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

AMFIC

Air Quality Monitoring and Forecasting in China

KNMI IAP NSMC TU/e

20 - 24 June 2011 | Prague | Czech Republic

捷克 布拉格 2011年6月20-24日

Outline

- European activities AMFIC:
  - Short Overview:
    - Air pollution monitoring by satellite
    - Forecast service of air pollution
  - Emission estimates (by Bas Mijling)
- Chinese activities AMFIC:
  - Validations and data application in China (by Peng Zhang)
  - Spatio-temporal variation of Methane (by Xingying Zhang)
  - Spatio-temporal variation of CO2 (by Wenguang Bai)

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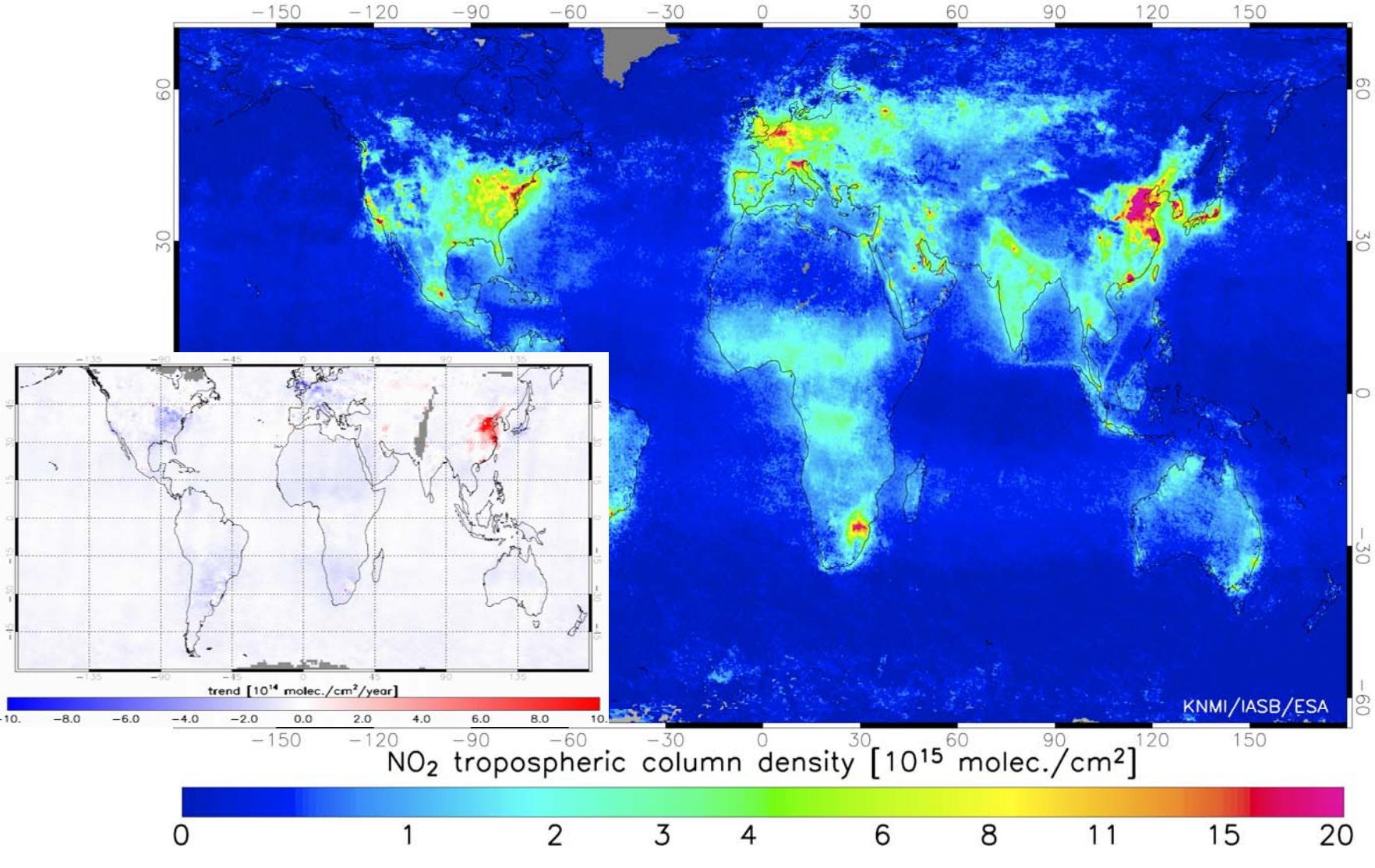
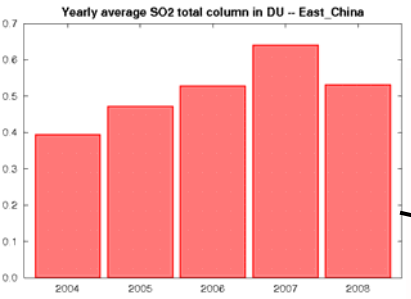
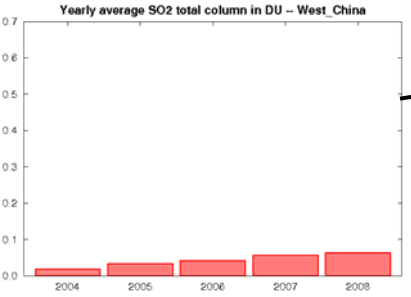
Tropospheric NO_2

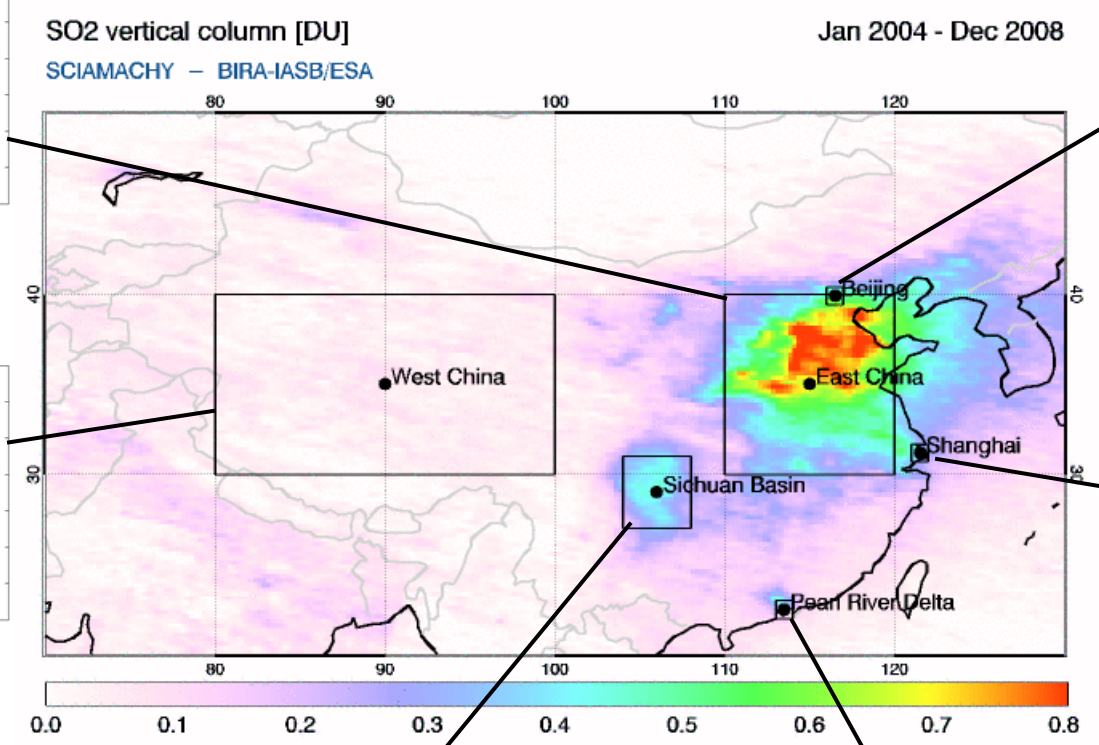
Mean tropospheric NO_2 column for 2004, SCIAMACHY

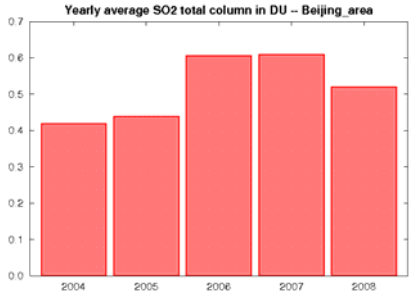


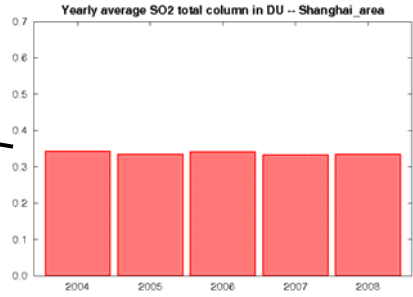
Tropospheric SO_2

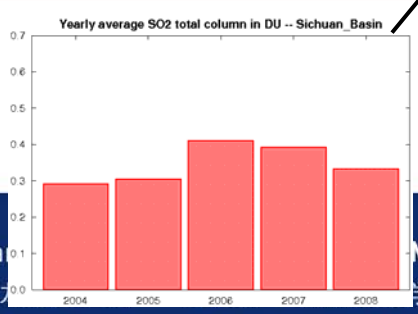


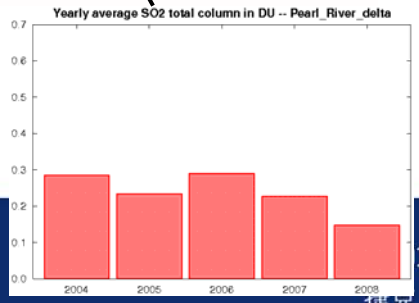






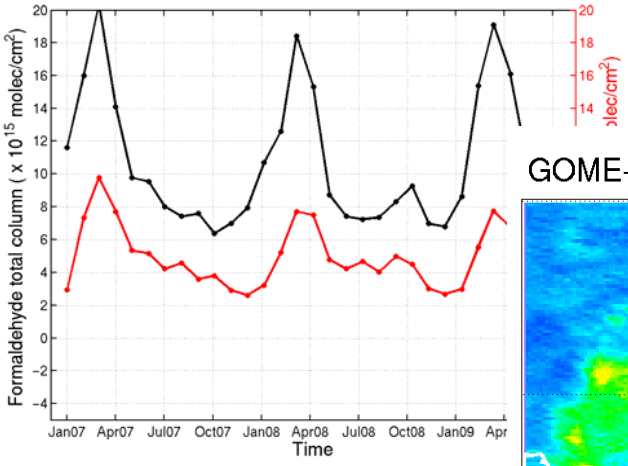




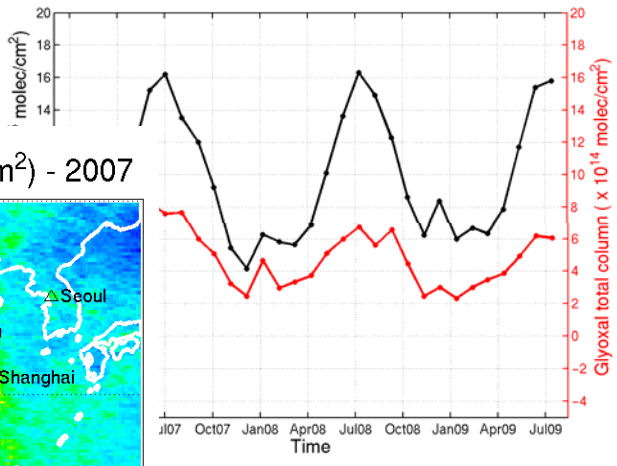


Combined Observations of Formaldehyde and Glyoxal with GOME-2.

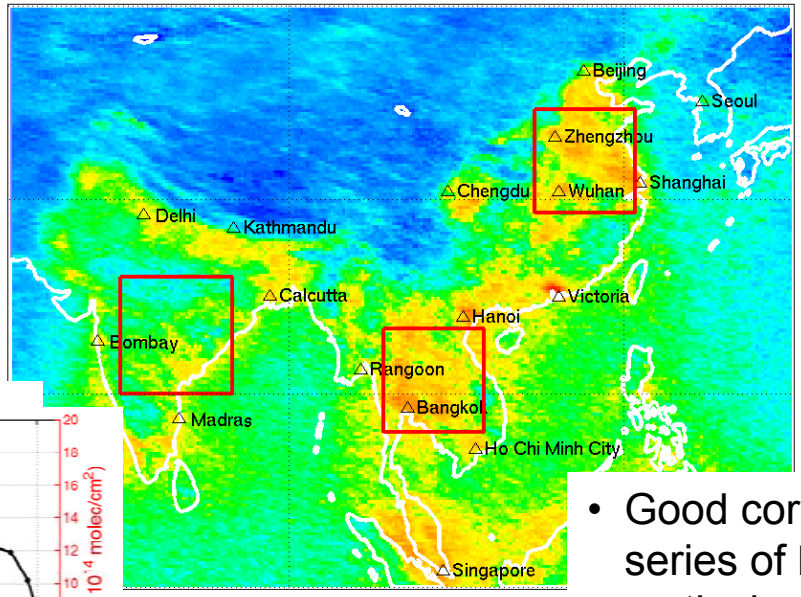
X 10^{15} **Southeastern Asia** X 10^{14}



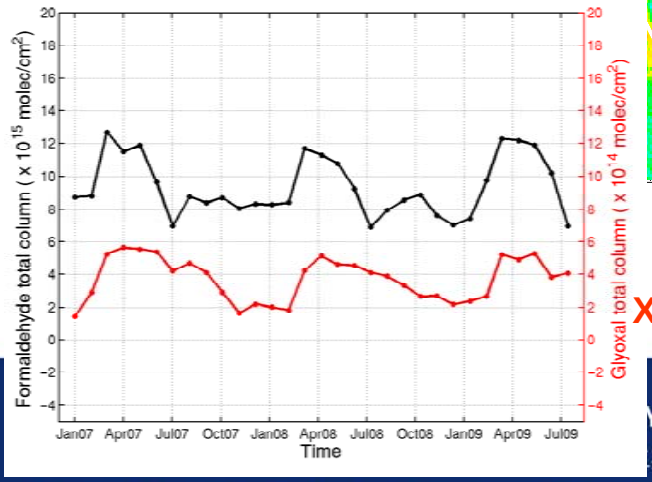
X 10^{15} **Eastern China** X 10^{14}



GOME-2 CHOCHO vertical columns (molec/cm^2) - 2007



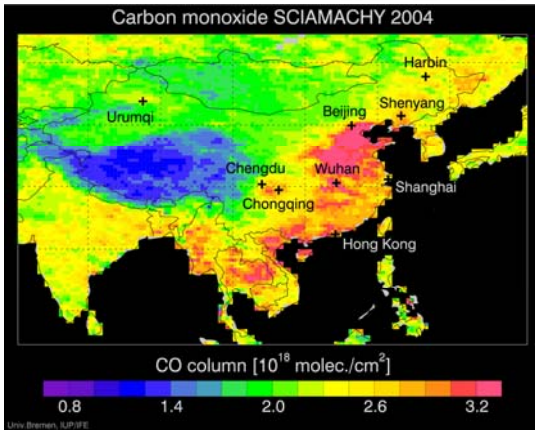
X 10^{15} **India**



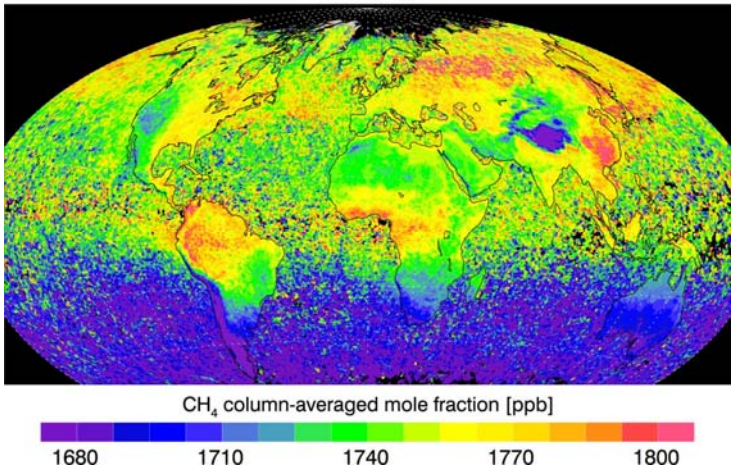
X 10^{14}

- 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.

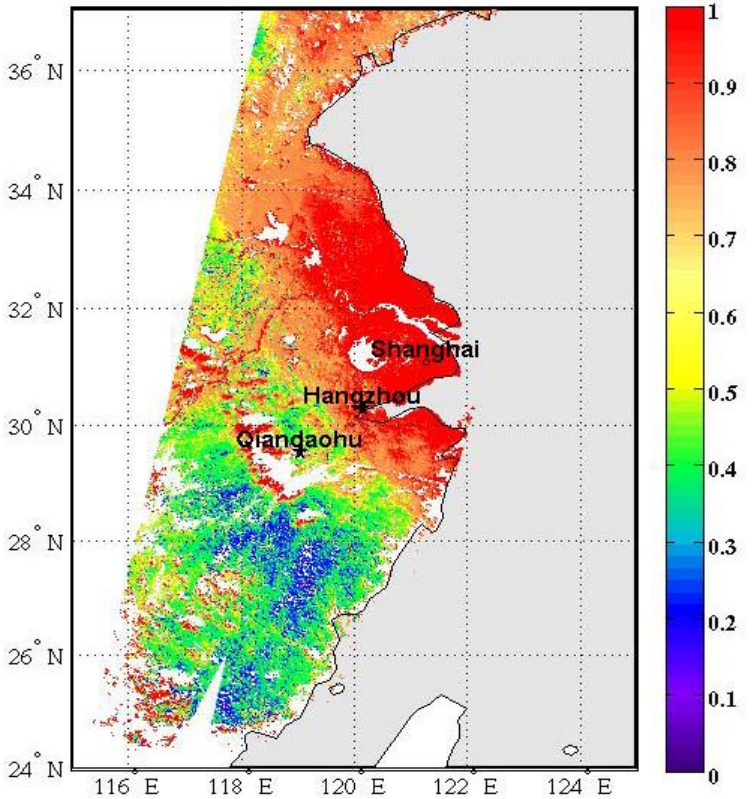
Other data products over China



Carbon monoxide



Methane



Aerosol

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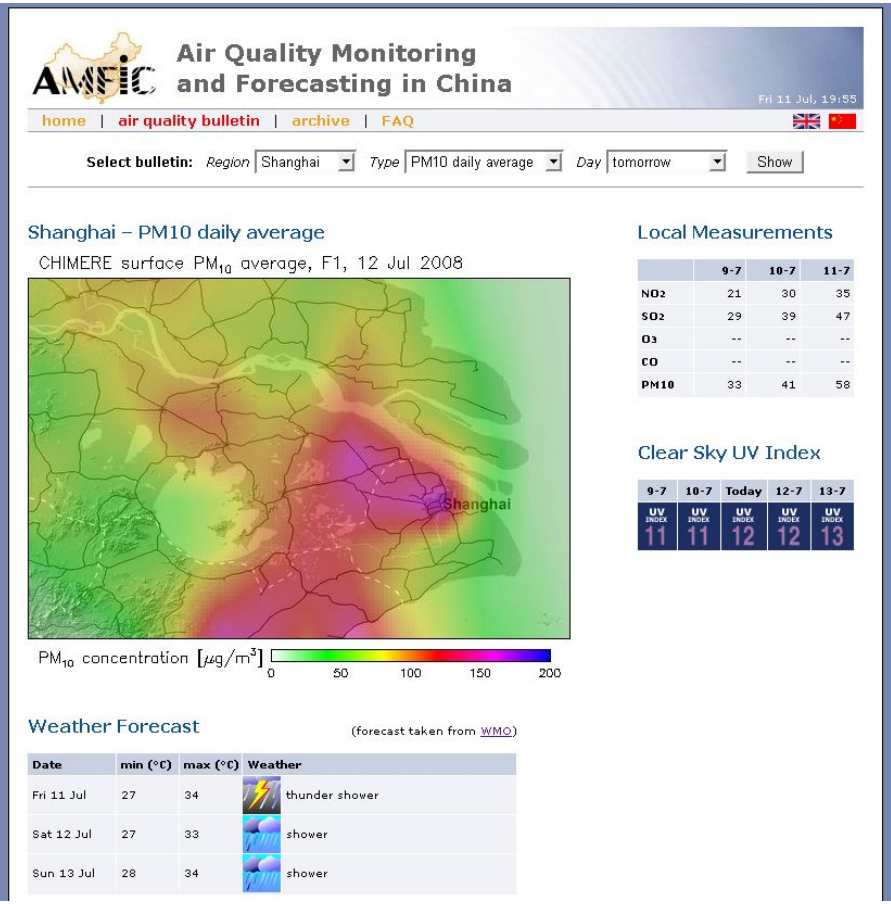
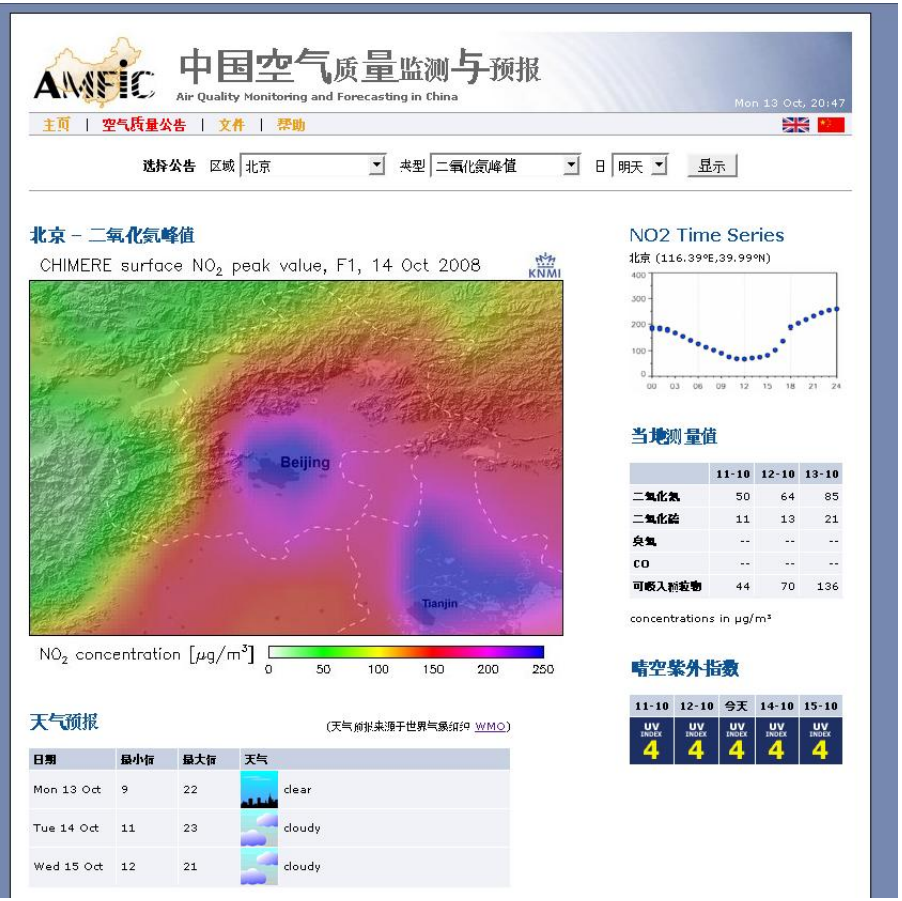
Air quality forecasting

- Forecast service:
  - Regional air quality model CHIMERE
  - Emission database INTEX-B 2006 (Zhang and Streets)
- Air quality study
  - Satellite-Model comparison shows a NO_2 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).

www.amfic.eu/bulletin

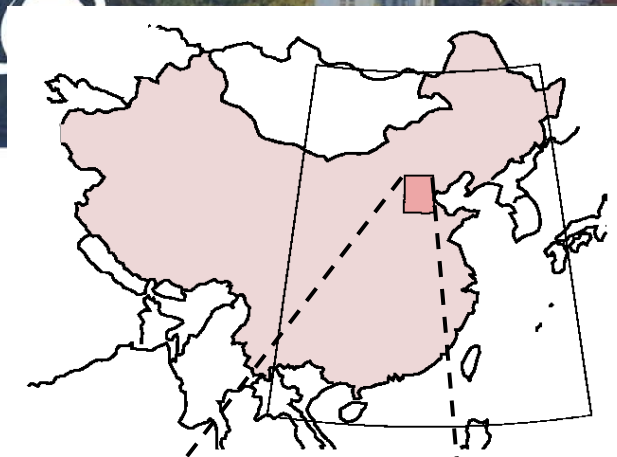




Daily air quality bulletin (NO2, PM10 and ozone) for today and two days ahead in East-China and several big cities in China.

NO_2 reductions detected during 2008 Olympic Games

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

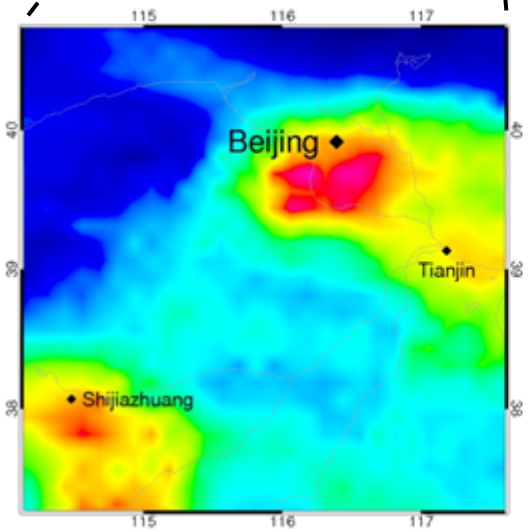


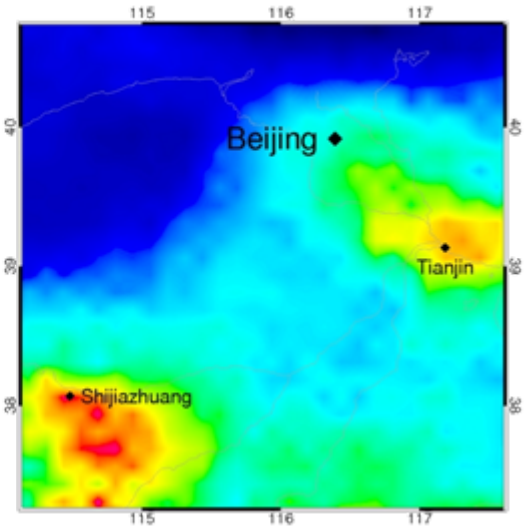
GOME-2, 2007

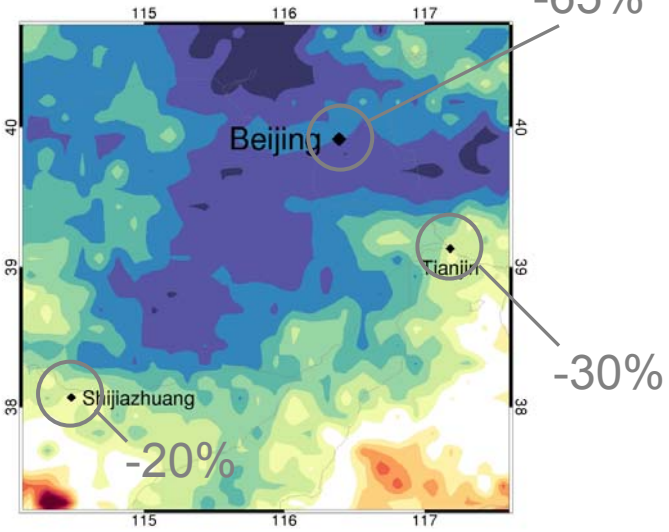
GOME-2, 2008

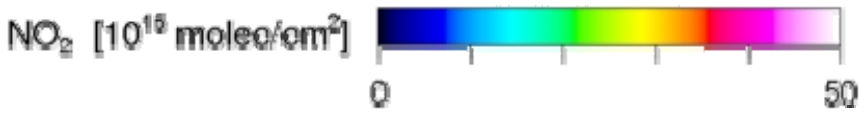
NO_2 reductions

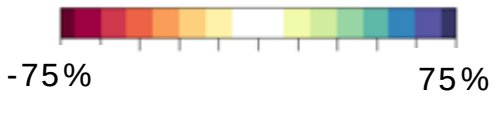
GOME-2 observations against CHIMERE simulations











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NOx 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

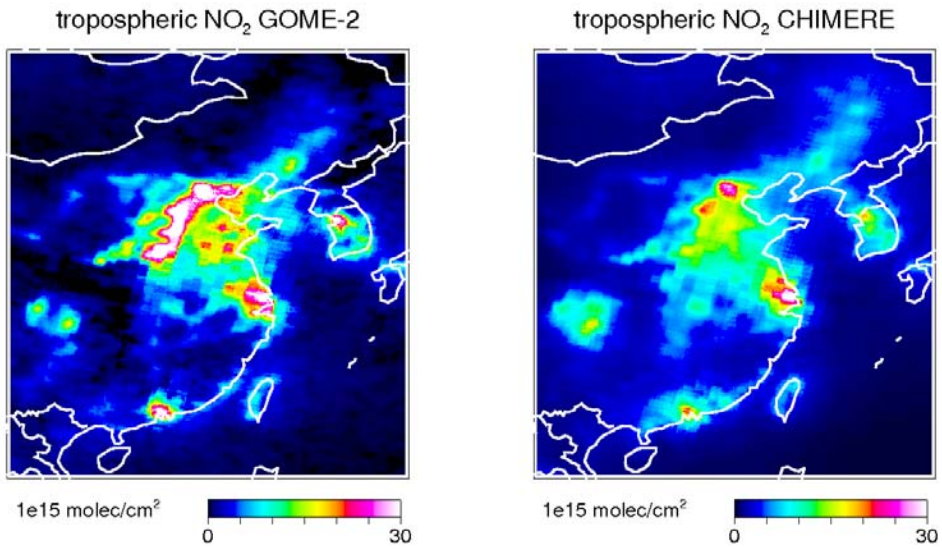
Basic tools

NO_2 retrievals from OMI and GOME2

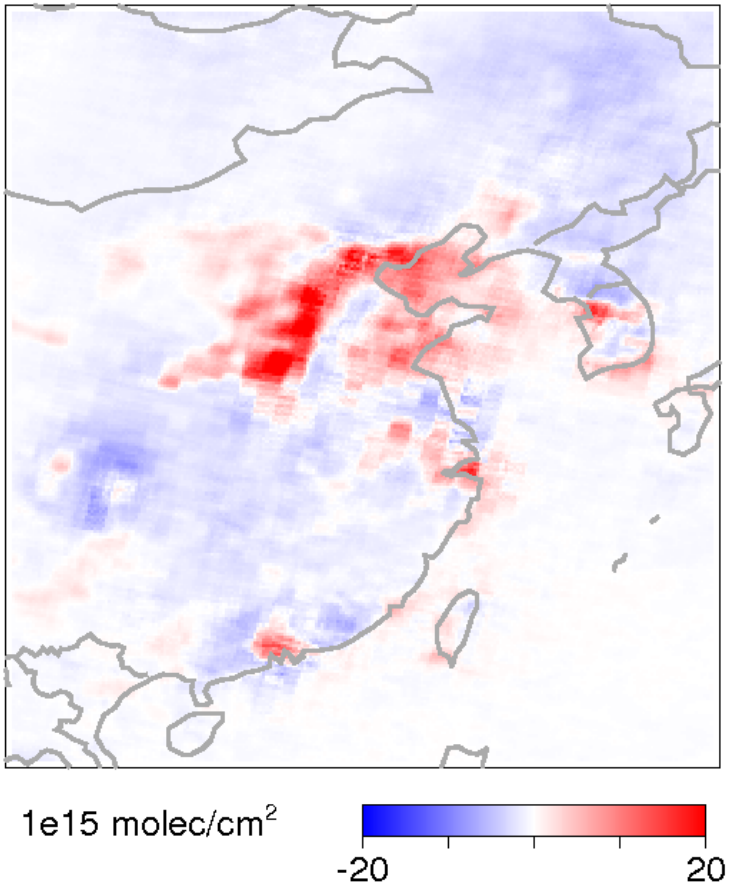
CHIMERE
0.25 °×0.25°

NO_2 concentrations: Satellite vs Model

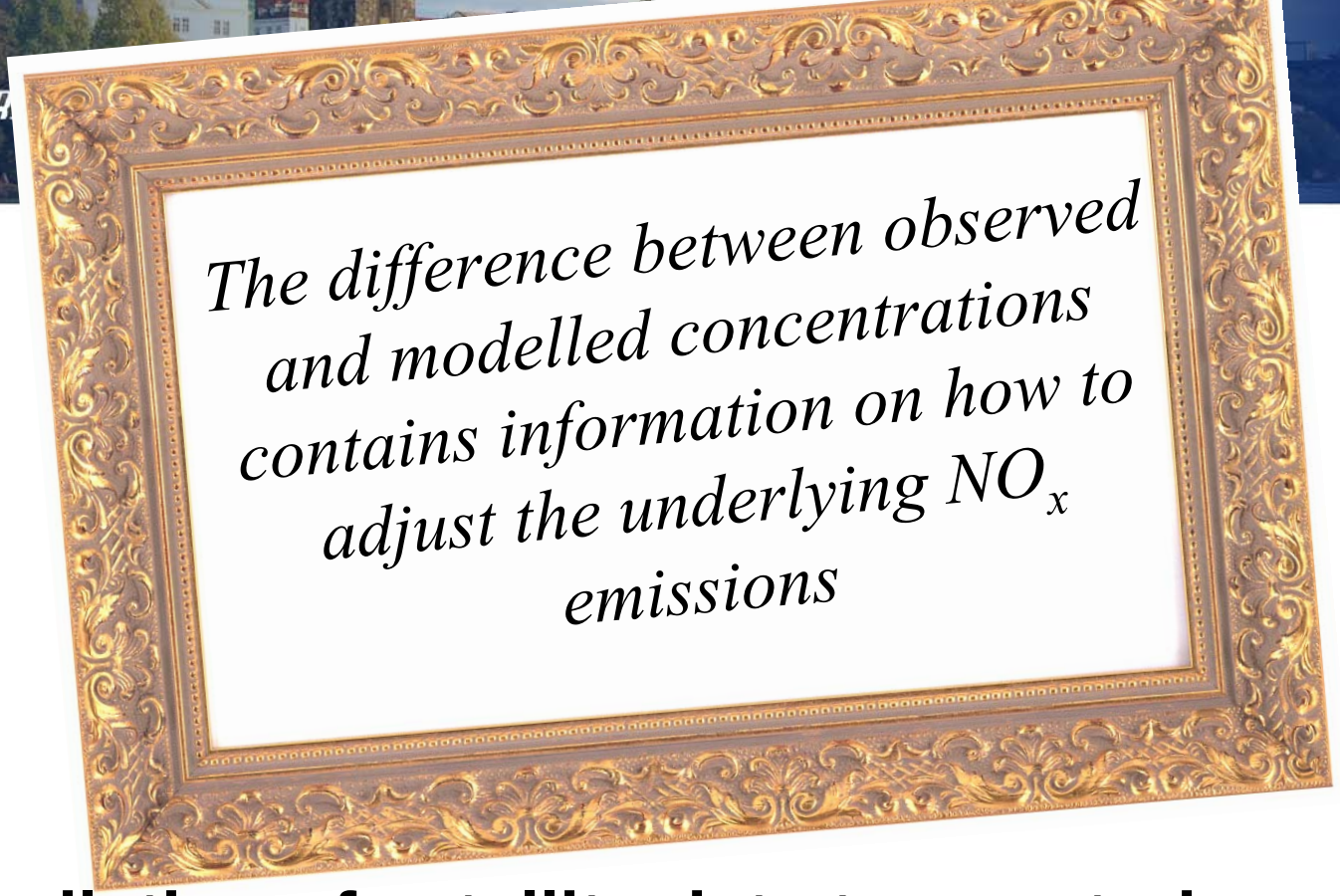
April-May 2008



GOME2 - CHIMERE



Mainly caused by incorrect NO_x emissions in CTM

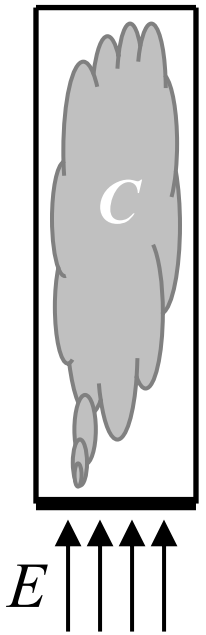


Assimilation of satellite data to constrain emissions

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

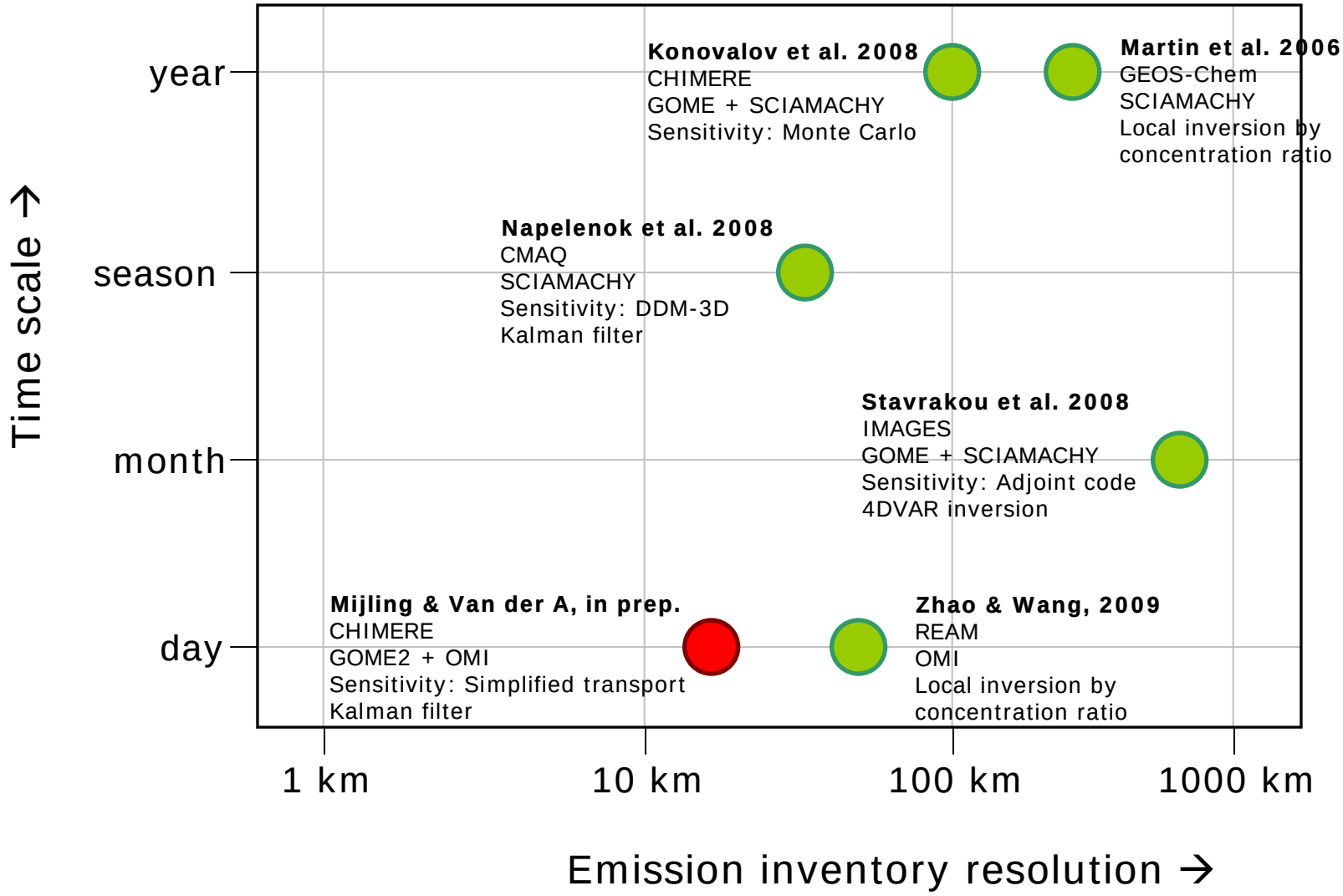
Sensitivity matrix

- 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):
  $E = \alpha C$, α determined from model runs

Overview other approaches



VECSO Algorithm

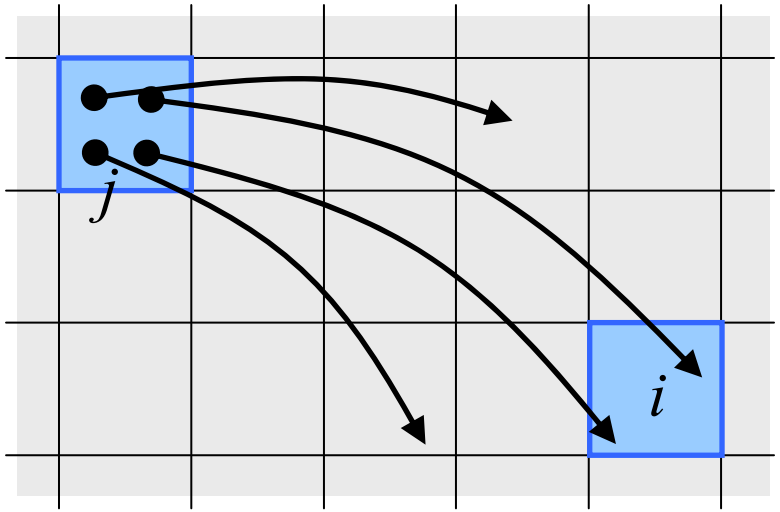
Variability of Emissions in China constrained by Satellite Observations

- Daily inversions of NOx emissions from NO_2 observations
  ➔ *fast algorithm!*
- On a 25 km^2 resolution over East China
  ➔ *include transport!*

New algorithm which uses a simplified 2D transport scheme

Including horizontal transport

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

Two concentration contributions

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

The concentration at $t=T$ is composed of

1. Transported and aged background concentration:

$$c_i(T) = \sum_j \exp\left(-T/\tau_j\right)\Omega_{j\to i}(T)b_j \quad \Rightarrow \quad \mathbf{c} = \mathbf{Gb}$$

2. Emitted and transported NO_x during the time interval:

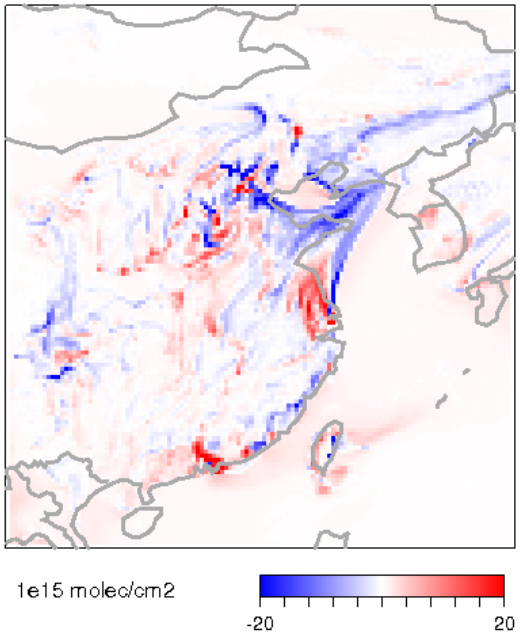
$$c_i(T) = \sum_j \left(\int_0^T \exp\left(-t/\tau_j\right)\Omega_{j\to i}(t) f_j(T-t)\mathrm{d}t \right) e_j \quad \Rightarrow \quad \mathbf{c} = \mathbf{He}$$

Effective lifetime

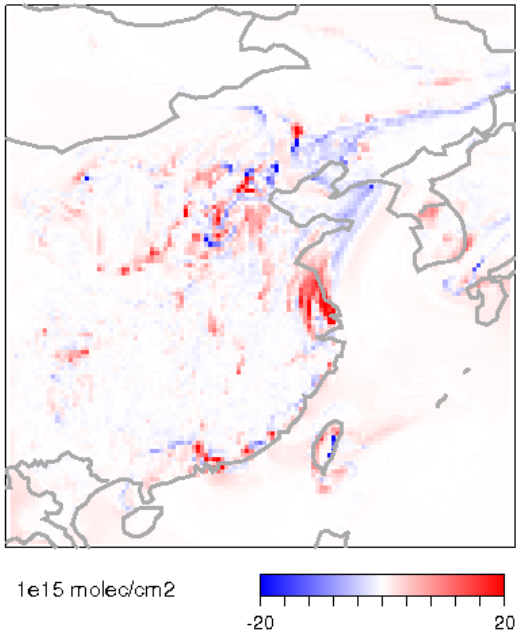
- Concentration from simplified 2D transport:
  $\mathbf{c}' = \mathbf{G}(\boldsymbol{\tau})\mathbf{b} + \mathbf{H}(\boldsymbol{\tau})\mathbf{e}$
- Compare with $\mathbf{c}$ from forward model run
- Fit lifetimes $\boldsymbol{\tau}$ which minimizes cost function
  $J(\boldsymbol{\tau}) = \| \mathbf{c}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

Results: lifetime fitting

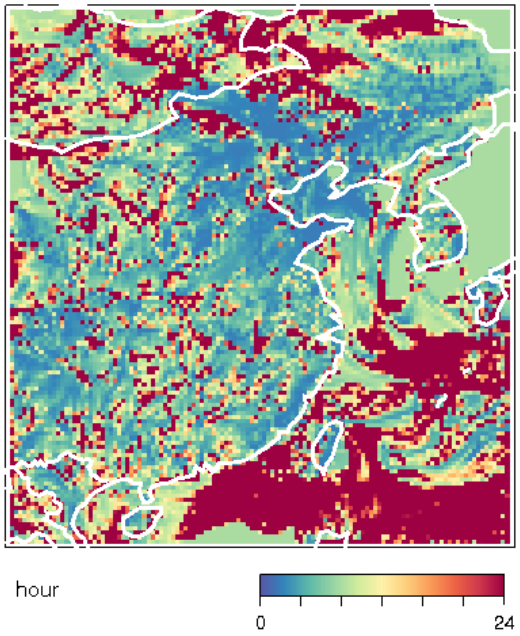
Initial residue
(lifetime NO_x 8h)



Final residue
(after 10 iterations)



fitted
NO_x lifetime

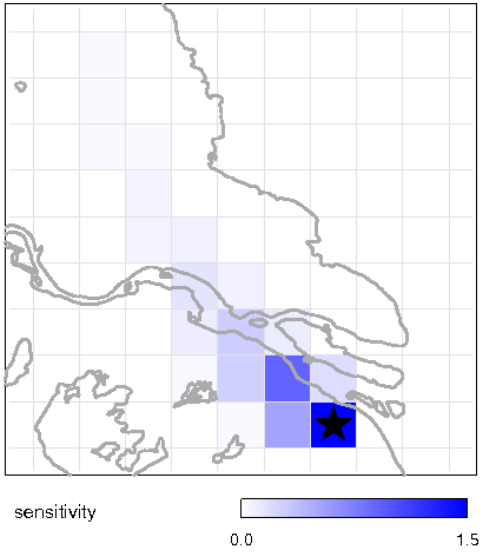


Residue CHIMERE – (Gb + He) for April 30th, 2008

Origen NOx column

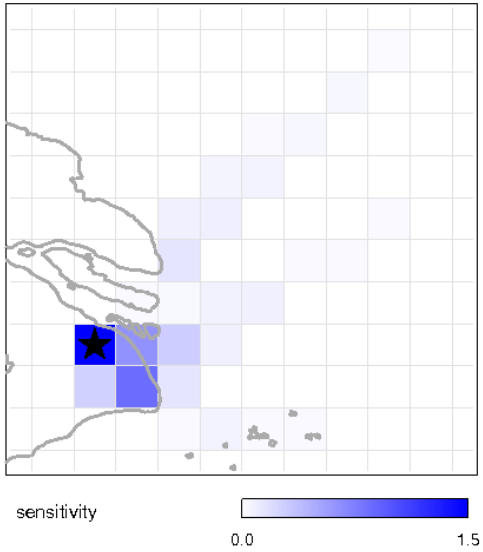
(downwind)

Sensitivities from Shanghai

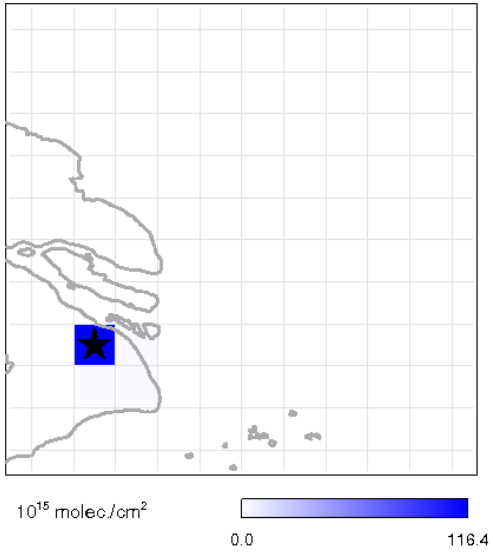


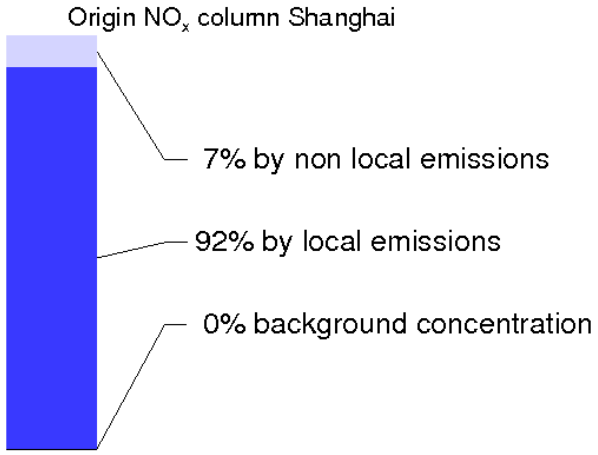
(upwind)

Sensitivities to Shanghai



Origen NOx column Shanghai

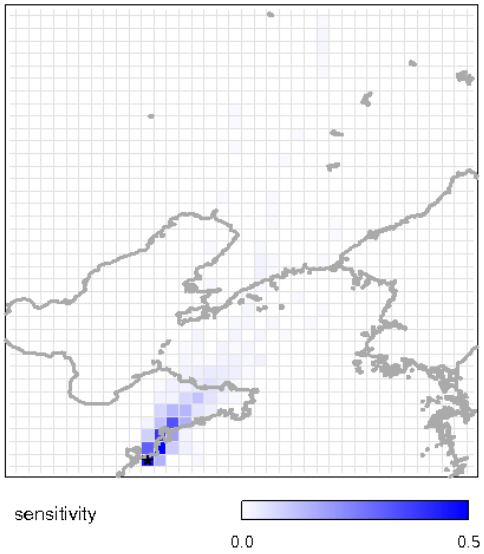




Origen NOx column

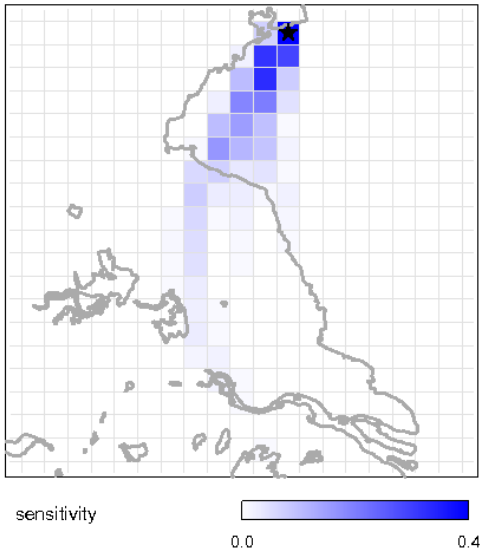
(downwind)

Sensitivities from Qingdao

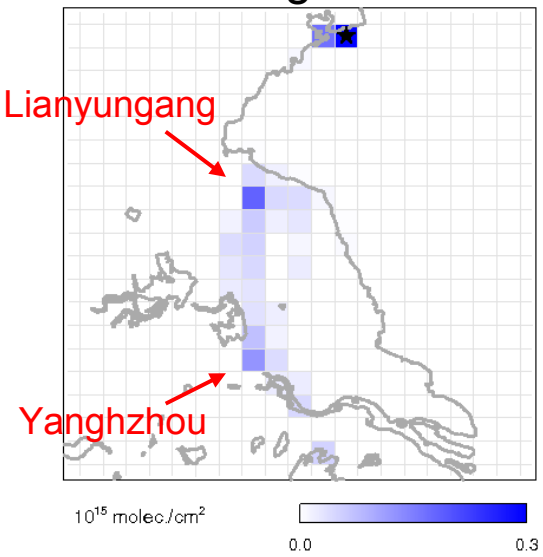


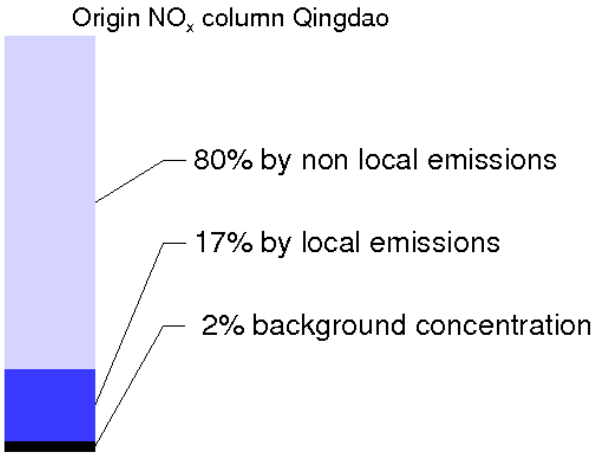
(upwind)

Sensitivities to Qingdao



Origen NOx column Qingdao





Inversion problem

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

$$H = \frac{\partial c_i}{\partial e_j}$$

Difference GOME-2 observation and model simulation over East China

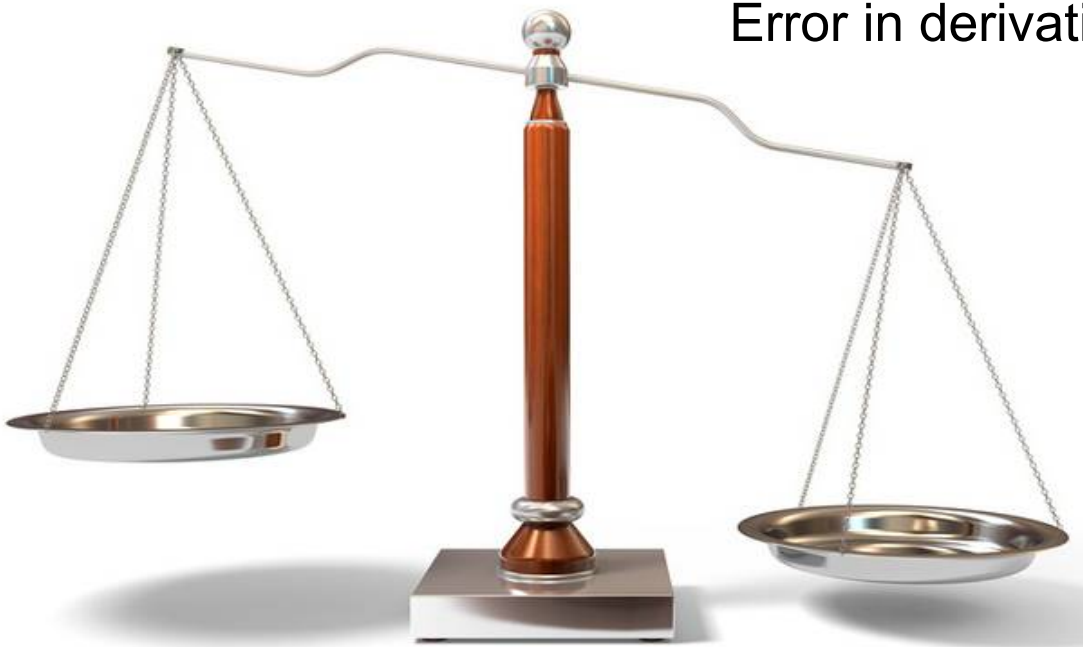
Sensitivity matrix ~ 2000×15000

Update emission inventory (0.25°) over East China

Analysis of emission

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

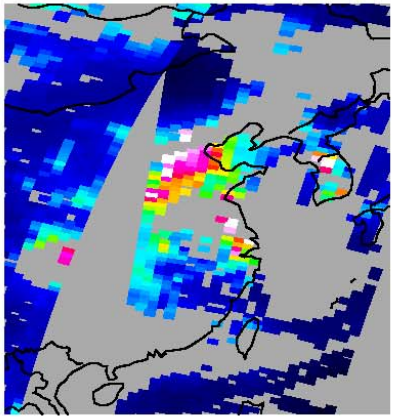
Kalman equations

State vector forecast	$\mathbf{x}^f(t_{i+1}) = M_i\,[\mathbf{x}^a(t_i)]$
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	$\mathbf{x}^a(t_i) = \mathbf{x}^f(t_i) + \mathbf{K}_i(\mathbf{y}_i^o - H_i\,[\mathbf{x}^f(t_i)])$
Error covariance analysis	$\mathbf{P}^a(t_i) = (\mathbf{I} - \mathbf{K}_i\mathbf{H}_i)\,\mathbf{P}^f(t_i)$

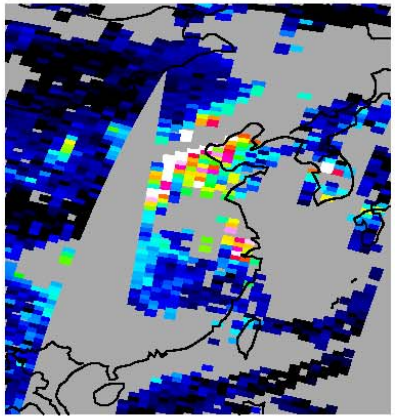
- $\mathbf{x}$ NO_x emissions
- $\mathbf{y}$ tropospheric NO_2 column observations
- M emission model
- H Observation operator, linking NO_x emissions to NO_2 concentrations
- $\mathbf{H}$ Linearization of H around $\mathbf{x}=\mathbf{x}^a$: $\mathbf{y} = \mathbf{y}^a + \mathbf{H}(\mathbf{x} - \mathbf{x}^a)$

1st Results: Inversion

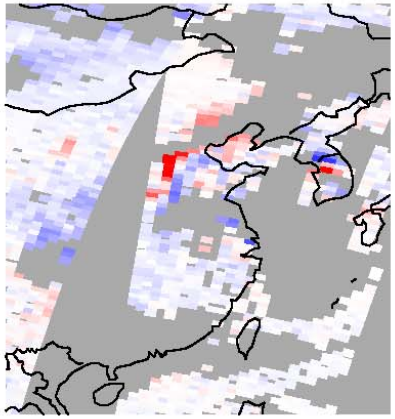
Model forecast



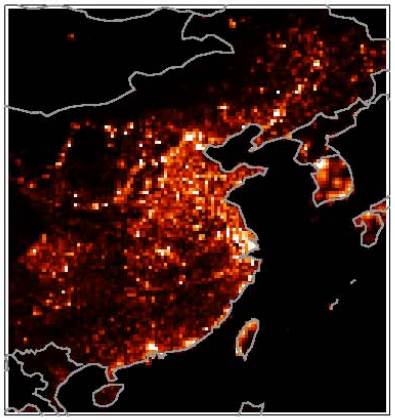
Satellite observations



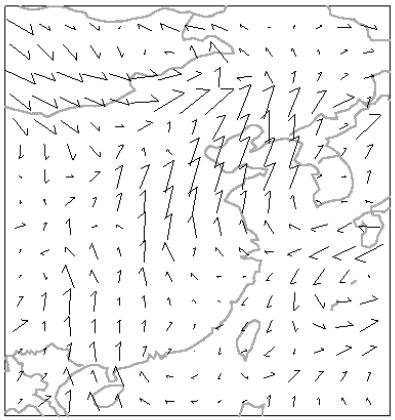
OmF



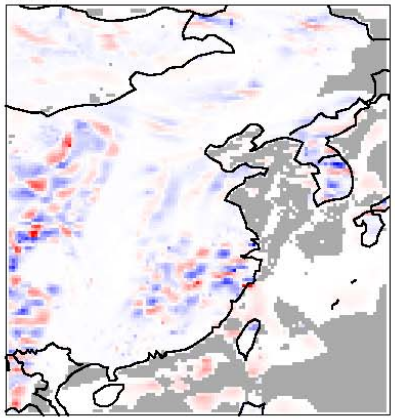
Old emission



Mean wind field



Emission update



Conclusion

- The presented method is a promising new technique for top-down emission estimates from satellite observations.
- The algorithm is fast (<1h), 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.

Dragon-2, 2nd phase

- Time series of NOx 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.


Thank you!