大气排放清单和大气遥感

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- **大气污染物**
  - 传统一次污染物 (源于排放): 二氧化硫 (SO_2), 氮氧化物 (NO_x), 一氧化碳 (CO), 可挥发性有机物 (VOC), 氨气 (NH_3), 气溶胶 (TSP, PM_{10}, $PM_{2.5}$, 黑碳, 有机碳等)
  - 二次污染物 (源于大气化学反应): 臭氧 (O3), 二次气溶胶 (包括SO_4^{2-}, NO_3^-, NH_4^+, 二次有机气溶胶等)
  - 新兴污染物: 持久性有机污染物 (POPs/PAH), 汞及其它重金属
- **温室气体**
  - 二氧化碳 (CO_2), 甲烷 (CH_4), 氧化亚氮 (N_2O),氢氟碳化物(HFCs), 全氟碳化物(PFCs), 六氟化硫(SF_6)
- **Both (short live climate forcers)**
  - 黑碳, 有机碳, SO_4^{2-}, 臭氧

排放源的分类　Sources Categories of Emissions

人为源
Anthropogenic

电厂，工业，居民，商业，交通，农业等

天然源
Natural

生物质燃烧
Biomass

森林火灾，草原火灾

生物源
Biogenic

植物，动物，细菌，病毒

地球源Geogenic

火山，土壤，水体，闪电








人类扰动模糊了人为源与天然源之间的界限

- 氮肥的使用加剧了土壤的氮氧化物排放
- 畜牧养殖业的发展增加了动物的甲烷排放
- 开垦、过度放牧使植物源排放减少，而沙尘排放增加
- 气候变化影响森林火灾的强度和频率
- 。。。。。。

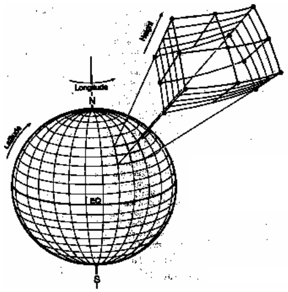
大气污染物和温室气体的来源

	SO2	NOx	CO	VOC	NH3	PM	BC	OC	Hg	CO2	CH4	N2O
人为源	√	√	√	√	√	√	√	√	√	√	√	√
生物质燃烧	√	√	√	√	√	√	√	√	√	√	√	√
生物源			√	√	√	√		√	√	√	√	√
土壤		√			√	√			√			√
火山	√					√			√	√		
水体	√					√			√		√	√
闪电		√										

排放源定量分析的研究目标

- **排放量 (magnitudes)**
- **空间分布特征 (spatial distribution)**
- **时间变化趋势 (trends)**

排放源的定量方法



Hein et al., GBC, 1997

Palmer et al., JGR, 2003

Inverse Modeling

Martin et al., JGR, 2003

Richter et al., Nature, 2005

Satellite

Bottom-up

Emissions

Top-down

Biomass

Anthropogenic

Biogenic

Andreae and Merlet, GBC, 2001

Duncan et al., JGR, 2003

Streets et al., JGR, 2003

Bond et al., JGR, 2004

Guenther et al., AE, 2000

Guenther et al., ACP, 2006

内容提要

- 自下而上的定量方法及示例
- 基于卫星遥感的定量方法及示例
- 大气污染物及温室气体全球排放量
- 未来的大气排放及其影响

自下而上的排放定量方法及示例

自下而上的排放定量方法

排放量 = 活动水平 × 排放因子

自下而上的排放定量方法示例

- **全球生物质燃烧排放数据库 (GFED)**
- **植被VOC排放模型 (MEGAN)**
- 人为源排放
  - 中国大气污染物排放清单
  - 北京市机动车污染物排放
- 全球排放的历史重构

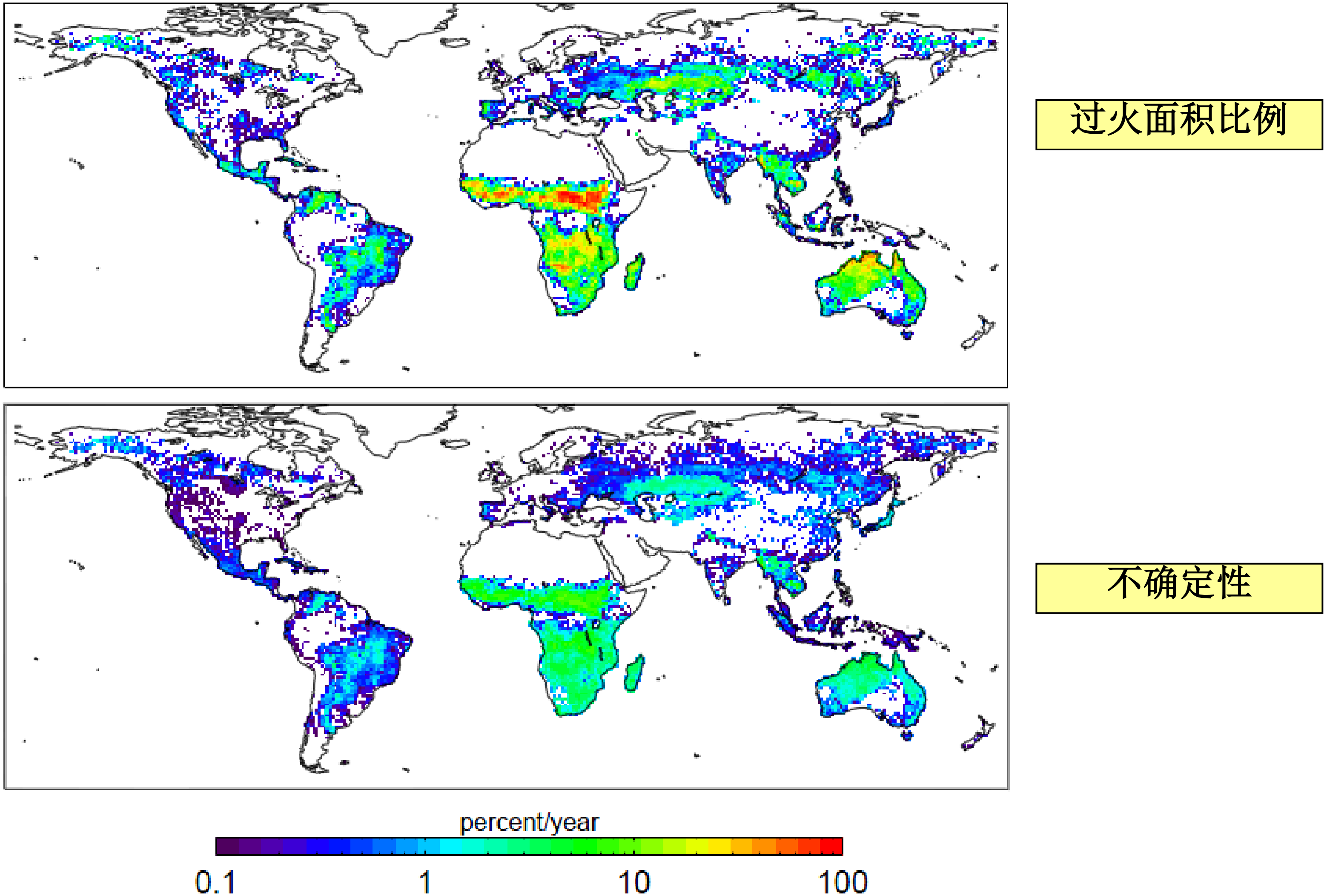
排放量 = 过火面积 × 燃料量×燃烧完全度 × 排放因子

Table 4. 1997–2004 average NPP, fuel loads, fire return time (FRT), and combustion completeness (CC) for different regions.

Region	NPP ($g\,C\,m^{-2}\,yr^{-1}$)	Fuel loads ($g\,C\,m^{-2}$)[1,2]			FRT (yr)	CC (-)[3]			Total area ($\times 10^6\,km^2$)[4]	Emissions ($g\,C\,m^{-2}\,yr^{-1}$)	Emissions/ total losses (%)[5]
		Biomass	Litter	All		Biomass	Litter	All			
BONA	266	1864	1641	3505	473	0.26	0.88	0.55	10.9	1918	1.5
TENA	488	1296	941	2237	513	0.25	0.79	0.48	7.8	1070	0.4
CEAM	573	1697	1742	3439	92	0.35	0.84	0.60	2.8	2062	3.8
NHSA	938	1051	773	1824	79	0.43	0.83	0.60	3.0	1088	1.5
SHSA	884	2143	1398	3541	117	0.48	0.86	0.63	14.9	2240	2.1
EURO	438	206	638	843	241	0.47	0.81	0.73	5.3	612	0.6
MIDE	46	42	194	235	4183	0.90	0.95	0.94	12.1	222	0.1
NHAF	417	296	409	705	10	0.40	0.79	0.63	14.7	441	9.9
SHAF	699	568	731	1299	13	0.32	0.75	0.56	9.8	734	8.1
BOAS	327	1745	1753	3499	158	0.24	0.88	0.56	15.2	1959	3.7
CEAS	256	93	247	341	106	0.58	0.91	0.82	18.1	278	1.0
SEAS	471	1190	1120	2311	51	0.29	0.77	0.52	6.7	1209	4.9
EQAS	847	3306	6593	9898	79	0.44	0.92	0.76	2.7	7542	10.1
AUST	329	104	252	356	16	0.57	0.88	0.79	8.1	280	5.3

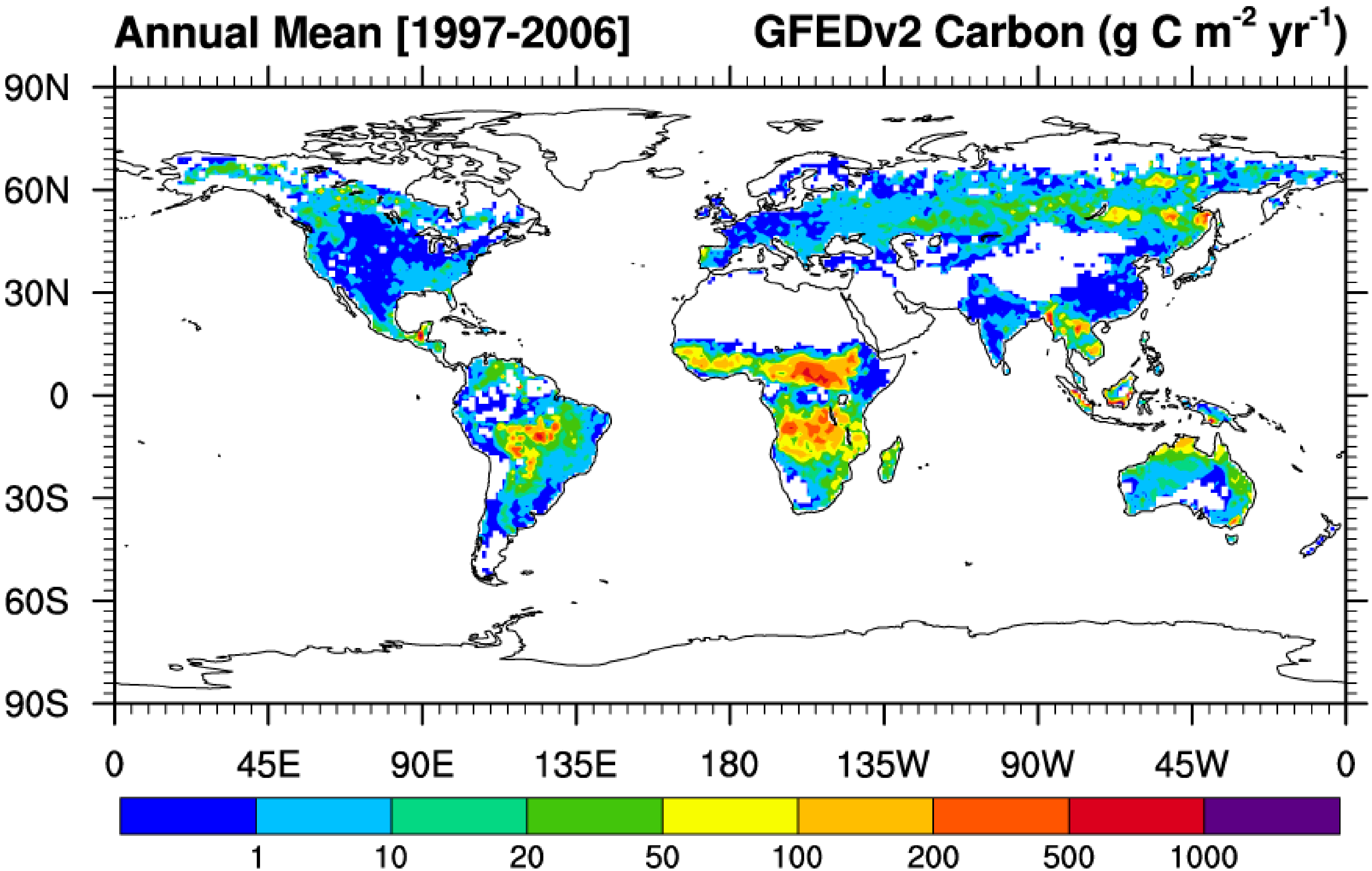
van der Werf et al., ACP, 2006

2001-2004年生态系统年均过火面积比例 (from MODIS fire count)



Giglio et al., ACP, 2006

1997-2006年生物质燃烧年均碳排放量



van der Werf et al., ACP, 2006

植被VOC排放模型 (MEGAN)

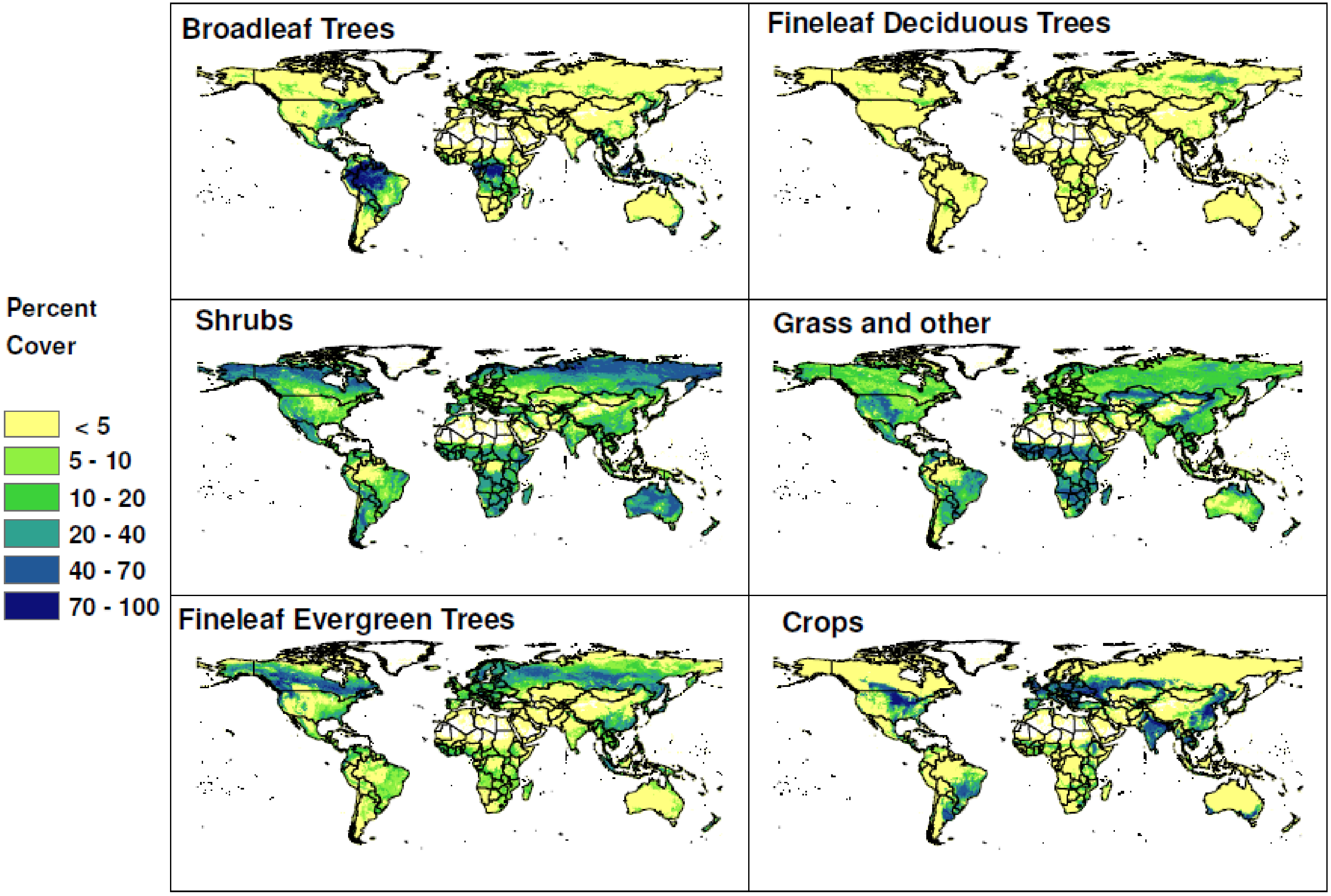
MEGAN estimates the net emission rate (mg compound m^{-2} earth surface h^{-1}) of isoprene and other trace gases and aerosols from terrestrial ecosystems into the above-canopy atmosphere at a specific location and time as

$$\text{Emission}=[\varepsilon][\gamma][\rho] \quad (1)$$

where ε (mg m^{-2} h^{-1}) is an emission factor which represents the emission of a compound into the canopy at standard conditions, γ (normalized ratio) is an emission activity factor that accounts for emission changes due to deviations from standard conditions and ρ (normalized ratio) is a factor that accounts for production and loss within plant canopies. The use of standard conditions enables emission

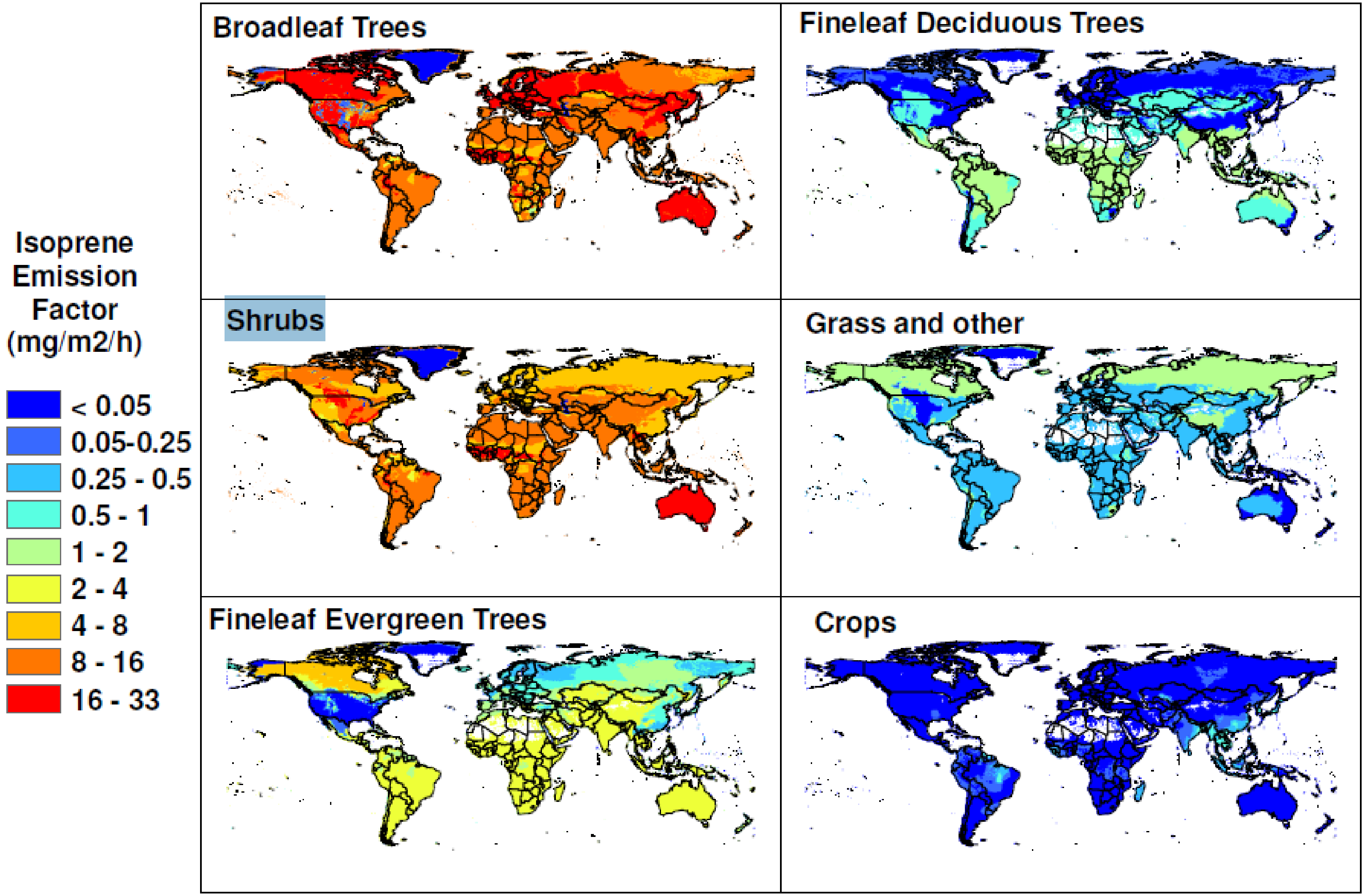
Guenther et al., ACP, 2006

全球植被类型分布



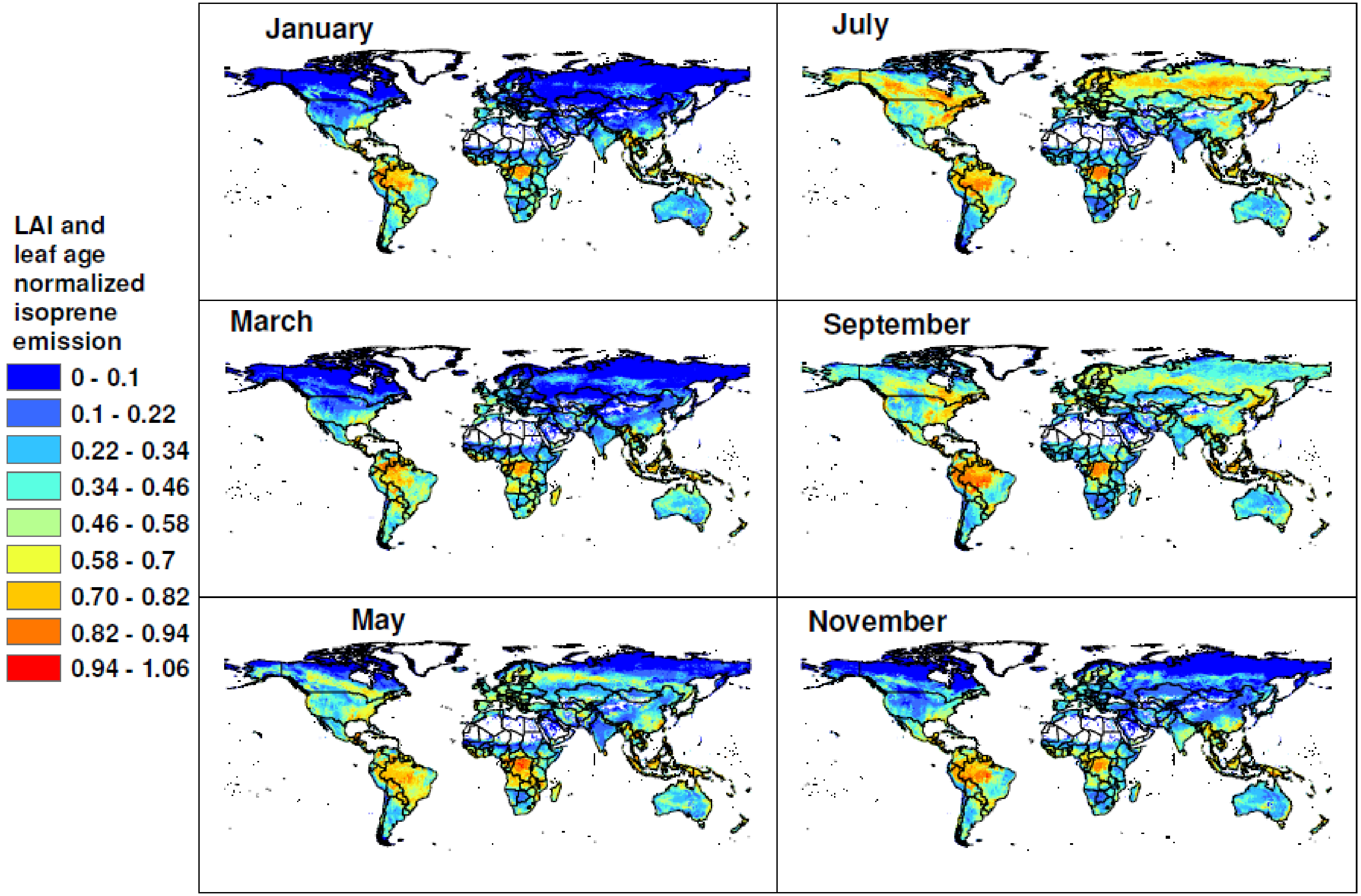
Guenther et al., ACP, 2006

不同植被类型的异戊二烯排放因子



Guenther et al., ACP, 2006

叶面指数和叶龄对标准排放因子的影响



Standard condition: LAI =5 m²/m², leaf age: 80% mature

Guenther et al., ACP, 2006

全球异戊二烯排放量

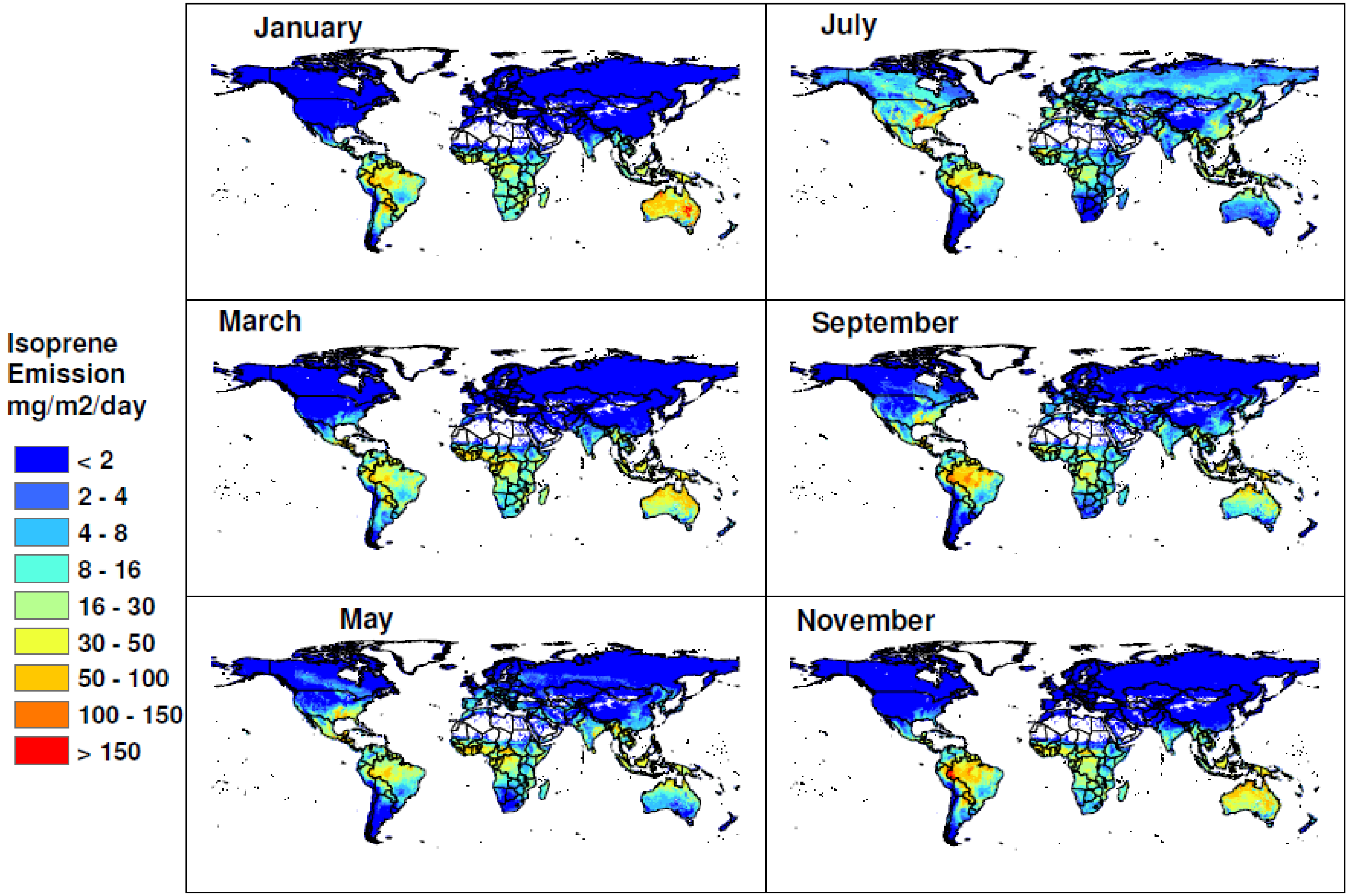


Fig. 10. Monthly average isoprene emission rates estimated with MEGAN for 2003.

Guenther et al., ACP, 2006

MEGAN模型对植被类型、叶面指数、气象参数的敏感性

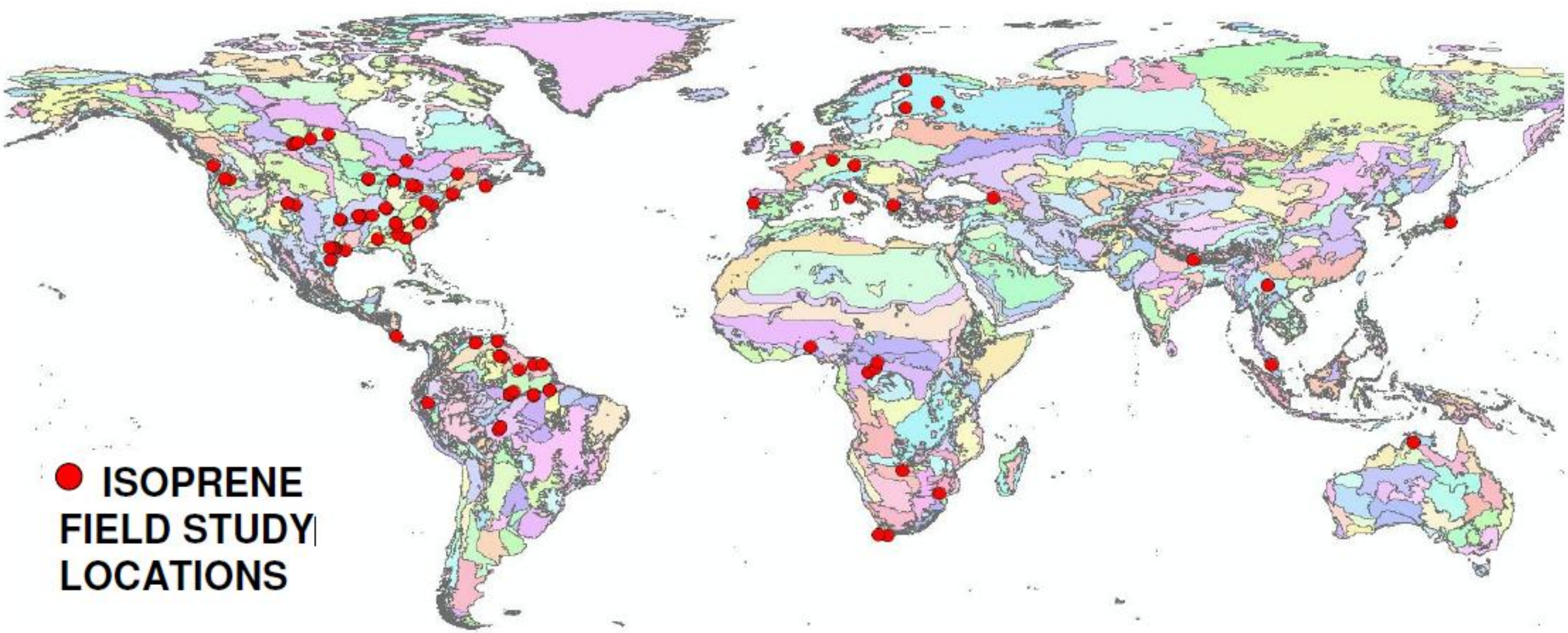
Table 4. MEGAN global input databases. Annual global isoprene emissions estimated for alternative (present day) databases are compared (% difference) to the emission estimated with the standard (MEGAN-P, MEGAN-L and MEGAN-W) databases.

Data type	Name	Spatial scale	Time period	description	Base data	Global Emission (% difference)	Base data reference
PFT	AVHRR1-P	~50 km	~2000	PFT	AVHRR	−7%	Bonan et al. (2002)
PFT	MODIS1-P	~50 km	~2000	PFT	MODIS	+15%	Tian et al. (2004)
PFT	MODIS2	~50 km	~2000	ecosystem	MODIS	+18%	Friedl et al. (2002)
PFT	G95-P	~50 km	~2000	ecosystem	Inventory	+2%	Olson (1992)
PFT	HYDE	~50 km	1700–1990	ecosystem	Model, inventory	−13%	Klein Goldewijk et al. (2001)
PFT	IMAGE	~50 km	2000–2100	ecosystem	Model	−11%	Alcamo et al. (1998)
PFT	MAPPS-P	~50 km	2000, 2100	ecosystem	Model	+24%	Neilson (1995)
PFT	IBIS	~8 km	1992	ecosystem	Model, inventory	+3%	Ramankutty and Foley (1999)
PFT	SPOT	~1 km	~2000	ecosystem	SPOT	−7%	http://www-gvm.jrc.it/glc2000/
PFT	AVHRR2	~1 km	~2000	land char.	AVHRR	+2%	DeFries (2000); Hansen (2000)
PFT	MODIS3	~1 km	~2000	land char.	AVHRR/MODIS	−0.3%	DeFries (2000); Hansen (2003)
PFT	MEGAN-P	~1 km	2001	land char.	MODIS, inventory	standard case	Kinnee et al. (1997)
LAI	AVHRR1-L	~50 km	~2000	Monthly	AVHRR	−11%	Bonan et al. (2002)
LAI	MODIS1-L	~50 km	~2000	Monthly	MODIS	+12%	Tian et al. (2004)
LAI	AVHRR3	~50 km	1981–2000	Monthly	AVHRR	+25%	Myneni et al. (1997)
LAI	G95-L	~50 km	~2000	Monthly	model, AVHRR	+24%	Guenther et al. (1995)
LAI	MAPSS-L	~50 km	~2000, 2100	Monthly	model	+29%	Neilson (1995)
LAI	MEGAN-L	~1 km	2000–2005	Monthly	MODIS	standard case	Zhang et al. (2004)
Weather	IIASA	~50 km	1960–1990 mean	Hourly	observations	+13%	Leemans and Cramer (1992)
Weather	CRU	~50 km	1900s–1980s	Hourly	observations	−11%	a
Weather	HadCM2	~300 km	1980s, 2080s	Hourly	A1 scenario	+15	b
Weather	CSM1	~300 km	1990s, 2090s	Hourly	A1 scenario	−11%	c
Weather	MEGAN-W	~200 km	1979–2004	Hourly	NCEP obs/model	standard case	Kanamitsu et al. (2002)
Weather	MM5	~100 km	2001–2004	Hourly	MM5 obs/model	−14%	Dudhia and Bresch (2002)

[a] http://ipcc-ddc.cru.uea.ac.uk/obs/get_30yr_means.html
[b] http://ipcc-ddc.cru.uea.ac.uk/sres/hadcm2_download/is92/gcm_data.html
[c] http://www.ccsm.ucar.edu/experiments/ccsm1.0/b030.A1/

Guenther et al., ACP, 2006

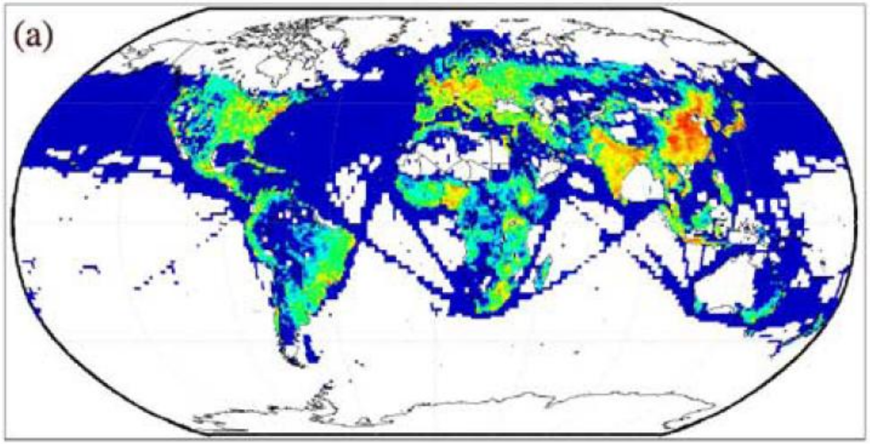
模型中异戊二烯通量测试数据的空间分布

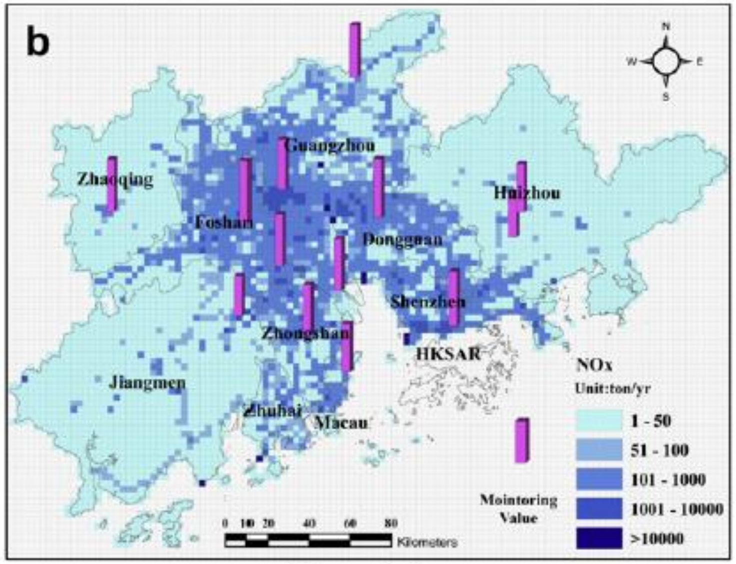


Guenther et al., ACP, 2006

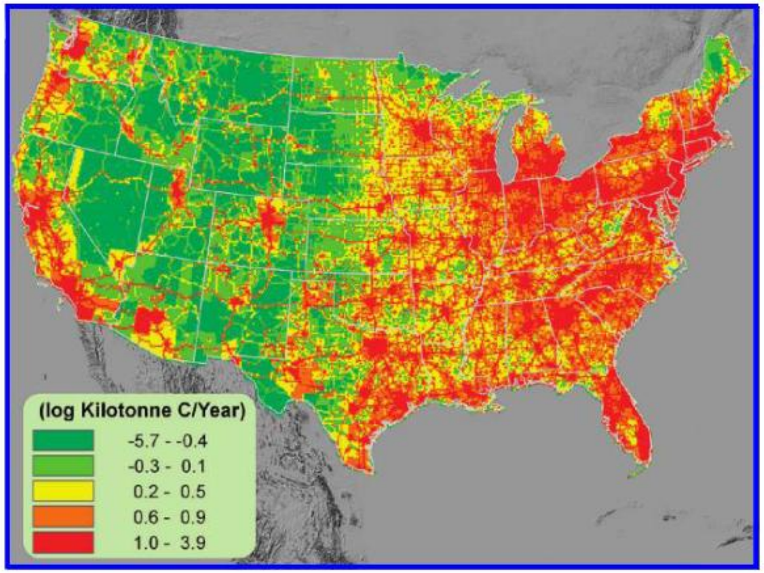
人为源排放清单的空间尺度

- 全球尺度
- 区域尺度
- 城市尺度





NO_x emissions



人为源排放自下而上的一般计算方法

The emissions of a particular species are estimated by the following equation:

$$E_i = \sum_j \sum_k A_{i,j,k} \left[\sum_m X_{i,j,k,m} EF_{j,k,m} \right] \quad (1)$$

For a given technology m, the net emission factor is estimated as follows:

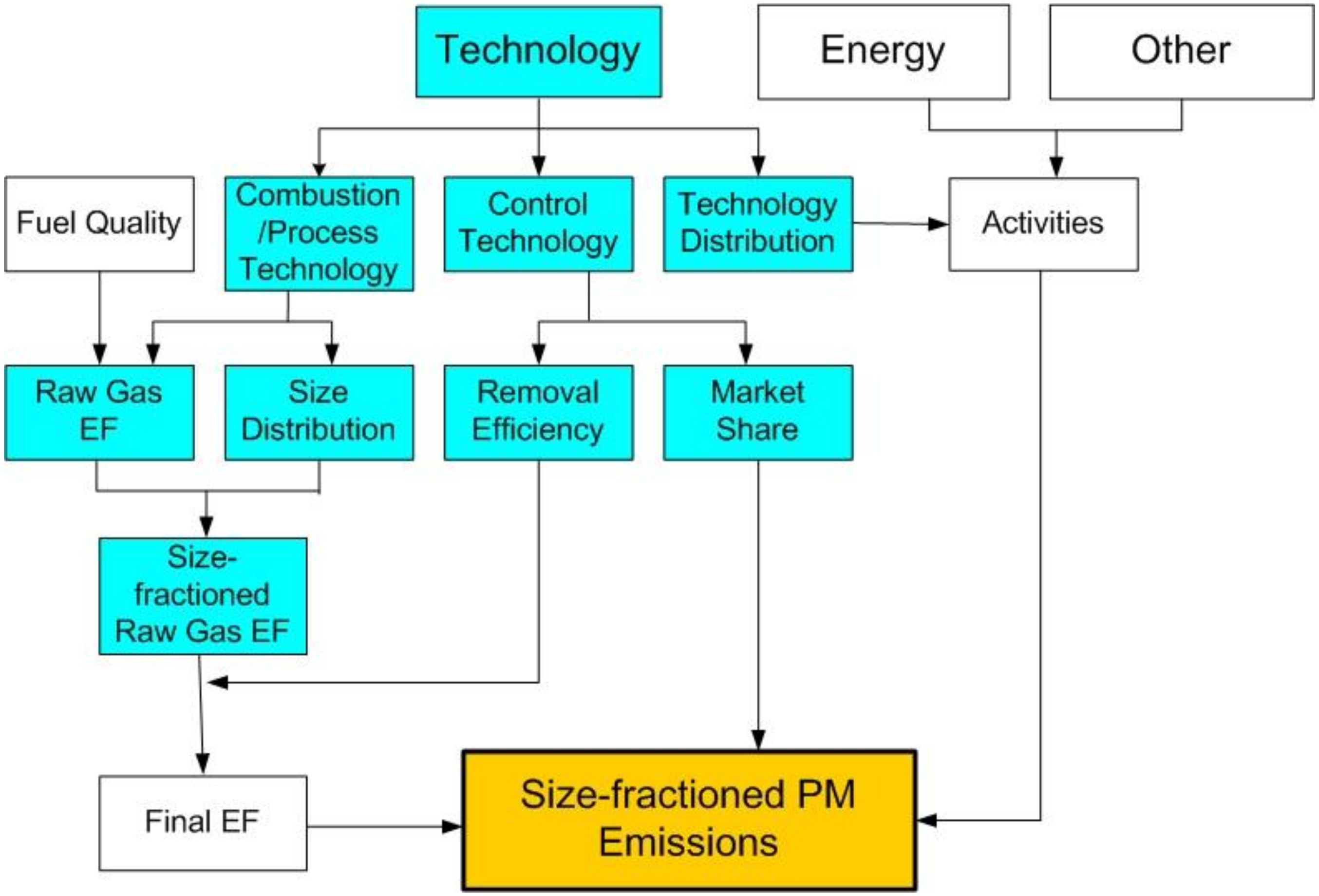
$$EF = EF_{\mathrm{RAW}} \sum_n C_n (1 - \eta_n) \quad (2)$$

where i represents the province (municipality, autonomous region); j represents the economic sector; k represents the fuel or product type; m represents the technology type for combustion and industrial process; n represents a specific control technology; A represents the activity rate, such as fuel consumption or material production; X is the fraction of fuel or production for a sector that is consumed by a specific technology; EF is the net emission factor; EF_{RAW} is the unabated emission factor; C_n is the penetration of control technology n; and η_n, is the removal efficiency of control technology n.

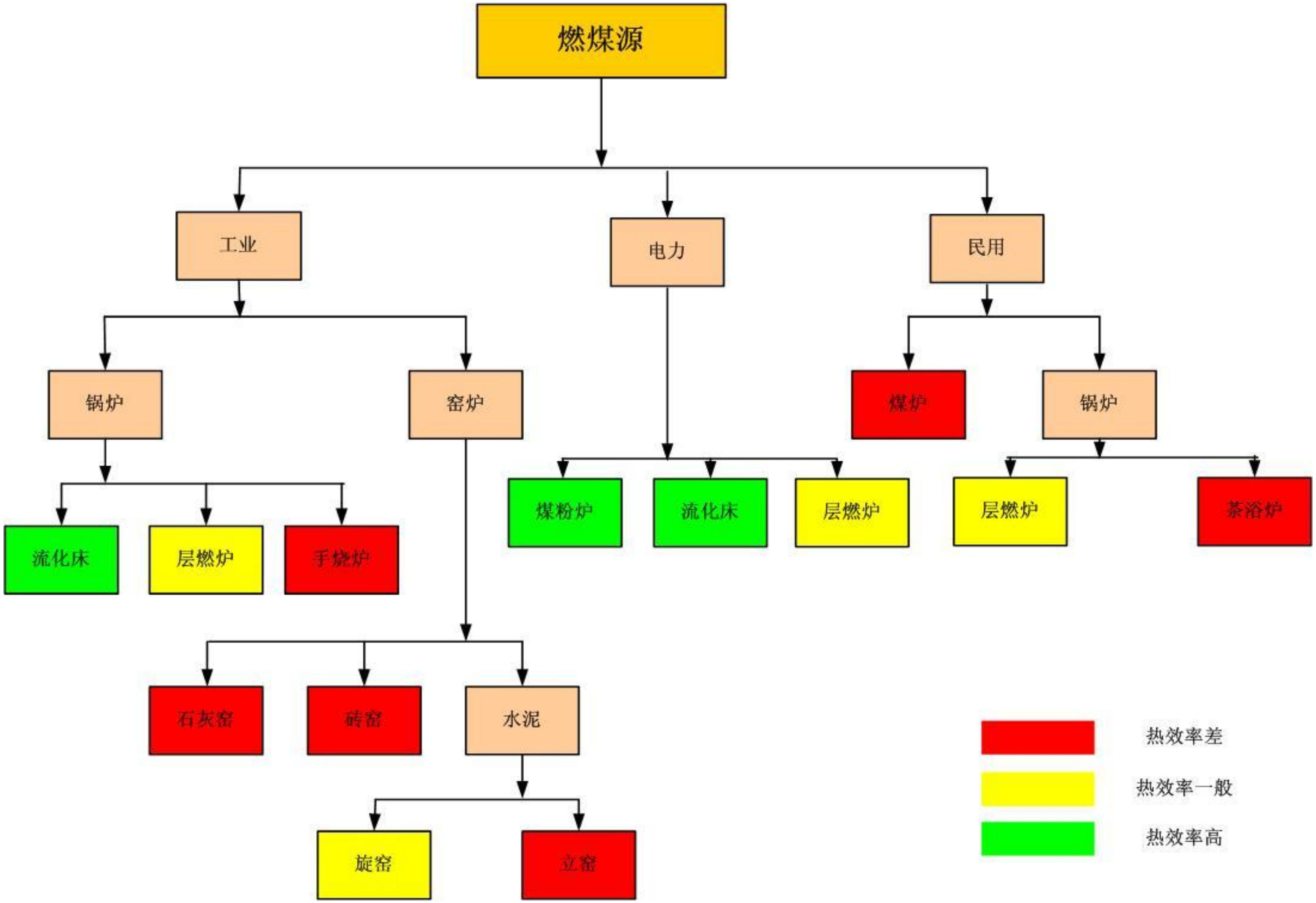
- **A: 北京市的电厂每年消耗煤炭1000万吨。**
- **X: 其中90%的电厂锅炉为煤粉炉, 10%为层燃炉。**
- **EF: 煤粉炉每燃烧一吨煤产生150kg 颗粒物, 层燃炉产生30kg。**
- **C: 所有的电厂都采用了电除尘器。**
- **η: 电除尘器对颗粒物的除尘效率为99.93%。**
- **北京市的电厂每年排放颗粒物**

$1000*10^4*(0.9*(0.15*(1-0.9993))+0.1*(0.03*(1-0.9993)) = 996$ 吨

基于技术的排放量计算模型



基于技术的排放量计算模型



活动水平数据的获取

Table 1. Activity levels for PM emission estimates in China in 2001.

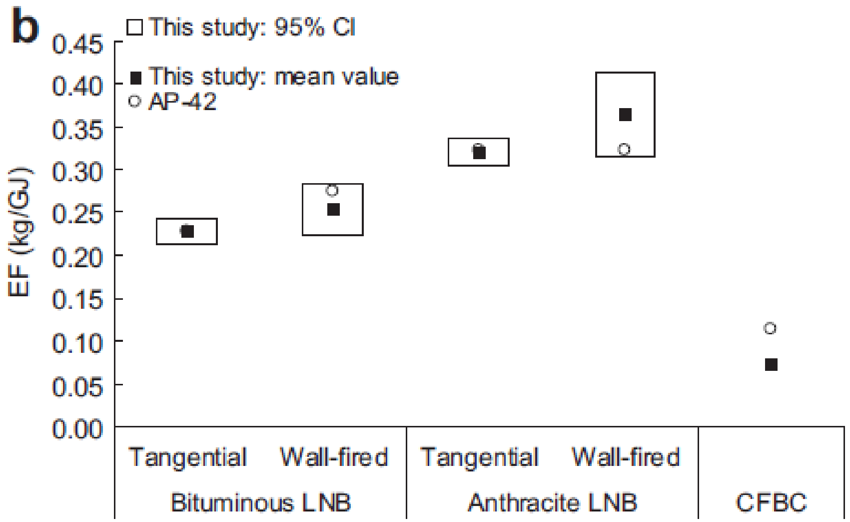
Sector	Fuel/product/vehicle type	Activity level	Reference
Power	Coal	675 Tg coal burned	NBS (2004)
Industry	Coal	187 Tg coal burned[a]	NBS (2004)
Industry	Coke	131 Tg coke produced	NBS (2002b)
Industry	Sinter	191 Tg sinter produced	AISIC (2002)
Industry	Pig iron	145 Tg pig iron produced	AISIC (2002)
Industry	Steel	153 Tg steel produced	AISIC (2002)
Industry	Cement	661 Tg cement produced	NBS (2002a)
Industry	Brick	560 billion bricks produced	NBS (2002b), Zhou *et al* (2003)
Industry	Lime	117 Tg lime produced	NBS (2002b), Zhou *et al* (2003)
Residential	Coal	170 Tg coal burned	NBS (2004)
Residential	Wood	171 Tg wood burned	NBS (2004)
Residential	Crop residue	305 Tg crop residue burned	NBS (2004)
Transportation	Passenger car	5.9 million vehicles	ACT (2002), He *et al* (2005)
Transportation	Light-duty gasoline truck	4.9 million vehicles	ACT (2002), He *et al* (2005)
Transportation	Mid-duty gasoline truck	0.6 million vehicles	ACT (2002). He *et al* (2005)
Transportation	Light-duty diesel truck	1.6 million vehicles	ACT (2002), He *et al* (2005)
Transportation	Heavy-duty gasoline truck	1.5 million vehicles	ACT (2002), He *et al* (2005)
Transportation	Heavy-duty diesel truck	3.5 million vehicles	ACT (2002), He *et al* (2005)
Transportation	Motorcycle	43.4 million vehicles	ACT (2002), He *et al* (2005)

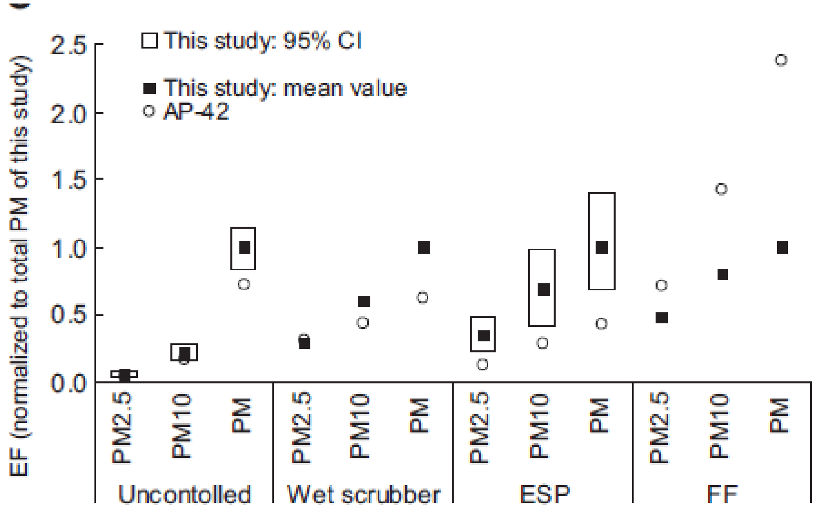
[a] Coal consumption in cement kilns, brick kilns and lime kilns was subtracted from total industry coal combustion to avoid double counting.

获取排放因子的几种典型方法

- 物料衡算
- 现场测试
- 模型计算

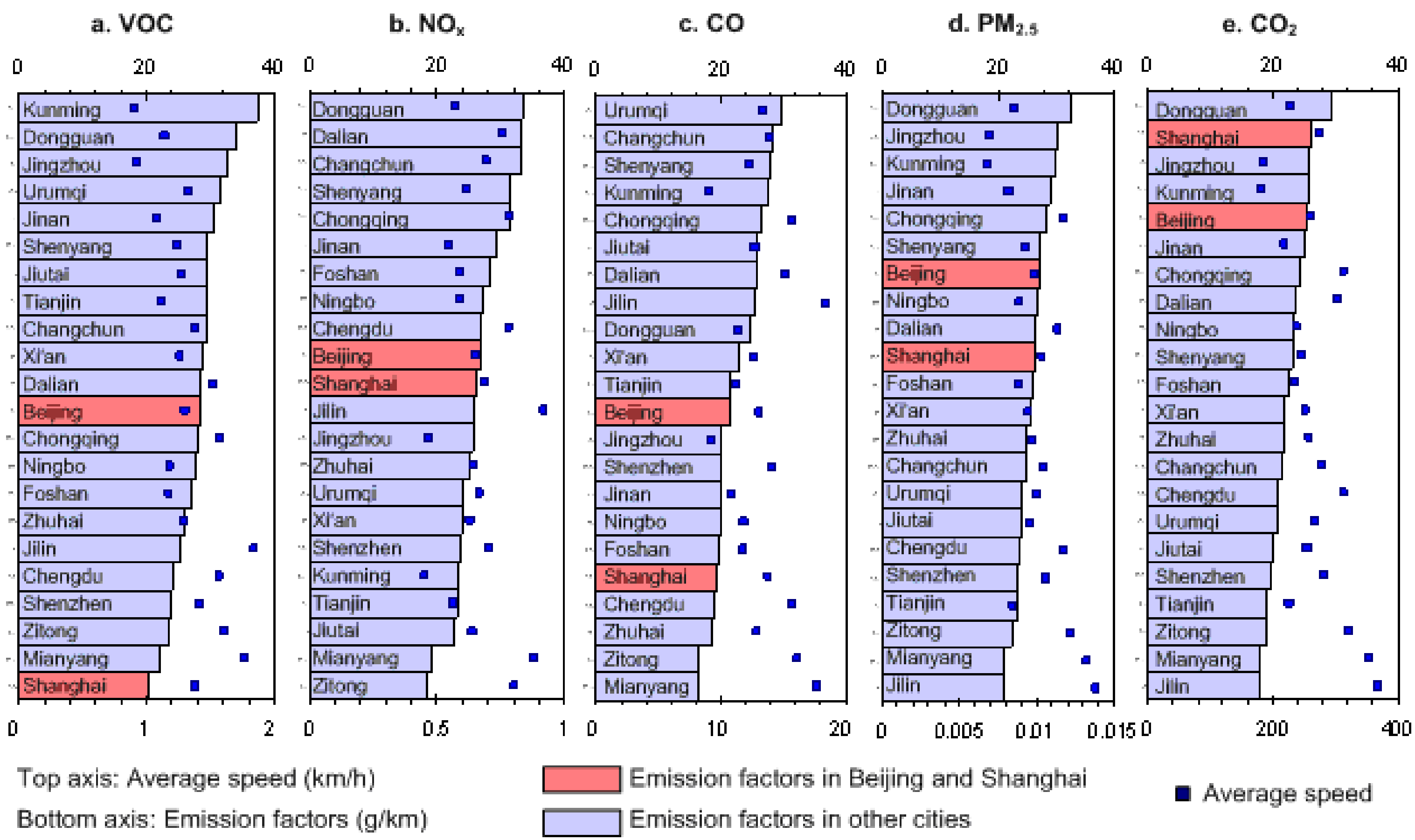
电厂排放因子的现场测试





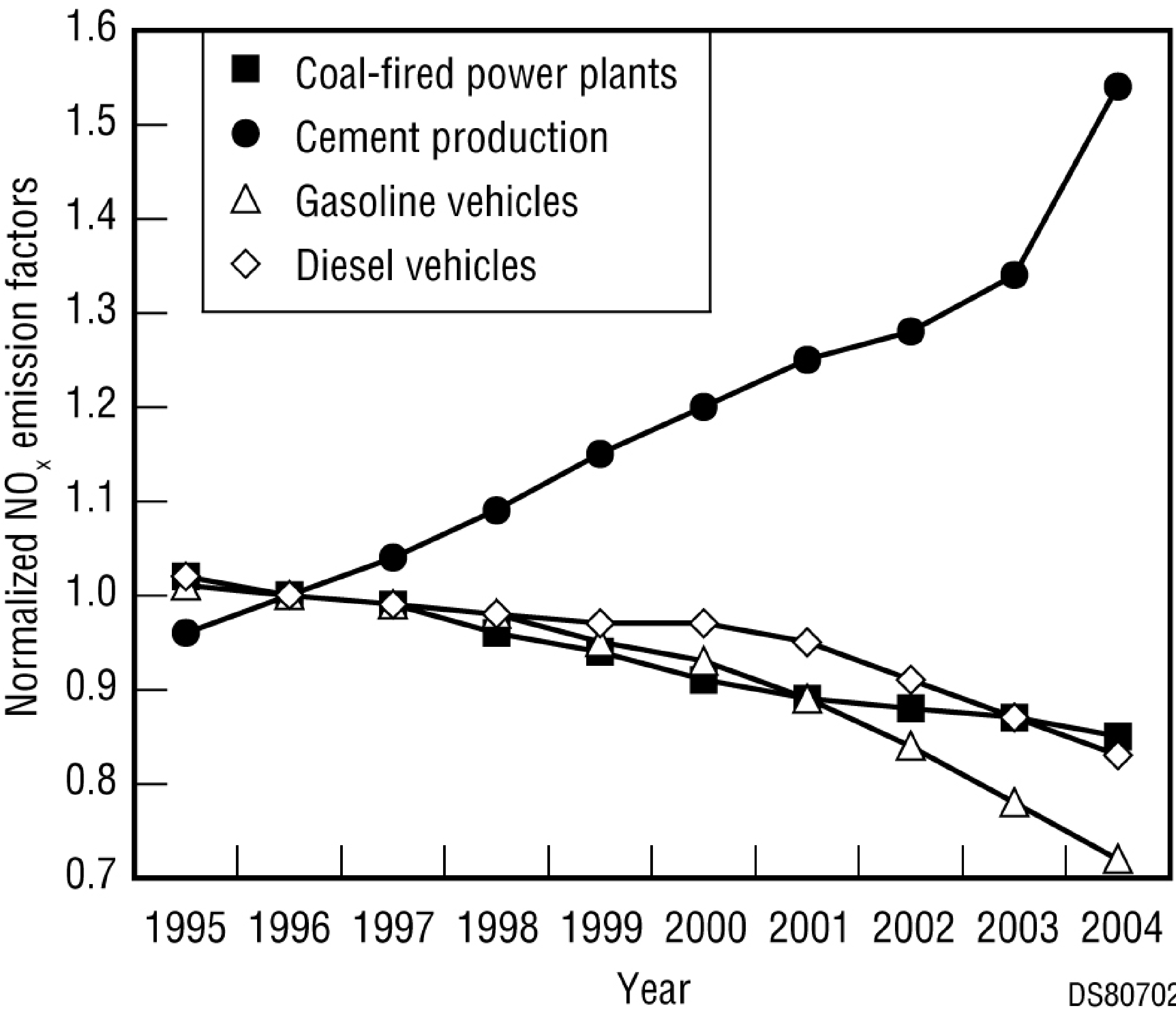
Zhao et al., AE, 2010

机动车排放因子的模拟



a. VOC
b. NOx
c. CO
d. PM2.5
e. CO2
Top axis: Average speed (km/h)
Bottom axis: Emission factors (g/km)
Emission factors in Beijing and Shanghai
Emission factors in other cities
Average speed

动态的排放清单计算方法：考虑技术进步对排放因子的影响



新型干法水泥

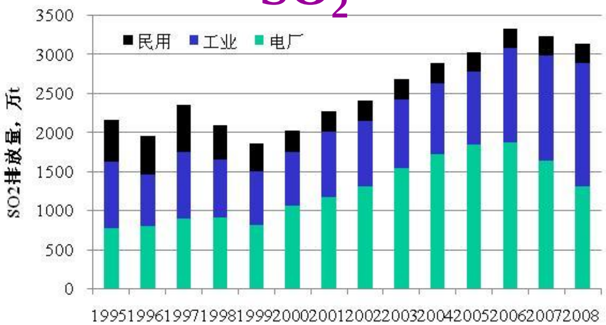
排放因子变化的影响因素

低氮燃烧技术

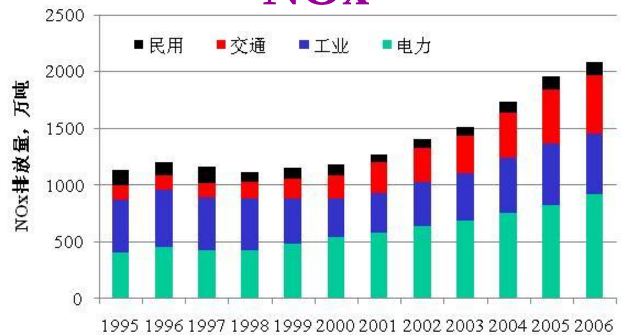
机动车排放标准

1990～2008年中国大气污染物排放变化趋势

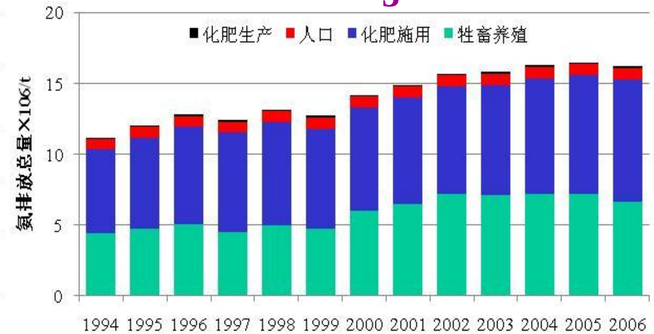
SO_2



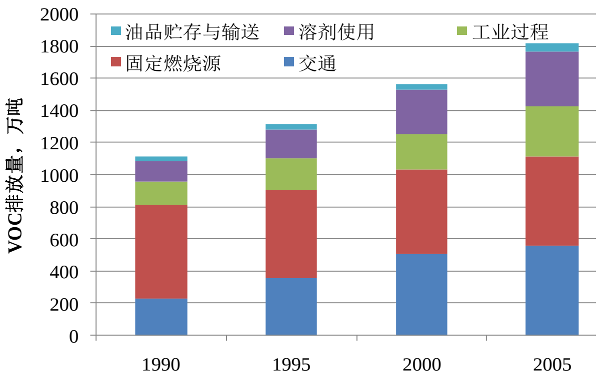
NOx



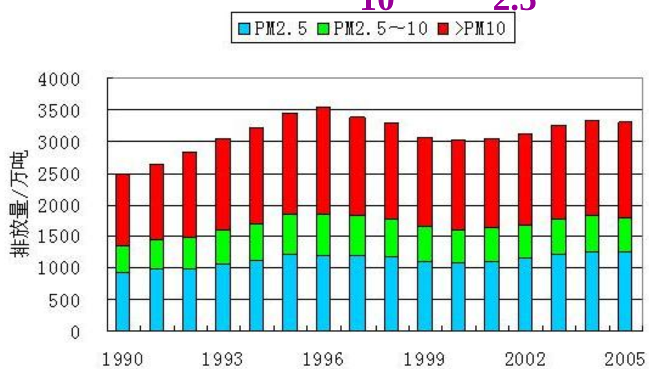
NH_3



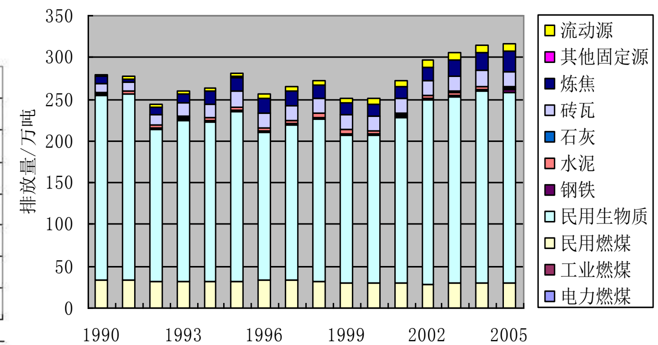
VOCs



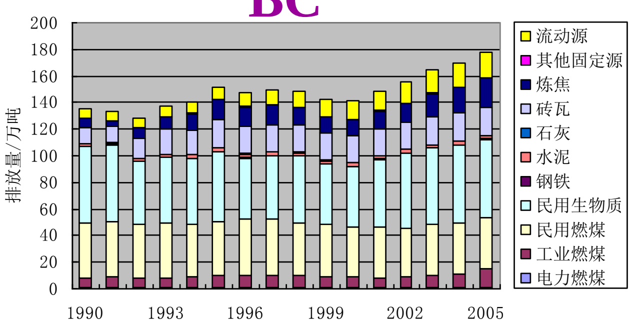
$PM/PM_{10}/PM_{2.5}$



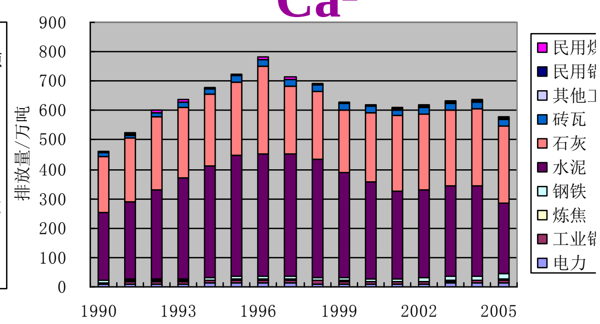
OC



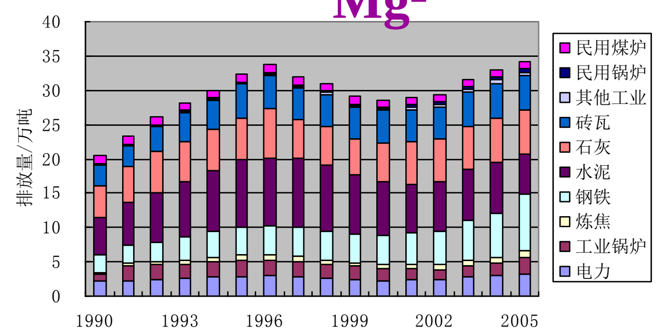
BC



Ca^{2+}



Mg^{2+}

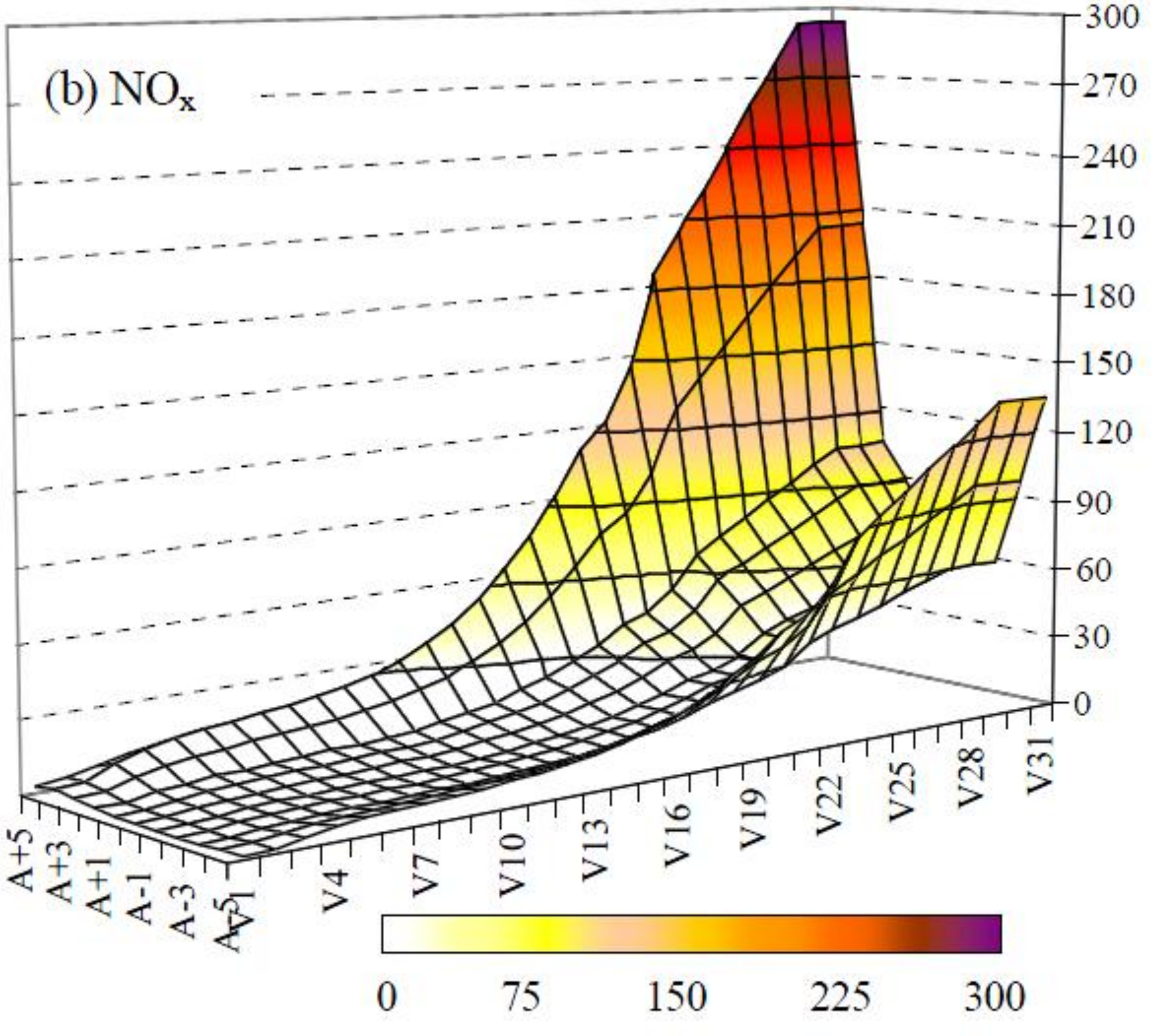


北京市城区机动车污染物排放

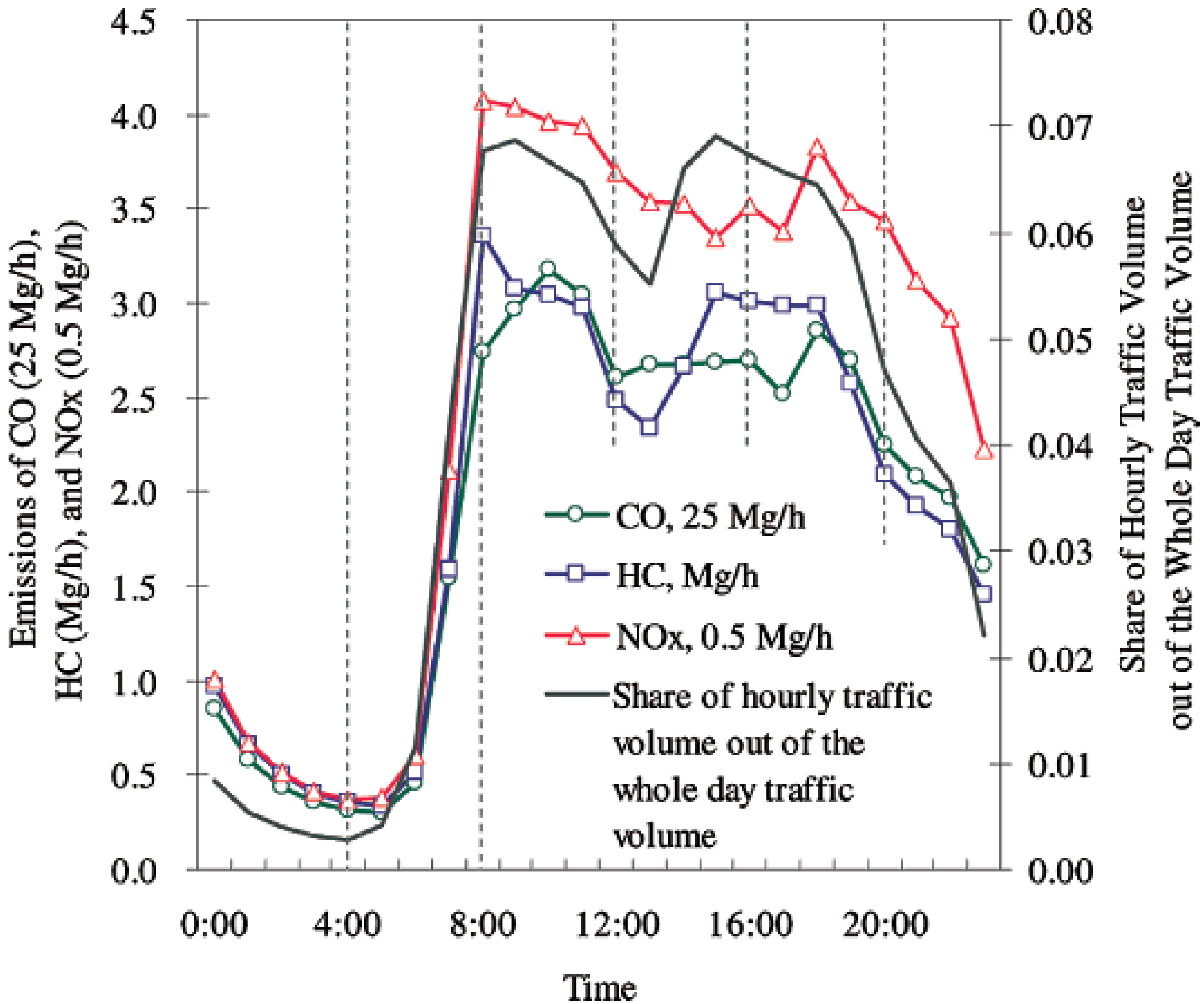
$$E_{i,j,k} = \sum_{t} [N_{i,j,t} \times f_i(v_t, a_t)] \qquad (1)$$

where $E_{i,j,k}$ is the amount of emissions, $N_{i,j,t}$ is the number of vehicles at moment t, and $f_i(v_t,\ a_t)$ is a function of the instantaneous emissions at speed v and acceleration rate a at moment t. Obviously, the following key parameters need

机动车排放水平与行驶状况 (速度，加速度) 之间 的关系



逐时交通流与机动车污染物排放



北京市区机动车污染物排放的时空分布

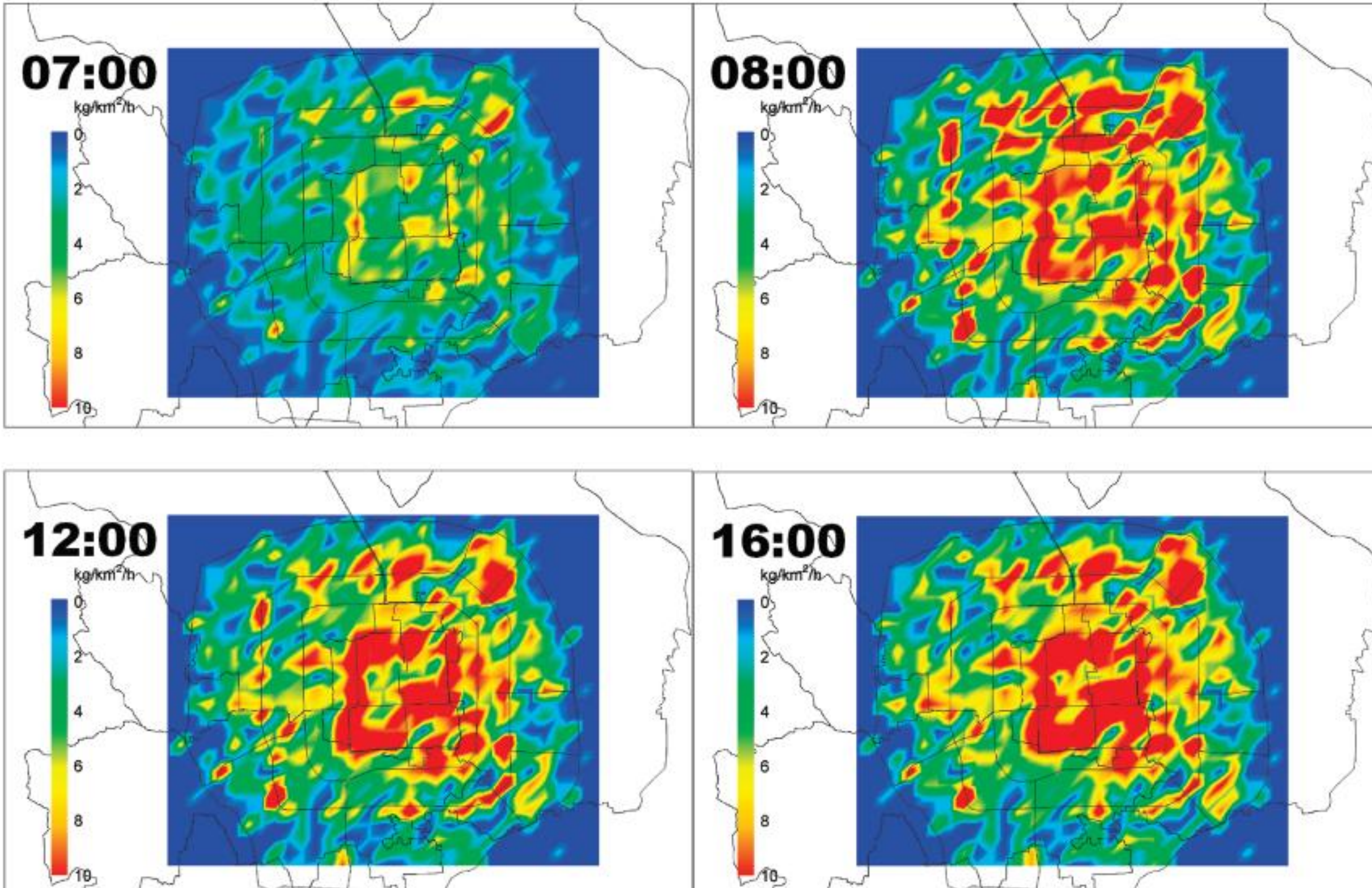
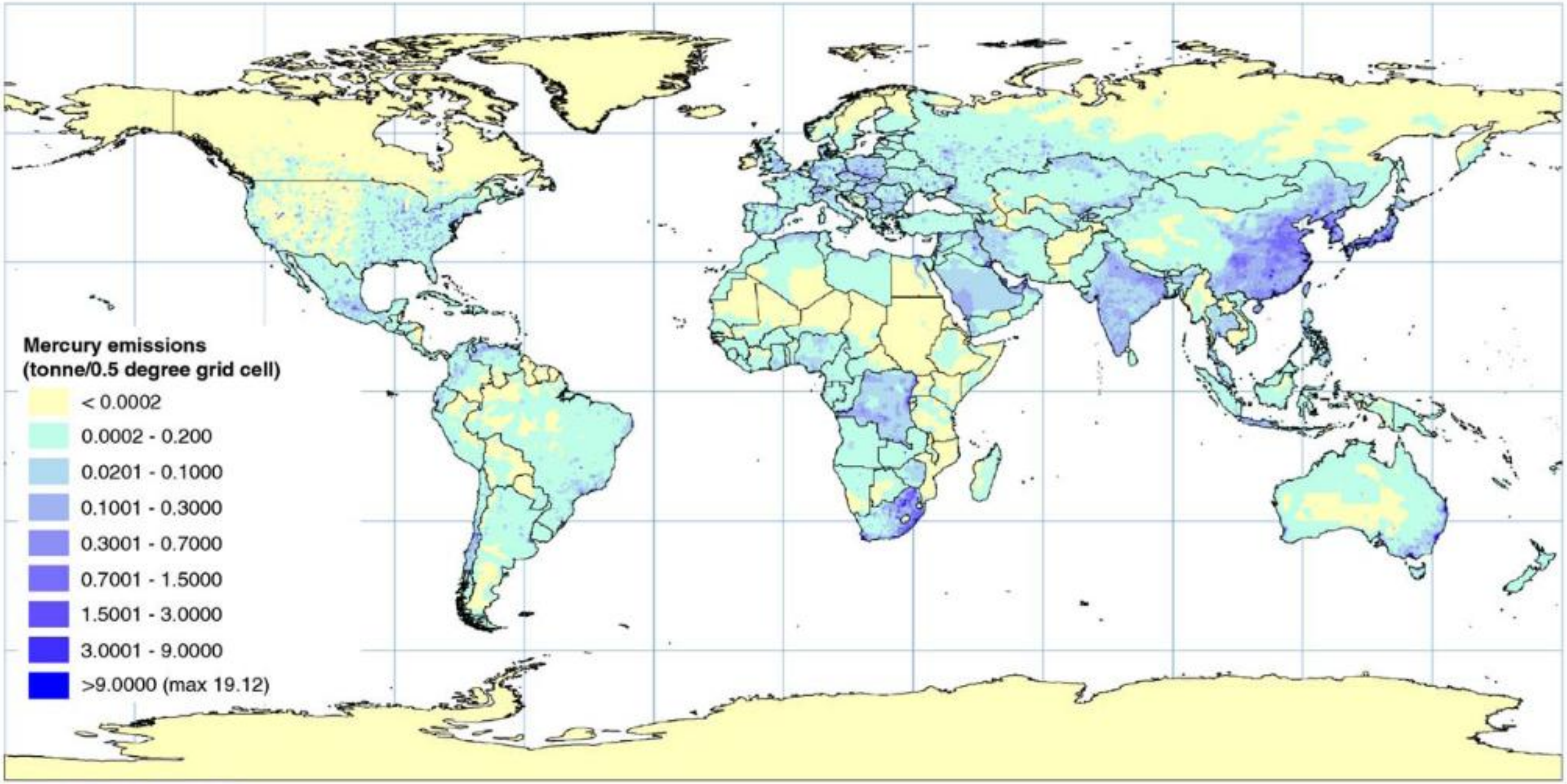


FIGURE 4. Spatial distributions of hot-stabilized emissions of NO_x from vehicles in Beijing.

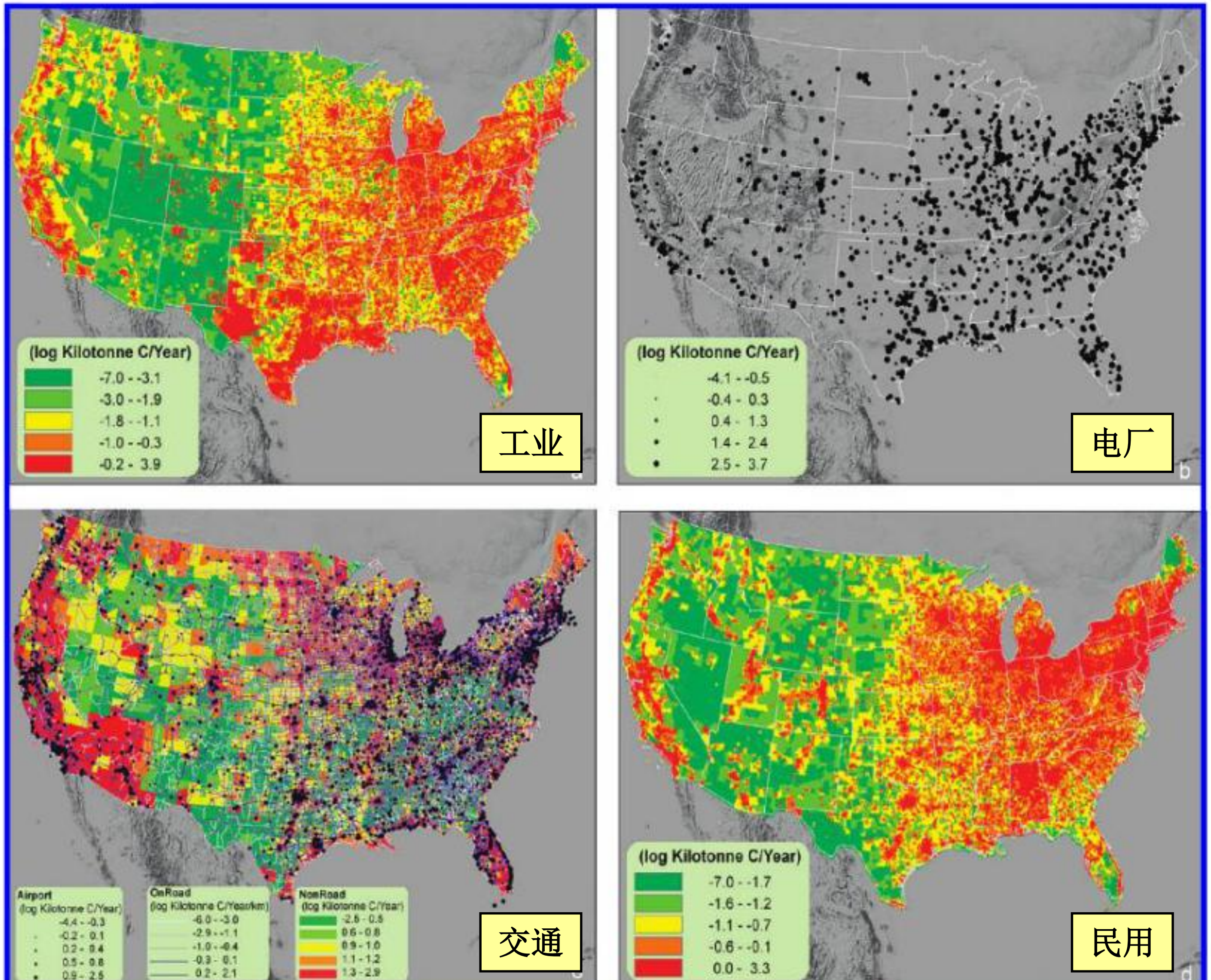
全球 0.5 度分辨率汞排放空间分布



no projection (geographic)

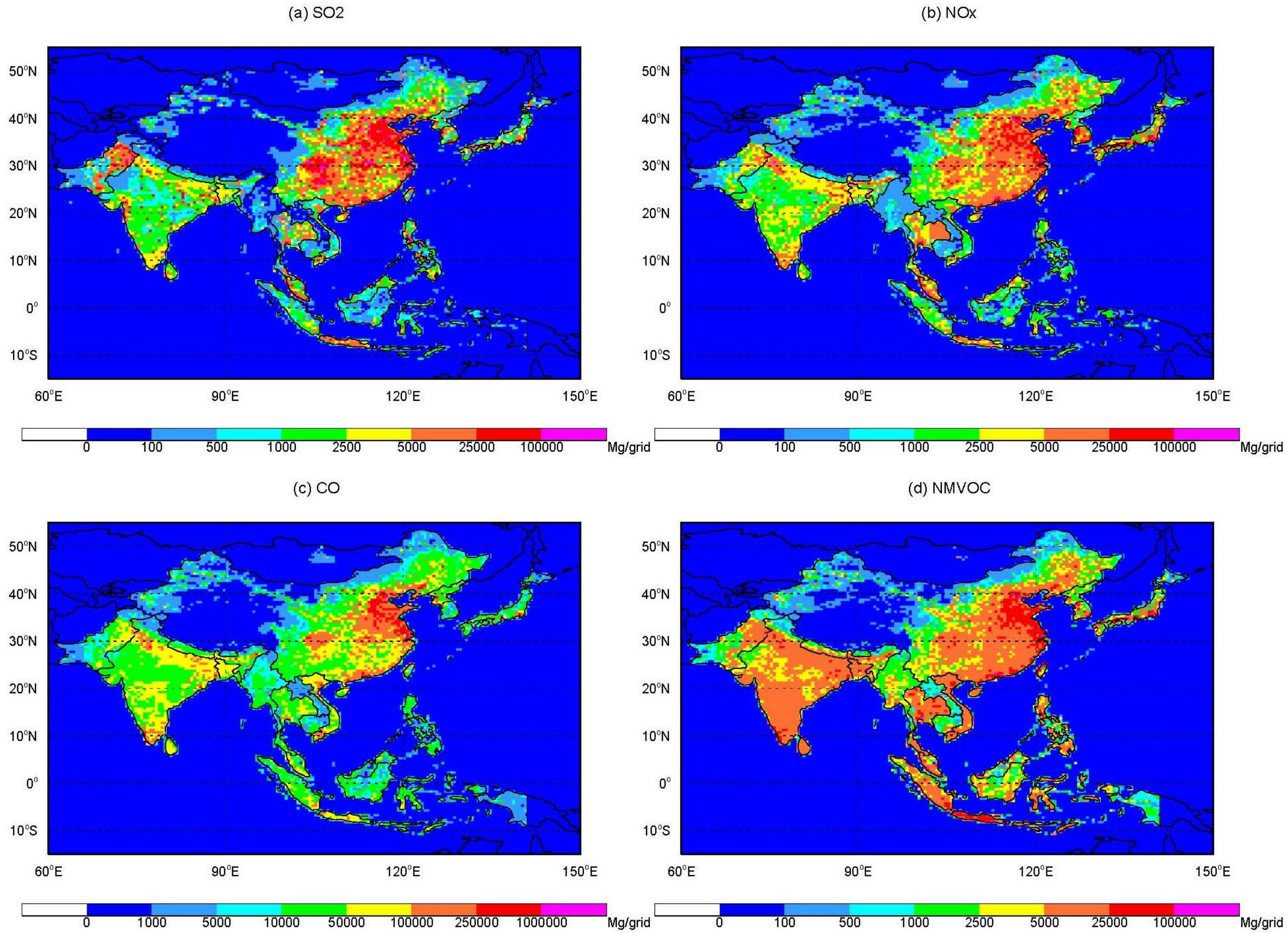
Wilson et al., AE, 2006

美国人为源 CO2 排放 10km 分辨率空间分布



Gurney et al., EST, 2009

2006年亚洲大气污染物排放空间分布



Anthropogenic only, 8 species, 0.5 degree resolution, 4 sectors, SAPRC-99 specitation.

Published in ACP, data available on http://mic.greenresource.cn/intex-b2006

全球人为源排放的历史重构

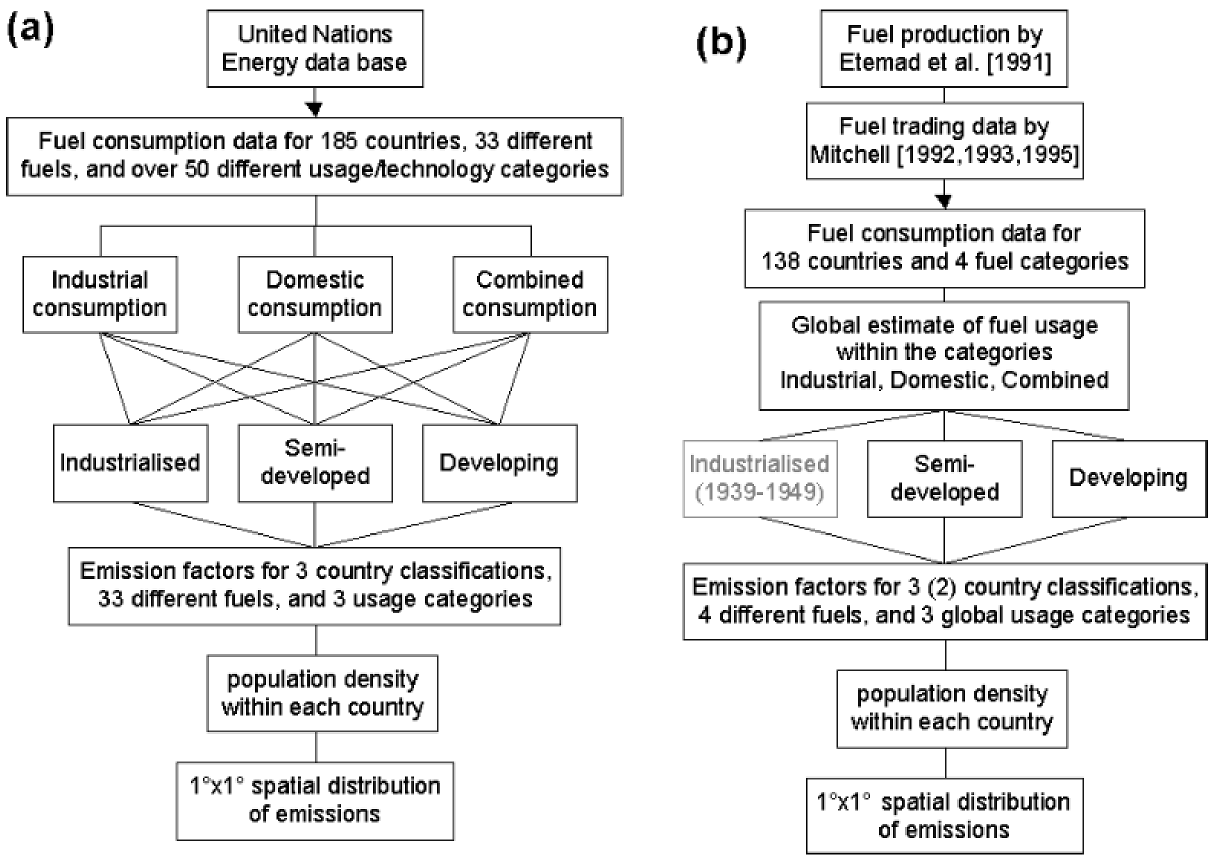
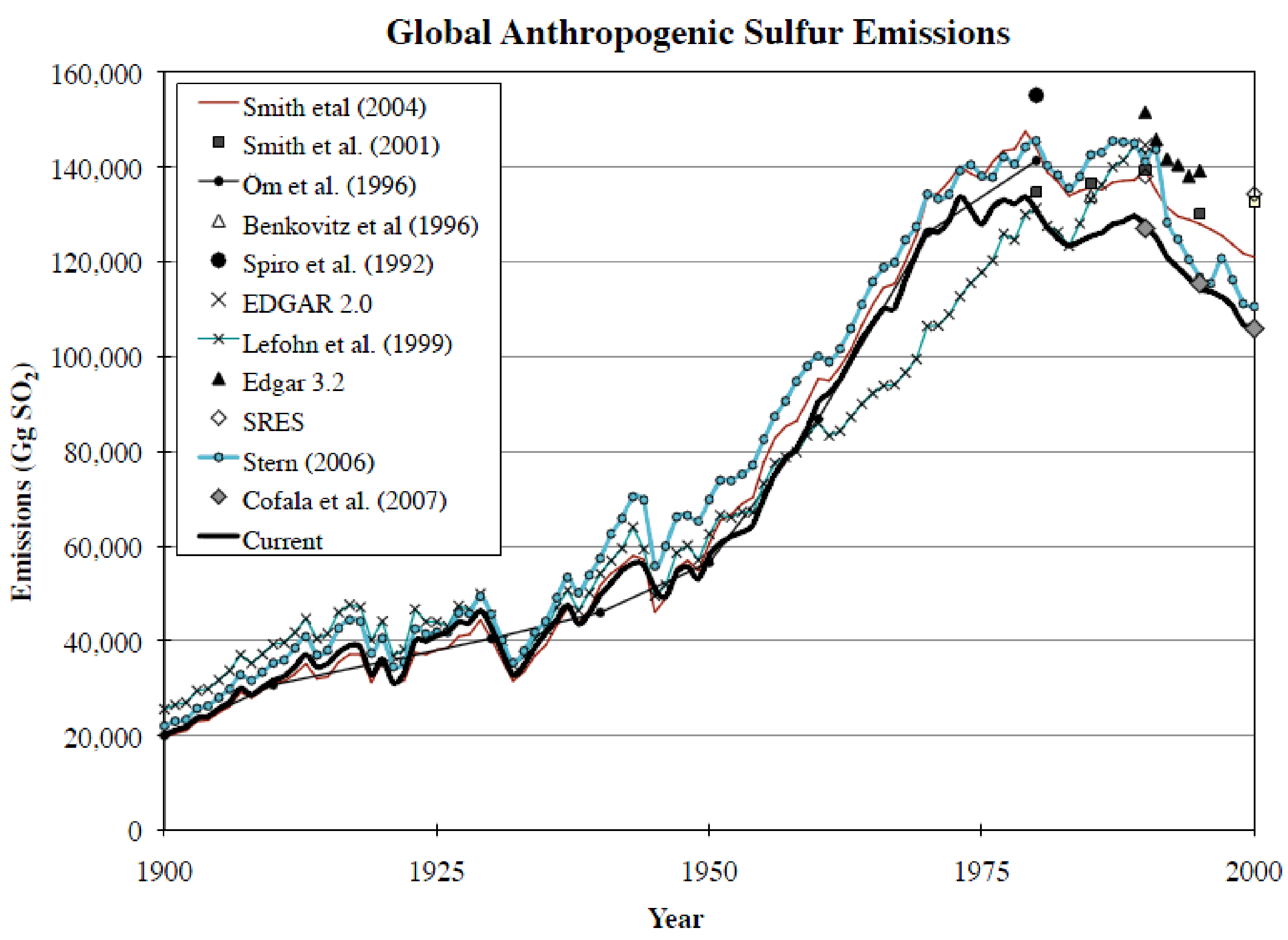


Fig. 1. Tree diagrams of the methods used for the inventory of **(a)** the period 1950–1997 and **(b)** the period 1860–1949.

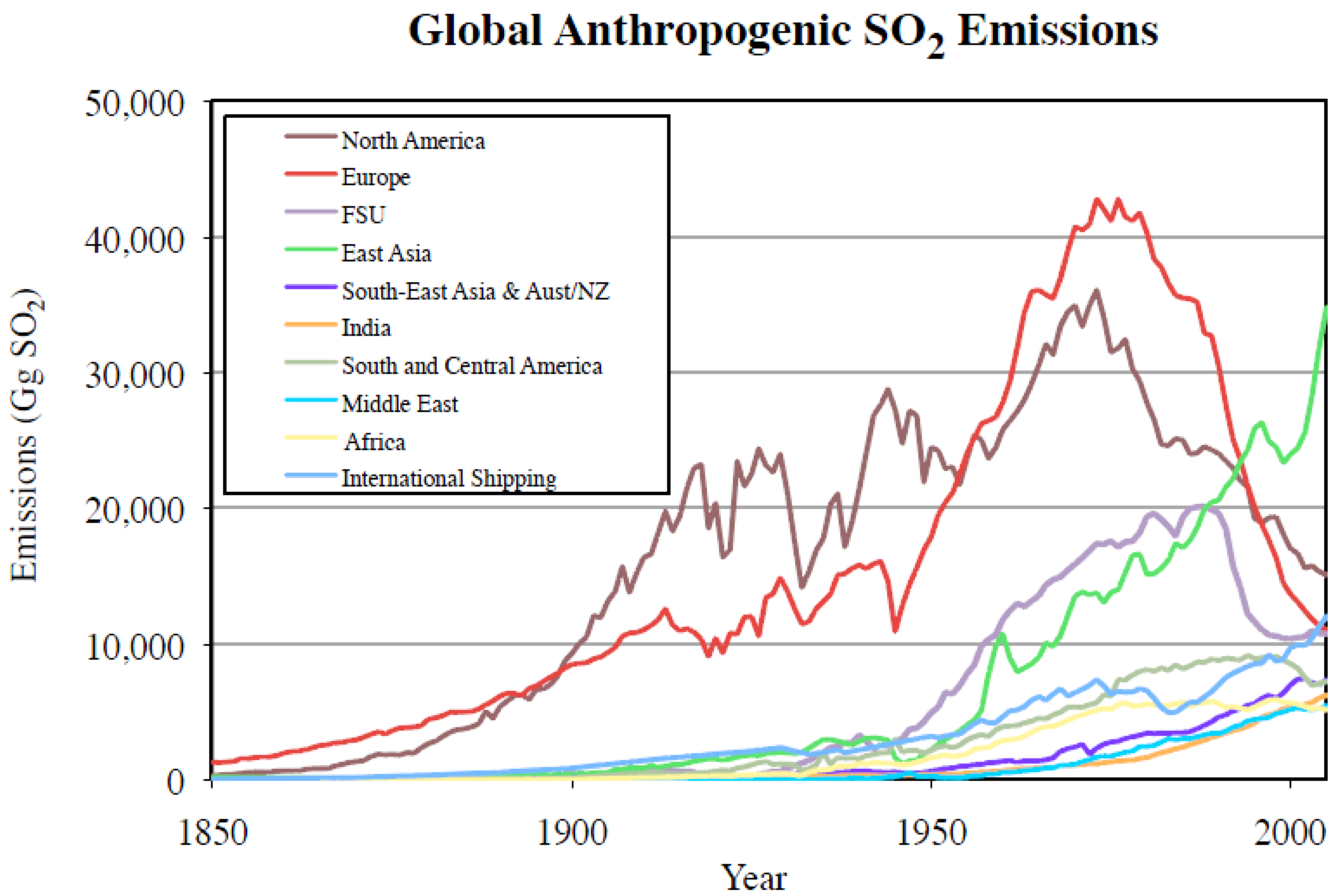
Junker et al., ACP, 2008

全球 人为源二氧化硫排放历史趋势



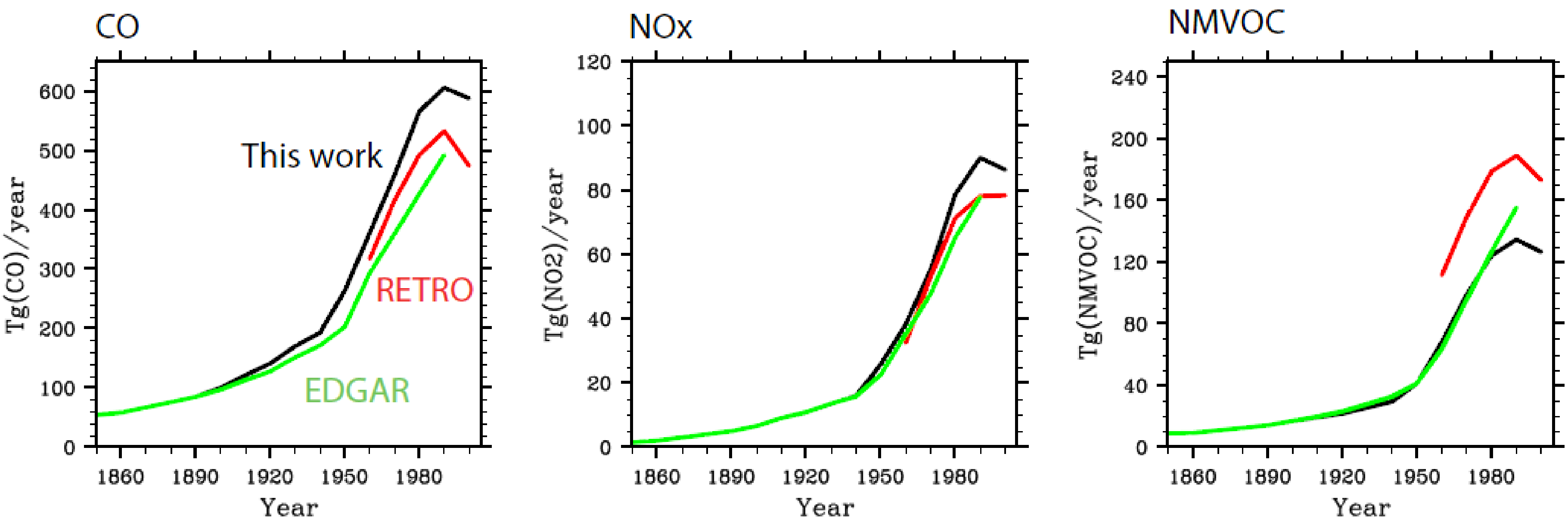
Smith et al., ACPD, 2010

全球 人为源二氧化硫排放历史趋势



Smith et al., ACPD, 2010

全球NOx, CO, VOC排放的历史趋势



Lamarque et al., ACP, 2010

全球BC和OC排放的历史趋势

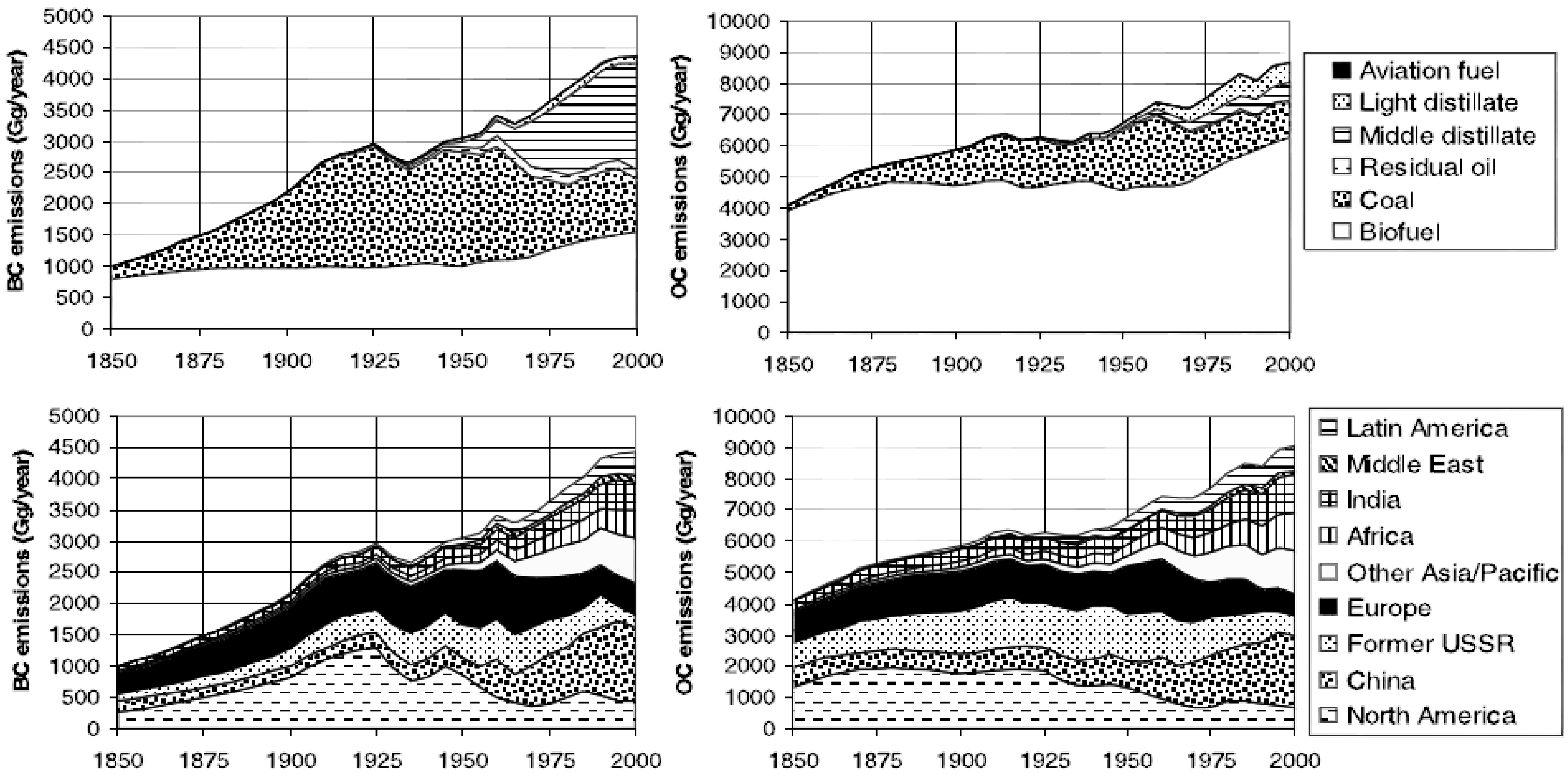
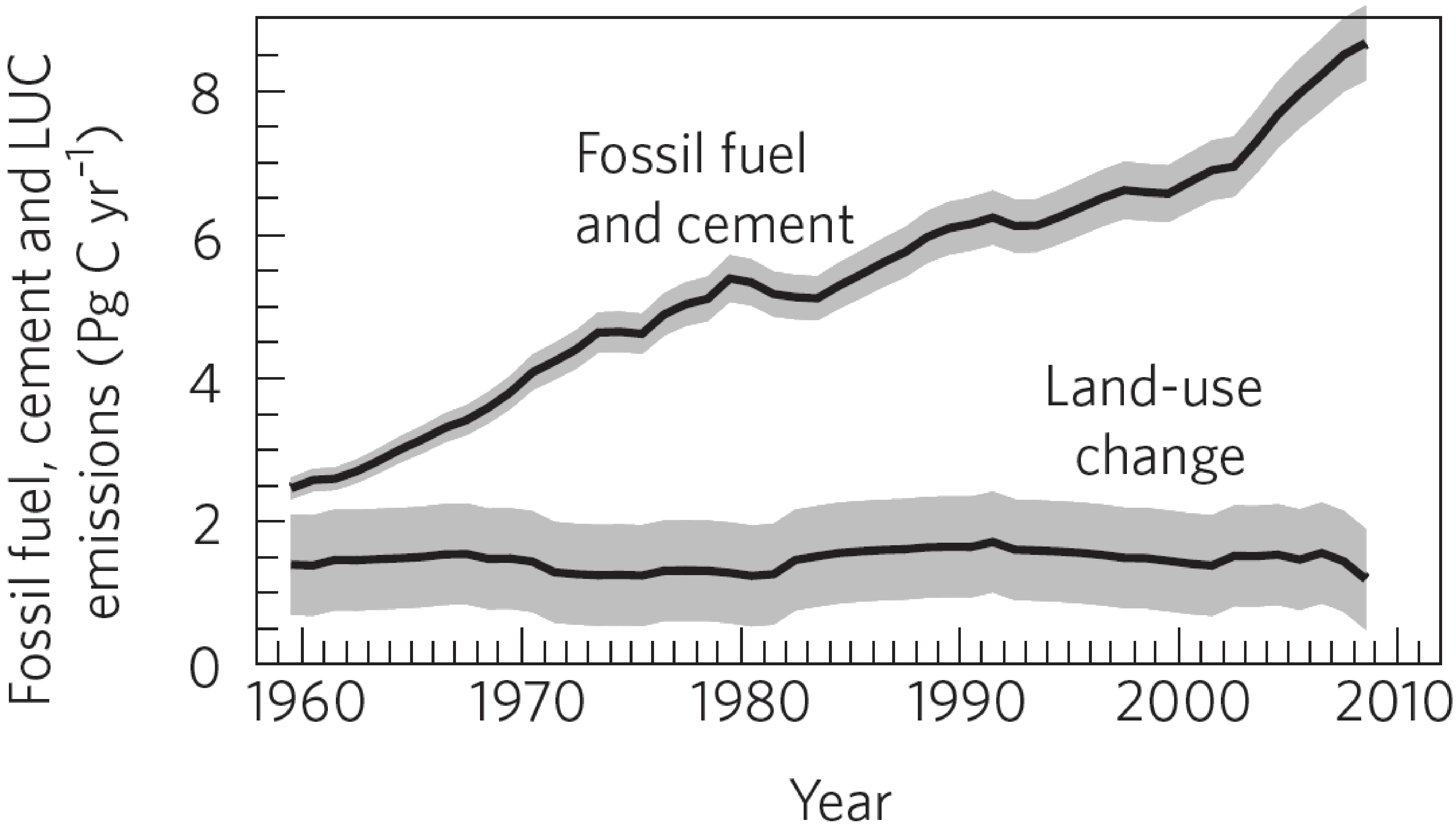


Figure 6. Emissions of (left) black carbon and (right) organic carbon. Emissions are segregated by (top) fuel and (bottom) region.

Bond et al., GBC, 2007

全球 CO2排放的历史趋势



Le Quere et al., Nature Geo. Sci., 2009

基于观测的定量方法及示例

基于观测的自上而下的排放定量方法

$$E = \alpha \times \Omega.$$

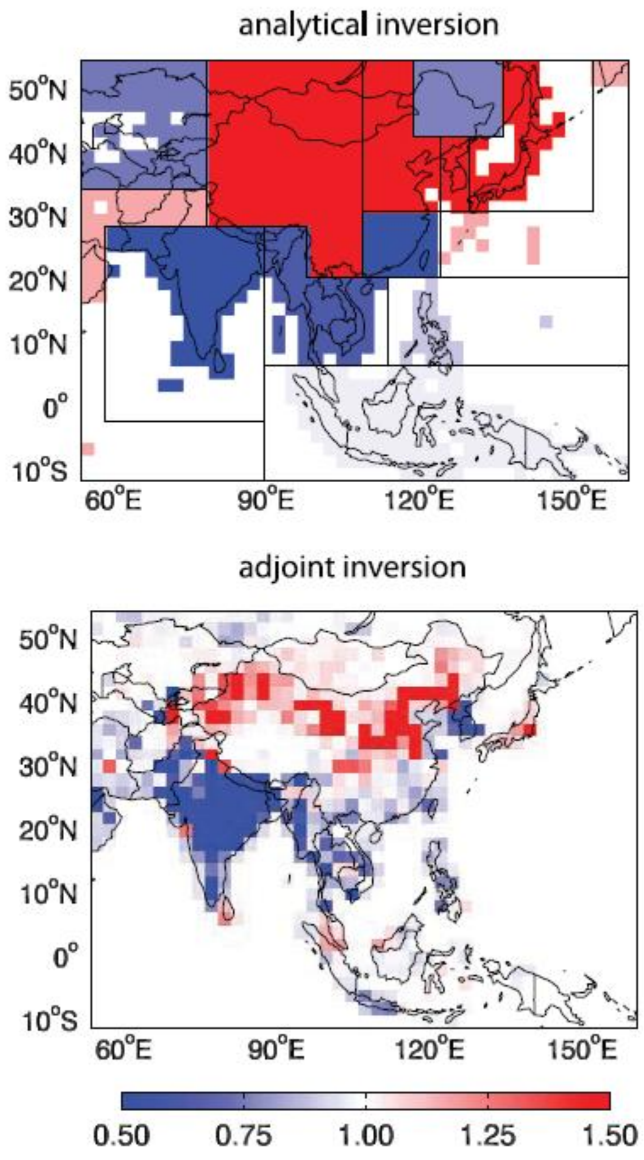
E:	排放量
Ω:	观测值
α:	观测值与排放之间的函数关系

观测值的来源

- 地面观测
- 飞机航测
- 卫星遥感观测

建立观测值与排放量之间函数关系的常用方法

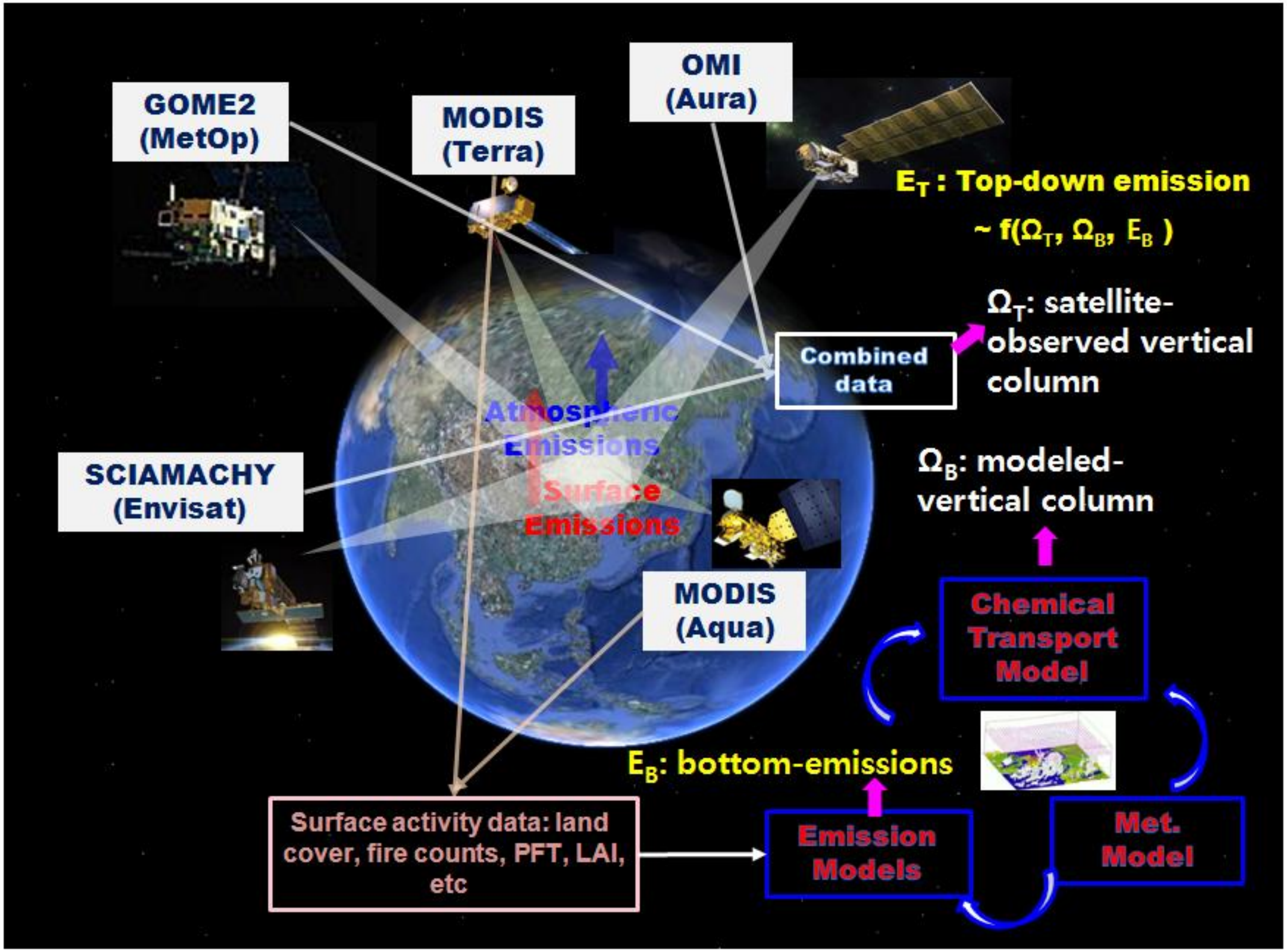
- 经验方法
- 大气化学模型
- 反演模型



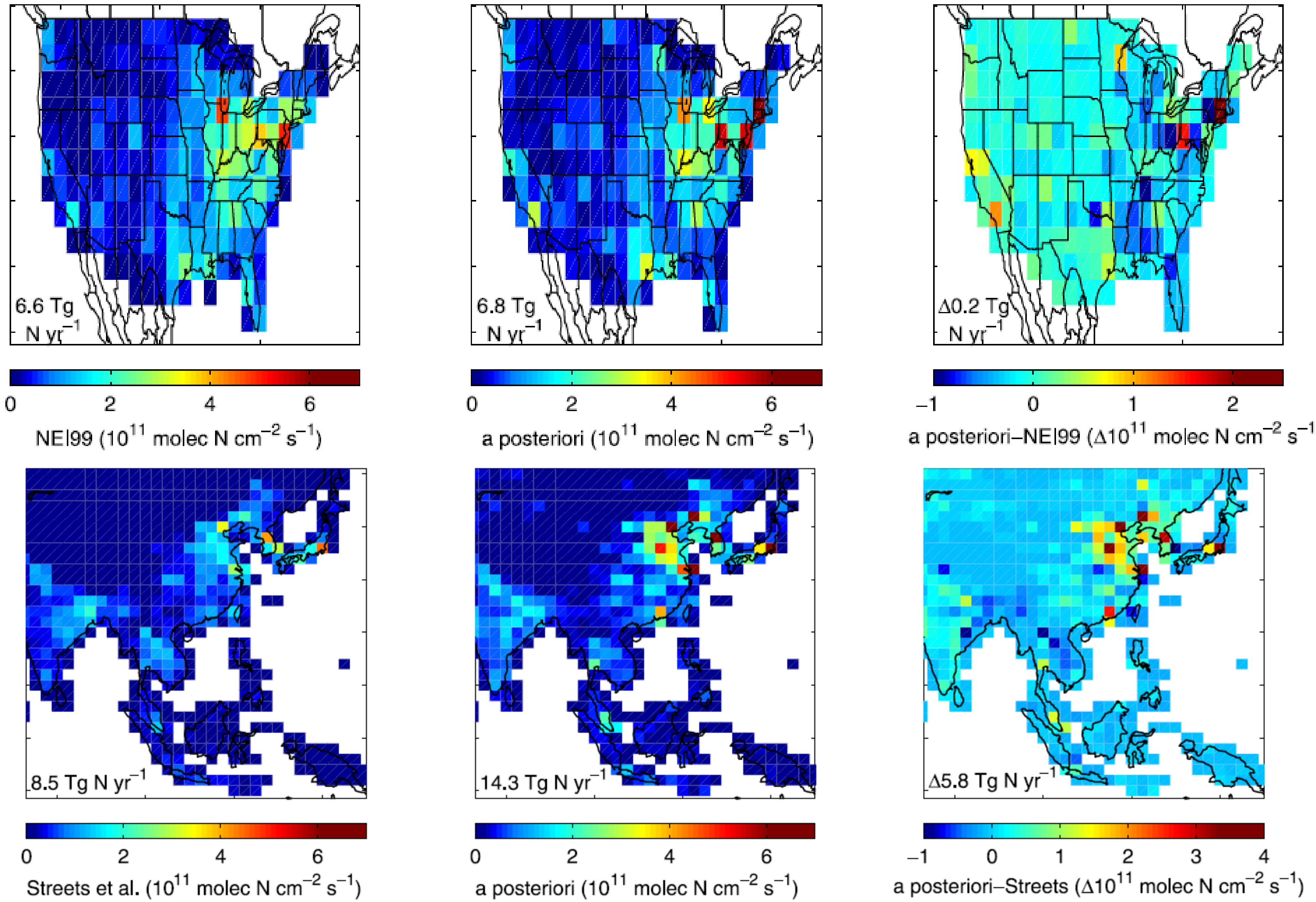
自上而下排放定量方法示例

- 利用卫星遥感观测反演地面排放量
- 卫星遥感监测地面排放变化

基于卫星观测的排放源定量

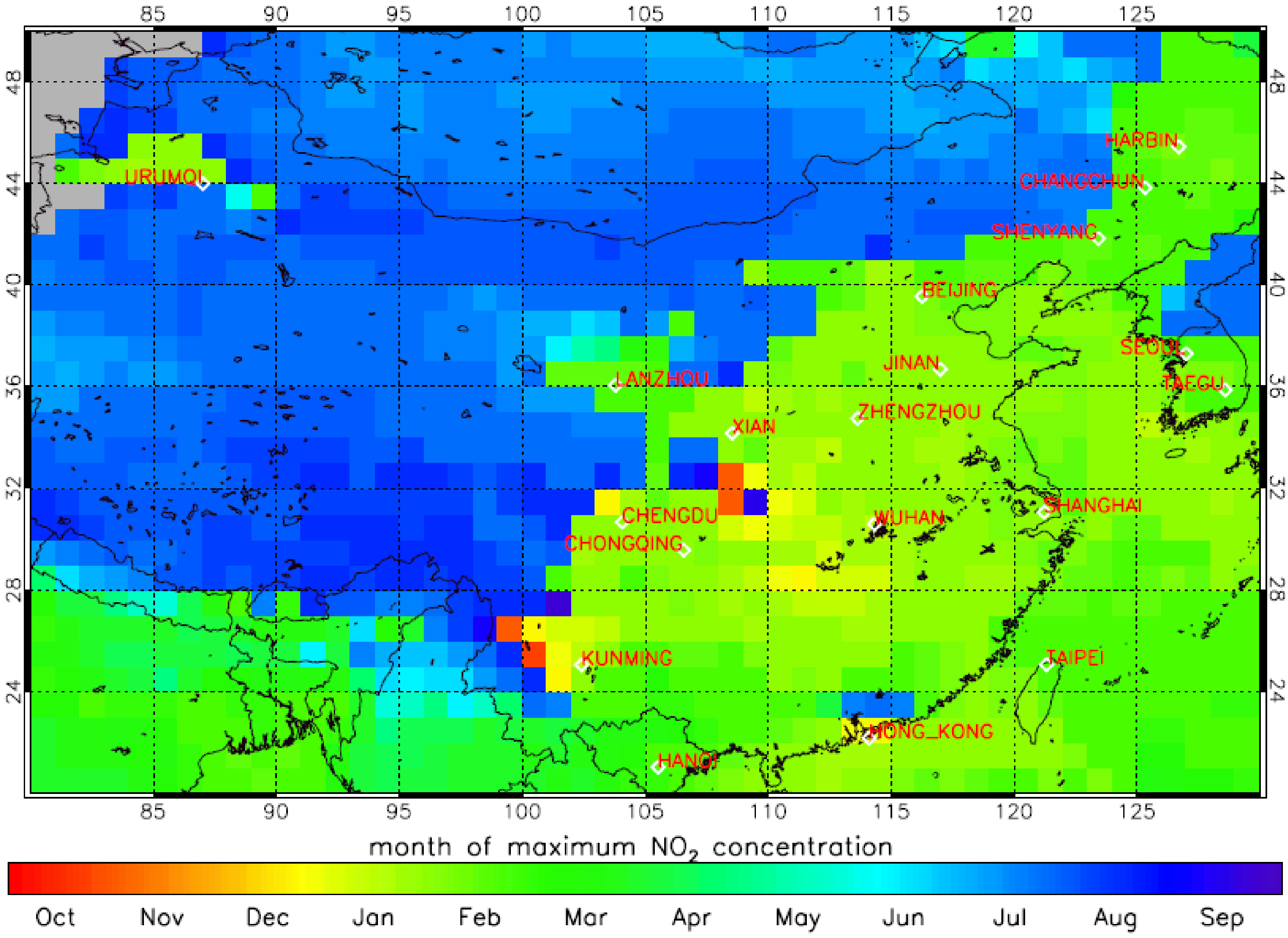


基于卫星反演的NOx排放清单



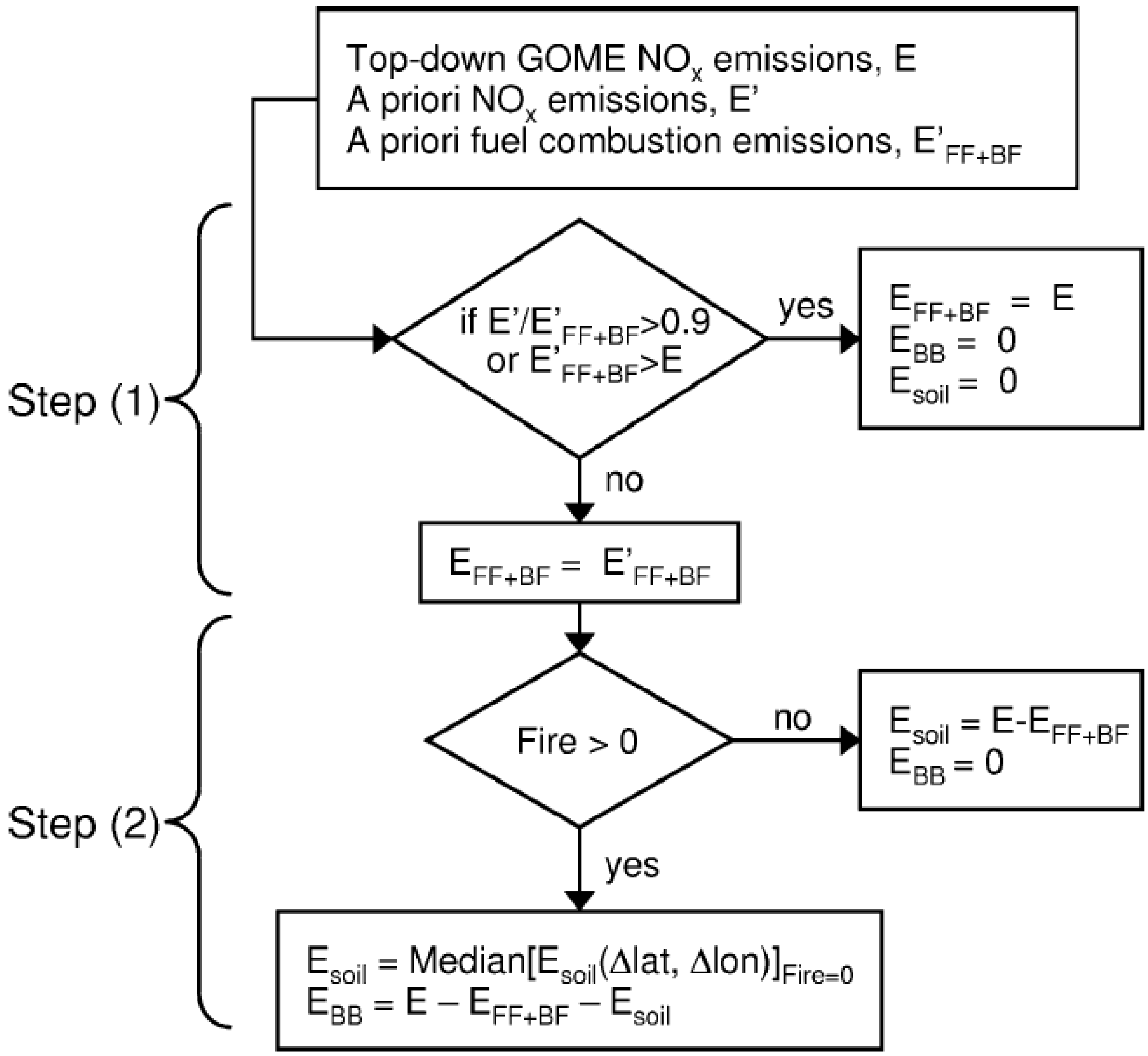
Martin et al., JGR, 2006

卫星观测 NO2 柱浓度出现最大值的月份



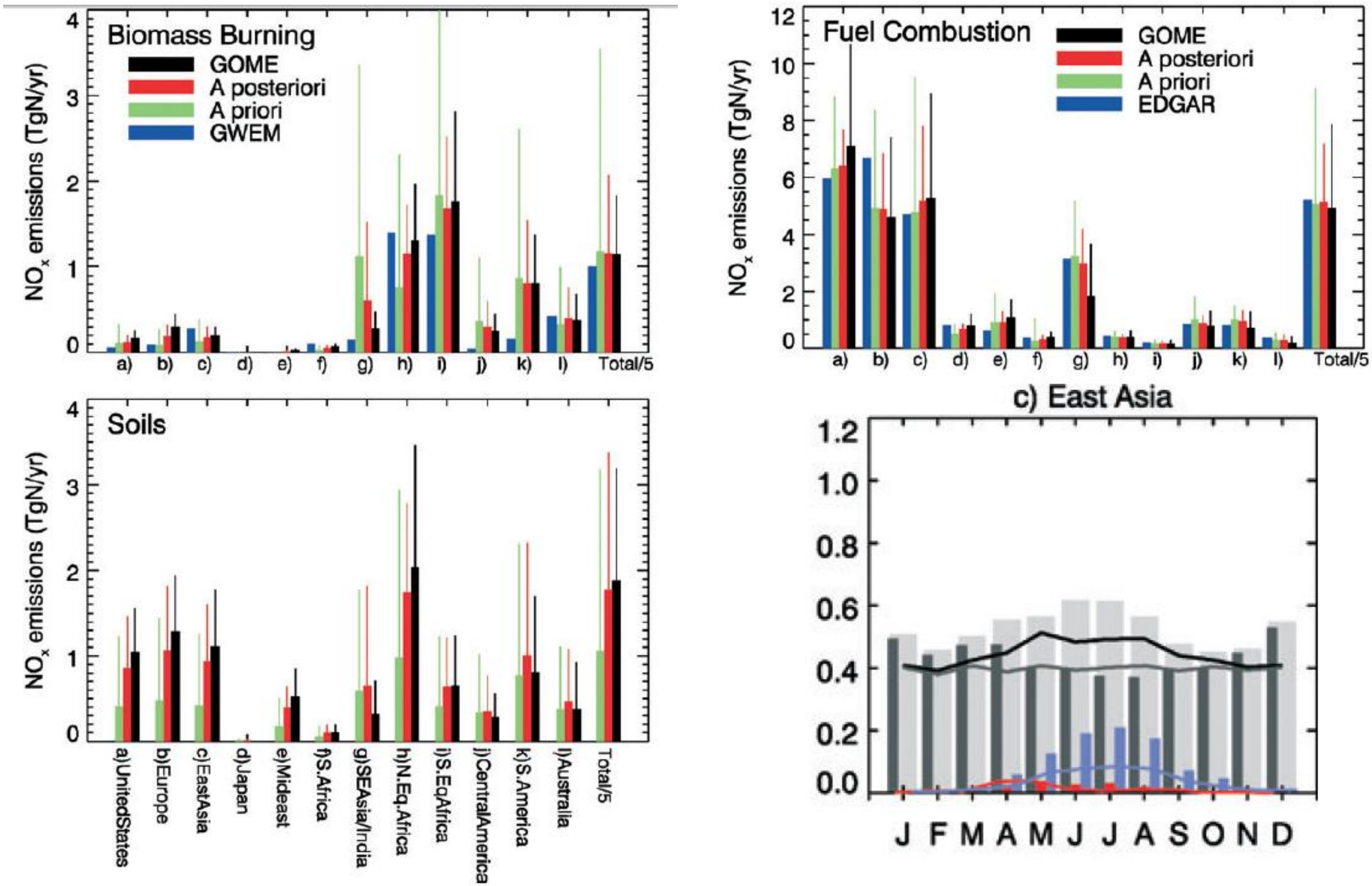
van der A et al., JGR, 2006

基于卫星观测反演不同排放源的NOx排放清单



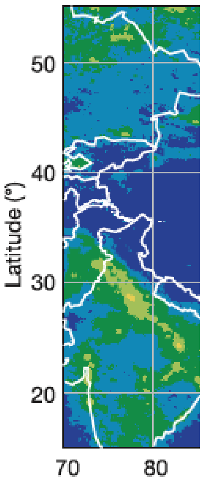
Jaegle et al., Friday Discuss., 2006

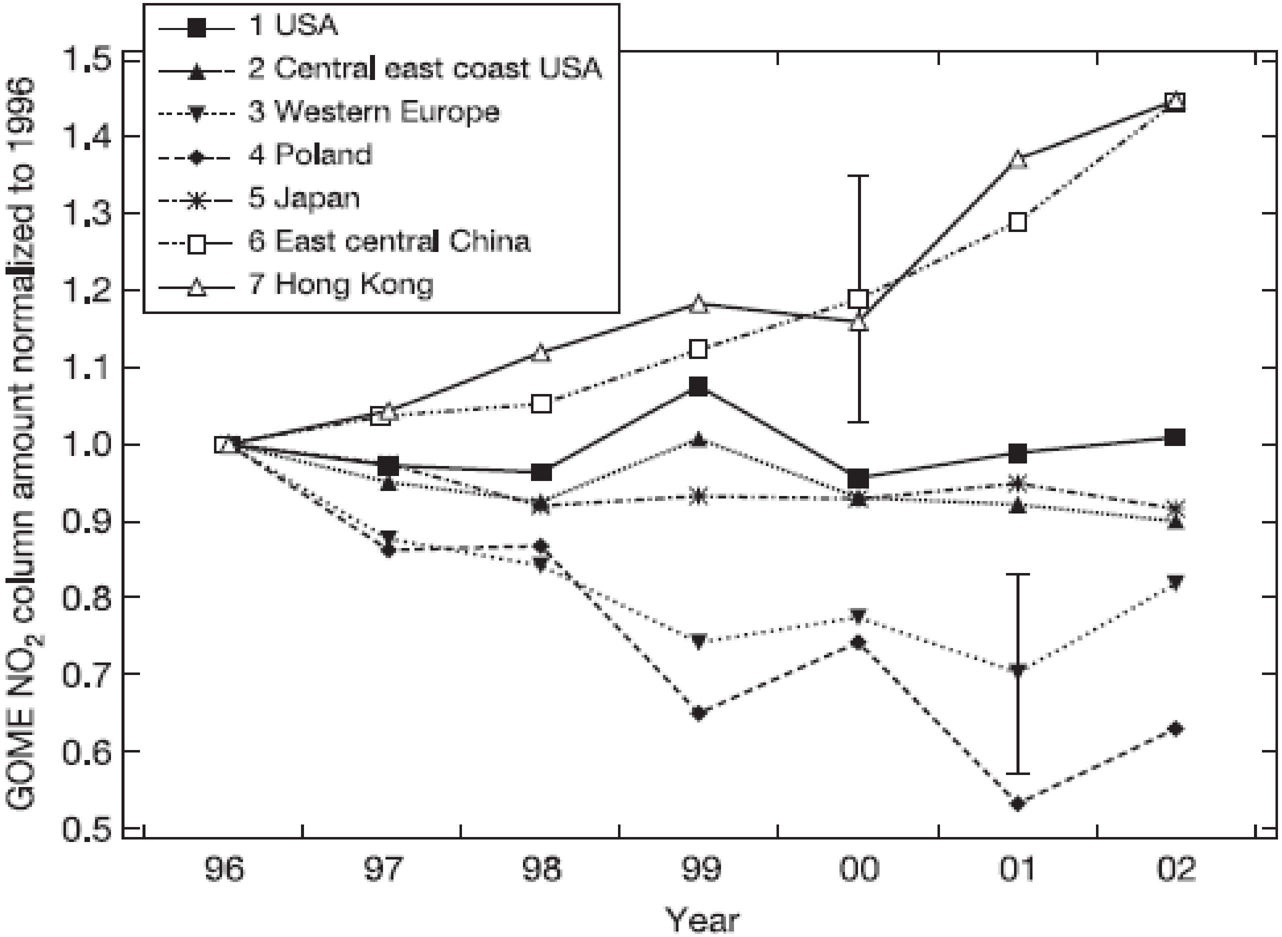
基于卫星观测反演不同排放源的NOx排放清单



Jaegle et al., Friday Discuss., 2006

卫星监测到中国地区NO2浓度快速增长





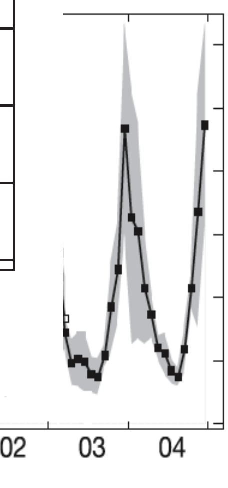
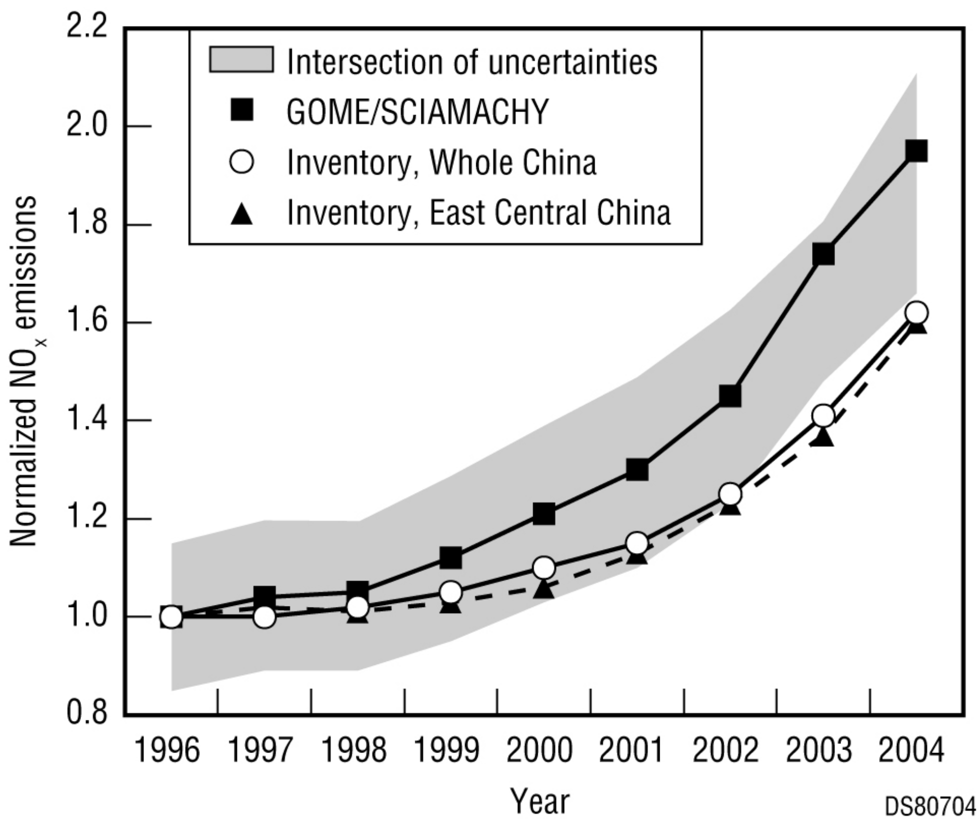


Figure 2 | SCIAMA
between Decembe
regions. SCIAMA
nonlinear colour scale has been used because of the large range of NO_2 vertical columns. The numbered rectangles indicate the regions used in Fig. 3.

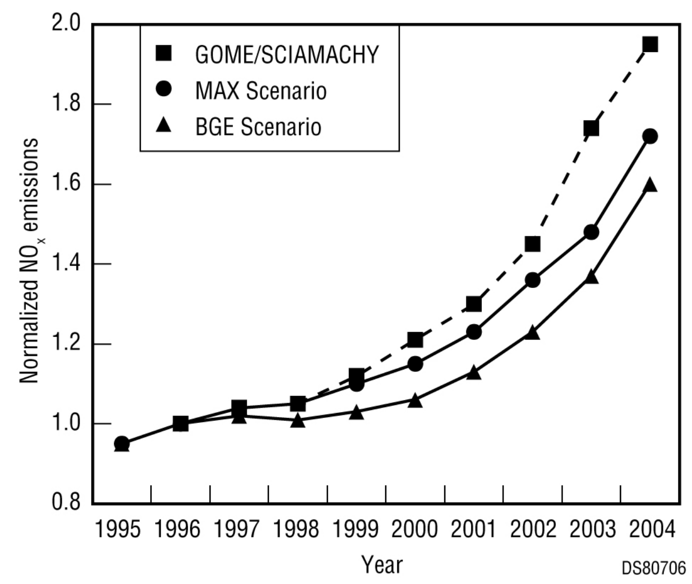
***Richter et al., Nature*, 2005**

排放趋势与卫星观测趋势间的比对

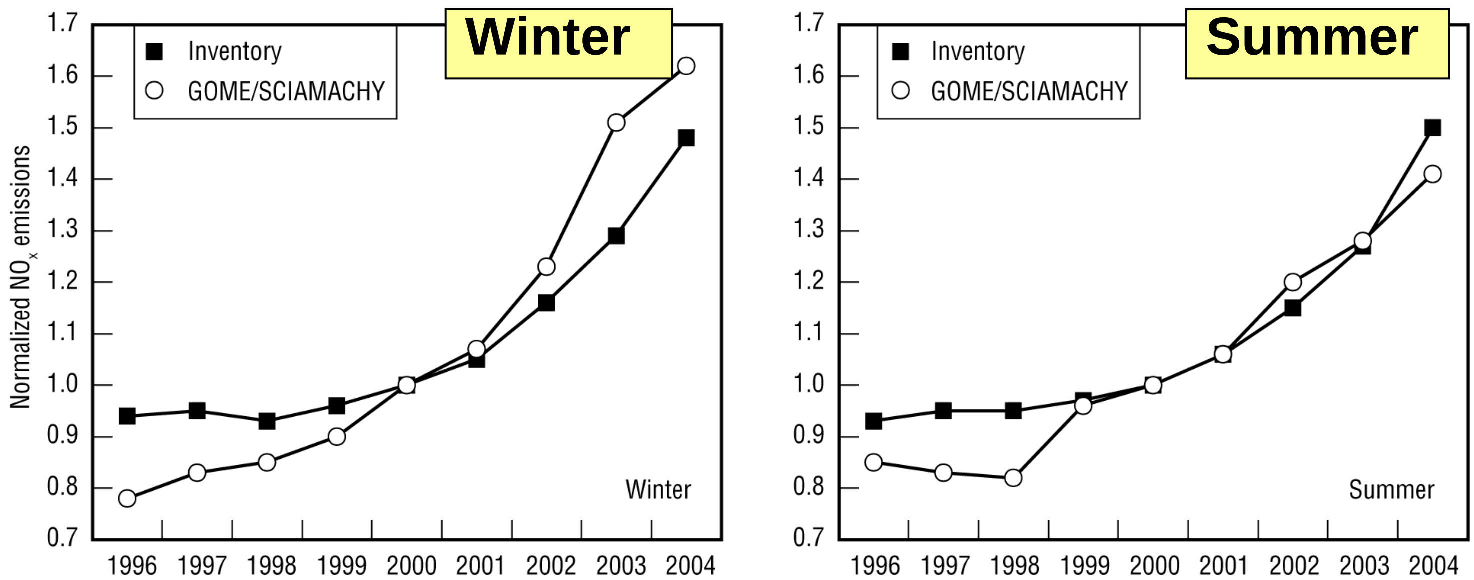


Both inventory and satellite retrievals show an accelerated increase

The satellite trend shows a faster increase than the inventory trend



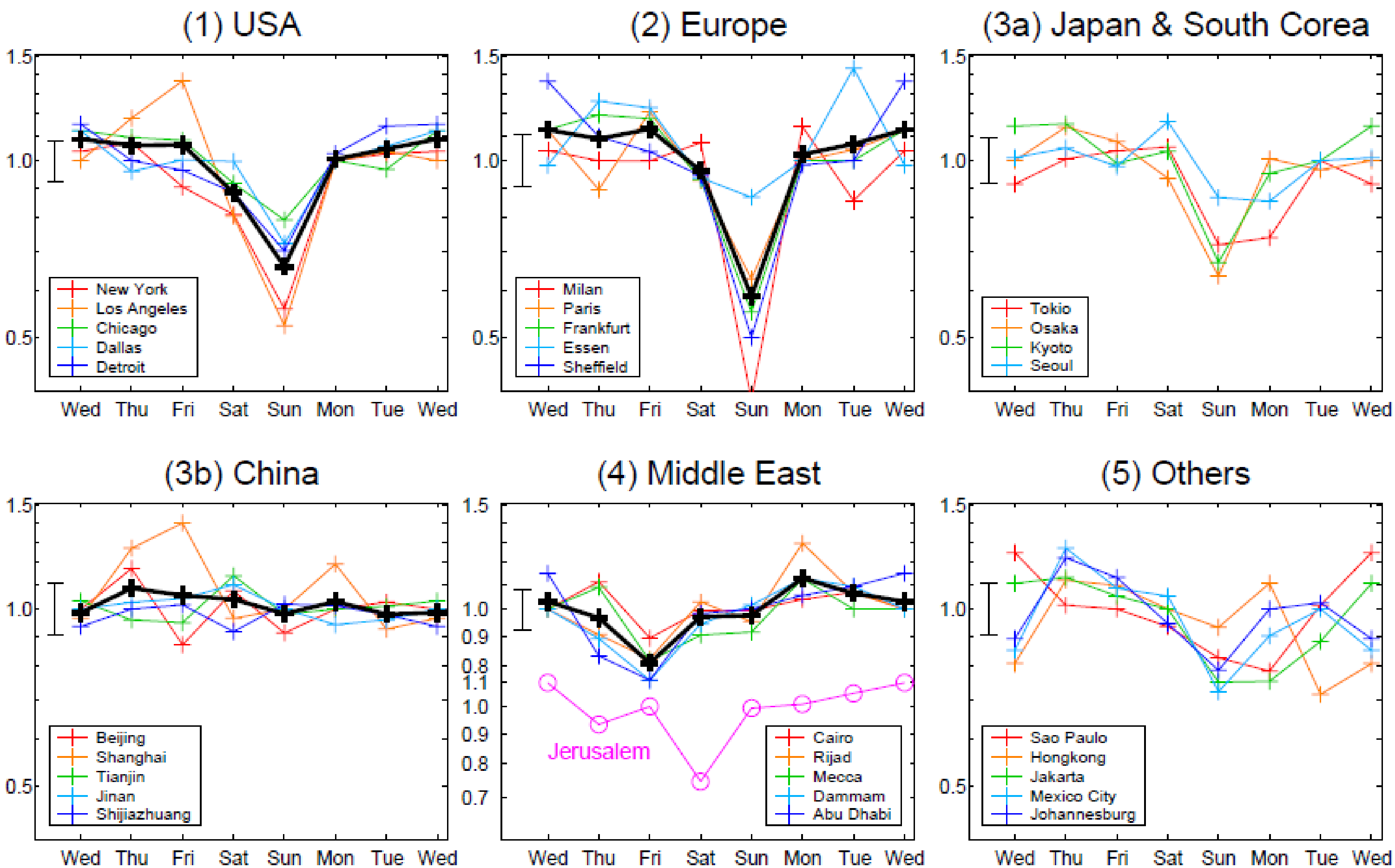
两种方法的结果在不同季节间存在差异



The bias in winter might come from a combination of

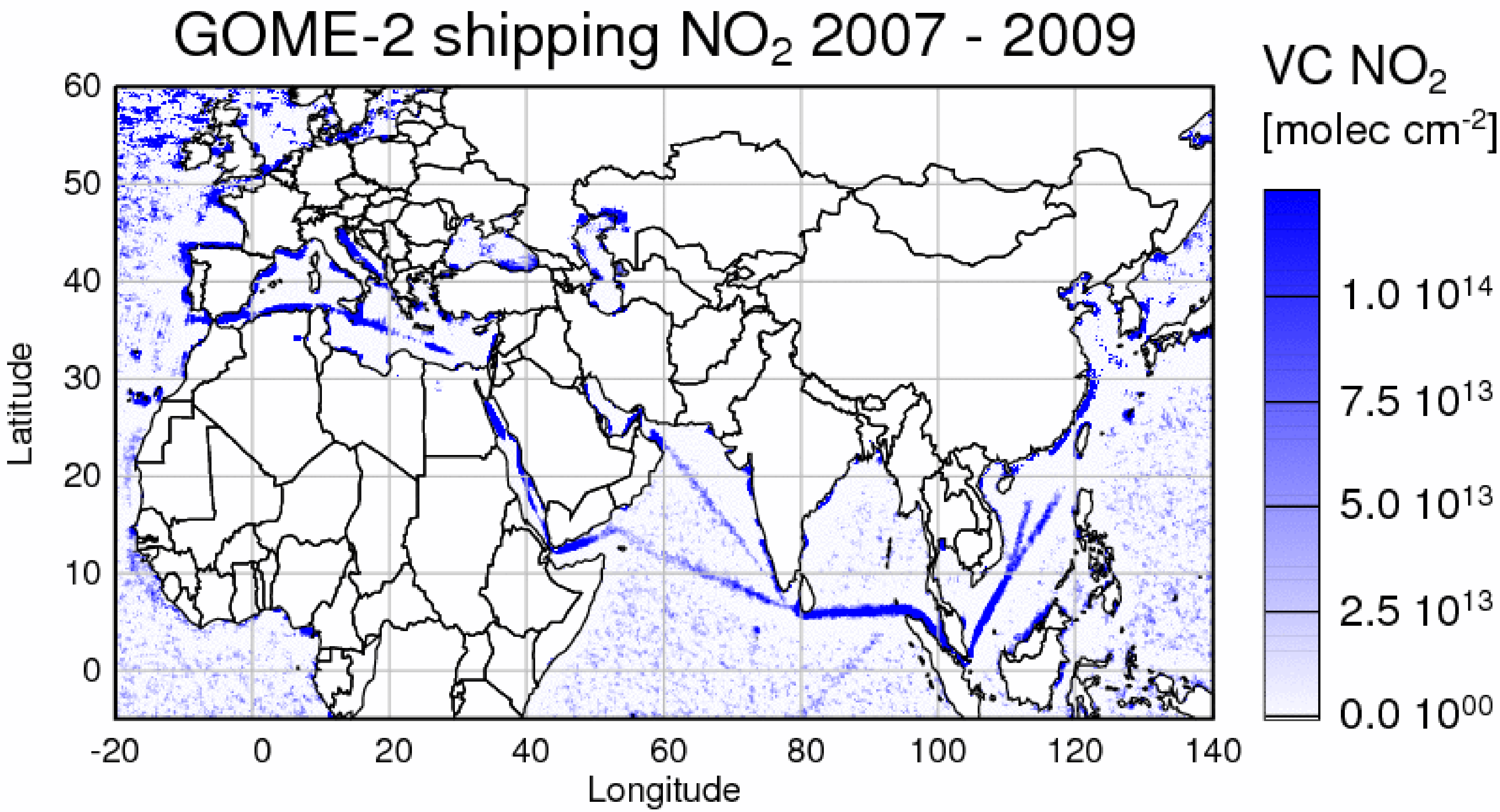
- *underestimates of seasonal variation in emissions*
- *large error of satellite retrievals in winter*
- *non-linear responses of NO_2 columns to NO_x emissions*

卫星观测排放变化的周末效应



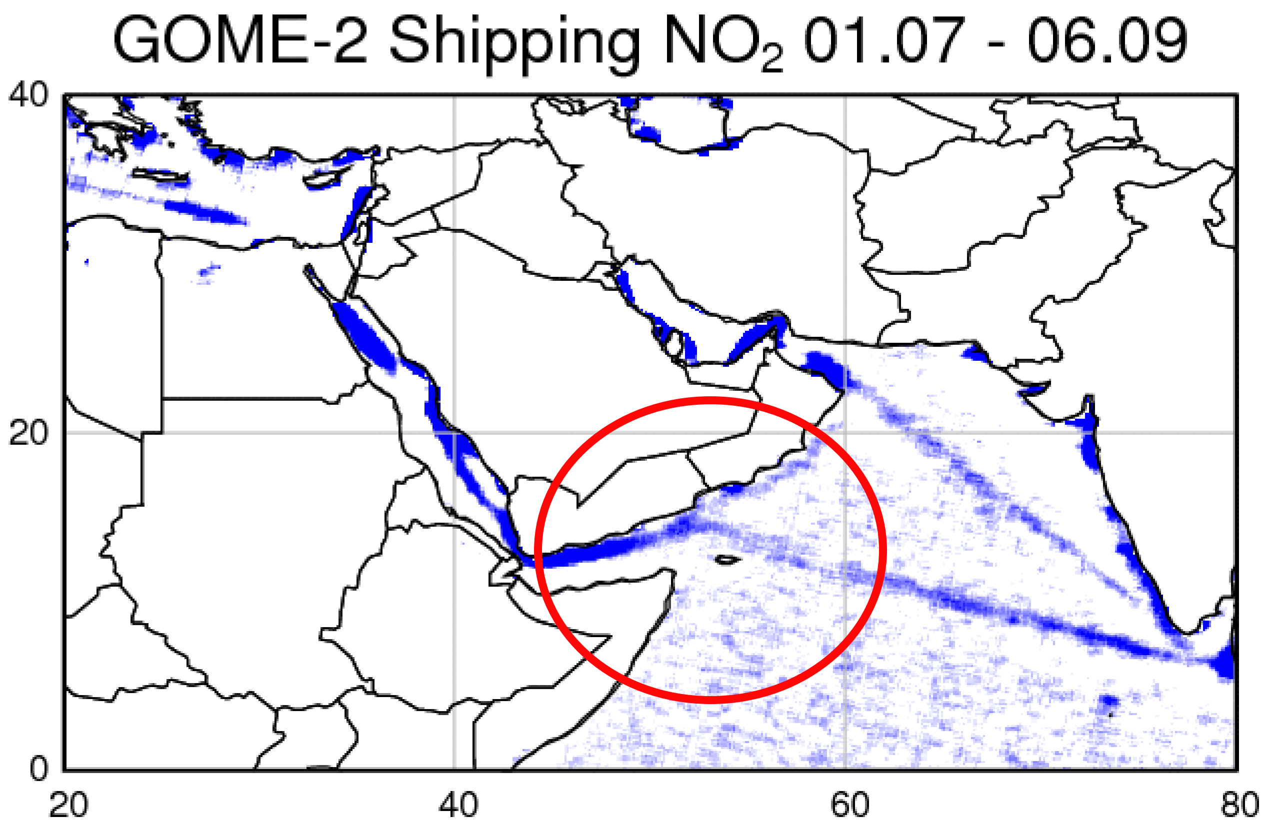
Beirle et al., ACP, 2003

国际航运的氮氧化物排放



From A. Richter

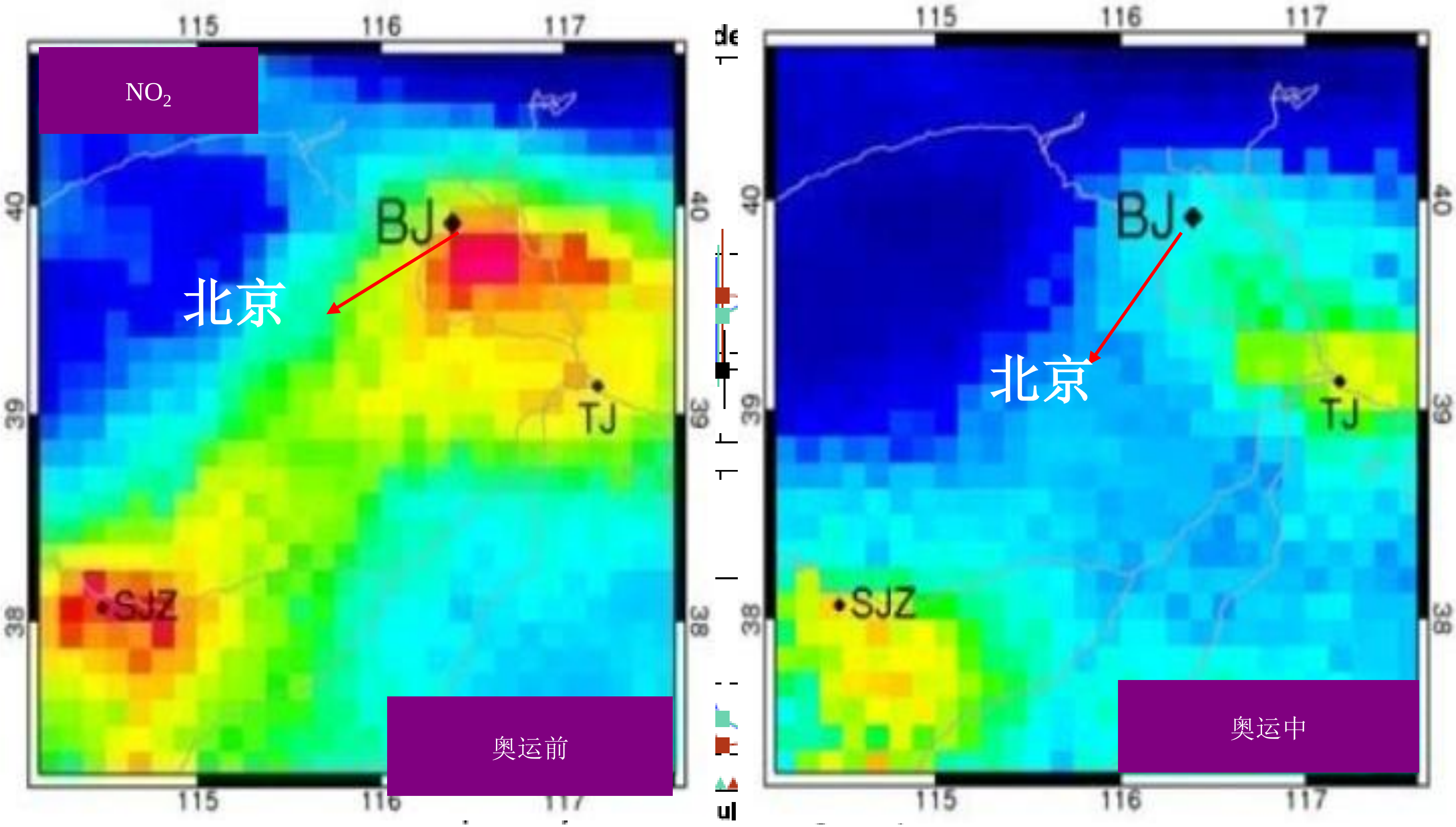
国际航运的氮氧化物排放



- **Pattern of ship emissions in the vicinity of Yemen changed since 2007**
- **Probably in response to pirate attacks**

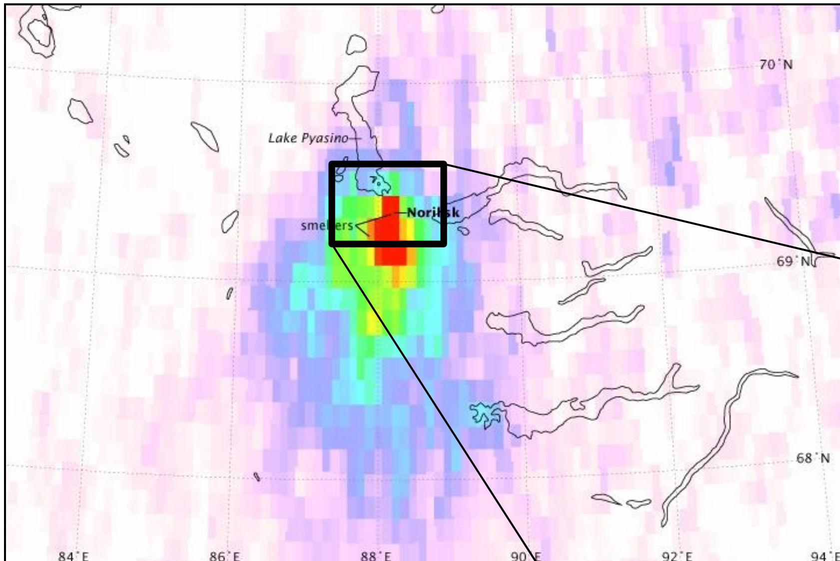
From A. Richter

卫星监测奥运期间污染物减排



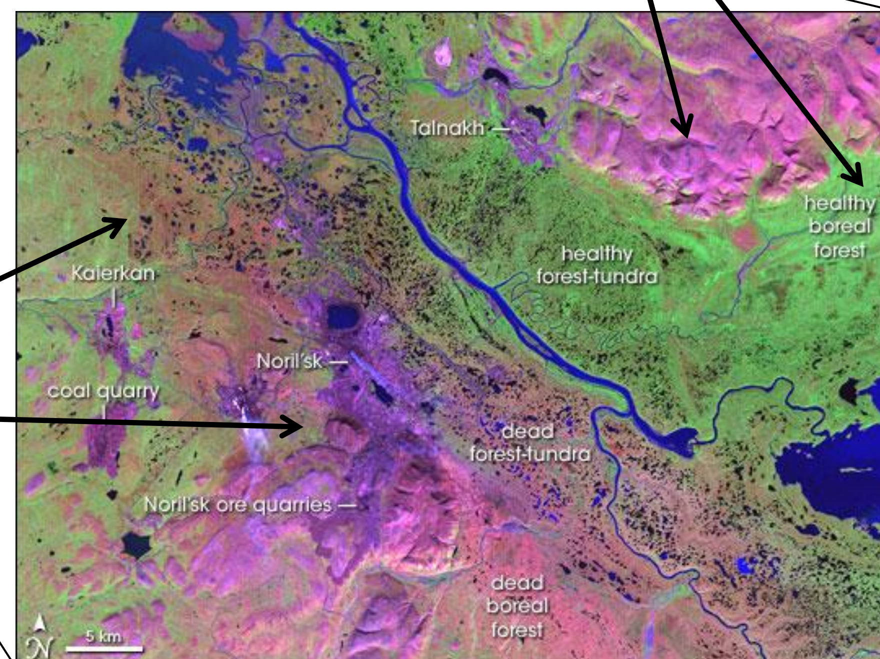
Witte et al., GRL, 2009

卫星观测到俄罗斯西伯利亚地区冶炼厂的SO2排放



Average (2005-2007) SO_2 burdens from the Norilsk facility, measured by the Ozone Monitoring Instrument on NASA's Aura satellite. By some estimates, 1 percent of the entire global emissions of SO_2 comes from this one city. Below is false-color image from LANDSAT ETM+

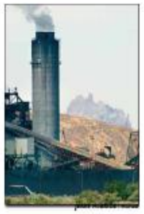
Healthy ecosystems



Severely damaged ecosystems

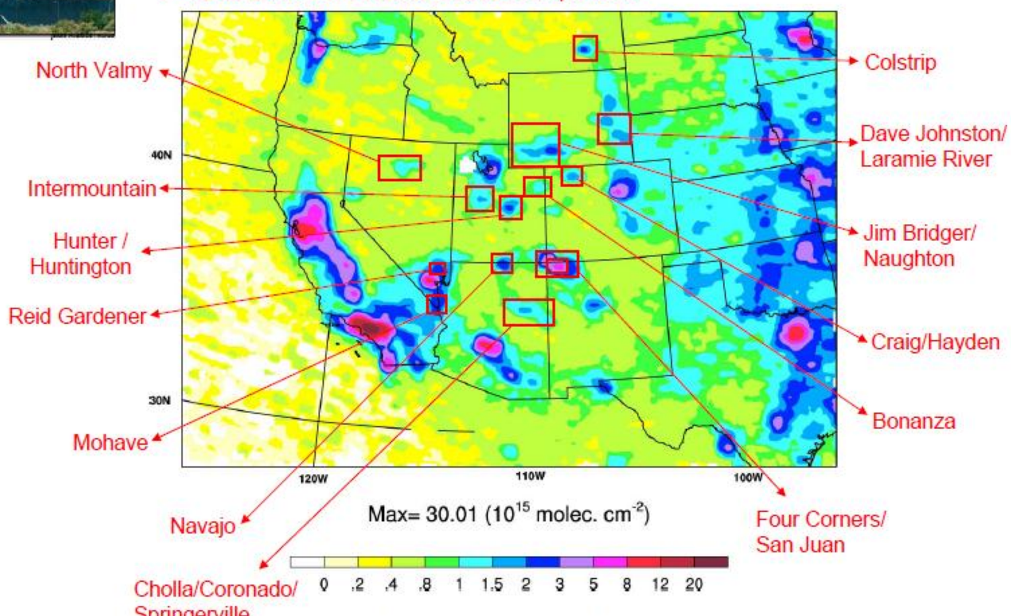
from Nick Krotkov, UMBC

卫星监测美国西部电厂排放



NO_x Emissions from Western US Power Plants

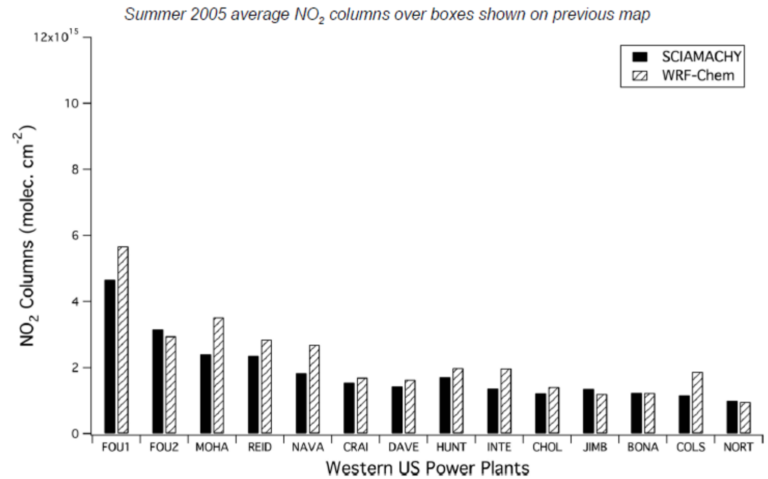
- *Isolated plants have discrete signatures in satellite retrievals*
- *Power plant emissions are measured continuously at each stack*
- *Currently no NO_x pollution controls on large coal-burning plants*
- ➢ *"Calibration" for satellite-model comparison*



SCIAMACHY, Summer 2005

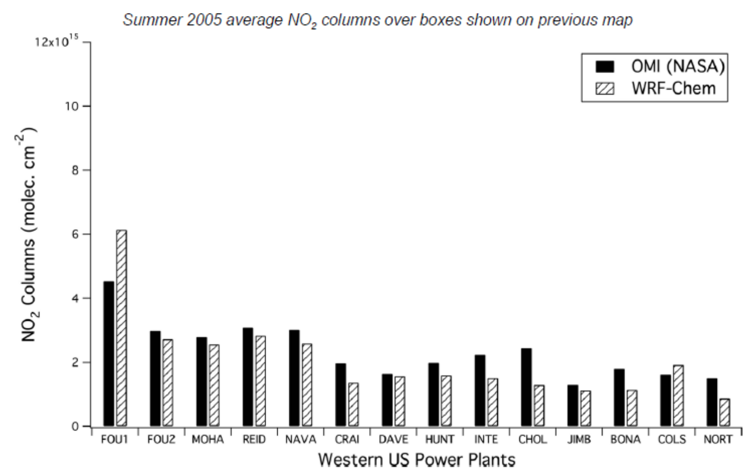
Satellite - Model NO_2 Column Comparison: Power Plants

Summer 2005 average NO_2 columns over boxes shown on previous map



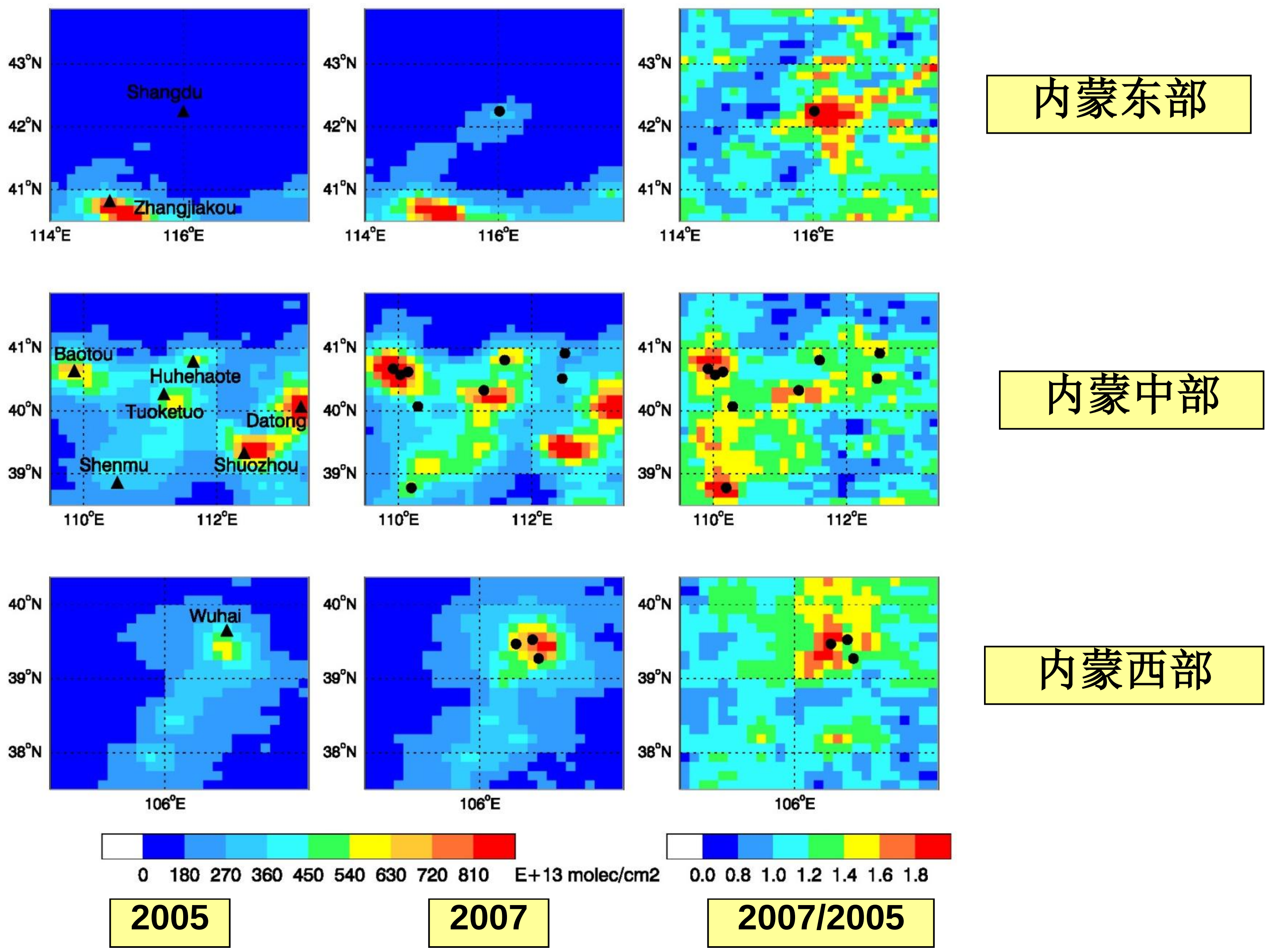
Satellite - Model NO_2 Column Comparison: Power Plants

Summer 2005 average NO_2 columns over boxes shown on previous map

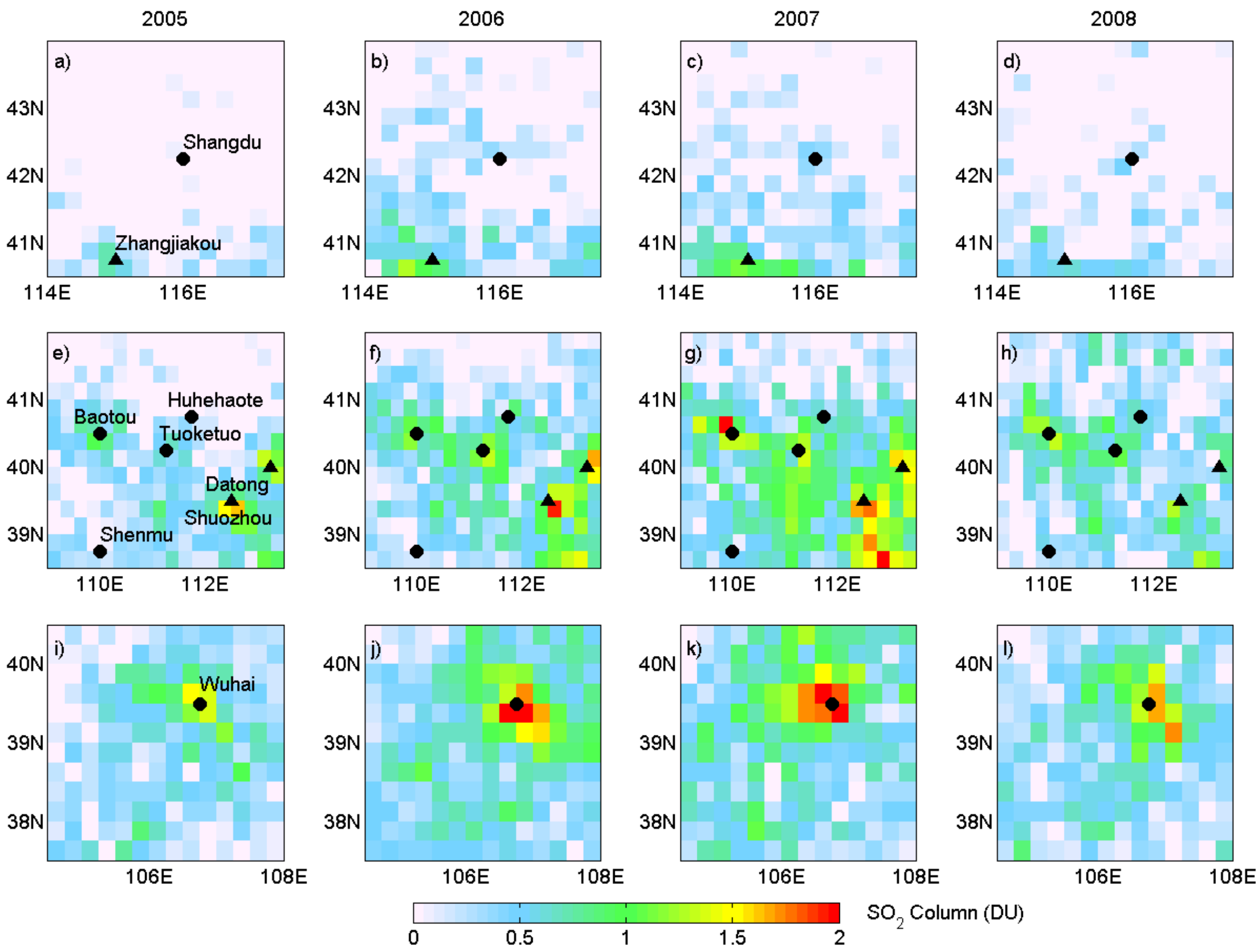


Kim et al., JGR, 114, 2009

卫星遥感对新增电厂排放的识别



卫星监测电厂污染控制装置的运行情况

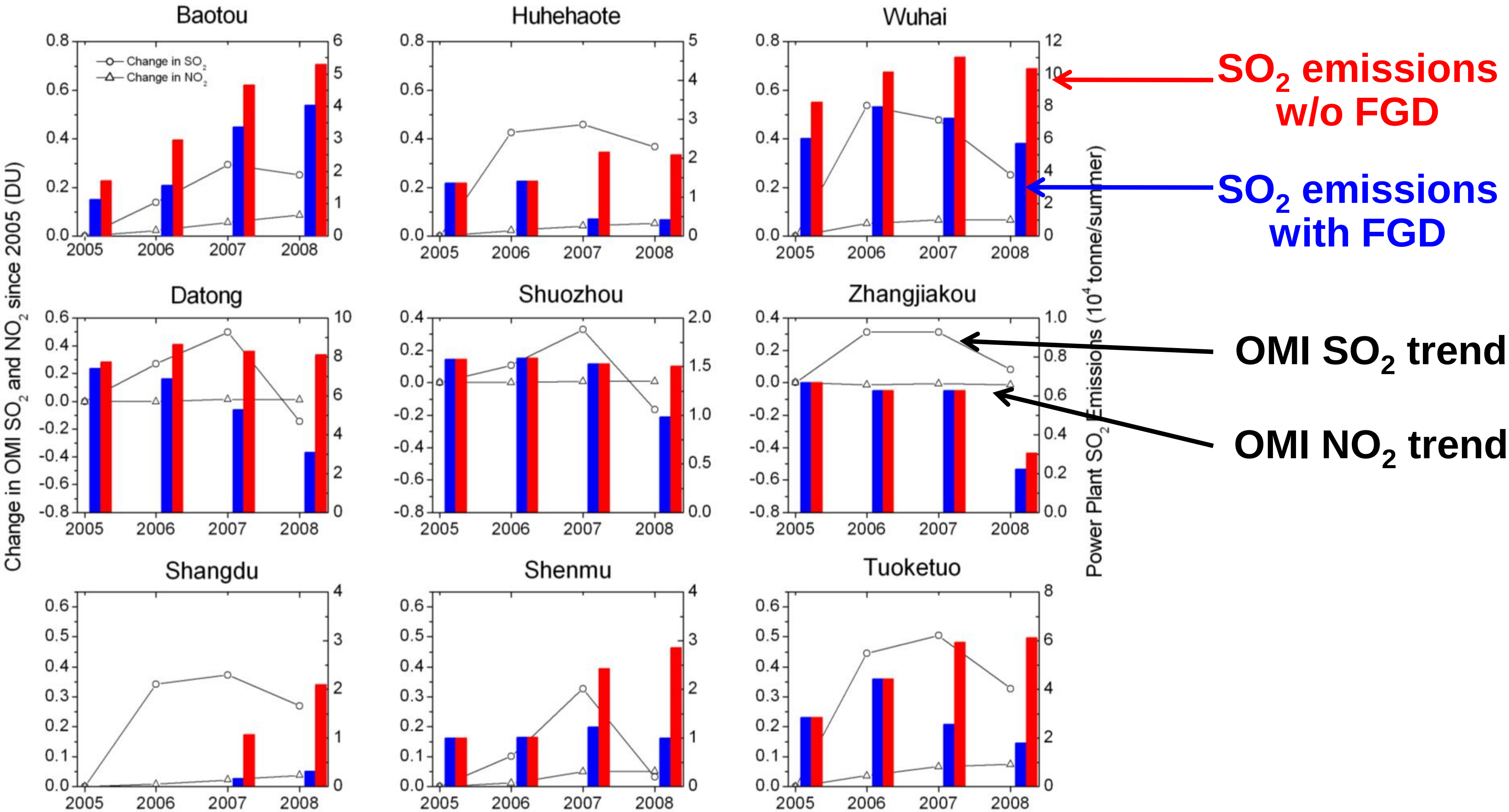


内蒙东部

内蒙中部

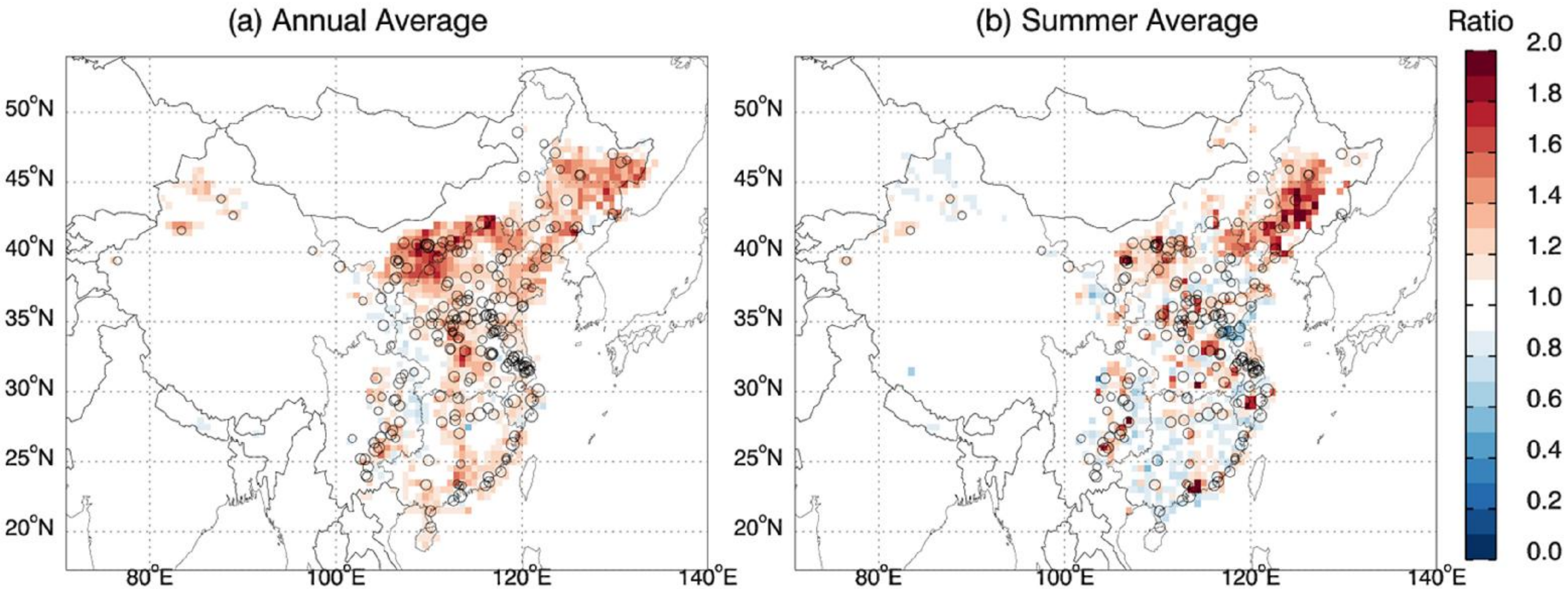
内蒙西部

卫星监测电厂污染控制装置的运行情况



卫星观测中国电厂排放增长

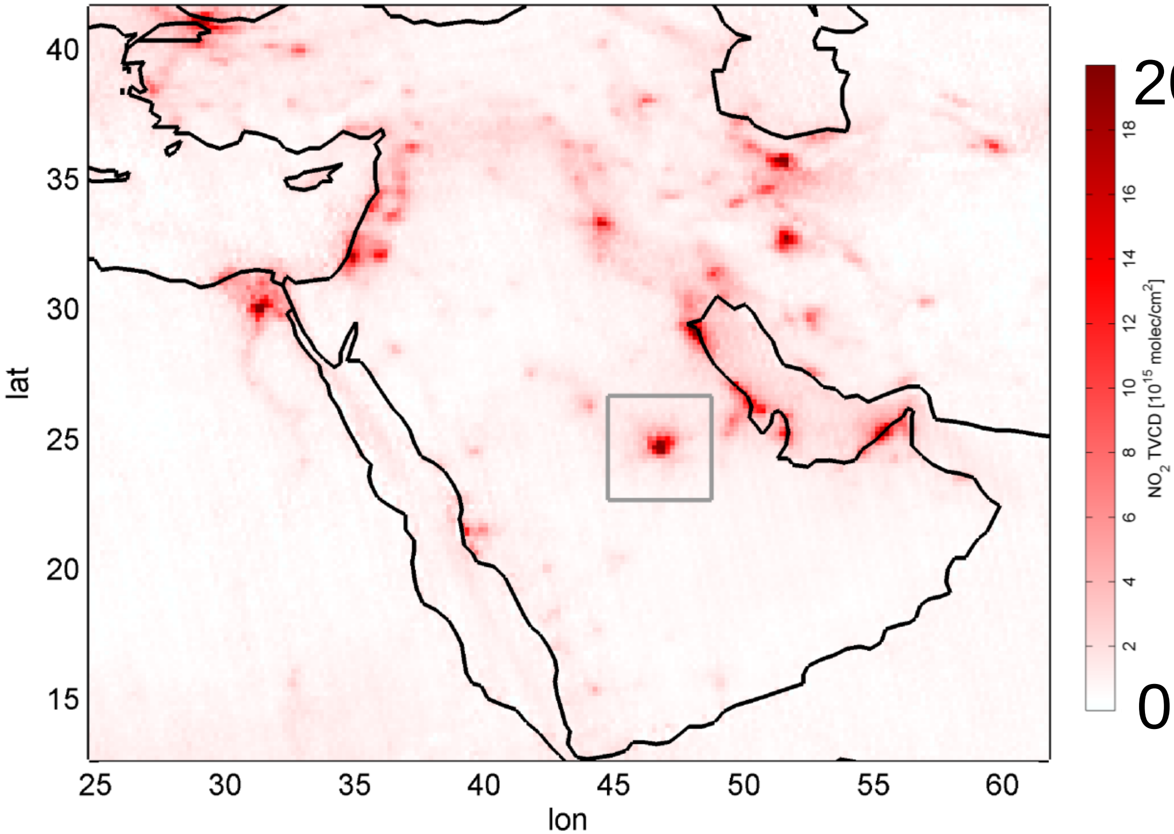
Ratio of OMI NO_2 (2007 to 2005)



- Open circles indicate the locations of the new power plants built in 2005-2007

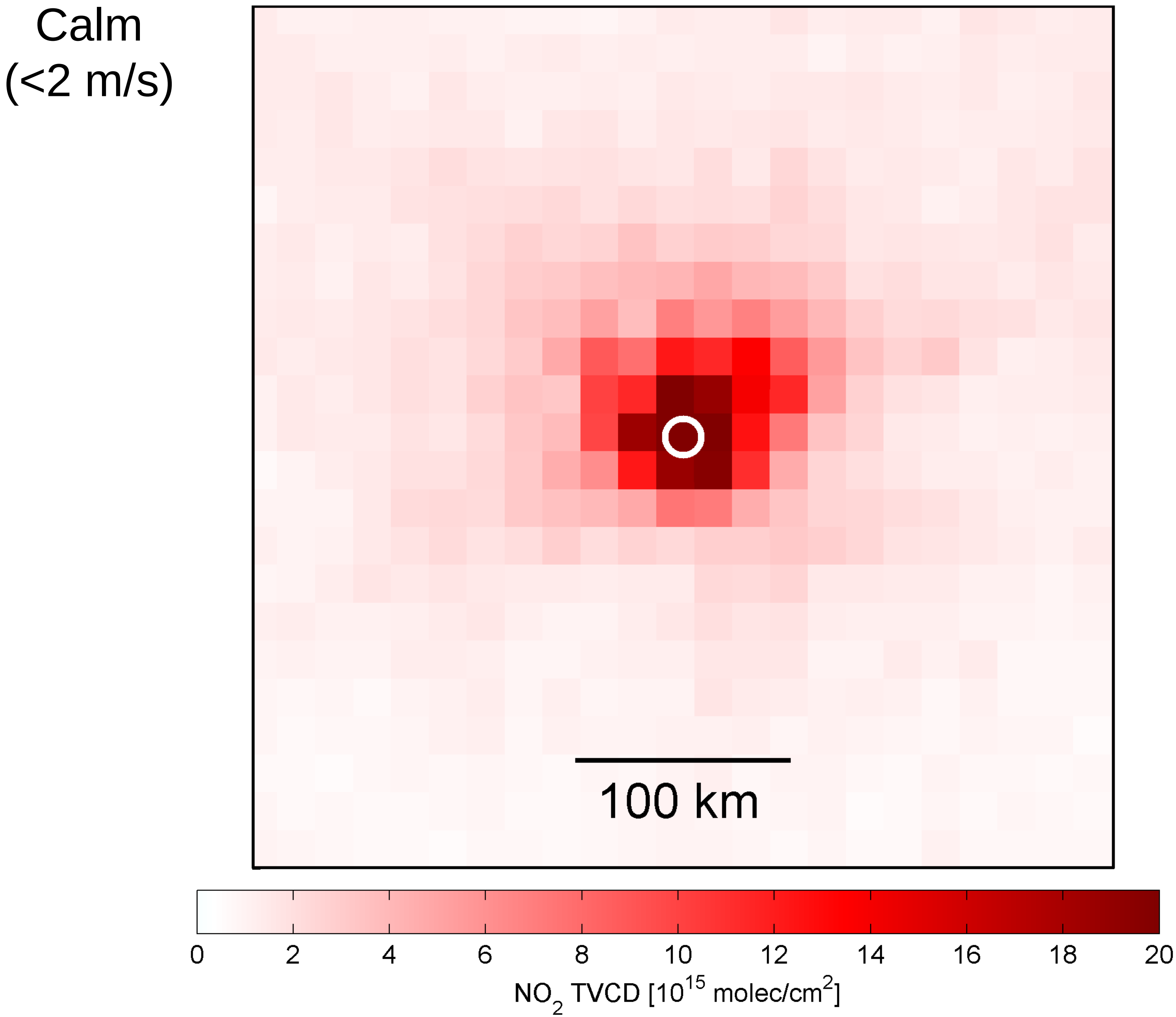
Wang et al., ACP, 2012

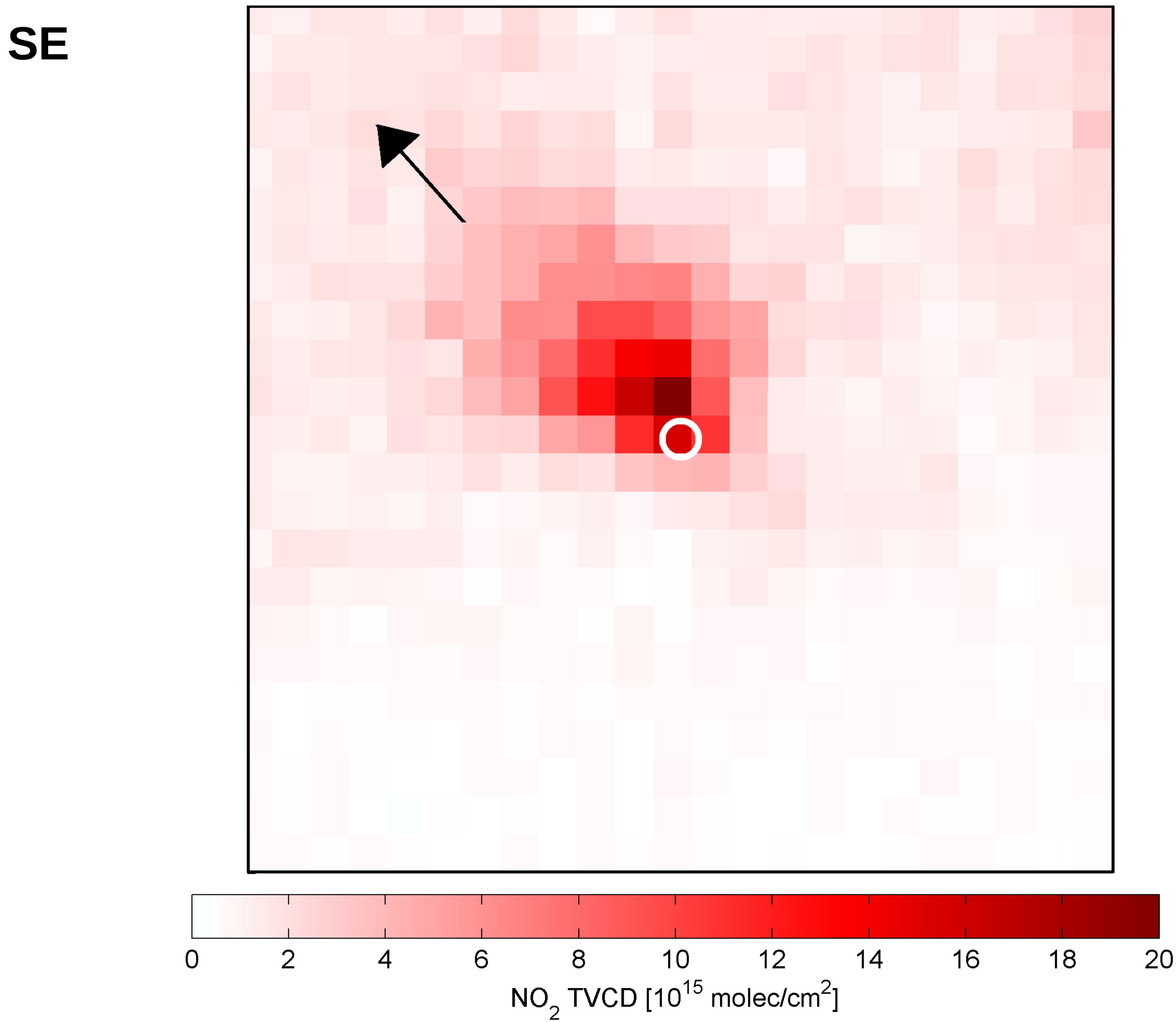
卫星反演大城市氮氧化物排放

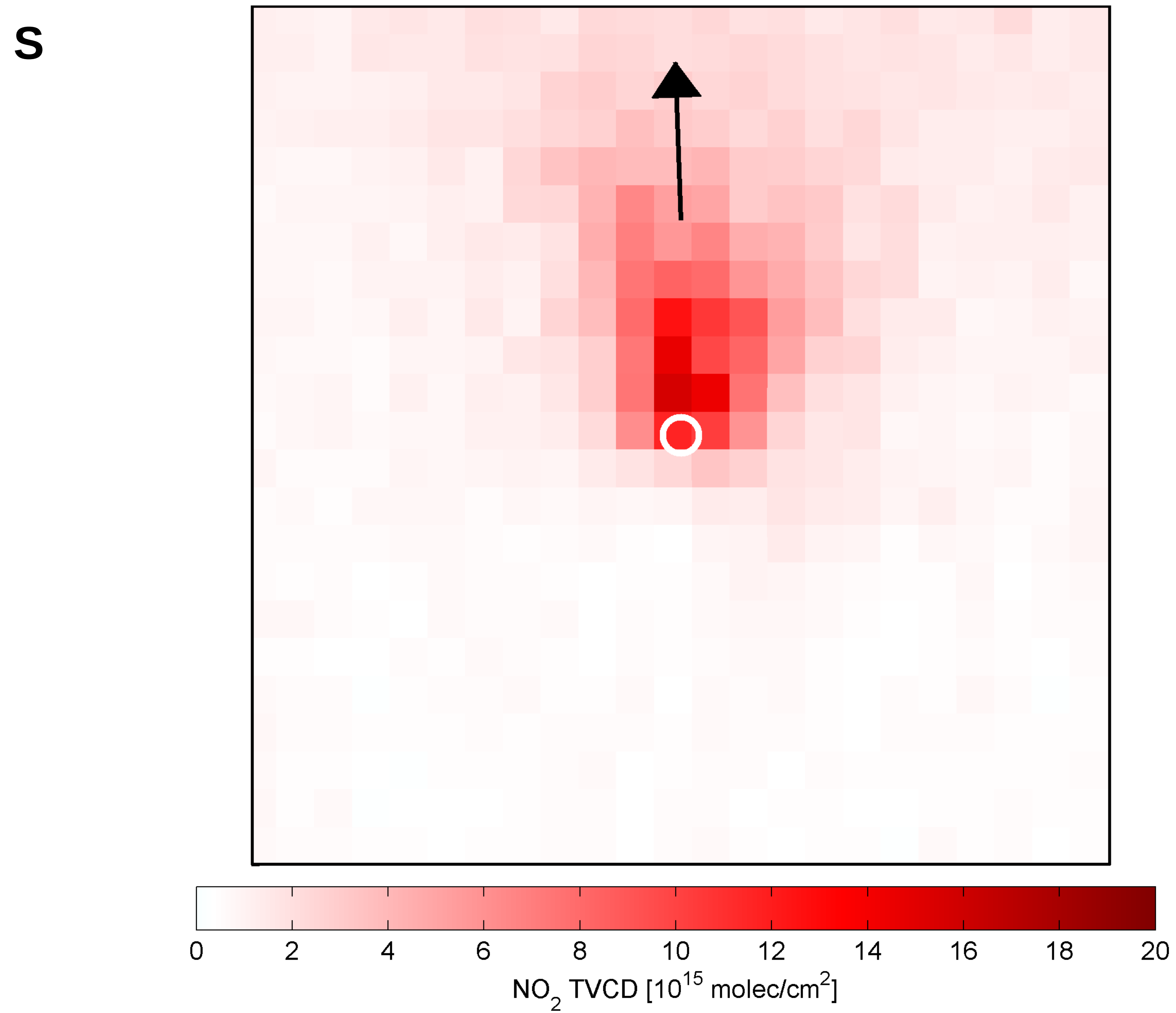


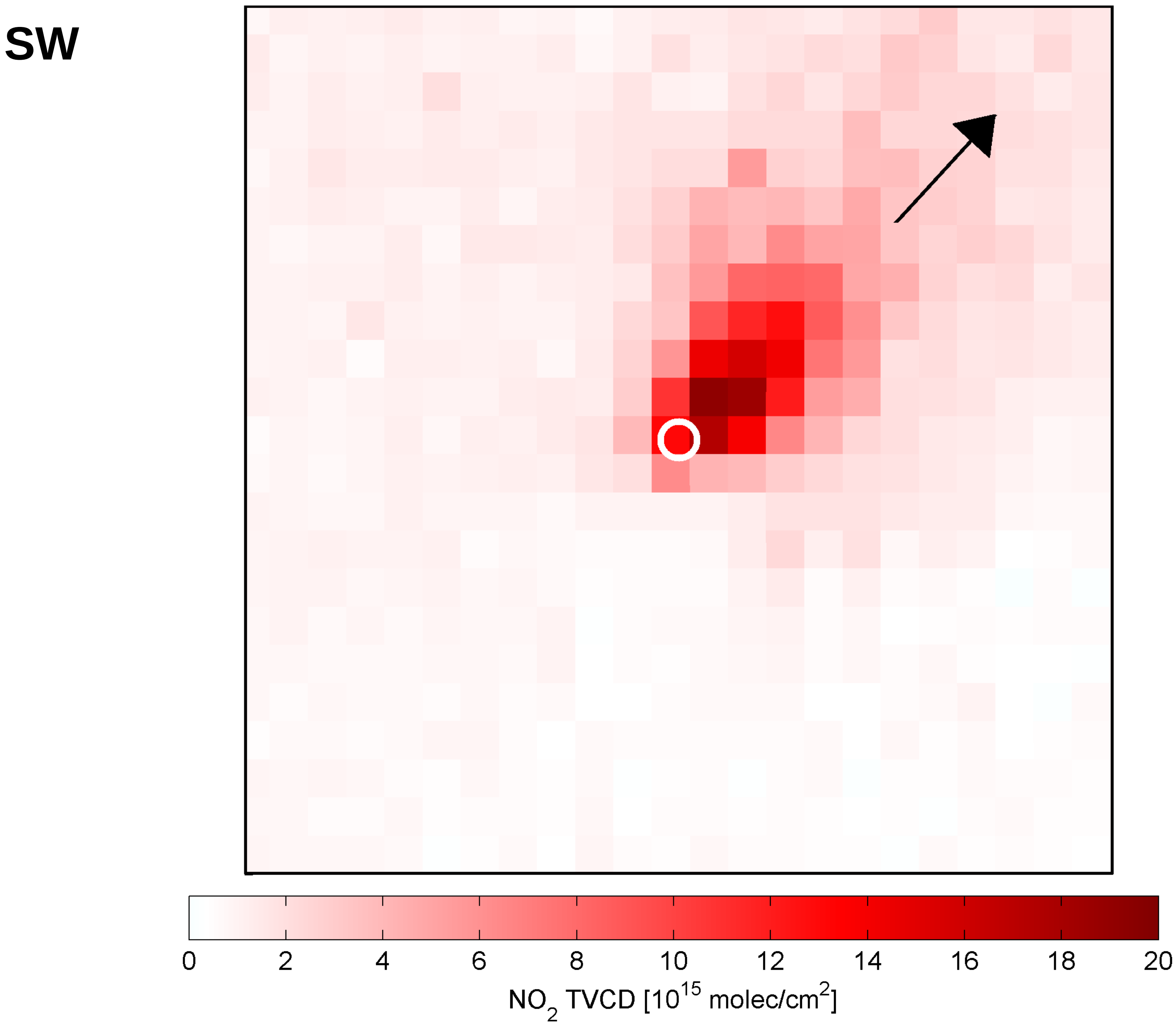
Mean tropospheric NO_2 TVCD in 10^{15} molec/cm^2 (OMI 2005-2009, cloud-free, calm (<2m/s))

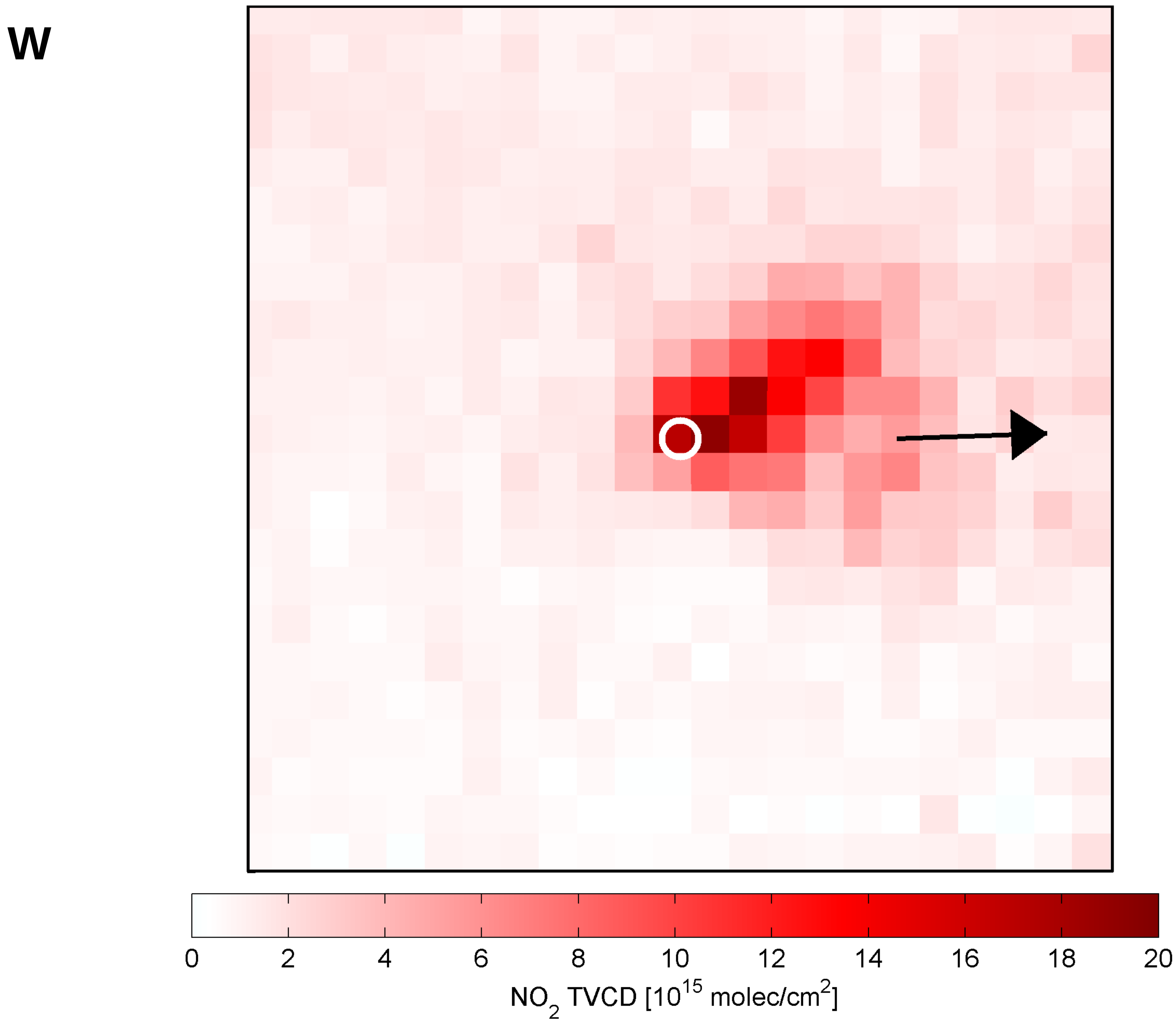
Beirle et al., Science, 2011

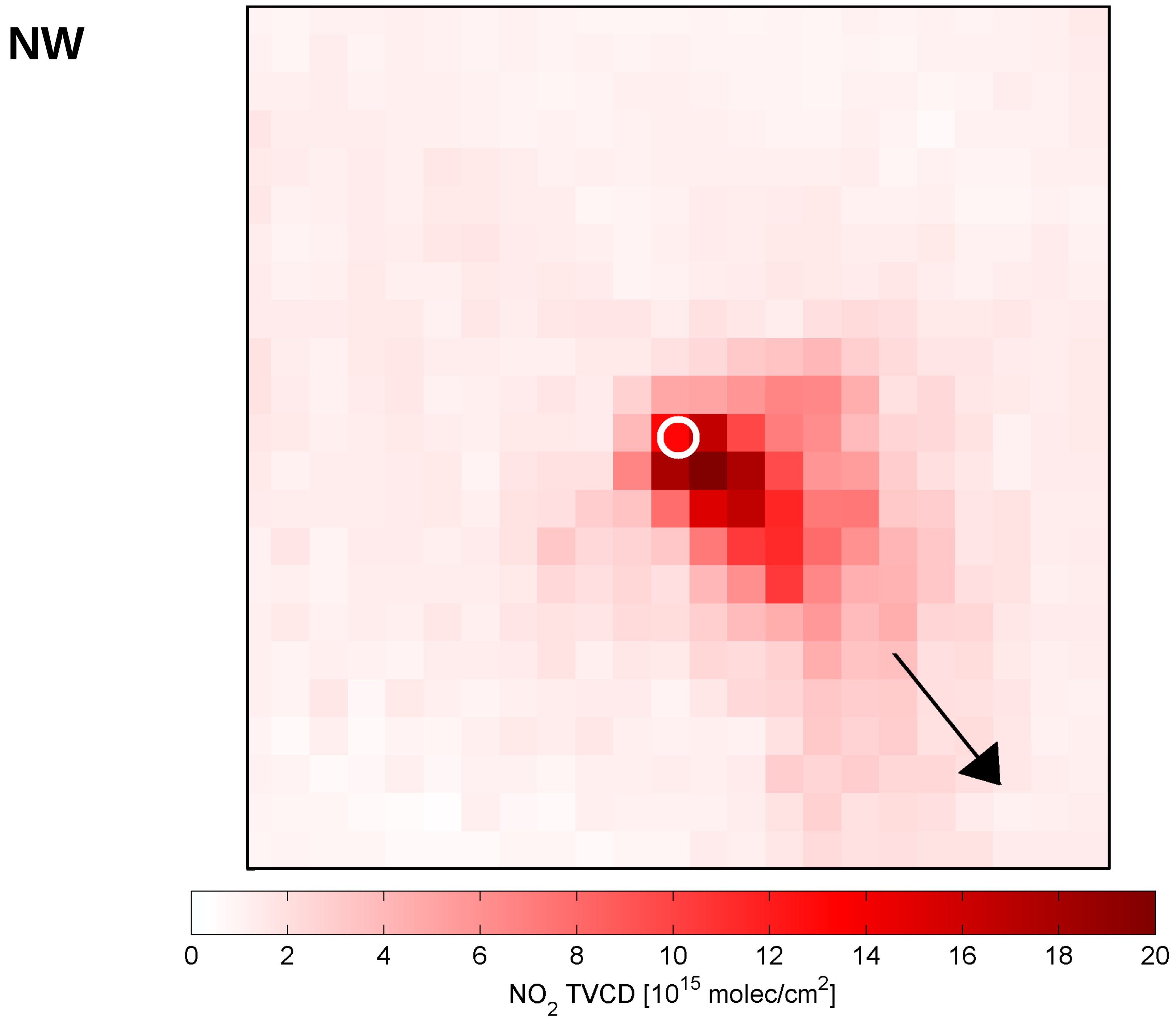

Calm
(<2 m/s)
100 km
0
2
4
6
8
10
12
14
16
18
20
NO$_2$ TVCD [10^{15} molec/cm^2]

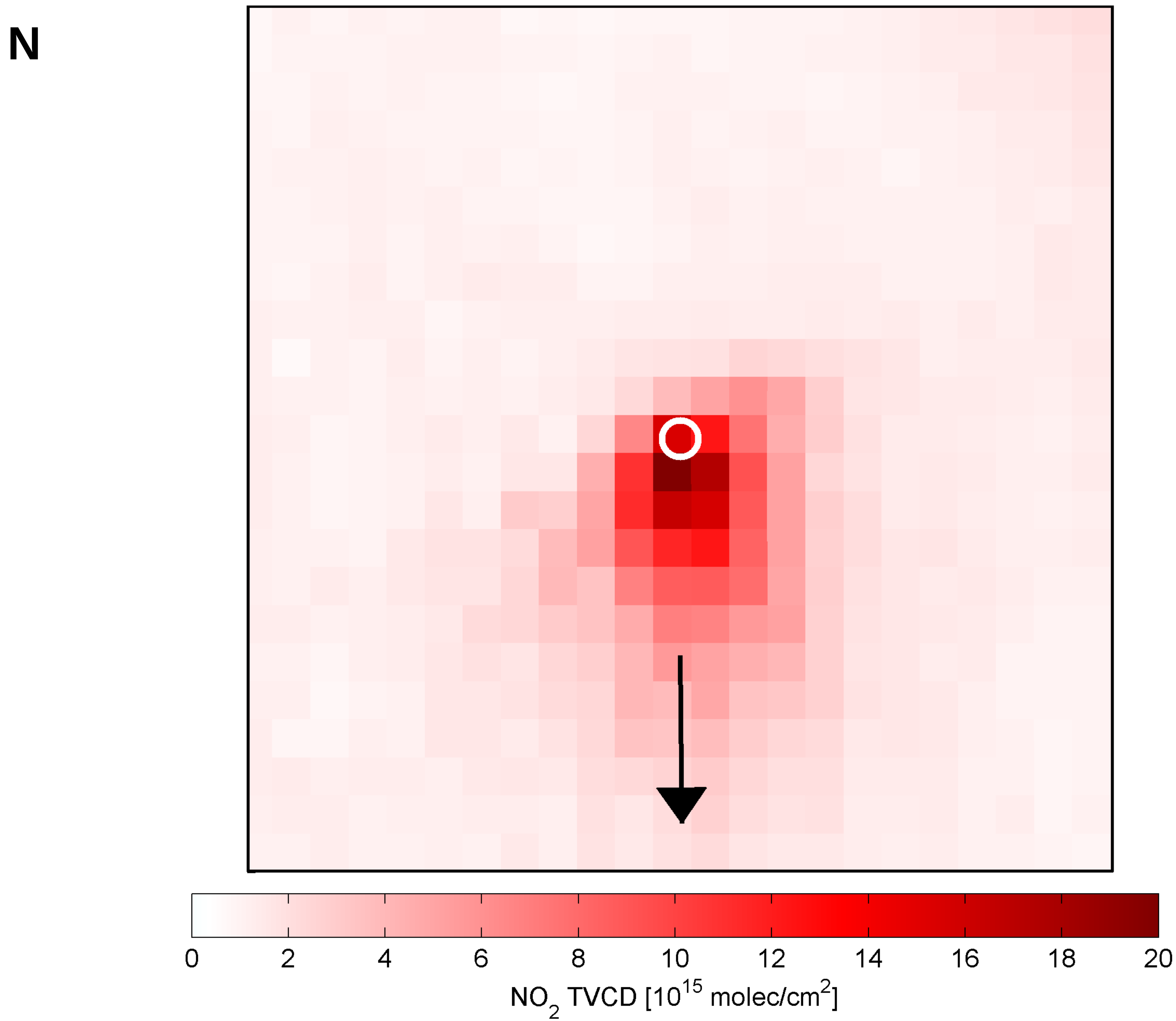

SE
0
2
4
6
8
10
12
14
16
18
20
NO2 TVCD [10^15 molec/cm^2]

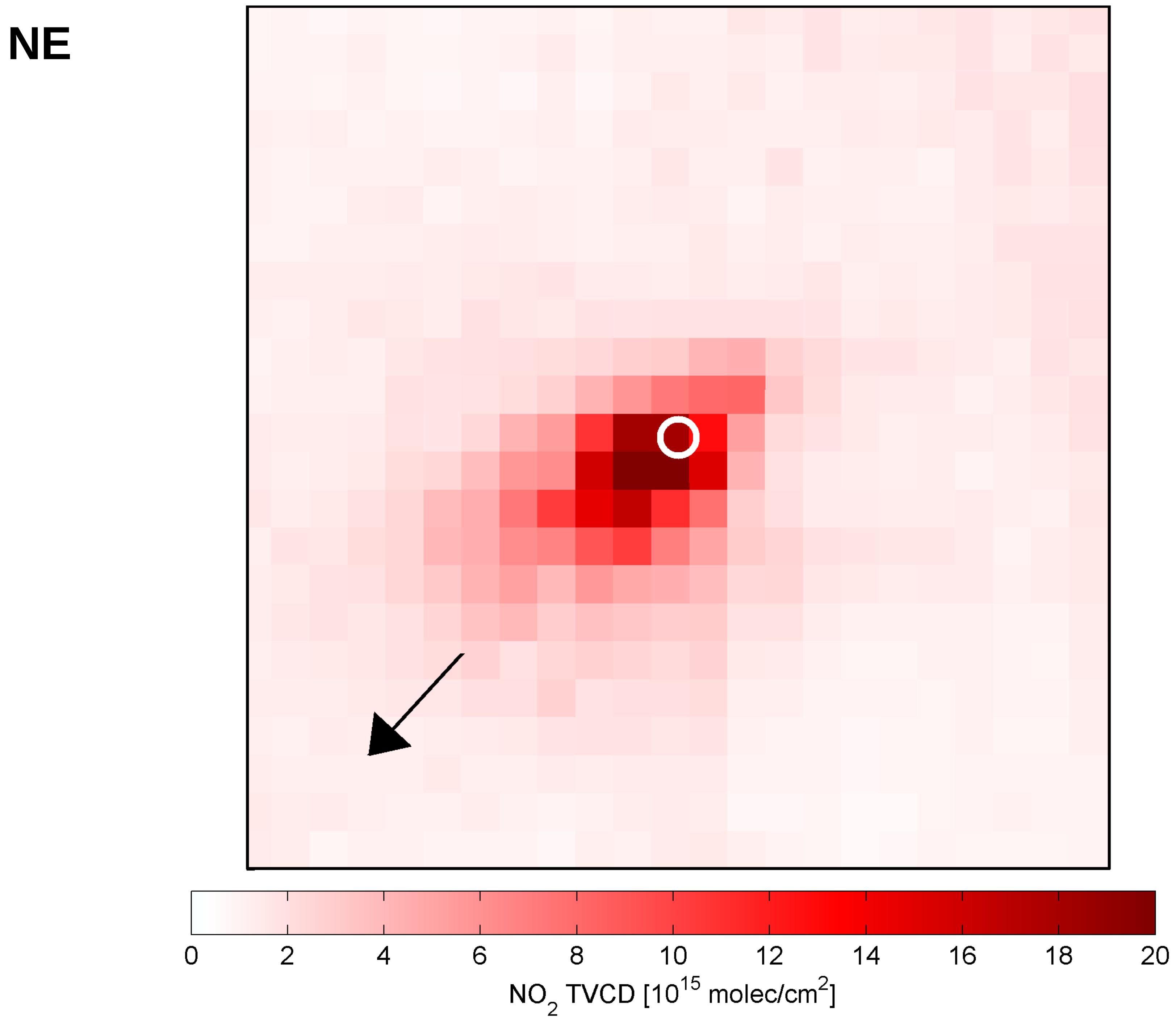

S
0
2
4
6
8
10
12
14
16
18
20
NO2 TVCD [10^15 molec/cm^2]


SW
0 2 4 6 8 10 12 14 16 18 20
NO2 TVCD [10^15 molec/cm^2]

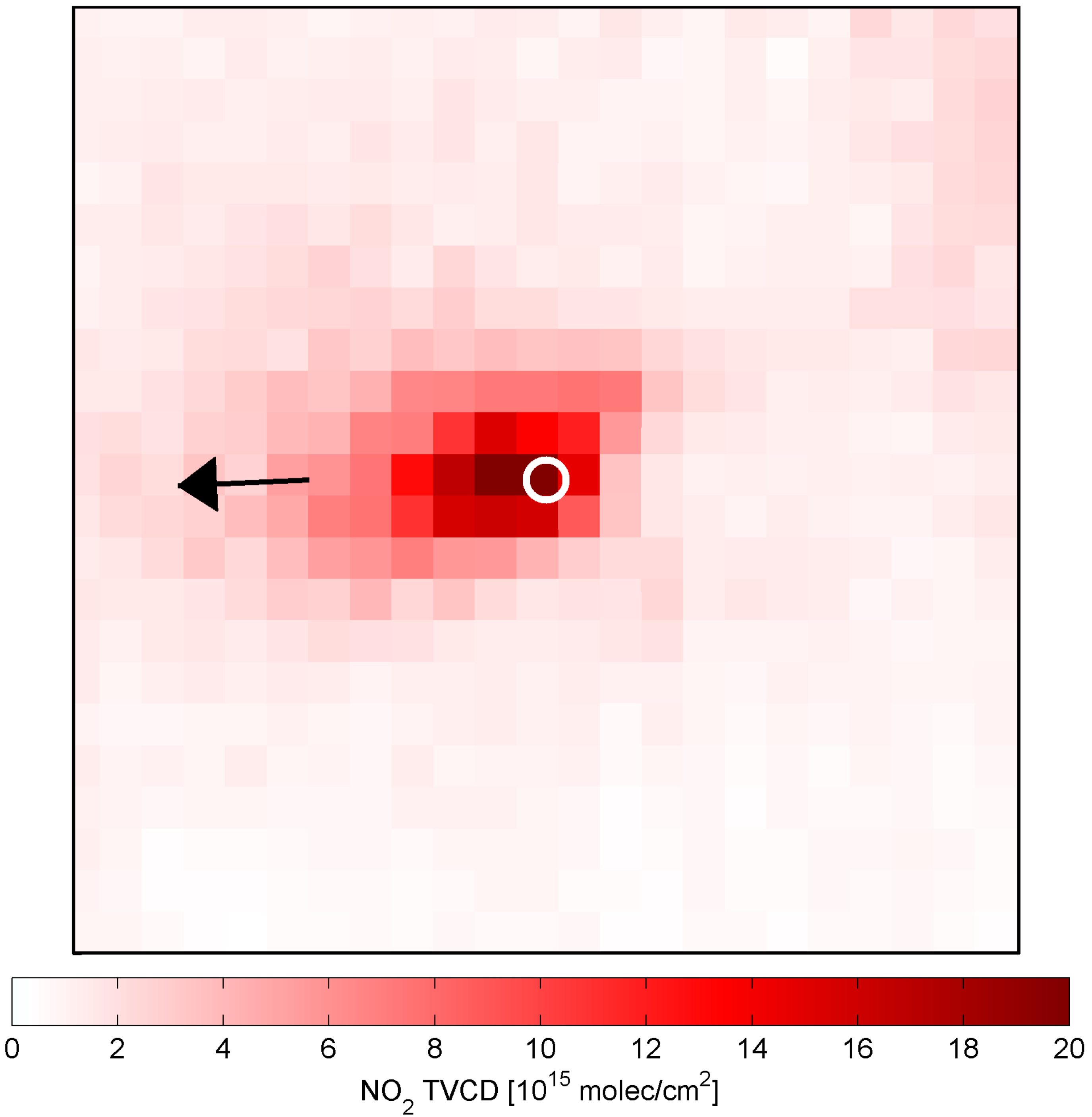

W
0
2
4
6
8
10
12
14
16
18
20
NO2 TVCD [10^15 molec/cm^2]

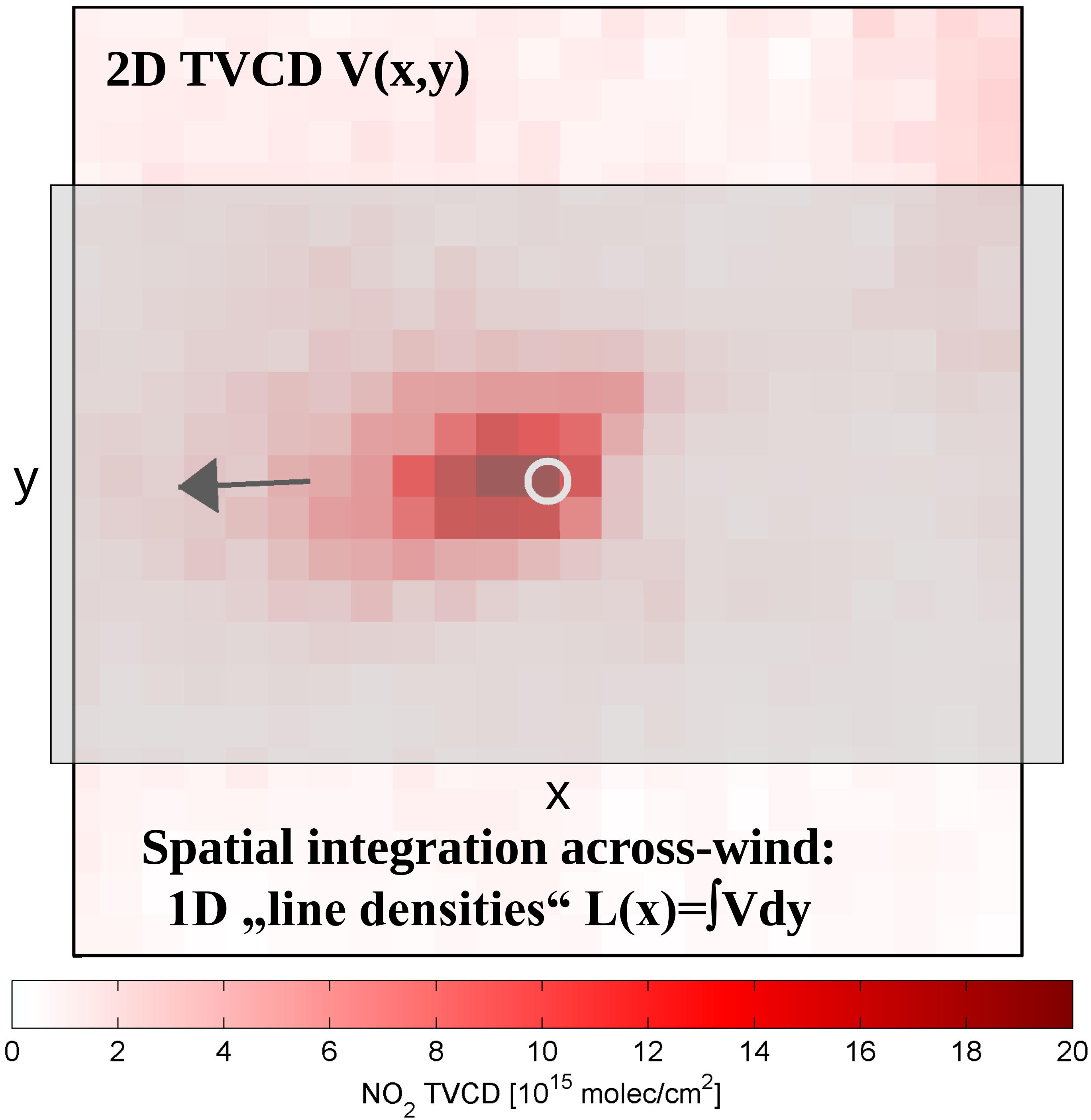

NW
0
2
4
6
8
10
12
14
16
18
20
NO_2 TVCD [10^{15} molec/cm^2]


N
0
2
4
6
8
10
12
14
16
18
20
NO2 TVCD [10^15 molec/cm^2]


NE
0
2
4
6
8
10
12
14
16
18
20
NO2 TVCD [10^15 molec/cm^2]

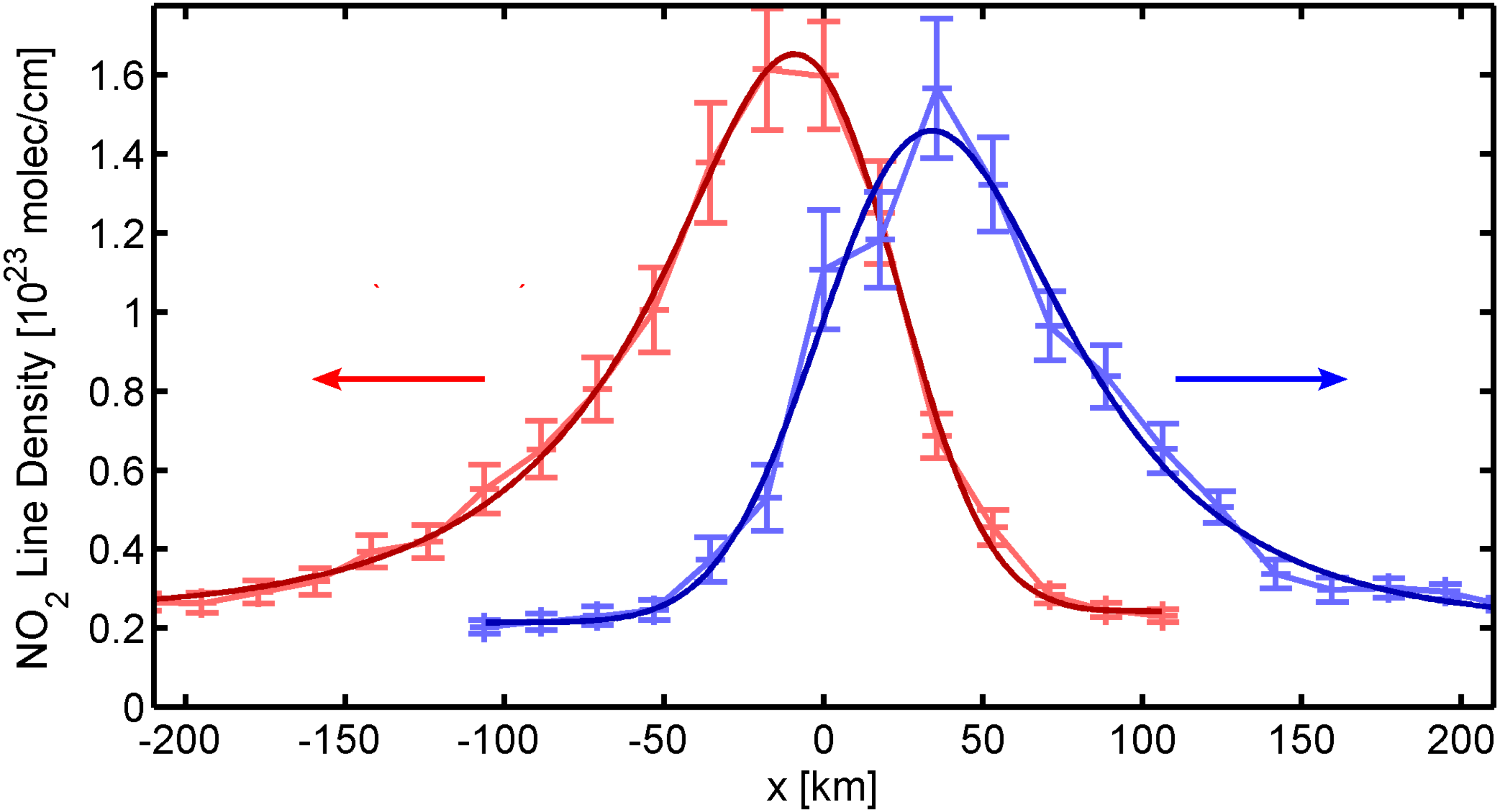
E




2D TVCD V(x,y)
y
x
Spatial integration across-wind:
1D „line densities“ L(x)=∫Vdy
0
2
4
6
8
10
12
14
16
18
20
NO2 TVCD [10^15 molec/cm^2]

Line densities

- **Fit model function smoothed**

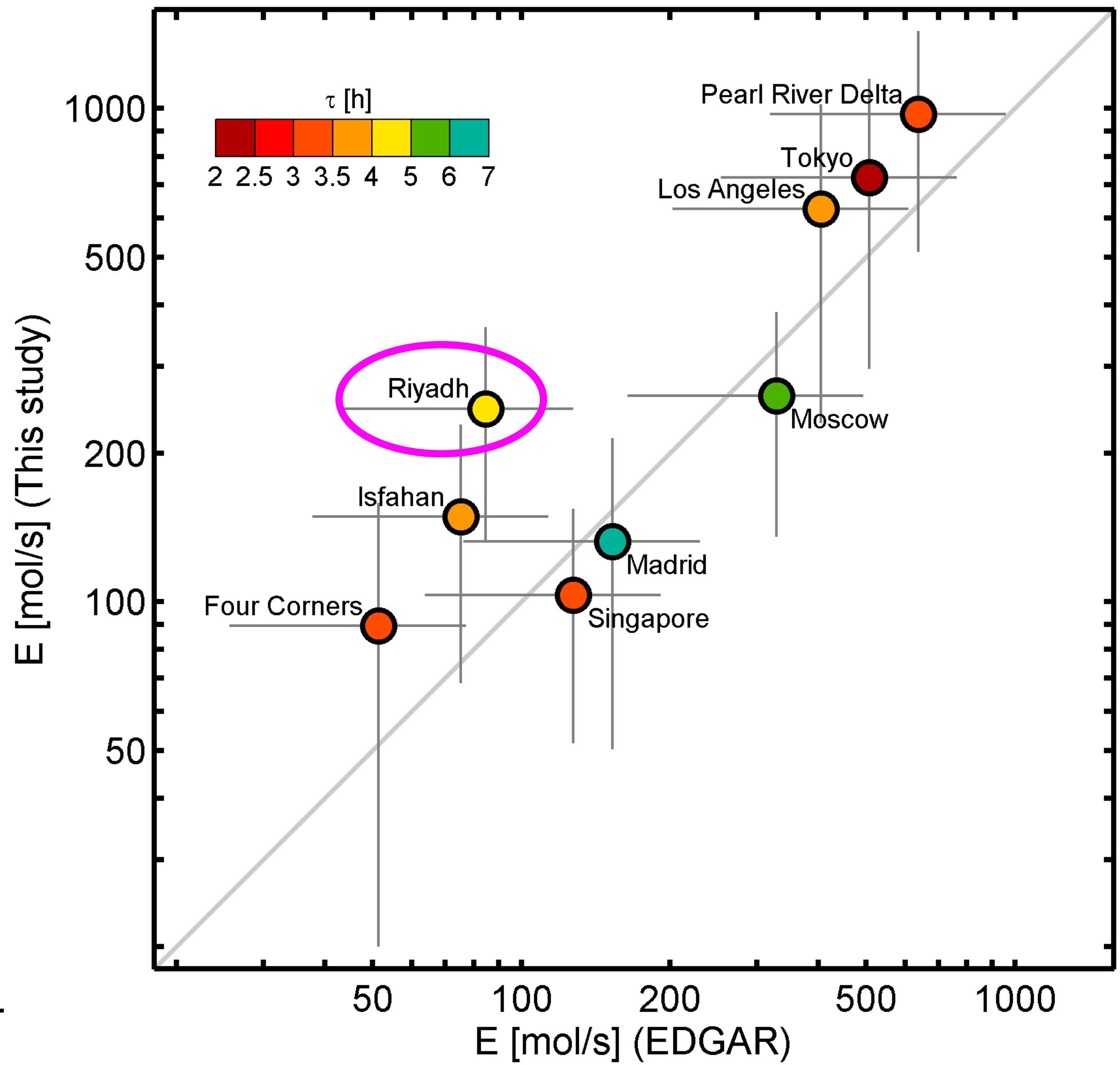


Light colours: Observed mean line densities for easterly (red) and westerly (blue) winds.
Dark colours: Respective fitted model functions

卫星反演大城市氮氧化物排放

Comparison to EDGAR (V4.1) for 2005

(integrated over 250×250 km²)



Beirle et al., Science, 2011

大气污染物及温室气体全球排放量

全球二氧化硫排放量

Table 1. Annual Global Sulfur Emissions in the GEOS-Chem Model for the year 2006

Source	Emission Rate, Tg S yr^{-1}
Fossil fuel on land	51.55
Ships[a]	4.72
Biomass burning	1.22
Biofuel burning	0.12
Aircraft	0.07
Volcano	6.55
Dimethyl sulfide (DMS)	21.05

[a]1.7 Tg are in coastal regions and 3.0 Tg in open ocean.

Lee et al., JGR, 2010

全球氮氧化物排放量

Table 1. A Priori Annual Global GEOS-Chem NO_x Emissions

Source	Emissions, Tg N
Fossil fuel combustion[a]	23.3 (11.5)[b]
Lightning	7.1 (4.2)
Biomass burning	6.0 (3.7)
Soils	7.1 (3.5)
Biofuels	2.2 (1.1)
Aircraft	0.5 (0.26)
Stratosphere	0.1[c] (0.05)

[a]Fossil fuel emissions are based on GEIA and scaled to 1998.
[b]Values for May–October are given in parentheses.
[c]The cross-tropopause NO_y flux is 0.5 Tg N yr^{-1} (including 0.1 Tg N yr^{-1} as NO_x and 0.4 Tg N yr^{-1} as HNO_3).

Martin et al., JGR, 2006

全球一氧化碳排放量

Region	Best prior estimates[2]				Inverse model results[3]
	Fossil fuel	Biofuel	Biomass burning	Total	Total
US[4]	35.2	2.5	2.6	40.2	49.5
Alaska and Canada[5]	1.4	0.4	15.4	17.2	21.4
Europe[6]	60.4	15.2	2.5	78.1	94.7
E Asia[7]	136	67.1	12.8	216	354
SE Asia[8]	43.6	45.7	83.4	173	306
S. America	15.8	16.6	86.6	119	183
Africa[9] (NH)	27.4	21.4	74.9	124	175
Africa[9] (SH)	6.48	10.1	74.0	90.3	168
Australia	4.1	1.3	17.2	22.6	40.5
Global	319	160	379	858	1350

Kopacz et al., ACP, 2010

全球汞排放量

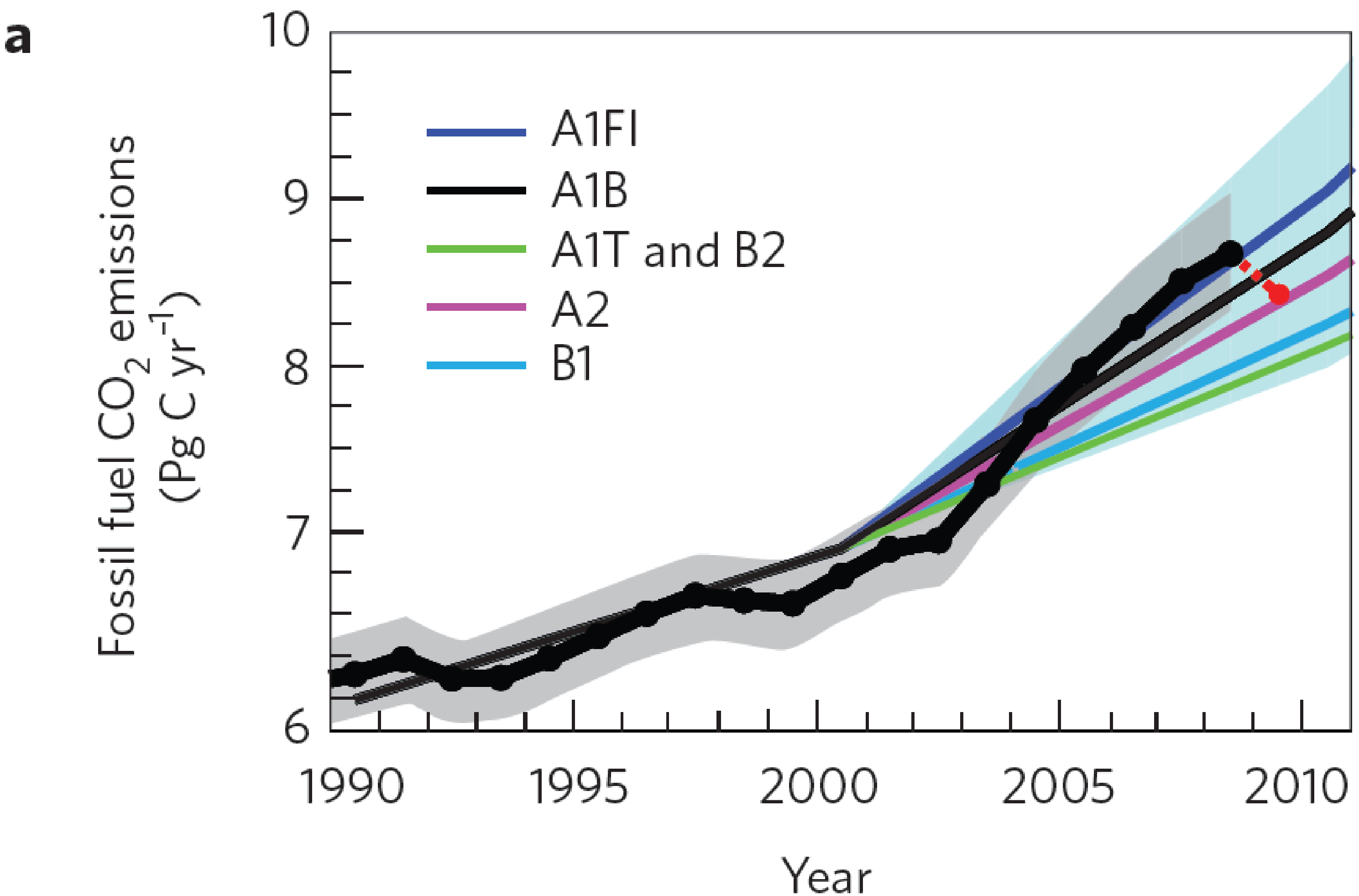
Table 1. Global mercury emissions by natural sources estimated for 2008.

Source	Mercury ($Mg\,yr^{-1}$)	Contribution (%)
Oceans	2682	52
Lakes	96	2
Forests	342	7
Tundra/Grassland/Savannah/ Prairie/Chaparral	448	9
Desert/Metalliferous/Non-vegetated Zones	546	10
Agricultural areas	128	2
Evasion after mercury depletion events	200	4
Biomass burning	675	13
Volcanoes and geothermal areas	90	2
TOTAL	5207	100

2008年全球人为源汞排放量: 2320吨

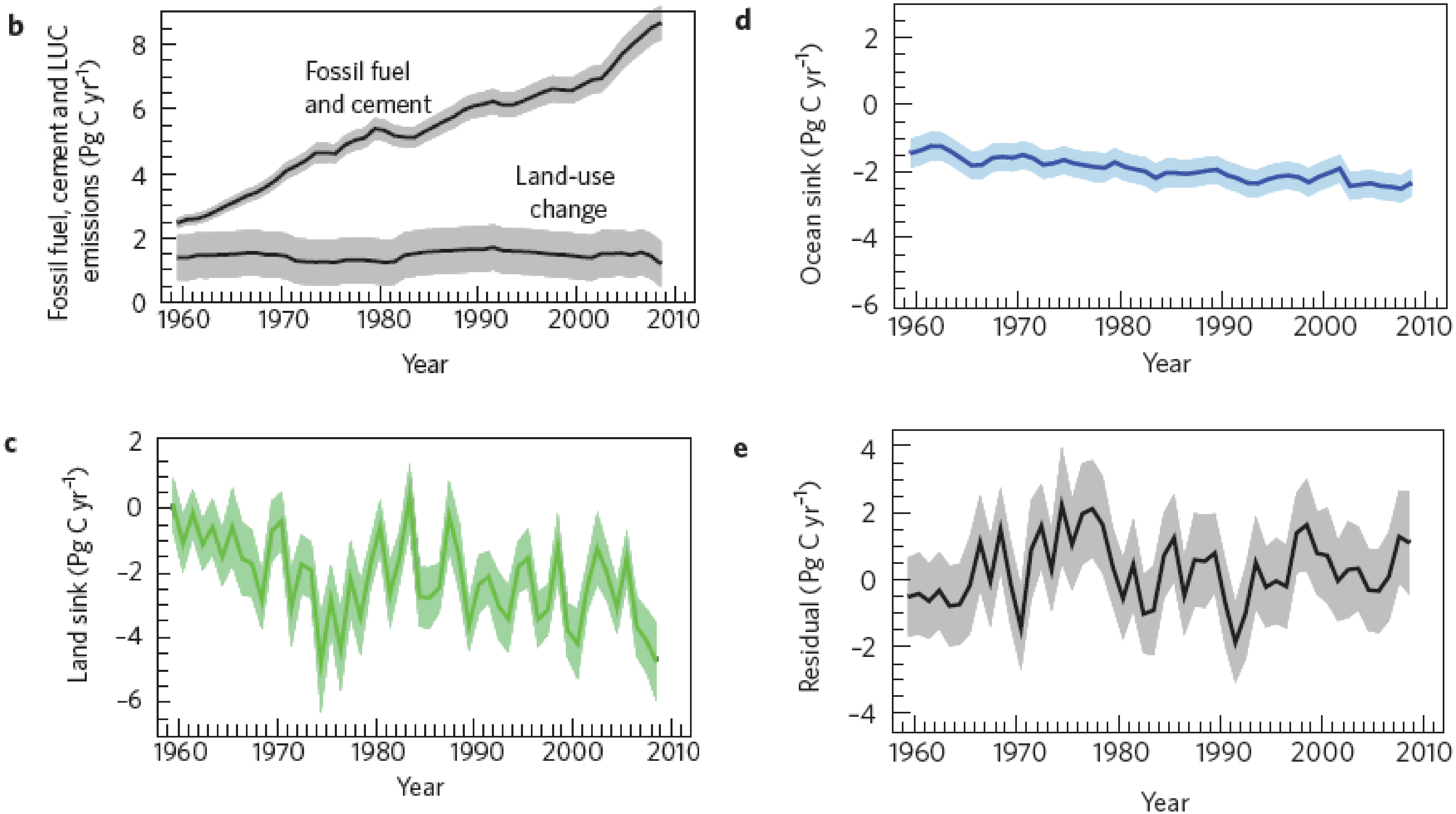
Pirrone et al., ACP, 2010

全球二氧化碳排放量



Le Quere et al., Nature Geo. Sci., 2009

全球二氧化碳源汇变化



Le Quere et al., Nature Geo. Sci., 2009

全球甲烷排放量

Table 1. Comparison of Methane Budget from this Study (in Tg/yr) with Previous Studies

Study	**This Study** A Priori		A Posteriori Best Guess	**EPA [2001; 2002]**	**Fung et al. [1991] (Scenario 7)**	**Hein et al. [1997] (Scenario 1)**	**Houweling et al.[1999]**
Budget Year(s)	Various		1994	1995	1980s	1983-1989	1993-1995
Total Source	590		506	--	500	575	505
Natural Sources	285		201	--	140	232	
Wetlands	260	a	176	--	115	232	
Bogs and Tundra	65		27	--	35	44	
Swamps	195		149	--	80	188	
Termites	20	b	20	--	20	--	
Hydrates	5	c	4	--	5	--	
Anthropogenic Sources	306		306	254	350	343	
Oil and Natural Gas	54	d	47	42	40	70	
Coal	33	d	30	25	35	33	
Landfills and Waste Water	55	d	49	55	40	40	
Animals	94	d	83	89	80	90	
Rice Paddies	39	d	57	30	100	69	
Biomass Burning (incl. Biofuel)	31	e	41	10	55	41	

Wang et al., JGR, 2003

未来的大气排放及其影响

中国发展电动车的未来碳排放

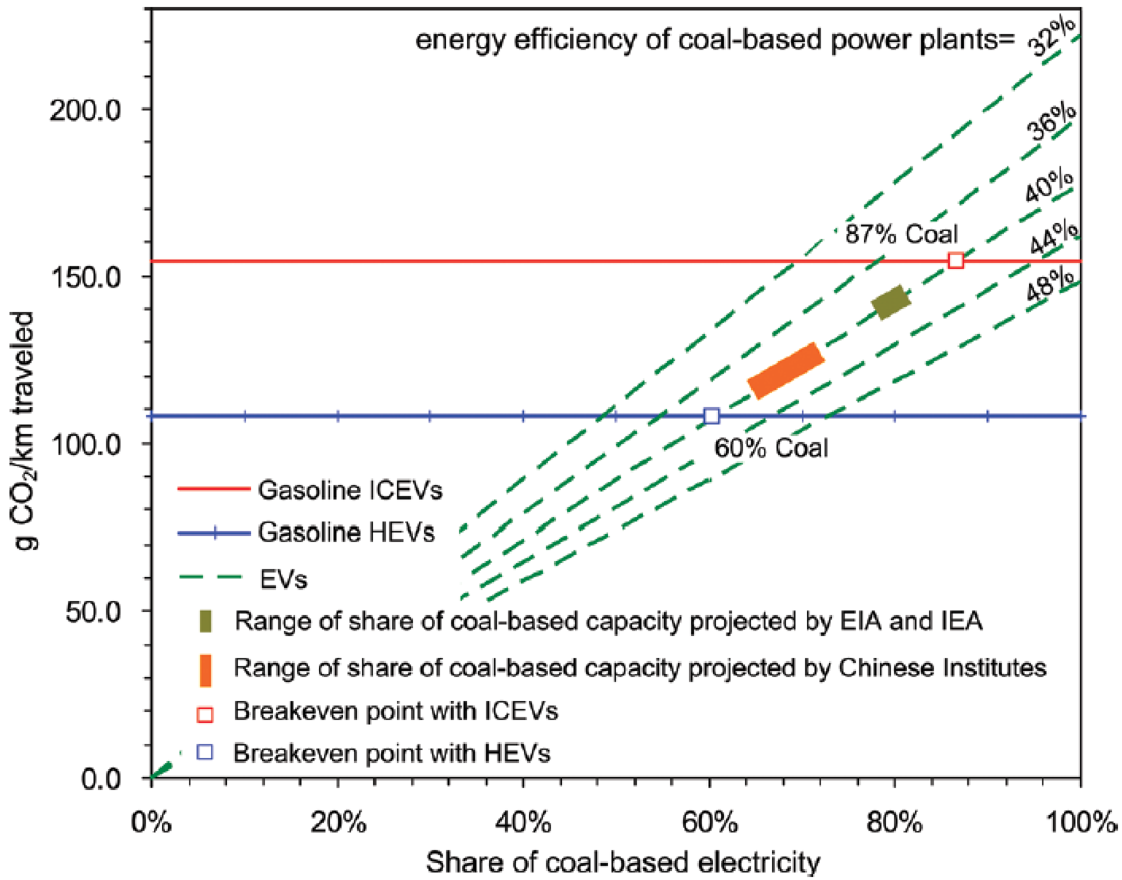
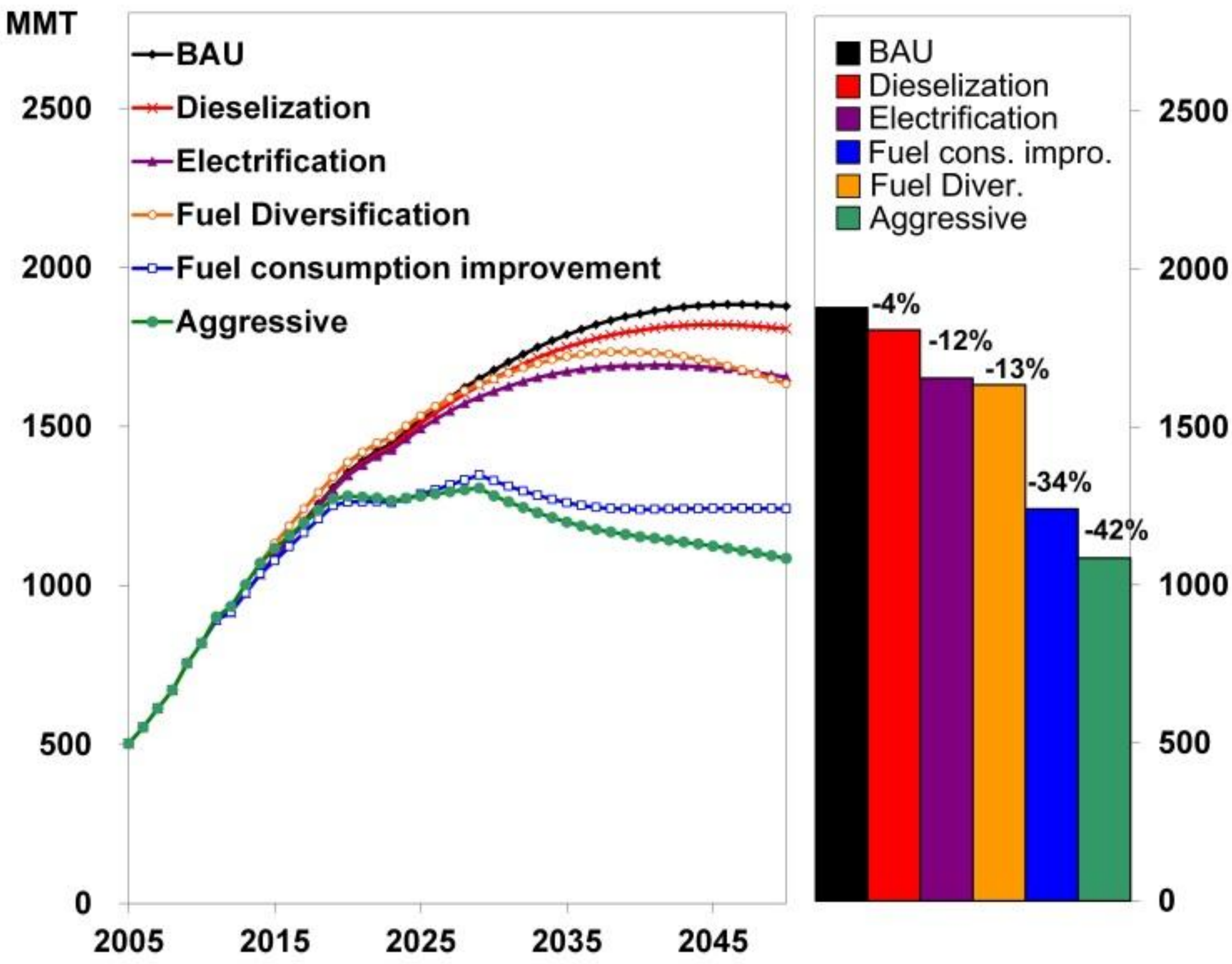
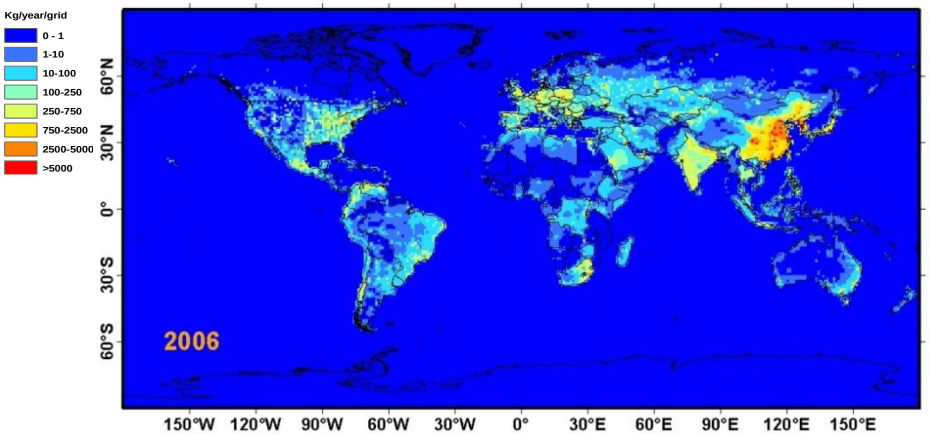


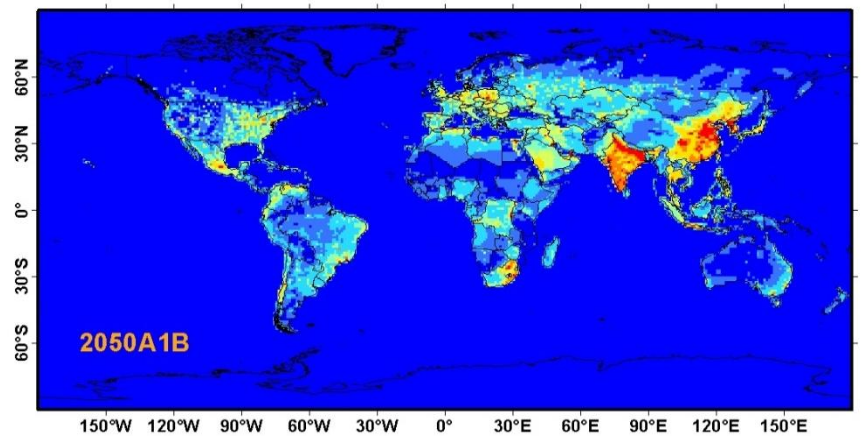
FIGURE 3. Future fuel-cycle CO_2 emissions of EVs as a function of the fraction of coal-based electricity.

中国未来交通系统的碳排放情景



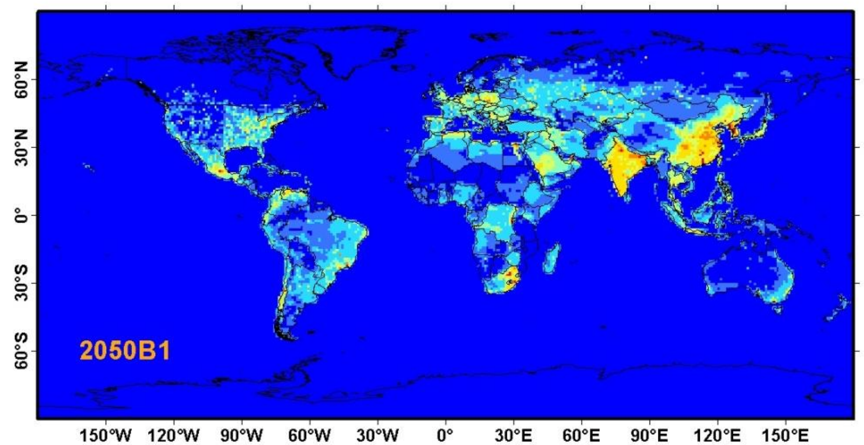
2050年全球汞排放量预测





汞一旦从地壳中释放，将在水-大气-土壤圈中长期循环

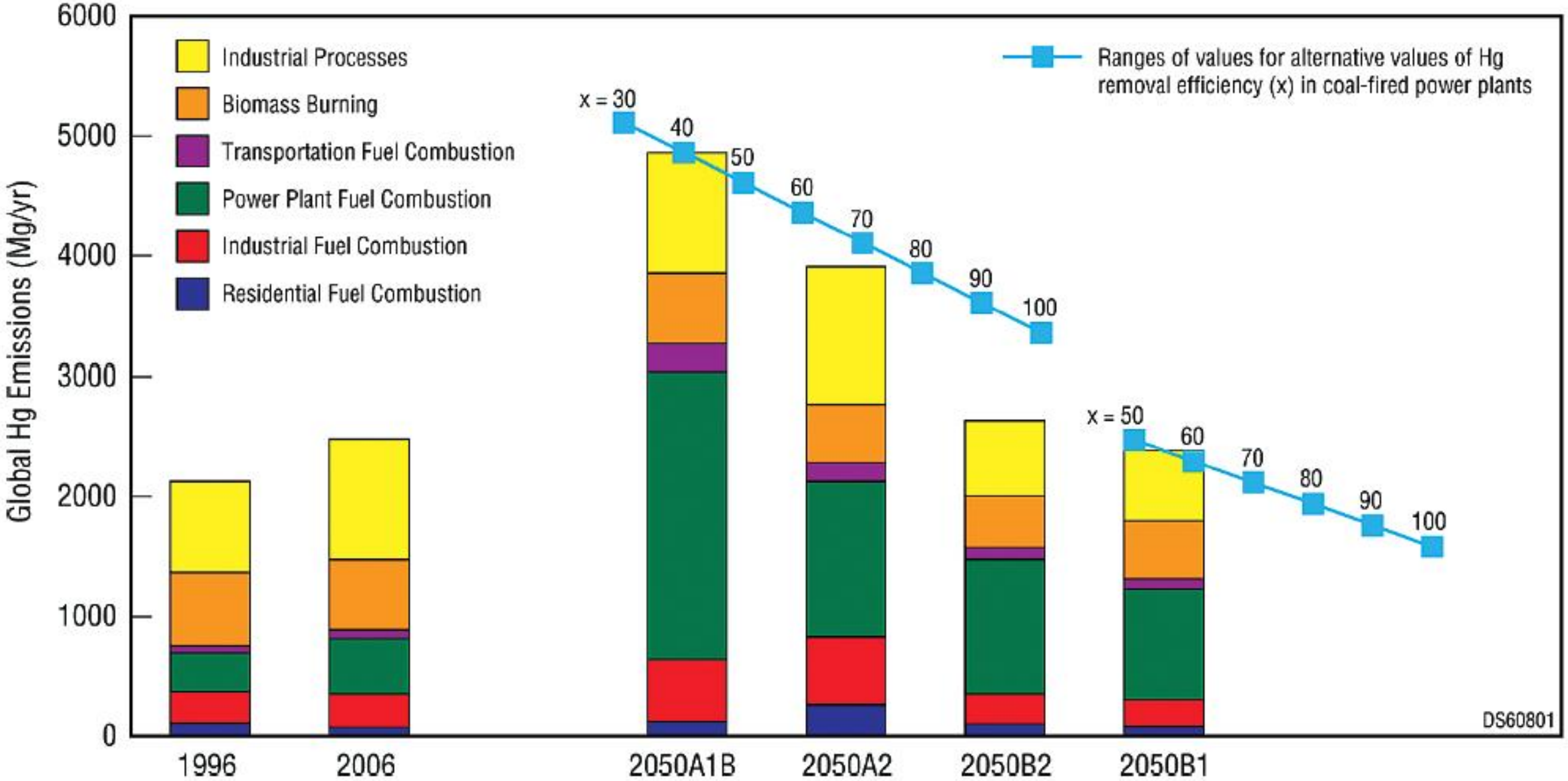
建立了基于技术的，包括152类排放源的列表模型，计算了IPCC 4种情景下的2050年全球汞排放量



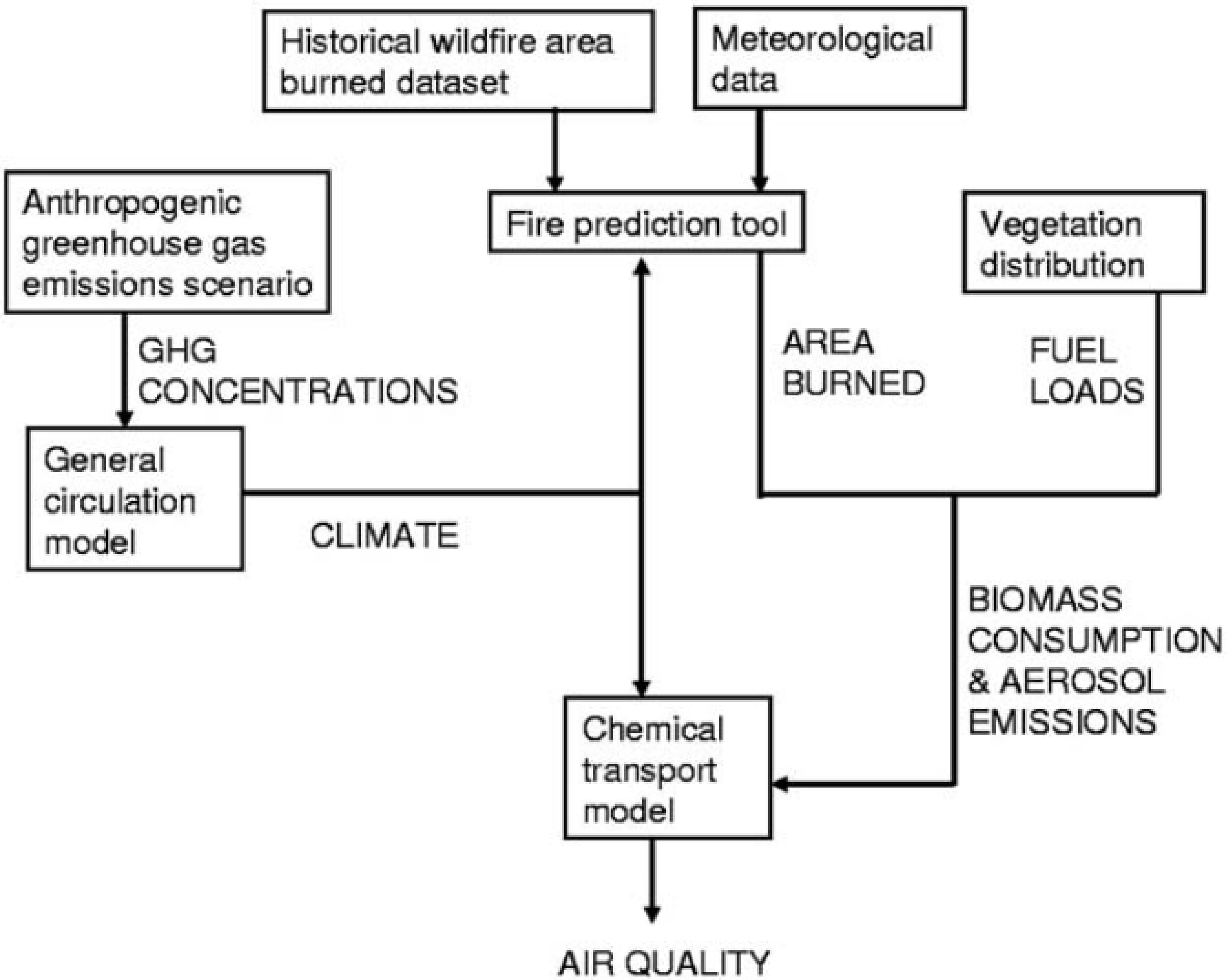
结论：未来全球汞排放将持续增长，增长幅度最高可达94%

A1B:全球化，高增长；**A2**：不均匀发展；**B1:** 高增长，高能效；**B2:** 地区均衡发展

燃煤电厂是削减未来全球汞排放的关键

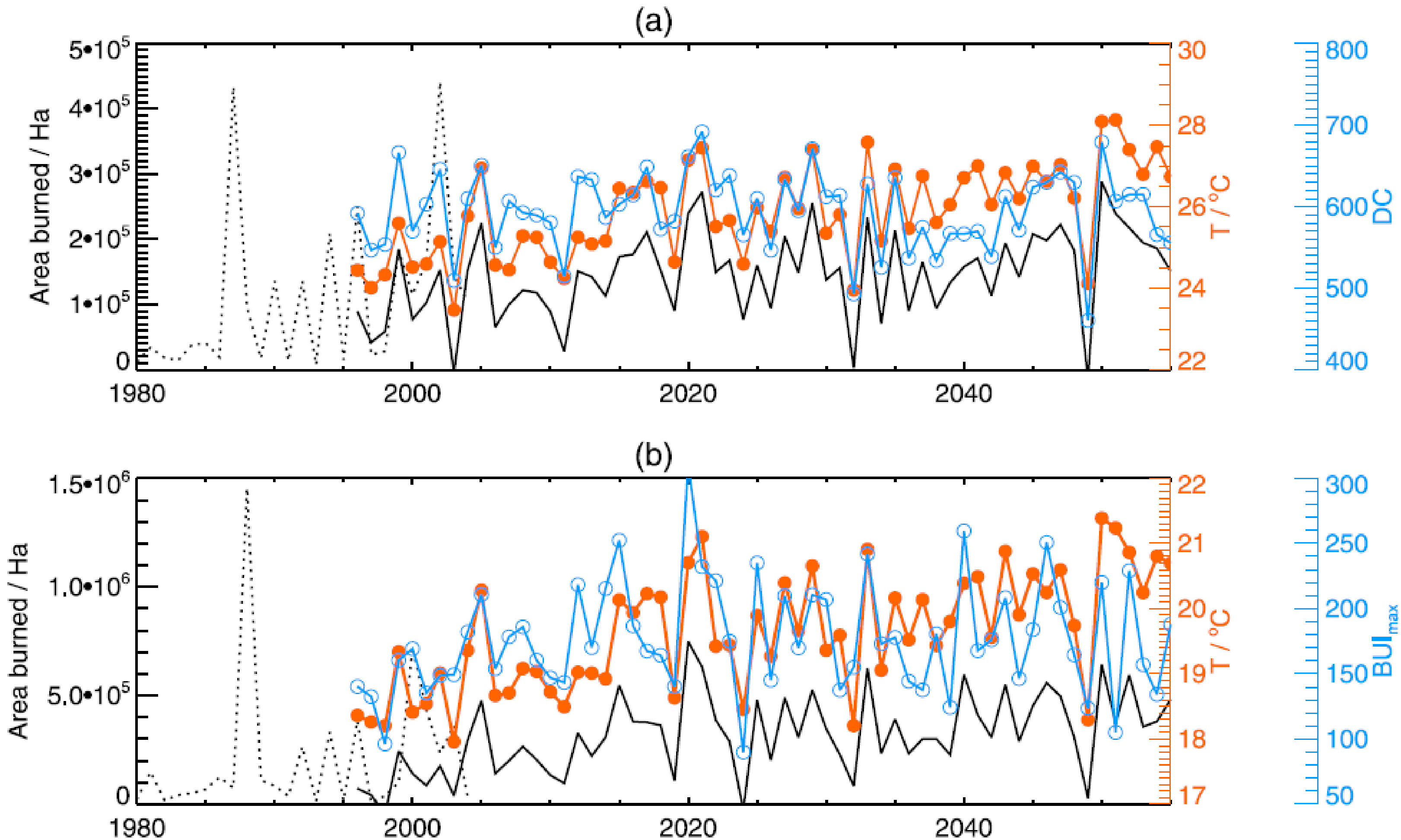


未来生物质燃烧排放变化



Spracklen et al., JGR, 2009

在气候变化背景下，未来生物质燃烧量将会增加



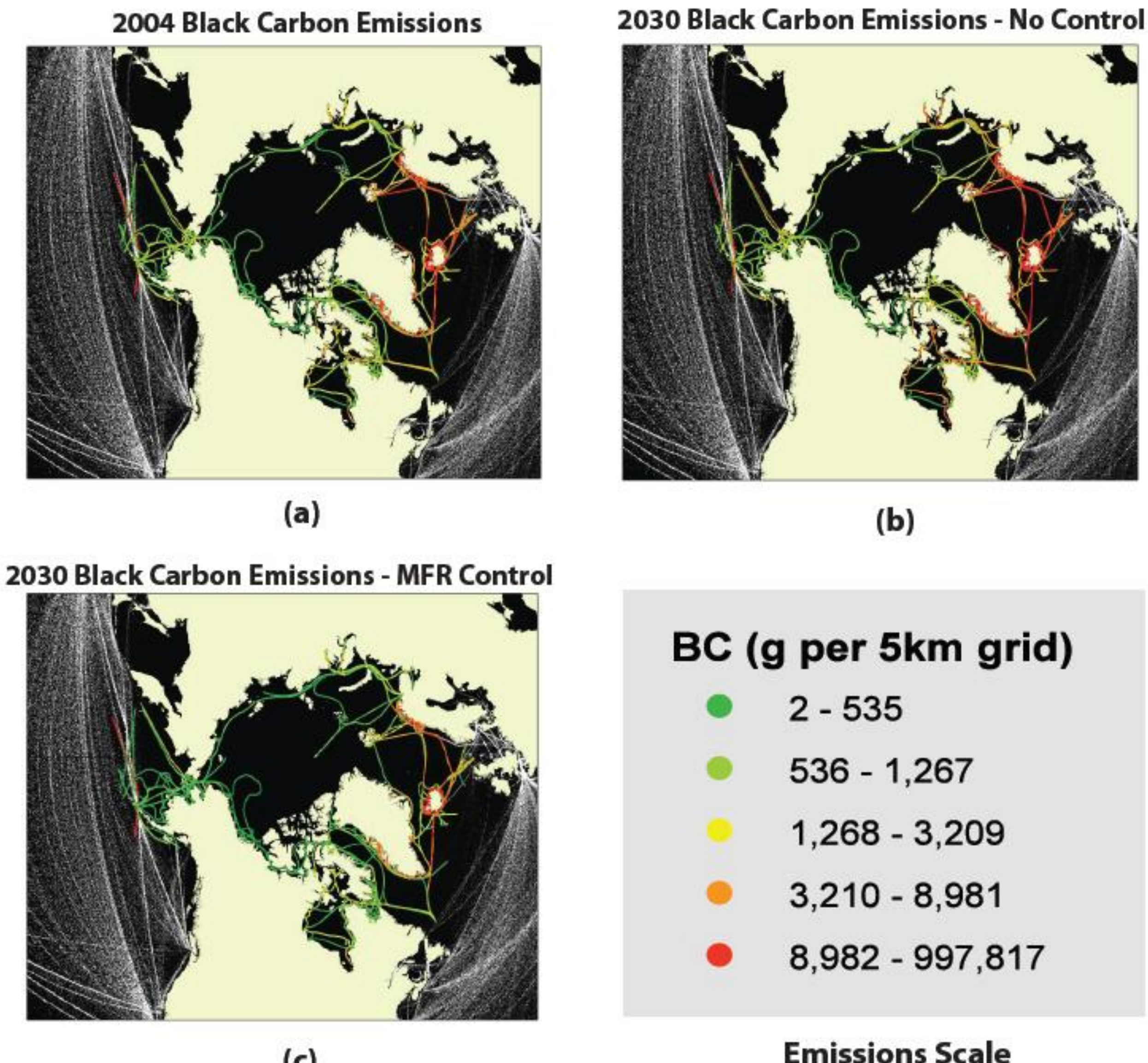
Spracklen et al., JGR, 2009

未来北极圈内航运导致的污染物排放

BAU Scenarios	2004	2020	2030	2050
CO_2 (mt/y)	8 100 000	11 000 000	14 000 000	24 000 000
NO_x as NO_2 (mt/y)	196 000	231 000	244 000	429 000
SO_x as SO_2 (mt/y)	136 000	34 000	43 000	76 000
PM (mt/y)[1]	13 000	4700	5900	10 000
CO (mt/y)	19 000	25 000	32 000	56 000
BC (mt/y)	880	1200	1500	2700
OC (mt/y)	2700	1300	1700	3000
MFR BC (mt/y)	880	360	460	800
MFR OC (mt/y)	2700	400	510	890

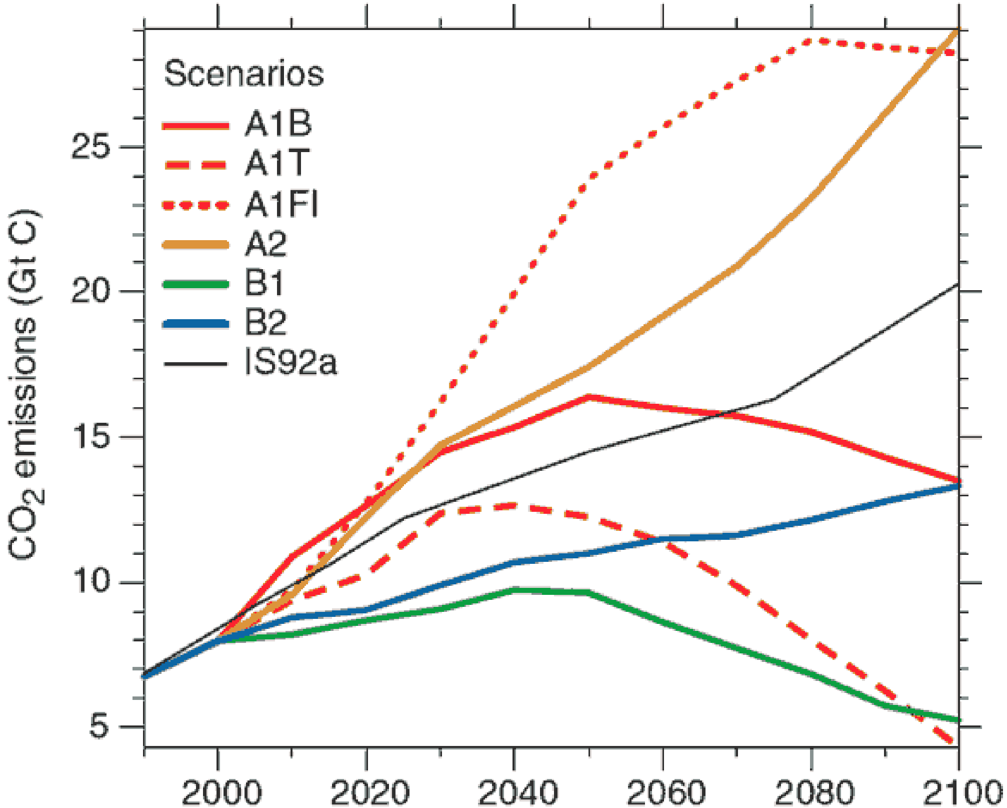
Corbett et al., ACP, 2010

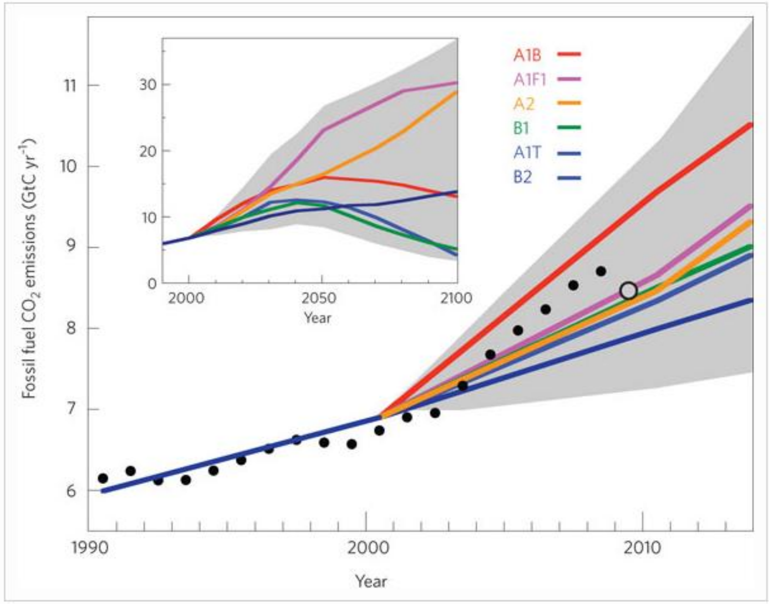
未来北极圈内航运导致的污染物排放



Corbett et al., ACP, 2010

未来CO_2排放





Manning, et al., Nature Geo. Sci. 2010

IPCC

Thanks!

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