



ESA - MOST Dragon 2 Programme

2011 DRAGON 2 SYMPOSIUM

中国科技部-欧洲空间局合作“龙计划”二期

“龙计划”二期2011年学术研讨会

Air quality Monitoring and Forecasting In China



TU/e

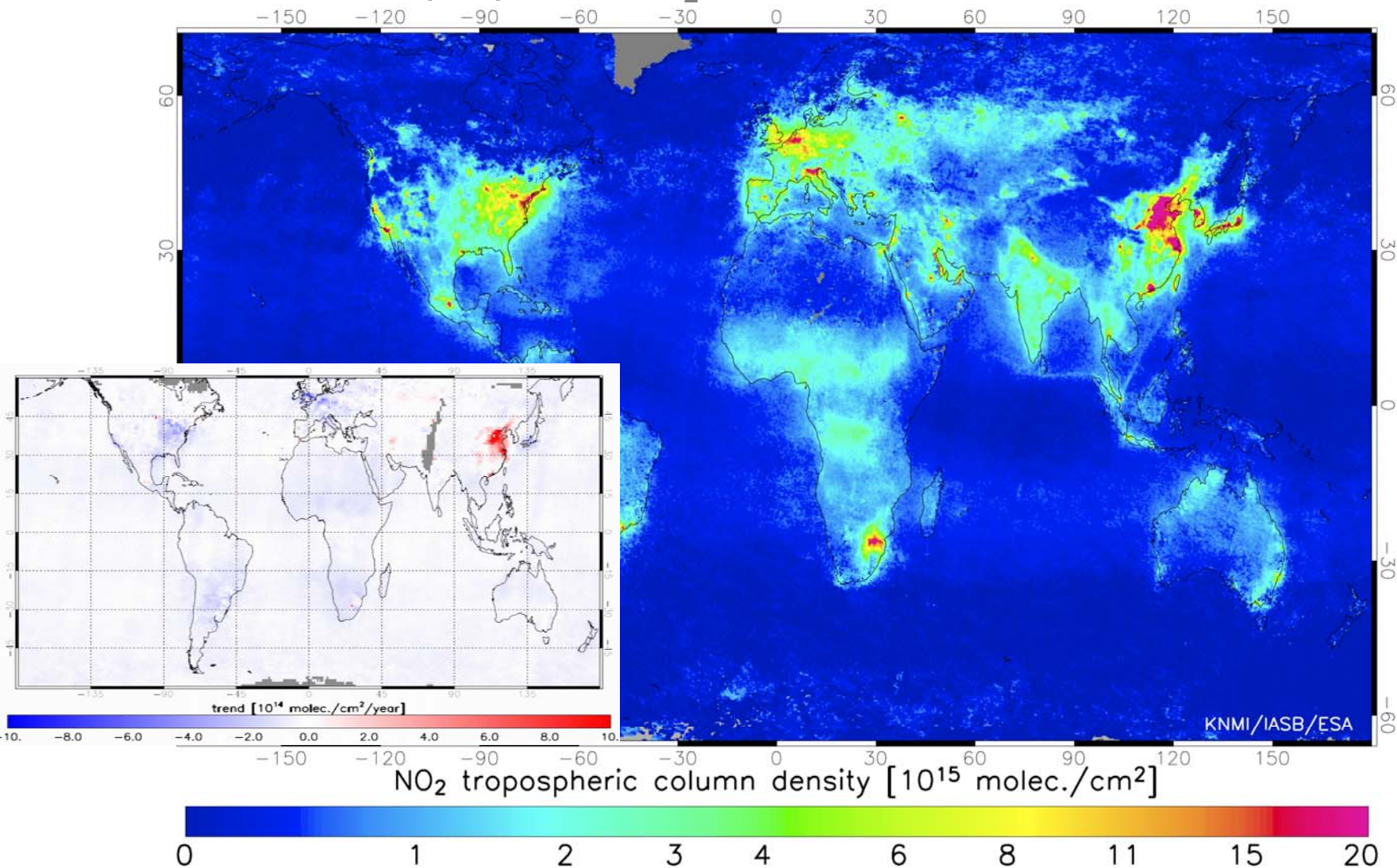
- European activities AMFIC:
 - Short Overview:
 - Air pollution monitoring by satellite
 - Forecast service of air pollution
 - Emission estimates (by Bas Mijling)
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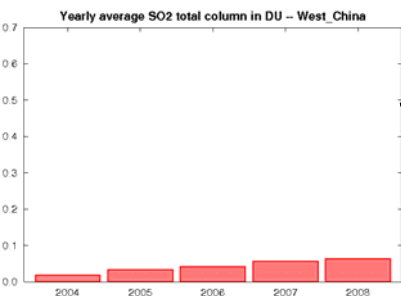
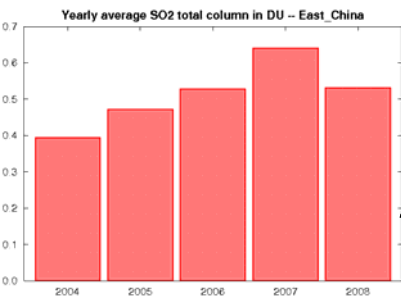
Tropospheric NO₂

Mean tropospheric NO₂ column for 2004, SCIAMACHY

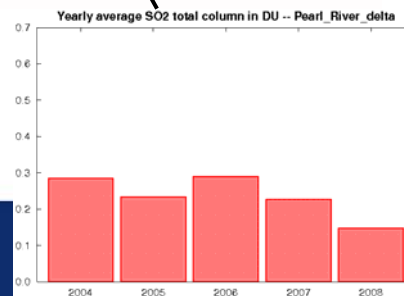
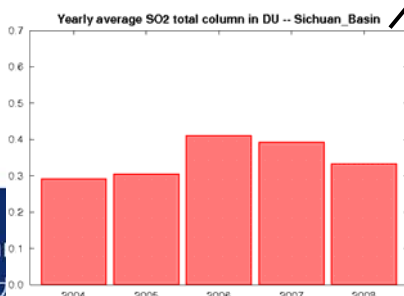
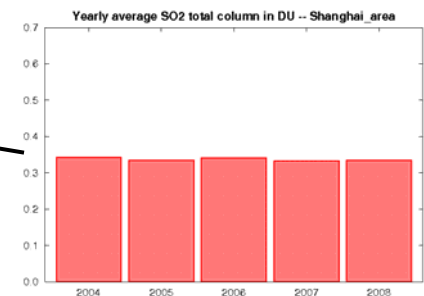
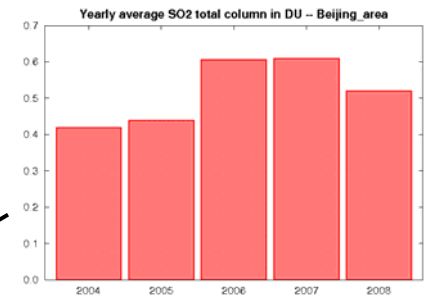
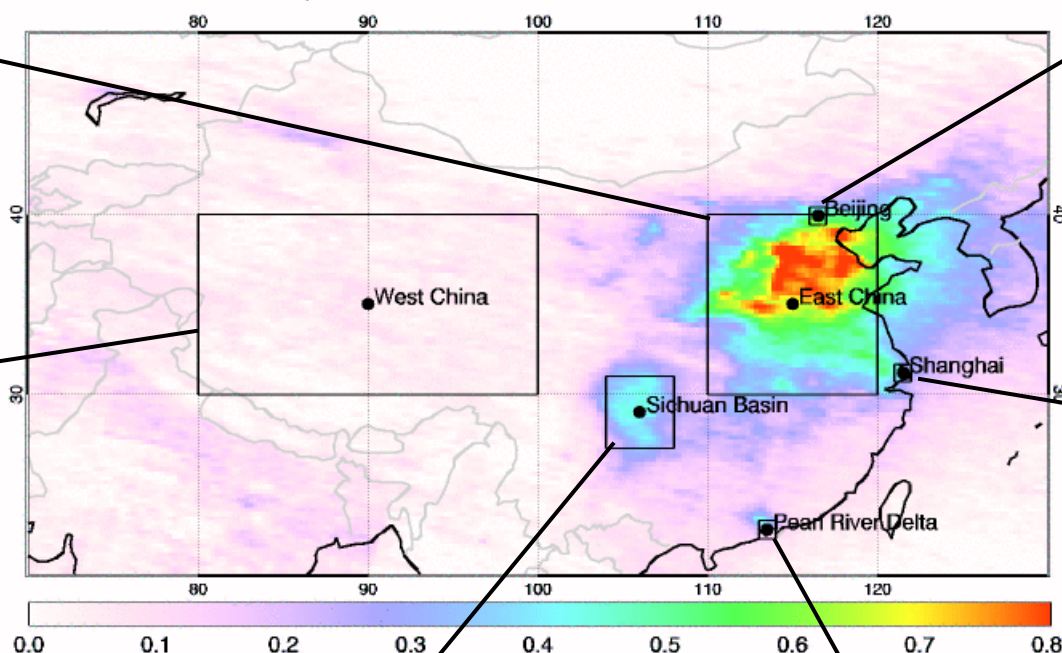




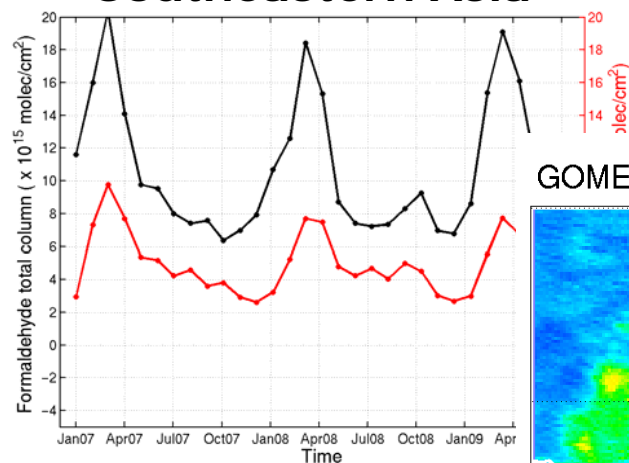
Tropospheric SO₂



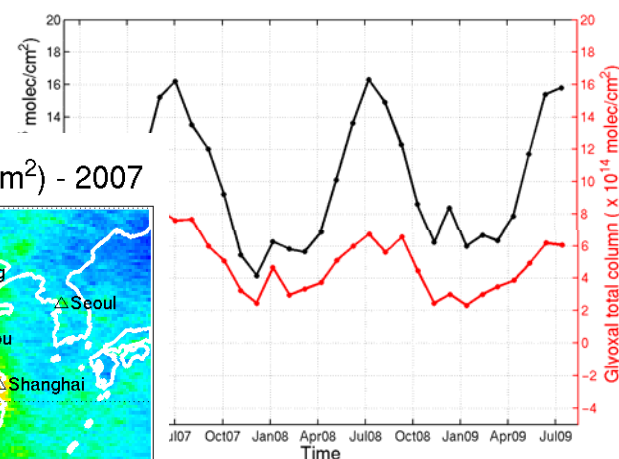
SO₂ vertical column [DU]
SCIAMACHY -- BIRA-IASB/ESA



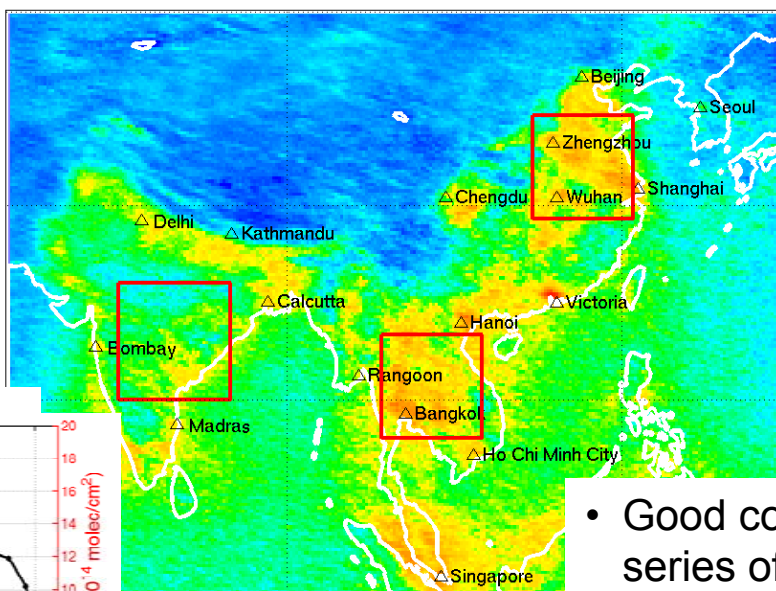
$\times 10^{15}$ Southeastern Asia $\times 10^{14}$



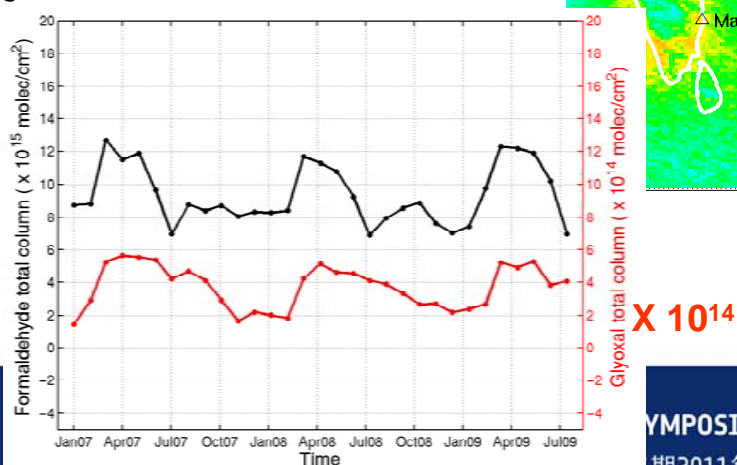
$\times 10^{15}$ Eastern China $\times 10^{14}$



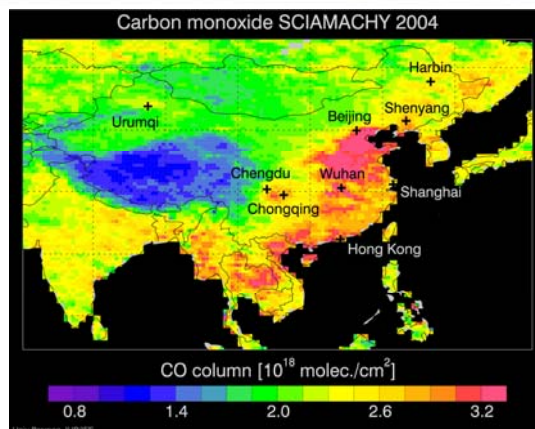
GOME-2 CHOCHO vertical columns (molec/cm²) - 2007



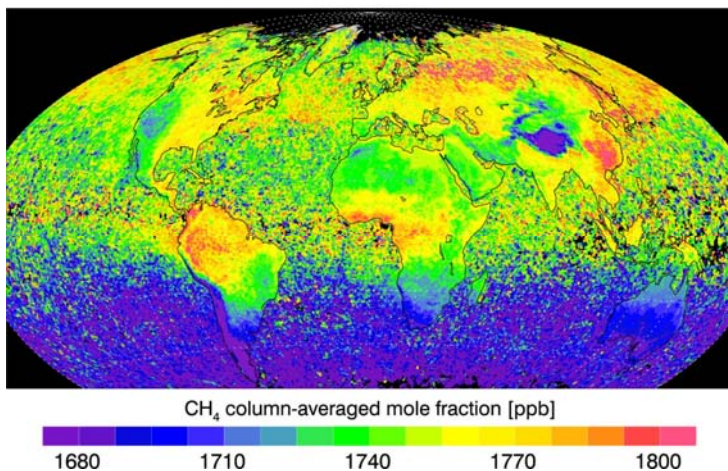
$\times 10^{15}$ India



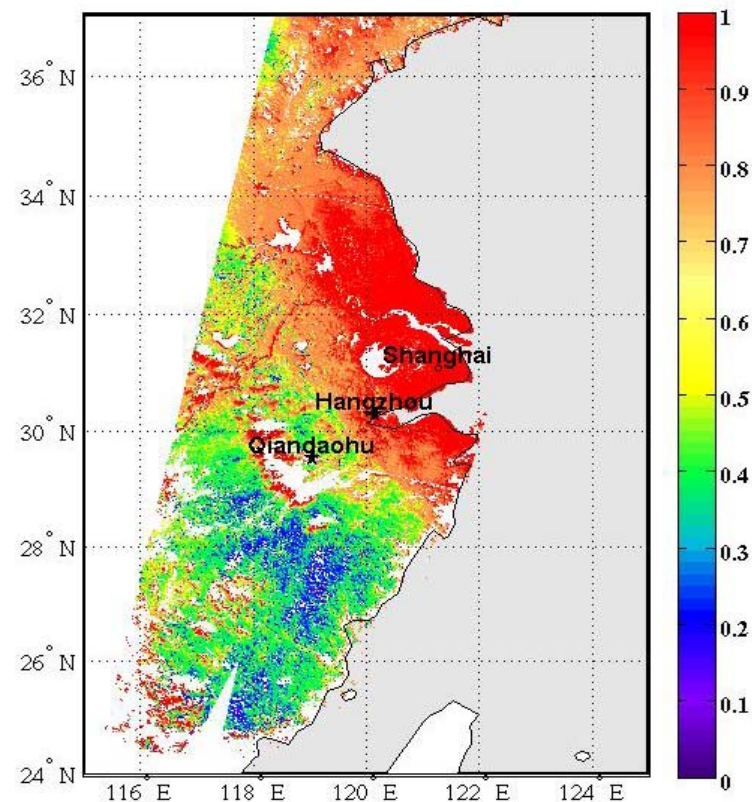
- Good correlation between the time series of **HCHO** and **CHOCHO** vertical columns.
- Comparisons of these data and their spatial/temporal variabilities with modelled columns can improve emission estimates.



Carbon monoxide



Methane



Aerosol

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Air quality forecasting

- Forecast service:
 - Regional air quality model CHIMERE
 - Emission database INTEX-B 2006 (Zhang and Streets)
- Air quality study
 - Satellite-Model comparison shows a NO₂ concentration reduction of ~60% during the Olympic Games in Beijing.
- Emission estimates
 - Emission inventory of 2006 is no longer relevant for the situation today, 5 year later (economic growth of almost 10 % per year).

AMFIC Air Quality Monitoring and Forecasting in China

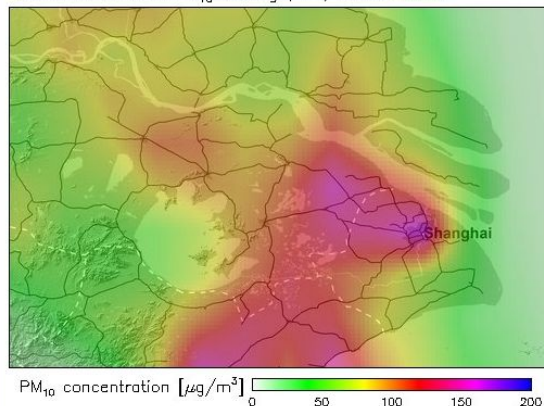
home | air quality bulletin | archive | FAQ

Fri 11 Jul, 19:55

Select bulletin: Region Type Day Show

Shanghai – PM10 daily average

CHIMERE surface PM₁₀ average, F1, 12 Jul 2008



Local Measurements

	9-7	10-7	11-7
NO ₂	21	30	35
SO ₂	29	39	47
O ₃	--	--	--
CO	--	--	--
PM ₁₀	33	41	58

Clear Sky UV Index

	9-7	10-7	Today	12-7	13-7
UV INDEX	11	11	12	12	13

Weather Forecast

(forecast taken from WMO)

Date	min (°C)	max (°C)	Weather
Fri 11 Jul	27	34	thunder shower
Sat 12 Jul	27	33	shower
Sun 13 Jul	28	34	shower

AMFIC 中国空气质量监测与预报

Air Quality Monitoring and Forecasting in China

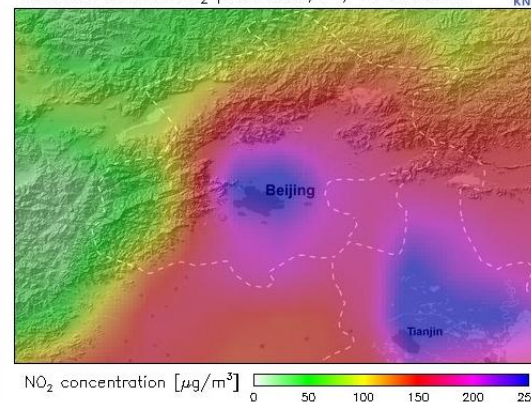
主页 | 空气质量公告 | 文件 | 帮助

Mon 13 Oct, 20:47

选择公告 区域 类型 日 显示

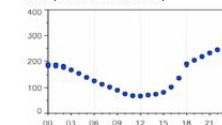
北京 – 二氧化氮峰值

CHIMERE surface NO₂ peak value, F1, 14 Oct 2008



NO2 Time Series

北京 (116.39°E, 39.99°N)



当地测量值

	11-10	12-10	13-10
二氧化氮	50	64	85
二氧化硫	11	13	21
臭氧	--	--	--
CO	--	--	--
可吸入颗粒物	44	70	136

concentrations in $\mu\text{g}/\text{m}^3$

晴空紫外指数

11-10	12-10	今天	14-10	15-10
UV INDEX	4	4	4	4

天气预报

(天气数据来源于世界气象组织 WMO)

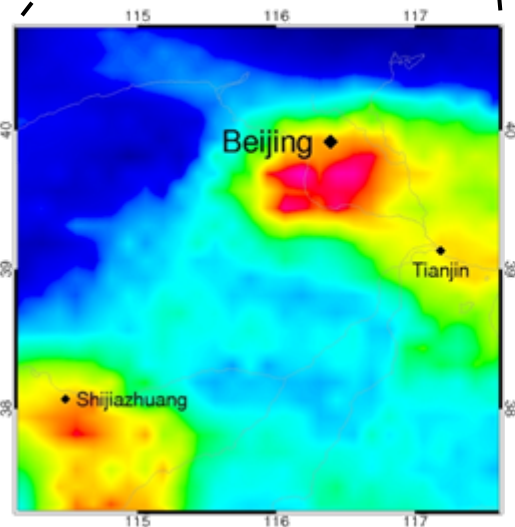
日期	最小值	最大值	天气
Mon 13 Oct	9	22	clear
Tue 14 Oct	11	23	cloudy
Wed 15 Oct	12	21	cloudy

Daily air quality bulletin (NO₂, PM₁₀ and ozone) for today and two days ahead in East-China and several big cities in China.

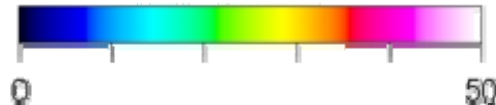
NO₂ reductions detected during 2008 Olympic Games

Mijling et al., Geophys. Res. Lett. (2009)

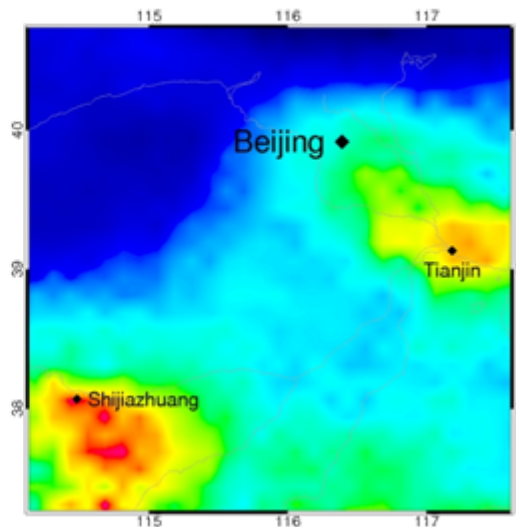
GOME-2, 2007



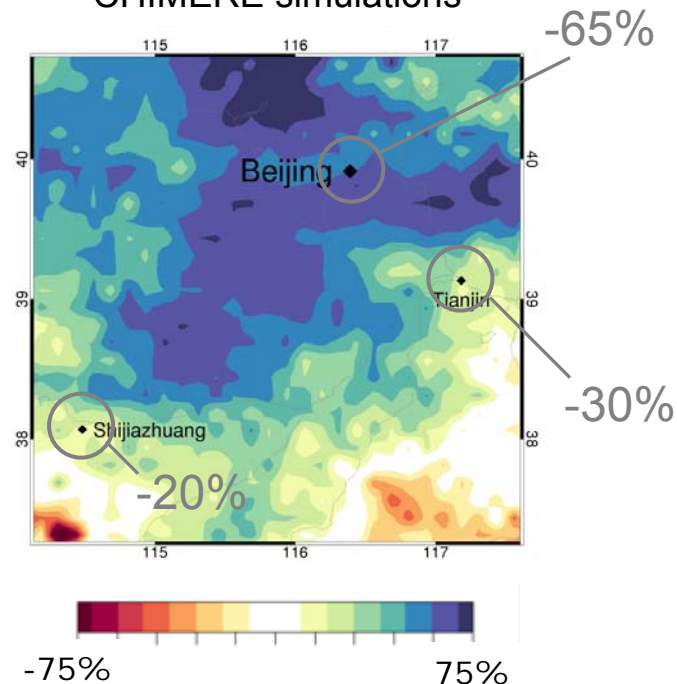
NO₂ [10^{15} molec/cm²]



GOME-2, 2008



NO₂ reductions
GOME-2 observations against
CHIMERE simulations



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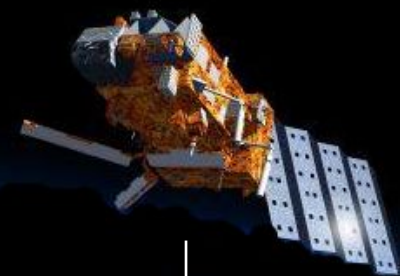
“龙计划”二期2011年学术研讨会

NO_x emissions in China constrained by satellite observations: a new inversion approach

Bas Mijling
Ronald van der A



Royal Netherlands
Meteorological Institute
*Ministry of Infrastructure and the
Environment*



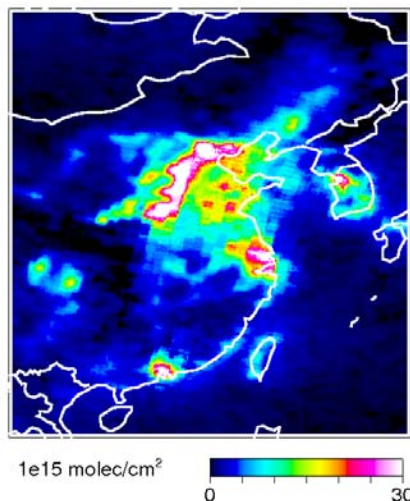
NO₂
retrievals from
OMI and
GOME2

CHIMERE
0.25 ° × 0.25 °

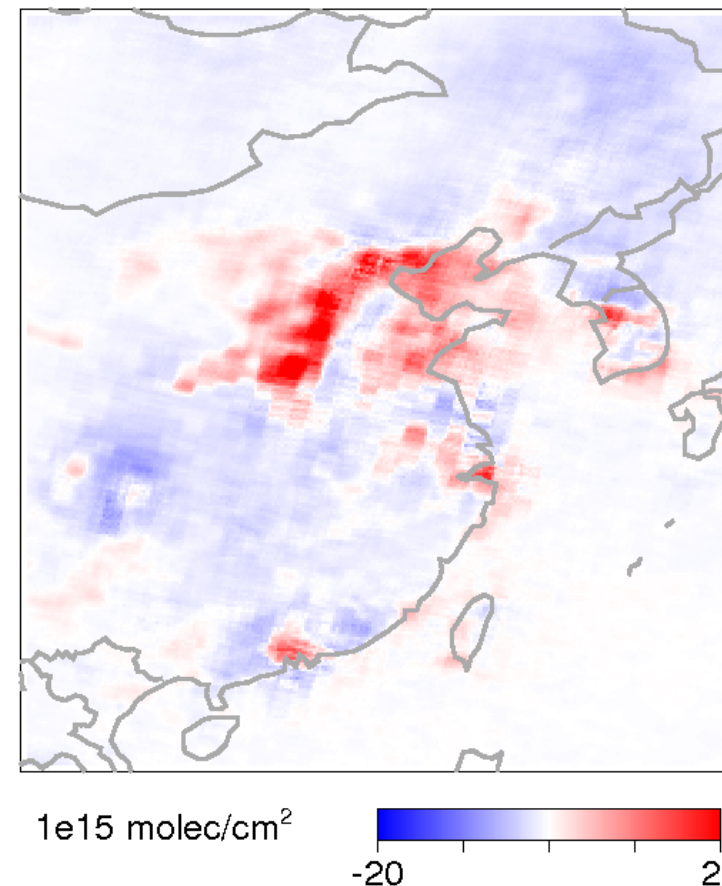
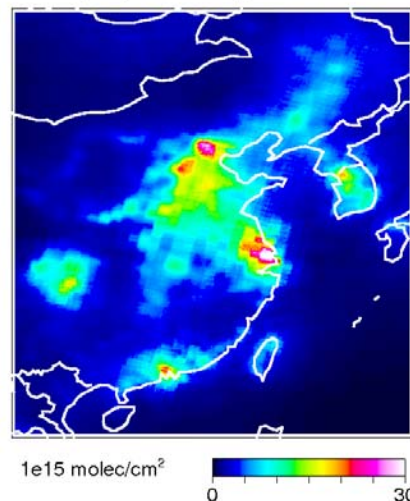
April-May 2008

GOME2 - CHIMERE

tropospheric NO₂ GOME-2



tropospheric NO₂ CHIMERE



Mainly caused by
incorrect NO_x
emissions in CTM

*The difference between observed
and modelled concentrations
contains information on how to
adjust the underlying NO_x
emissions*

Assimilation of satellite data to constrain emissions

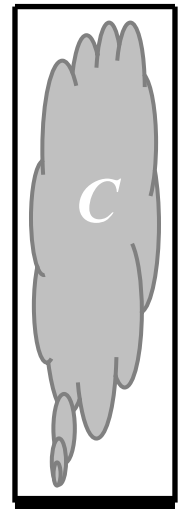
- Will improve NO_x emission inventories
- Will improve simulated NO_2 concentrations (and therefore air quality forecasts)
- Will reveal NO_x emission trends

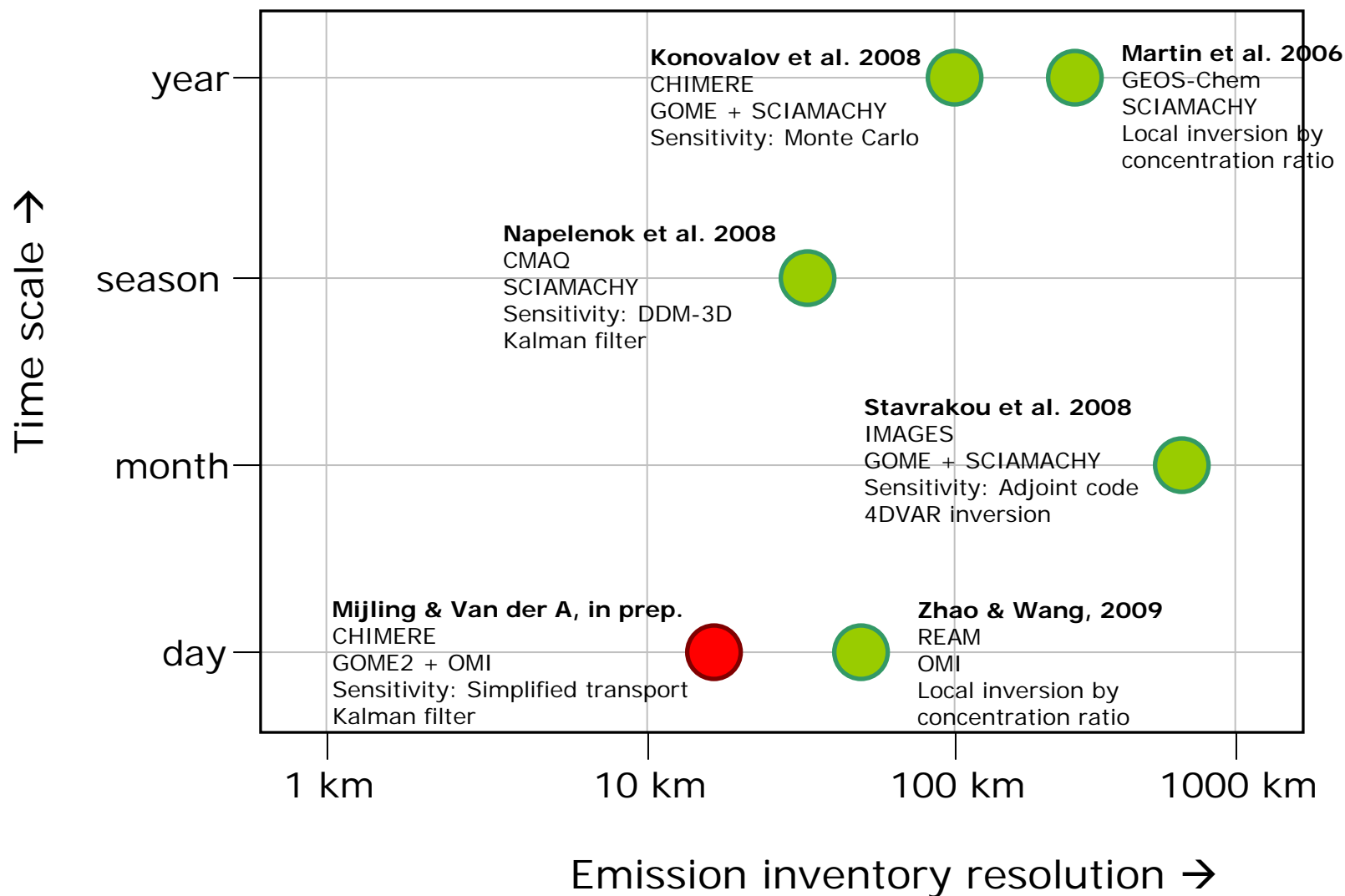
- Key to the inversion is the relation of the emission in a grid cell on the concentration in other grid cells:

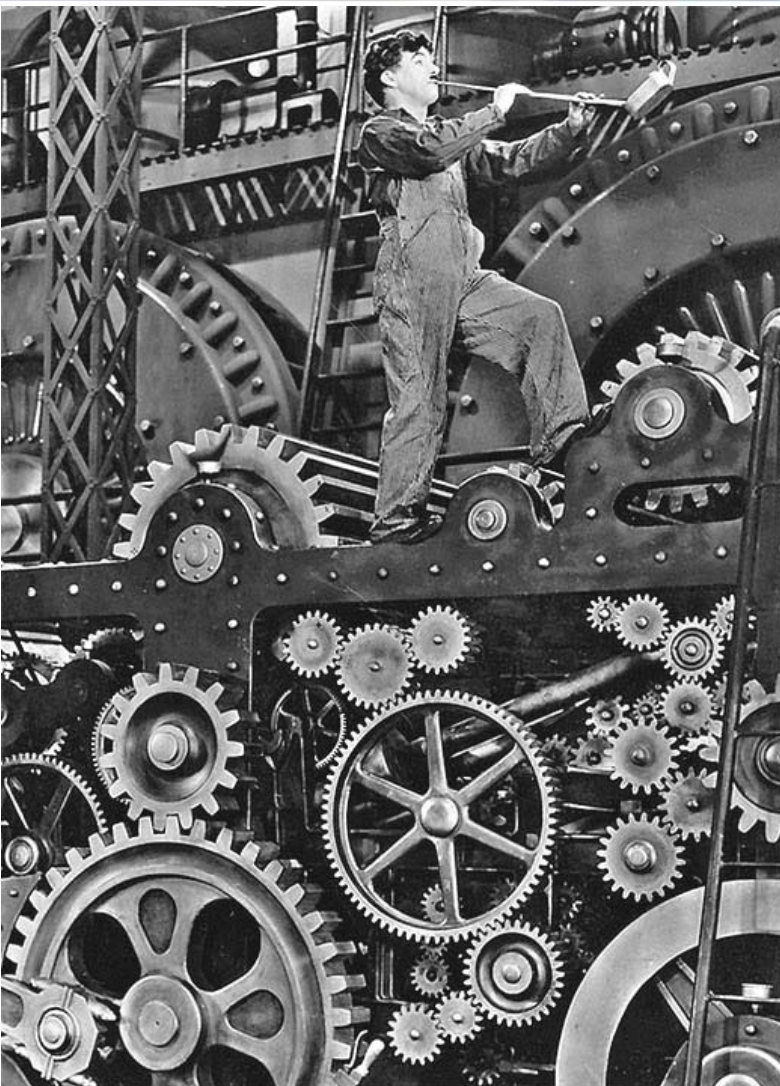
$$H_{ij} = \partial c_i / \partial e_j$$

- Easy case: No transport (Martin *et al.*, 2006):

$$E = \alpha C, \alpha \text{ determined from model runs}$$





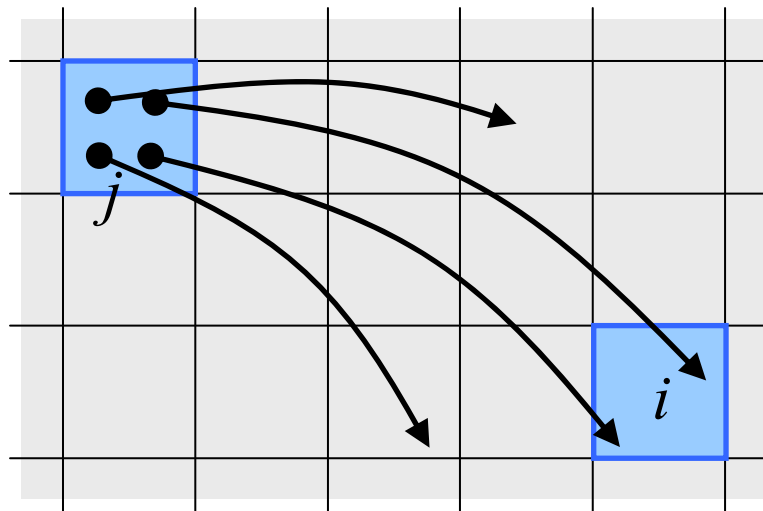


Variability of Emissions in China constrained by Satellite Observations

- Daily inversions of NO_x emissions from NO₂ observations
→ *fast algorithm!*
- On a 25 km² resolution over East China
→ *include transport!*

New algorithm which uses a simplified 2D transport scheme

Transport matrix Ω describes how an emitted plume is transported over the model grid.



here: $\Omega_{j \rightarrow i} = 0.5$

- Transport of NO_x column along representative isobaric trajectory calculations
- Neglect turbulent diffusion

Consider a time interval $t=[0,T]$ (24 hours)

The concentration at $t=T$ is composed of

1. Transported and aged background concentration:

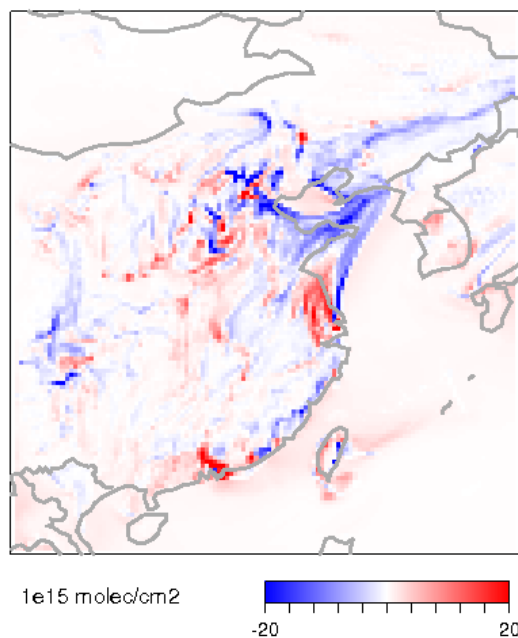
$$c_i(T) = \sum_j \exp(-T/\tau_j) \Omega_{j \rightarrow i}(T) b_j \Rightarrow \mathbf{c} = \mathbf{G} \mathbf{b}$$

2. Emitted and transported NO_x during the time interval:

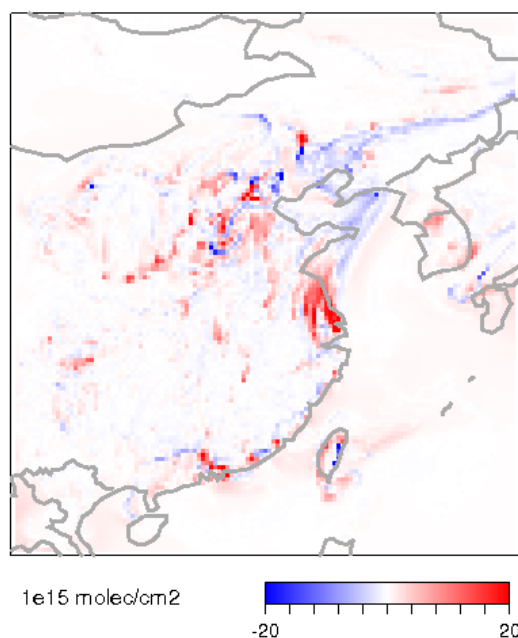
$$c_i(T) = \sum_j \left(\int_0^T \exp(-t/\tau_j) \Omega_{j \rightarrow i}(t) f_j(T-t) dt \right) e_j \Rightarrow \mathbf{c} = \mathbf{H} \mathbf{e}$$

- Concentration from simplified 2D transport:
 $\mathbf{c}' = \mathbf{G}(\boldsymbol{\tau})\mathbf{b} + \mathbf{H}(\boldsymbol{\tau})\mathbf{e}$
- Compare with \mathbf{c} from forward model run
- Fit lifetimes $\boldsymbol{\tau}$ which minimizes cost function
 $J(\boldsymbol{\tau}) = \| \mathbf{c} - \mathbf{G}(\boldsymbol{\tau})\mathbf{b} - \mathbf{H}(\boldsymbol{\tau})\mathbf{e} \|^2$
- Complicating factors:
 - Large size of matrix \mathbf{G} and \mathbf{H} ($n \sim 15000$)
 - Dependency of matrix elements on $\boldsymbol{\tau}$

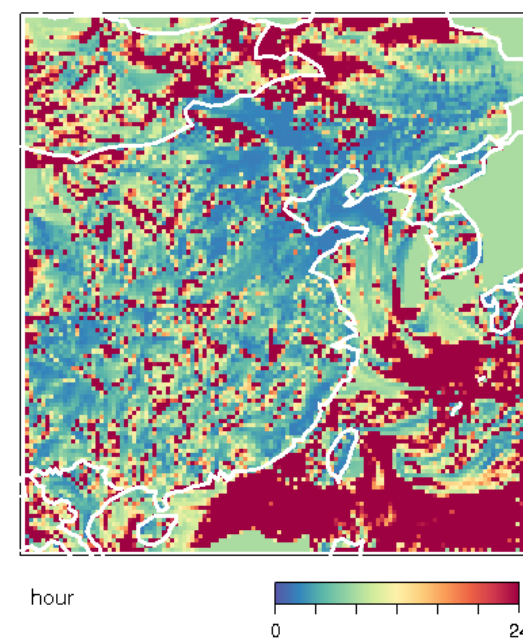
Initial residue
(lifetime NO_x 8h)



Final residue
(after 10 iterations)



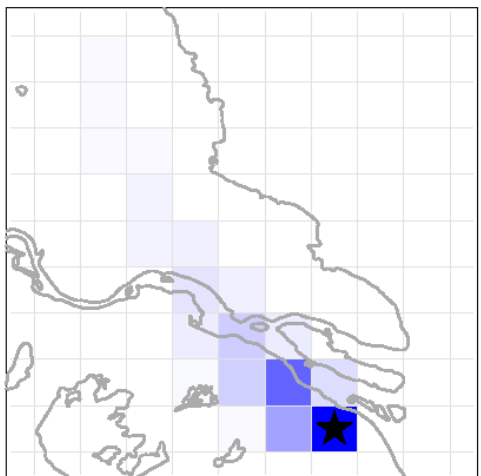
fitted
 NO_x lifetime



Residue CHIMERE – (Gb + He) for April 30th, 2008

(downwind)

Sensitivities from Shanghai



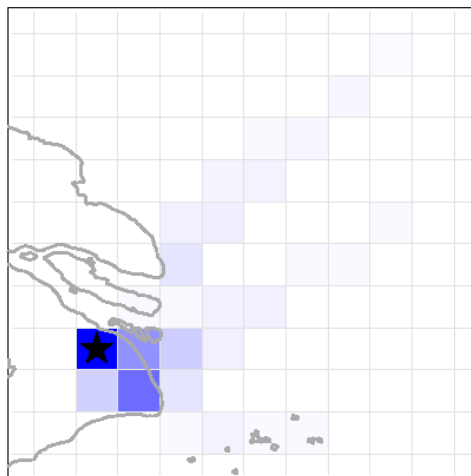
sensitivity

0.0

1.5

(upwind)

Sensitivities to Shanghai

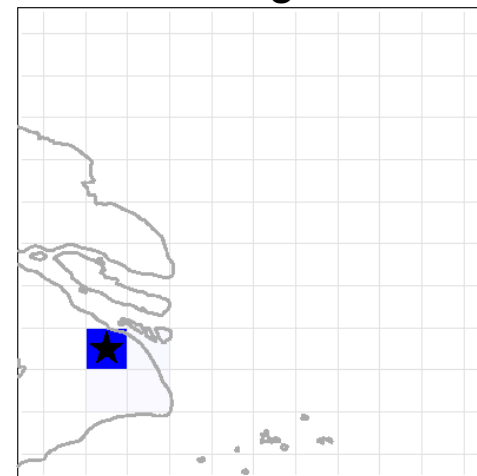


sensitivity

0.0

1.5

Origin NO_x column
Shanghai



10^{15} molec./cm²

0.0

116.4

Origin NO_x column Shanghai



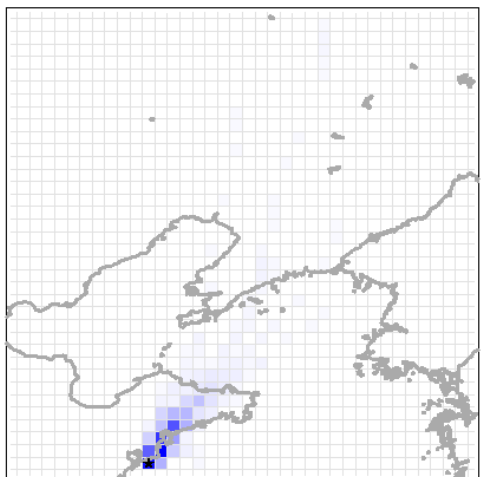
7% by non local emissions

92% by local emissions

0% background concentration

(downwind)

Sensitivities from Qingdao



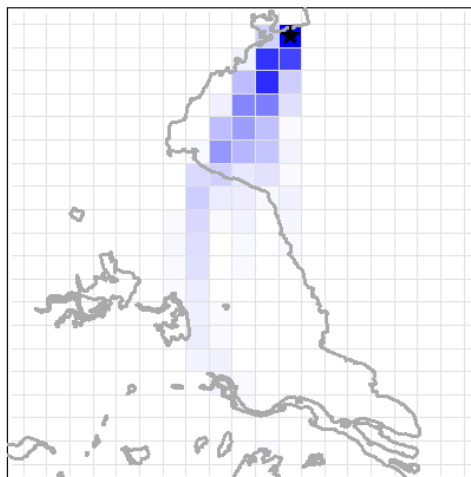
sensitivity

0.0

0.5

(upwind)

Sensitivities to Qingdao

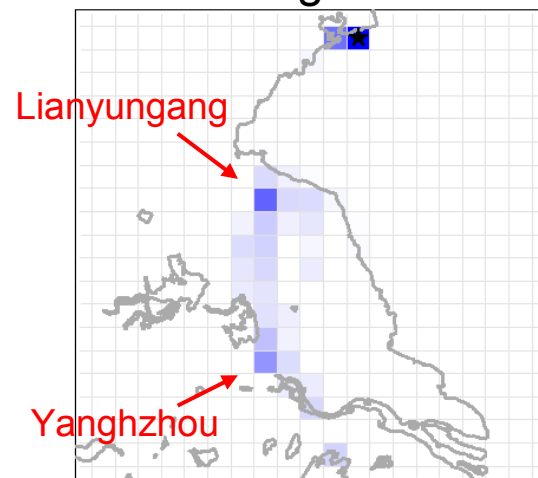


sensitivity

0.0

0.4

Origin NO_x column
Qingdao



Lianyungang

Yangzhou

10^{15} molec./cm²

0.0

0.3

Origin NO_x column Qingdao



80% by non local emissions

17% by local emissions

2% background concentration

$$\Delta c = H \Delta e$$

The diagram illustrates the inversion problem equation $\Delta c = H \Delta e$. On the left, Δc is represented by a vertical green rectangle. In the center, the matrix H is represented by a large green rectangle containing the partial derivative $\frac{\partial c_i}{\partial e_j}$. On the right, Δe is represented by a vertical green rectangle. An equals sign is placed between the first and second rectangles.

Difference GOME-2
observation and
model simulation
over East China

Sensitivity matrix
~ 2000×15000

Update emission
inventory (0.25°)
over East China

Error in emission inventory;
Error in emission forecast

Error in observation;
Error in model simulation;
Error in derivation sensitivities



Small errors:
More weight on emission apriori

Small errors:
More weight on observations

State vector forecast	$\mathbf{x}^f(t_{i+1}) = \mathbf{M}_i [\mathbf{x}^a(t_i)]$
Error covariance forecast	$\mathbf{P}^f(t_{i+1}) = \mathbf{M}_i \mathbf{P}^a(t_i) \mathbf{M}_i^T + \mathbf{Q}(t_i)$
Kalman gain matrix	$\mathbf{K}_i = \mathbf{P}^f(t_i) \mathbf{H}_i^T [\mathbf{H}_i \mathbf{P}^f(t_i) \mathbf{H}_i^T + \mathbf{R}_i]^{-1}$
State vector analysis	$\mathbf{x}^a(t_i) = \mathbf{x}^f(t_i) + \mathbf{K}_i (\mathbf{y}_i^o - \mathbf{H}_i [\mathbf{x}^f(t_i)])$
Error covariance analysis	$\mathbf{P}^a(t_i) = (\mathbf{I} - \mathbf{K}_i \mathbf{H}_i) \mathbf{P}^f(t_i)$

\mathbf{x} NO_x emissions

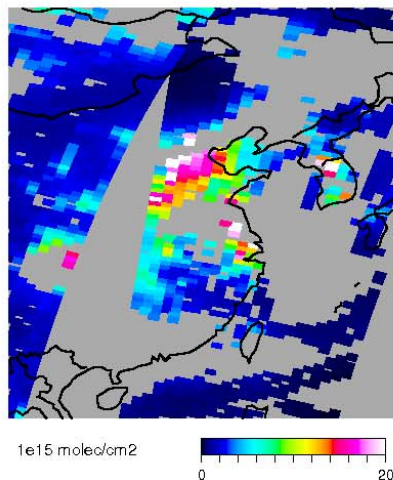
\mathbf{y} tropospheric NO₂ column observations

\mathbf{M} emission model

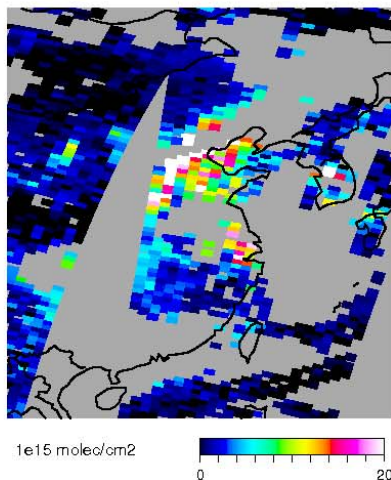
\mathbf{H} Observation operator, linking NO_x emissions to NO₂ concentrations

\mathbf{H} Linearization of \mathbf{H} around $\mathbf{x}=\mathbf{x}^a$: $\mathbf{y} = \mathbf{y}^a + \mathbf{H}(\mathbf{x} - \mathbf{x}^a)$

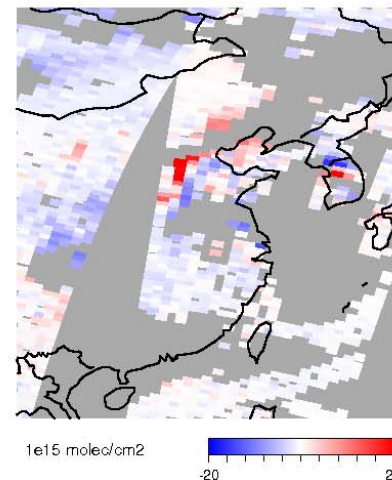
Model forecast



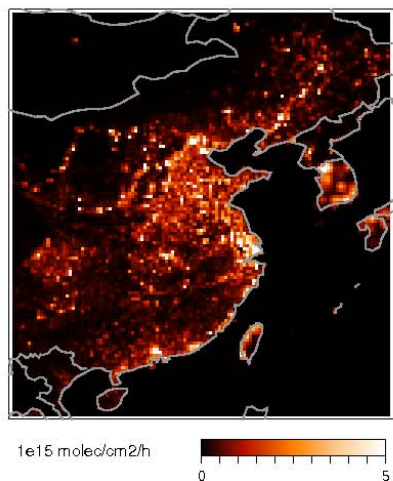
Satellite observations



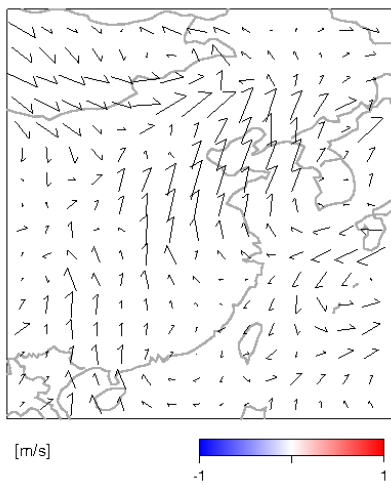
OmF



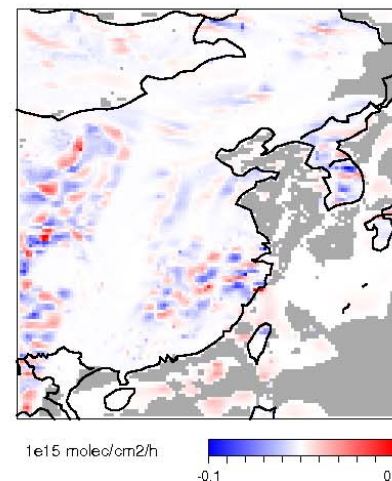
Old emission



Mean wind field



Emission update



- The presented method is a promising new technique for top-down emission estimates from satellite observations.
- The algorithm is fast ($<1\text{h}$), enabling daily assimilation of satellite data.
- The algorithm only needs a forward CTM run; CTM is treated as a black box.
- The algorithm can be applied to other short lived species such as SO_2 and HCHO .

- Time series of NO_x emission data using GOME-2 / OMI data and CHIMERE model.
- Validation of the results with ground data from our Chinese partners.
- Case studies of air quality measures of mega-events
 - Beijing Olympic Games (August-September 2008)
 - Shanghai World Expo (May-October 2010)
 - Guangzhou Asian Games (November 2010)
- Influence of the improved emission inventory on air quality forecasting in East China.
- Operational air quality forecast service at www.amfic.eu based on most recent emissions.

A high-angle, black and white photograph of a very busy multi-lane road at night. The road is filled with cars, their headlights and taillights creating a dense pattern of light. A few pedestrians are visible on the sidewalks. In the background, a stone bridge with multiple arches spans the road, and buildings are visible on the far bank. The overall scene conveys a sense of intense activity and congestion.

Thank you!