STUDY ON THE ALGORITHM OF INVERSING CARBON DIOXIDE IN SEAWATER ON LANDSAT8/OLI DATA

Zhonglin Wang[1], Miaofen Huang[2*], Zhen Sun[3], Ying`en Huang[4], Yang Zhuang[5], Zhongyong Sun[6], Tao Zhang[7]
[1]Dalian Ocean University, No. 52-2 Heishijiao Street, Shahekou District, Dalian 116023, China,
Email: wzllin@126.com
[2]Guangdong Ocean University, No. 1, Haida Street, Mazhang District, Zhanjiang 524088, China,
Email: hmf808@163.com
[3]Dalian Ocean University, No. 52-2 Heishijiao Street, Shahekou District, Dalian 116023, China,
Email: sz_0224@163.com
[4]Guangdong Ocean University, No. 1, Haida Street, Mazhang District, Zhanjiang 524088, China,
Email: bao_zugong@126.com
[5]Guangdong Ocean University, No. 1, Haida Street, Mazhang District, Zhanjiang 524088, China,
Email: zhuangyang_libra@qq.com
[6]Dalian Ocean University, No. 52-2 Heishijiao Street, Shahekou District, Dalian 116023, China,
Email: sun_idea@163.com
[7]Dalian Ocean University, No. 52-2 Heishijiao Street, Shahekou District, Dalian 116023, China,
Email: 18840861947@163.com

KEY WORDS: Carbon dioxide in seawater, Landsat8/OLI, CDOM

ABSTRACT: It is the important meaning to grasp the characteristics of spatial distribution and variation of total CO_2 concentration in the sea water, which affects the level of atmospheric CO_2 and is the decisive factor of the degree of ocean acidification. The article, based on the data which were measured in the Pearl River Estuary in November 2013 and February 2013, is erecting the model of the distribution of the total CO_2 concentration in the sea water which is adaptable for the retrieval of data of Landsat8 OLI. The model takes the CDOM as intermediate material which can be detected by ocean color remote sensing and has good adaptability for the estuary which is affected by freshwater runoff. The model will be applied for the Pearl River Estuary to require the spatial distribution graph of the total concentration of CO_2 in water in November 2013. The results showed that: (1) the use of the measured data to validate the values estimated from remote sensing model, the calculated relative error is 8%, indicating that the model has a high accuracy rate (2) the values of CO_2 in the Pearl River estuary is between 26-70 mg / L, offshore higher than the open sea and western higher than the central and eastern, coinciding with the actual measurement data.

1. PREFACE

In 2015, nearly 200 countries reached Paris Agreement, which one agreement is important, According to national ownership contribution, each country should check anthropogenic emissions and removals of greenhouse gas, while accounting for the carbon dioxide is the key point to this study. Ocean as the largest carbon reservoir on the earth's surface, determines the consistence level of atmospheric CO_2, so researching of ocean carbon dioxide system is very concerned (Falkowski, 2000). Slow growth of Plankton and coral caused by ocean acidification, which due to the sea to absorb a lot of carbon dioxide, reduction of population and a series of ecological problems, and the content of carbon dioxide in seawater directly affects photosynthesis of phytoplankton, also the oceans primary productivity have a significant impact.

And so far most of the study of ocean carbon dioxide concentrates in the partial pressure of sea surface carbon dioxide and the air-sea flux studies, but less research of carbon dioxide content in water, especially in the direction of remote sensing research is more focused on the study of gas flux: The continental margins as a whole is a weak CO2 sink (K. 2000), (0.1 PgC yr^{-1} downward flux between atmosphere and margins). Studies in the mouth of the Mississippi River show that retrieval pCO_2 distribution with CDOM (Colour Dissolved Organic Matter) have good adaptability (Lohrenz, 2006).

*Corresponding author: hmf808@163.com

In this article, we get to remote sensing of CDOM absorption coefficient as the intermediate medium, to invert the content of carbon dioxide in seawater. In this paper, the temperature and salinity data and the inherent optical quantity data of two cruises in the Pearl River estuary are collected in the field in Nov.2013 and Feb.2014, A model was established for the inversion of the total concentration of carbon dioxide in water using Landsat 8/OLI data through CDOM. It provides reference for the inversion of CO_2 concentration in the South China Sea.

2. STUDY SEA AREAS AND DATA

Study sea areas covers Southern South China from 21 ° ~ 22 ° N, 113 ° ~ 114 ° E, include the Pearl River Estuary and adjacent waters. Estuary area is affected by human activities, external sea water are relatively clean. 29 observation stations were set up (See Figure 1), and tested separately on November 2013 and February 2014. Due to the poor sea conditions, some of the sampling points are abandoned, which makes the reduction of offshore data. With the high demand for spectral measurement of weather stability, we obtained 33 scene spectral measurement data, 46 CDOM valid samples in total and 42 effective temperature and salinity data by cruising twice. Finally 42 group data can be used in our research

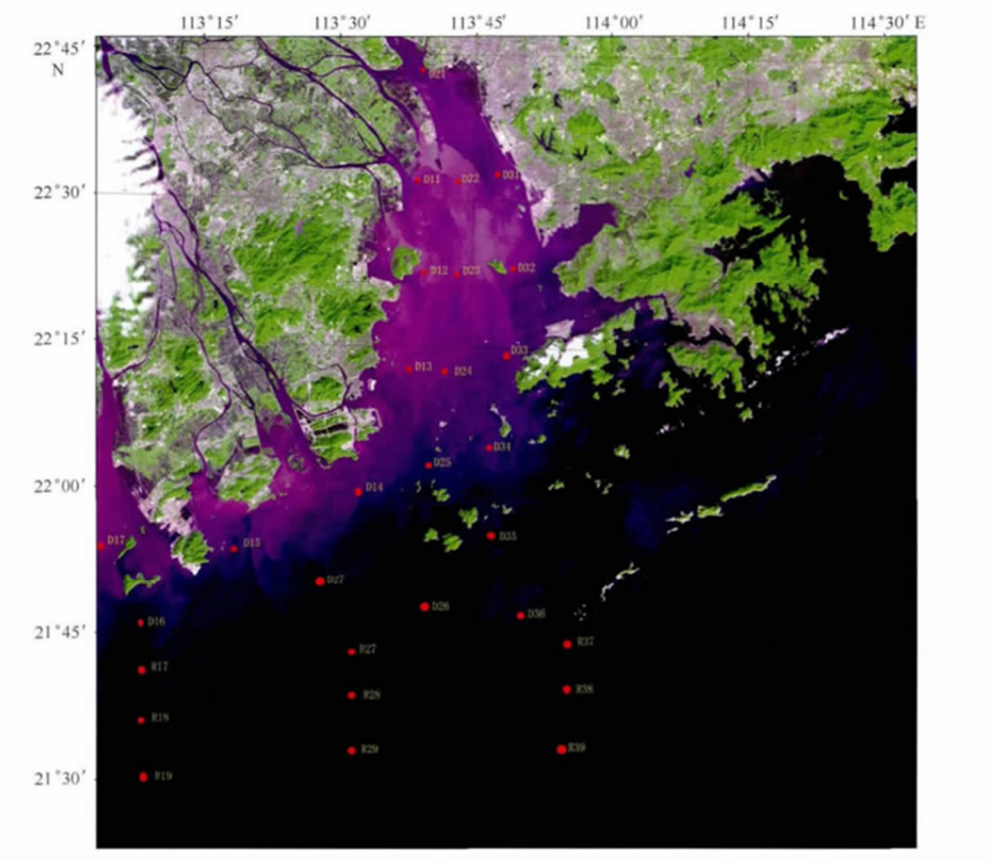

Figure 1 The distribution of sampling sites

The absorption coefficient of CDOM is measured by the standard from the State Oceanic Administration. Calculated as follows (Li, 2006):

$$a_g(\lambda) = 2.303\{[OD_s(\lambda) - OD_{bs}(\lambda)] - OD_{null}(\lambda)\}\ L^{-1} \qquad (1)$$

Where, $a_g(\lambda)$ is the absorption coefficient of CDOM (m^{-1}), L is the optical length of colorimetric ware (typically the value is 0.1 m), $OD_s(\lambda)$ is the optical density of samples compared with the pure water (dimensionless), $OD_{bs}(\lambda)$ is the optical density of black water compared with the pure water (dimensionless), $OD_{null}(\lambda)$ is the optical density of samples residual absorption in the long wavelength visible light and near infrared wave band (dimensionless). We calculated the average of spectral absorption coefficient at 435 ~ 445nm as $a_g(440)$.

According to the International Oceanographic tables (Lewis,1982), we converted salinity data to practical salinity use the temperature data. Then according to the Specifications for oceanographic survey- Part 6 : Marine biological survey, we compute total CO_2, calculated as follows(Standardization Administration,2007):

$$\rho(CO_2) = (0.067 * S - 0.05) * 12000 \qquad (2)$$

Where, $\rho(CO_2)$ is concentration of total carbon dioxide (mg/m^3), S is practical salinity (dimensionless).

Water spectral was measured with Above-Water Method (Tang, 2004), by ASD FieldSpec.

3. MODEL BUILDING

When the atmospheric CO_2 get through the air - sea interface into the aqueous phase, to establish the system of carbon dioxide, also known as the carbonate system, including CO_2, H_2CO_3 in free state, HCO_3^- , CO_3^{2-}, in ions state. their total amount is called the total carbon dioxide (ΣCO_2), It can be found that the content of the total carbon dioxide is combined affected by seawater PH, alkalinity, salinity and temperature, theoritically, as long as the four basic parameters of the carbon dioxide measurement system DIC (dissolved inorganic carbon,) or TCO_2 (total carbon dioxide) Alk (alkalinity)or TA (total alkalinity), pCO_2 (carbon dioxide partial pressure) or fCO_2 (fugacity of carbon dioxide), PH of the two is able to study on carbon dioxide system, because the other two can be calculated by thermodynamic relations (Millero, 1995), and according to a study in the coastal estuary, the horizontal distribution of carbon dioxide is mainly affected by salinity control, with increasing salinity, total carbon dioxide increases linearly (Gu, 1984), so you can use practical salinity to calculate the content of total carbon dioxide in seawater (Standardization, 2007), salinity and CDOM are closely related, CDOM is one of the three components that color remote sensing can detect , Studies on inverse of CDOM in the Pearl River estuary, and build remote sensing reflectance model to inversion a_g (440)(Huang, 2015).
Based on CDOM inversion mode from reflectance ratio (Bower, 2004), we established CDOM extraction model for the Pearl River Estuary by situ spectral data and Landsat 8 spectral response function:

$$a_g(440) = 0.0723*\exp(0.0723\ (R4/R2)) \qquad (R^2=0.83) \qquad (3)$$

Wherein, a_g (440) is concentration of absorption coefficient in 440nm of CDOM (m^{-1}), *R4* and *R2* are the reflectivity of Band 4 and Band 2.
Analysis of field data, we find the absorption coefficient of CDOM and total CO_2 are positively correlated. Absorption coefficient of CDOM is higher offshore, while $\rho(CO_2)$ is also high overall. $a_g(440)$ low in the external waters, at the same time, $\rho(CO_2)$ is less content.

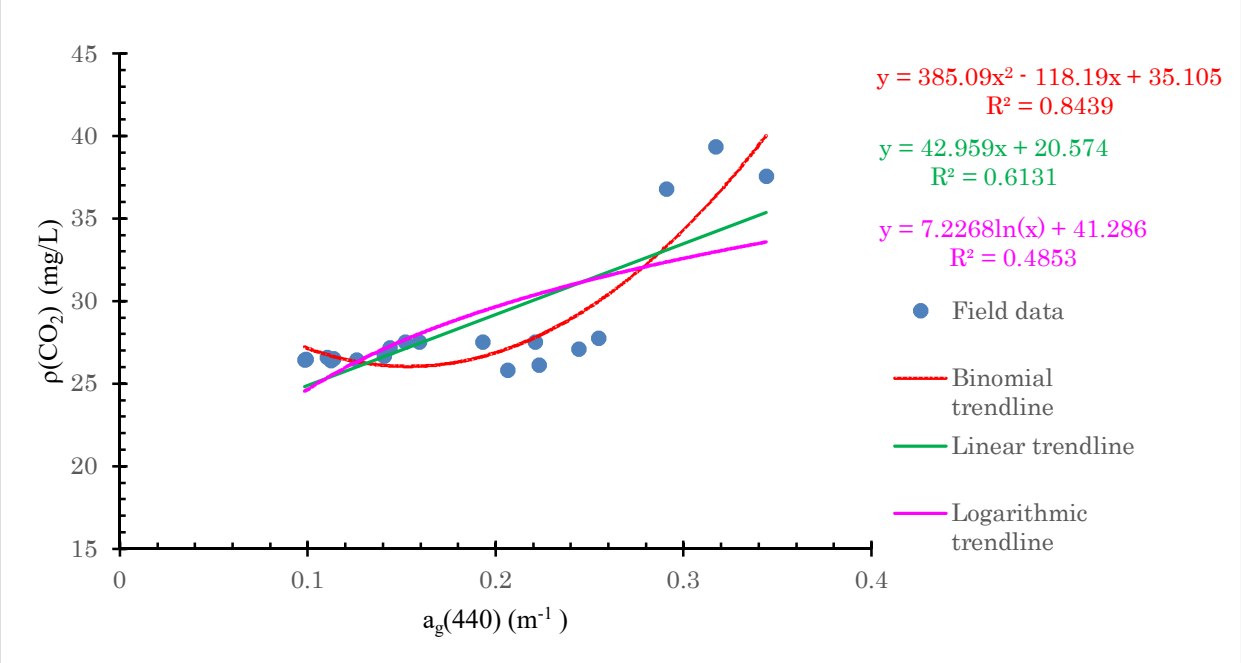

Figure 2 Relationship diagram of total carbon dioxide and $a_g(440)$

We build the retrieval model of total CO_2 in water from absorption coefficient of CDOM, which is based on the 20 group data by cruising twice on November 2013 and February 2014. Model is as follows:

$$\rho(CO_2) = 385.09a_g(440)^2 - 118.19a_g(440) + 35.105 \qquad (R^2 = 0.84) \qquad (4)$$

Where, $\rho(CO_2)$ is concentration of total carbon dioxide (mg/L),$a_g(440)$ is concentration of absorption coefficient in 440nm of CDOM (m^{-1}).

Table 1 The estimate error value of $\rho(CO_2)$

No.	$a_g(440)$ (m^{-1})	Measured data of $\rho(CO_2)$ (mg/L)	Estimated data of $\rho(CO_2)$ (mg/L)	D-value	Relative error
1	0.10505	26.54304	26.93881	-0.396	1.49%
2	0.113058	26.52696	26.66495	-0.138	0.52%
3	0.128377	26.84454	26.27866	0.566	2.11%
4	0.148402	26.91288	26.04626	0.867	3.22%
5	0.185973	26.5666	26.44355	0.123	0.46%
6	0.206668	25.7314	27.12674	-1.39	5.42%
7	0.242294	27.07826	29.07553	-1.99	7.38%
8	0.289354	36.01416	33.14824	2.866	7.96%

4. APPLICATION MODE

The model will be applied for the Pearl River Estuary to require the spatial distribution graph of the total concentration of CO_2 in water in November 2013.

Select Landsat 8 OLI data, track number 122-44&122-45, acquisition time was November 29, 2013, close to sea investigation time, cloud cover is 3.4% and 11.5%, image quality is good. The data is from geo-spatial data cloud of Computer Network Information Center, Chinese Academy of Sciences. The product is at Level-1T. Generally, after systematical radiometric correction, geometric correction of ground control points, and DEM topographic correction, it can be directly used without geometric correction. According to research requirements, we carried out radiometric calibration of data and converted DN value without physical significance into water-leaving radiance value that can reflect radiometric characteristics of the sea surface. As satellite signals are affected by scattering and absorption of atmospheric molecules and aerosols, in order to obtain true water-leaving radiance value of sea surface, atmospheric correction must be executed before inversion of total CO_2 concentration in the water body. The paper mainly used the FLAASH atmospheric correction module of remote sensing image processing software to complete corresponding atmospheric corrections of remote sensing image. At the same time, in order to improve inversion efficiency, unnecessary images and images with excessive cloud layers were trimmed. MNDWI index model (Xu, 2005) was adopted to extract the water body within the research area. The lower threshold was set as T=0.6 to extract the water body. Then, the CDOM extraction model for Pearl River Estuary proposed by formula (3) and formula (4) (i.e. inversion model of total CO_2 concentration of water body) were applied to the data, so as to obtain the spatial distribution diagram of total CO_2 concentration.

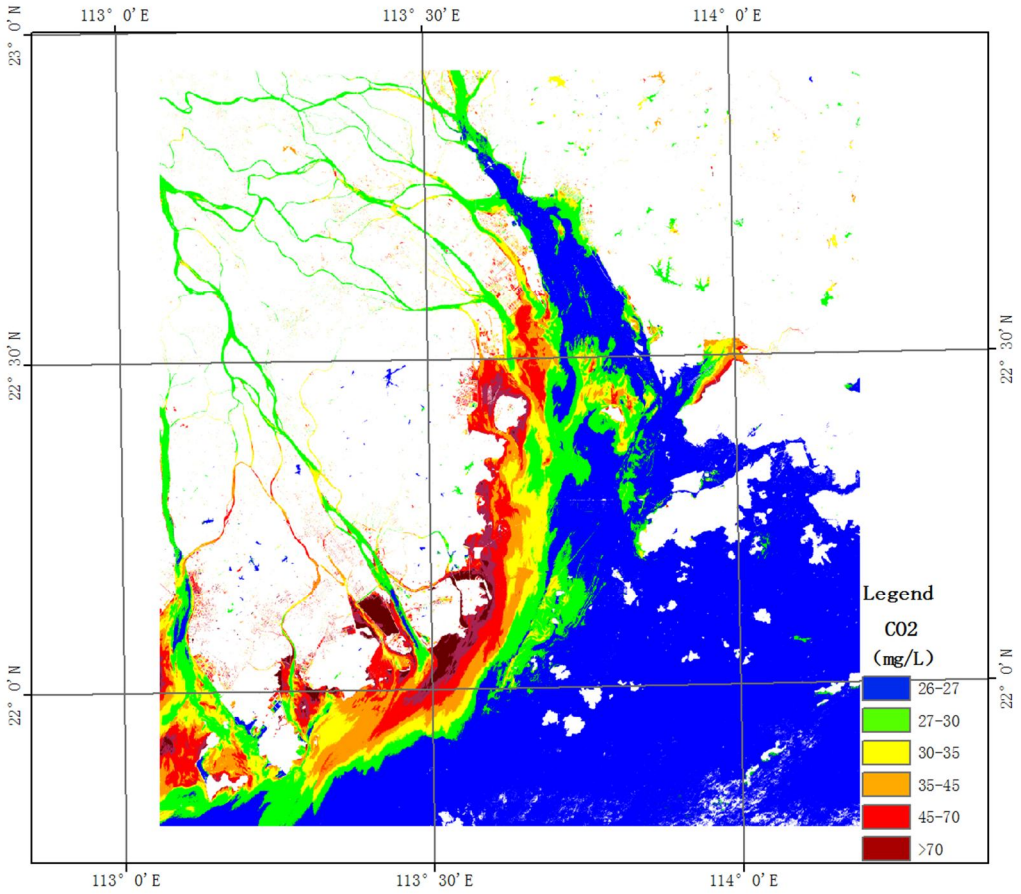

Fig. 3 spatial distribution diagram of total CO_2 concentration.

As shown as figure 3, the total CO_2 concentrations of Pearl River Estuary and adjacent sea areas mainly approximate 26-45mg/L. According to research, the total CO_2 concentration of sea water is 34-56mg/L (Shen, 2002). As the date on which the images were acquired is in winter with low temperature, the solubility of CO_2 reduces, leading to overall reduced CO_2 concentration. In addition, the CO_2 content in euphotic layer is relatively low (Shen, 2002), while water layers below it are added with CO_2 from organic decomposition and have increased CO_2 solubility due to increased pressure. Therefore, the spatial distribution data of total CO_2 concentration obtained from inversion of remote sensing images basically matches with the distribution characteristics derived from actual measuring data. In winter, within Pearl River Estuary sea area, the CO_2 concentration of west coastal sea area is much higher than that of central sea area and east sea area, and the CO_2 concentration of coastal sea area is higher than that of external sea area. So, the data acquired this time is in accordance with the data obtained by actual measuring flights in 2013 and 2014.

5. CONCLUSIONS

The estuary of the Pearl River as an important economic activity area in China, is greatly influenced by human. It is the important meaning to grasp the characteristics of spatial distribution and variation of total CO_2 concentration in the sea water, which affects the level of atmospheric CO_2 and is the decisive factor of the degree of ocean acidification. The article, based on the data which were measured in November 2013 and February 2013, is erecting the model of the distribution of the total concentration via utilizing retrieval of the CDOM as intermediate material which is as the one of three optical characteristics and can be detected by ocean color remote sensing. And the article also carries out the Retrieval of the total concentration of CO_2 which is in the sea area of estuary of the Pearl River in winter by the data of Landsat8 OLI. The result is consistent with the actual measurement data, and provides the basis further understanding CO_2 emissions and source of the South China Sea.

ACKNOWLEDGEMENT

This work was funded by National Natural Science Foundation of China under contract No. 41271364, and supported by program for scientific research start-up funds of Guangdong Ocean University under contract No. E16187.

REFERENCES

Bowers D G, Evans D, Thomas D N.,2004. Interpreting the colour of an estuary. Estuarine, Coastal and Shelf Science, 59, pp13-20

Falkowski P, Scholes R J, Boyle E, et al., 2000. The global carbon cycle: a test of our knowledge of earth as a system. Science, 290, pp. 291-296.

Gu Deyu, Yang Xuling Wang Weiqiang, 1984. The carbon dioxide system in the XiaMen harbor water. Taiwan Strait, 3(2), pp. 144-150.

Huang Miaofen, Wang Difeng, Xing Xufeng, et al., 2015. The research on remote sensing mode of retrieving a_g (440) in Zhujiang River Estuary and its application. Haiyang Xuebao, 37(7), pp. 67-77.

K.-K. Liu, L. Atkinson, et al., 2000. Exploring Continental Margin Carbon Fluxes on a Global Scale. American Geophysical Union, 81 (52), pp. 641-644.

Lewis, Perkin, 1982. Practical salinity scale 1978: Conversion of existing data. Marine Technology, 03, pp. 150-162

Li Tongji, 2006. Marine optical investigation procedures of project 908, China Ocean Press, pp. 136

Lohrenz S E, Cai W J., 2006. Satellite ocean color assessment of air-sea fluxes of CO_2 in a river-dominated coastal margin. Geophysical Research Letters, 33 (1), pp. L01601- L01604.

Millero F J., 1995. Thermodynamics of the carbon dioxide system in the oceans. Geochim Cosmochim Acta, 59 (4), pp. 661-677.

Standardization Administration of the People's Republic of China, 2007. Specifications for oceanographic survey-Part 6: Marine biological survey, pp.10-11

Shen Yingguo, Shi Bhang, 2002. Marine Ecology.China Science Press, pp. 88-89.

Tangjun Wu, Tian Guoliang, et al., 2004. The Methods of Water Spectra Measurement and Analysis Ⅰ: Above-Water Method. Journal of Remote Sensing, 8(1), pp37-44

Xu Hanqiu., 2005. A study on information extraction of water body with the modified normalized difference water index (MNDWI). Journal of Remote Sensing, 9(5), pp. 489-595.