Temporal variations of CO₂ concentration near land surface and its response to meteorological variables in Heihe River Basin, northwest China

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Abstract: Atmospheric CO₂ concentration (CC) near land surface and meteorological variables have been measured at four sites, named Yeniugou (alpine meadow and permafrost), Xishui (mountainous forest), Linze (oasis edge) and Ejina (lower desert), respectively, in Heihe River Basin, northwest China. The results showed that, the half-hourly CC at night was larger than during daytime, and the daily averaged CC was the largest in winter. The averaged CC of 932 ppm at the Linze was about 418 ppm, was about 366 ppm in the 762 d at the Ejina. In the same period from September 23 to November 9, 2004, the averaged CC was about 625, 334, 436 and 353 ppm, at Yeniugou, Xishui, Linze and Ejina, respectively. The linear relationship between daily averaged CC and air temperature T was negative, between CC and relative humidity (RH) was positive. The linear CC-atmospheric pressure (AP) relationship was negative at the Linze and Yeniugou, was positive at the Ejina. The relationship between CC and global radiation R was exponent, and soil temperature T was negative linear, and soil water content was complex. The correlation between CC and wind speed was not existent. Using meteorological variables together to simulate CC, could give good results.

Keywords: CO₂ concentration; meteorological variables; Heihe River Basin

Introduction

Worldwide concern with global change and its effects on the environment requires a better understanding and quantification of the processes contributing to global change (Fang and Moncrieff, 2001). The increase in the concentration of atmospheric carbon dioxide since the mid-nineteenth century is now well documented (Houghton et al., 1996). It is generally accepted that the continuous increase in atmospheric CO₂ is attributed to human activities, of which burning fossil fuel makes up the largest portion, and the CO₂ concentration (CC) in the air is rising with increasing human activities (Duan et al., 2001). The amount of organic C and human activities in arid regions is relative rare, and the arid ecosystem is very sensitive to climate change (West et al., 1994). Accurate measurements of CC in arid regions where the CO₂ data are deficient, not only could provide input for global warming models (Raich and Schlesinger, 1992; Bowden et al., 1993; Holland et al., 1995; Thierion and Laudelout, 1996; Lavigne and Ryan, 1997; Buchmann and Schulze, 1999; Schlesinger and Andrews, 2000), but also could quantity the relationship between CC and meteorological variables (Edwards, 1975; Brunnell et al., 1977; Buyanovsky et al., 1986; Howard et al., 1993; Davidson et al., 2000; Ouyang and Zheng, 2000). Here we present the spatial and temporal variations of atmospheric CC near land surface and the CC-meteorological variables relationships in Heihe River Basin of the Arid Regions of northwest China (ARNC).

1 Materials and methods

1.1 Site description

The four sites (Table 1) in this study locate in the Heihe River Basin. Heihe River, originating from the Qilian Mountains, running through the Hexi Corridor and scattering in the deserts, is one of the largest inland rivers in ARNC, with a drainage area of 130000 km².

1.2 CO₂ concentration and microclimate

An ENVIS system EERIL 3 (Environmental monitoring system for Cold and Arid Region Environmental and Engineering Research Institute, Lanzhou) (IMKO GmbH) was used at each site. The data logger read the data every half an hour.

The EERIL 3 measures soil volume water content (W (%)), liquid, TRIME-EZ (IMKO), soil moisture suction (Pa) and soil temperature (T, °C), T8, IMKO) at 7 soil layers (0-160 cm depth). The system also measures atmospheric pressure (AP (Pa), PTB100, Vaisala), CO₂ concentration (CC (ppm), GMM222, Vaisala), air temperature (T (°C), HMP45D, Vaisala), relative humidity (RH (%), HMP45D, Vaisala), global radiation (R (W/m²), CM7B, Kipp and Zonen), wind speed (W, (m/s), LISA, SG GmbH), wind direction (RITA, SG GmbH) and precipitation (P (mm), RGS50, SH GmbH). There are also 3 probes to measure soil heat flux (H, (W/m²)), HPFO1, Campbell) at 5 cm depth, several probes to meaure sapflow, and the system could be added other sensors according to the

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research requirements.

Atmospheric CC probe, based on NDIR Single-Beam Dual-Wavelength principle, was installed at 2.5 m height above ground at the four sites. The GMM220 series modules incorporate the industrial CARBOCTA Sensor. Its curial parts are made of silicon; this gives the sensor outstanding stability over both time and temperature. Since water vapor, dust and most chemicals do not affect the measurements, the GMM220 series modules can be used in harsh and humid environments. For the requirements of the long-term field works in the environment with large variation of air temperature, the GMM220 probe was chosen. The GMM220 probe is stable in a 2-year period, and it can be removed, reattached or replaced at any time without the need for calibration and adjustment. However, the accuracy of the GMM220 is relatively low, with a value of ±20 ppm (including repeatability and calibration uncertainty) at the 25°C (http://www.vigo.com.pl/dane/apk/gazy/GMM220 Kat.pdf). The GMM220 probe at the Ejina and Linze sites was installed in May, 2002, while the probe at the Xishui and Yenigou sites was installed in September, 2004. The GMM220 probes at the Ejina and Linze sites were replaced with 2 new probes in May, 2004, and the replaced ones would be sent to VAISALA for calibration, using the same gas standards.

2 Results and discussion

2.1 Variations of atmospheric CO2 concentration

The atmospheric CC at night was larger than at daytime in growing season (Fig.1a) because of the difference between vegetation respiration and photosynthesis process (Julie et al., 2002; Miyama et al., 2003), although the CO2 efflux from soil surfaces to the atmosphere was low due to the lower soil temperature at night (Kabwe et al., 2002; Scala et al., 2003; Maestre and Cortina, 2003). In non-growth season, the CC was also larger at night (Fig.1b). At the time, the vegetation respiration and photosynthesis processes were rare and the CO2 efflux from soil surface was very low according to the positive correlation between CO2 efflux and soil temperature (Edward, 1975; Brunnell et al., 1977; Buyanovsky et al., 1986; Howard and Howard, 1993; Davidson et al., 2000; Ouyang and Zheng, 2000; Elberling, 2003). Why the CC was higher at night than at daylight time in un-growth season? It may be caused by the variance of atmospheric pressure (Fig.1c and Fig.1d), or by the decomposition of soil microorganism, or other unknown factors. The similar results were also found at Phoenix, USA (Sherwood et al., 2002).

The atmospheric CC was the largest in winter, and the least in summer at the Linze and Ejina sites (Fig. 2). Although the CC data at the Xishui and Yenigou sites were only measured in autumn, one could deduce the same results from its varied trend in Fig.2. In winter, the vegetation photosynthesis processes stopped, and human burning fossil fuel for warm made up, thus the CC increased.

From Fig.2 and Table 2, during the period from 23 Sep. to 9 Nov., 2004, when the CC were measured at all the 4 sites, the CC at the Yenigou was the largest, where the precipitation was the most, the air temperature was the lowest, the soil water content was the highest, and the soil temperature is low. The CC at the Ejina was very low, where the precipitation was least (Table 1 and Table 2), the soil organic C was very low because of its desert landform, and the human activity was few. The CC in the end of the growing season at the Xishui was the least (Table 2) because of respiration processes of forest and bush wood that could absorb massive CO2. The human activity at the Xishui was also very rare. Kurganova et al. (2003) reported that the CO2 efflux from soil
surface to atmosphere was larger in cold seasons than in warm period, and was larger from grass underlying surface than forest soil in Russia, which was similar to the variations of atmospheric CC in Heihe River Basin (Table 1, Fig.2 and Table 2).

2.2 Relationship between CC and meteorological variables

Relationships between CC and meteorological variables are shown in Figs. 3, 4 and 5 and in Tables 3, 4 and 5. The F-test method (Snedecor and Cochran, 1989) was used to evaluate the significance of the correlativity.

The relationship between daily averaged CC and $T$ was negative linear (Fig.3a, Fig.4a, Fig.5a and Fig. 6a) that was different from the positive relationship between CO$_2$ efflux from soil surface to atmosphere and $T$ (Fang and Moncrieff, 2001), and the correlation was the highest at the Linze, Ejina and Xishui (Fig.3a, Fig.4a and Fig.6a) among the relationships between CC and meteorological variables. The relationship between CC and RH at the Linze and Ejina was positive linear with relatively high $R^2$ value (Fig.3b and Fig.4b). The relationships between CC and RH at Yeniougou and Xishui were not notable (Fig.4b and Fig.5b), and the reason might be the daily data series at these two stations were too short. The linear CC-AP relationship was negative at Linze and Yeniougou (Fig.
The relationship between \( CC \) and \( W \) (the measured data were liquid) was not evident at the Linze and Ejina. At the Linze, when \( W \) was larger than about 60%, the \( CC \) was little affected by \( W \) (Figs. 3i-1). When \( W \) was less than about 60%, there were evident two or more linear relationships between \( CC \) and \( W \) as shown in Figs. 3i-1. Similar phenomenon was also found at the Ejina (Fig.4e). The phenomenon showed that, in different soil water transfer process, the response of \( CC \) to \( W \) was different. While at the Yenigou and Xishui, the linear relationship between \( CC \) and \( W \) at most soil profile was evident (Tables 4 and 5). Because that the data at these two stations were only measured in late autumn to early winter, 2004, and the soil water transfer process was consistent.

The correlation relationship between \( CC \) and \( W \), was not existent in daily scale, and at each station, the relationship between these two variables was similar.
Fig. 4. Relationship between CO₂ concentration (CC) and meteorological variables at the Ejina.
T: air temperature, RH: relative humidity, AP: atmospheric pressure, R: global radiation, W: soil liquid water content;
F-test: a: F-value=2140.42, α=0.01; b: F-value=966.48, α=0.01; c: F-value=1391.9, α=0.01; d: F-value=1500, α=0.01.

Table 4: Relationships between daily average CO₂ concentration (CC) and soil temperature (T) and soil liquid water content (W) at different soil profiles at Yiningou.

<table>
<thead>
<tr>
<th>Soil depth, cm</th>
<th>Relationship</th>
<th>R²</th>
<th>F-value</th>
<th>F-test</th>
<th>Relationship</th>
<th>R²</th>
<th>F-value</th>
<th>F-test</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>CC=−2.6W+690.4</td>
<td>0.56</td>
<td>124</td>
<td>α=0.01</td>
<td>CC=−4.0T+635.7</td>
<td>0.65</td>
<td>165</td>
<td>α=0.01</td>
</tr>
<tr>
<td>20</td>
<td>CC=−3.9W+712.0</td>
<td>0.60</td>
<td>147</td>
<td>α=0.01</td>
<td>CC=−5.1T+641.3</td>
<td>0.58</td>
<td>135</td>
<td>α=0.01</td>
</tr>
<tr>
<td>40</td>
<td>CC=−3.0W+711.9</td>
<td>0.52</td>
<td>105</td>
<td>α=0.01</td>
<td>CC=−9.0T+663.1</td>
<td>0.60</td>
<td>142</td>
<td>α=0.01</td>
</tr>
<tr>
<td>60</td>
<td>CC=−3.6W+731.3</td>
<td>0.37</td>
<td>57</td>
<td>α=0.01</td>
<td>CC=−11.3T+674.2</td>
<td>0.60</td>
<td>146</td>
<td>α=0.01</td>
</tr>
<tr>
<td>80</td>
<td>CC=−7.5W+774.5</td>
<td>0.28</td>
<td>37</td>
<td>α=0.01</td>
<td>CC=−6.8T+652.0</td>
<td>0.59</td>
<td>139</td>
<td>α=0.01</td>
</tr>
<tr>
<td>120</td>
<td>CC=−62.3W+1486.8</td>
<td>0.05</td>
<td>4.9</td>
<td>α=0.05</td>
<td>CC=−17.6T+699.4</td>
<td>0.59</td>
<td>137</td>
<td>α=0.01</td>
</tr>
<tr>
<td>160</td>
<td>CC=148.6W−497.2</td>
<td>0.32</td>
<td>44</td>
<td>α=0.01</td>
<td>CC=−15.2T+692.6</td>
<td>0.60</td>
<td>142</td>
<td>α=0.01</td>
</tr>
<tr>
<td>0—160</td>
<td>CC=−5.8W+743.7</td>
<td>0.57</td>
<td>130</td>
<td>α=0.01</td>
<td>CC=−7.8T+654.7</td>
<td>0.62</td>
<td>154</td>
<td>α=0.01</td>
</tr>
</tbody>
</table>

Table 5: Relationships between daily average CO₂ concentration (CC) and soil temperature (T) and soil liquid water content (W) at different soil profiles at Xishui.

<table>
<thead>
<tr>
<th>Soil depth, cm</th>
<th>Relationship</th>
<th>R²</th>
<th>F-value</th>
<th>F-test</th>
<th>Relationship</th>
<th>R²</th>
<th>F-value</th>
<th>F-test</th>
</tr>
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<tbody>
<tr>
<td>0</td>
<td>CC=−0.9W+348.4</td>
<td>0.45</td>
<td>37</td>
<td>α=0.01</td>
<td>CC=−1.2T+333.4</td>
<td>0.47</td>
<td>40</td>
<td>α=0.01</td>
</tr>
<tr>
<td>20</td>
<td>CC=−1.8W+356.9</td>
<td>0.14</td>
<td>7.7</td>
<td>α=0.01</td>
<td>CC=−1.8T+338.4</td>
<td>0.46</td>
<td>40</td>
<td>α=0.01</td>
</tr>
<tr>
<td>40</td>
<td>CC=15.0W+134.6</td>
<td>0.41</td>
<td>32</td>
<td>α=0.01</td>
<td>CC=−2.2T+341.1</td>
<td>0.47</td>
<td>40</td>
<td>α=0.01</td>
</tr>
<tr>
<td>60</td>
<td>CC=29.1W+257.3</td>
<td>0.19</td>
<td>11</td>
<td>α=0.01</td>
<td>CC=−2.7T+342.7</td>
<td>0.46</td>
<td>40</td>
<td>α=0.01</td>
</tr>
<tr>
<td>80</td>
<td>CC=−1.2W+358.3</td>
<td>0.19</td>
<td>11</td>
<td>α=0.01</td>
<td>CC=−3.1T+345.5</td>
<td>0.47</td>
<td>40</td>
<td>α=0.01</td>
</tr>
<tr>
<td>120</td>
<td>CC=−41.0W+980.0</td>
<td>0.43</td>
<td>34</td>
<td>α=0.01</td>
<td>CC=−4.5T+352.1</td>
<td>0.49</td>
<td>43</td>
<td>α=0.01</td>
</tr>
<tr>
<td>160</td>
<td>CC=32.9W+819.1</td>
<td>0.52</td>
<td>50</td>
<td>α=0.01</td>
<td>CC=−6.2T+359.9</td>
<td>0.48</td>
<td>42</td>
<td>α=0.01</td>
</tr>
<tr>
<td>0—160</td>
<td>CC=3.4W+389.8</td>
<td>0.36</td>
<td>25</td>
<td>α=0.01</td>
<td>CC=−2.5T+341.3</td>
<td>0.49</td>
<td>43</td>
<td>α=0.01</td>
</tr>
</tbody>
</table>

to that in Fig. 6d.

2.3 General responses of CC to meteorological variables

From Section 2.2, there were some correlations between CC and each measured meteorological variable. That was to say that, the CC was affected by
the most observed meteorological variables. The general responses of $CC$ to meteorological variables were shown in Eqs. (1)–(4) and in Fig. 7.

Linze:

$$CC = -2.8T + 0.2R + 1.2A_P + 387.3e^{-0.15} - 0.6T - 99934.6$$  \hspace{1cm} (1)

where $T$ was $T$, at 20 cm depth. The $F$-test value of Eq. (1) is 2910, which is much larger than the standard $F$-value (about 3.0) when $alpha=0.01$.

Ejinra: $CC = -4.7T + 0.2R + 0.005A_P + 31.8e^{-0.012}$

$+ 0.2T - 42.4$  \hspace{1cm} (2)

Xishui: $CC = -1.6T + 0.03R - 0.01R + 1.1A_P - 0.3W_s$ 

$+ 2.0W - 0.4P - 340.1$ \hspace{1cm} (3)

where $W$ was soil surface liquid $W$.

Yeniugou: $CC = -3.4T + 0.2R + 0.01A_P + 249.3e^{-0.004}$

$- 2.1T + 2.2W + 5.4W - 172.5$ \hspace{1cm} (4)

where $T$ is $T_s$ at soil surface. The $F$-test value of Eqs. (2)–(4) is of 4658, 17 and 109, respectively, which is much larger than the standard $F$-value (about 3.0, 3.1 and 2.9, respectively) when $alpha=0.01$.

From Fig. 7, the simulation results were very good except that at the Xishui. Although the simulation results were not very good at the Xishui, the $R^2$ value was larger than the $R^2$ value of any correlation in Fig. 6 and Table 5. The simulation results at the Yeniugou were much better than the correlation between $CC$ and any single meteorological variable (Fig. 5 and Table 4).

3 Conclusions
The half hourly atmospheric CO₂ concentration (CC) near land surfaces in Heihe River Basin was larger at night than in daytime in both the growing season and the un-growth season.

The daily averaged CC was larger in winter than in other seasons at the four sites in Heihe River Basin. From alpine meadow (Yeniugou), oasis edge (Linze), to lower desert (Ejin) of Heihe River Basin, the daily averaged CC decreased along with the decrease of altitude. The CC of mountainous forest (Xishui) is low because of the high forest cover. During the observed period, the daily averaged CC was about 625, 335, 436 and 353 ppm, at the Yeniugou, Xishui, Linze and Ejin, respectively.

The linear relationship between daily averaged CC and air temperature T was negative, between CC and relative humidity RH was positive. The linear CC-atmospheric pressure AP relationship was negative at the Linze and Yeniugou, was positive at the Ejin. The relationship between CC and global radiation R was exponent, and soil temperature Tₛ was negative linear, and soil water content was complex. The correlation between CC and wind speed was not existent. Using above meteorological variables together to simulate CC, could give good results.

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