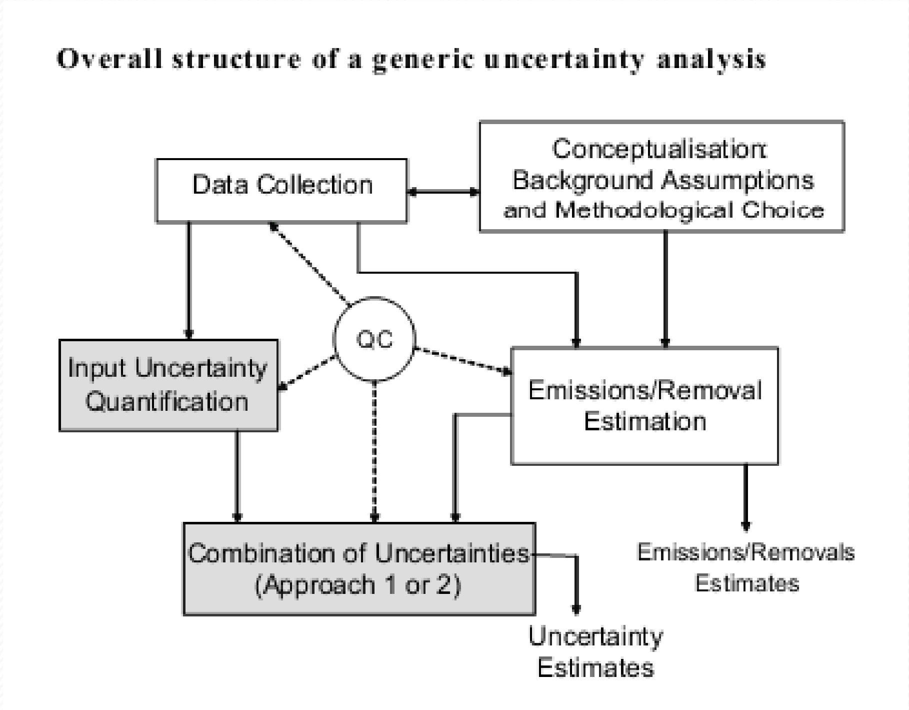
A Monte Carlo analysis of uncertainties of inventory estimates of CH_4 and CO_2 emissions in Nanjing and the Yangtze River Delta

----YangDong

1. Background

Uncertainty estimates are an essential element of a complete inventory of greenhouse gas emissions and removals.



Source: IPCC

Winiwarter and Rypdal (2001), Eggleston et al . (1998) and Monni et al. (2004) provide examples of Monte Carlo analysis applied to national GHG inventories to estimate uncertainties both in overall emissions and emissions trends.

More detailed descriptions and applications of this method are presented in *Bevington and Robinson (1992), Manly (1997), Morgan and Henrion (1990), and Cullen and Frey (1999).*

2. Monte Carlo methods

2.1 Source of Monte Carlo methods

Monte Carlo methods are a class of computational algorithms that rely on repeated random sampling to compute their results. They were central to the simulations required for the Manhattan Project .

2.2 Basic ideas and principles

- **Basic ideas：** When the required solution of the problem is the probability of certain events, or the expectations of a random variable , we can use a "test" method to get the frequency of such events, or the average of this random variable, and use them as the solution of the problem.
- **Principles：** It is based on a probability model and the simulation results is regarded as the approximate solution.

2.3 Particular Pattern

Monte Carlo methods vary, but tend to follow a particular pattern:

- Construct or describe the probability of the process;
- Sampling from a known probability distribution;
- Establish various estimators.

2.3.1 Construct or describe the probability of the process

Monte Carlo methods can be roughly divided into two categories:

- The problem itself has intrinsic randomness;
- The problem can be transformed into some kind of random distribution of the number of features.

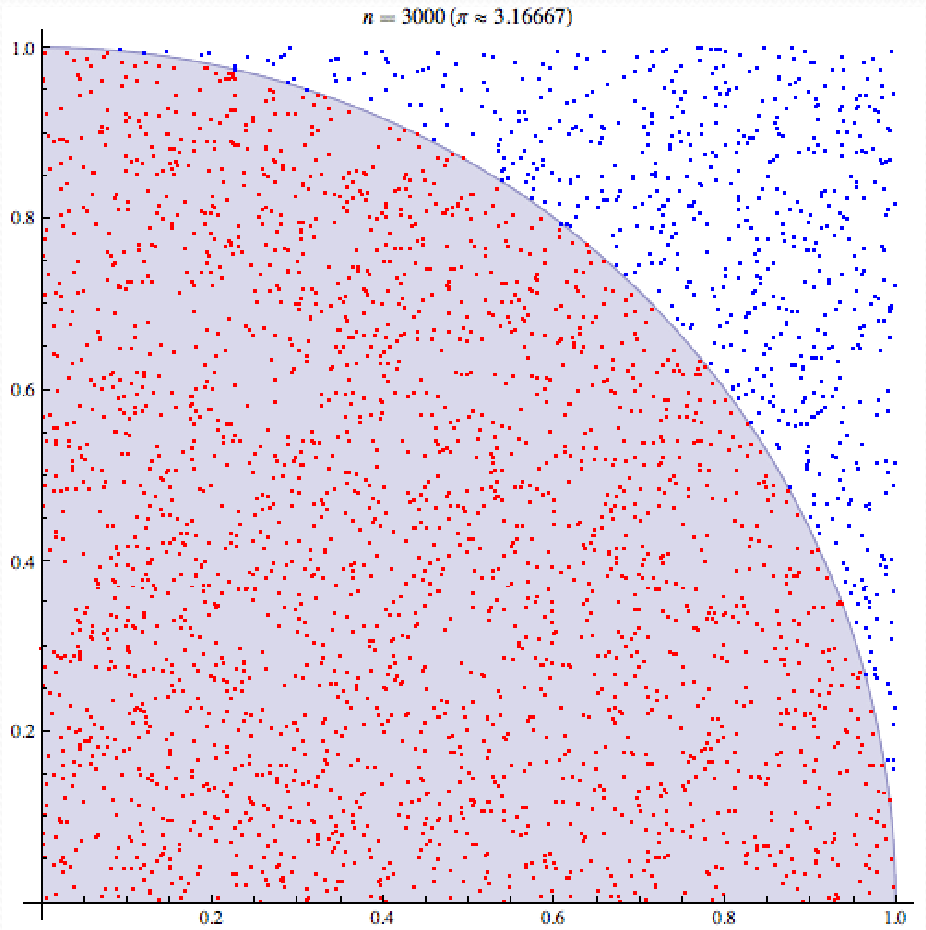
2.3.2 Sampling from a known probability distribution

Construct a probabilistic model and extracted random variables (or random vector) by the model . It can generally be called by the package, or extract a uniformly distributed random number structure.

2.3.3 Establish various estimators

After the realization of the simulation experiment, we will determine a random variable, as required by the solution of the problem. Establish various estimates ,equivalent to the inspection and registration of the simulation results.

2.3.4 Example



2.4 Advantage of Monte Carlo methods

- The computational complexity of this method is no longer dependent on the dimension;
- Suit for the study of complex system.

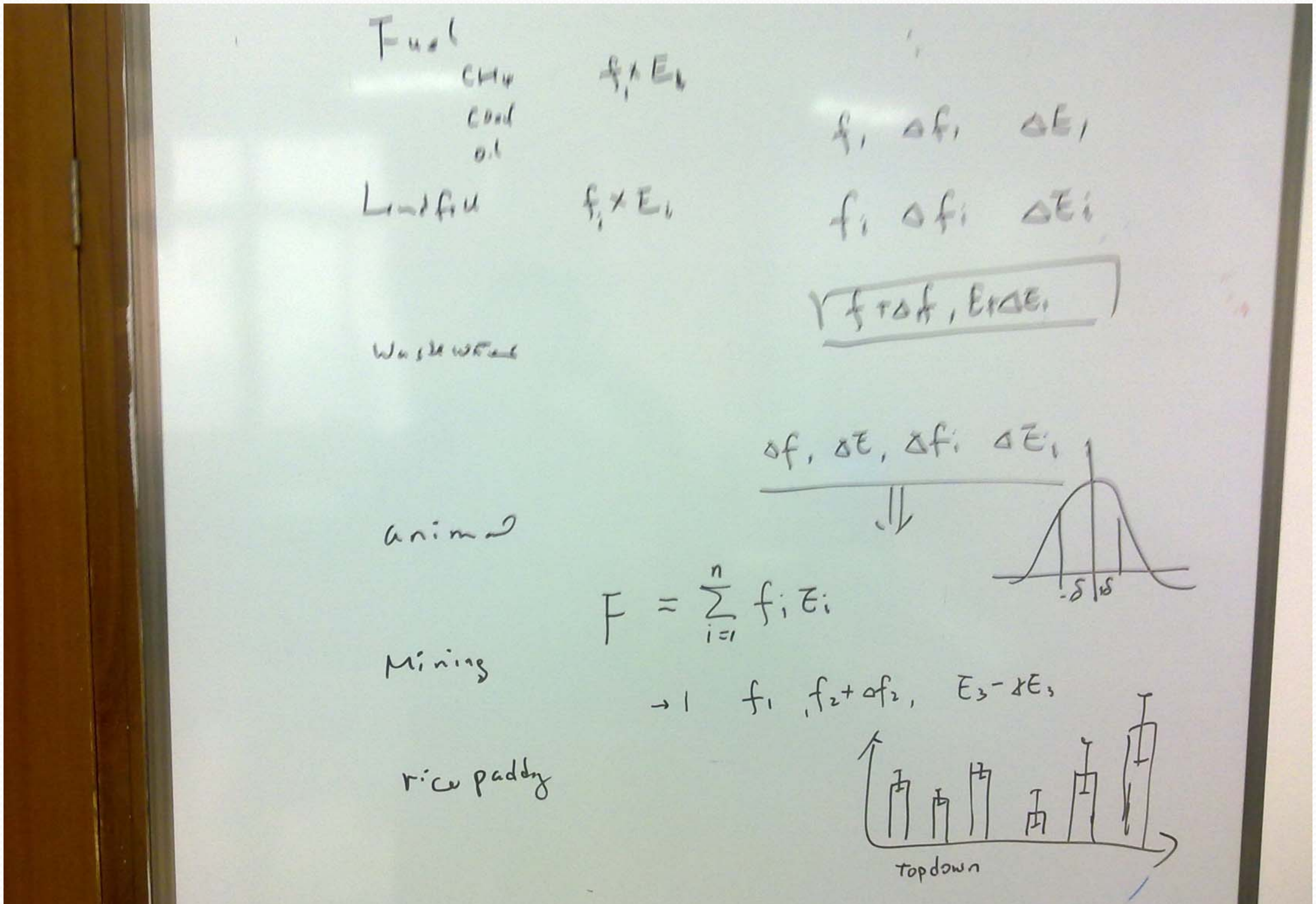
2.5 Monte Carlo and random numbers

- Random numbers are the basic tools for Monte Carlo simulation
- Random number generation is the problem of sampling .

A . Generate random numbers using physical methods ;

B . mathematical recurrence formula .The sequence---pseudo- random number .

3、 Monte-Carlo and GHG Uncertainties



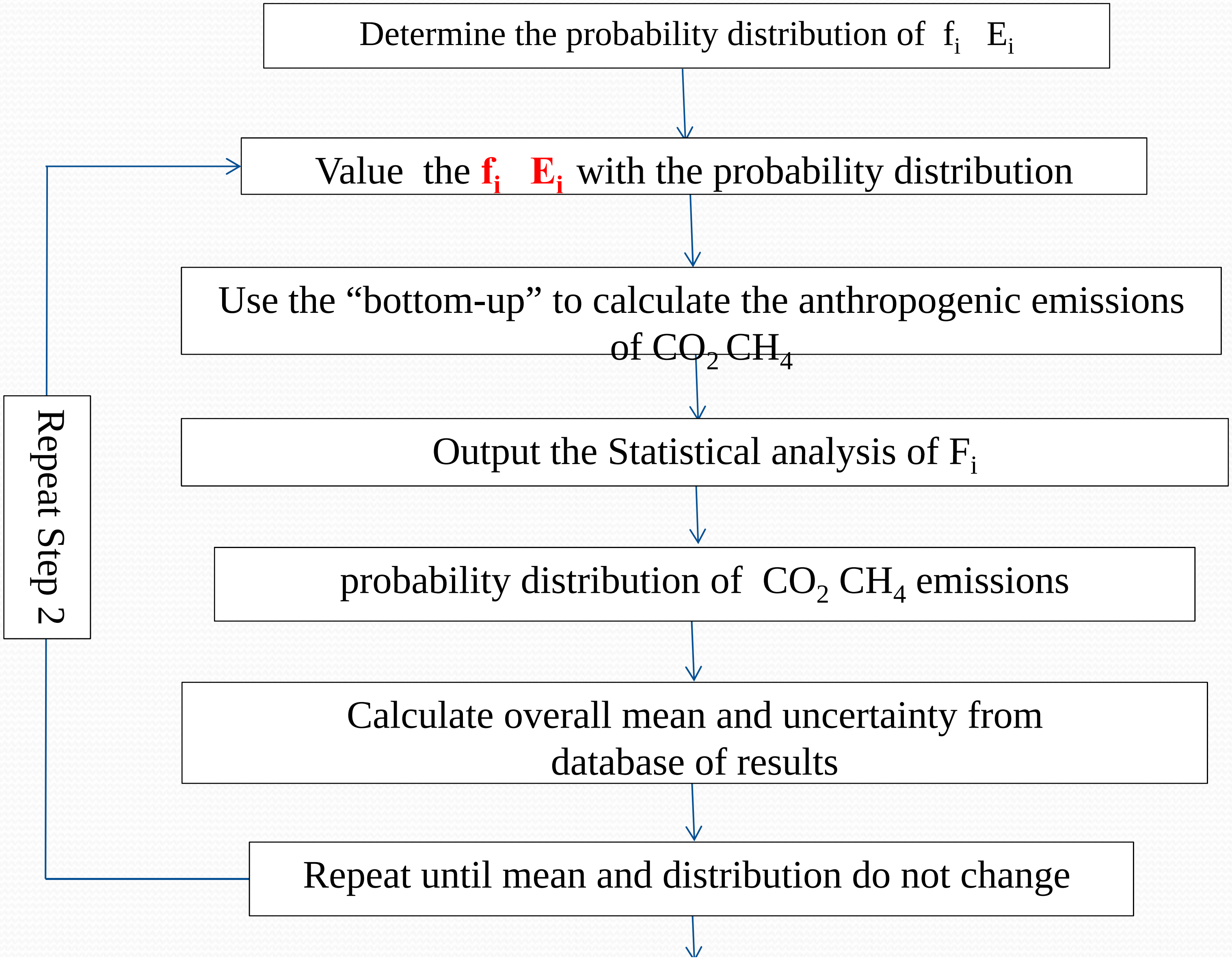
$$F = \sum_{1}^{n} (f_i + \Delta f_i) \times (E_i + \Delta E_i)$$

3.1 The principle of Monte Carlo analysis

to select random values of emission factor, activity data from within their individual probability density functions, and to calculate the corresponding emission values.

repeated many times, and the results of each calculation run build up the overall emission probability density function.

3.2 Illustration of Monte Carlo method



3.3 Parameter selected approach

3.3.1 Uniform distribution

If the parameters is evenly distributed(minimum: a; maximum: b), the cumulative probability density function is:

$F(x) = (x-a)/(b-a), a<x<b$

x: expected value of CO_2 CH_4 ($\sum f_i$) a: $\sum f_i \times E_{i(min)}$;

b: $\sum f_i \times E_{i(max)}$

If rand= F(x) ,

$$\sum f_i = \sum f_i \times E_{i(min)} + rand \times [\sum f_i \times (E_{i(max)} - E_{i(min)})]$$

3.3.2 Triangular distribution

the **triangular distribution** is a continuous probability distribution with lower limit a, upper limit b and mode c, where $a < b$ and $a \le c \le b$. The probability density function is given by :

$$\sum f_i = \begin{cases} \dfrac{(x-a)^2}{(b-a)(c-a)}, & \text{for } a \le x \le c \\ 1 - \dfrac{(b-x)^2}{(b-a)(b-c)}, & \text{for } c < x \le b \end{cases}$$

c: mode （$\sum f_i \times E_{i(\text{best})}$）。

$$\sum f_i = \begin{cases} \sum f_i \times E_{i(min)} + \sqrt{rand \times [\sum f_i \times (E_{i(max)} - E_{i(min)}) \times \sum f_i \times (E_{i(best)} - \sum E_{i(min)})]}, & \left(0 < rand < \dfrac{\sum f_i \times (E_{i(best)} - \sum f_i \times E_{i(min)}}{\sum f_i \times E_{i(max)} - \sum f_i \times E_{i(min)}}\right) \\ \sum f_i \times E_{i(max)} + \sqrt{(1 - rand) \times [\sum f_i \times (E_{i(max)} - E_{i(min)}) \times \sum f_i \times (E_{i(max)} - \sum E_{i(best)})]}, & \left(\dfrac{\sum f_i \times (E_{i(best)} - \sum f_i \times E_{i(min)}}{\sum f_i \times E_{i(max)} - \sum f_i \times E_{i(min)}} < x < 1\right) \end{cases}$$

3.4 Nanjing GHG uncertainty

Table 1. CH_4 emissions by category in Nanjing (units : ton)

Category	CH_4(min)	CH_4(mean)	CH_4(max)
Fuel	1.01E+03	3.35E+03	1.04E+04
Landfill	5.48E+04	6.15E+04	6.84E+04
Wastewater	1.40E+04	1.40E+04	1.40E+04
Livestock	3.53E+03	5.05E+03	6.56E+03
Bioenergy	2.42E+03	3.35E+03	5.57E+03
Total	7.57E+04	8.72E+04	1.05E+05

MATLAB code of Monte Carlo (NJ-CH4):

```
n=20000; %随机点数(可增加点数)
x=(1006+(10393-1006)*rand(1,n))+(54800+(68400-54800)*rand(1,n)) +13967+
(3530+(6560-3530)*rand(1,n))+(2420+(5570-2420)*rand(1,n));
 %产生20000个最小值到最大值的随机数

xx=61000:1000:91000; %画概率密度图的区间
nx=histc(x,xx);  %计算x在xx每个小区间内的点数
px=nx/n;

sumpx=cumsum(px);

subplot(1,2,1)
bar(xx(1:end-1),px(1:end-1));
title('概率密度')

subplot(1,2,2)
plot(xx(1:end-1),sumpx(1:end-1));
title('累积概率密度')
```

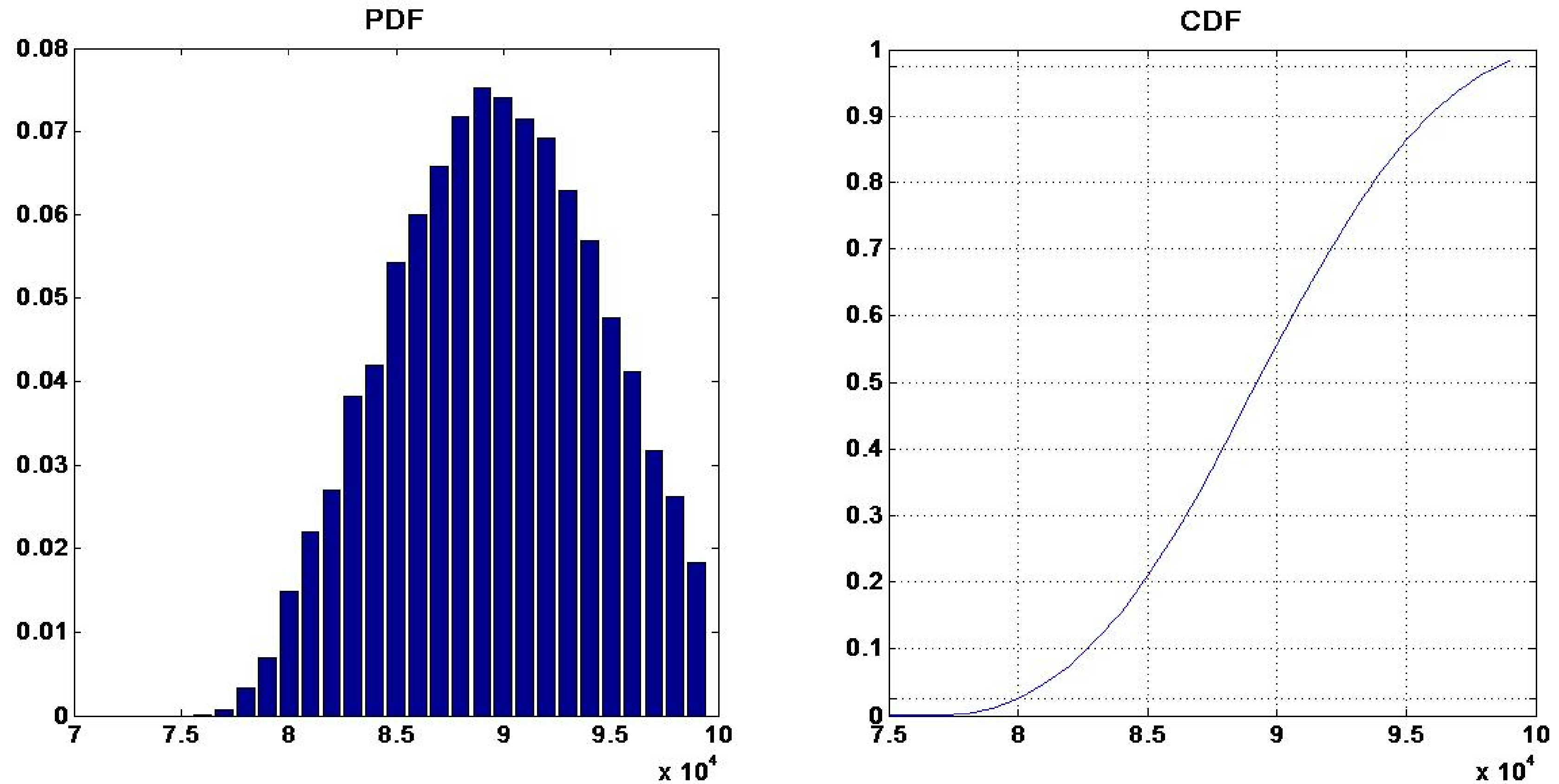


Figure 1. uncertainty estimate of CH_4 (Nanjing)

MC(95%): CH_4(min)=80000(ton) ; CH_4(max)=98500(ton)

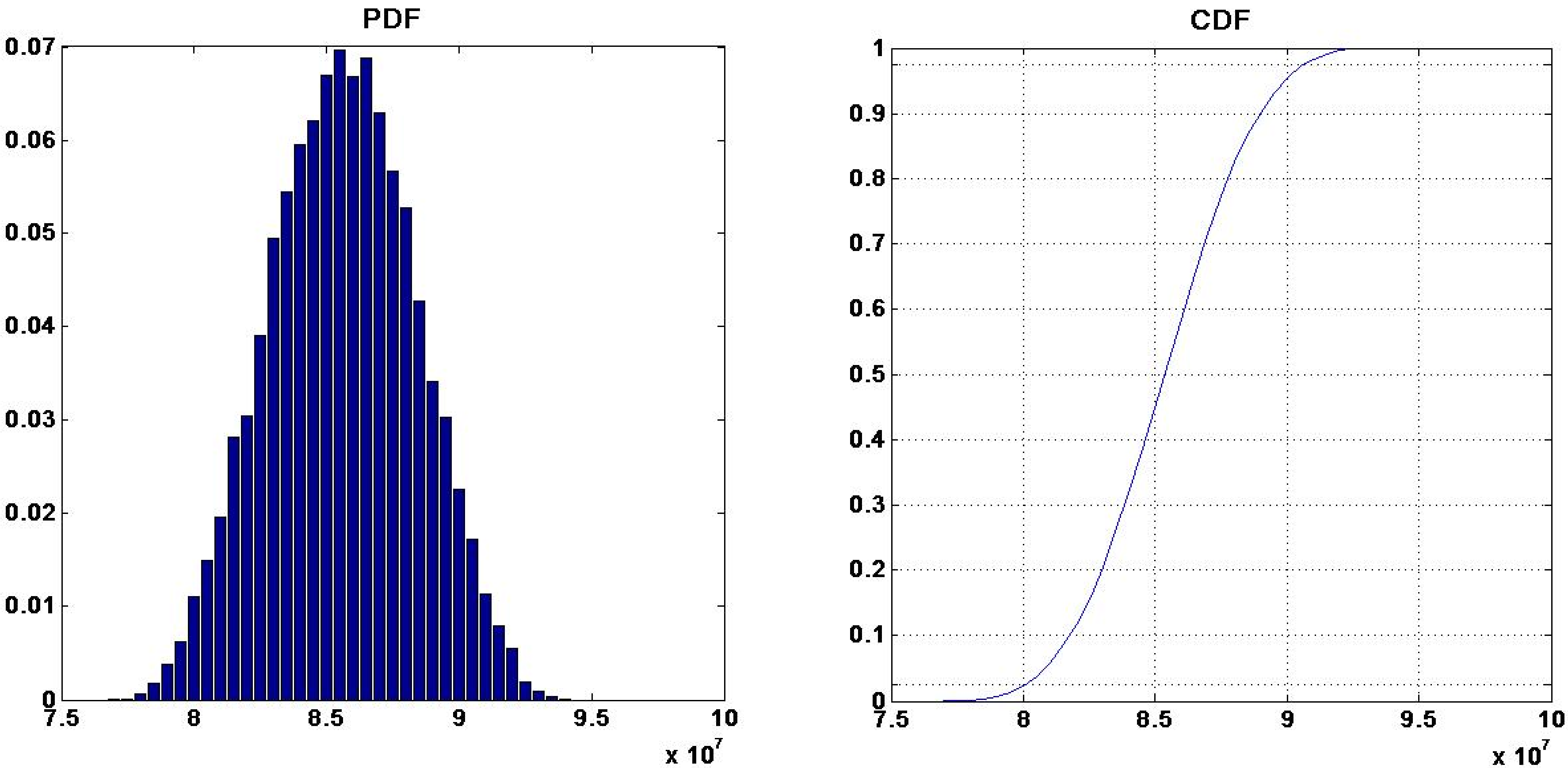


Figure 2. uncertainty estimate of CO_2 (Nanjing)

MC(95%): CO_2(min)=80000000(ton) ; CO_2(max)=90600000(ton)

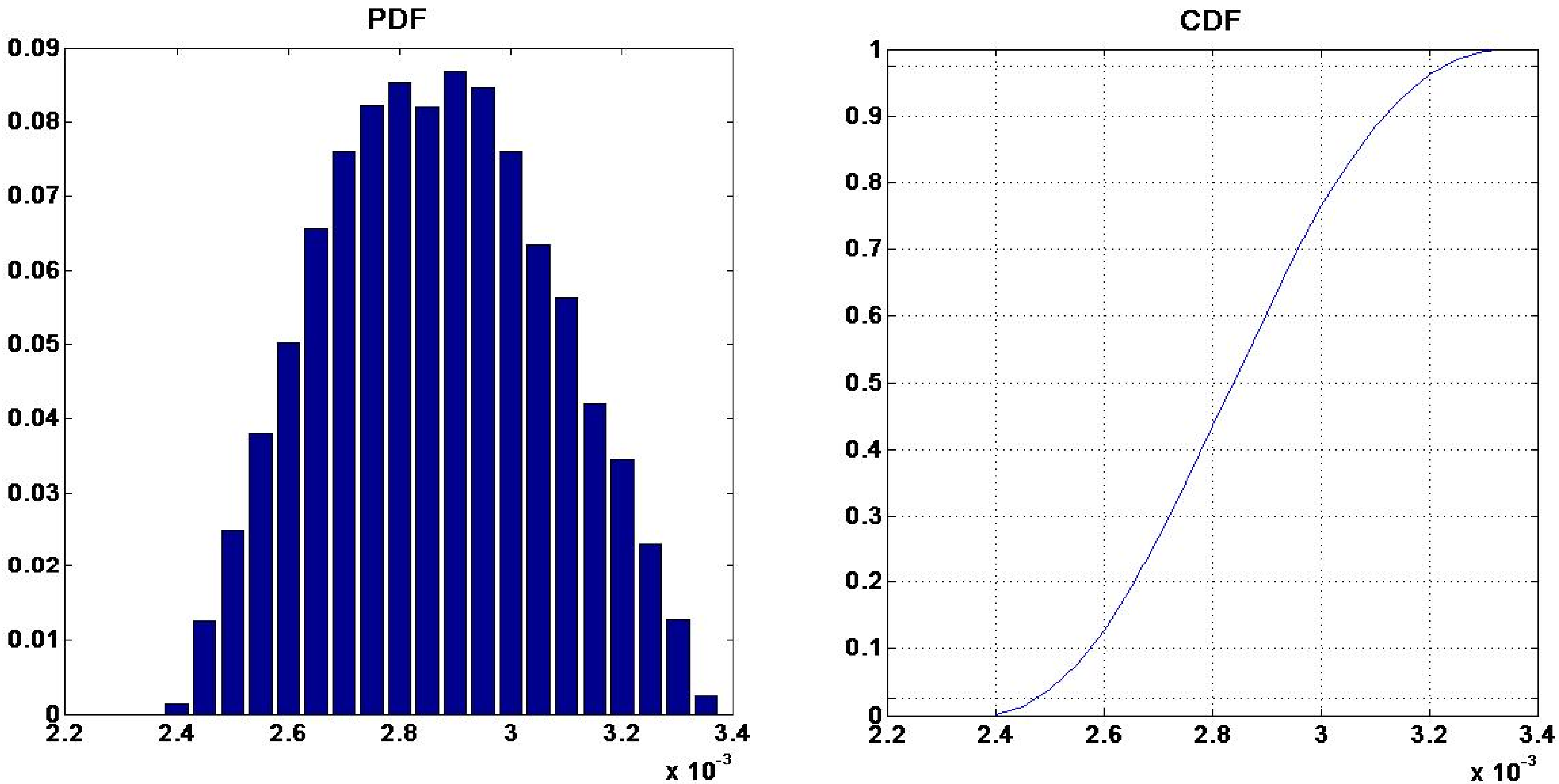


Figure 3. uncertainty estimate of emissions ratio(Nanjing)

MC(95%): emissions ratio (min)=0.0025 ; emissions ratio(max) =0.0032

3.5 YRD GHG uncertainty

Table 2. CH_4 emissions by category in YRD (units : ton)

Category	CH_4(min)	CH_4(mean)	CH_4(max)
Fuel	8.54E+03	2.85E+04	8.83E+04
Landfill	5.70E+05	5.79E+05	5.87E+05
Wastewater	1.76E+05	1.76E+05	1.76E+05
Livestock	2.75E+05	3.93E+05	5.11E+05
Bioenergy	1.56E+05	2.16E+05	3.84E+05
Coal mining	1.35E+06	1.39E+06	1.44E+06
Total	2.53E+06	2.78E+06	3.180E+06

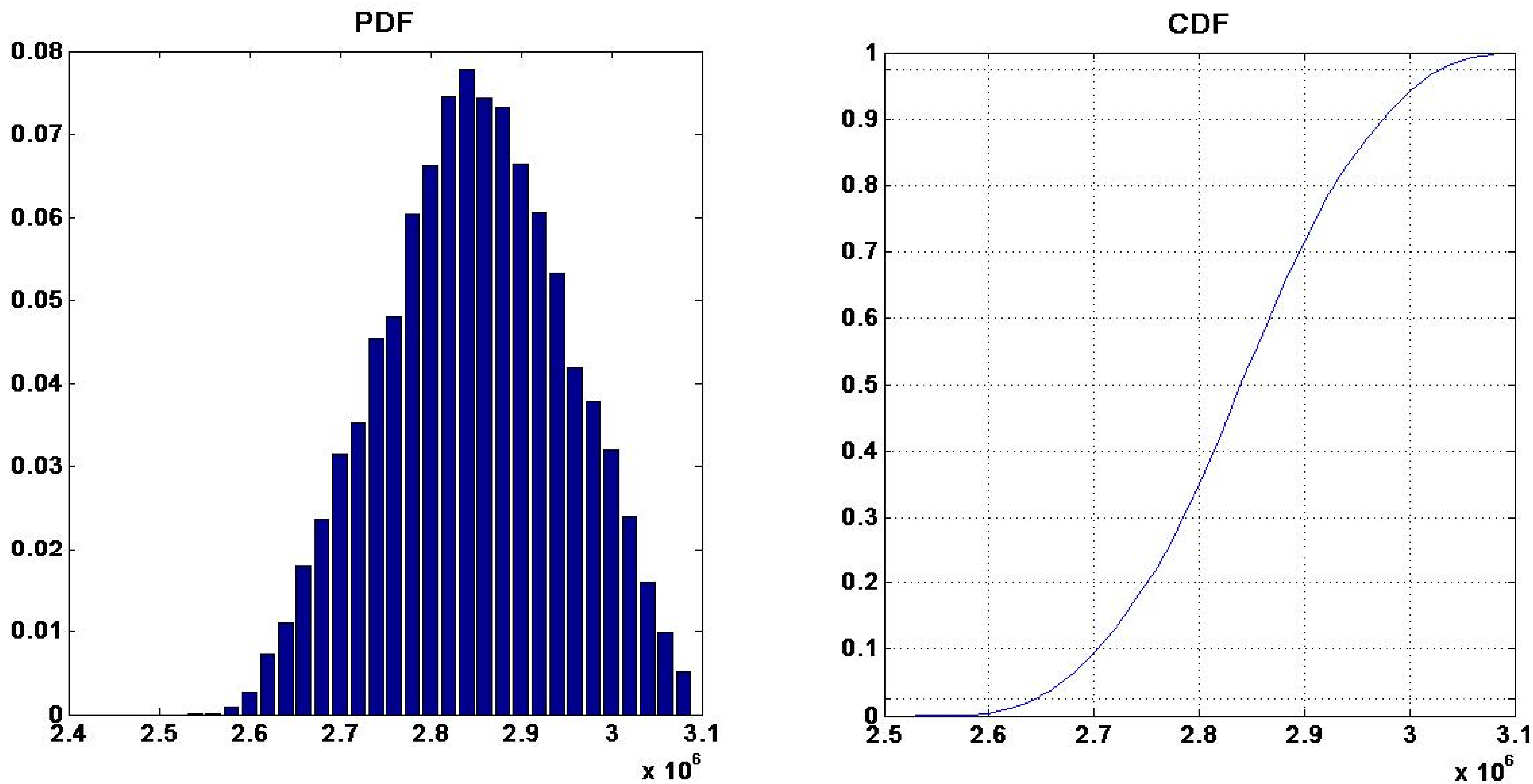


Figure 4. uncertainty estimate of CH_4

MC(95%): CH_4(min)=2650000(ton) ; CH_4(max)=3040000(ton)

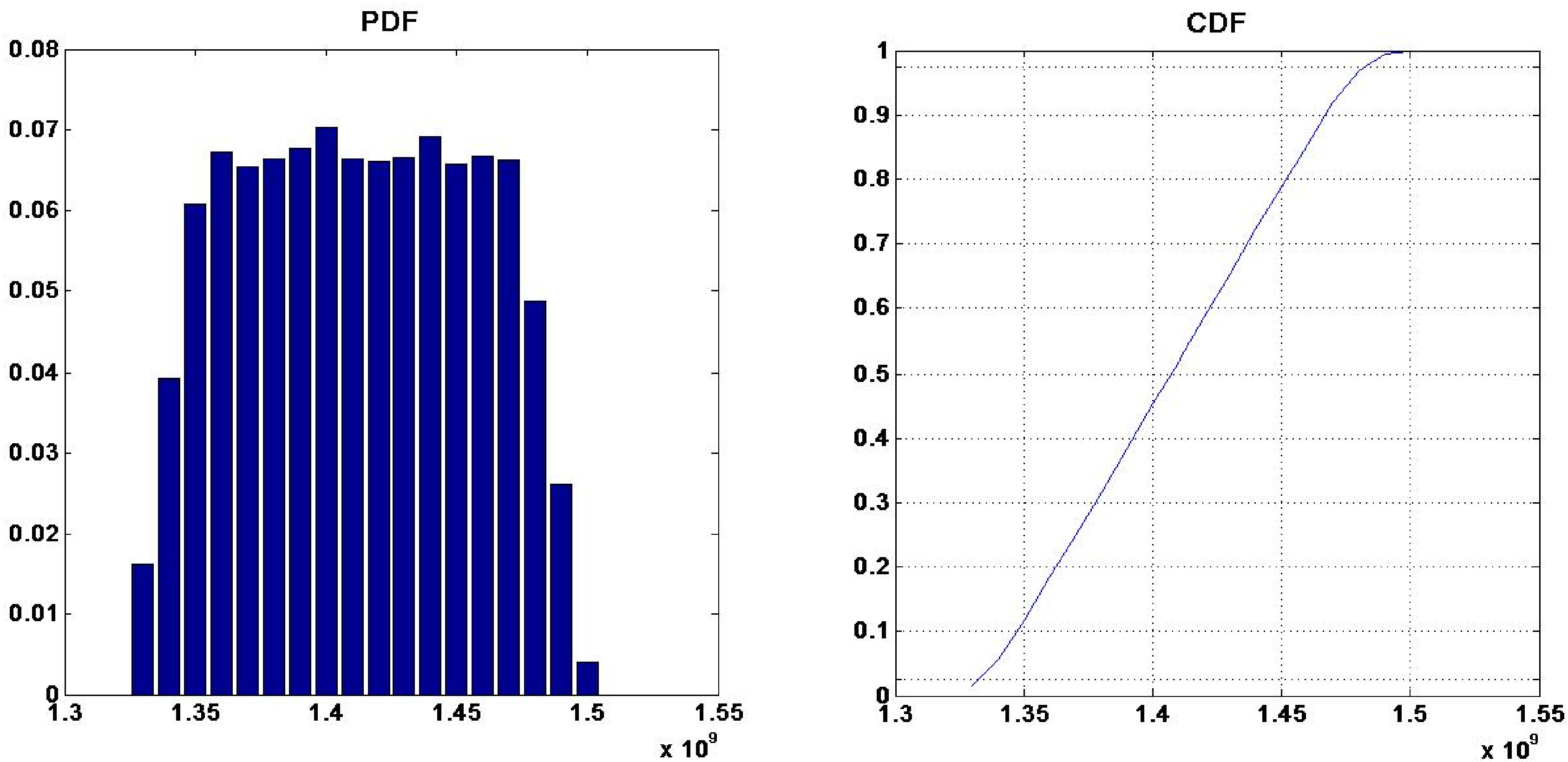


Figure 5. uncertainty estimate of CO2

MC(95%): CO_2(min)=1440000000(ton) ; CO_2(max)=1590000000 (ton)

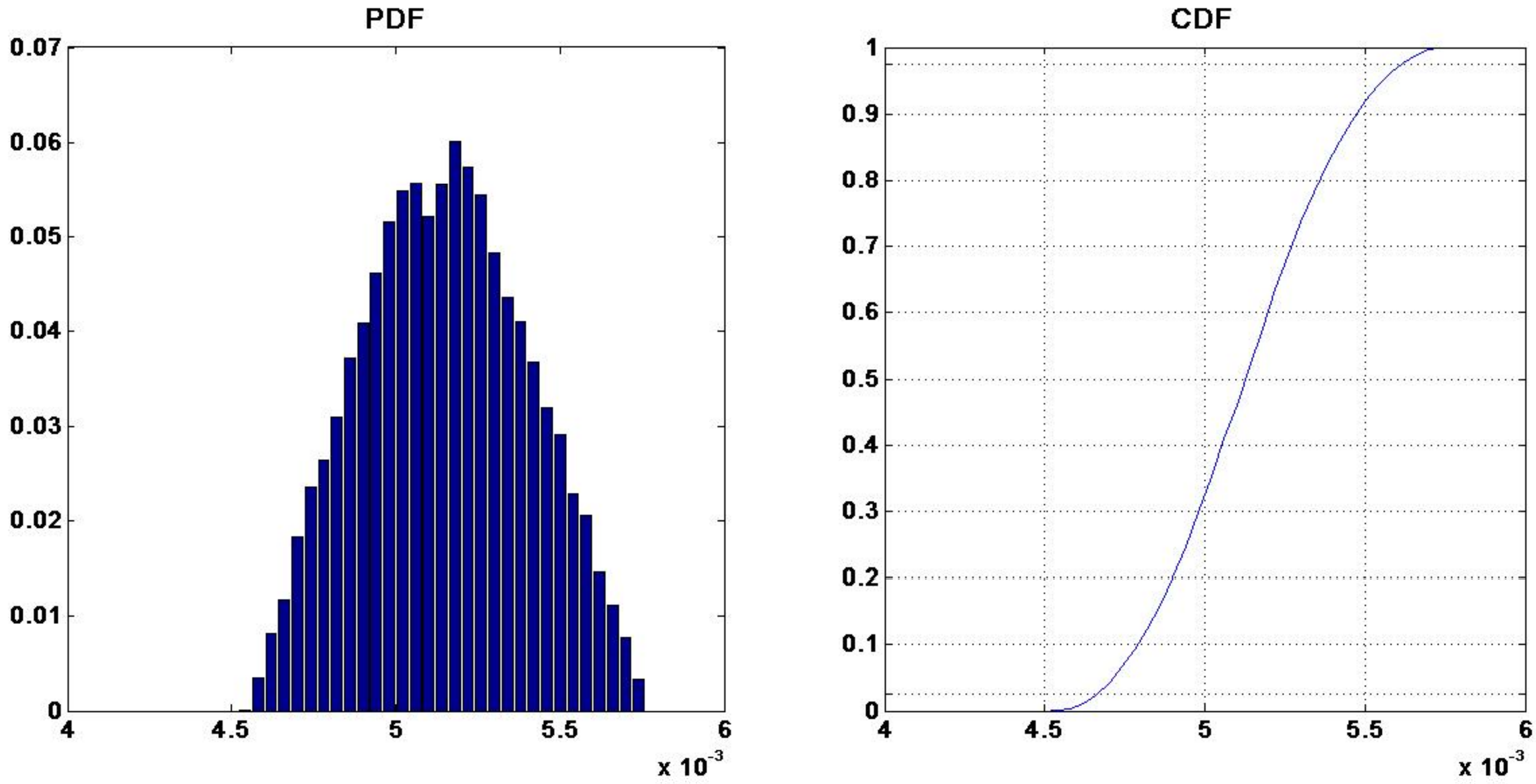


Figure 6. uncertainty estimate of emissions ratio

MC(95%): emissions ratio (min)=0.0047 ; emissions ratio(max)=0.0056

3.6 Comparisons of emissions ratio

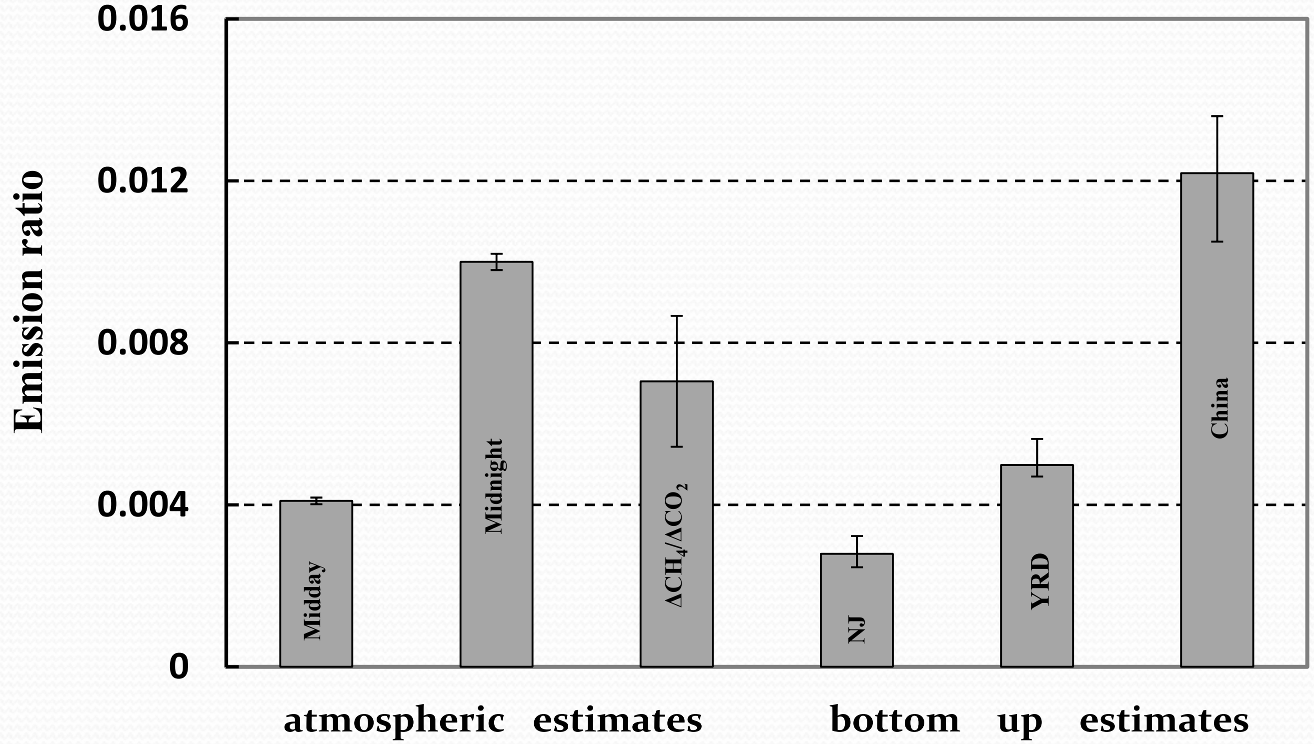


Figure 7. comparisons of emissions ratio: atmospheric estimates, bottom up estimates for Nanjing, YRD and China

THANK YOU!