Monitoring and Simulation of CO₂ Exchange of Coastal Wetland Ecosystem in the Liaohe Delta Wetland, China

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Abstract. Eddy correlation technique was used to obtain the carbon fluxes (2012 and 2013) in the coastal wetlands of the Liaohe Delta. The carbon flux daily data were used to validate the biogeochemical models that are parameterized by data such as meteorology and water level (Wetland-DNDC). The observation results showed that the trend of carbon flux in the Liaohe Delta is absorption in growing season and weak discharge in non-growing season. The model results showed significant linear correlation with the observation, the simulation result was relatively correct. The results showed that the trend of Reed output is consistent with that of simulation. The annual carbon sequestration capacity was estimated to be 1502.24g CO₂·m⁻² on an average in the recent 30 years, with a fluctuating increase trend. Further analysis explained the correlation between environmental factors such as temperature, precipitation and CO₂ content and the annual carbon sequestration amount. Correlation between CO₂ content and annual absorption was followed by temperature, with no correlation with precipitation. The carbon sequestration capacity of the Liaohe Delta increases with change of climate.

1. Introduction

Reed is a typical vascular plant in coastal wetlands. Its hollow aeration tissue enables it to keep gas exchange under flooding condition. As the salt tolerance range of Reed can reach 0.3%, the predominant population is easy to form in the coastal wetlands. The total coverage can reach more than 90%, only a small amount of associated species are distributed in lower layer, and the output can reach up to 14-15t/hm². Coastal wetland in the Liaohe Delta is the largest warm temperate coastal wetland in Asia, with the largest Reed wetland area in the world [1]. Although coastal wetlands are important in the global carbon cycle, there is no widely applicable carbon estimation model of ecosystem. Most models don’t consider the dynamic effects of changes in Water table level on greenhouse gas input and output. Li’s (2000)[2] first DNDC model adapts to simulate greenhouse gas emissions from rice ecosystems and so on, it is limited only to paddy fields. As permanent or temporary flooding characteristics of wetland system are different from that of rice, Zhang (2002)[3]develops the Wetland-DNDC model, which is applicable to the CO₂ exchange change forecast for wetland vegetation ecosystems that are driven by hydrology. The model has been validated in simulations of greenhouse gases in wetland ecosystems in different countries[4-7].

This study monitors and obtains the 2-year time series carbon flux daily data, and provides reliable verification data for simulation. As a region dramatically affected by climate change, the Applying eddy correlation technique test model to simulate the greenhouse gas emission/absorption of Reed wetlands in the Liaohe Delta, is very important to improve climatic adaptability of coastal wetlands, adjust the...
structure and function of coastal wetland ecosystems, protect coastal wetlands and enhance carbon sinks. This method also enables us to better predict the trend of future climate change on the carbon balance of wetlands.

2. Methods

2.1. Site Description
Liaohe Delta was located at the junction of estuaries of the Greater Liaohe River, Liaohe River (Shuangtaizi River) and the Daling River, and connected the Bohai Sea. The observation area was selected at the Field Experiment Base of Panjin Wetland Ecosystem, Shenyang Institute of Atmospheric Environment, China Meteorological Administration (40°56′N, 121°58′E) (Figure 1). The dominant vegetation in the area was perennial herb wetland Reed (Phragmites communis). The growing season was from April to October and the flowering season was in August. It began to germinate from the middle to late April and grew buds from underground rhizomes.

2.2. EC Measurements
The EC observation system (Figure 2) was installed at 40°56′29″ N, 121°57′36″ E, and a 90% footprint of the contribution area of the EC observation system was reed. The system consisted of a precision 3-axis sonic anemometer, an open-path CO\textsubscript{2}/H\textsubscript{2}O analyzer (Li-7500, Licor, Lincoln, NE, USA), and data collector (Li-7550, Licor, Lincoln, NE, USA). The CO\textsubscript{2} flux is calculated as:

$$F_c = \bar{w} \rho_c$$

Where $F_c$ is the CO\textsubscript{2} flux, is the instantaneous deviation of the vertical wind speed, and the mean value, i.e., the disturbance value; $\rho_c$ is the instantaneous disturbance value of the CO\textsubscript{2} density; and $w\rho_c$ is the covariance of the vertical wind speed and the CO\textsubscript{2} density.

2.3. Wetland-DNDC model
The model has four interacting components: hydrologic and thermal conditions, plant growth, and soil carbon dynamics. Solid lines are for matter flows, and dashed lines are for information flows. Wetland-DNDC model is available at http://www.dndc.sr.unh.edu, Model simulation framework such as Figure 3 components: Hydrologic and thermal conditions, plant growth, and soil carbon dynamics. Solid lines are for matter flows, and dashed lines are for information flows. Rectangles are for major state variables, and circles are for gas emissions.

The model-driven measured data came from the positioning tests for each parameter and the
literatures in same region that were collected, as well as the model default parameters.

(1) Daily meteorological: This study used daily PRE, daily $\text{Tem}_{\text{max}}$ and $\text{Tem}_{\text{min}}$ that were monitored by the Wetland Microclimate Observation Station from 1984 to 2013, and written into files in the format required by the DNDC model and stored in the model.

(2) Hydrological information: The hydrological data was obtained using the Water table level that was actually observed, and the WTL meter was a WTL gauge (YSI600, YSI, USA).

(3) Atmospheric background CO$_2$ concentration: For the carbon dioxide concentration, the observation results of World Data Center for Greenhouse Gases (WDCGG) were used (2017)[8].

(4) Phyto-physicochemical data: The harvesting method was to randomly obtain the 3 fresh Reed samples on the ground of one-square meter[9]. The root digging method was to obtain root 1m underground. It was killed out at 105°C for 0.5h, dried to constant weight at 80°C. We weighed it and calculated the crown ratio. It was crushed to pass through 60 mesh sieve. The laboratory analysis was conducted for it. Potassium dichromate oxidation method was used directly determinate the organic carbon content in plant parts. The root/shoot ratios in different months were obtained according to the sampling and weighing results (Table 1). The root/shoot ratios from April to September were 119.5, 3.9, 2.0, 1.2, 1.4, and 1.5, respectively. Initial C of system was set to zero due to regular harvesting in January of each year.

Table 1. Carbon density (carbon content) of Reed plant organs.

|                | Leaves | Stems | Fibrous root | Rhizome |
|----------------|--------|-------|--------------|---------|
| Carbon density(g/kg) | 377    | 410   | 298          | 331     |
| SD             | 0.874  | 1.490 | 0.605        | 0.193   |
| CV             | 0.023  | 0.036 | 0.020        | 0.006   |

(5) Physicochemical data of soil: The soil texture of Reed wetland was typical clay by referring to China Soil Database 1998-2010 positioning monitoring data (Database of soil nutrients in natural ecosystems). The physicochemical analysis indexes of soil included soil bulk density, pH (digital pH meter) and soil organic matter (SOM). Other parameters included soil bulk density, soil porosity and saturated hydraulic conductivity.
(6) Land management information: Included historical observation data such as the harvest period, irrigation date, and flood type data. The water irrigation and drainage were conducted once a year, irrigation was in May each year, and the drainage was in September. The harvest period was in early January every year when the soil is completely frozen, and the type of irrigation was set to alternation of wetting and drying. There was no man to add fertilizer.

3. Results

3.1 Simulation results

The eddy observation results showed that the seasonal changes of CO$_2$ exchange in 2012 and 2013 are similar, and the changes are consistent with growth of Reed (Figure 4). Before shoot of Reed grew out in January to mid-April, the daily CO$_2$ emissions gradually increased. After Reed buds grew out in late April - May, the plants were small and had less ability to absorb CO$_2$. From June to July, Reed had larger biomass to large leaf area and had the most vigorous growth, and the absorption flux of CO$_2$ was significantly higher than that of other months, with the maximum daily fluxes of 27.17 g·CO$_2$·m$^{-2}$·d$^{-1}$ (June 26, 2012) and 32.60 g·CO$_2$·m$^{-2}$·d$^{-1}$ (June 22, 2013). The total amount of absorption in June - July accounted for 70% of that in the whole year. In August, the soil respiration increased with rising of temperature, and the Reed transformed from vegetative growth to reproductive growth. The CO$_2$ net absorption flux of Reed community decreased gradually. The CO$_2$ emission from November to February next year wasn’t obvious, the soil frozen litter and soil organic matter decomposed slowly, and the soil respiration made the wetland show weak CO$_2$ emission. It was in the “V” in the growing season and in "U" in the non-growing season. April and September and October when the growing season and the non-growing season connected were months with the largest CO$_2$ emissions in the wetland. The basic exchange of CO$_2$ was 0 in December-January. For observation and comparison of Wetland-DNDC simulation and eddy correlation system, overall trend showed a good correlation (Figure 4). The model more accurately reflected the changes of indexes in stages.

![Figure 4](image1.png)

**Figure 4.** Comparison of observed and simulated daily carbon dioxide fluxes in 2012-2013.

![Figure 5](image2.png)

**Figure 5.** Correlation analysis of between modeled and observed.
All the annual changes were absorption and linear relationship between the two was $y = 1.125x - 0.3075$ and $R^2 = 0.6846$ (Figure 5). The simulation results were relatively correct, but the model didn’t simulate release of carbon by the ecosystem in early growing season. The observed carbon sequestration in 2012 was 2296.84 g·CO$_2$·m$^{-2}$, with a simulated result of 1547.06 g·CO$_2$·m$^{-2}$. The observed carbon sequestration in 2013 was 2296.84 g·CO$_2$·m$^{-2}$, while the simulated result was 1696.5 g·CO$_2$·m$^{-2}$ that is lower. The simulated release amount from January to March was lower than the observed one, and it didn’t simulate the release of carbon by ecosystem in the early growing season.

3.2 Simulation of 1984-2013

The annual average carbon absorption in the Liaohe Delta is 1.50 kg·CO$_2$·m$^{-2}$·a$^{-1}$ (SD±140.34 g·CO$_2$·m$^{-2}$·a$^{-1}$), which means a carbon sink. The interannual variation is significant and rises in a fluctuated manner. Carbon sequestration increases by 73 g·CO$_2$·m$^{-2}$, with the largest carbon sequestrations in 1994, 1997 and 2001. According to statistics of large Reed fields with fixed areas in the Liao River Basin that have been conducted by the statistical bureau since 1994, the average annual output is $5.065 \times 10^4$ t (SD±6.43×10$^4$ t) for the Reed - the air dried matter after harvesting in winter (Liaoning Yearbook, 2016).

As shown in Figure 6, the output data is consistent with the fluctuating trend of carbon dioxide absorbed by simulated unit area, and the Pearson correlation coefficient is 0.771** (significant correlation at 0.01 level), indicating that the model also has some explanatory effects on output of Reed for many years under the artificial control conditions.

![Figure 6. Carbon sequestration simulation and Reed output curve of wetland in the past 30 years.](image)

In the recent 30 years, the CO$_2$ content increased from 344.3 ppm (1984) to 395.8 ppm (2013), with the increase rate of 17.2 ppm·10$^{-1}$·a$^{-1}$. The correlation coefficient between CO$_2$ content and CO$_2$ absorption is the highest (Figure 7a). The Pearson correlation coefficient between the two is $R^2 = 0.439$ (significant correlation at 0.01 level). Average temperature is 9.55°C (Figure 7b) in the past 30 years, and rate of temperature rise is 0.24 °C·10$^{-1}$·a$^{-1}$. The correlation coefficient between the two is $R^2 = 0.201$ (which doesn’t pass the significant test above 0.05 level), indicating that temperature rise is not significantly related to increase of carbon sequestration in Reed wetlands. In the recent 30 years, there are large differences in the annual precipitations between years (Figure 7c), and the correlation coefficient is $R^2 = 0.125$ (which doesn’t pass the significant test above 0.05 level) (Table 2).
4. Conclusions and discussion

Using the eddy correlation technique from 2012 to 2013 to obtain the measured precision data, we verified and corrected the Wetland-DNDC model that is suitable for wetlands in Liaohe Delta. The model took into account climate, soil physiochemical, soil carbon cycle, plant carbon cycle and hydrological process and obtained daily results of carbon flux. The simulated values and the eddy measured values reached a good fit on the two-year time scale, with $R^2$ of 0.68. There were a trend of absorption in growing season and a weak discharge in the non-growing season, of which the absorption from June to July accounted for 70% of that in the whole year. Carbon exchange in the Liaohe Delta in the past 30 years were analyzed through simulation, and the results showed that annual variation is significant, and the simulated value and statistical data of Reed output reached a very good fit at the 20-year time scale. It affects the succession direction of Reed population. The appropriate water conditions are in favor of development of Reed population.

Eddy correlation method validated the daily carbon flux data and output data verified the annual carbon sequestration data. The average carbon sequestration in Liaohe Delta of 1.50 kg·m$^{-2}$ is close to that of Reed wetlands in the Yangtze River Delta (1.63 kg·m$^{-2}$) and in the Yellow River Delta (1.56 kg·m$^{-2}$) [10], which is equivalent to 4 times of the average carbon sequestration capacity of Chinese terrestrial plants and 5 times of that of global vegetation [11] and is a huge carbon sink. Although the wetlands in Yellow River Delta and Liaohe Delta are similar in size, only about 20% of the wetlands in Yellow River Delta are covered by Reed and common seepweed herb, so that the total carbon sequestration capacity is lower than that of Liaohe Delta [12]. The statistics of Reed output in this area for many years were used for verification and the results showed that the trend of Reed output in this wetland is consistent with that of simulation. Studies showed that there is a good correlation between wetland carbon sequestration and CO$_2$ concentration, the future change of background CO$_2$ concentration affects the carbon sequestration of wetland. As CO$_2$ background concentration and air temperature increase, the CO$_2$ absorption capacity of coastal wetlands in Liaohe Delta increases.

Acknowledgments

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