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Interactive comment on "Synthesis of observed air–sea CO_2 exchange fluxes in the river-dominated East China Sea and improved estimates of annual and seasonal net mean fluxes" *by* C.-M. Tseng et al.

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An item-by-item response to Reviewer #1's comments We thank Dr. Joe Salisbury for his helpful comments and suggestions; his critiques have been addressed carefully, and the manuscript improved. The following is detailed point-by-point responses to Dr. Salisbury's comments.

General comments

1A-1. The work outlined in this manuscript provides monthly estimates of in-water pCO2 and air-sea flux for the East China Sea (ECS). A rich set of ship observations and AVHRR SST satellite data spanning 14 years (1998-2011), are synthesized. From averaged regional data, in-water pCO2 and air sea flux estimates are derived and found to be robust functions of Changjiang River discharge and SST.

Firstly, we thank Dr. Salisbury's recognition of the rich dataset we reported in the manuscript.

1A-2. Although promising, the work is compromised from its dependence on empirical relationships drawn from interpolated fields. This presents several difficulties in understanding the physical, chemical and biological bases for the estimates. Exactly why do the algorithms work? How the Changjiang River actually affects solubility, net community productivity and dilution of carbonate parameters is not adequately explained, nor is the effect of winter mixing, which is addressed somewhat arbitrarily. In places the logic is hard to follow and the sentence structure awkward. The manuscript needs quite a bit of work, but should be resubmitted after major revisions.

We are grateful that Dr. Salisbury consider this study promising. It is not trivial that we have collected an amazing and valuable decade-long dataset, and, therefore, we would argue that the results are novel and important. However, the questions on the physical and biological processes, why the algorithms work, the effects of the Changjiang River discharge and winter mixing need be addressed. We will discuss these issues in more details in the revised text by adding more information on chemical hydrography, e.g., distributions of nutrients and Chl-a. We will report better statistic relationships and more significant correlations between CO2 uptake and river discharge, related to the riverine nutrient induced biomass growth.

1A-3. Understanding how the world's largest rivers affect ocean ecosystems and carbon sequestration is critical work. I would appreciate a deeper exploration and analysis of this important data set. My recommendations for a resubmission include separate analyses of control regions within the ECS, better statistical analyses (only r2 is

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presently used) and a more theoretical approach addressing how variations in NCP, solubility and mixing of TA and DIC affect in water pCO2 and air-sea flux.

We totally agree that how large rivers affect ocean ecosystems and the carbon cycle is a critical issue. We will revise the manuscript heeding every comment carefully by providing more in-depth discussion and doing better statistic analyses.

Technical comments:

P13977 – L5, How was the biological sequestration identified? I could not find this.

We have added the chlorophyll-a and N+N data in and made the statistic correlation analyses and figures below to show the biological uptake of CO2 in warm periods.

Table A-1 Correlation coefficient matrix for areal - means of pCO2 and other environmental variables in the ECS shelf in summer months from 1998 to 2011 (n=10) *Changjiang discharge Plume area (S<31) Sea-to-air CO2 Flux ïĄďpCO2 pCO2water N+N Chl-a Changjiang discharge 1.00 Plume area 0.81 1.00 Sea-to-air CO2 Flux -0.97 -0.89 1.00 ïĄďpCO2 -0.92 -0.83 0.94 1.00 pCO2water -0.98 -0.80 0.94 0.96 1.00 N+N 0.70 0.88 -0.71 -0.75 -0.73 1.00 Chl-a 0.88 0.60 -0.65 -0.81 -0.82 0.72 1.00 *Average Changjiang River discharge data collected at Datong station during the LORECS cruise period. Regression results between other variables and Changjiang discharge were obtained for the ten cruises, not including OR1-686 (6/19∼6/26, 2003). Before that cruise, the typhoon SOUDELOR (6/16∼6/18, 2003) passed over east of the ECS shelf toward Korea and Japan. Such a typhoon effect anomalously induced the more diluted plume area through enhanced rainfall in lower watershed of Changjiang River below Datong station. However, high typhoon-induced CRD was not recorded at Datong which is 624 km upstream from the river mouth.

The following figure shows the whole ECS CO2 uptake significantly correlated with the magnitudes of the river plume and of the Changjiang discharge and the amounts of N+N and of Chl-a in summer. Apparently, the amount of the CO2 uptake in the

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ECS shelf in summer is determined by the plume area e.g., Changjing Diluted Waters (CDW, Salinity$\leq$31), in which there were high nutrients and high biomass growth. The biological sequestration of the CO2 takes place mostly in the CDW plume area of the ECS shelf in warm seasons.

Figure A-1. Relationships between the amounts of ïĄďpCO2 and magnitudes of the CDW plume area and of the Changjiang discharge (a) and N+N and Chl-a (b) in summer from July 1998 to July 2011 in the ECS shelf. "-"indicates uptake of CO2 by shelf water from the atmosphere. The best fit lines by a linear regression analysis (n=10, all p values <0.001) are shown in plume area and Chl-a (solid line) and in Changjiang discharge and N+N (dashed line), respectively. The Changjiang discharge denotes average Changjiang River discharge data collected at Datong station during the LORECS cruise period. The red circle symbol denotes the OR1-686 cruise (6/19∼6/26, 2003) was excluded from the regression with the discharge.

P13979 – L29 Net community production includes the respiration term.

The word "/respiration" was deleted.

P13980 – L1-3, explain the processes. Heating and biological uptake of DIC drive pCO2 in different directions.

We fully agree that heating and biological uptake of DIC drive pCO2 in different directions. High SST in summer enhances the high pCO2 and then favors the release of CO2 to the atmosphere. However, the better stratification favors phytoplankton growth, which in turn draws down pCO2. So, the sentence concerned was modified. "The dominant processes in the ECS take place with typically active biological uptake of CO2 in warm periods in the Changjiang plume area. Although higher SST favors CO2 release to the atmosphere, better stratification favors phytoplankton growth, which draws down pCO2. Besides only a thin layer of warmer water could be degassed. In the end, the biological effect outweighs the warming effect. On the other hand, although intense physical mixing occurs in the cold season, the lower temperature increases the solubility of CO2 in the cold seasons (Tseng et al., 2011; Chou et al., 2011).

L21-22, “freshening nutrient source” Reword.

The phrase “..freshening nutrient source” was reworded. The CRD as the dominant riverine nutrient source of the ECS played a key influence on modulating the CO2 uptake (Tseng et al., 2011).

P13981 – L9, 3/4 of the cruises were during the summer. How does this affect the results?

It is true that the number of observations in cold seasons is limited. However, we believe the limited cold-season data are accurate and coherent, and, therefore, representative. The proposed hypothesis is based on the following argument. Essentially the cold season condition is controlled by cooling and vertical mixing, while the plume area is small. Therefore, the winter conditions are less variable in comparison to the warm season condition. In summer, the conditions are mainly controlled by the Changjiang discharge, which is quite variable. Therefore, it is necessary to conduct more surveys in the summer.

In the summer, by contrast, the conditions are mainly controlled by the Changjiang discharge, which is quite variable. Because the magnitude of the Changjiang plume in warm seasons determines the CO2 uptake amount in the ECS shelf, it is necessary to conduct more cruises in summer to observe the conditions with high discharges of Changjiang. Consequently, the rich summer data allow us to delineate the effect of runoff variation on the biological uptake of CO2.

P13981 – L16, indicate depth of intake. Did it vary between cruises? This may be important, especially in shallow river lenses.

Water samples were underway collected about at the depth of 5 m. It didn’t vary among cruises. The water depths of the sampling stations were greater than 30 m during all cruises.

P13982 – L9, “AVHRR agreed well. . .” The AVHRR-SST (observed) relationship does not look that great in figure 2. A 1-2 degree C bias or error could translate into an estimate error of ∼10-30 uatm

There indeed exist small differences between AVHRR-SST and observed shipboard-SST. The differences may be derived from the following: (1) systematic errors; (2) timescale differences (The shipboard-SST data averaged from data collected during 10-15 days of the cruise, but the satellite data are monthly averages) ; (3) probable errors of the satellite data due to cloud interferences. Nevertheless, the AVHRR-SST correlates well linearly with shipboard observations (as shown in Fig. 2). It indicates there are possibly systematic errors involved. After calibrating the satellite data, the overall averaged deviation between them are lower than 0.5 oC (an estimated error of <10 uatm., see the Fig. A-2). In the East China Sea, the differences in SST between adjacent months are, however, about 2.3âĎČwhich are much greater than the possible errors in satellite-SST. It demonstrates that errors in the remotely sensed SST do not affect significantly the calculation of the monthly variability in CO2 solubility.

Figure A-2. Differences between the calibrated satellite data and shipboard observed SST from 1998 to 2011. The overall averaged RMSEs (root mean square error) are lower than 0.5 oC (e.g., RMSE in Region S: 0.37âĎČand Region B: 0.49âĎČ, respectively)

P13983 – L19-22, The averaging of wind can create serious biases. See Wanninkhof et al., 2002 and Jiang et al, 2008.

We are grateful that Dr. Salisbury points out this important issue. The quality and treatment of wind speed data indeed have a critical effect on the reliability of the flux estimates of air-sea CO2 exchange. In the manuscript, we present the monthly pCO2 flux estimates since the modeled pCO2 was generated on a monthly basis from CRD and SST. Therefore, the monthly CO2 fluxes were computed by using the monthly averaged wind data which were in-situ collected at PenGaYi station in the ECS. As for the bias from the averaging of wind speed, we will address later and further estimate tempo-spatial variations in wind field of the ECS shelf in the future.

P13984, Section 3.1. The SST may be representative, but certainly not the SSS. One of the main points here is that the changing discharge affects the pCO2 and a-s flux. Certainly the magnitude of CRD affects SSS distributions

Thank for the reviewer's typical concerns. Tseng et al (2011) had proposed the CRD changes against with strengths of Kuroshio and Taiwan warm current in the ECS affect the pCO2 distribution and air-sea exchange flux. That means that changes in CRD, affecting the SSS distribution (CDW: $S \leq 31$, plume area), have a significant effect on CO2 uptake dynamics. We may certainly believe the SSS is still representative like SST. In the river-dominated ECS shelf, most variables are strongly controlled by mixing. i.e., well correlated with SSS. The relationships were mostly a reflection of mixing between the Changjiang runoff and the open shelf water. A perfect relationship between salinity and CDW ($S \leq 31$ or CRD) was obtained. i.e., the more CDW we observed, the less average SSS we found due to the more freshwater discharge into the ECS. So we can see the salinity is a proxy of CDW or vice versa. Drawdown of CO2 occurs in the mixing zone in the open shelf, where the biological pump kicks in. The concurrent mixing and biological processes are responsible for the observed correlations.

The areal mean SSS in S region and B region should be relatively resemble and positively correlated. Changes in SSS in S region must be positively related to those in B region. It does not need the SSS in region S and B shall be the same, but both of variability be consistent. It refers the SSS in B region shall be higher than that in S region. Tseng et al (2011) the SSS distribution is as a result of the mixing between the CRD and the open ocean waters. Since the area in B region is bigger than S region, the more saline water will be weighted in contribution.

Figure A-3. Relationships between areal mean SSS and hydrographic variables in the whole ECS (i.e., region A). *A triangle denotes the data obtained from the cruise of OR1-686 (6/19∼6/26, 2003). In the plot of Chl-a vs. salinity, a triangle-circle is outlier the regression line. That is because before that cruise, the typhoon SOUDELOR (6/16∼6/18, 2003) passed over east of the ECS shelf toward Korea and Japan. Such a typhoon effect anomalously induced the more diluted plume area and then enhanced high Chl-a levels.

P13984-5, Section 3.2, This section does not adequately relate low summer pCO2 to CRD. The present description is too qualitative and anecdotal. Does the measured limiting nutrient flux support the apparent DIC uptake, even when the surface is warming? Please use some quantification in this section. Also, the near-coastal areas of Changjaing Plume have very high pCO2 values (see Gao et al, 2008, Peisong et al, 2013). Are these regions considered in the overall statistics? Could they change the results?

As mentioned above, we will add the biogeochemical data e.g., chlorophyll-a and nutrient data in and further make the statistic correlation analyses (Table A-1) and figures (Fig. A-1,-3) to adequately relate low summer pCO2 to CRD. Some results have been discussed in Tseng et al. (2011). As the above figures show, the amount of the CO2 uptake in the ECS shelf in summer is well related to the plume area (salinity≤31) determined by CRD, in which there were high nutrients and high biomass growth. The biological sequestration of the CO2 takes place mostly in the CDW of the ECS shelf in warm seasons. It apparently shows the measured limiting nutrient flux support the apparent DIC uptake, even when the surface is warming. Further, we consider the amount of nutrient discharged and the amount of CO2 taken up by the sea to see if their relationship which agrees with the Redfield condition. The preliminary results show the nutrient flux exported to the sea enough support the apparent DIC uptake estimated by air-sea exchange.

It has been reported that near-coastal areas of the Changjaing plume have very high pCO2 values. That is due to strong respiration in low salinity river-mouth zone (Zhai et al., 2009, Mar. Chem). However, the source area is small relative to the plume sink area in the open shelf based on the weighted statistic analyses. It doesn't change our results at all.

P13986, Section 3.3 How does the apparent low bias in AVHRR affect the pCO2(w) estimate in equation 5?

The data quality of AVHRR-SST have been mentioned above. After the calibration against the shipboard measurements, the pCO2 estimates should be reasonable since the bias in AVHRR has been minimized.

P13987 – L1-10, I cannot follow the link between the climatological mixing index and numerical change in TA and DIC that would lead to +57.4 uatm average difference between the algorithm and the observations. This could be evidence that entrainment is important and its interannual variability could be important factors that should be considered. How does knowledge of a 14.4% increase in the amount of deep water entrained into the surface help without knowing the change in DIC and its relative buffering arising from the mixing? It seems that the pCO2 estimates for whole period between December and April could be compromised (see mixing ratios in Fig S3) unless you had a quantitative measure of mixing on DIC and TA. This highlights another potential problem with having poor coverage during these months (only 3 cruises throughout the entire series).

The empirical algorithm proposed in the manuscript was obtained during the warm cruises from May to November. It was applied to predict the time-series pCO2 in the ECS shelf. Then, the modeled pCO2w correlate well linearly with the observed ones. The deviations between the modeled mean pCO2 and observations from January to November were small (see in the supporting material). A 57.4 uatm (14.4%) increase in the amount of deep water entrained into the surface was obtained from the differences between the observation on a January cruise and modeled NpCO2. This empirically determined value allows us to estimate the replenishment of CO2 by mixing. We agree that this is an issue we need to pay more attention to and should obtain more data to

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confirm it.

P139888 – L15-20, How will changes the CRD alter the future projections of the ECS sink term? Following the reasoning presented in the manuscript, the increasing delta, must in part be due to decreasing CRD.

The question raised by Dr. Salisbury had been addressed by Tseng et al. (2011). In the paper, the CRD changes indeed alter the ECS sink. The reduction in CO2 uptake was quantitatively projected due to reduction of the CRD. It may hence be that the increasing delta pCO2 presented in the manuscript in part due to decreasing CRD under the climate and anthropogenic changes e.g., the operation of Three Gorges Dam and water transferring scheme from the south to north in China.

Figure captions:

Figure A-1. Relationships between the amounts of ïĄďpCO2 and magnitudes of the CDW plume area and of the Changjiang discharge (a) and N+N and Chl-a (b) in summer from July 1998 to July 2011 in the ECS shelf. “-“indicates uptake of CO2 by shelf water from the atmosphere. The best fit lines by a linear regression analysis (n=10, all p values <0.001) are shown in plume area and Chl-a (solid line) and in Changjiang discharge and N+N (dashed line), respectively. The Changjiang discharge denotes average Changjiang River discharge data collected at Datong station during the LORECS cruise period. The red circle symbol denotes the OR1-686 cruise (6/19∼6/26, 2003) was excluded from the regression with the discharge.

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Figure A-3. Relationships between areal mean SSS and hydrographic variables in the whole ECS (i.e., region A). *A triangle denotes the data obtained from the cruise of OR1-686 (6/19∼6/26, 2003). In the plot of Chl-a vs. salinity, a triangle-circle is outlier the regression line. That is because before that cruise, the typhoon SOUDELOR (6/16∼6/18, 2003) passed over east of the ECS shelf toward Korea and Japan. Such a typhoon effect anomalously induced the more diluted plume area and then enhanced high Chl-a levels.

References:

Chou, W.-C., Gong, G.-C., Tseng, C.-M., Sheu, D.-D., Hung, C.-C., Chang, L.-P., and Wang, L.-W.: The carbonate system in the East China Sea in winter, Marine Chemistry, 123, 44–55, 2011. Tseng, C.-M., Liu, K.-K., Gong, G.-C., Shen, P.-Y., and Cai, W.-J.: CO2 uptake in the East China Sea relying on Changjiang runoff is prone to change, Geophysical Research Letters, 38, L24609, doi:10.1029/2011GL049774, 2011. Zhai, W., and Dai, M.: On the seasonal variation of air-sea CO2 fluxes in the outer Changjiang (Yangtze River) Estuary, East China Sea, Mar. Chem., 117, 2-10, 2009.

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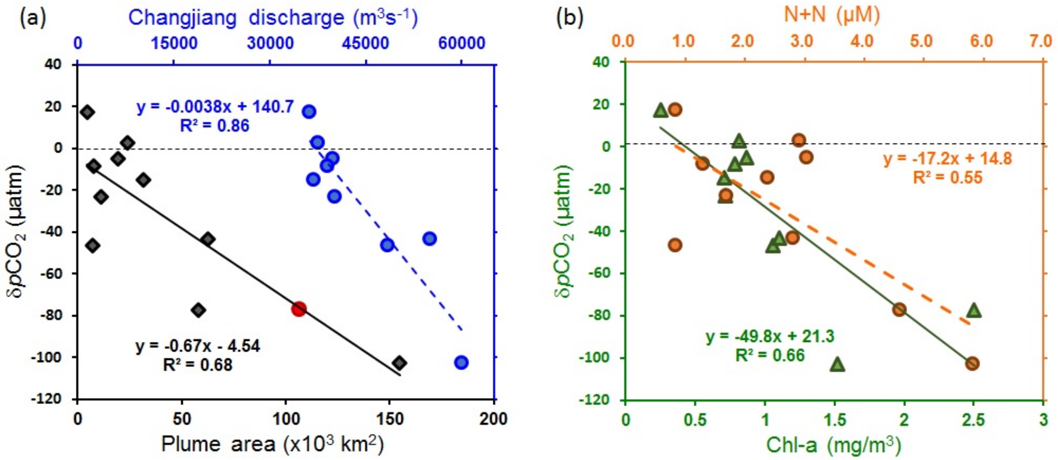

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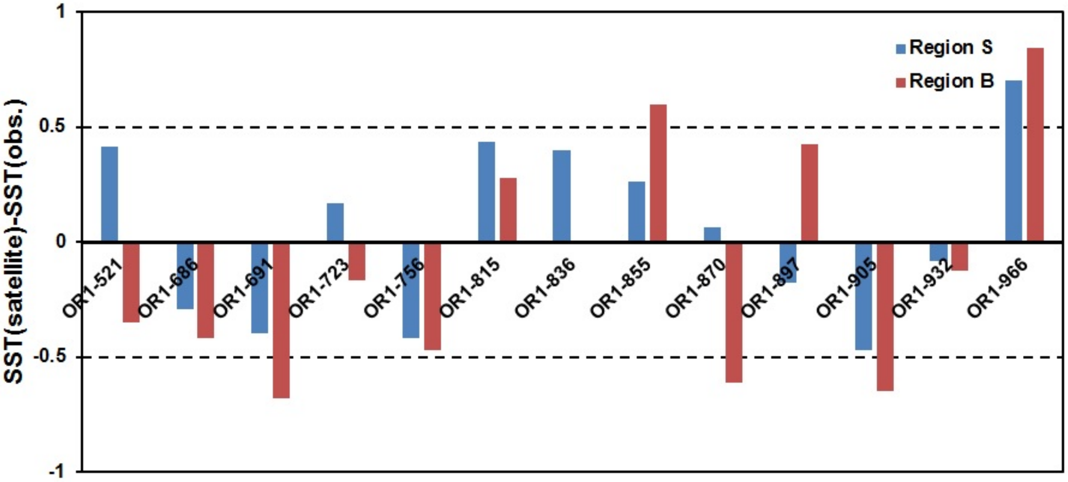

Fig. 2. Figure A-2. Differences between the calibrated satellite data and shipboard observed SST from 1998 to 2011. The overall averaged RMSEs (root mean square error) are lower than 0.5 oC (e.g., RMSE in Reg

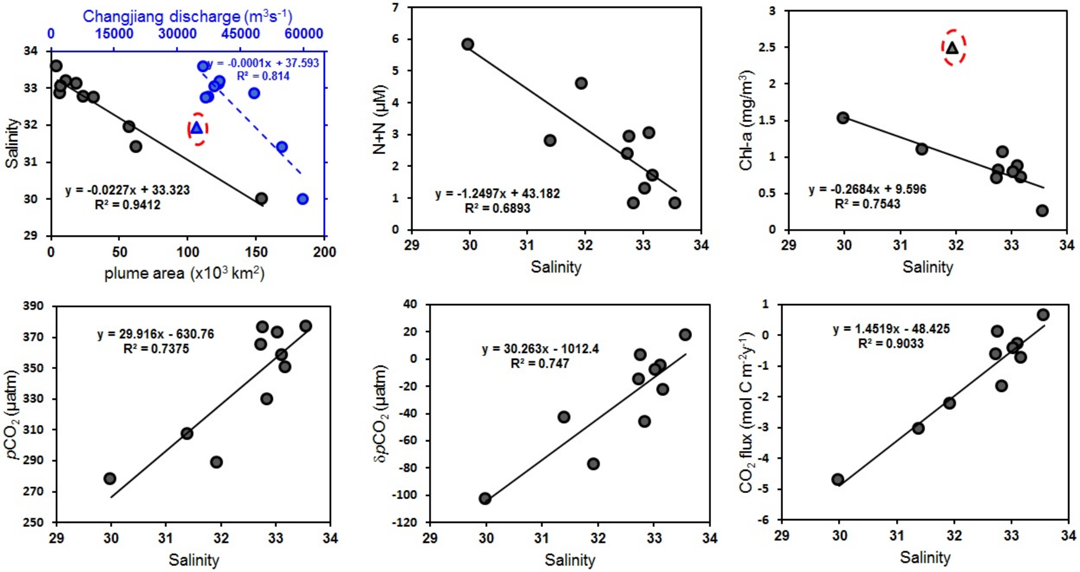

Fig. 3. Figure A-3. Relationships between areal mean SSS and hydrographic variables in the whole ECS (i.e., region A). *A triangle denotes the data obtained from the cruise of OR1-686 (6/19∼6/26, 2003). In th

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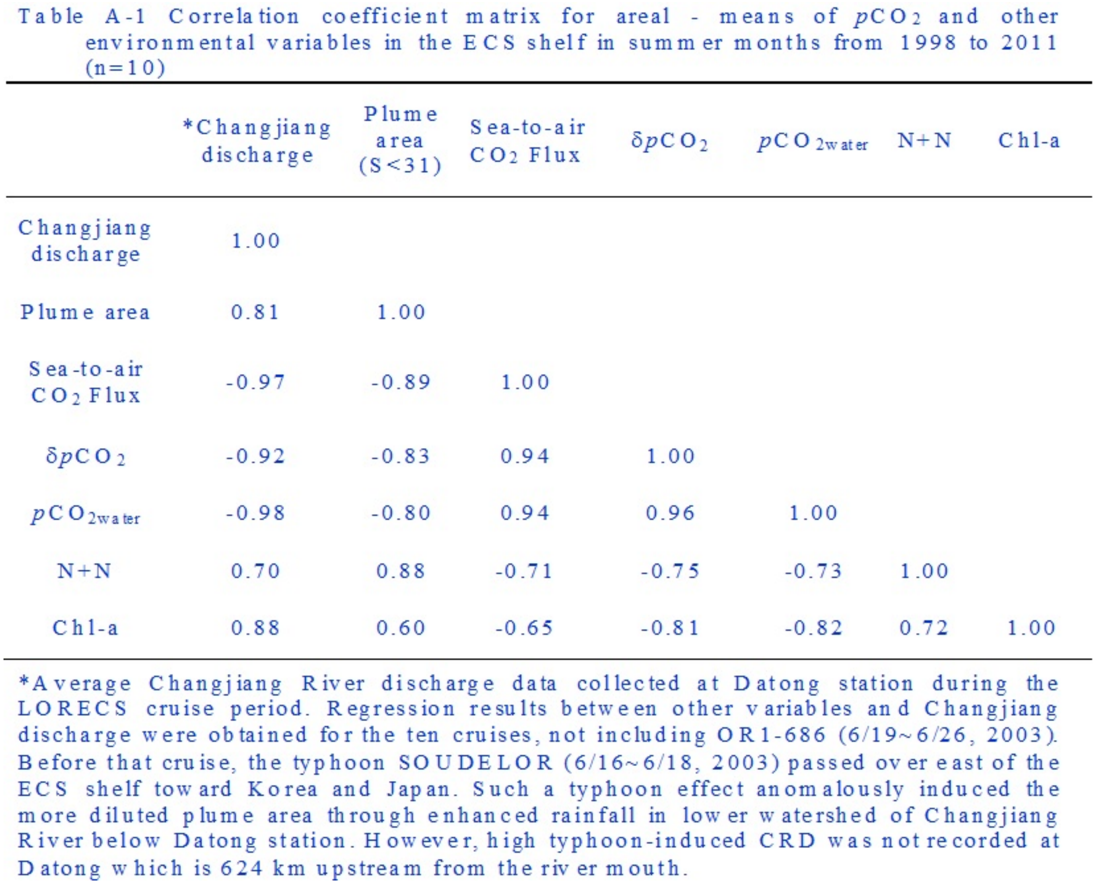

Table A-1 Correlation coefficient matrix for areal - means of pCO_2 and other environmental variables in the ECS shelf in summer months from 1998 to 2011 (n=10)

	*Changjiang discharge	Plume area (S<31)	Sea-to-air CO_2 Flux	δpCO_2	pCO_{2water}	N+N	Chl-a
Changjiang discharge	1.00						
Plume area	0.81	1.00					
Sea-to-air CO_2 Flux	-0.97	-0.89	1.00				
δpCO_2	-0.92	-0.83	0.94	1.00			
pCO_{2water}	-0.98	-0.80	0.94	0.96	1.00		
N+N	0.70	0.88	-0.71	-0.75	-0.73	1.00	
Chl-a	0.88	0.60	-0.65	-0.81	-0.82	0.72	1.00

*Average Changjiang River discharge data collected at Datong station during the LORECS cruise period. Regression results between other variables and Changjiang discharge were obtained for the ten cruises, not including OR1-686 (6/19~6/26, 2003). Before that cruise, the typhoon SOUDELOR (6/16~6/18, 2003) passed over east of the ECS shelf toward Korea and Japan. Such a typhoon effect anomalously induced the more diluted plume area through enhanced rainfall in lower watershed of Changjiang River below Datong station. However, high typhoon-induced CRD was not recorded at Datong which is 624 km upstream from the river mouth.

Fig. 4. Table A1-1