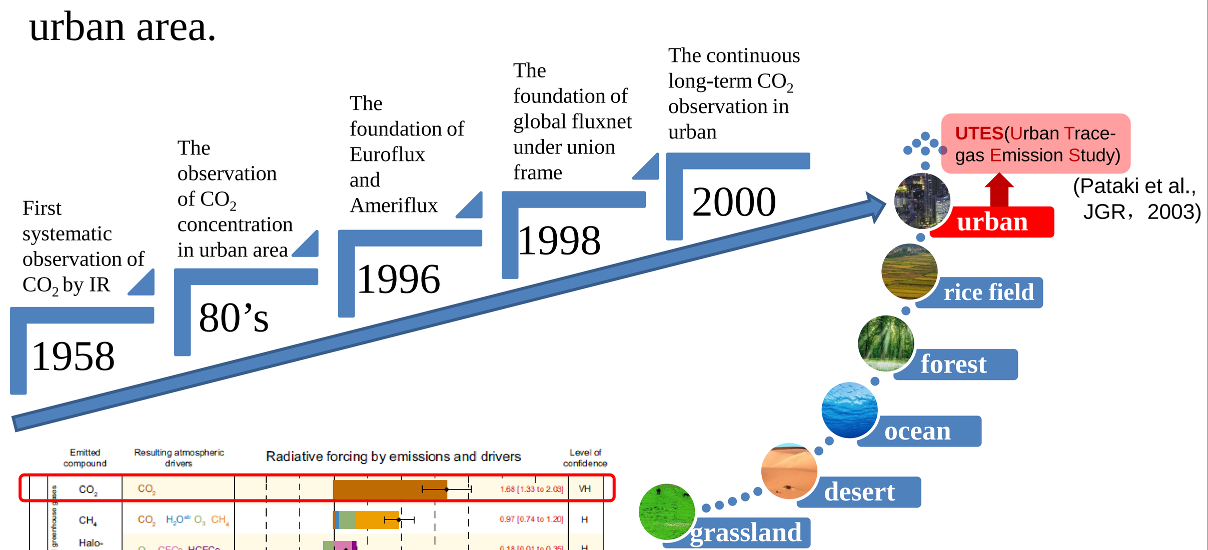
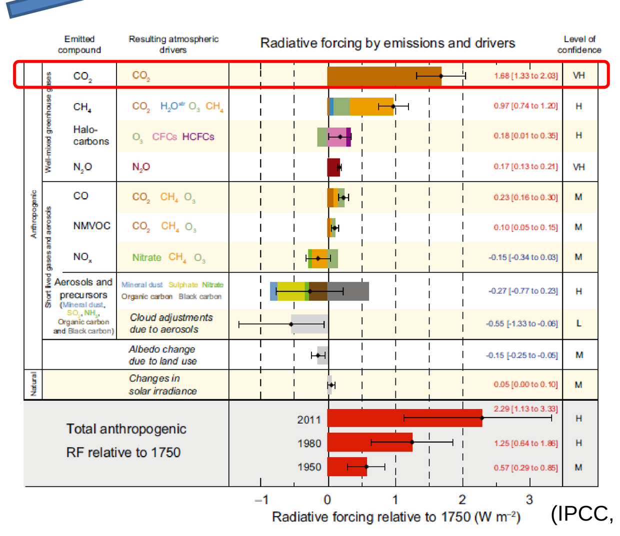
Characteristics of CO_2 Concentration and Flux in Beijing Urban Area

Xueling CHENG*, Yujue LIU, Xiaoman LIU, Fei HU
LAPC, Institute of Atmospheric Physics, Chinese Academy of Sciences, Beijing, 100029
*contact: chengxl@mail.iap.ac.cn

Introduction

As one of the most important green house gas discharged by human daily activities, CO_2 concentration in urban area showed a significant augment tendency in recent years. Under this background, the "Strategic Priority Research Program - Climate Change: Carbon Budget and Relevant Issues" of the Chinese Academy of Sciences has been implemented. Our work is to study the characteristics of CO_2 concentration and flux in the urban area.





(IPCC, 2013)

Outcome
Urban CO_2 Emission inventory;
Source (gasoline combustion) and convergence (Vegetation photosynthesis) of urban CO_2;
NEE of urban CO_2…

Shortcoming
Short observation period;
Lack of knowledge on vertical distribution;
Complex turbulence flux in urban…

The observation data

With the turbulence data measured by open path eddy covariance system of Beijing 325m meteorological tower, CO_2, H_2O, and wind field data of 10 Hz at 7 different heights were measured from February 2012 to now.

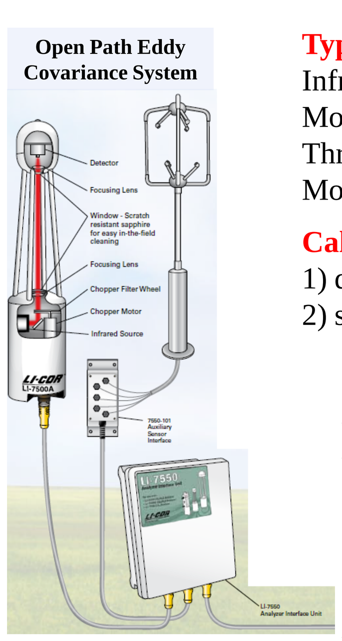

(Song and Wang, AR, 2012)

Beijing is the capital of China, and is a mega city whose environmental effects are focused on by sciences. Beijing 325m tower records the change of the urban, and is useful to study the CO_2 flux change in urban.

Beijing 325m Synthetic Meteorological Tower under urban heterogeneous layer

The tower, built in August 1979, is located in 39° 58′N, 116° 22′E, whose elevation is 49m. It is 1km north form the 3rd Ring Road, and 200m west of the north-south Beijing—Tibet Expressway, and 50m south of the east-west Beitucheng West Road. The average building height was approximately 50m in the southern direction and approximately 20m in all other directions.

Quality Control



(Li-7500 Instruction Manual, 2009)

Type
Infrared Gas Analyzer
Model Li7500, Li-Cor Inc, Lincoln Nebraska, USA;
Three Dimensional Ultrasonic Anemometer
Model Windmaster Pro, Gill Instruments Ltd, Hampshire, UK.

Calibration
1) determining the values of calibration coefficients;
2) setting zero and span.

Accuracy

Windmaster Pro				Li-7500			
Value	Unit	Frequency	Accuracy	Value	Unit	Frequency	Accuracy
u	m/s	10Hz	<1.5% RMS	ρ_c	ppm	10Hz	<1% of reading
v	m/s	10Hz	<1.5% RMS				
w	m/s	10Hz	<1.5% RMS	ρ_v	mmol/mol	10Hz	<2% of reading
T_s	℃	10Hz					

10Hz Original Data

Pre-processing
1. Determine average period
2. Despike (threshold, precipitation, icing, etc.)
3. Coordinate rotation (DR)

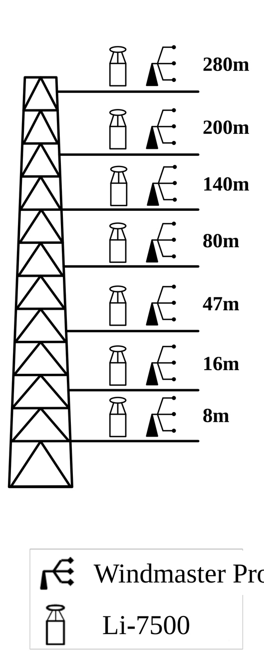
Flux revision
1. Flux calculation by Eddy Covariance
2. Frequency response correction
3. Ultrasonic virtual temperature correction
4. WPL

Quality Assessment
1. Turbulence steady state test
2. Turbulence development test
3. Synthetical test
4. Abandonment class 9 data

Output
1. Original data and half averaged values
2. Turbulence flux (EC term, storage term, horizontal advection term)
3. Boundary layer parameters (average elements, roughness, stability)

Installation

- **Height:** 8m, 16m, 47m, 80m, 140m, 200m, 280m.
- **Location:** in the northwest boom faced prevailing wind.
- **Maintenance:** to calibrate, clean, and repair regularly.



Debugging

- On March 8, 2012,the initial assembly was completed, and the data was continuously collected.
- On May 8, 2012, data loss, instrument debugging, equipment back to the factory, etc.
- On July 8, 2012, data was complete, the quality of data was tested.
- On Dec. 1, 2012, the data on 7 levels were recorded completely and continuously.

Data

- From Dec. 1, 2012 to Dec. 31, 2015.

Despiking

•Threshold

$|i-\bar{x}|>4\sigma$, i is original data, $\bar{x}$ is 30min averaged value, σ is standard deviation (Vickers and Mahrt, J. Atmos. Ocean Tech., 1997; Guo et al., Science China D, 2008).

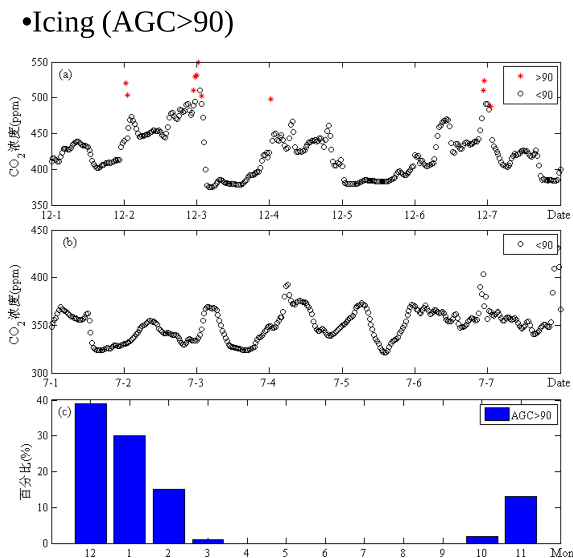
•Precipitation

1h before and after precipitation, during the period of precipitation.

•Abnormality

diag>255 including Hard Spikes caused by outage etc, and Soft Spikes caused by unsteady power

•Icing (AGC>90)


AGC>90 in (a)Dec 1-7,2012, (b)July 1-7, 2013, (c)Dec. 1, 2012- Nov. 30, 2013

Air density fluctuation correction

1) **WPL** (Webb et al., Quart. J .R. Met. Soc.,1980)
It is assumed that the dry air mass conservation is to eliminate effects of the expansion and the compression of dry air on the CO_2 flux.

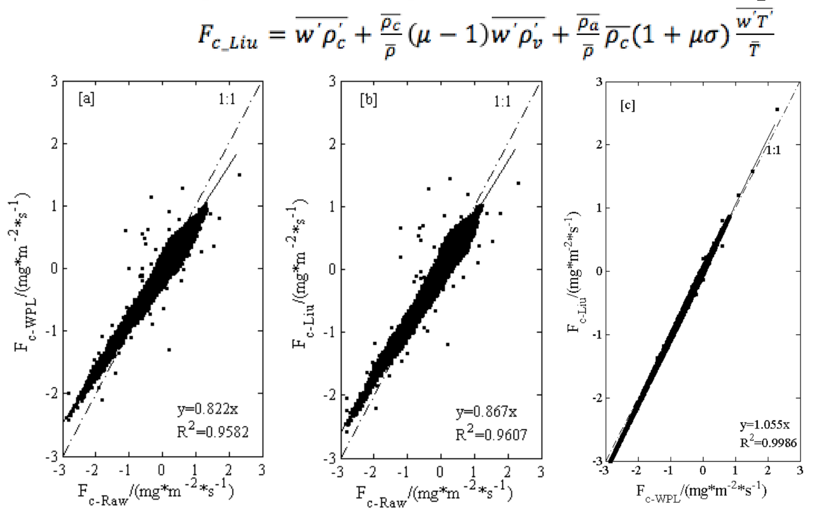
$$Fc_{wpl} = \overline{w'\rho_c'} + \mu \cdot \frac{\overline{\rho_c}}{\overline{\rho_a}} \cdot \overline{w'\rho_v'} + (1+\mu\sigma) \cdot \overline{\rho_c} \cdot \frac{\overline{w'T'}}{\overline{T}}$$

2) **Revised WPL** (Dijk et al., https://www.researchgate.net/publication/40123739_The_principles_of_surface_flux_physics_Theory_practice_and_description_of_the_ECPACK_library, 2004)
In the software library ECPACK of eddy covariance method, the mean vertical velocity and flux exchange with the surface of heat, water vapor and horizontal momentum.

$$Fc_{ECPACK} = \overline{w'\rho_c'} + \mu\frac{\overline{\rho_c}}{\overline{\rho_a}}\overline{w'\rho_v'} + (1+\mu\sigma+k)\overline{\rho_c}\frac{\overline{w'T'}}{\overline{T}} + 2k\overline{\rho_c}\frac{\overline{w'u'}}{\overline{u}}$$

3) **Liu method** (Liu et al., BLM 2005)
From the of expansion and compression of moist air, the CO_2 flux is derived.

$$F_{c\_Liu} = \overline{w'\rho_c'} + \frac{\overline{\rho_c}}{\overline{p}}(\mu-1)\overline{w'\rho_v'} + \frac{\overline{\rho_a}}{\overline{p}}\overline{\rho_c}(1+\mu\sigma)\frac{\overline{w'T'}}{\overline{T}}$$

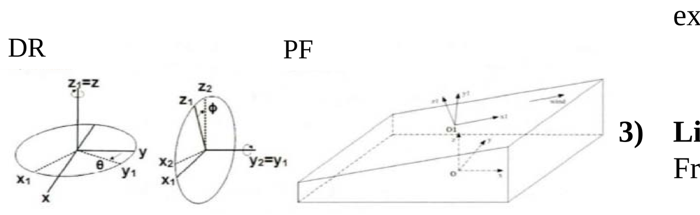


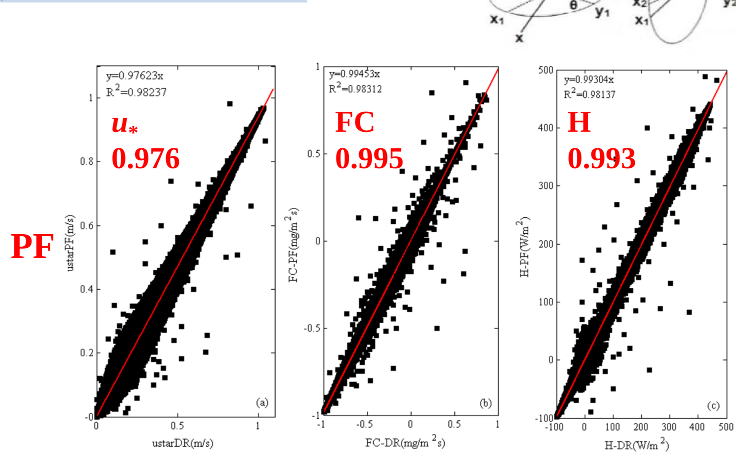
Data are get from Dec. 2012 to Dec. 2013, dots are the half hour averaged values of 1st and 15th in every month, and total numbers are 8064.

Comparison
1. All revised methods made CO_2 flux decrease.
2. The revised amplitude of WPL method is a little larger than that of Liu method.

Coordinate Rotation

a) Double rotation
b) Planar fit

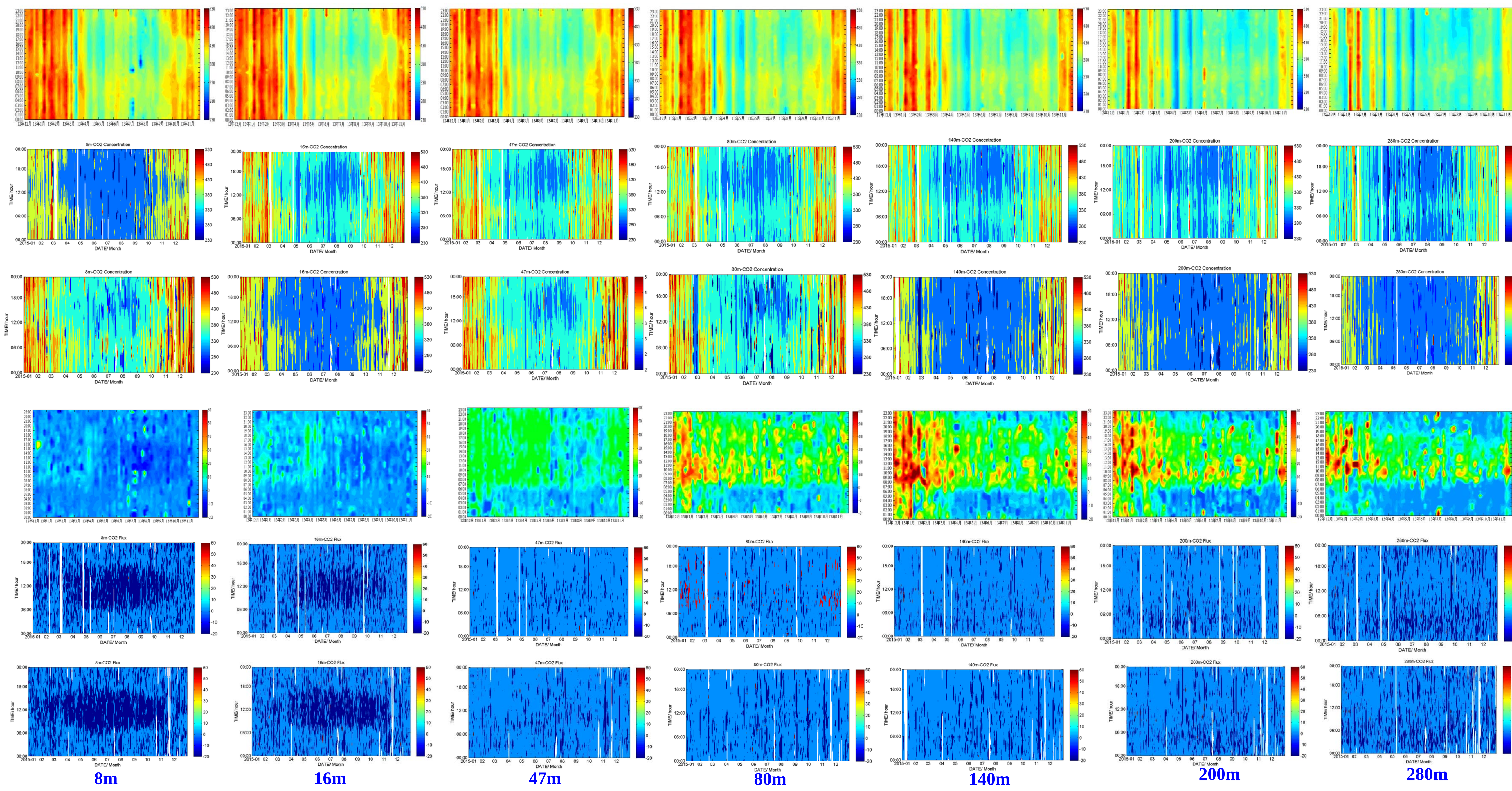




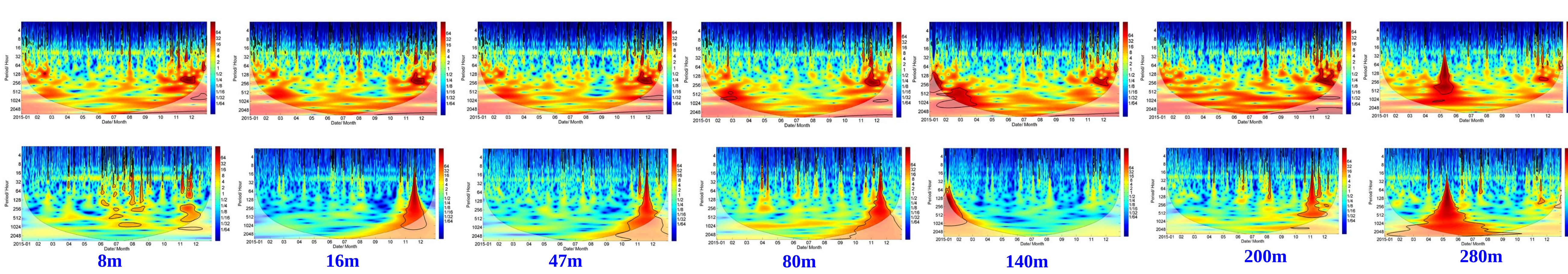
Data are get from Dec. 2012 to Dec. 2013, dots are the half hour averaged values of 1st and 15th in every month, and total numbers are 8064.

Comparison
1. The revised results are almost same, only a little less by PF than that by DR.
2. The site of 325m tower is flat, so DR is more suitable here than PF.

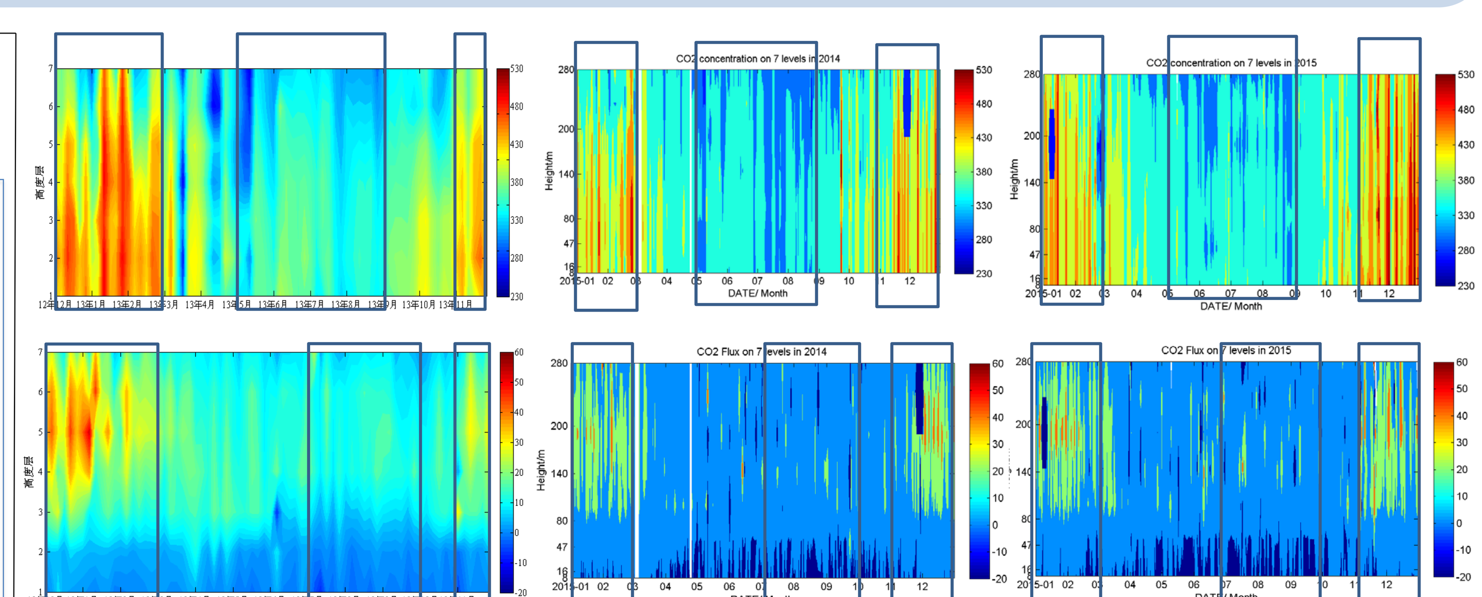
CO_2 concentration and flux from 2013 to 2015 on seven levels



Diurnal pattern of CO_2 concentration (the upper three lines in 2013, 2014, and 2015, the legend unit is ppm) and CO_2 flux (the lower three lines in 2013, 2014, and 2015, the legend unit is μmol/m⁻²s⁻¹) of monthly averaged. The abscissas are 12 months in a year, and the ordinates are 24 hours in a day. Both the CO_2 concentration and CO_2 flux decrease year after year. The positive fluxes represent net efflux, whereas negative values represent net uptake, of CO_2 by the environment. And the efflux above 80m decreased from 2013 to 2015 because the "Atmospheric Pollution Prevention and Control Action Plan" released by the Chinese State Council on September 10, 2013.

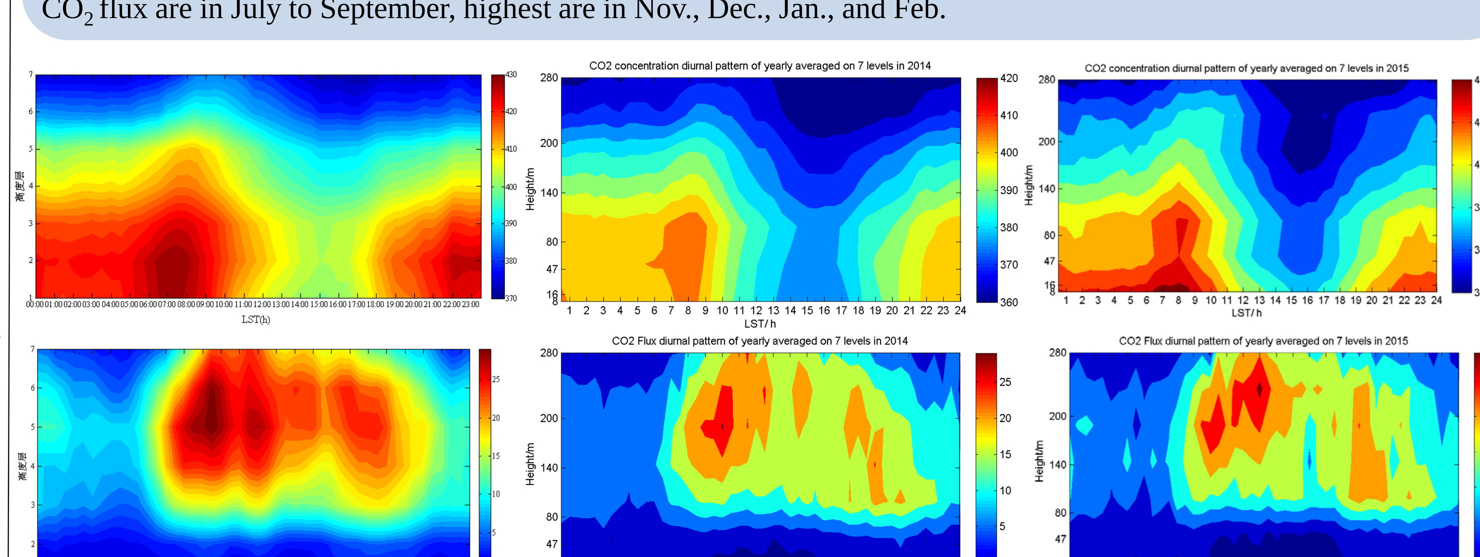


The local wavelet power spectrum of CO_2 concentration (upper line) and CO_2 flux (lower line) using the Morlet wavelet, normalized by $1/\sigma^2$. The left axis is the Fourier period (in hr). The bottom axis is time (month). The shaded contours are at normalized variances whose magnitudes are presented by the legend. The thick contour encloses regions of 5% significance level against red noise. The lighter shade regions on either end indicate the cone of influence (COI), where edge effects become important. Strong variations of the wavelet coefficients were observed. There are clearly common features in the wavelet power of CO_2 concentration on different levels such as the significant peak in the 256 hr band around December. And on 280m height, there are high power in the 32–512 hr band on May. The factors to form these periods should be studied. For CO_2 flux, it seems not be common on different levels, there are several significant peaks in summer near the ground, and peaks in winter below 280m, where the peak is from spring to summer on 280m height. The matlab wavelet coherence package can be download in http://noc.ac.uk/using-science/crosswavelet-wavelet-coherence (Grinsted et al., NPG, 2004).



The first line is CO_2 concentrations on 7 levels in 2013, 2014, 2015. The annual averaged CO_2 concentrations are 407.3ppm, 383.2ppm, 391.8ppm in 2013, 2014, 2015 respectively. the lowest CO_2 concentrations are in May to August, highest are in Nov., Dec., Jan., and Feb.

The second line is CO_2 flux on 7 levels in 2013, 2014, 2015. The annual averaged CO_2 fluxes are 26.3 kg m⁻²y⁻¹, 13.8 kg m⁻²y⁻¹, 12.9 kg m⁻²y⁻¹ in 2013, 2014, 2015 respectively. Comparing to 20.6 kg m⁻²y⁻¹ in 2008 (Song and Wang, AR, 2012), the flux increased 27.7% in 2013, and decreased 33%, 37.4% in 2014 and 2015 respectively. The lowest CO_2 flux are in July to September, highest are in Nov., Dec., Jan., and Feb.



The first line is CO_2 concentrations diurnal pattern of yearly averaged in 2013, 2014, 2015 on 7 levels. There is a "double peak" type, the morning peak begins at 5:00 o'clock, crests at 7:00-8:00 o'clock, decreases at 9:00 o'clock; the evening peak begins at 18:00 o'clock, crests at 22:00-23:00, then decreases. The valley is at 15:00.

The second line is CO_2 flux diurnal pattern of yearly averaged in 2013, 2014, 2015 on 7 levels. Above 47m, there is a "triple peak" type, the morning peak is at 9:00, noon peak is at 12:00, evening peak is at 18:00. Below 47m, the flux is about 0.

Conclusion

According to the analysis of data from 2013 to 2015, the results indicate that: CO_2 yearly averaged concentration value decreases with height and each passing year. Its maximum value appears in winter by reason of vegetation withering, city heating and enhanced inversion; and the minimum value appears in summer due to the influence of strong convection system and vegetation carbon sequestration. Accordingly, by the wavelet analysis, the significant peak in the 256 hr band was found around December, which indicates the factor with about 10 days period is important to the maximum value of winter CO_2.

At all observation heights, the diurnal variation of CO_2 concentration displayed a very clear cycle with double peaks corresponding to city morning and evening transportation rush time. But for CO_2 flux, the cycle with triple peaks appeared above 47m because in the area close to ground, CO_2 flux was more strongly influenced by surface vegetation distribution and was not net uptake.