全球及城市温室气体监测和观测典型案例研究

姚波
复旦大学大气与海洋科学系

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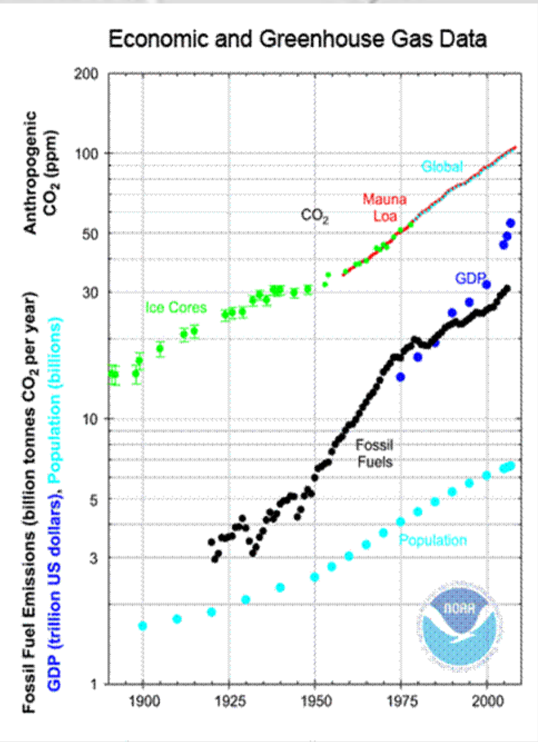
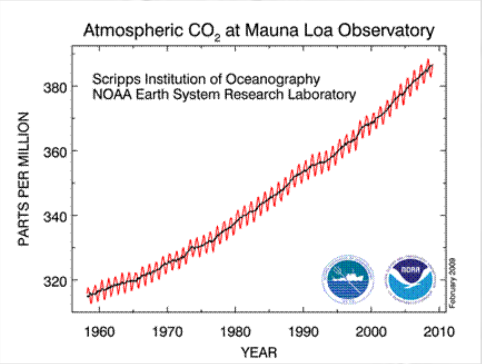
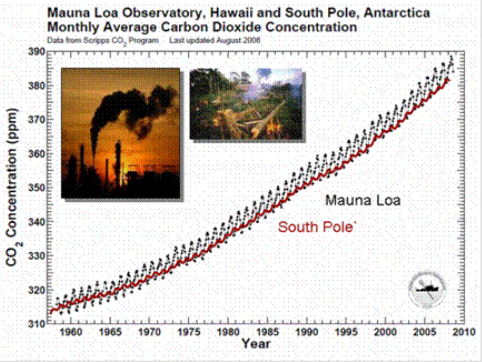
大气温室气体监测的作用

大气温室气体浓度网络化监测分析是历次《政府间气候变化专门委员会IPCC》评估报告、《联合国气候变化框架公约UNFCCC》等的数据来源和科学基础。







围绕双碳目标

- ✓ 支持二氧化碳达峰：人为CO_2排放量
- ✓ 支持碳中和：所有温室气体净排放量
- ✓ 温室气体国家/省级清单：不同行业所有温室气体
- ✓ 碳交易市场：重点企业CO_2排放量，预计将扩展
- ✓ 温室气体减排政策：不同行业不同温室气体排放

传统温室气体排放计算方法基于统计清单

巴黎协定-温室气体清单:

$$排放 = \Sigma_{ij} 活动水平_{ij} \times 排放因子_{ij}$$

利用经济和能源统计数据估算:

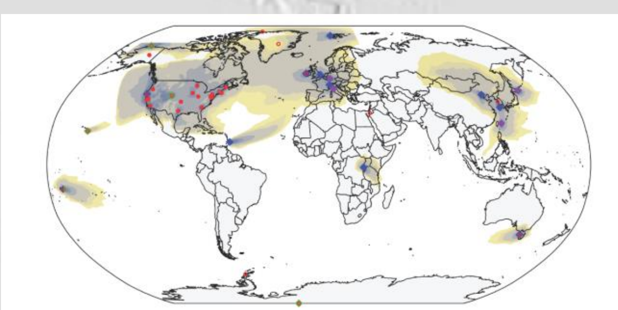
i＝行业　j＝物种

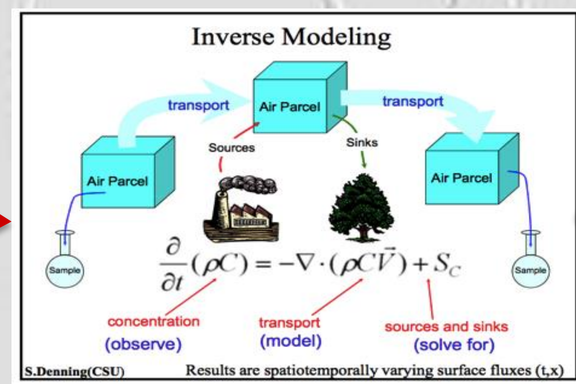
方法系统，可操作性强
详细空间信息?
实时动态信息?
准确性需要独立验证
——无法监测无组织排放和非法排放

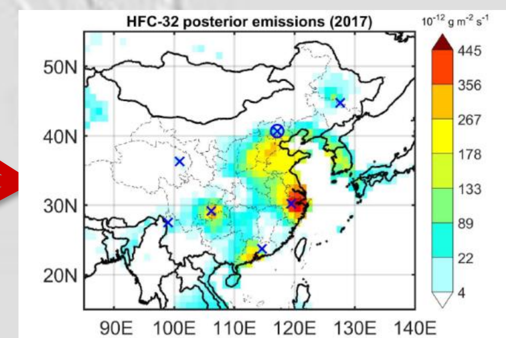
如何弥补清单法的不足？

尤其是对非法排放和无组织排放的定位和定量？

温室气体排放量计算的新方法
基于大气浓度的排放监测







大气监测体系
地面+卫星+飞机+……

反演模型
Flexpart、NAME、Carbon Tracker……

温室气体
源汇排放分布

优势：
1.远距离监测，客观性强
2.监测全部排放，包括非法排放
3.可实现高时空分辨率、甚至实时动态

前提：
1. 高精度监测技术
2. 合理的监测站点分布
3. 高分辨率、实时动态的反演模型

IPCC：基于大气浓度的温室气体排放监测法2019年被完整提出

- *Comparison of greenhouse gas emission estimates with atmospheric measurements*: Guidance on comparison of greenhouse gas emission estimates with atmospheric measurement has been updated and elaborated to reflect the state of science for atmospheric measurements and their application to improving national greenhouse gas inventories. These approaches can be used to provide additional scientific verification of inputs and results for particular categories and gases, and therefore help countries to target areas of uncertainty. The most notable advances were achieved in the application of inverse models of atmospheric transport for emission estimates at the national scale. Thus, atmospheric measurements are being used to provide useful quality assurance of the national greenhouse gas emission estimates. The guidance highlights key components and steps that can be applied when using atmospheric measurements and inverse models for comparison with

6.10.2 Comparisons with atmospheric measurements

[Update/Elaboration of the section 6.10.2 of the *2006 IPCC Guidelines*].

《IPCC 2006清单指南2019更新》

首次完整提出基于大气浓度反演温室气体排放量、进而验证传统清单结果的方法

1 **CHAPTER 6**

2 **QUALITY ASSURANCE/QUALITY**
3 **CONTROL AND VERIFICATION**

两种温室气体排放量计算方法需要互相补充

国际上估算温室气体源汇主要有两种方法：

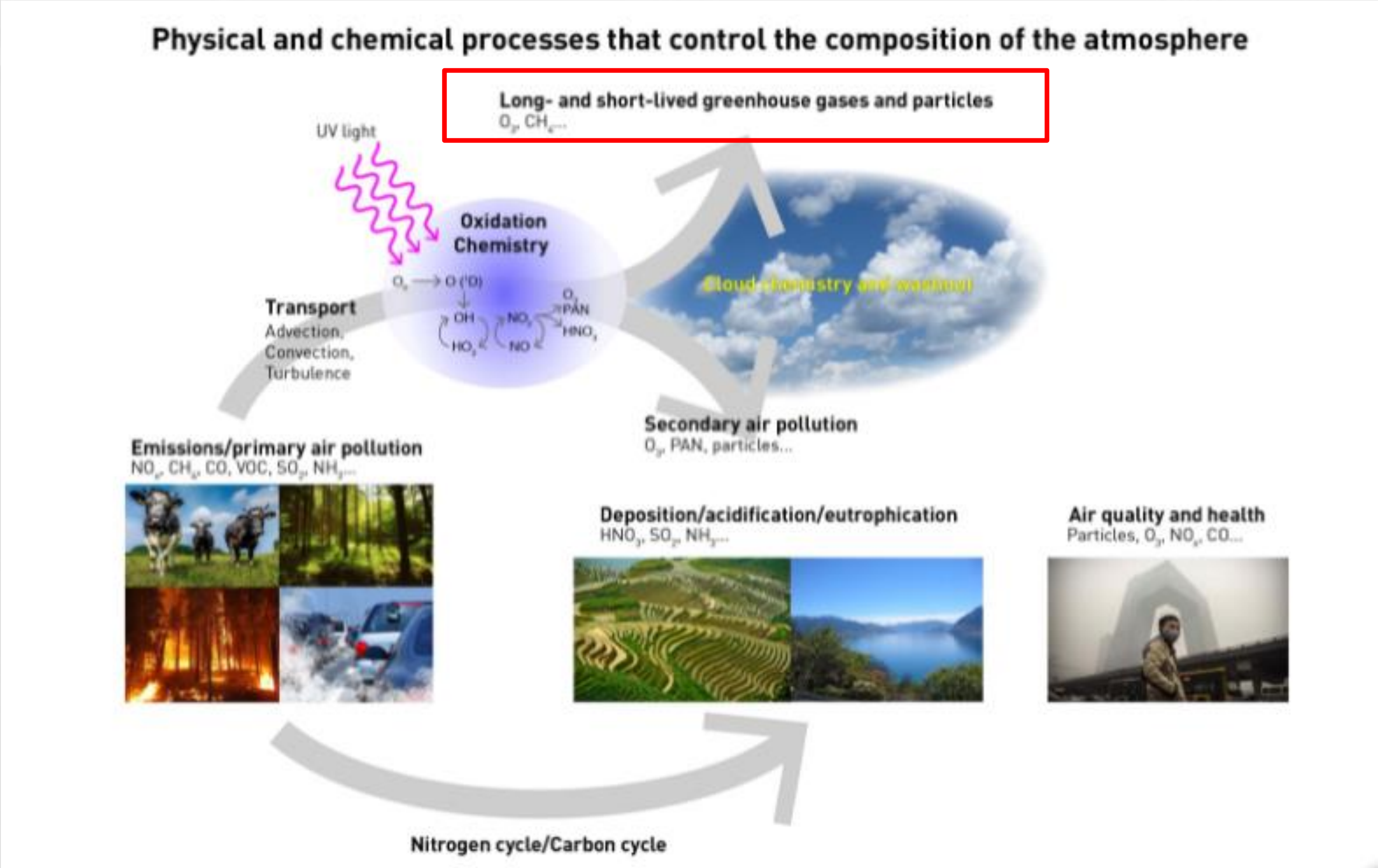
** 分部门、分行业、分地域调查，用源汇清单、排放因子等“自下而上”估算：无法统计意外排放，周期长

** 地面、飞机、高塔、航船、卫星资料，结合气象资料和模式“自上而下”推算：无法区分不同行业，难以和排放主体对应，技术不成熟

二者互为补充和验证，才能更加及时准确地测算全球-国家-省市-企业温室气体排放状况

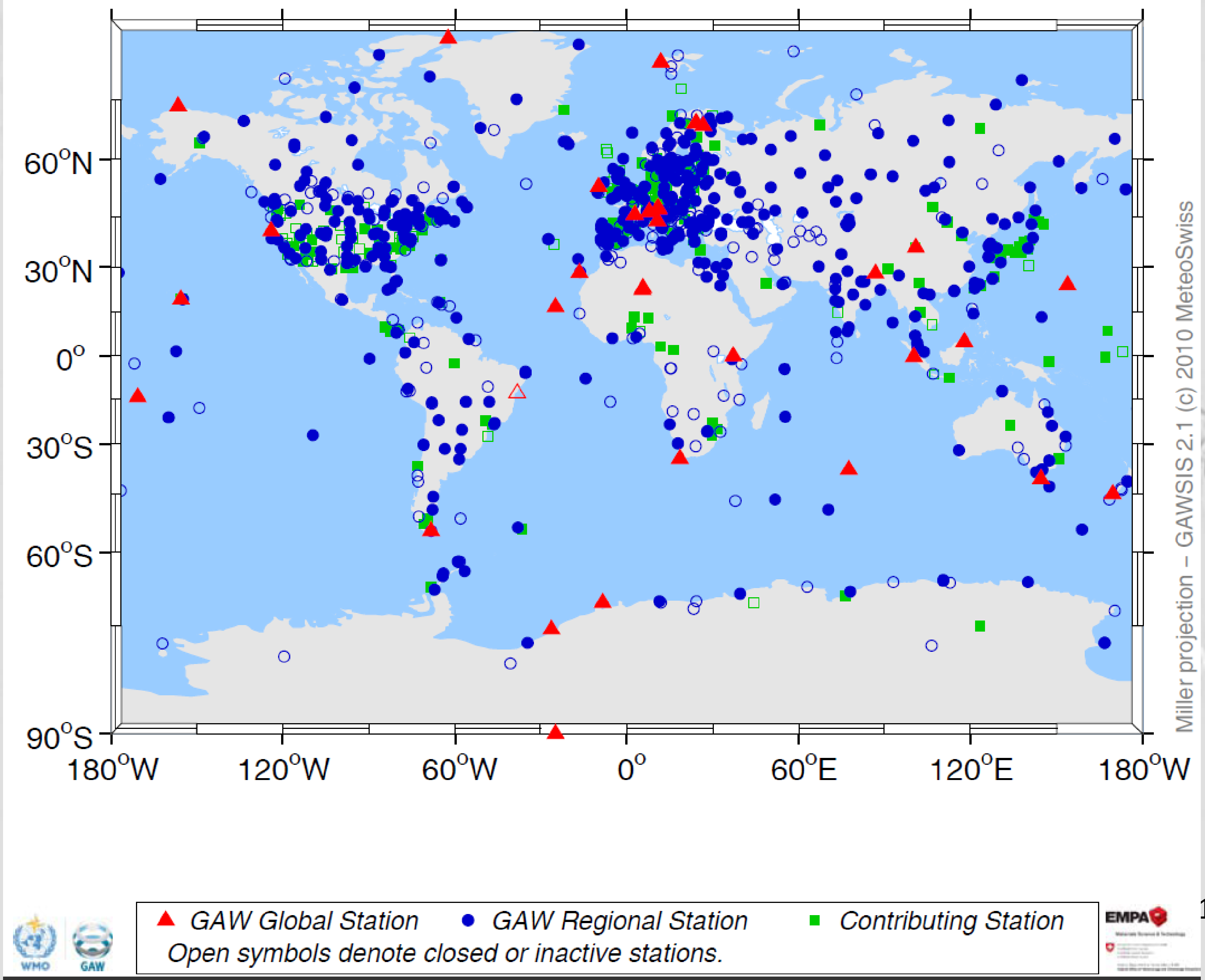
世界气象组织/全球大气观测网温室气体监测体系

自上世纪五十年代起，世界气象组织开始了大气化学的观测网，后整合为全球大气观测网（GAW）



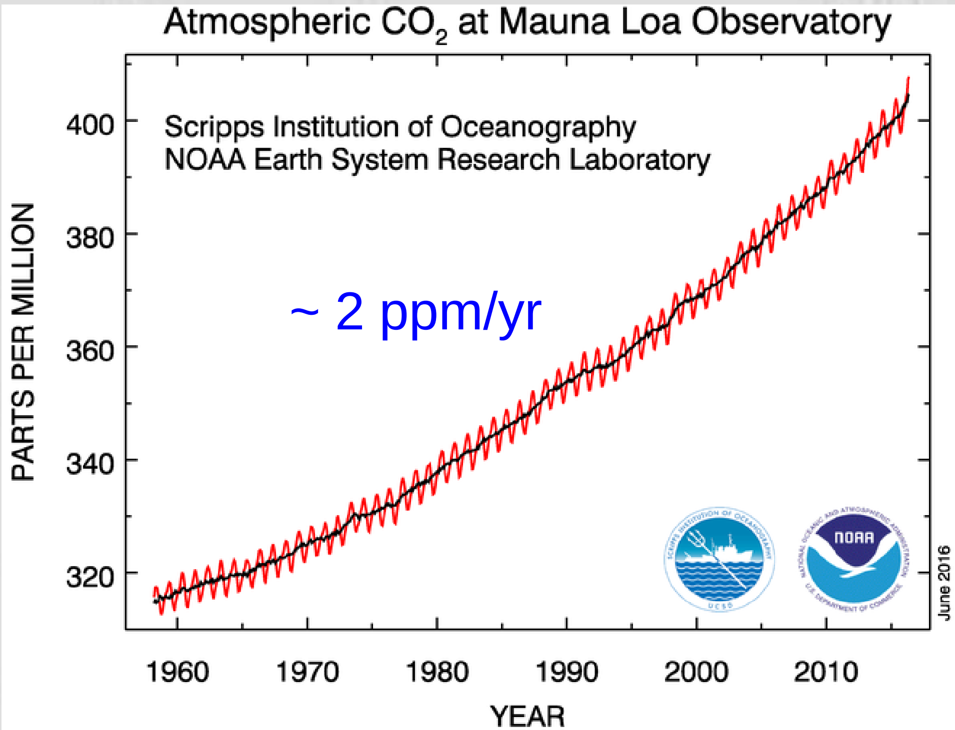
关注六大类大气成分，其中之一为温室气体

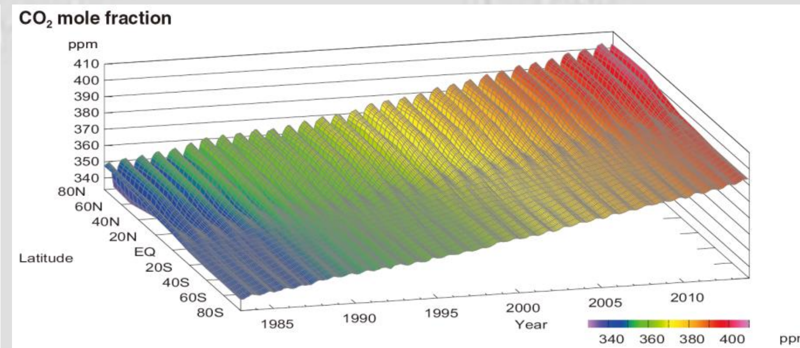
逐步建立遍布全球的观测体系

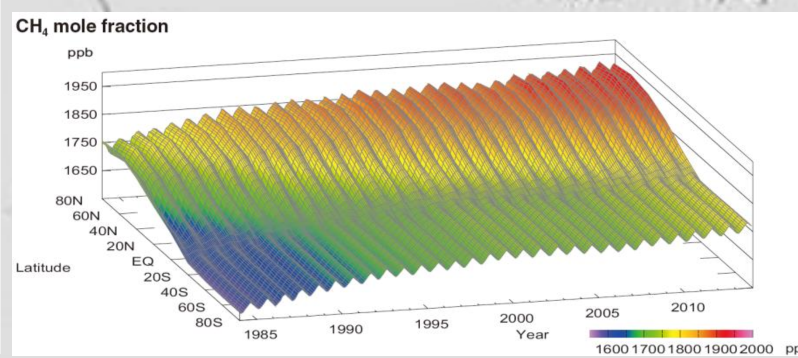


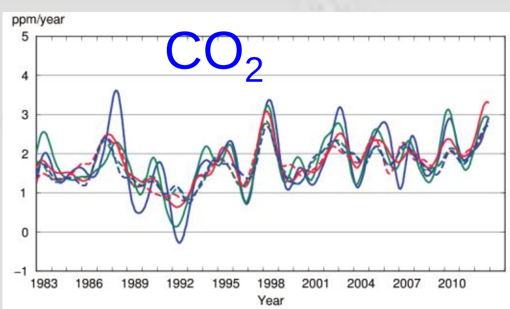
困难：本底大气温室气体观测难点——波动较小

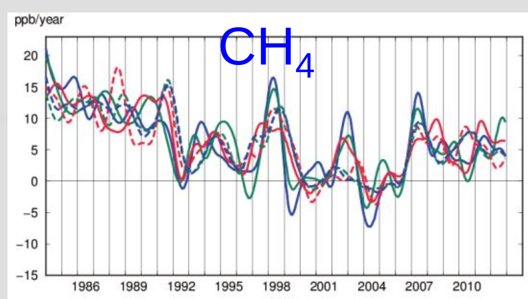
例如：温室气体本底年浓度变化较小，CO_2: 2 ppm/yr, CH_4:5-10 ppb/yr, N_2O:0.5-0.7 ppb/yr

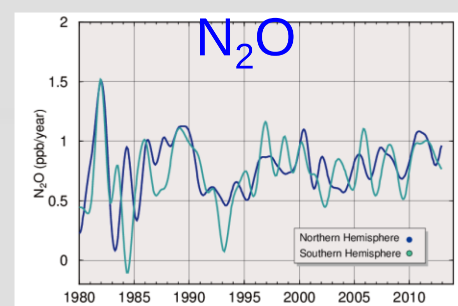












WMO/GAW温室气体实验室间可比性要求

Table 1 - Recommended compatibility of measurements of components discussed

Component	Compatibility goal		range in the unpolluted troposphere
CO_2	± 0.1 ppm	(± 0.05 ppm in the southern hemisphere)	360 … 430 ppm
$\delta^{13}C$-CO_2	± 0.01 ‰		-7.5 … -9 ‰ vs. VPDB
$\delta^{18}O$-CO_2	± 0.05 ‰		-2 … +2‰ vs. VPDB
$\delta^{13}C$ – CH_4	± 0.02 ‰		-80… -20‰ vs. VPDB
δD – CH_4	± 1 ‰		-400 … +0‰ vs. VSMOW
$\Delta^{14}C$-CO_2	± 1 ‰		0 … 70‰
O_2/N_2	± 2 per meg		-250 … -550 per meg (vs. SIO scale)
CH_4	± 2 ppb		1700 … 2100 ppb
CO	± 2 ppb		30 … 300 ppb
N_2O	± 0.1 ppb		320 … 335 ppb
H_2	± 2 ppb		450 … 600 ppb
SF_6	± 0.02 ppt		6 … 10 ppt

0.025%

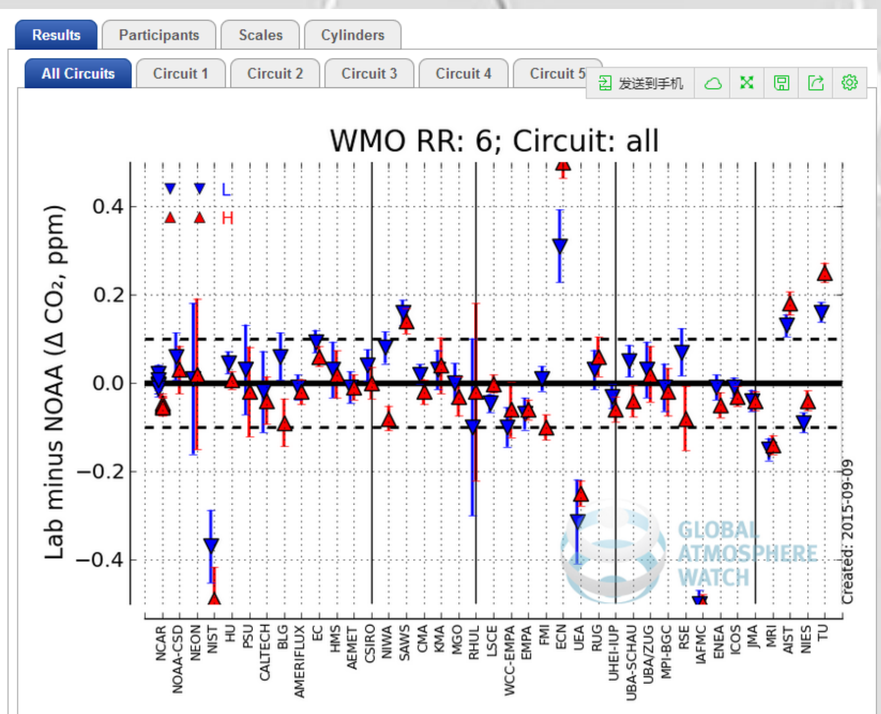
0.1%

0.03%

世界气象组织/全球大气（WMO/GAW）观测框架体系

WMO/GAW组织的多种考核盲样比对

- WMO/GAW温室气体巡回比对（Round-Robin），每2年一次；
- WMO/GAW亚洲区WCC甲烷巡回比对（Intercomparison），每2年一次；
- WMO/GAW质量控制中心WCC现场质量督查（每2-4年一次）。



WMO巡回比对（2014年）

Table 2 Results of Methane Reference Gas Intercomparison for Asia from 2011 to 2012

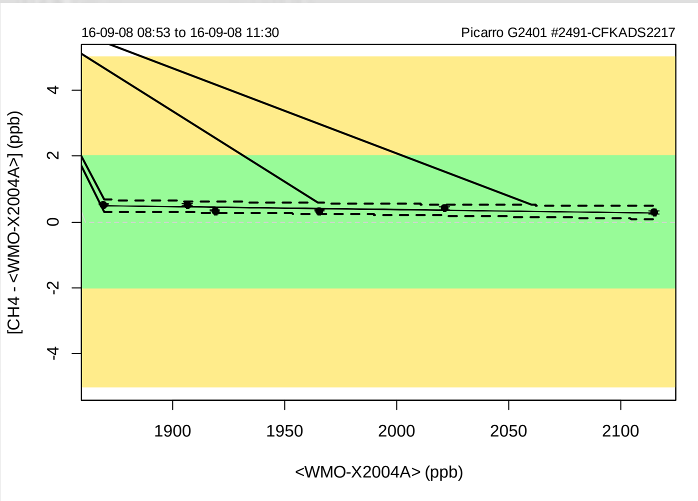
Laboratory and Location	Date of Measurement	Cylinder Number CPB31288 Concen-tration (ppb)	SD (ppb)	No	CPB31289 Concen-tration (ppb)	SD (ppb)	No	instrument
JMA Tokyo, Japan	June 8-9, 2011	1740.5	1.6	10	1878.1	1.5	10	SHIMADZU GC-14BPF
CMA Mt. Waliguan, China	September 13, 2011	1741.2	0.9	3	1878.7	0.4	3	Agilent 6890N
	September 20, 2011	1740.6	0.1	4	1879.0	0.1	4	Picarro G1301
CMA Central Laboratory in Beijing, China	October 14-17, 2011	1740.0	1.1	14	1879.1	0.5	17	Agilent 6890N
	October 20, 2011	1739.6	0.1	11	1878.8	0.1	11	Picarro G1301
KMA Anmyeon-do, Republic of Korea	December 1, 2011 - January 27, 2012	1739.2	0.88	10	1878.1	0.84	10	Agilent G1530A
JMA Tokyo, Japan	March 21-22, 2012	1740.2	0.9	10	1878.2	1.0	10	SHIMADZU GC-14BPF

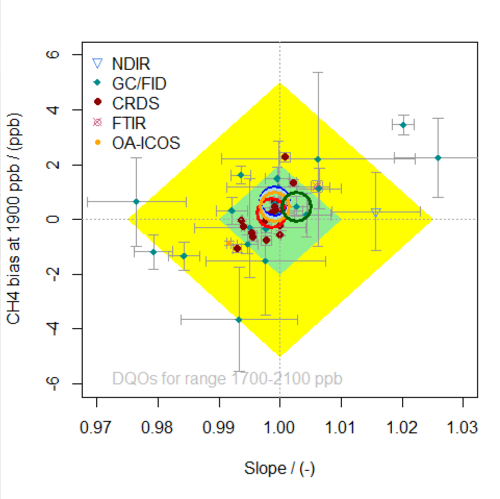
SD: Standard deviation; No: Number of measurements

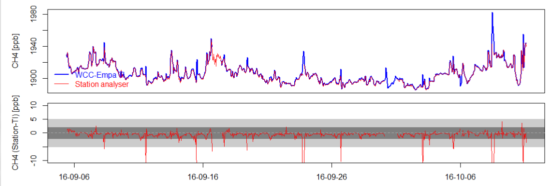
WMO巡回比对 （2012年）

世界标校中心（WCC）观测质量督查

每2-3年1次，对成员单位中心实验室和野外台站现场考核。







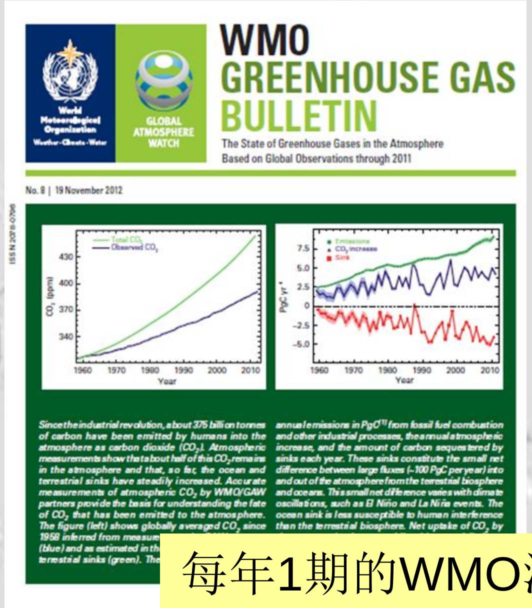
比对观测

考察内容：

- ✓ 观测系统硬件
- ✓ 观测人员的技术水平
- ✓ 规章制度和操作规范性
- ✓ 盲样考核

建立统一的数据中心，发布数据产品

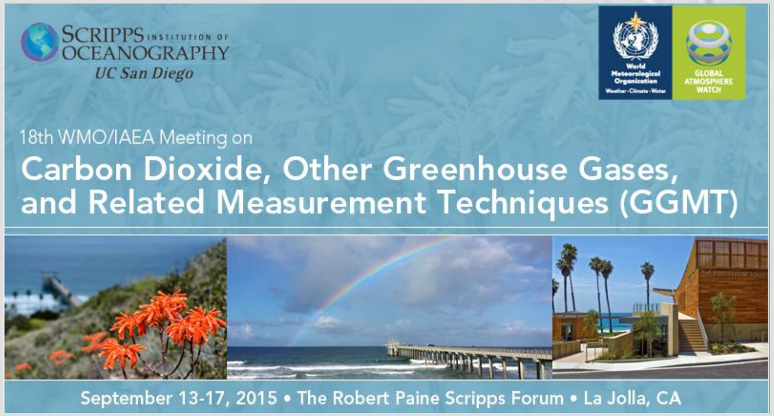
一系列措施保障了观测质量和统一溯源，是建立统一数据中心和产品的前提



每年1期的WMO温室气体公报

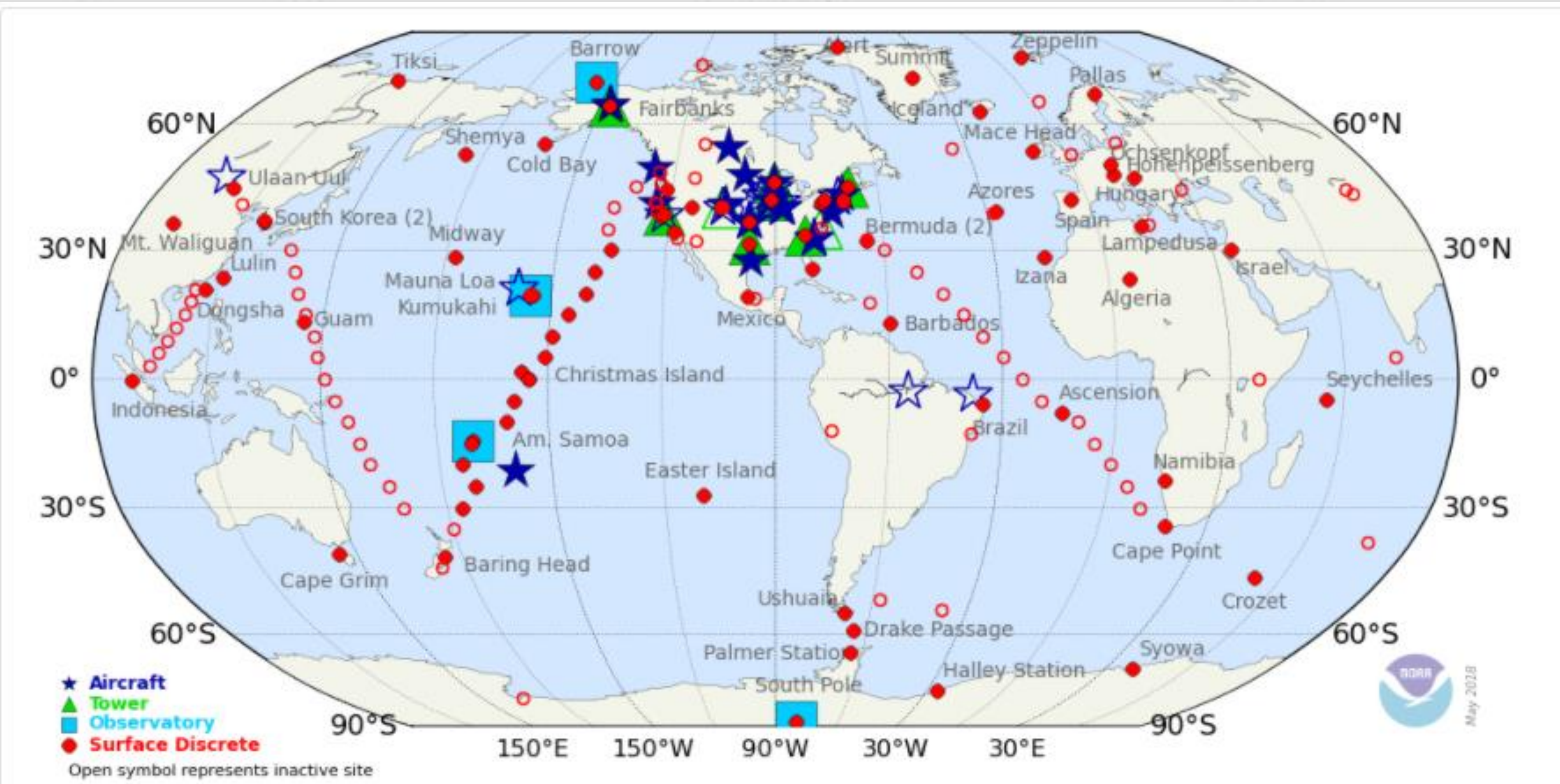
频繁的集中技术交流

- ✓ 每2年1次的国际二氧化碳技术会议
- ✓ 每年2次的先进的全球大气实验网（AGAGE）工作会
- ✓ 每年1次NOAA全球监测研讨会



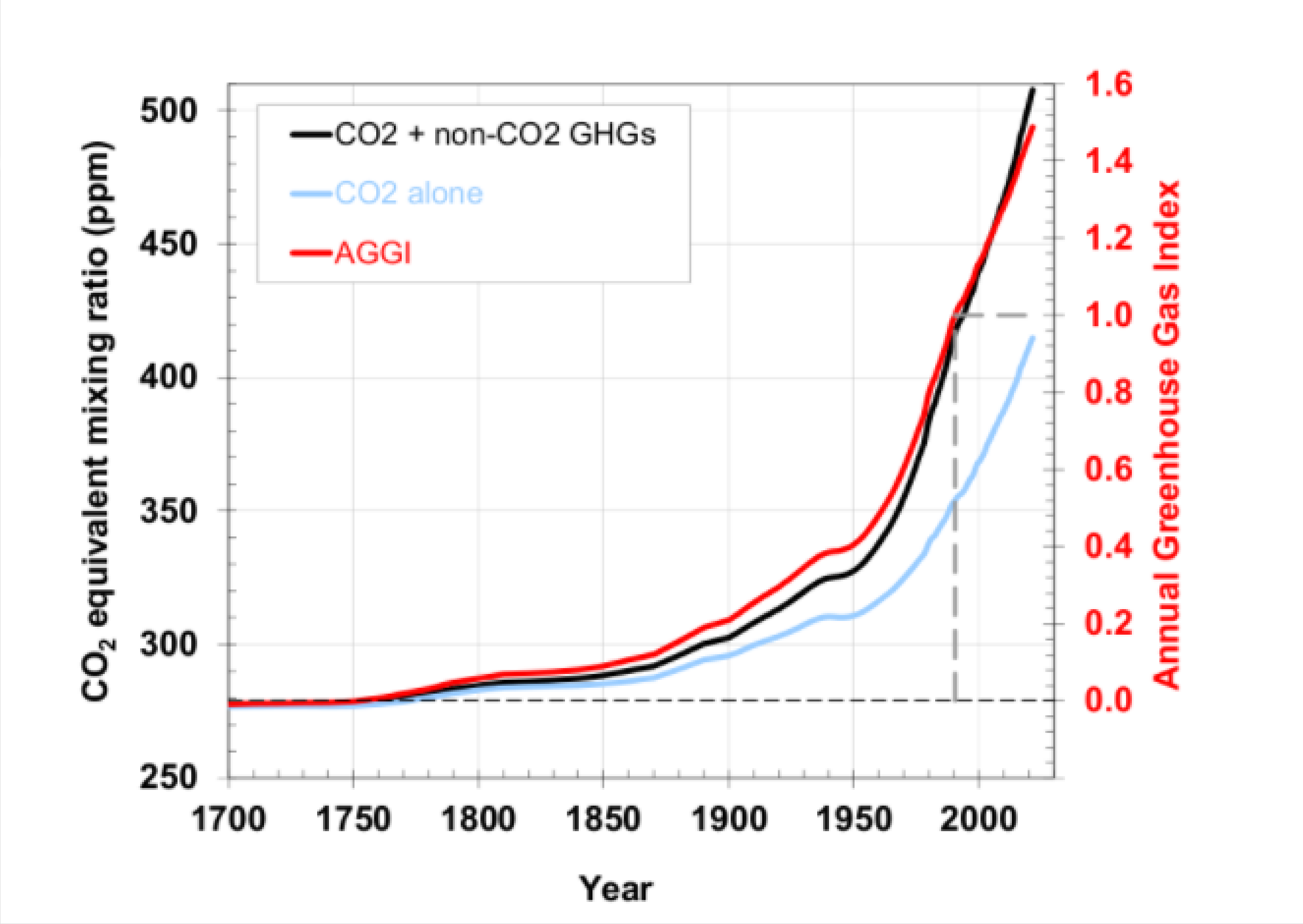
美国国家与海洋大气管理局温室气体监测体系

美国国家海洋与大气管理局（NOAA）温室气体监测网络

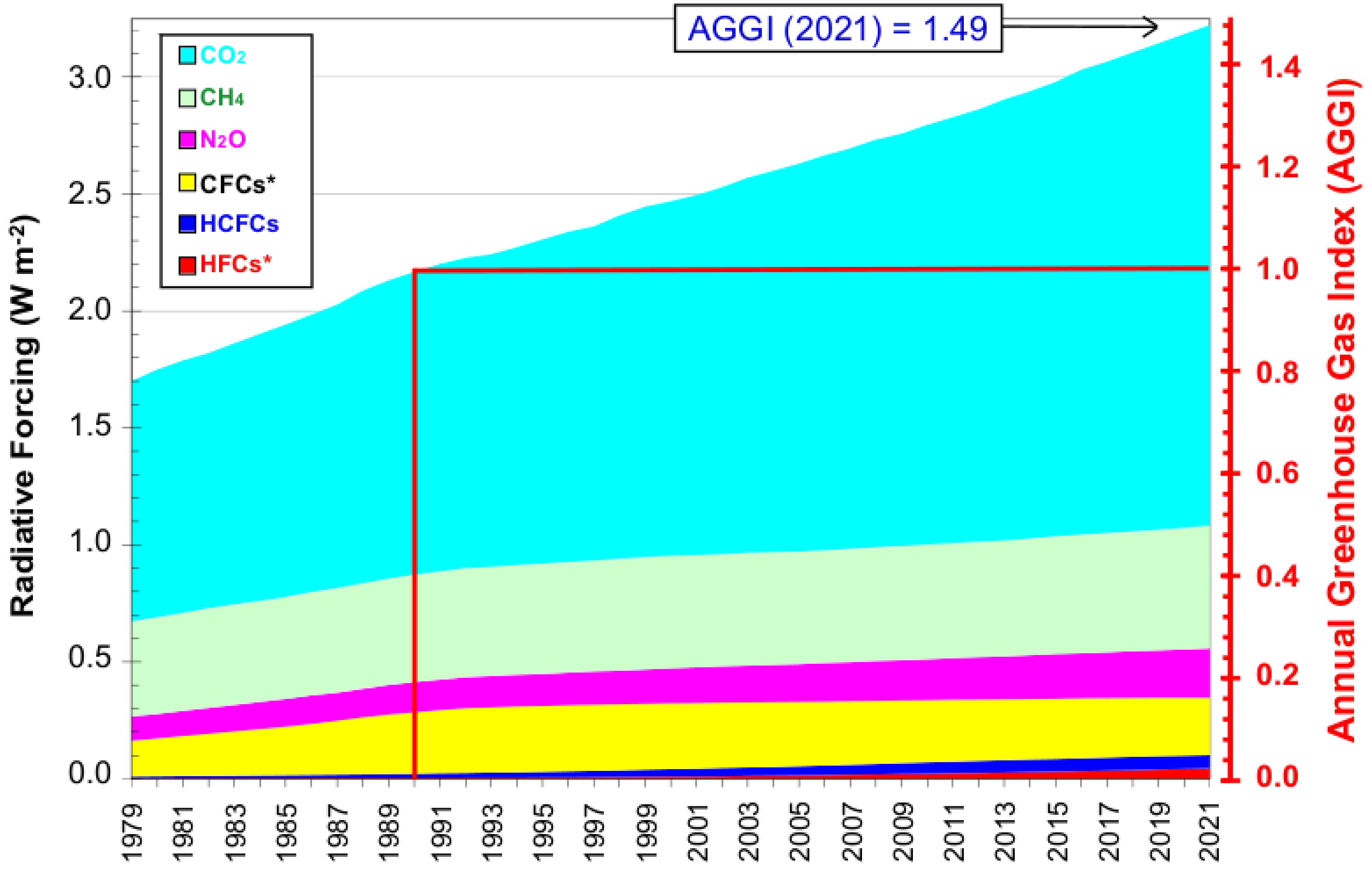


统一的监测标准，高质量控制要求
对全球温室气体监测数据贡献>50%, 主导国际评估

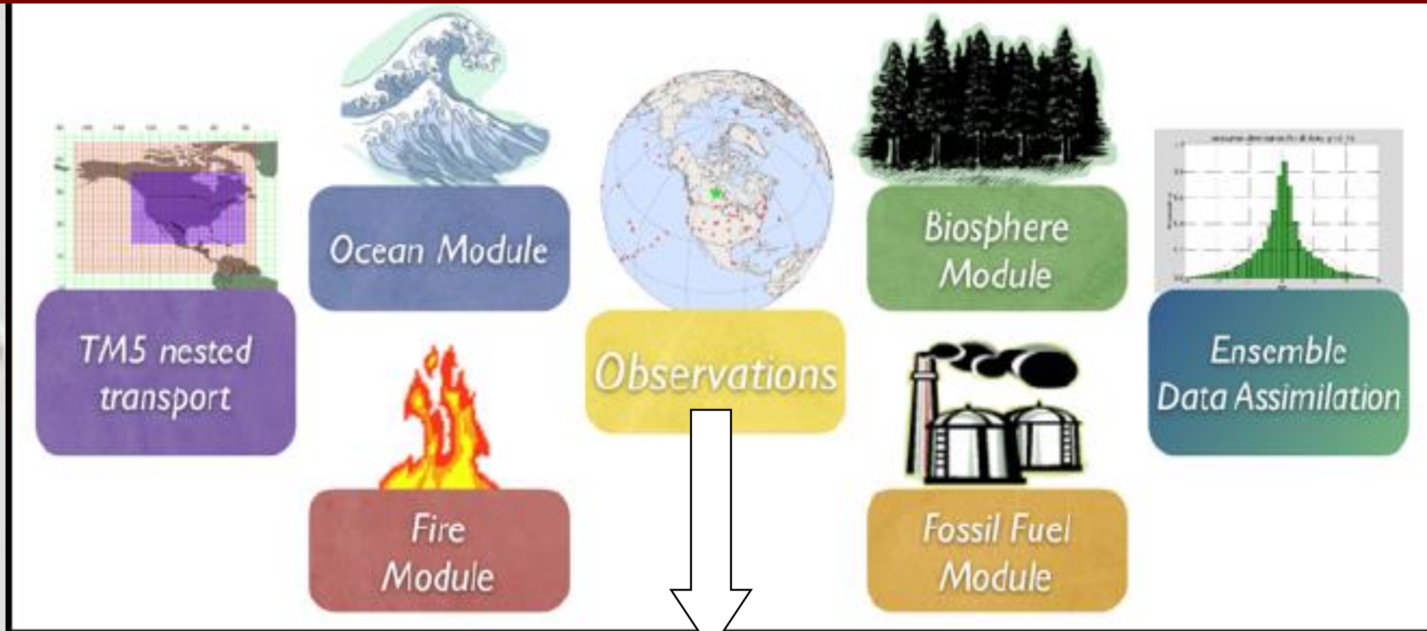
主要产品——温室气体同化数据库



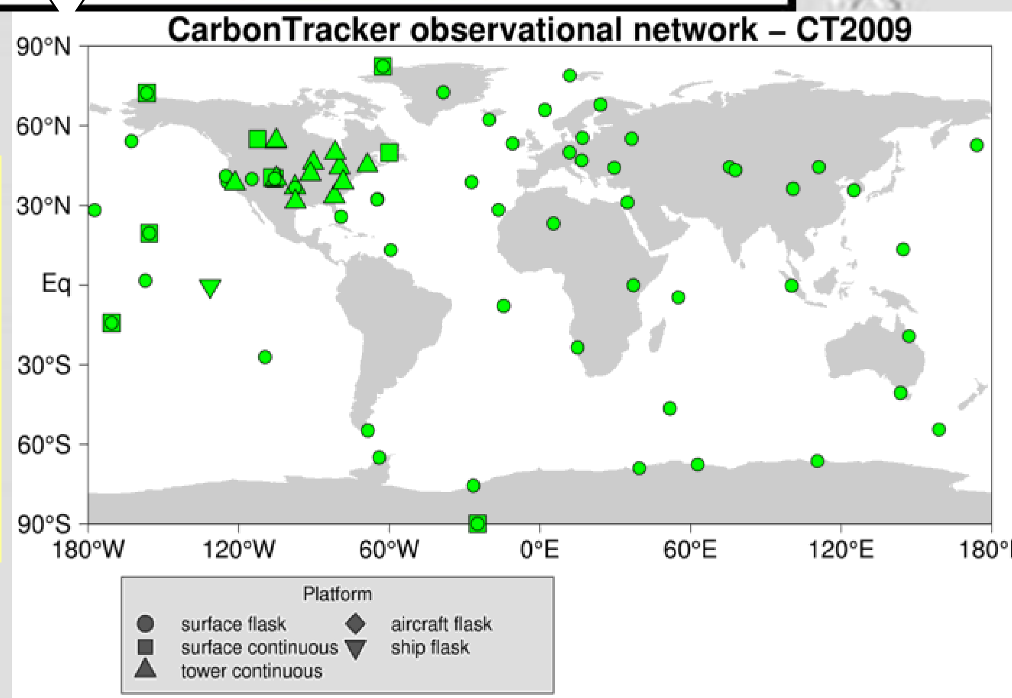
主要产品——年度温室气体指数（AGGI）



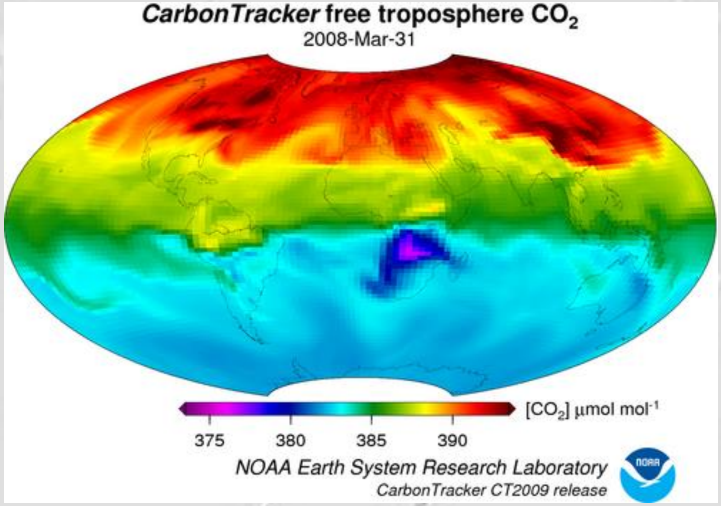
二氧化碳排放模型-Carbon Tracker

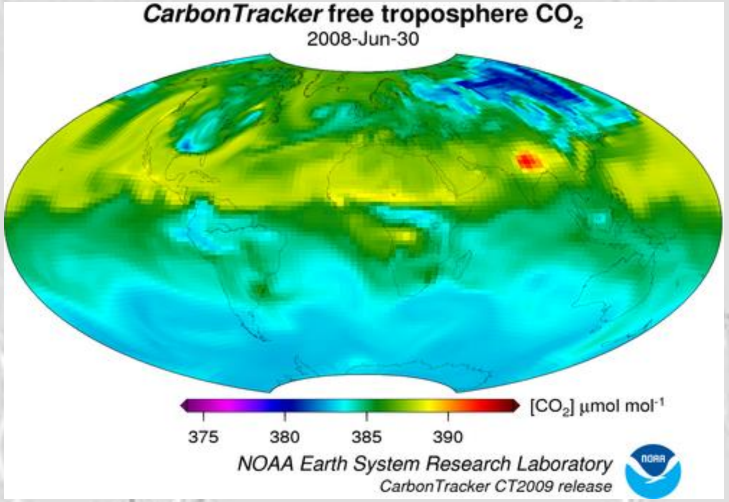


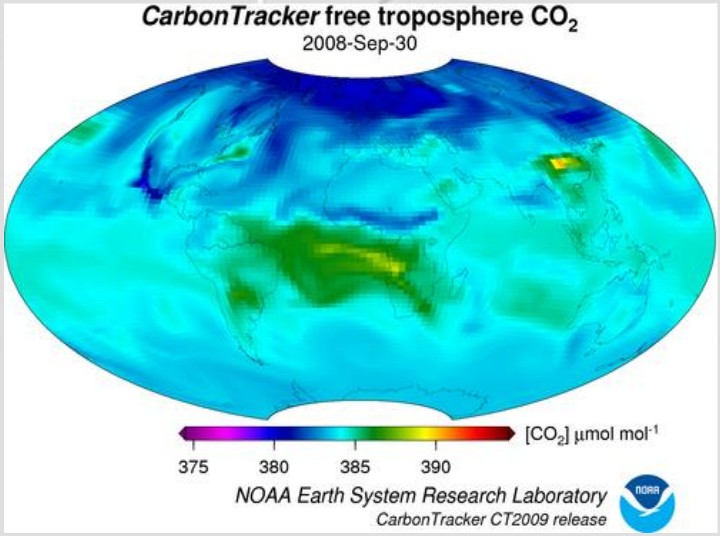
利用网络化观测的大气CO_2浓度数据，结合同期的气象资料，利用多个模块耦合的反演模型计算排放源和吸收汇的动态变化

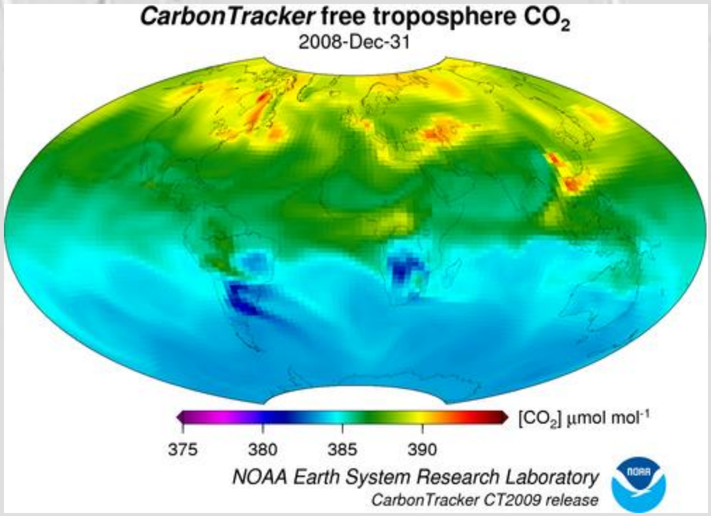


美国NOAA模式反演的碳排放产品
Carbon Tracker









全球温室气体综合信息系统计划

IG³IS

近年来全球-洲际-城市的研究计划纷纷设立

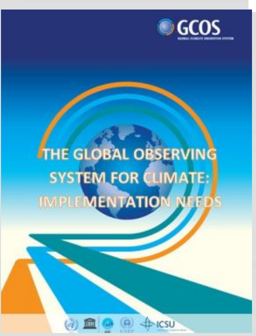
全球

TransCom

UNEP United Nations Environment Programme

WORLD METEOROLOGICAL ORGANIZATION

GLOBAL ATMOSPHERE WATCH



GCOS implement. plan 2016 (draft)

CEOS report 2014

洲际

ICOS integrated carbon observation system

European Research infrastructure (ESFRI)


Towards a European Operational Observing System to Monitor Fossil CO_2 emissions

Final Report from the expert group

Copernicus Europe's eyes on Earth

Climate Change Service

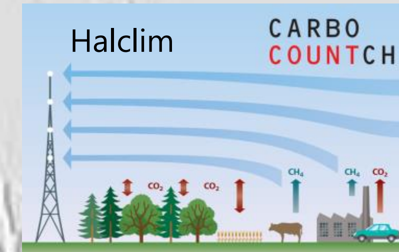
RESEARCH & INNOVATION Participant Portal

2 current H2020 calls

esa climate change initiative

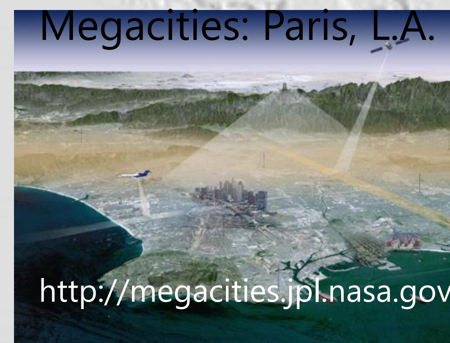
国家/城市

CH:



UK: GAUGE project

Megacities: Paris, L.A.



eit Climate-KIC

C40 CITIES

Covenant of Mayors Committed to local sustainable energy

世界气象组织成立“全球温室气体综合信息系统”计划和UNEP、UNFCCC合作

✓统筹组织全球不同尺度的各温室气体监测计划

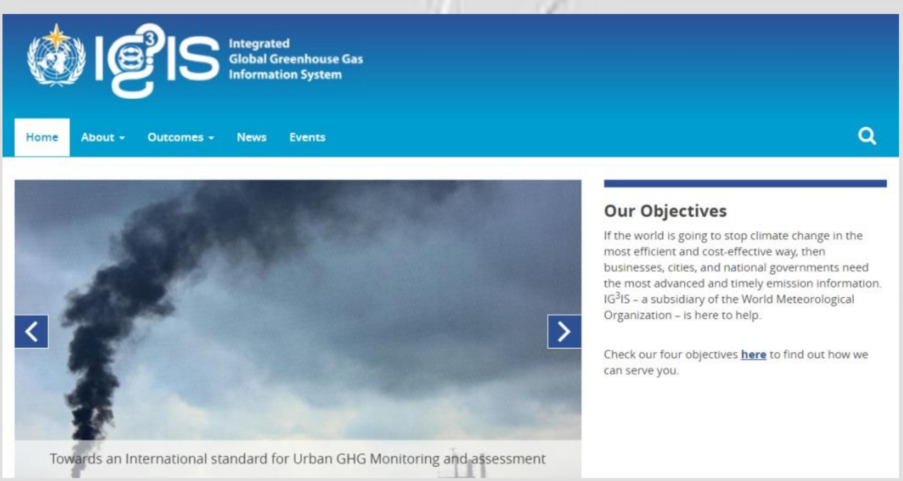
✓全球：建立官方的基于大气浓度的温室气体排放核算方法学

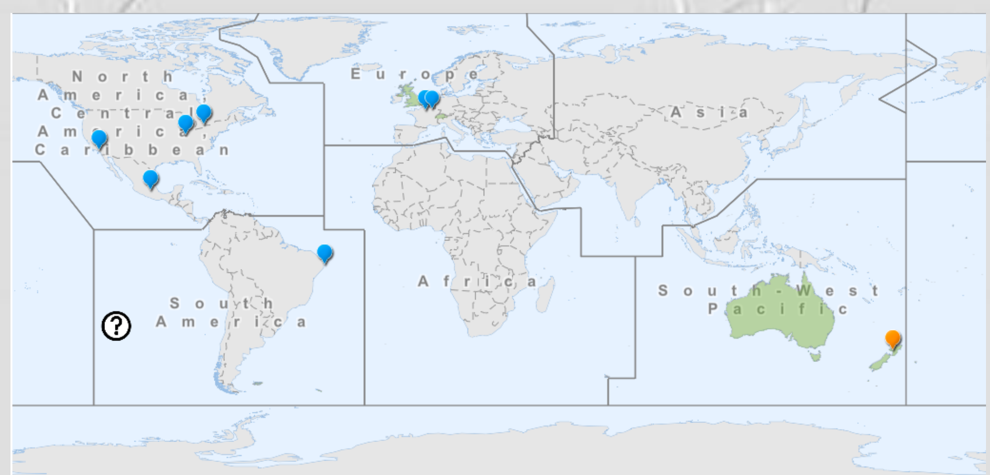
✓国家：推动基于大气浓度的排放核算纳入国家清单

✓城市：指导城市和企业核算温室气体排放和减排评估

✓遴选国际示范性项目，推荐最优做法

✓2020年4月成立第一届科学指导委员会，本人入选委员





组织编写了城市温室气体排放监测最优做法指南已完成征求意见，即将发布

WORLD METEOROLOGICAL ORGANIZATION

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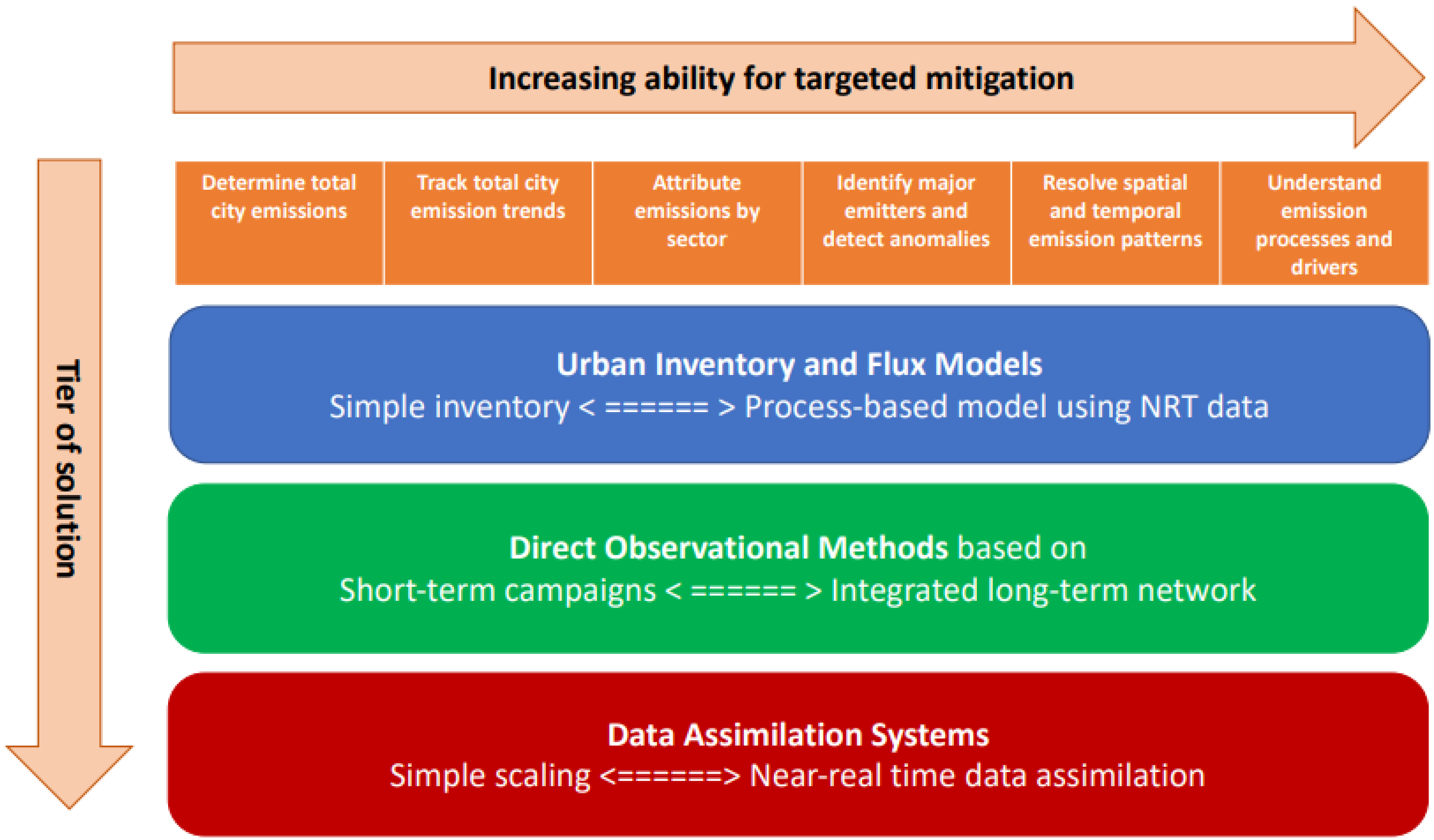
IG3IS Urban Greenhouse Gas Emission Observation and Monitoring Best Research Practices

05-11-2021

These Best Practice Guidelines are intended to provide technical guidance on current state-of-the-art technologies in urban greenhouse gas information systems. It lays out the available methodologies and how they can best be implemented, as well as guidance on the end-user outputs that might be obtained from each methodology. There are many unresolved challenges

https://community.wmo.int/news/ig3is-urban-greenhouse-gas-emission-observation-and-monitoring-best-research-practices

国家（区域）温室气体排放监测最优做法指南正在编写中



Increasing ability for targeted mitigation
Determine total city emissions
Track total city emission trends
Attribute emissions by sector
Identify major emitters and detect anomalies
Resolve spatial and temporal emission patterns
Understand emission processes and drivers
Tier of solution
Urban Inventory and Flux Models
Simple inventory < ====== > Process-based model using NRT data
Direct Observational Methods based on
Short-term campaigns < ====== > Integrated long-term network
Data Assimilation Systems
Simple scaling <======> Near-real time data assimilation

Table of Contents

DRAFT

涵盖最新发展的多种观测手段

地面

高塔

地基遥感

传感器

移动

固定观测

移动观测

卫星

飞机

廓线探空

飞艇观测

卫星观测

高塔站点观测

4.1. Tower and other elevated point observations

Monitoring atmospheric mole fractions of greenhouse gases from elevated points in and around cities aims to measure the enhancements in these mole fractions due to urban emissions. Measuring at elevated points such as roof tops or higher (tall towers, mountains) and sites downwind of the city, compared to surface measurements performed at the street level, makes it possible to extend the footprint of the observations and to reduce as much as possible the surface layer vertical gradients.

高密度观测

4.11. Dense networks

Dense networks are an approach to urban GHG emissions assessment that relies on large numbers of sensors, each with a small, locally dominated, footprint of two-five kilometres diameter that overlaps with the footprint of adjacent observing stations. In principle, such networks could use any instruments, however, in practice low cost sensors make the idea attractive. The conceptual advantages of the approach include 1) much lower capital investments than some of the alternatives, 2) the small footprint of each sensor allows for more direct attribution to individual source types, 3) addition of low cost air quality observations can enhance attribution to sectors for an incremental additional cost that is a small percentage of overall capital cost and 4) there is a square root N advantage in signal to noise of some analyses. Within the mix of approaches described in this document, dense networks are a newer idea, one that is not as extensively vetted as the others.

观测站网布局

B.a.3.1 Determination of ideal measurement locations

The minimum configuration of an urban network is usually to have two towers upwind and downwind of the city in the direction of the prevailing winds in order to have as many mole fraction gradients as possible with a background site (the upwind site ; see also Section 4.12 and Annex B.I. on background selection). To increase the number of situations where the upwind to downwind gradient of the city is measured, a network of towers on the outskirts of the city seems to be the preferred option. In addition to one or more upwind-downwind pairs, dedicated site(s) downwind of specific hot-spots may be desirable. Depending on the signal and the distance from the hot spot low-cost sensors may be appropriate for such purpose. Furthermore, in regions where low windspeed situations often occur and the urban emissions accumulate, it may be useful to install a measurement site within the city itself to quantify the local urban CO_2 dome by calculating the excess of mole fraction measured at that site relative to background mole fraction level (as defined in Section 4.12) (e.g. Xueref-Remy et al, 2018; Mitchell et al., 2018; Karion et al., 2021).

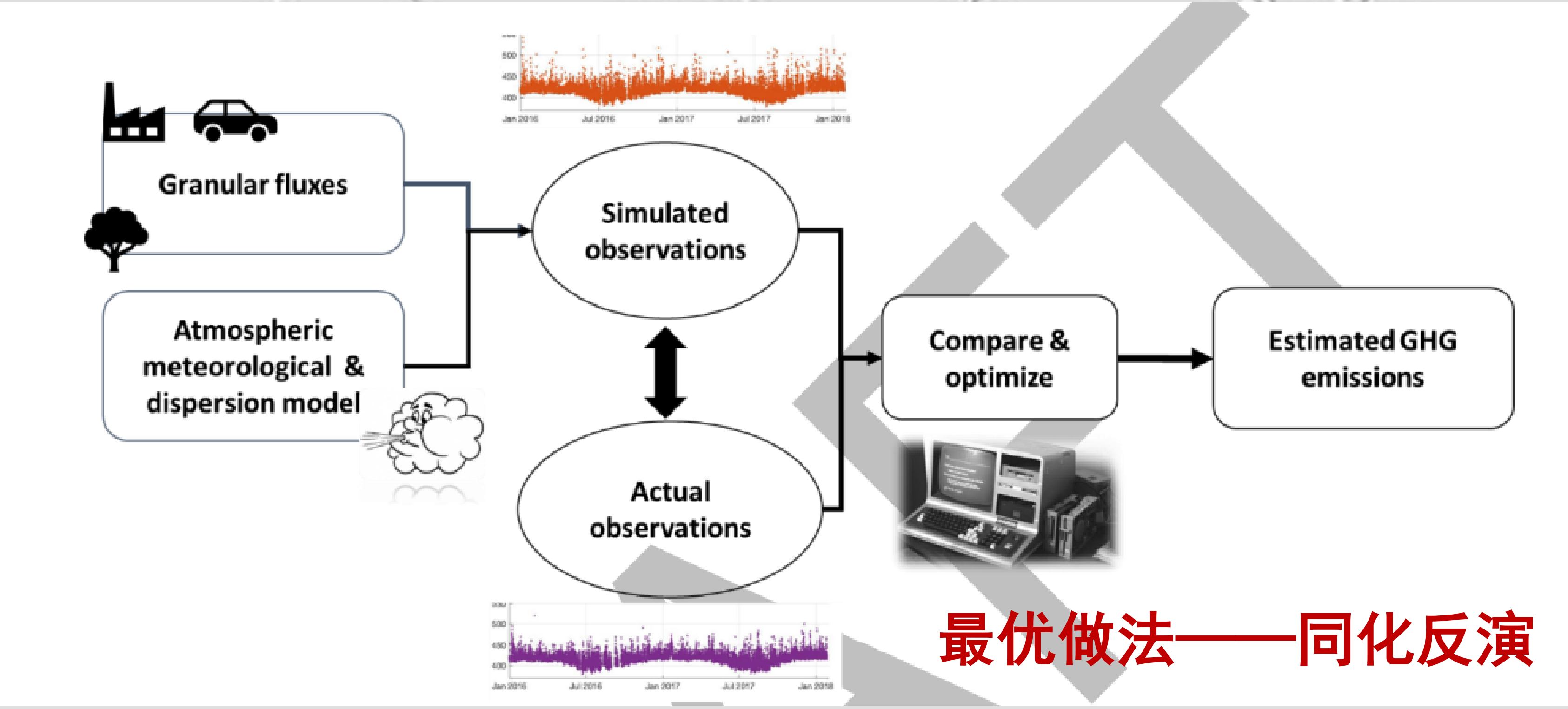
2点→沿着主导风向多点→关键排放区下风向增加站点

观测量估算

4.6. Mass Balance Analysis

The mass balance method is a conceptually simple approach that does not rely on numerical transport modelling or sophisticated statistical methods. Greenhouse gas emission estimates have been made for many cities across the world using an aircraft mass balance approach based on the conservation of mass principle.

简单——质量平衡法



最优做法——同化反演

国际示范性碳监测网络

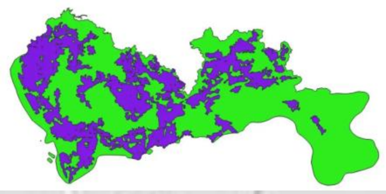
区域尺度 → 城市尺度

重庆市
面积8.24万平方公里
人口3200万

哈尔滨市
面积5.31万平方公里
人口1000万

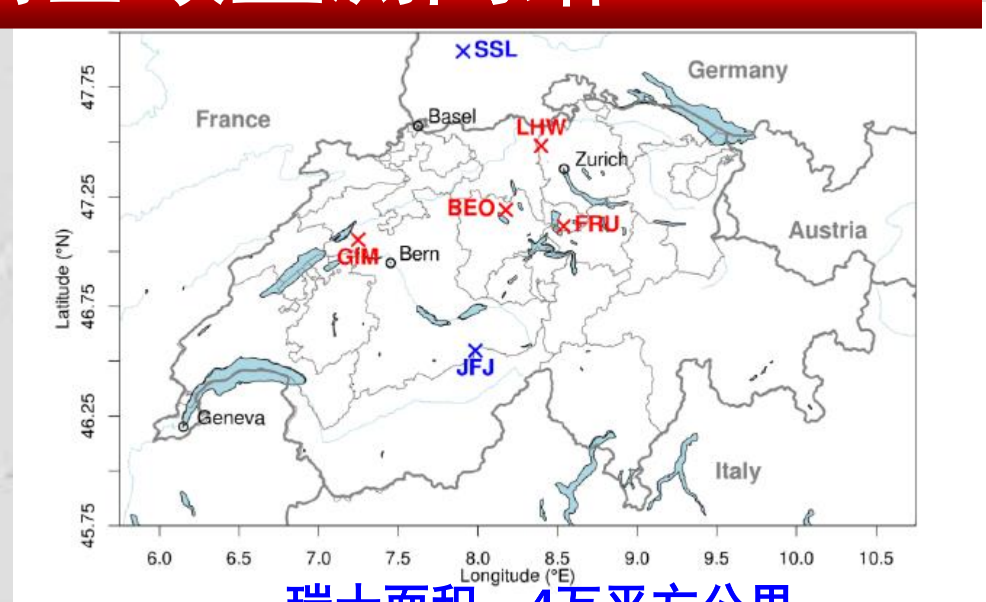
……

上海市
面积6340平方公里
人口2500万



深圳市
面积2000平方公里
人口1800万

示范1：瑞士碳监测网络

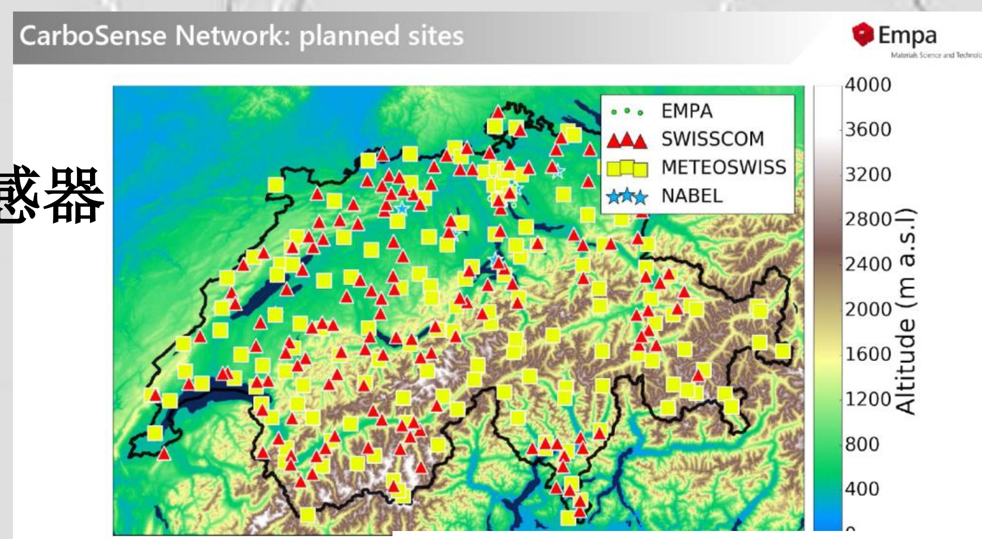


含氟气体：1个站、比值相关模型

CH_4/N_2O：5个站，大气反演模型

瑞士面积：4万平方公里

杭州面积：1.68万平方公里



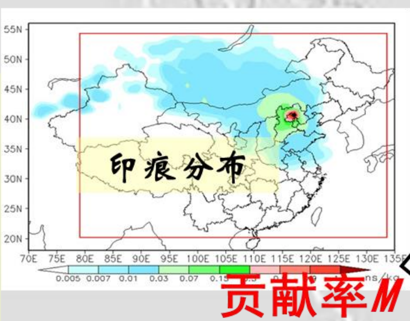
CO_2：5个高精度站+小型传感器

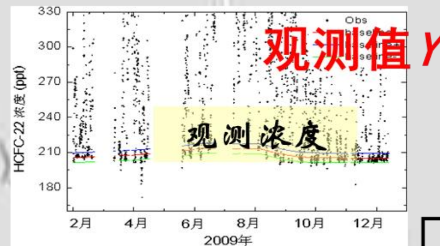
Federal Office for the Environment, 2020

CH_4和N_2O排放计算

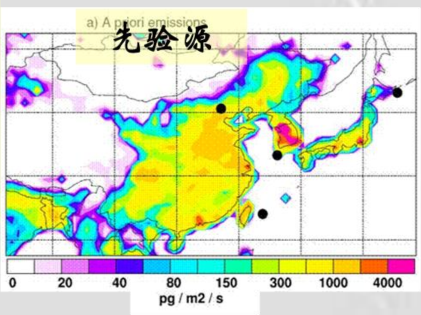
Flexpart模型反演

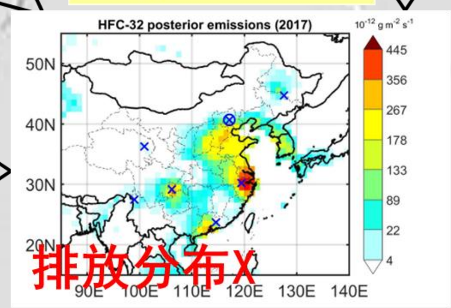
Top-down 源反演





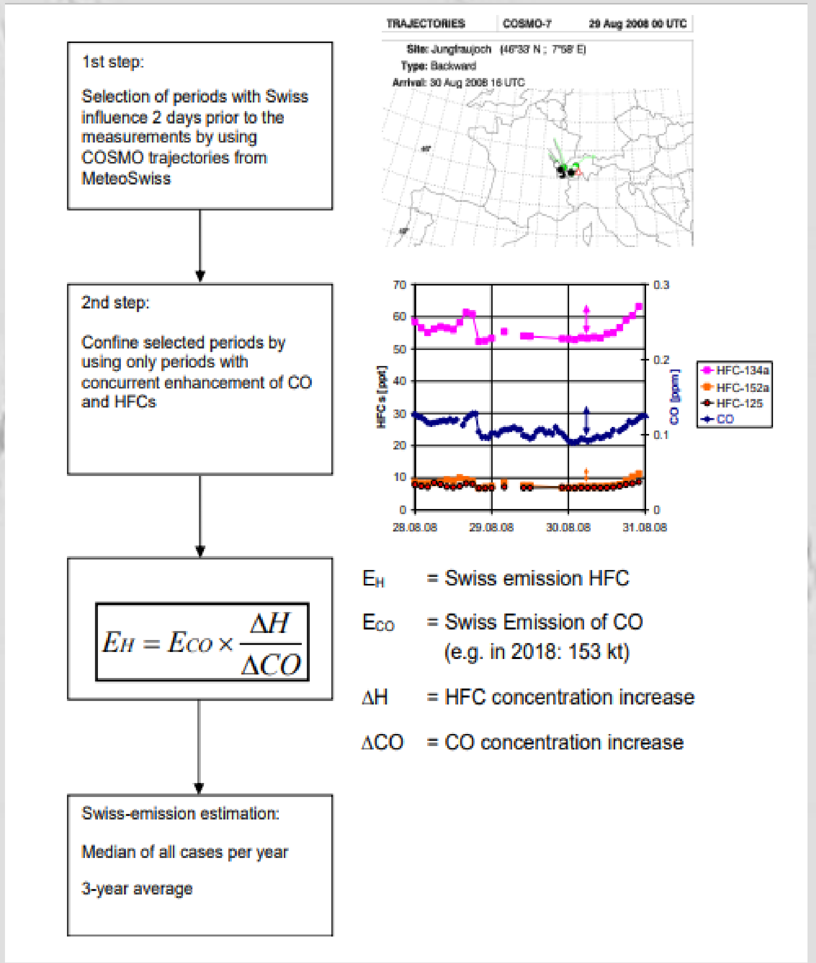
$$M_{ij}X_i = Y_j$$





含氟气体排放计算

示踪物比值相关法



瑞士温室气体排放结果

Switzerland's

Greenhouse Gas Inventory

1990–2018

National Inventory Report

Including reporting elements under the Kyoto Protocol

Submission of April 2020
under the United Nations Framework Convention on Climate Change
and under the Kyoto Protocol

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

Swiss Confederation

Federal Office for the Environment FOEN

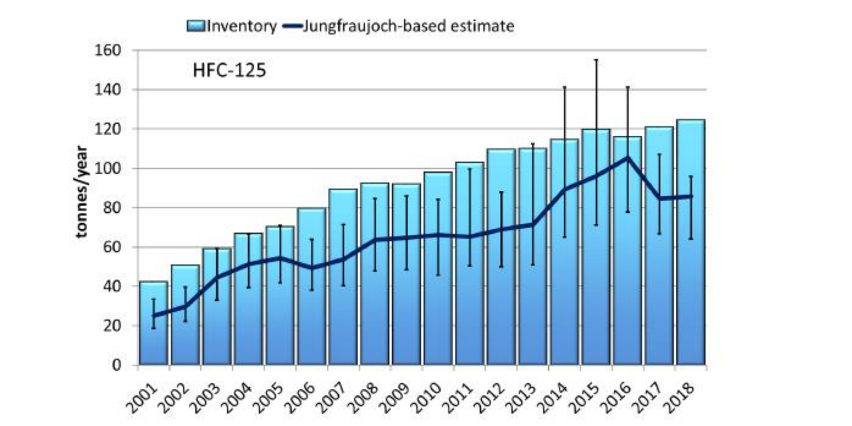
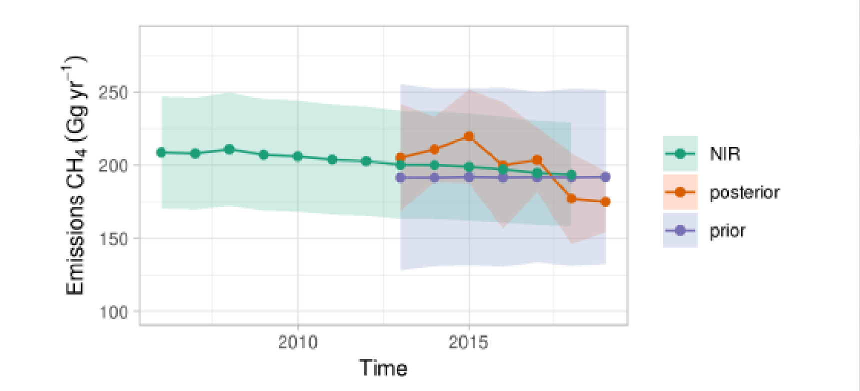


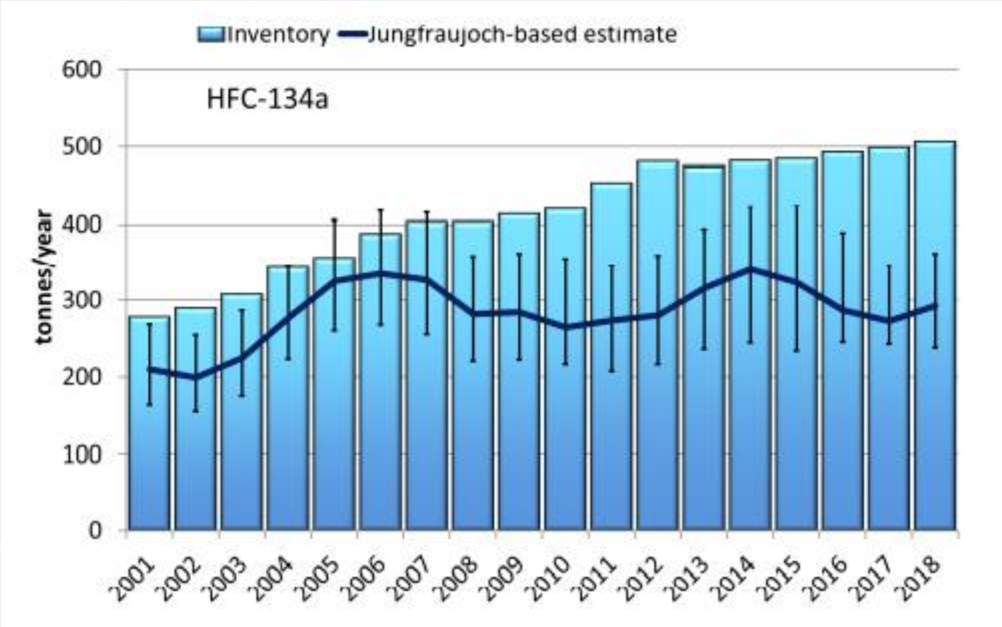
Figure A – 5 Comparison of HFC-125 emissions from Switzerland: Inventory and estimates from measurements at Jungfraujoch.

瑞士HFC和甲烷排放比对结果



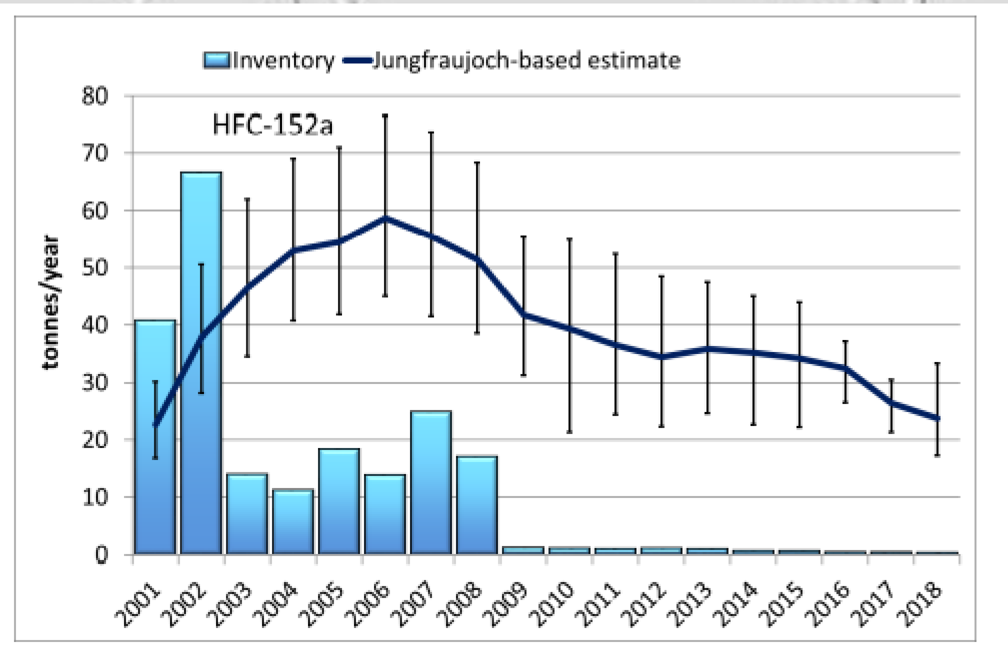
包括物种：HFC、SF_6、CH_4、N_2O

清单结果>监测排放



监测排放>清单结果

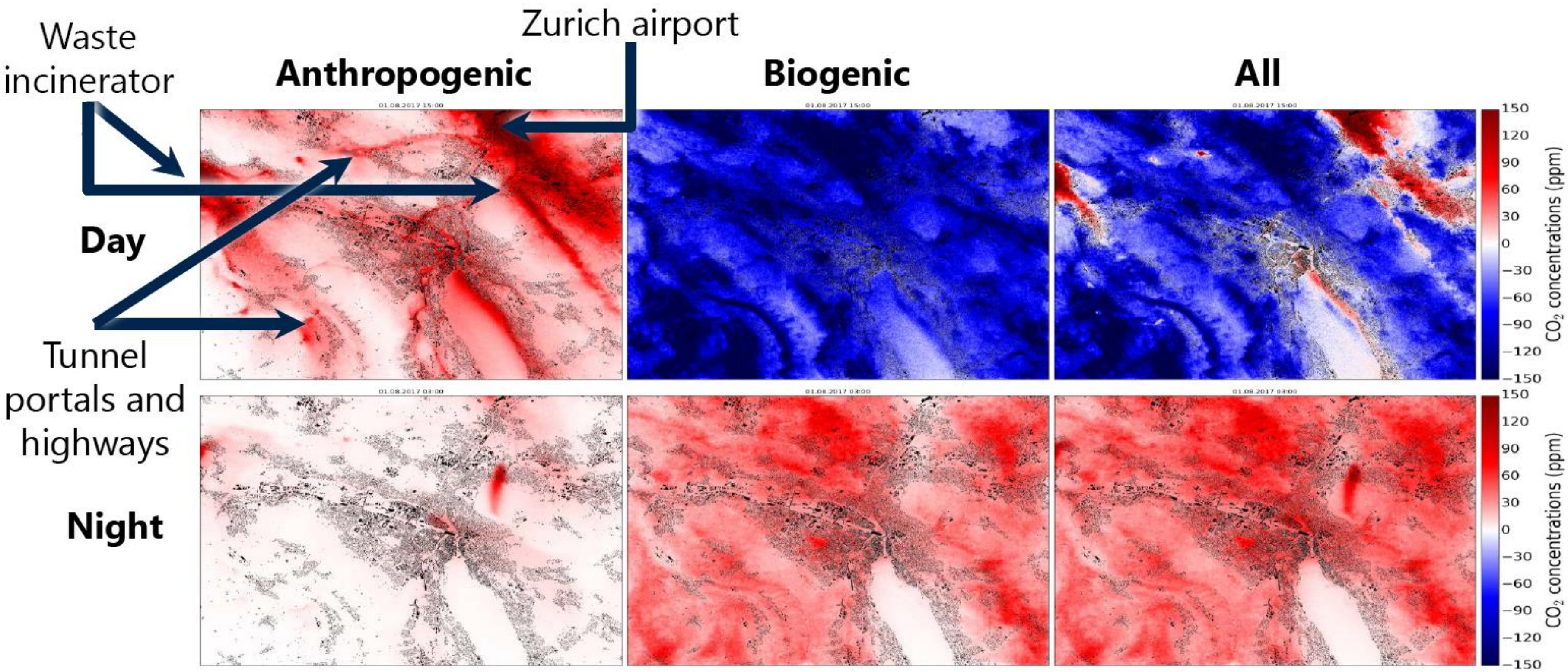
失踪源?



苏黎世周边小尺度碳排放模拟

High-resolution simulations of CO_2 in the city of Zürich

Empa
Materials Science and Technology

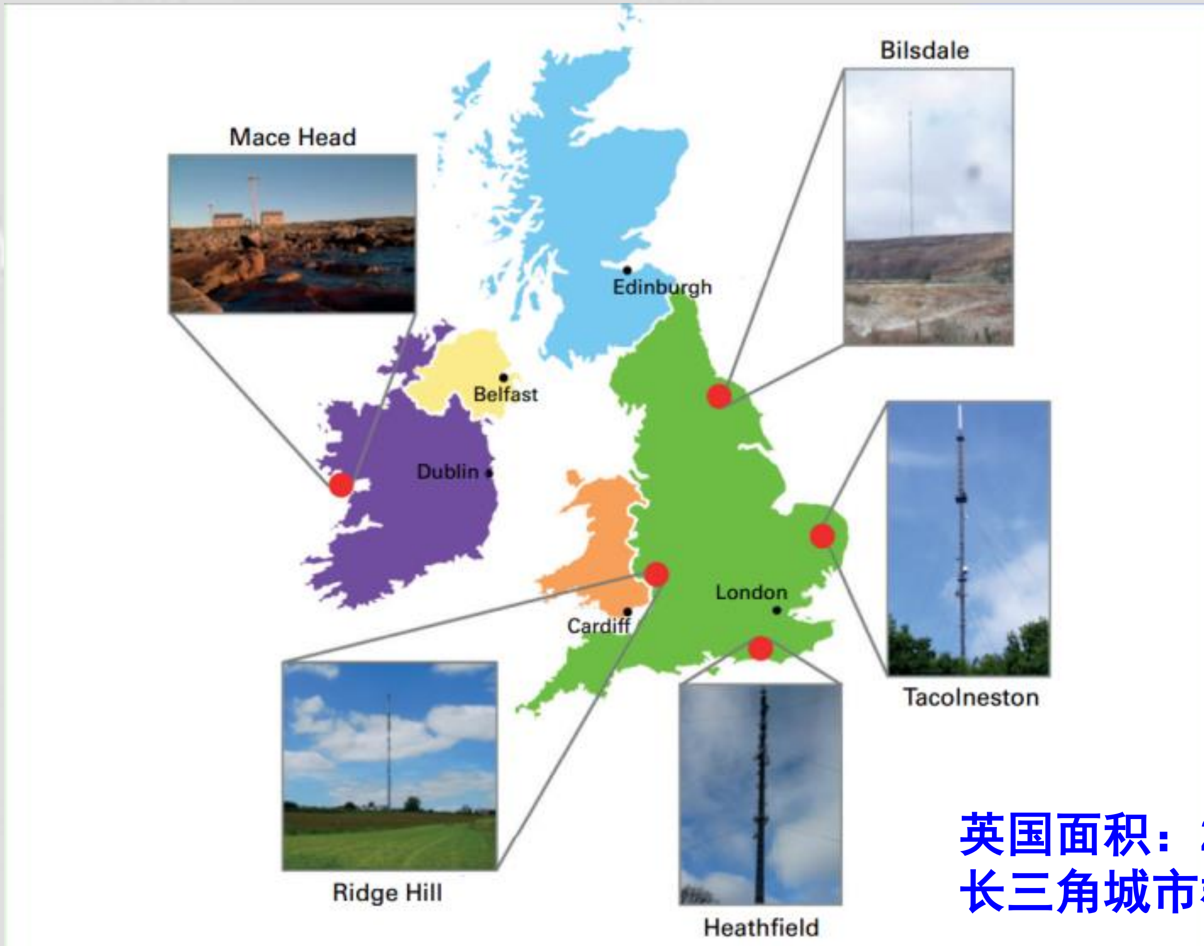


- Few dominating hot spots of anthropogenic emissions
- Photosynthesis compensate most anthropogenic emissions during daytime

小尺度模拟需要高分辨率地形和气象数据

来自S. Henne

示范2：英国温室气体监测网络



Met Office

University of BRISTOL

REPORT TO BEIS

LONG-TERM ATMOSPHERIC MEASUREMENT AND INTERPRETATION

(OF RADIATIVELY ACTIVE TRACE GASES)

BEIS contract number: GA0201

Annual Report (Sept 2017 - Sept 2018)

Date: 10th September 2018

University of Bristol: Simon O'Doherty, Kieran Stanley, Matt Rigby, Ann Stavert

Met Office: Alistair Manning, Alison Redington

INSCON: Peter Simmonds

Terra Modus Consultants Ltd: Dickon Young

University of East Anglia: Bill Sturges, Adam Wisher

University of Edinburgh: Paul Palmer

NPL: Chris Rennick, Tim Arnold

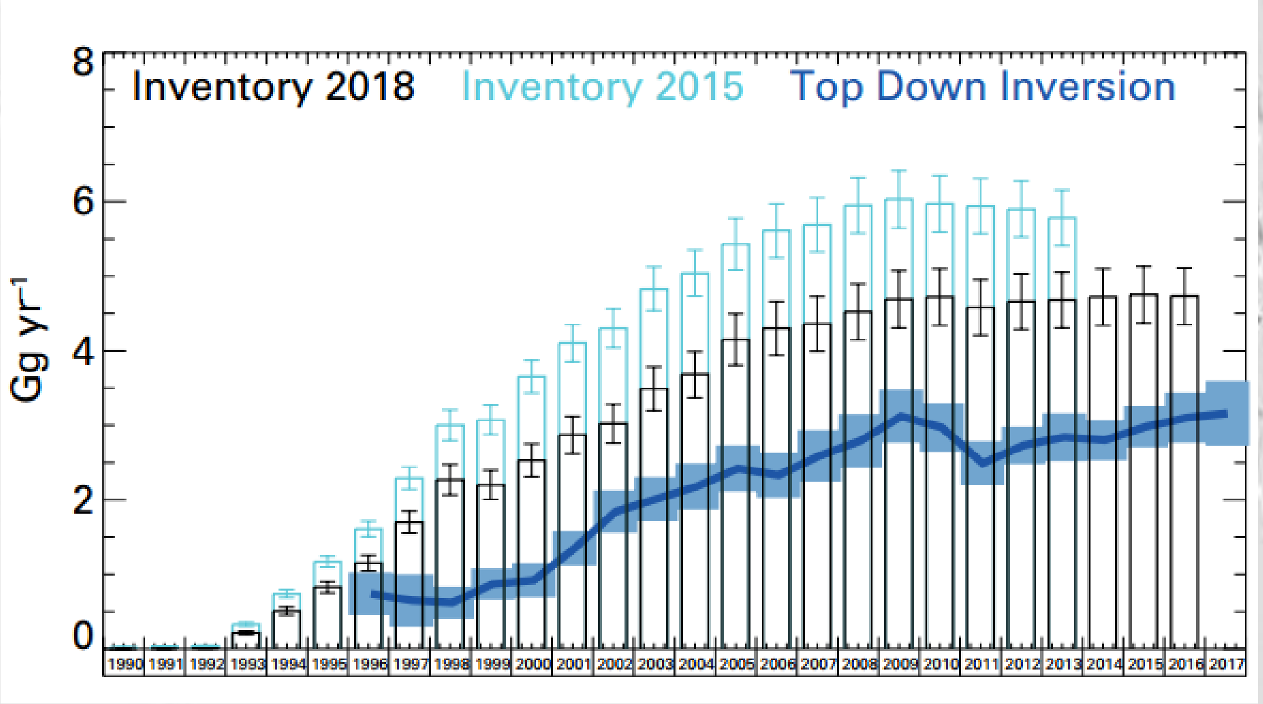
英国面积：24万平方公里

长三角城市群：21.17万平方公里

包括物种：HFC、SF_6、PFC、NF_3、CH_4、N_2O

反演结果和清单的比较

所有气体：NAME模型反演



BEIS to investigate this further and an industry expert partly revised the United Kingdom HFC-134a inventory estimates.

提交的国家清单仍有科学问题需要解决

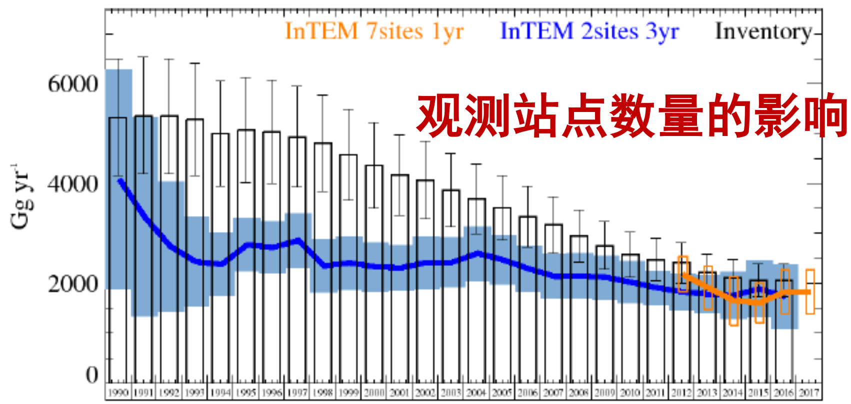


Figure 2: CH_4 UK Emission estimates (Gg yr^{-1}) from the UNFCCC Inventory (black) and InTEM with global meteorology: 3-year MHD+CBW (blue) and 12-month DECC + GAUGE + CBW network (orange). The uncertainty bars represent 1 std.

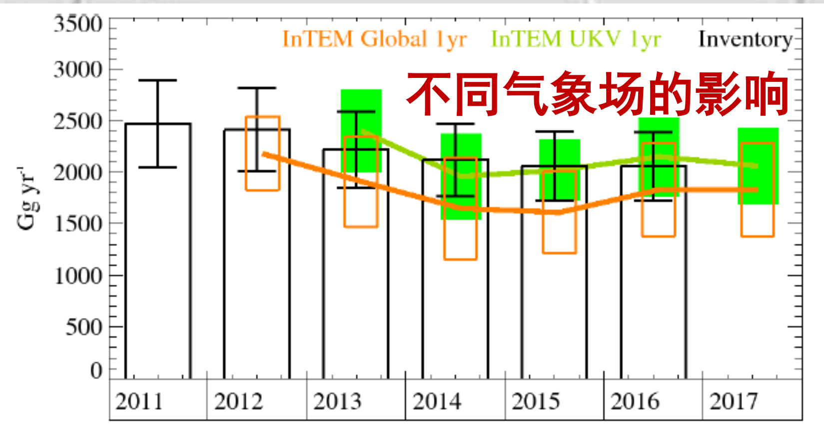


Figure 3: CH_4 emission estimates for the UK (Gg yr^{-1}) from the UNFCCC Inventory (black) and InTEM using the DECC + GAUGE + CBW observations, 1-year inversions with different meteorology: (orange) global meteorology and (green) 1.5 km high resolution meteorology. The uncertainty bars represent 1 std.

基于监测的人为源CO_2排放纳入国家清单技术难度大

6 Estimating biogenic and anthropogenic CO_2

There remains no single, robust methodology to isolate $ffCO_2$ from atmospheric measurements of CO_2 alone.

There has been concerted modelling efforts to understand the performance of the current $^{14}CO_2$ network over Europe to quantify fossil fuel CO_2 ($ffCO_2$) (Wang et al, 2017, Wang et al, 2018), and the added benefit of increasing the spatial and temporal coverage of these measurements. Results from $^{14}CO_2$ data collected within the NERC-funded GAUGE project over the UK are still in preparation, but early results suggest care must be taken to remove the signal from the nuclear processing industry.


Met Office
University of BRISTOL

REPORT TO BEIS

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University of Edinburgh: Paul Palmer

NPL: Chris Rennick, Tim Arnold

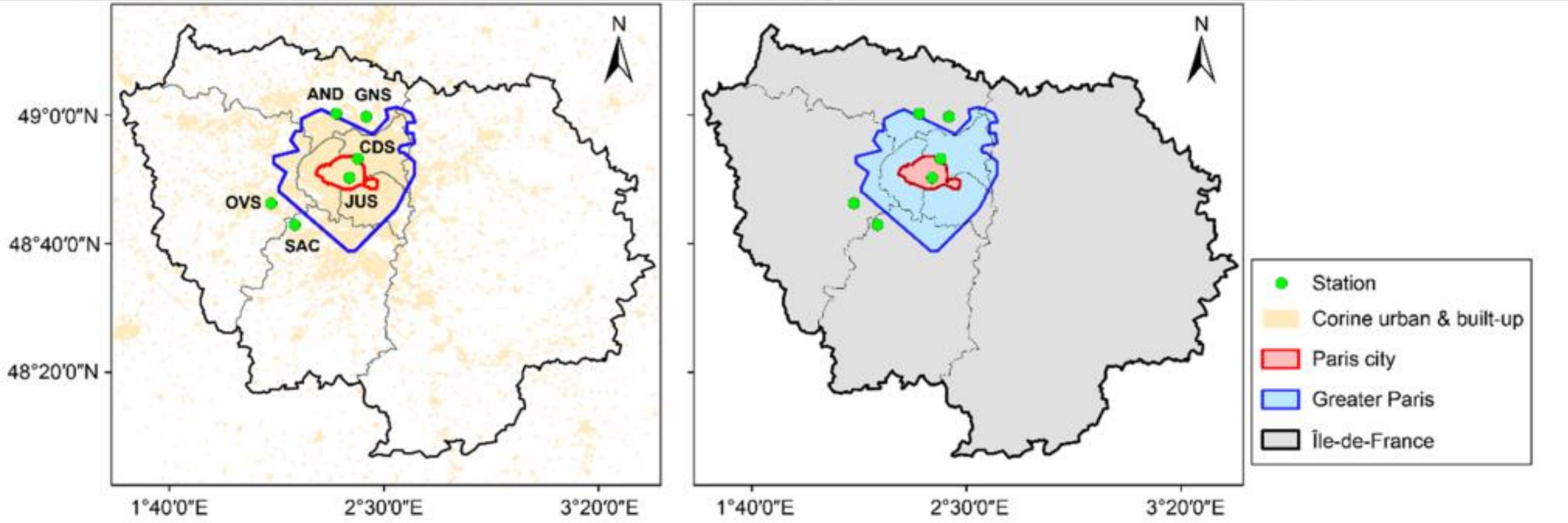
开展^{14}C观测可以定量化石燃料CO_2排放

示范3：巴黎碳监测项目

CO_2柱总量和廓线观测——城市上下风向浓度
排放量计算——质量平衡法

http://www.chasing-greenhouse-gases.org/coccon-in-paris

CO_2浓度观测网

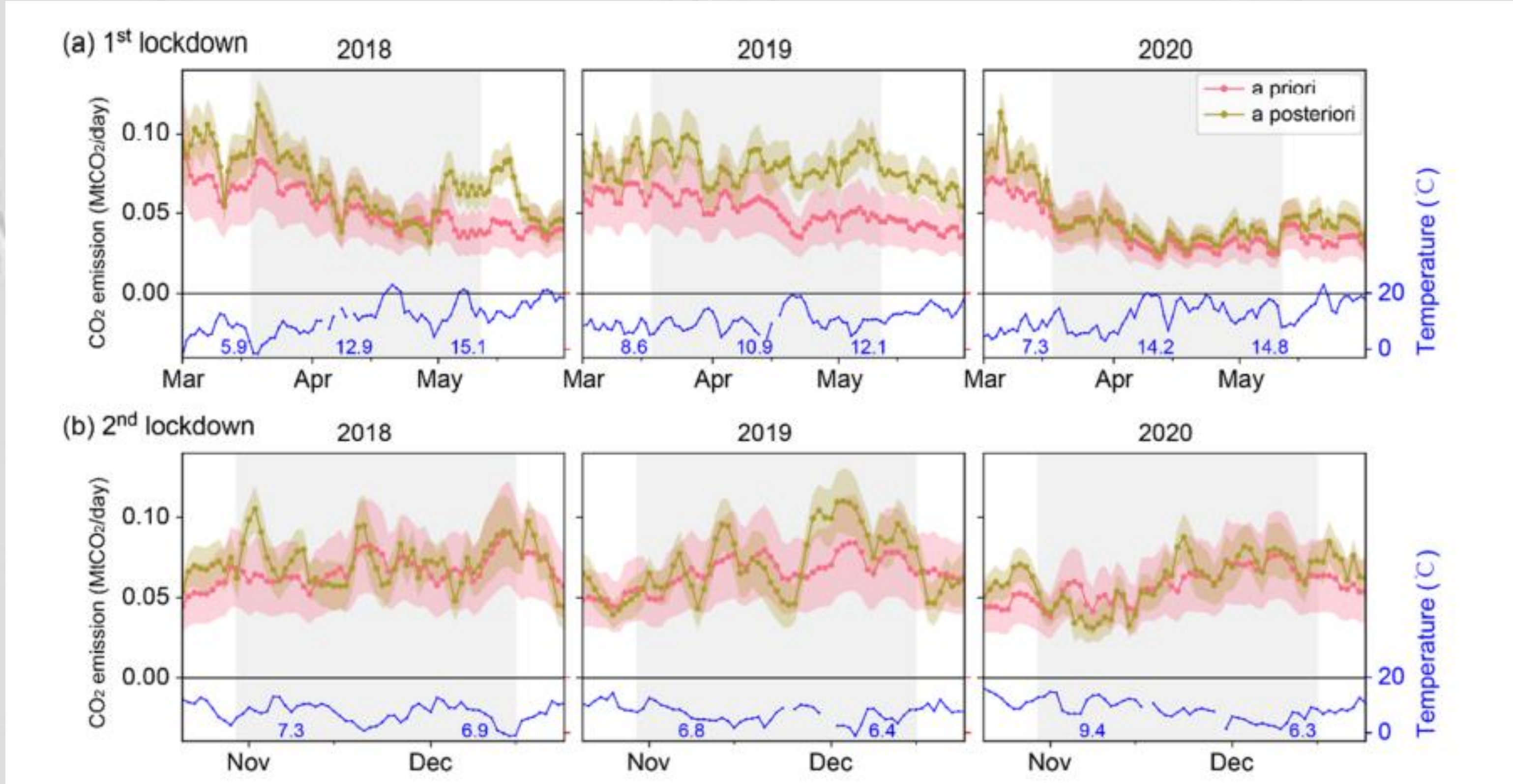


✓观测仪器：高精度CRDS观测系统

✓配套观测：气象要素（100m）

Lian et al., 2022

模拟的新冠疫情管控期间逐日CO_2排放



Lian et al., 2022

✓传输模式：1km WRF-Chem

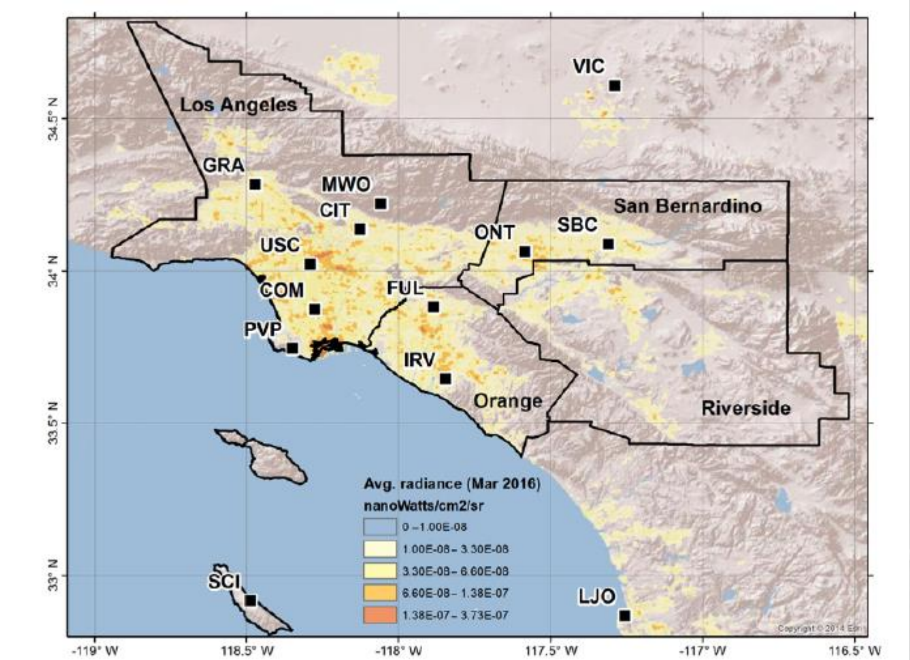
✓先验源：准实时人为源CO_2 Origins.earth

✓同化反演算法：贝叶斯算法

✓两次管控期间CO_2排放量分别比往年同期下降约50%和20%

示范4：洛杉矶碳监测项目

洛杉矶碳监测项目
——高精度CO_2在线观测系统



Verhulst, K. R. et al., 2017

15个站点中有9个高塔站（塔高>40米）

Code	Full site name	Inlet height (m a.g.l.)	Site elevation (m a.s.l.)	Lat (° N)	Long (° W)	Analyzer
VIC	Victorville[a]	100/100/50	1370	34.61	117.29	Picarro G2301
GRA	Granada Hills[a]	51/51/31	391	34.28	118.47	Picarro G2401
USC-1	downtown LA (University of Southern California)[b, c]	50	55	34.02	118.29	Picarro G2301
USC-2	downtown LA (University of Southern California)[b, c]	50	55	34.02	118.29	Picarro G2401
COM	Compton[a]	45/45/25	9	33.87	118.28	Picarro G2401
FUL	Fullerton (CSU Fullerton)[b]	50	75	33.88	117.88	Picarro G2401
IRV	Irvine (UC Irvine)[b]	20	10	33.64	117.84	Picarro G2301
SCI	San Clemente Island[a]	27	489	32.92	118.49	Picarro G2401
ONT	Ontario[a]	41/41/25	260	34.06	117.58	Picarro G2301
CNP	Canoga Park*	15	245	34.19	118.6	Picarro G2301
LJO	La Jolla (Scripps Pier)[b]	13	0	32.87	117.25	Picarro G2301
CIT-1	Pasadena (Caltech, Arms Laboratory)[b,d,*]	10	230	34.14	118.13	
CIT-2	Pasadena (Caltech, Millikan Library)[d,*]	48	230			Picarro G2401
MWO	Mt. Wilson[b,e,*]	3	1670	34.22	118.06	
PVP	Palos Verdes Peninsula[b,*]	3	320	33.74	118.35	
SBC	San Bernardino[a,b,*]	27/58	300	34.09	117.31	Picarro G2301

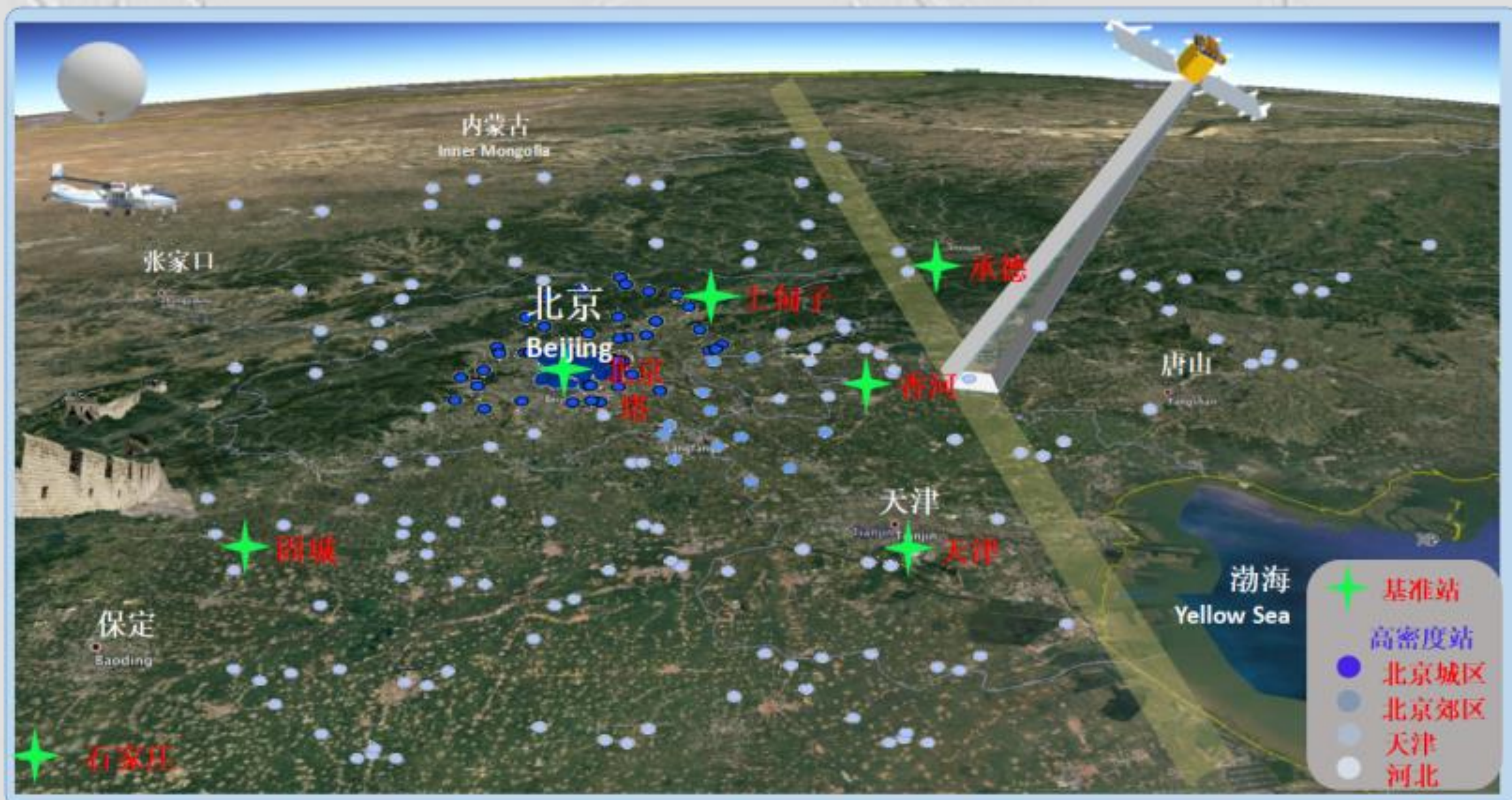
示范5：京津冀城市群碳监测项目

强化观测：航飞、移动车、激光雷达等

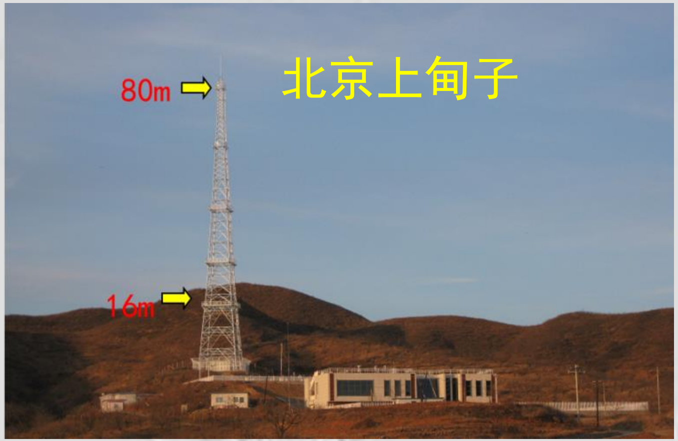
高精度大气基准站观测

高密度微型化组网观测

中国和国际3+3颗碳卫星

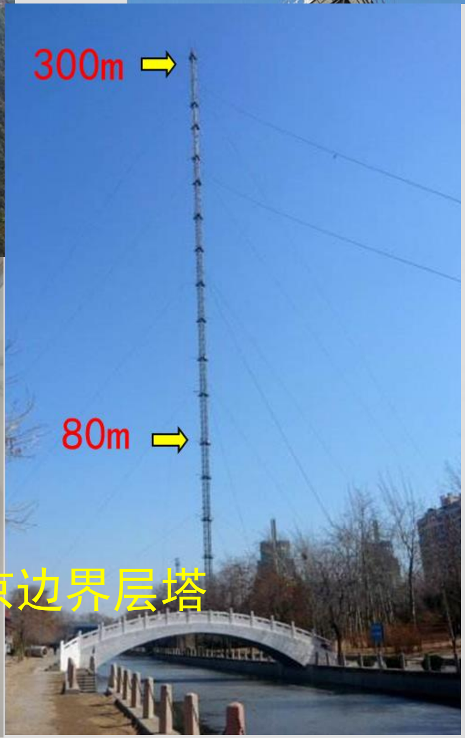


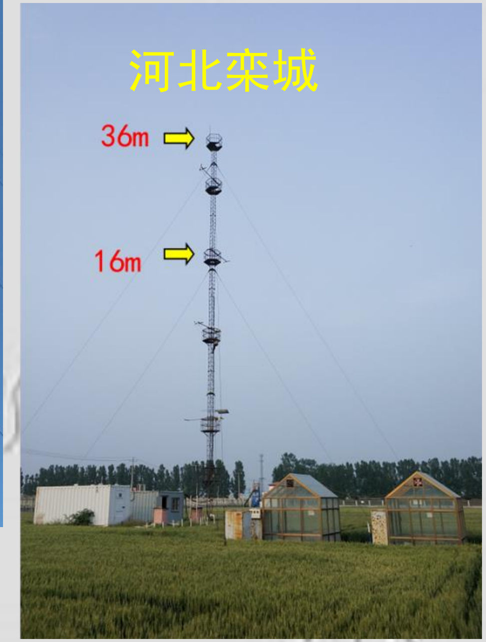
预期目标：小时尺度公里网格的碳排放准实时动态显示

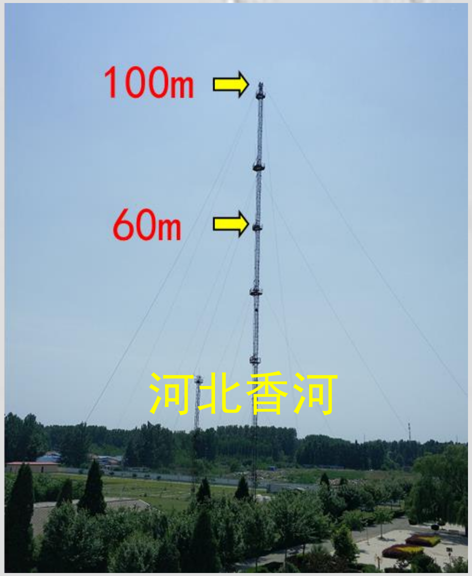

北京上甸子
80m
16m


河北兴隆

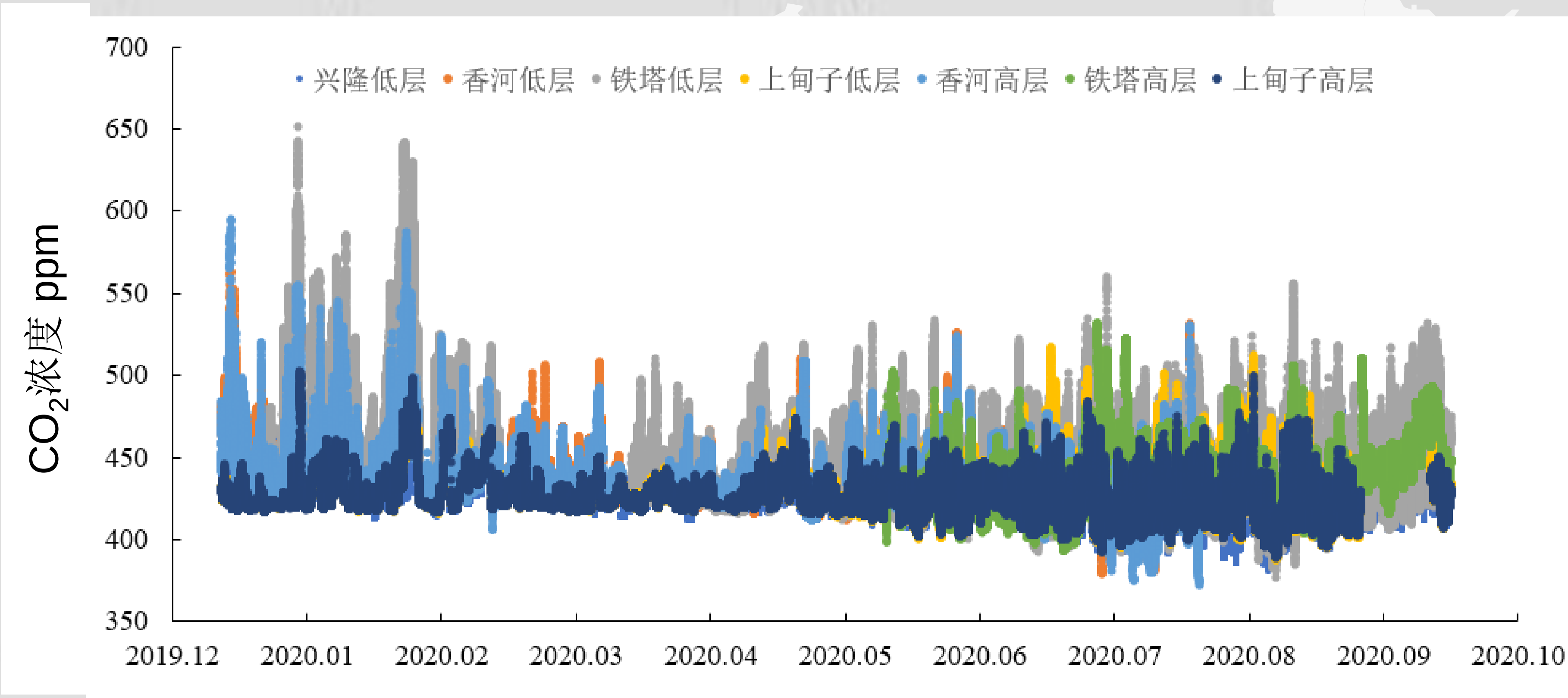

255m
天津边界层塔


300m
80m
北京边界层塔


河北栾城
36m
16m


100m
60m
河北香河

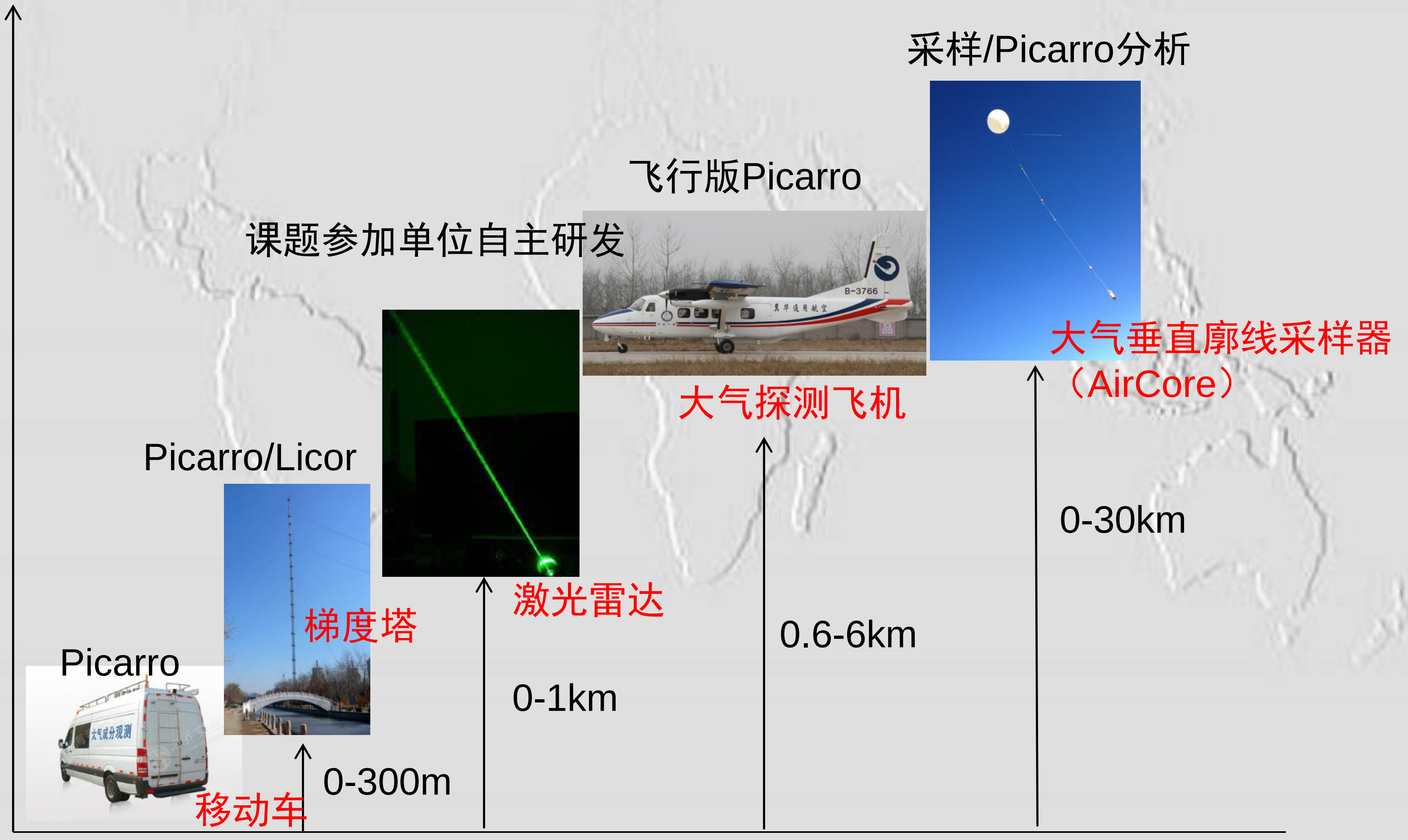
城市群的CO_2浓度变化大



仪器选型多样化

高精度基准站+多个中精度传感器

研究不同高度范围的5种大气CO_2浓度垂直分布研究技术



CO_2同化：贝叶斯反演系统 (拉格朗日观点)

风场: WRF

+

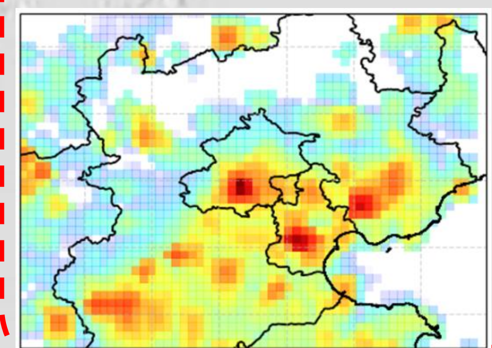
碳足迹: STILT

同化器

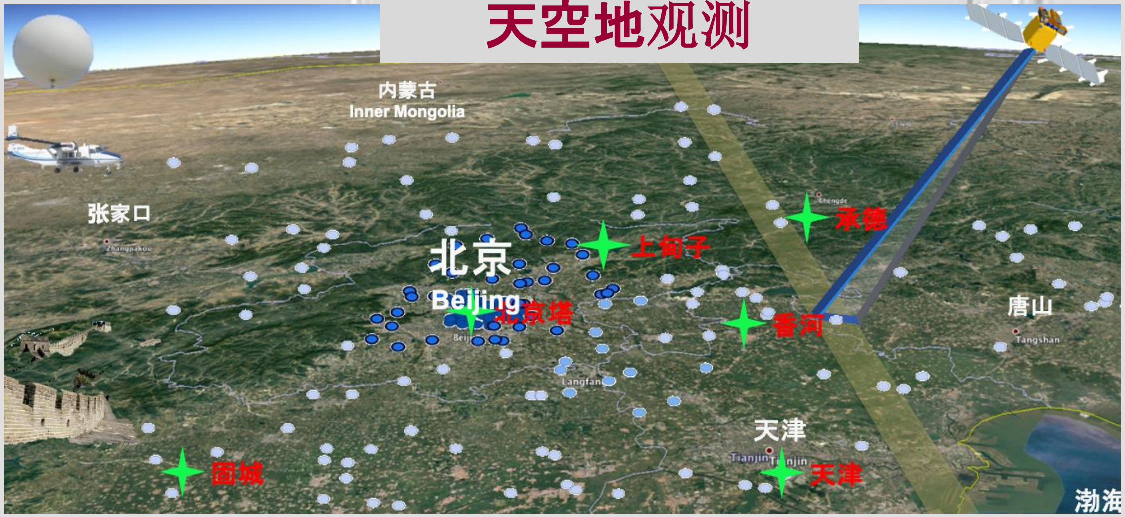
Bayesian反演

$$J(x) = (x - x^b)^T P^{-1} (x - x^b) + (y^o - H(x))^T R^{-1} (y^o - H(x))$$

排放通量产品



天空地观测



曾宁研究员组提供

甲烷同化方法：贝叶斯反演
模式：英国气象局NAME” (Nuclear Accident ModEl)

This involves solving $\nabla_{\mathbf{x}} J(\mathbf{x}) = 0$ where J is the cost function defined as follows:

$$J(\mathbf{x}) = \frac{1}{2}(\mathbf{y} - \mathbf{H}\mathbf{x})^T \mathbf{R}^{-1} (\mathbf{y} - \mathbf{H}\mathbf{x}) + \frac{1}{2}(\mathbf{x} - \mathbf{x}_{prior})^T \mathbf{P}^{-1} (\mathbf{x} - \mathbf{x}_{prior}) \quad [1]$$

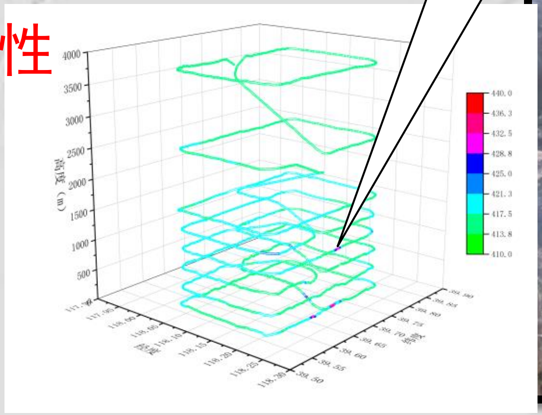
x是状态向量，代表甲烷排放的网格集合， $\mathbf{x}_{prior}$ 是先验的排放估计。矢量**y**是大气甲烷观测值。**P**和**R**分别是先验误差协方差矩阵和观测误差协方差矩阵。**H**是雅可比（ Jacobian ）矩阵，表示测量浓度对排放变化的敏感性，可通过化学传输模型计算。

无组织排放的准确定位
机载温室气体高精度监测

- ✓ 基于温室气体高精度商业主机（适用低压环境）
- ✓ 已成功应用美国空中国王和国产运-12飞机
- ✓ 质量平衡法估算城区排放总量
- ✓ 可实现无色无味温室气体“无组织排放”的准确定位和定量

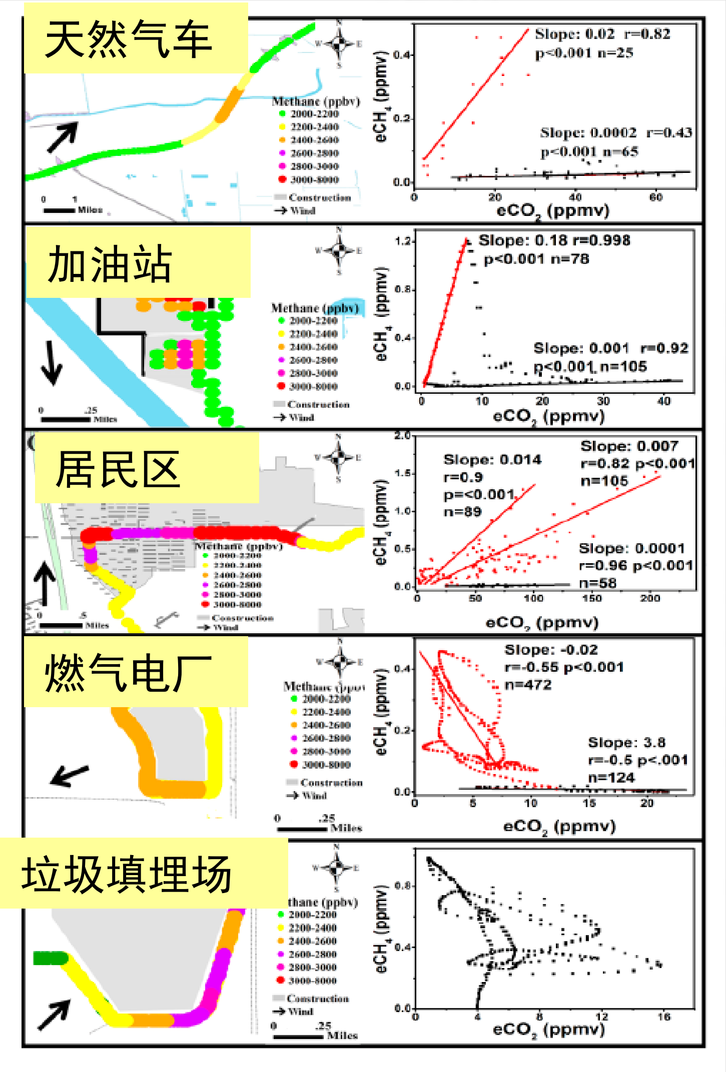
用于监管的可行性

无组织排放



车载二氧化碳和甲烷高精度监测和源追踪

- ✓ 温室气体高精度高频主机，配合GPS、气象探头、采样模块，可以实现“未知源”的准确定位
- ✓ 可在普通轿车/MPV安装，使用范围广
- ✓ 获得不同排放源的温室气体“指纹”信息，可用于进一步甄别城市温室气体的来源



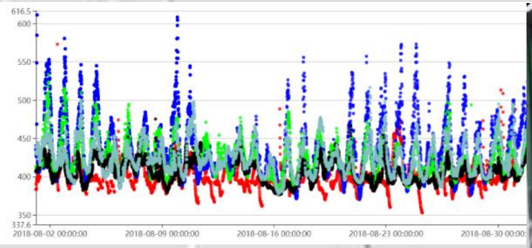
Liu, Han*, Yao* et al., 2021

Sun, Yao*, et al., 2019

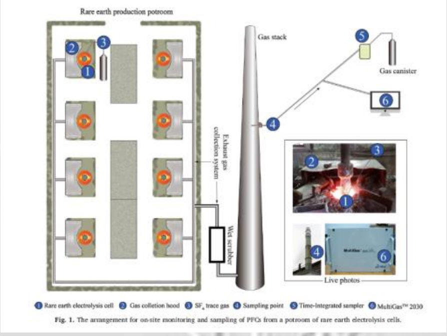
未来展望

区域-城市-企业多尺度温室气体排放监测和比对
多种手段的综合应用——区域反演+未知源确认定位

梯度塔高精度在线监测



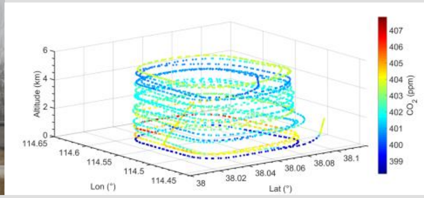
高密度组网监测

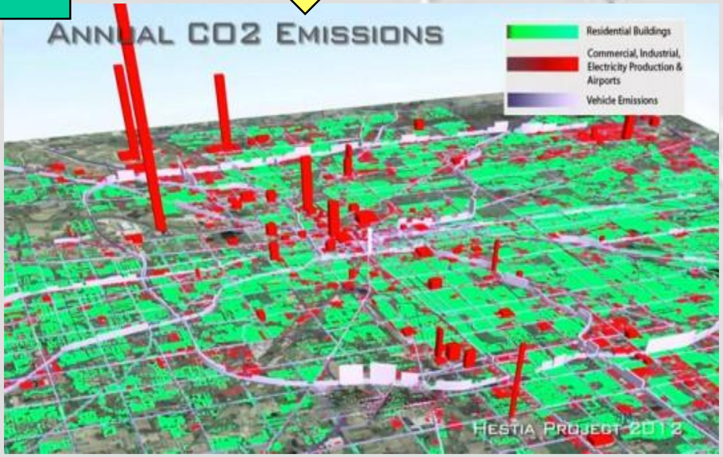


排放源在线监测

车载监测

飞机/无人机航测





清单法

敬请批评指正！

yaobo@fudan.edu.cn

部分内容见《城市碳监测案例》http://www.allaboutair.cn/a/reports/2022/0809/644.html