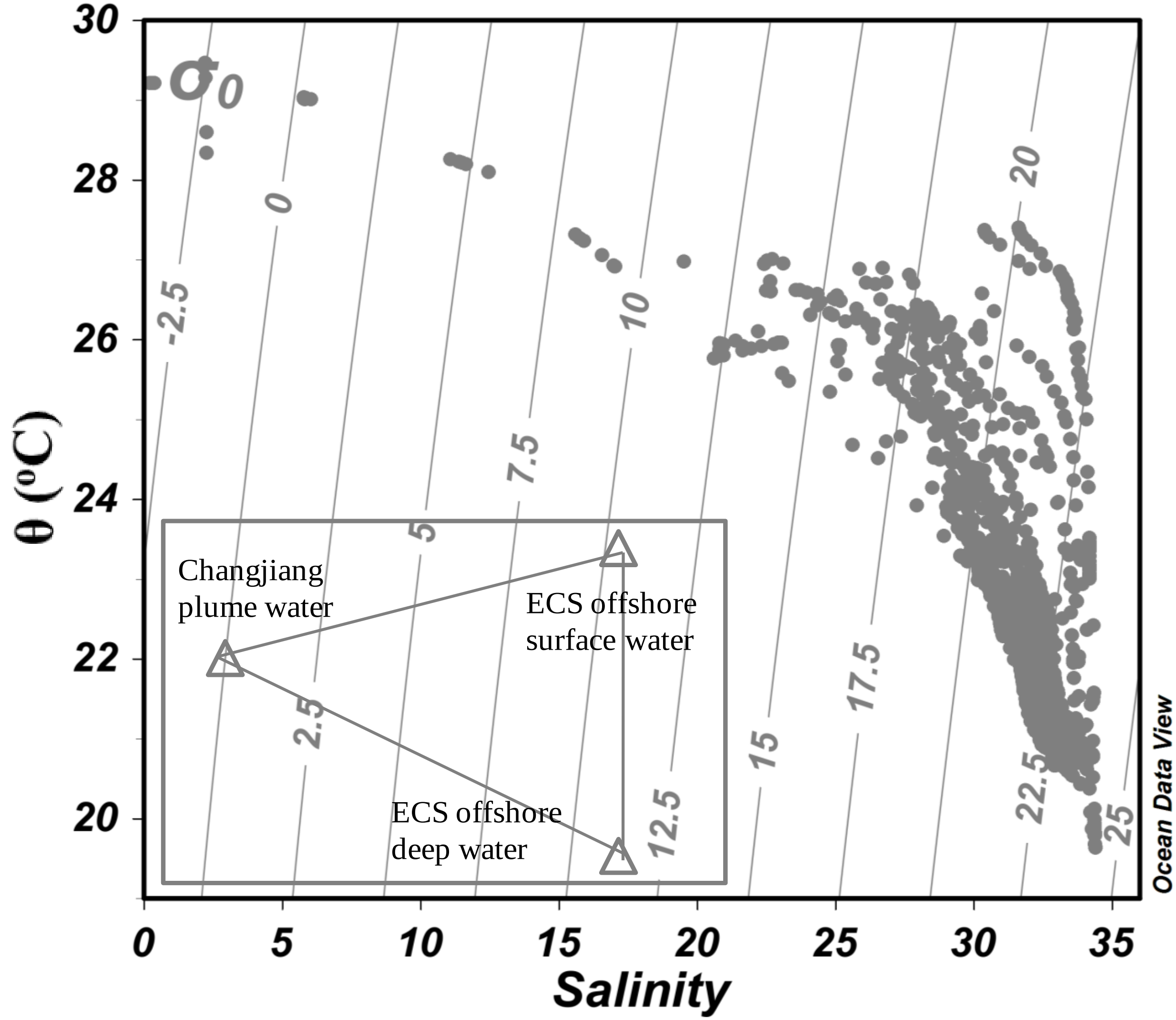


Table 2 Summary of the end-member values of the cruise in August 2011.

End-members	θ (°C)	S	DIC (μmol kg^{-1})	TA (μmol kg^{-1})	DIN (μmol L^{-1})	DIP (μmol L^{-1})	$Si(OH)_4$ (μmol L^{-1})
CP	25.7	21.0	1920.0	2106.0	59.0	1.03	52.0
ESW	29.2	33.4	1991.0	2286.0	0.1	0.02	2.0
EDW	18.9	34.7	2018.0	2284.0	3.69	0.55	22.0

θ and S denote the potential temperature and temperature. CP, ESW and EDW are represented the Changjiang plume water, ECS offshore surface water and ECS offshore deep water respectively.

$$f_{CP} + f_{ESW} + f_{EDW} = 1 \quad (1)$$
$$f_{CP}\,\theta_{CP} + f_{ESW}\,\theta_{ESW} + f_{EDW}\,\theta_{EDW} = \theta_{in\ situ} \quad (2)$$
$$f_{CP}\,S_{CP} + f_{ESW}\,S_{ESW} + f_{EDW}\,S_{EDW} = S_{in\ situ} \quad (3)$$

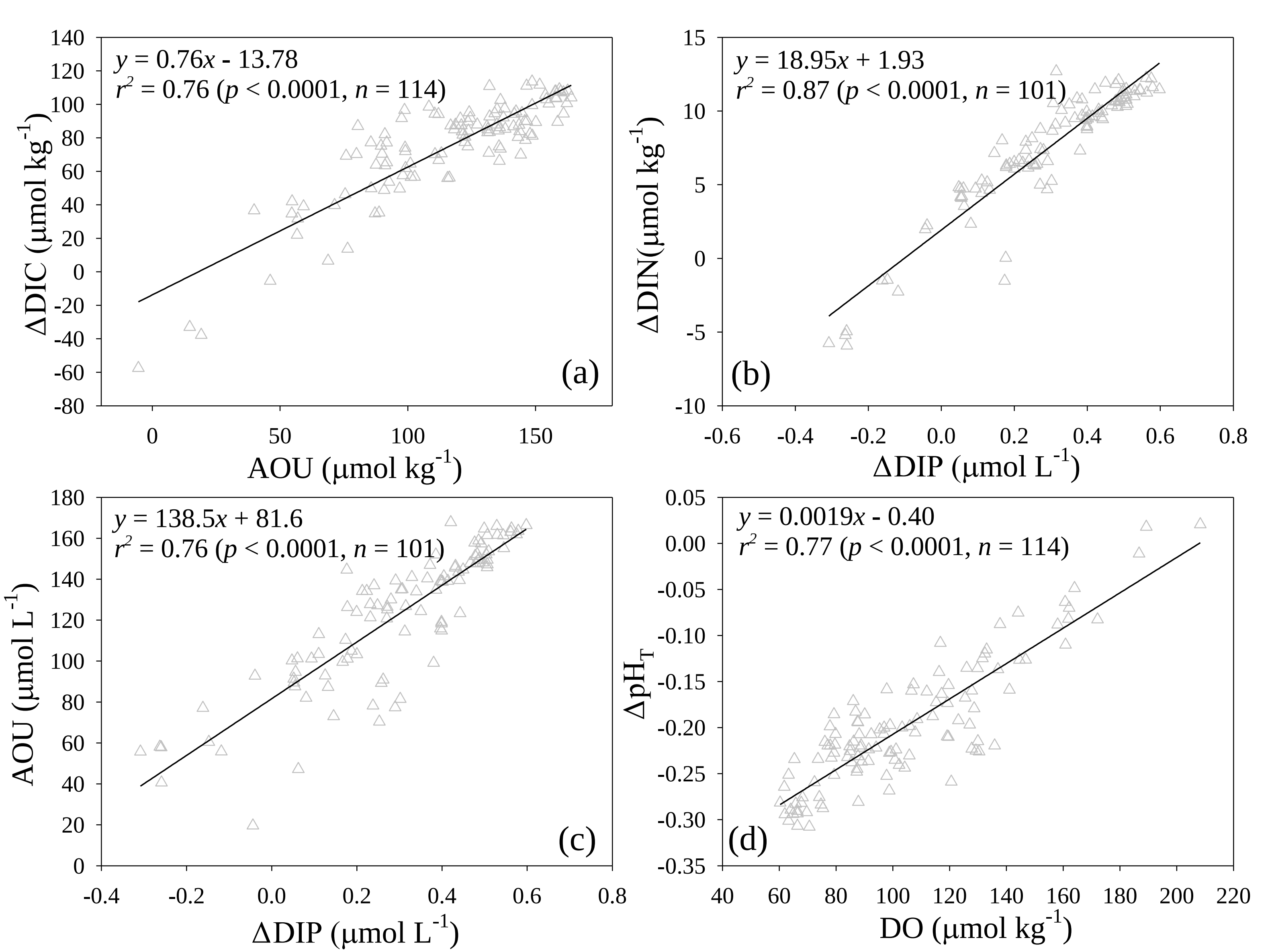
f_{CP}, f_{ESW}, f_{EDW}: percentage of each members
θ_{CP}, θ_{ESW}, θ_{EDW}: the temperature of each members
S_{CP}, S_{ESW}, S_{EDW}: the salinity of each members

$$V_{cons.} = f_{CP}\,V_{CP} + f_{ESW}\,V_{ESW} + f_{EDW}\,V_{EDW} \quad (4)$$

$V_{cons.}$: conservative values of any variables
V_{CP}, V_{ESW} and V_{EDW} : concentrations of three end-members waters for this variable

$$\Delta V = V_{meas.} - V_{cons.} \quad (5)$$

ΔV: difference between the conservative ($V_{cons.}$) and measured ($V_{meas.}$) concentrations



The correlations between △DIC and AOU (a), △DIN and △DIP (b) , AOU and △DIP (c), and $\triangle pH_T$ and Do concentration (d). All data collected from the August cruise with depth > 10 m were selected. The solid lines are the simulated correlations of our results. The estimated linear regressions with r^2 and p values are also showed.

- Both of these slopes were well coincided with the Redfield ratios which were 0.77 and 138 for ΔDIC/AOU and AOU/ΔDIP respectively.

These results indicated that aerobic respiration of organic material is the main process during the hypoxia formation

- The estimated ΔDIN/ΔDIP of our study was 18.95 also very close to the Redfield N/P ratio with a value of 16.0, higher ΔDIN/ΔDIP ratio was also reported by previous studies off Changjiang estuary (Harrison et al., 1990; Wang et al., 2003).

Question?

- The hypoxia in August:

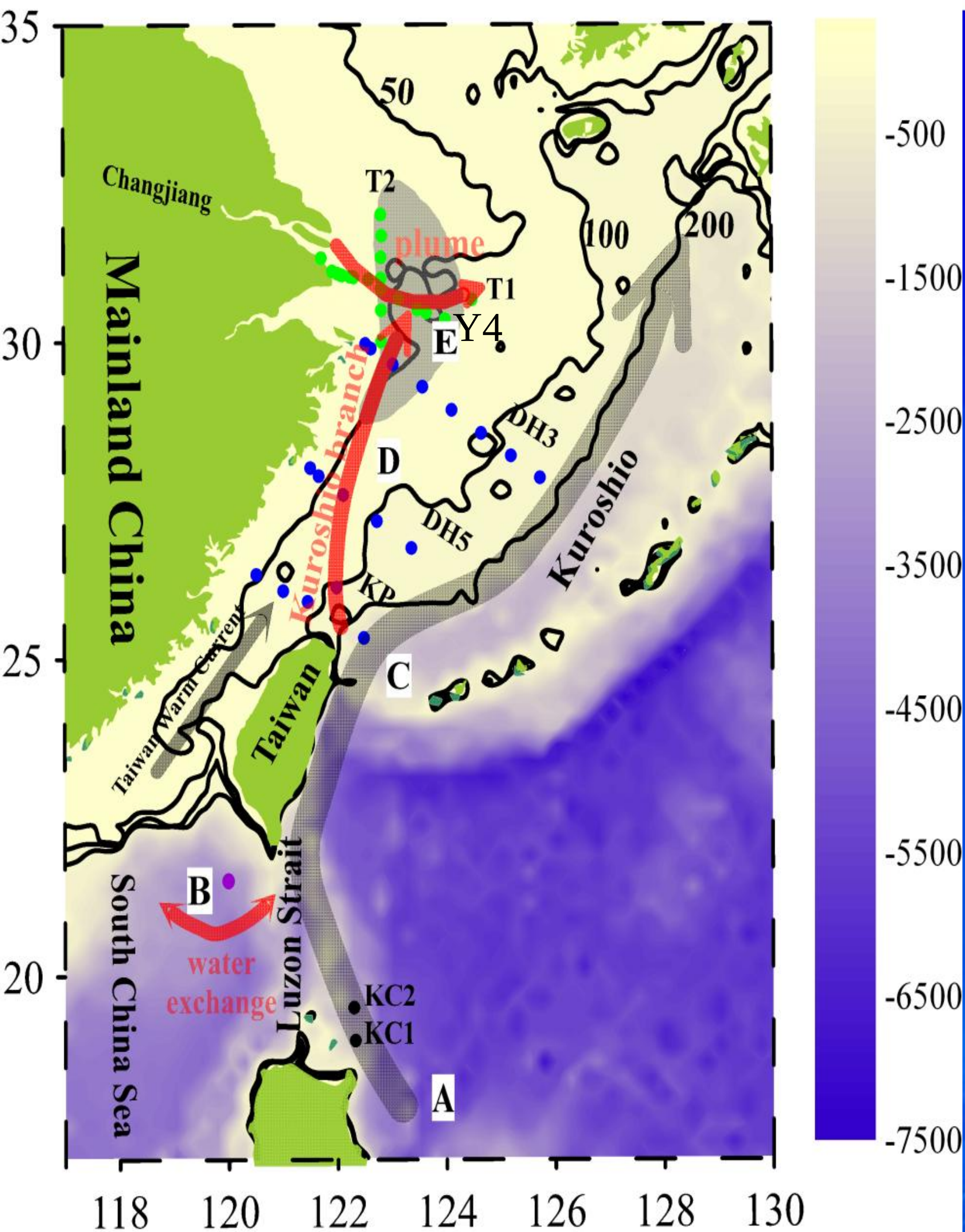
  Typhoon “Muifa” passed on 2011-8-7

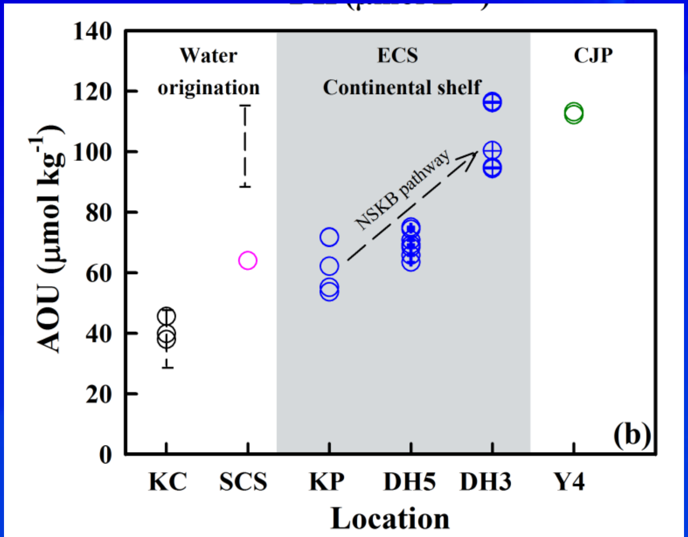
  Hypoxia first observed on 2011-8-24.

Hypoxia development time is less than 20 days

- CR: 4.0 ± 1.6 μmol O_2 L^{-1} day^{-1}

Indicted: the hypoxia is developed base on low DO concentration water.





AOU increase: ~60 to ~100 μmol kg^{-1}
DO concentration in the subsurface water < 130 μmol kg^{-1}

Qian et al., 2015

- During the summer time, Taiwan Warm Current is the main water mass dominating in the bottom layer off Changjiang estuary (Su, 1998; Chen, 2009; Zhu et al., 2011).
- DO value about 4.27 mg L^{-1} (Li et al., 2002).

Short summary 2

- The aerobic respiration is the main process during the hypoxia development and caused the variations of DIC, DO and nutrients concentrations in the subsurface water

- The subsurface water with lower DO concentration comes from Taiwan Warm Current and its higher aerobic respiration rate are the two essential conditions cause the summer hypoxia off Changjiang estuary.

Discussions:

- Roles of aerobic respiration on hypoxia development

- The role of Taiwan Warm Current on Hypoxia formation.

- Aerobic respiration enhance the water acidification

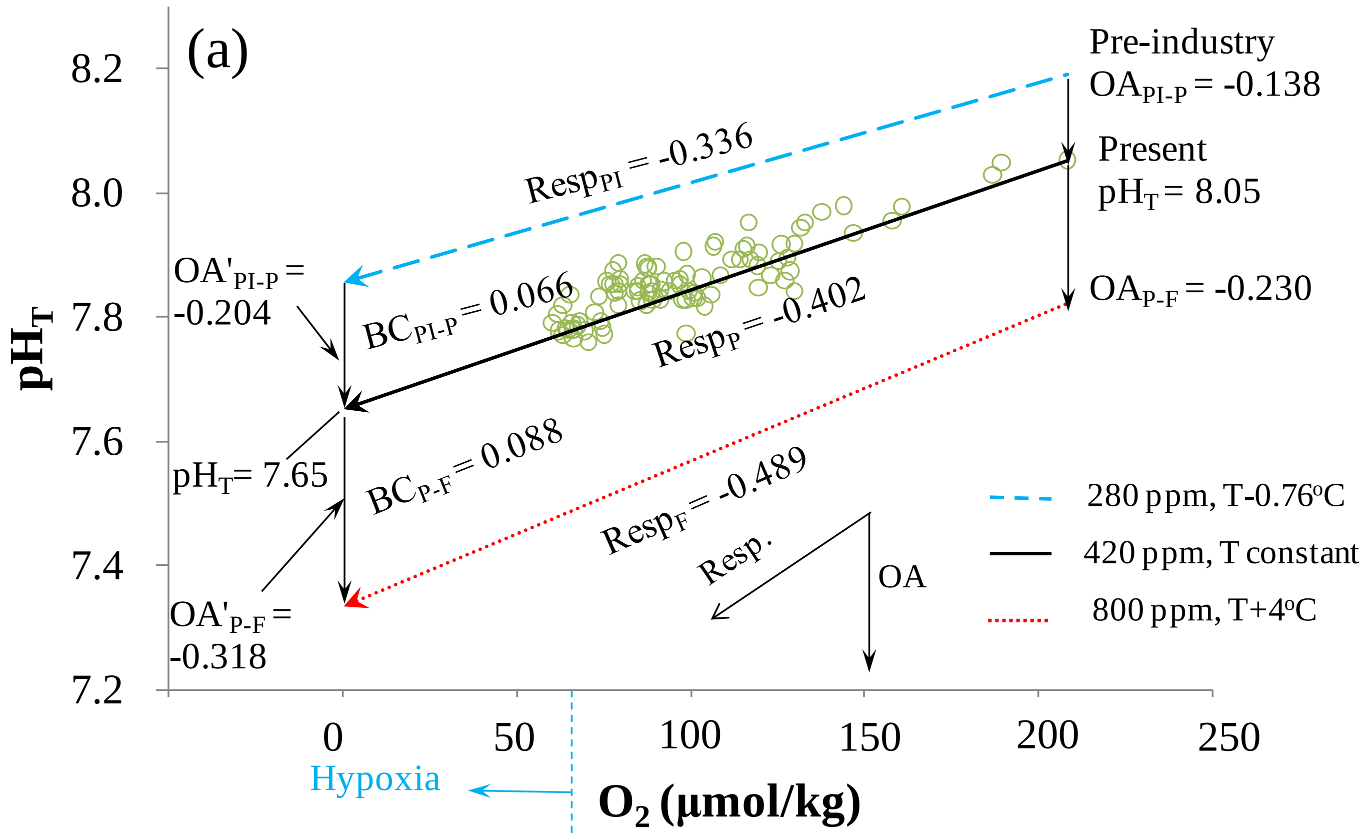
- The offshore water was assumed to be the source for the inner and middle shelf waters
- It was equilibrated with the atmosphere and could reflect the changes of atmospheric CO_2.

salinity	33.27	temperature	26.71 ^{o}C
pressure	10.47 db	TA	2228.0 μmol kg^{-1}
DIC	1937.3 μmol kg^{-1}	$[NO_3+NO_2]$	0.99 μmol kg^{-1}
phosphate	0 μmol kg^{-1}	silicate	3.5 μmol kg^{-1}
$p\mathrm{CO}_2$	420 ppm	pH_T	8.05

- Keep: salinity， nutrients, pressure, CR rates constant
- Temperature and CO_2：
  - Pre-industry:280 ppm，T-0.76ºC
  - Year 2100 :800 ppm，T+4ºC
  - Present day: 420 ppm, T ºC

- $DIC_{PI} = 1859.2\ \mu mol\ kg^{-1}$
- $DIC_F = 2030.7\ \mu mol\ kg^{-1}$

- TA:O = 17/138; DIC:O = -106/138



The relationships between subsurface DO and pH under pre-industrial (or PI, light blue dashed line), present (or P, dark solid line) and future (or F, red dashed line) CO_2 condition and temperature. The changes of temperature and CO_2 levels are according to IPCC (2007). pH drawdown due to uptake of anthropogenic CO_2 (or ocean acidification, OA), respiration (Resp.) and weakening carbonate buffer capacity (BC) were shown respectively. In the model, all the data points from the survey in August 2011 with salinity > 31, depth > 10m were presented. Assumed that CR was not influenced by temperature, and under DO-depleted scenarios.

Conclusions

- Hypoxia zone observed in the subsurface water off Changjiang estuary in August 2011.
- The processes of hypoxia formation were observed in August 2011.
- The aerobic respiration is the main process during the hypoxia development.
- The subsurface water with lower DO concentration comes from Taiwan Warm Current and its higher aerobic respiration rate are the two essential conditions cause the summer.
- Hypoxia formation time in summer is less than 20 days
- In the future, more pH_T-drops would be caused by elevated aerobic respiration activity. The coastal water would be more vulnerable to ocean acidification.

Thanks for your attention!