Using satellite NO_2 measurements to infer multiannual changes in CO_2 emissions in China

E. V. Berezin, I. B. Konovalov

Institute of Applied Physics, Nizhny Novgorod, Russia

P. Ciais
LSCE, CNRS -CEA –UVSQ, Gif sur Yvette, France

A. Richter
IUP, University of Bremen, Bremen, Germany

S. Tao
Peking University, Beijing, China

G. Janssens-Maenhout
JRC, Ispra (Va), Italy

M. Beekmann
LISA, CNRS, *Créteil, France*

E.-D. Schulze
MPI for Biogeochemistry, Jena, Germany

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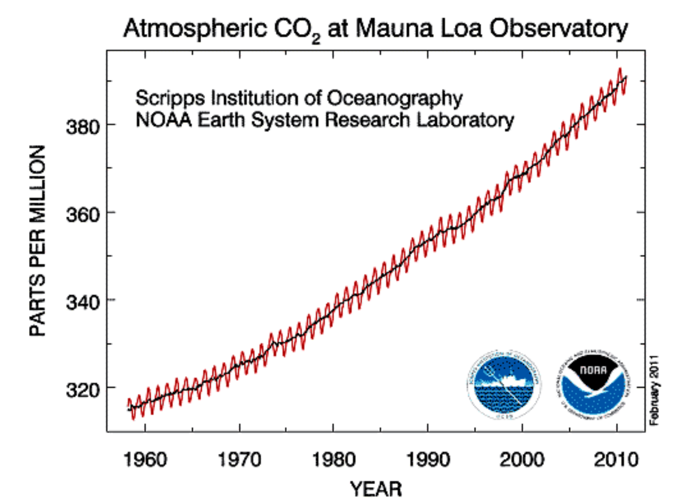
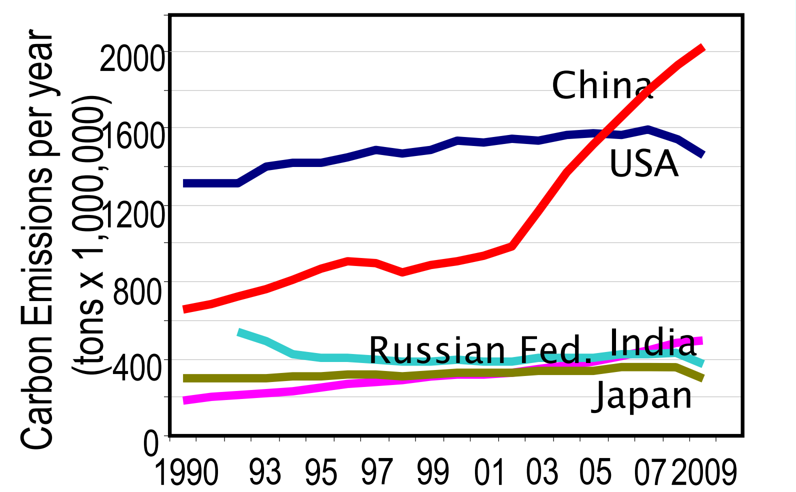
MOTIVATION

CO_2 is the major greenhouse gas whose atmospheric concentration is growing

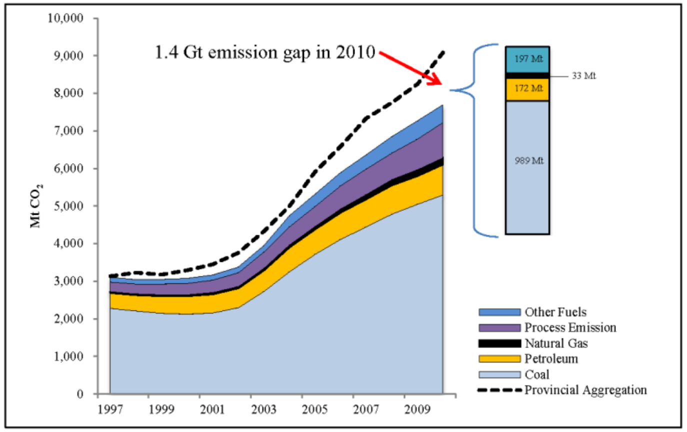


Anthropogenic emissions is likely the major factor driving the atmospheric CO2 increase



[Global Carbon Project (GCP), 2010]

"Bottom-up" CO2 emissions estimates are rather uncertain and need to be validated by measurements



Guan et al., Nature, 2012

The potential of CO_2 measurements (both satellite and ground based) to constrain anthropogenic CO_2 emissions is limited because of long life-time of CO_2, small variability and large vegetation fluxes

IDEAS OF THE STUDY

[Berezin et al., ACPD, 2013]

- Using "top-down" estimates of emissions of co-emitted species (NO_x in the given case) to (indirectly) constrain emissions of CO_2 [Rivier et al., 2006; Brioude et al., 2012 …]
- Using satellite NO_2 measurements to characterize temporal evolution of anthropogenic NO_x emissions [Richter et al., 2005; Zhang et al., 2007; Konovalov et al., 2008, 2010; Wang et al., 2012…]

MAIN OBJECTIVES OF THE STUDY

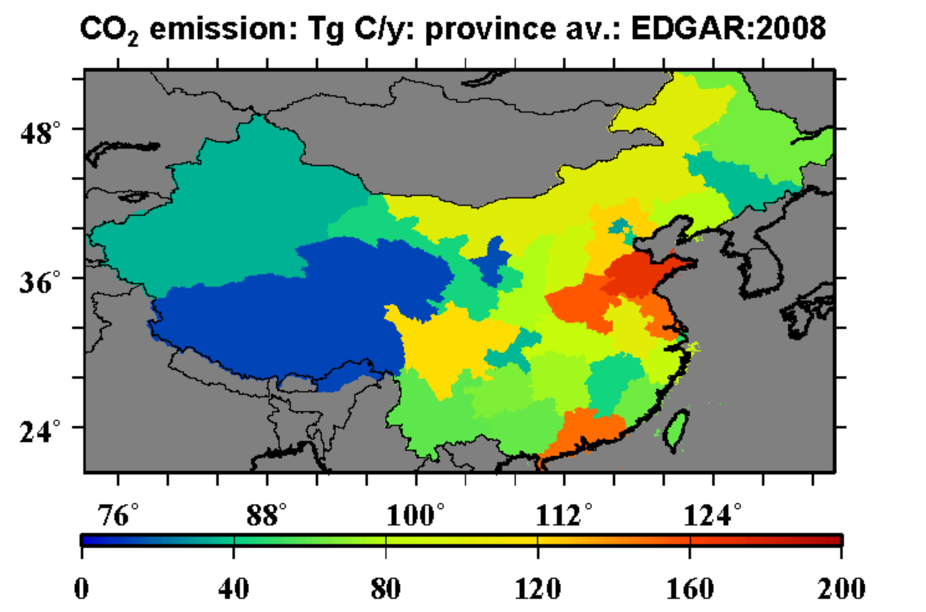
- Estimation of multi-annual changes in CO_2 emissions from China by using satellite NO_2 measurements

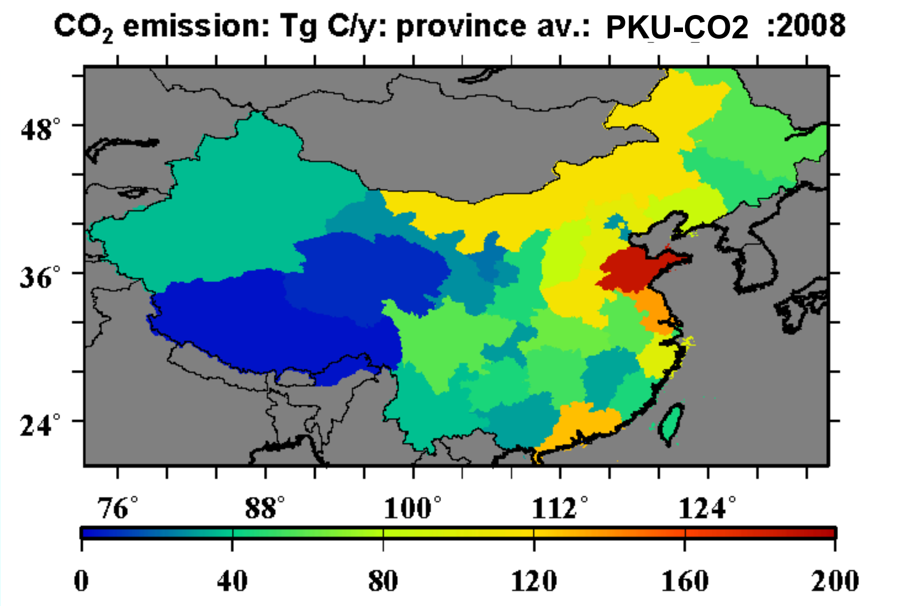
- Comparative analysis of “top-down” and different “bottom-up” CO_2 emission estimates (including the data of the EDGAR, GCP and PKU-CO2 emission inventories)

INPUT DATA

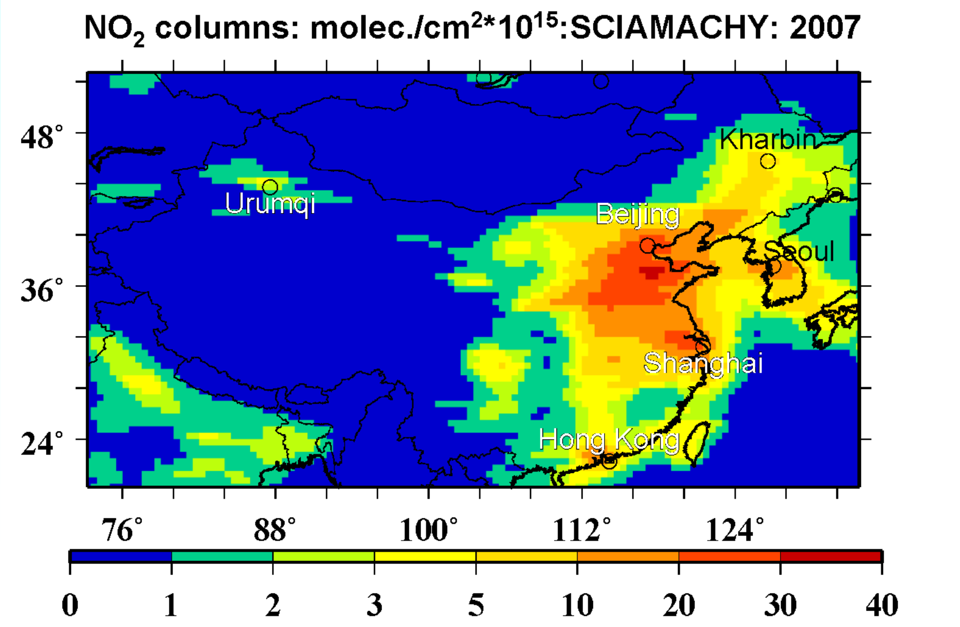
- **Monthly mean GOME tropospheric NO_2 columns over the period of 1996-2002** (Tropospheric excess NO_2 columns Version 2 data product of University of Bremen)
- **Monthly mean SCIAMACHY tropospheric NO_2 columns over the period of 2003-2008** (Tropospheric excess NO_2 columns Version 0.7 data product of the University of Bremen) . SCIAMACHY data are preliminary spatially smoothed as in Konovalov et al., 2010 to simulate the smoothing introduced by the GOME measurements
- **Annual (1996-2008) data of the EDGAR V4.2 global anthropogenic emission inventory**, provided with the resolution of 0,1°×0,1°, NO_x &CO_2
- **Annual (1996-2008) data of the GCP global CO_2 anthropogenic emission inventory** (national totals)
- **National CO_2 emission inventory (PKU-CO2) by Peking University**; the annual data are provided on provincial level for three years (1997, 2002, 2008)
- **Tropospheric NO_2 columns simulated with the CHIMERE chemistry transport model** (spatial resolution : 1°×1°, 12 layers up to 200 гПа; chemistry: MELCHIOR1 (300 reactions)+aerosols; anthropogenic emissions: EDGAR v4.1; biogenic (soil) emissions: MEGAN; boundary conditions: LMDZ-INCA; meteorology: WRF-ARW driven by the NCEP re-analysis data)

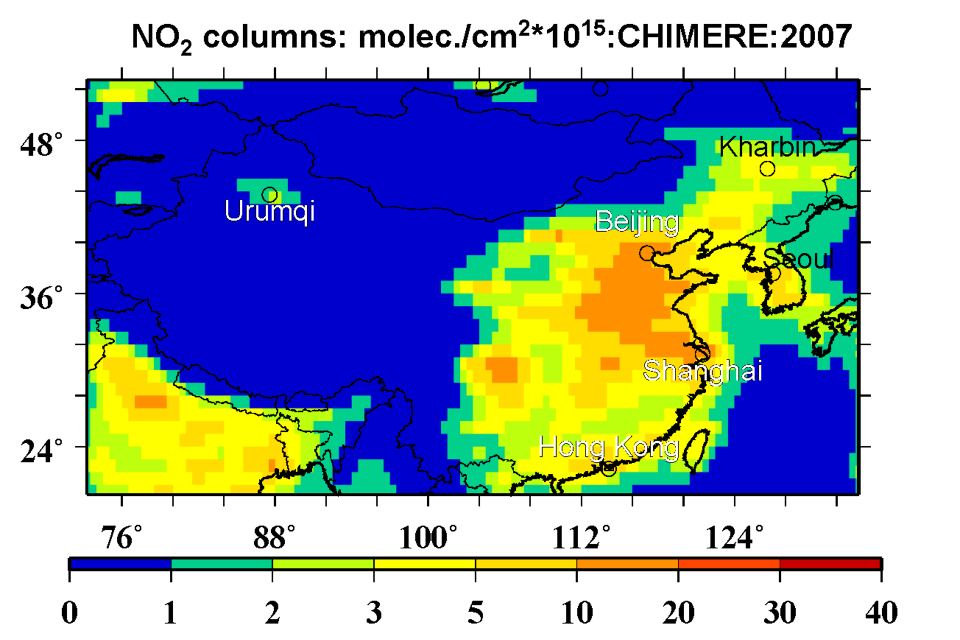
SPATIAL DISTRIBUTION OF CO_2 EMISSIONS





TROPOSPHERIC NO_2 COLUMNS





ESTIMATION OF CO_2 EMISSION CHANGES: THE METHOD

$$C_i \approx \alpha_i E_i^{(NOx)} + C_{bi}$$

$$\alpha_i \approx (C_{0i} - C_{bi}) / E_0^{(NOx)}$$

$$E_t^{(NOx)} \Big/ E_0^{(NOx)} \approx \Sigma_{i=1}^{12} \left(\frac{C_i - C_{bi}}{C_{0i} - C_{bi}} \right)$$

$$E_t^{(CO2)j} \Big/ E_t^{(CO2)k} \approx F^j \Sigma_{i=1}^{12} \left(\frac{C_i^j - C_{bi}^j}{C_{0i}^k - C_{bi}^k} \right) \Big/ F^k \Sigma_{i=1}^{12} \left(\frac{C_i^k - C_{bi}^k}{C_{0i}^k - C_{bi}^k} \right)$$

C_i - the tropospheric NO_2 columns for a month i
$E_i^{(NOx)}$ - anthropogenic NO_x emissions in China
α_i - the sensitivity of the NO_2 columns to changes of the NO_x emissions
C_{bi} (g) - the "background“ tropospheric NO_2 columns
$E_0^{(NOx)}$ – constant monthly emissions in the model

$$F = \frac{E_t^{(CO2)}}{E_t^{(NOx)}} \longleftarrow$$

the average NO_x-to-CO_2 emission conversion factor for a given year (from EDGAR)

THE ASSUMPTIONS AND SENSITIVITY TEST CASES

(1) the impact of NO_x emitted in a previous month on the NO_2 columns in a given month is negligible;
(2) the transport of NO_x into a considered region from outside is also negligible;
(3) the long-term changes in natural NO_x emissions are much smaller than the trends in anthropogenic emissions;
(4) the impact of interannual changes in $\boldsymbol{C_0}$ and $\boldsymbol{C_b}$ due to meteorological variability and other factors can be disregarded

Case A:

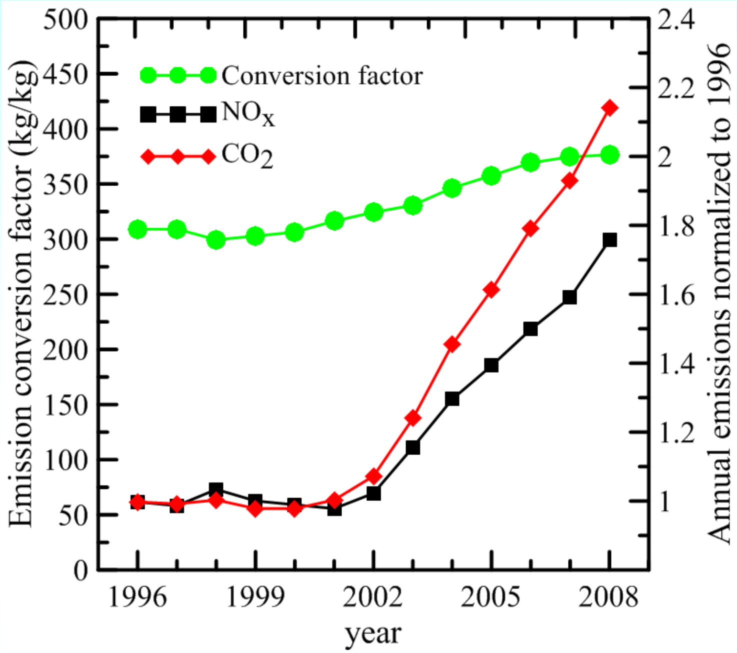
$$E_t^{(CO2)j} \Big/ E_t^{(CO2)k} \approx F^j \sum_{i=1}^{12} \left(\frac{C_i^j - C_{bi}^j}{C_{0i}^k - C_{bi}^k} \right) \Big/ F^k \sum_{i=1}^{12} \left(\frac{C_i^k - C_{bi}^k}{C_{0i}^k - C_{bi}^k} \right)$$

Case B: $C_b = 0$

Case C: $C_b = 0$; the seasonal cycle in NO_x emissions is absent:

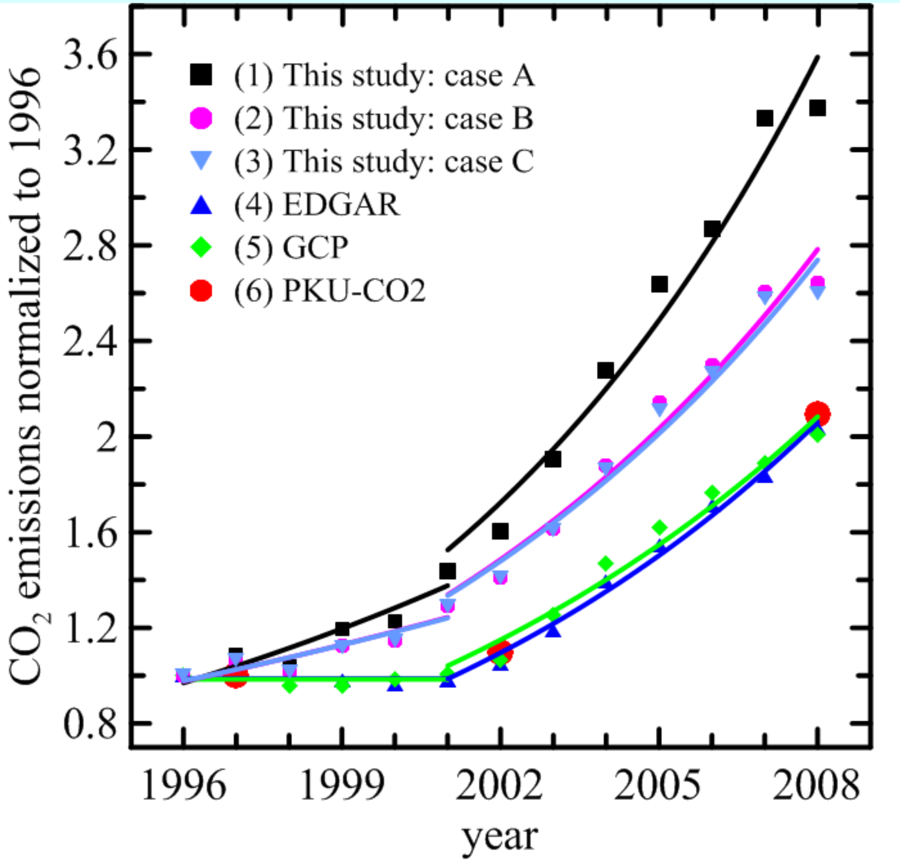
$$E_t^{(CO2)j} \Big/ E_t^{(CO2)k} \approx \frac{F^j}{12F^k} \sum_{i=1}^{12} \left(\frac{C_i^j}{C_i^k} \right)$$

MULTIANNUAL CHANGES OF CO_2 AND NO_x EMISSIONS IN CHINA



Multiannual evolution of the CO_2 and NO_x anthropogenic emissions in China and the behavior of the corresponding NO_x-to-CO_2 emission conversion factor according to the EDGAR emission inventory. The emissions are normalized to their values in 1996.

THE RESULTS: THE TRENDS IN TOTAL CO_2 EMISSIONS



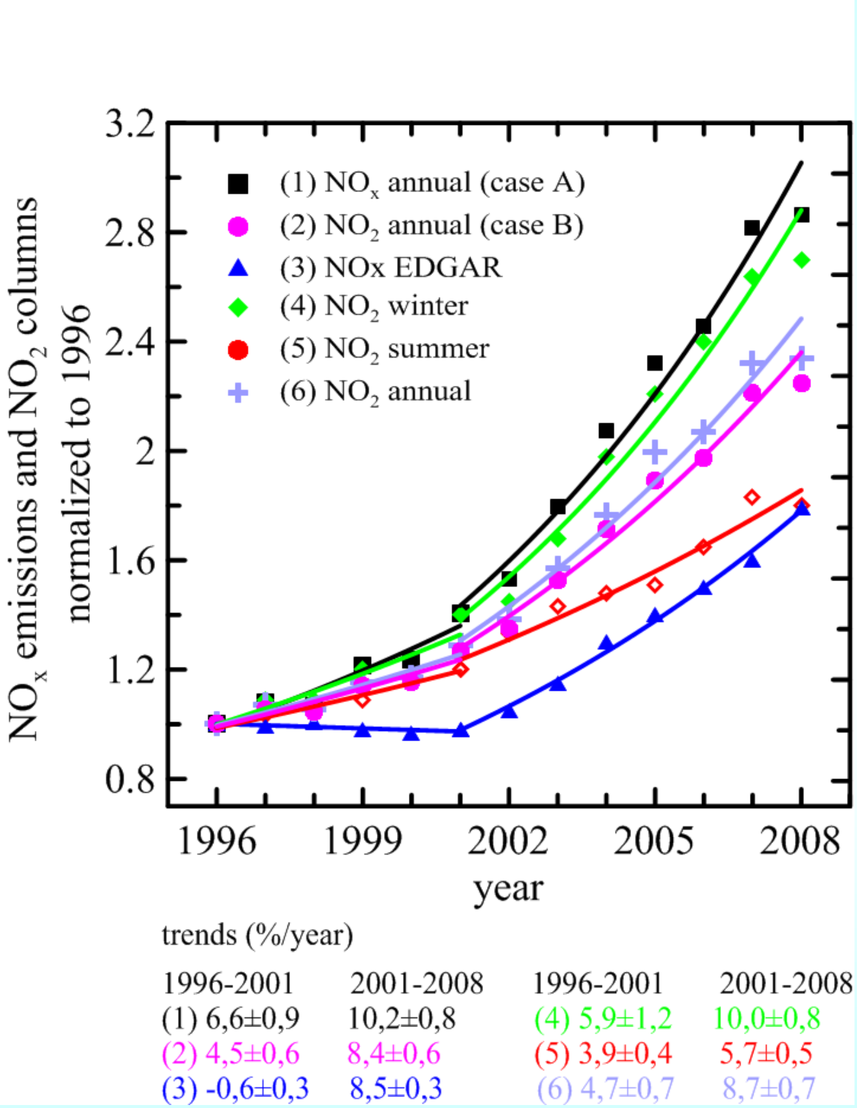
trends (%/year)

	1996-2001	2001-2008		1996-2001	2001-2008
(1)	6,8±1,2	12,1±0,9	(4)	-0,6±0,3	10,5±0,4
(2)	4,8±1,1	10,5±0,8	(5)	-0,1±0,6	9,9±0,7
(3)	4,8±1,1	10,3±0,8			

NB: To evaluate emission trends, we built exponential approximations ($A \cdot exp(kt)$, where A and k are the optimized parameters of the fits, and t is time in years) independently for two periods: 1996-2001 and 2001-2008. These two periods were chosen taking into account a sharp bend in the time series of the EDGAR emissions for China between 2000 and 2002

The measurement-based estimates are statistically different from the trends in the EDGAR NO_x emissions in the period from 1996 to 2001

THE RESULTS: THE TRENDS IN TOTAL NO_x EMISSIONS

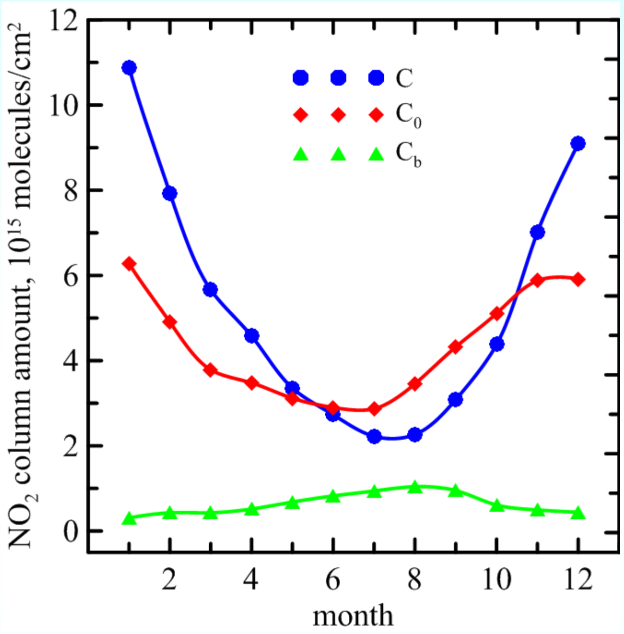


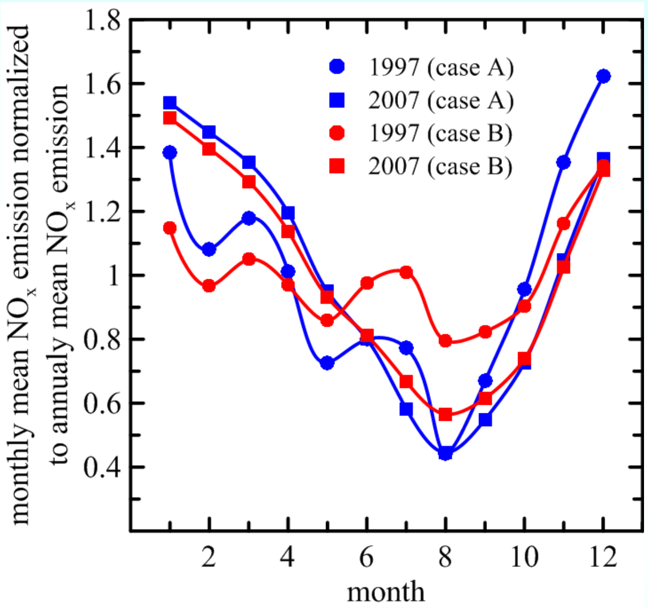
NB: The difference in the trends in NO2 columns in summer and winter is probably due to significant contribution of biogenic emissions to the tropospheric NO_2 columns in summer

The difference between the bottom-up and top-down estimates may be due to the fact that activities of an increasing number of small private enterprises dealing with coal mining and electricity generation in China are not properly reflected in national statistics [Akimoto et al. 2006; Guan et al. 2012]

The top-down estimates are statistically different from the trends in the "bottom – up" (EDGAR) NO_x emissions in the period from 1996 to 2001

SEASONAL CYCLE IN ANTHROPOGENIC EMISSIONS

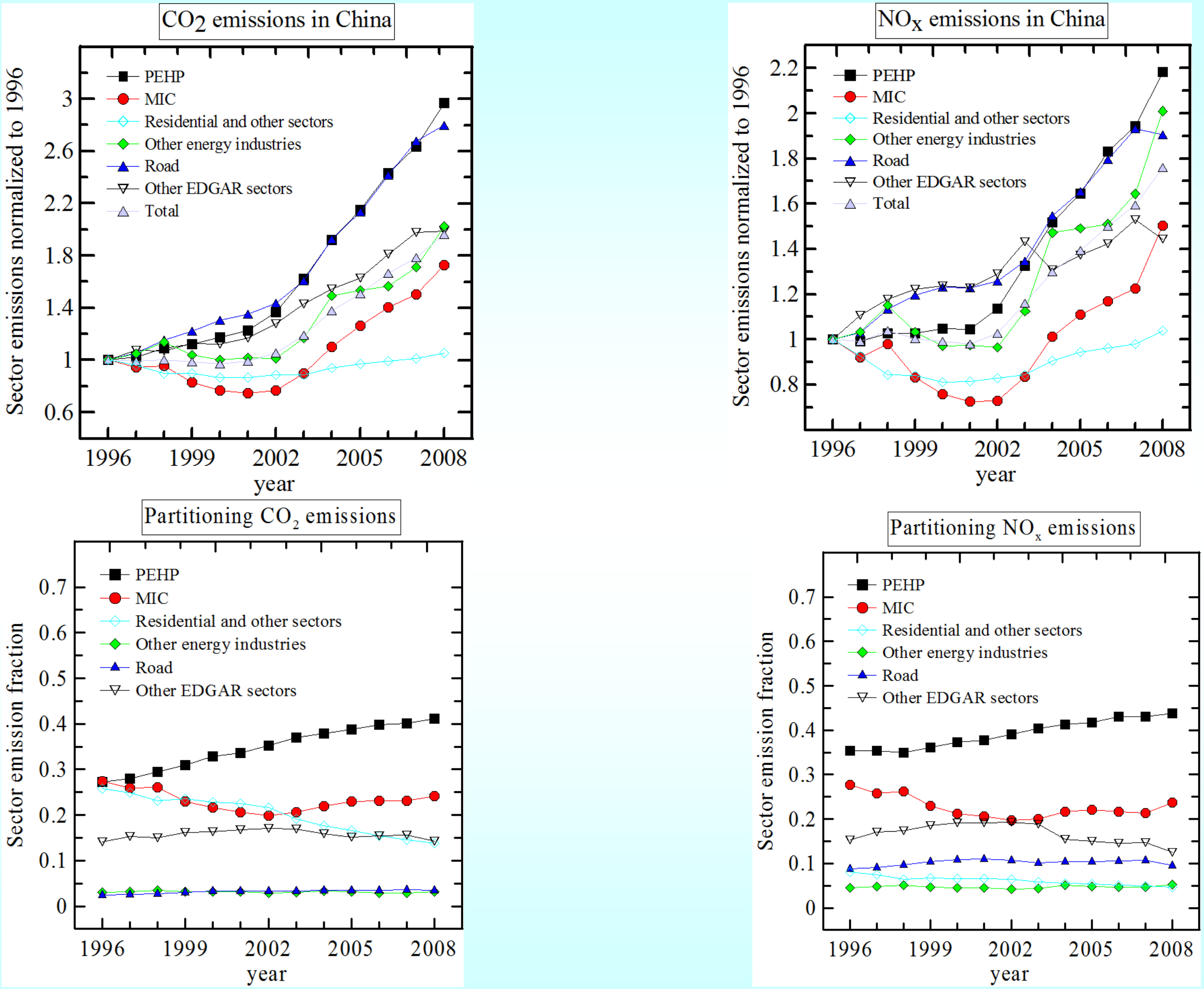




The ratio of the maximum and minimum monthly NO_x emissions is found to be of 3.6 and 1.7 in 1997 and 3.4 and 2.7 in 2007 in the cases A and B, respectively

For comparison: this ratio have been estimated to be 1.3 by Zhang et al., 2007 (bottom up), 1.5 by Jaeglé et al. 2005 (top down), 2.1 by Wang et al. 2007

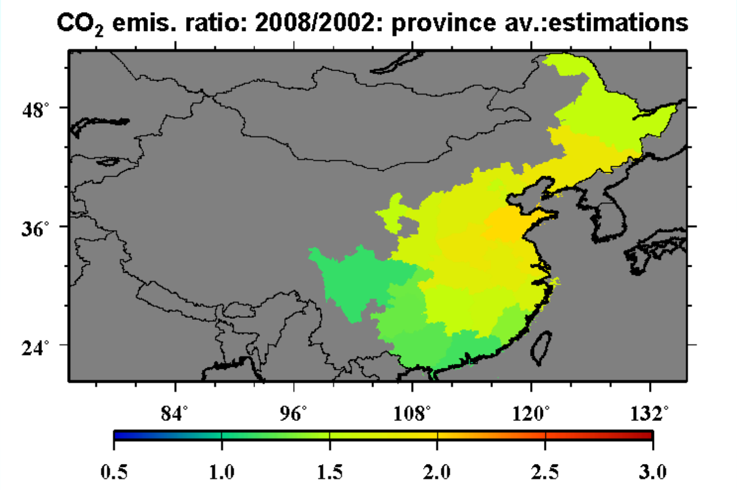
THE EDGAR SECTOR DATA ANALYSIS

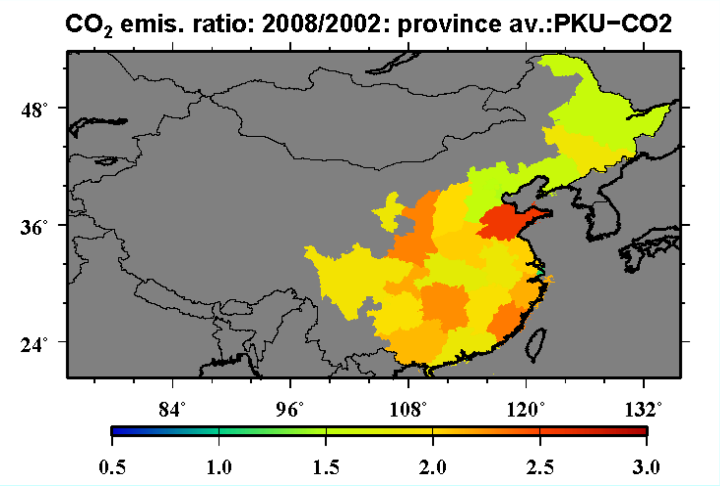


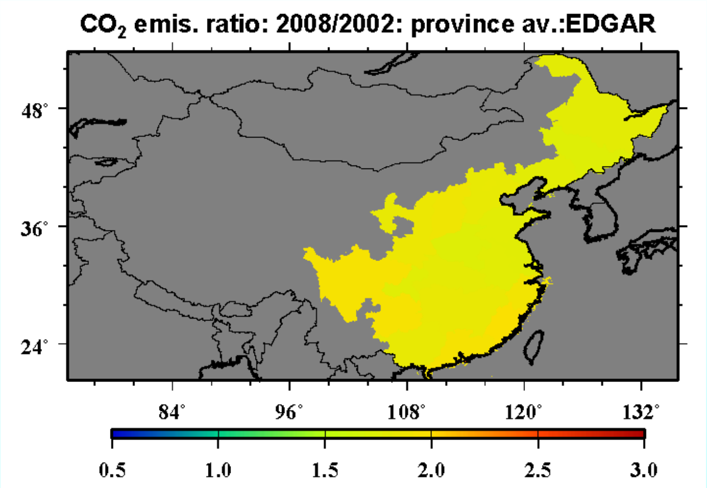
PEHP-public electricity and heat production; MIC- manufacturing industries and construction

ANALYSIS OF THE SPATIAL DISTRIBUTION OF CO_2 EMISSION CHANGES

Magnitudes of the ratio of CO_2 emission estimates in the year 2008 to those in 2002



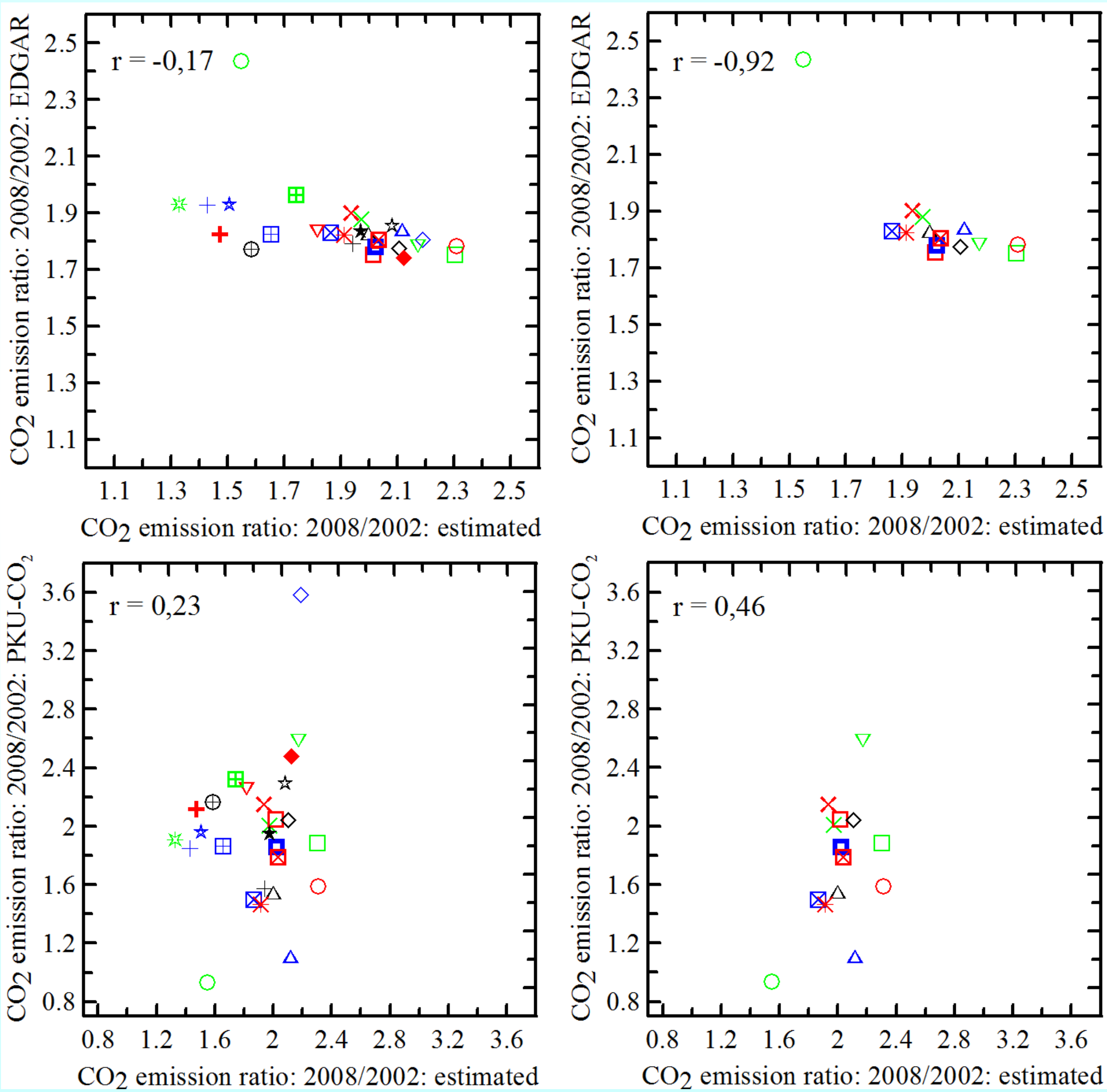




ANALYSIS OF THE SPATIAL DISTRIBUTION OF CO_2 EMISSION CHANGES (2008/2002)

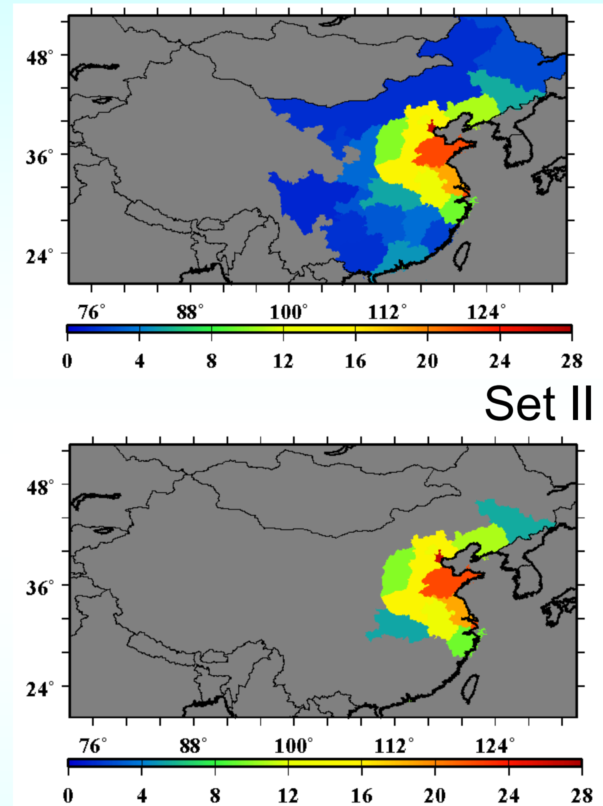
Set I

Set II



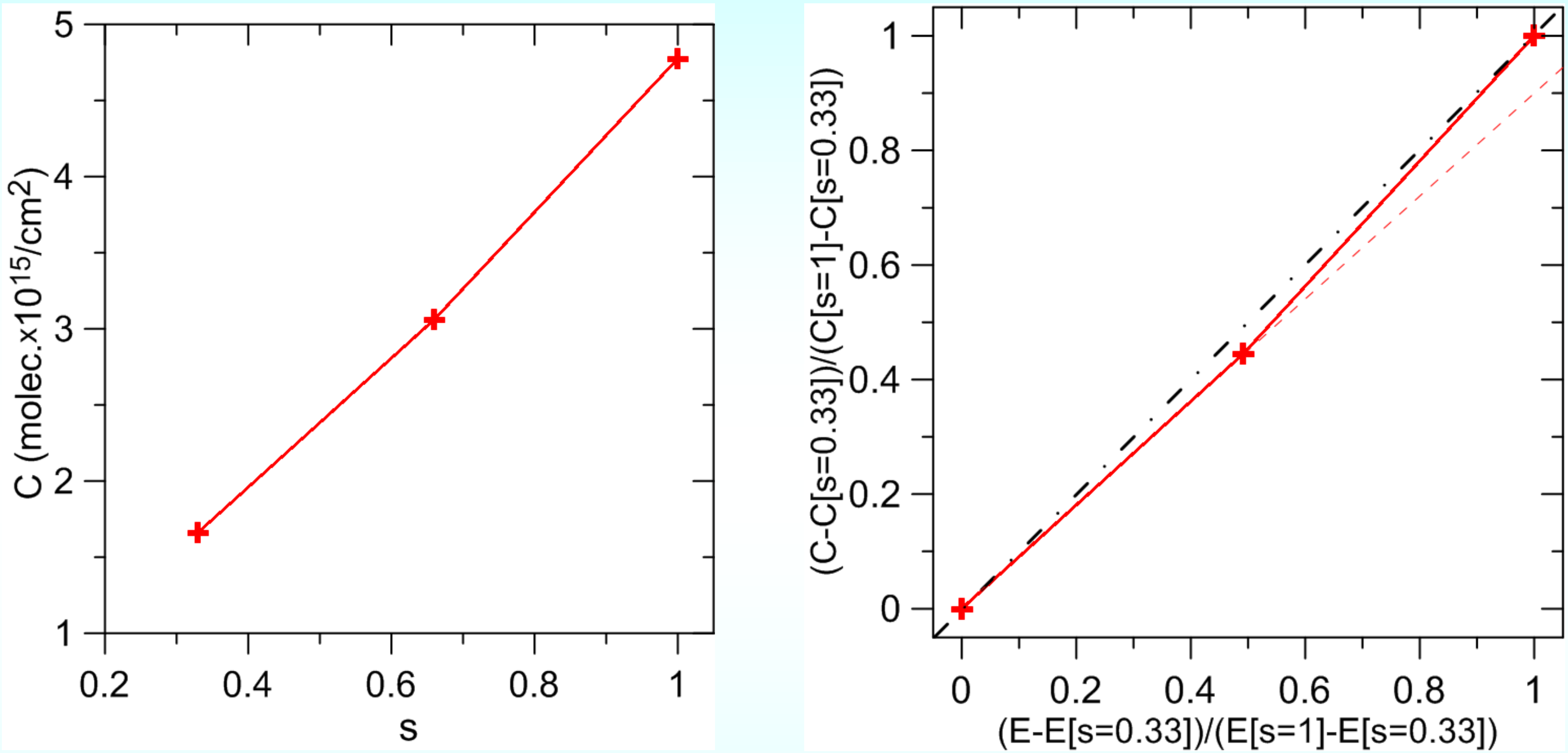
Set I

Set II



The provinces of China for different threshold levels, $[NO_2]_c$, of the annual mean measured tropospheric NO_2 columns: (top) $[NO_2]_c=1\cdot10^{15}$ and (bottom) $[NO_2]_c=5\cdot10^{15}$ molecules/cm^2

THE IMPACT OF THE CHEMICAL NONLINEARITY



CONCLUSIONS

- Tropospheric NO_2 measurements provide useful information about anthropogenic CO_2 emission sources collocated with the sources of NO_x emissions; this study may open up a "new dimension" in applications of such measurements

- The top-down estimates confirm the increasing rate of CO_2 emission changes in China in the period from1996 to 2008, but results of our analysis also suggest that nonlinearity of CO_2 emission changes over China strongly exaggerated in the emission inventories.

- A significant quantitative difference is revealed between the bottom-up and top-down estimates of the CO_2 emission trend in the period from 1996 to 2001; this difference confirms results of earlier studies by Akimoto et al. [2006] and Guan et al. [2012].

THANK YOU!