SI-Traceable Greenhouse Gas Emission Inventory Measurement in a Megacity

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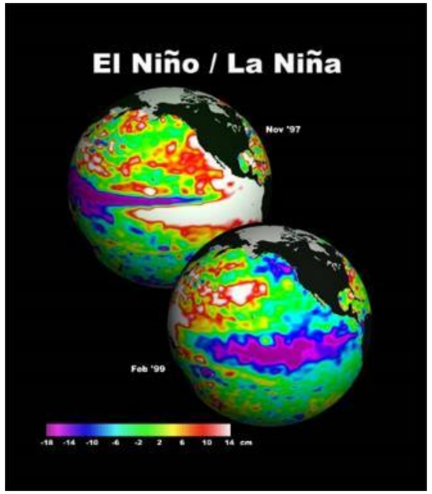
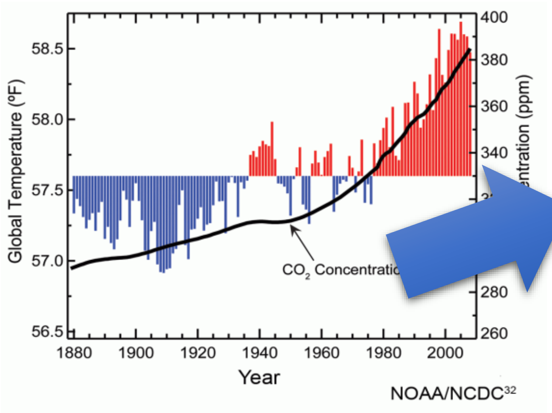
Contents

Background

China's Commitments





Greenhouse gas

Local – National – Global level

- CO_2 、 CH_4 、 CO…

Better Life

Air pollutant

Local – National Level

- SO_2、CO、NO_x、HCl、VOCs
- Aerosol(PM2.5 et al)

Inventory
GHGs & Air Quality

Environment Protection & Promote Human Well-Being

Data Quality
What, Where & When?

China's National and International Commitment To Greenhouse Gas Emission Mitigation

History of International GHG Reduction Efforts - UNFCCC

Bali Action Plan- COP 13 (UNFCCC 2007)

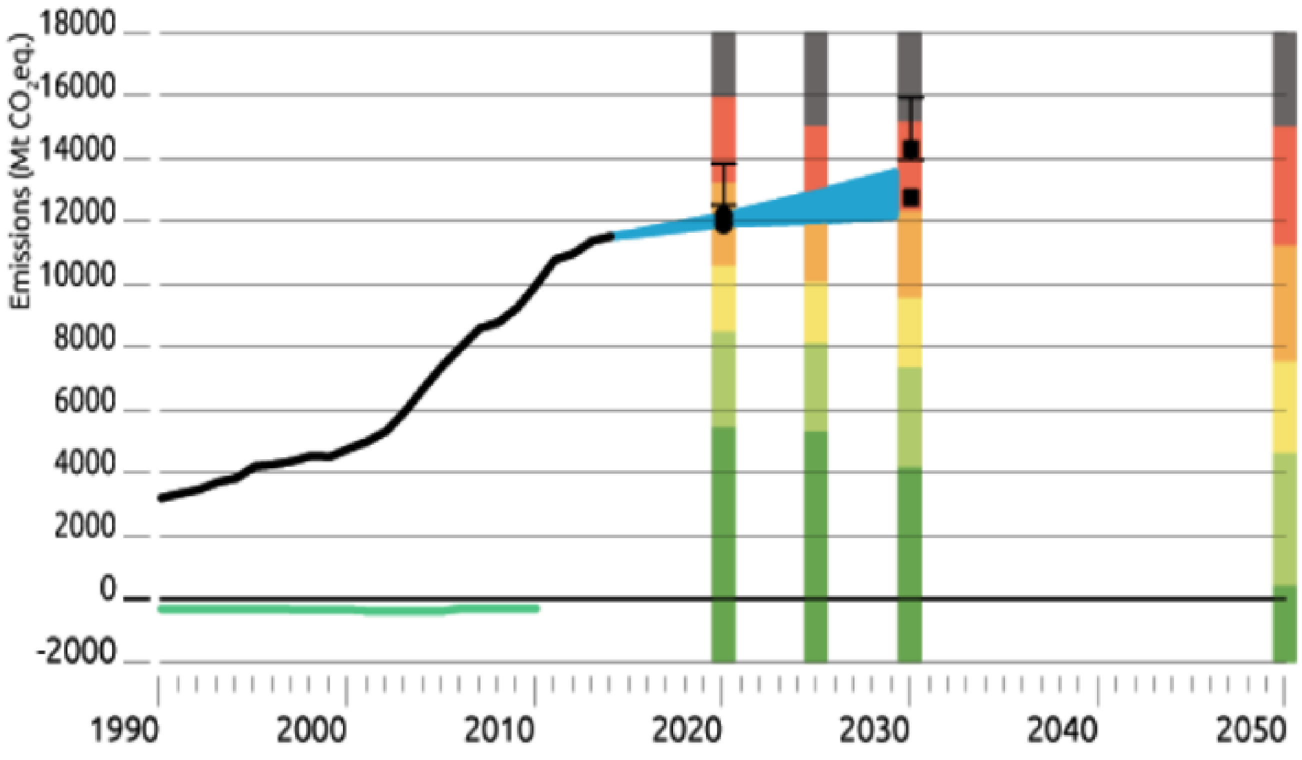
- Measurable – Emissions are capable of being measured
- Reportable – Measured, and therefore, reported
- Verifiable – *Independent* validation of reported emissions data

Copenhagen Pledge-COP 15 (UNFCCC 2009)

- Carbon intensity: -40% to -45% below 2005 by 2020
- Non-fossil share of energy supply: 15% in 2020
- Forest cover: +40 million hectares by 2020 compared to 2005
- Forest stock: +1.3 billion m³ by 2020 compared to 2005

Paris Agreement target-COP 21 (UNFCCC 2015)

- Intended Nationally Determined Contributions (INDCs)
  - Voluntary GHG Reduction Pledges determined by each nation
- 162 submissions of 190 parties to the UNFCCC
- Peak CO_{2eq} emissions latest by 2030
- Carbon intensity: -60% to -65% below 2005 by 2030
- Non-fossil share of energy supply: 20% in 2020
- Forest stock: +4.5 billion m³ by 2030 compared to 2005



China's Current and Projected Emissions

Background

- In 2020, President Xi officially announced to the world that "China will strive to achieve peak carbon dioxide emissions by 2030 and carbon neutrality by 2060";

Metrology support for "China Carbon Emission Trade Exchange (CCETE)" and "Peak carbon dioxide emissions & carbon neutrality"

	Data Quality of Carbon Emission Inventory for China	MRV data quality in the CCETE
Issues	At present, China has the compilation of greenhouse gas inventory mainly refers to the "1996 Inventory Guidelines". A large number of industries have incomplete emission statistics and poor data quality.	Adopt a fuel-based accounting method, only pursue this accounting method is consistent (The methodology is the same), and the accuracy of the emission data is not considered.
Proposals	➢ Use emission-side monitoring to improve the quality of Carbon Emission Inventory data for China ➢ Adopt advanced measurement and metrology methods to fill the gaps in emission factor data ➢ Use "top to down" emission measurement technology as a verification and correction method for national, provincial, urban, and regional carbon emission inventories ➢ Make "top to down" technology a new method of inventory compilation	➢ Develop a high-accuracy monitoring and measurement method for the emission-side ➢ Metrology supports the quality of corporation emission data ➢ Corporations choose emission-side or fuel-side methods independently ➢ Make requirements for graded management of corporation uncertainty of measurement ➢ To be a "fourth party" verification agency
Targets	➢ Achieve mutual recognition of carbon emission data between China and the international community ➢ Enhancing the right of China to speak in international negotiations on greenhouse gas emission reduction	➢ Improve the quality of CCETE data ➢ Establish a data foundation for realizing the connection of CCETE in different countries

GHG and Air Pollutants Emissions and Determination Methods

Emission Inventory Determination/Quantification Methods

- Mass Flow to and from the Atmosphere
- Anthrogenic (Human Activity) and Biogenic (Natural Activity)

$$\dot{M}_{GHG} = A_f * E_f$$

$\dot{M}_{GHG}$ – GHG Mass Flux

A_f – Activity Factor

E_f – Emission Factor

Inventory Compilation

$$\dot{M}_{GHG} = \dot{M}_{Total} * C_{GHG}$$

$\dot{M}_{GHG}$ – GHG Mass Flux

$\dot{M}_{Total}$ – Total Atm. Mass Flow

C_{GHG} – GHG Mass Fraction

Environmental Observation

- **Two Approaches to Determining GHG and Air Quality Emissions**
  - Traditional approach uses the characteristics/properties of emissions sources and sinks to determine emissions, compile these data to develop inventory reports
  - Make atmospheric observations of the concentrations of GHG's and pollutants coupled with meteorological parameters to determine quantities in the atmosphere

LETTER 《Nature 2015》

doi:10.1038/nature14677

Reduced carbon emission estimates from fossil fuel combustion and cement production in China

Zhu Liu[1,2,3], Dabo Guan[4,5], Wei Wei[6], Steven J. Davis[2,7], Philippe Ciais[8], Jin Bai[9], Shushi Peng[8,10], Qiang Zhang[4], Klaus Hubacek[11], Gregg Marland[12], Robert J. Andres[13], Douglas Crawford-Brown[14], Jintai Lin[15], Hongyan Zhao[4], Chaopeng Hong[4,16], Thomas A. Boden[13], Kuishuang Feng[11], Glen P. Peters[17], Fengming Xi[2,18], Junguo Liu[19,20,21], Yuan Li[5], Yu Zhao[22], Ning Zeng[23,24] & Kebin He[16]

Harvard University
Chinese Academy of Science
California Institute of Technology
Tsinghua University
Peking University
Nanjing University
Beijing Forestry University
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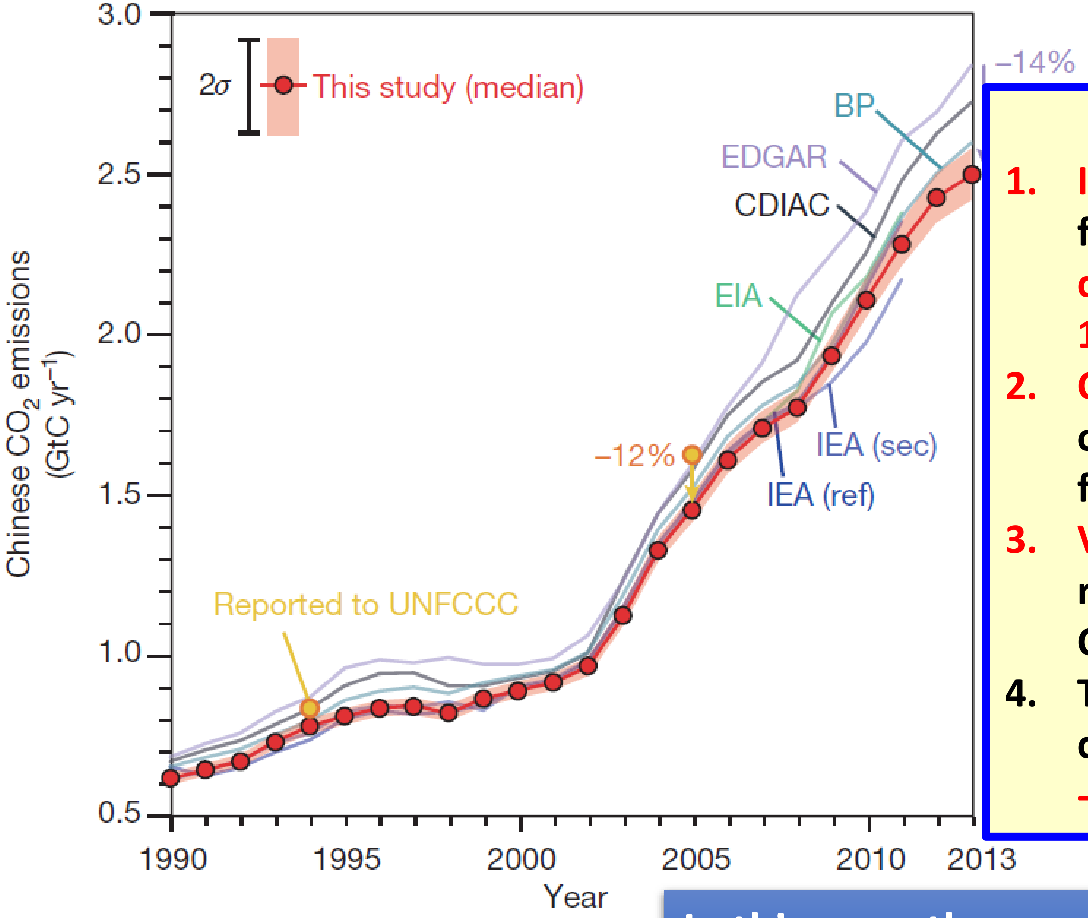
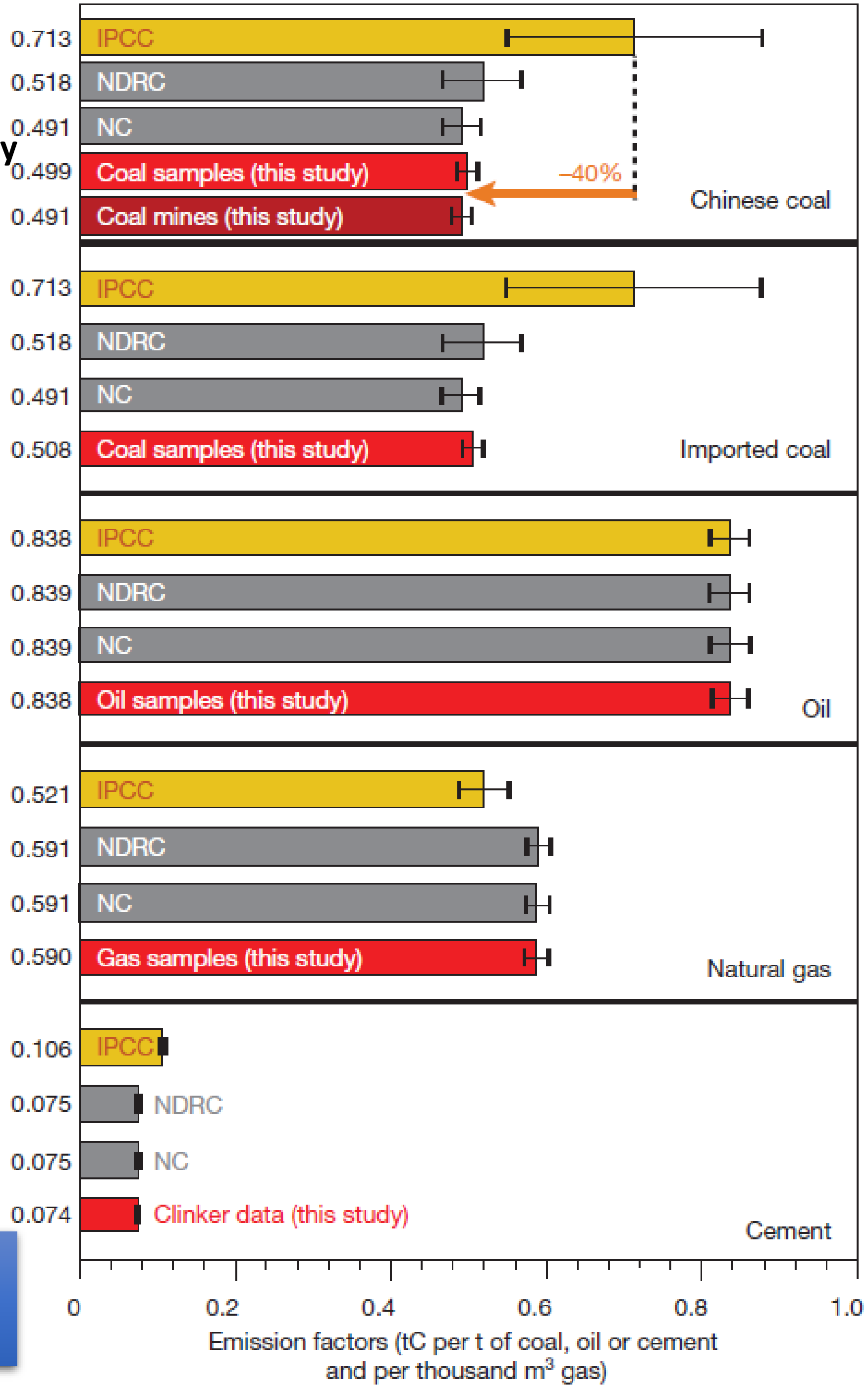


Main Conclusions

1. **Inventories of China's total fossil fuel carbon emissions in 2008 differ by 0.3 Gt of carbon, or 15%;**
2. **Conflicting estimates of energy consumption and emission factors**
3. **Very few actual measurements representative of the mix of Chinese fuels**
4. **The revised emission factors differ from IPCC defaults by -40%, +13% and -1%.**



In this case, these researchers found that the reported emissions were larger than their results.

Toward Accuracy in Emissions Determinations

Quantifying Atmospheric Greenhouse Gas Flows

$$\dot{M}_{GHG} = \dot{M}_{Total} * C_{GHG}$$

$\dot{M}_{GHG}$ – GHG Mass Flow

$\dot{M}_{Total}$ – Total Atm. Mass Flow

C_{GHG} – GHG Mass Fraction

Atmospheric Observations

Comparison Framework

Emissions Quantified with Differing Independent Methods

$$\dot{M}_{GHG} = A_f * E_f$$

$\dot{M}_{GHG}$ – *GHG Mass Flux*

A_f – *Activity Factor*

E_f – *Emission Factor*

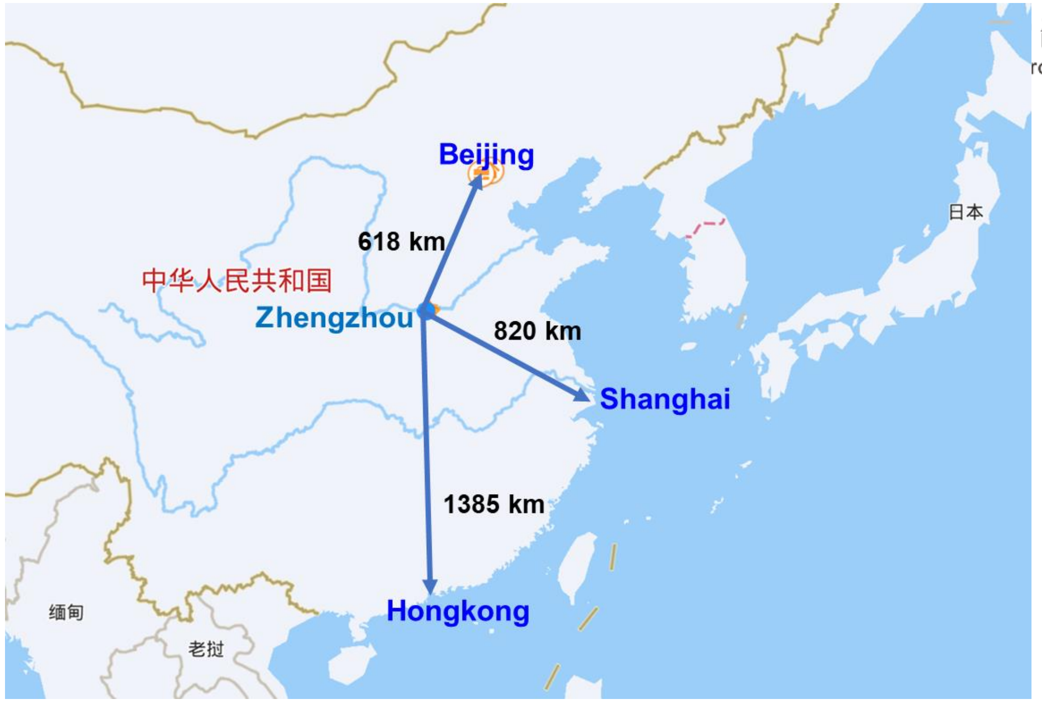
Inventory Compilation

- **Joining Traditional Inventory Data & Methods with Atmospheric Observing Methods Results in Higher Confidence in the Combination of the Two**
  - Relies on the strength of one method improving the weaknesses of the other methods
    - Detection of unknown or previously unquantified emission sources
    - Results from each method provide a means of identifying areas of improvement for the other
  - Higher accuracy results in the combination to achieve greater quality quantification capabilities
- **An Internationally-Recognized Means of Comparison Between Quantification Methods is Needed**
  - Development and recognition of quantification methods with uncertainties
  - Agreement on quantitative data quality and method performance metrics
  - Information exchange protocols advancing mitigation efforts

Bilateral Agreement
NIM and NIST Cooperation

- **2015 NIST and NIM signed a cooperative agreement on GHG measurements**
- **2017 NIM began the GHG & AQ emissions monitoring project to improve data quality**
  - **Approach similar to the NIST Urban Trace Gas Measurements Testbed System**
    - **atmospheric observation and emissions modeling – Develop a comparison framework**
    - **Stationary/point source emission metrology – power plant smoke stack measurements**
    - **Traffic emission observation system**
    - **Will be part of NIST-Supported Integrated Global GHG Information System (IG^3IS)**
- **Continued cooperation between NIM and NIST**
  - **Inversion model analysis for urban GHG flux measurements**
  - **Point source emission metrology**
  - **Reference gas metrology**
  - **Information sharing in urban GHG gas flux measurements area**

Zhengzhou GHG and AQ Measurements Project



研究院
rology,China

- **NIM and Zhengzhou City Shared support for measurements & data quality research**
- **GHG & AQ monitoring**
  - **GHG: CO_2, CH_4**
  - **AQ: SO_2, NOx, CO, O_3, $PM_{2.5}$, PM_{10}**
- **Develop and demonstrate measurements and analyses suitable for standardization that estimate GHG and AQ emissions for a wide range of city types.**
- **Supports local government policy to control pollution more effectively by improving emissions inventory data quality & reporting accuracy**
- **Collaboration between NIST and NIM have been very important to NIM in initiating this project**
  - **This cooperation has, and will continue to, benefit both NIST and NIM**
  - **Provides an example for the International metrology community in this area of measurement science**

Data Quality

- Point Source Metrology
  - Uncertainty for flow measurement reduced to <5%
    - Flow measurement by pitot tube calibrated on National stationary gas flow standard
  - Uncertainty for gas concentration measurement reduced to <5%
    - National reference gas standard also recognized internationally thru the CIPM
- Traffic Emission Observation
  - Traffic emission observation for CO_2, NOx, PM & VOC
- Uncontrolled industry gas emission measurement
  - Uncertainty will be 5%~15% depending on the boundary conditions
- Reference gas metrology – Assuring quality of field reference standards for environmental monitoring
  - Statistical sampling of specialty gas suppliers to maintain mole fraction quality
  - NIM Traceable Reference Materials Program

Emission Control Using Science-Based Methods

- Emission Flux from bottom-up and top-down methods
  - Comparability between independent methods across the city gives greater confidence in the effectiveness of emission controls
  - Independent methods provide mitigation policy managers with:
    - information to control and make adjustments to implementation of mitigation policy
    - Reduction target achievement
- Traffic emission will tell where and how much pollution from traffic is occurring to support traffic restriction policies.
  - License plate information provides emission factor information to more accurately estimate emissions with good temporal and spatial resolution
- Emission from point source will be a good measure to support the emission tax and also environment law enforcement.
- Precise emission flux measurement will support the clean air plan in China and also give the mayor a strong confidence on the city's policy.
  - Measurement of pollutant quantity in air coming into the city will be quantified so that the city has data specific to itself and is not influenced by pollution originating outside its boundaries.

CEMs Calibration (Point source)

- **Establish a CEMs flowrate traceability chain to solve the problem of emission data quality, and reduce the uncertainty of emission data to about 2% ~ 5% (more than 10%)**

社会公用计量标准证书

Certificate of Measurement Standard for Public Service

[2020] 国社量标 计证字第 363 号

根据《中华人民共和国计量法》第六条的规定，批准你单位建立的计量标准作为社会公用计量标准。

This is to certify that the measurement standard set up in your unit is authorized to be used for public service in accordance with article 6 of the Law on Metrology of the People's Republic of China.

建标单位 中国计量科学研究院
Possessor of the measurement standard

计量标准名称 常压大口径气体流量标准装置 代码 12314930
Name of measurement standard Code

测量范围 流速范围：（0.55～59.32）m/s 流量范围：（908～104840）m^3/h
Measuring range

不确定度或准确度等级或最大允许误差 流速：U_{rel}=0.58%，(k=2) 流量：U_{rel}=0.61%，(k=2)
Uncertainty/accuracy class/maximum permissible error

发证日期 2020 年 03 月 23 日
Date issued

有效期至 2024 年 03 月 22 日
Date of expiry

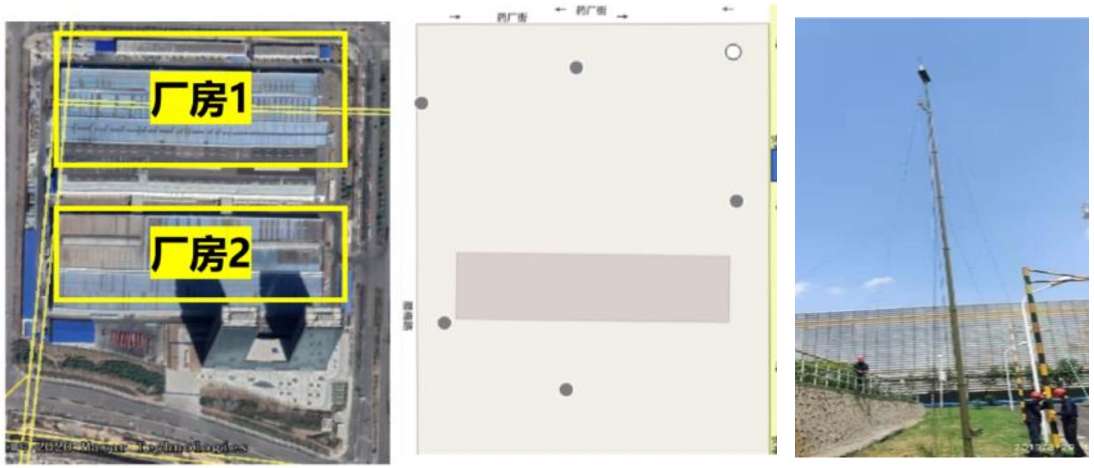
Smoke Stack Simulator(SMSS)

Fugitive emission monitoring (surface source)

- Use mobile monitoring laboratory or differential absorption lidar to monitor the concentration distribution of pollutants in the atmosphere of large and medium-sized point emission sources.
- Through the inversion calculation of air pollutants in a small area, the location and size of fugitive emission sources in factories or villages are accurately located, and the real-time monitoring of the total emission of the whole plant is realized by measuring the relationship between fugitive and organized emission. The uncertainty is less than 10%.

Applications Scenarios of DIAL

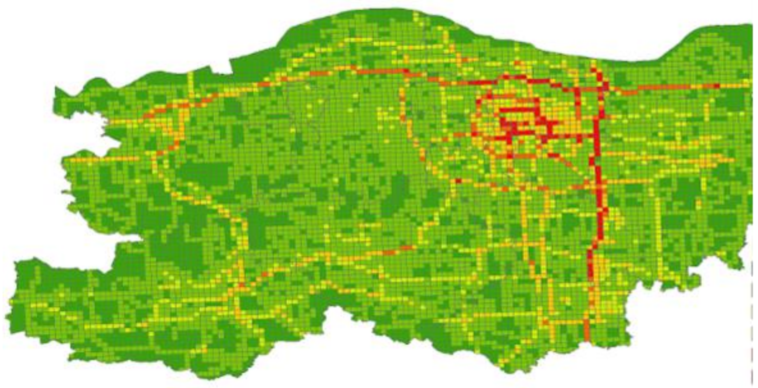
The inversion monitoring and measurement technology for small area



Traffic hourly high resolution emission inventory

- Based on the multi-source traffic static and dynamic data obtained in cooperation with the transportation department, a high-resolution **(1km × 1km, road section-level)** and real-time **(hourly)** monitoring system for urban road traffic emissions is established. This system provides a dynamic and real-time traffic emission inventory, helping city administrators build a precise and efficient city traffic control and management mode

Distribution of traffic NOx emission in Zhengzhou in 2020



Real-time traffic emission inventory (1 hour)

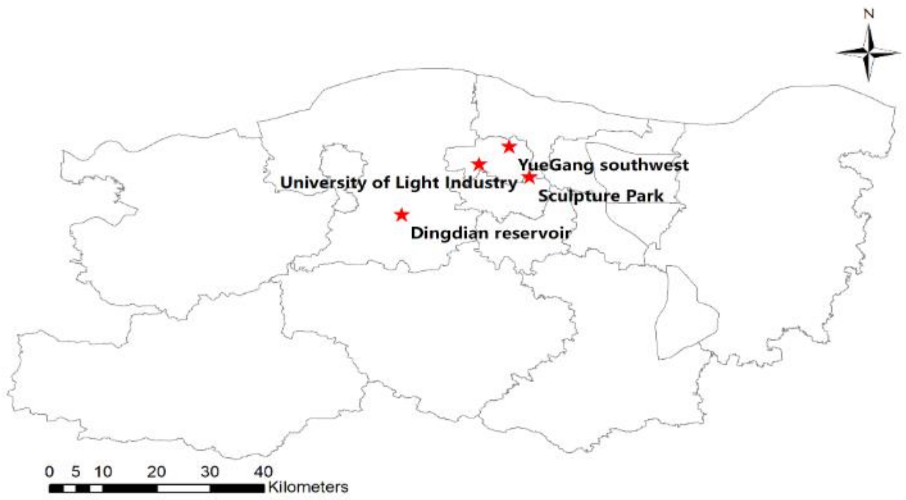
- **Most of the vehicles running within the Fourth Ring Road are urban vehicles, and most of them are scheduled bus or public service vehicles, resulting in large fluctuations in daytime and night emissions, especially urban expressways and trunk roads.**

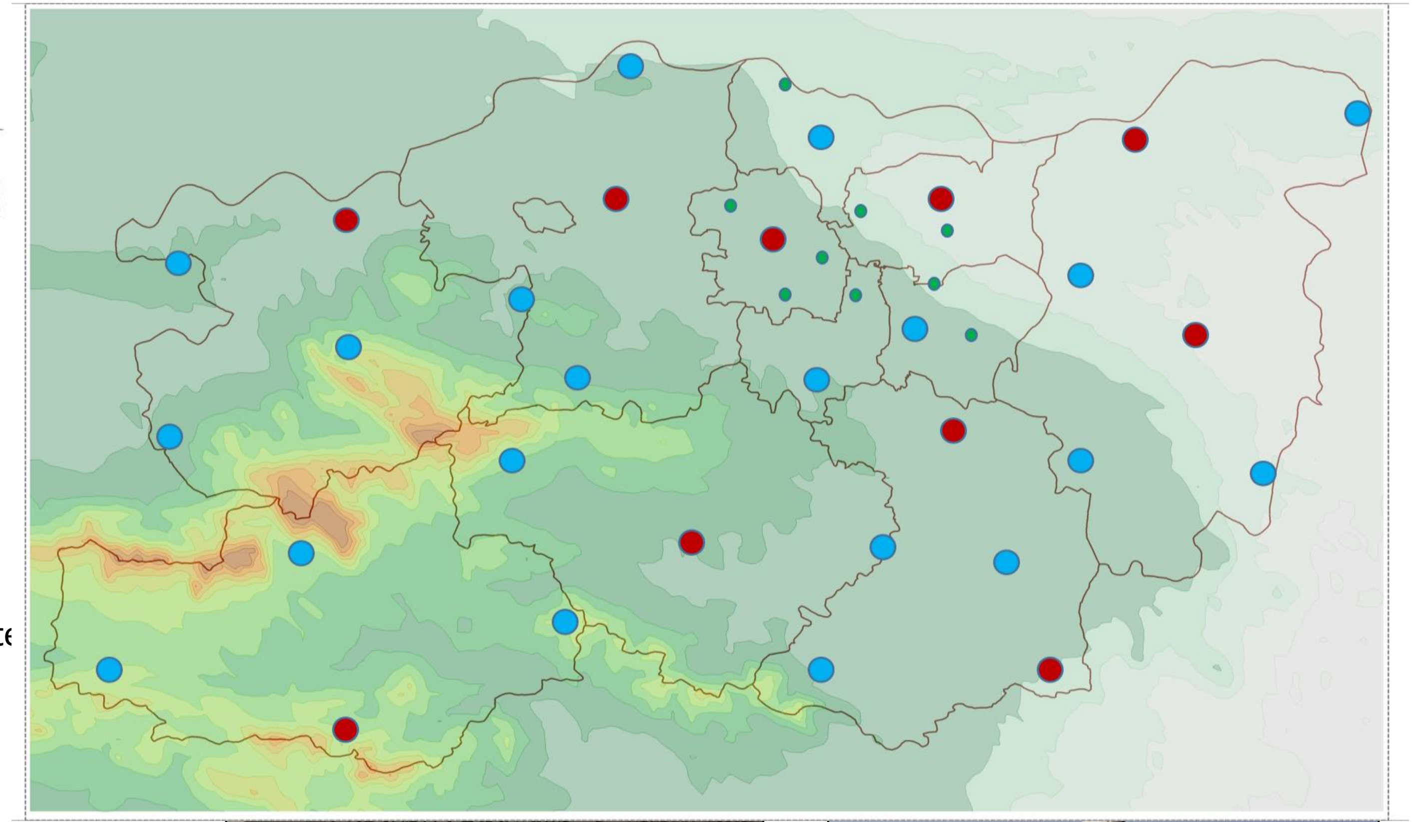
NO_x Emission distribution from Road network

CO_2 Emission distribution from Road network

Tower-Based Measurement Stations

- **Construction of measurement stations**





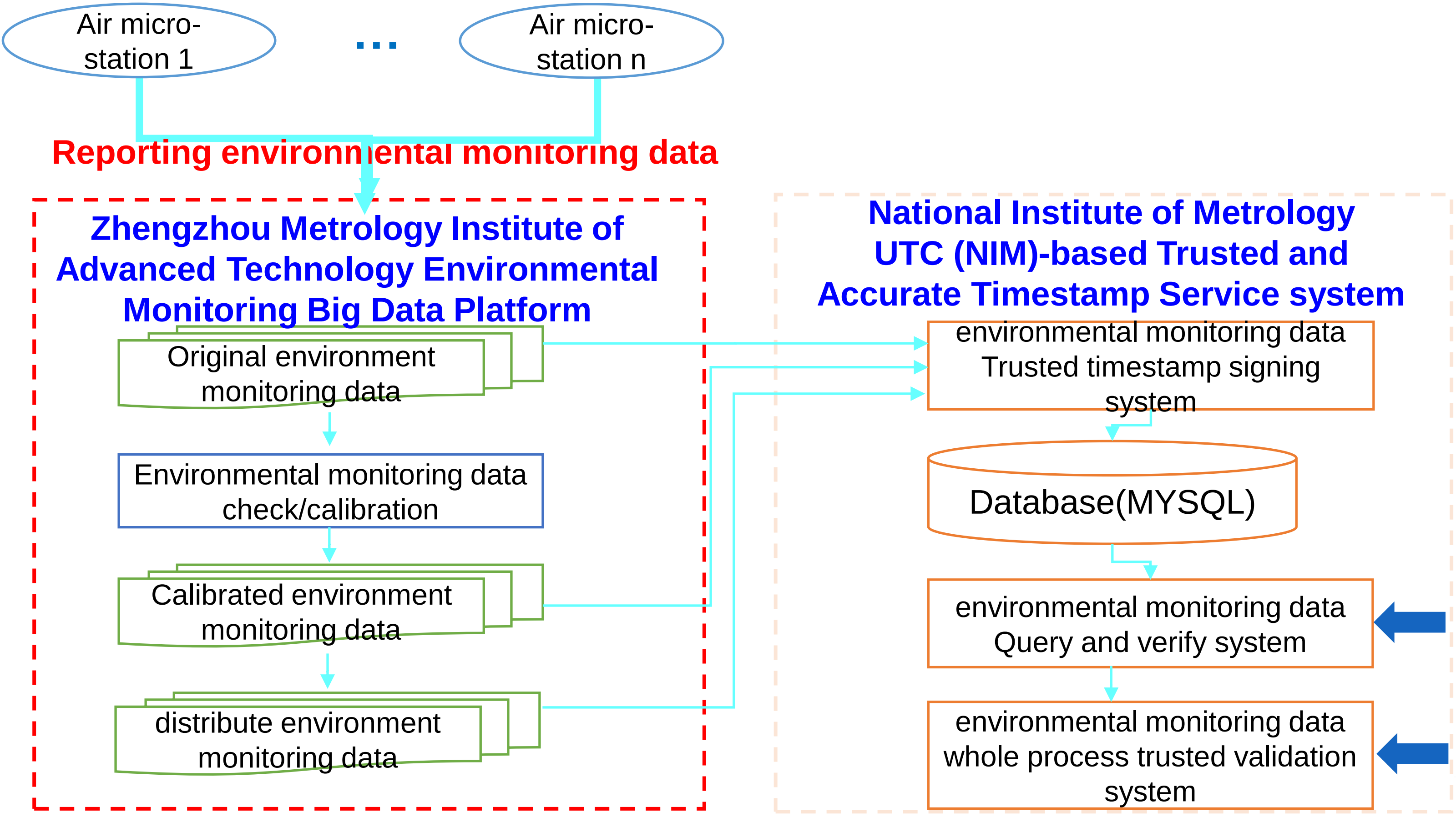
- Four tower-based measurement stations have been constructe high-precision real-time monitoring data include:

- **Particulate matters（PM_{10} , $PM_{2.5}$ ）、**
- **Greenhouse gases（CO_2 , CH_4 ）、**
- **Pollutant gas（CO, SO_2 , NO_2 , NO , NOx , O_3 , NH_3）**
- **Meteorological data such as wind speed, wind direction, temperature, humidity and atmospheric pressure.**

Number	Station name	Construction completion time	Time of data start recording
1	Dingdian reservoir	2020.4.30	2020.7.28
2	YueGang southwest	2020.4.30	2020.7.28
3	Sculpture Park		2020.12.1
4	University of light industry		2020.12.1

UTC (NIM)-based Trusted and Accurate Timestamp Service

Combining with the UTC (NIM) time source, modern encryption technology and new digital anti-counterfeiting technology to develop a trusted and reliable system for the whole process of environmental monitoring data

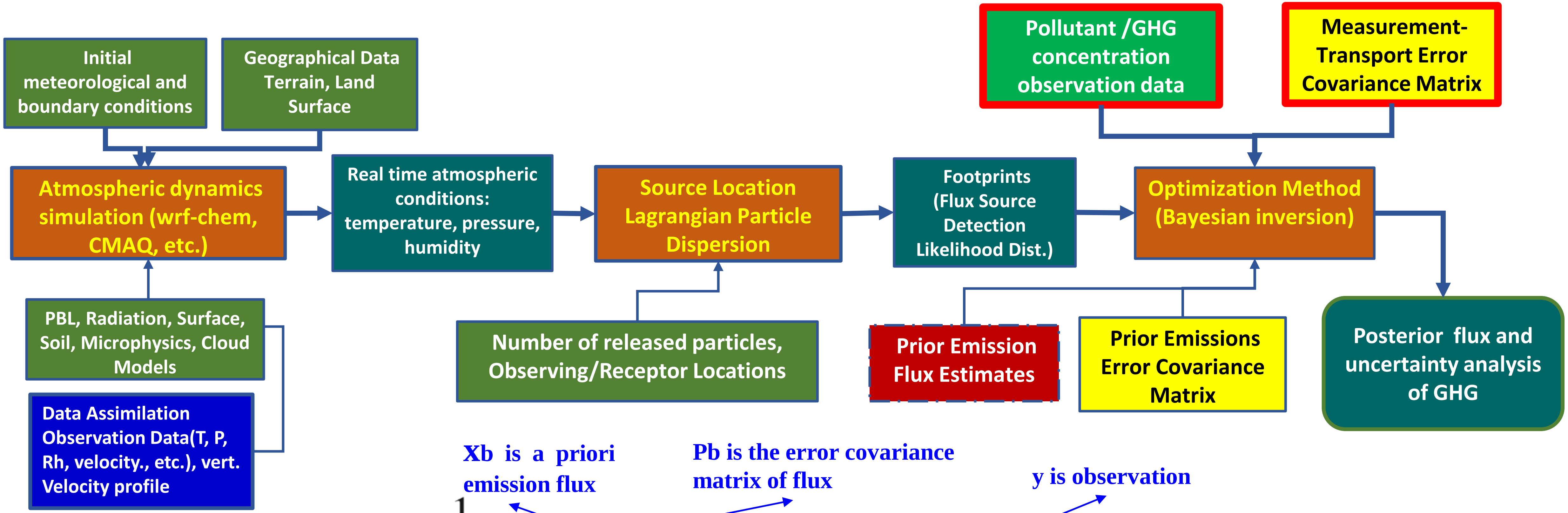


Judicial Forensics

Data Storage Content	
	Environmental monitoring data package data received time, monitoring time, devices ID...
	Hash value of the environmental monitoring data package Use Chinese national cryptographic algorithm S3
	Timestamp signing certificate of the environmental monitoring data package Use SM3+SM2 to generate the timestamp certificate

Emission inversion based on tower-based measurement data

- ➢ **Based on high-precision measurement data of air pollutants and carbon concentration, establish emission inversion inventory with high temporal and spatial resolution.**



Xb is a priori emission flux

Pb is the error covariance matrix of flux

y is observation

$$J(x) = \frac{1}{2}[(x - x_b)^T P_b^{-1}(x - x_b) + (Hx - y)R^{-1}(Hx - y)]$$

x is a posteriori emission flux

H is the influence function, calculated by the atmospheric transport model

R is the covariance matrix of observation error

Emission inversion based on tower-based measurement data

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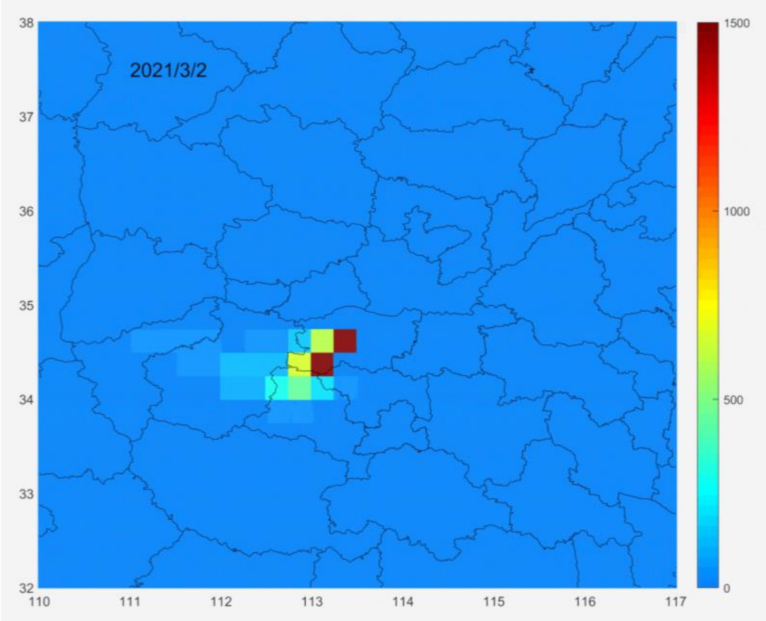
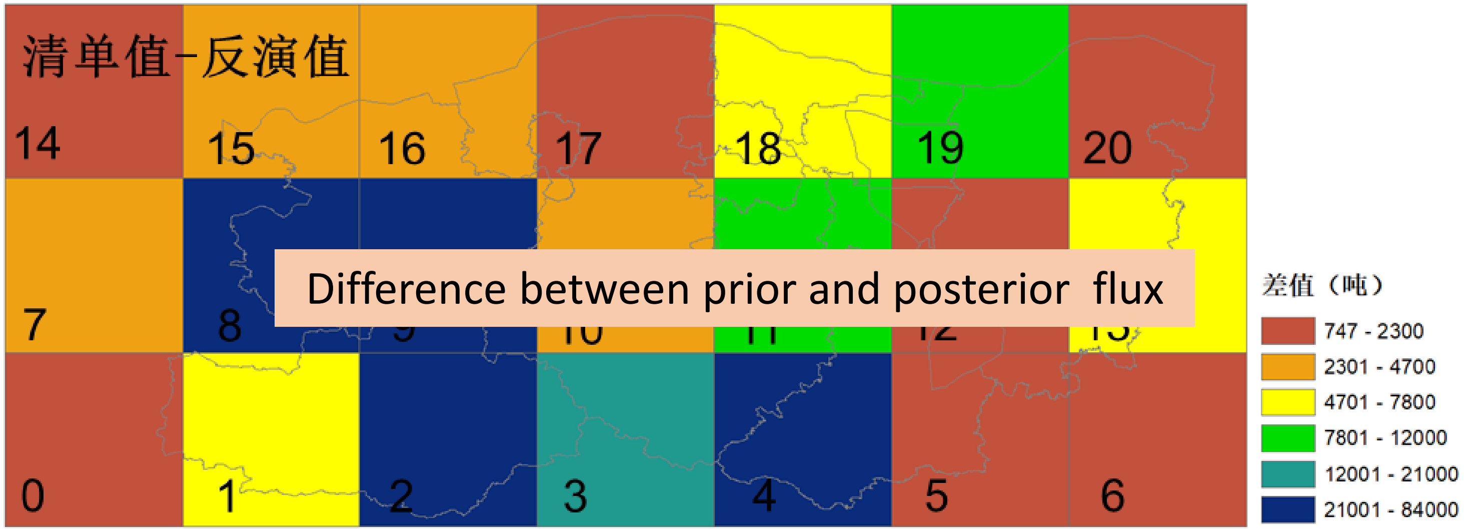
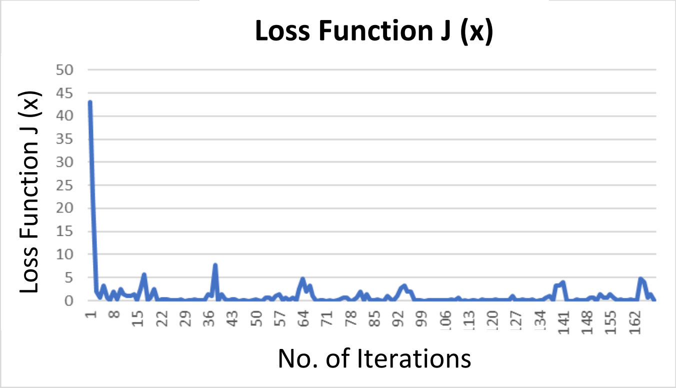
National Institute of Metrology,China

- Using the atmospheric transport model, the influence function of grid flux on the concentration of the tower-based measurement is obtained;





- Combined with the prior flux information and concentration observation value, the iterative inversion is carried out for 176 hours, and the curve of loss function J (x) is obtained



- Compared with the prior flux, the posterior CO_2 flux decreased by 3.07%, about 0.23 Mt.

Summary

中国计量科学研究院
National Institute of Metrology,China

NIM – Zhengzhou Institute of Advanced Measurement Technology

Measurement-Based Tools overcomes key barriers of **Self Reported Inventories** to deliver actionable insights

1: Accurate measurement → **2: Inversion model** → **3: Suggestions to stakeholders**

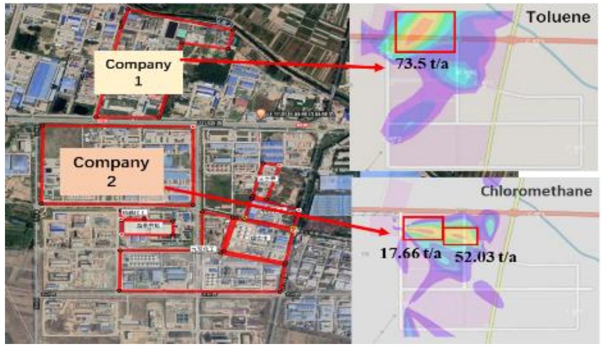
Precise, real-time gas of measurement of GHG and air pollutants

Provides city-wide information maps on emissions

Identify and recommend optimal emission-reduction scheme

An application in VOCs monitoring in Zhengzhou City in 2020

1: Measurement of VOCs using accurate equipment in the target area → **2: Calculating the emissions of VOCs in the area using the inversion model** → **3: Providing specific suggestions on pollution control for the local government**



- *Identify emission location*
- *Emission quantification*
- *Discharge plant modification*
- *The treatment of emission sites*

Thanks for your attention!