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The trend of sulfur dioxide emissions in China after 2000

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Outline

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Introduction

- SO₂ emission in China contributes to about one-fourth of the global emission and more than 90% of East Asia emission since 1990s.

e.g. Streets et al., 2006, 2009; Ohara et al., 2007

- Sulfur-contained air pollutants are reported to be transported long distances from Asia continent to Northwestern Pacific, North America and the rest of northern hemisphere.

*e.g. Aikawa et al., 2010; Lin et al., 2008;
Huebert et al., 2003; Jacob et al., 2003*

- The SO₂ emission in China changed dramatically since 2000. However few works focused on the year-by-year trends during this period.

*e.g. REAS up to 2003; TRACE-P 2000;
INTEX-B 2006; GAINS 2005*

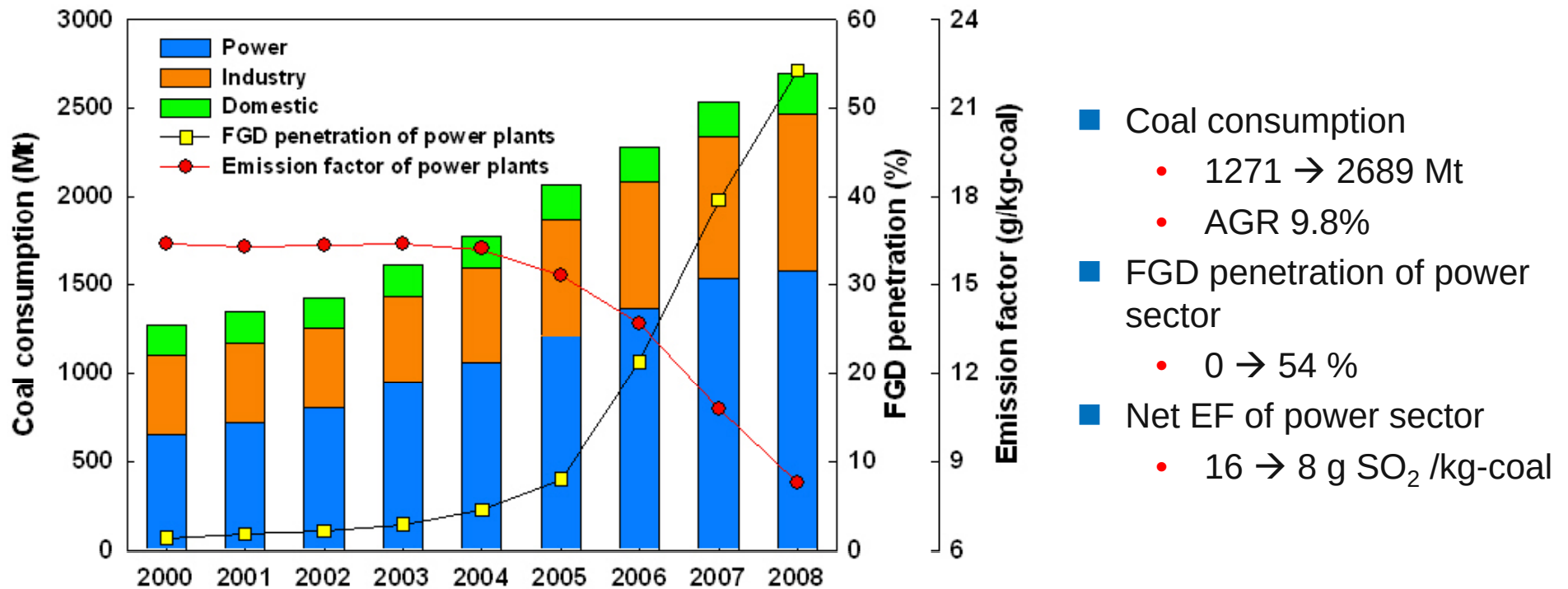
Purpose

- I. Estimate the historical SO₂ emission from China based on the dynamic technology penetration and the dramatic activity growth after 2000**
- II. Compare the SO₂ emission data with a variety of sulfur related quantities to provide a better understanding of the impact of SO₂ emission in China across the East Asian region**

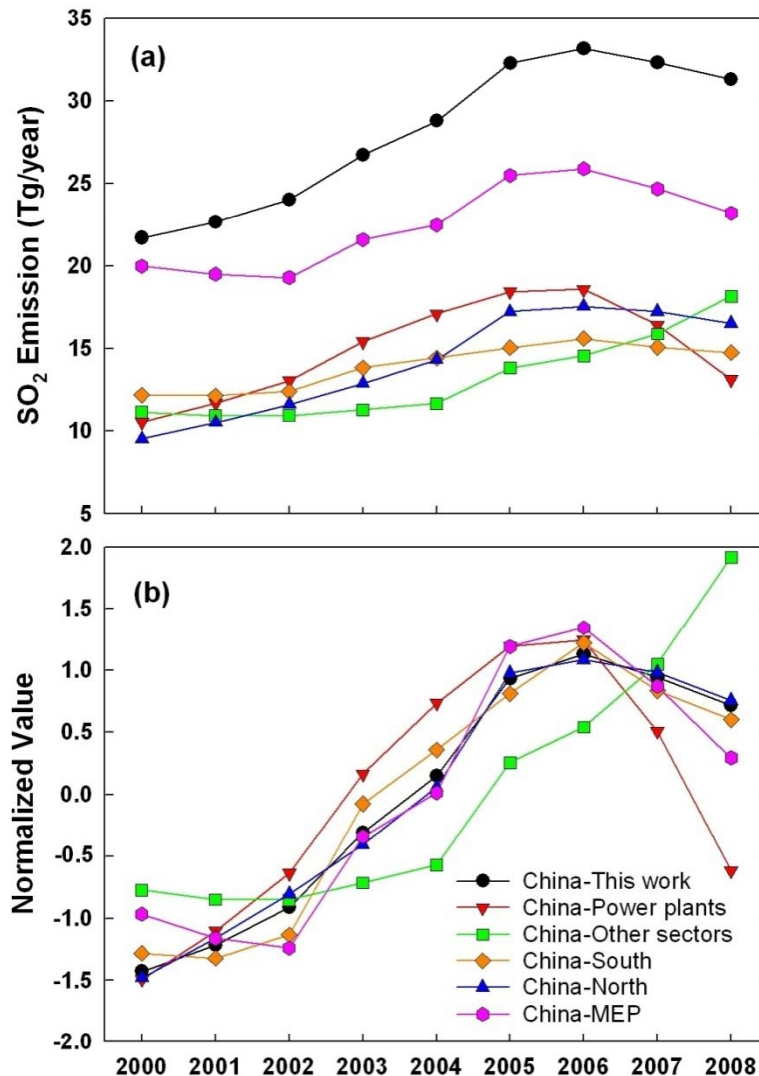
Method and data sets

■ Estimation of anthropogenic SO₂ emission in China

- A detailed technology-based methodology specifically for China
- 4 major sectors: power, industry, domestic and transportation
- Provincial activity data, fuel properties, and control strategies

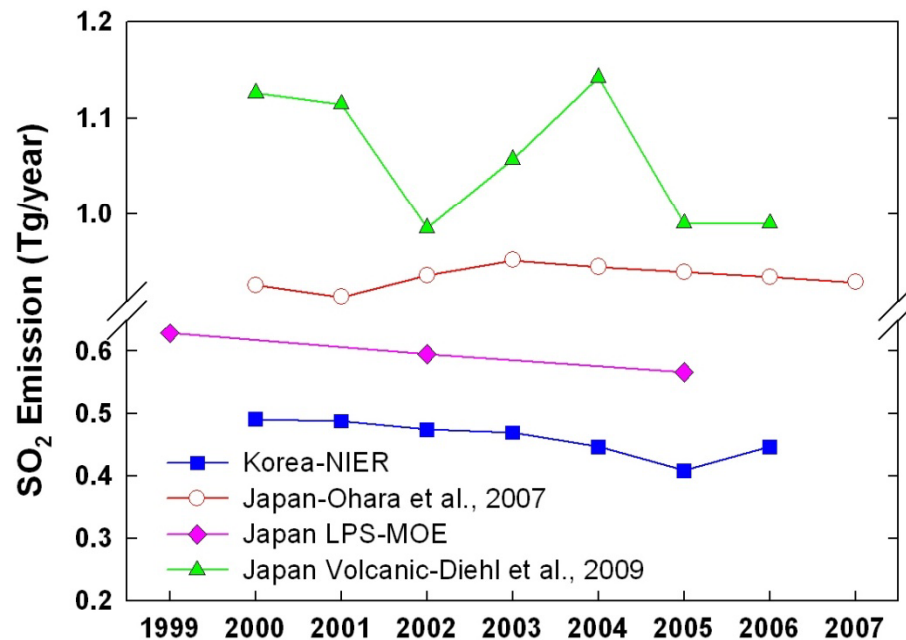


SO₂ emission in China after 2000



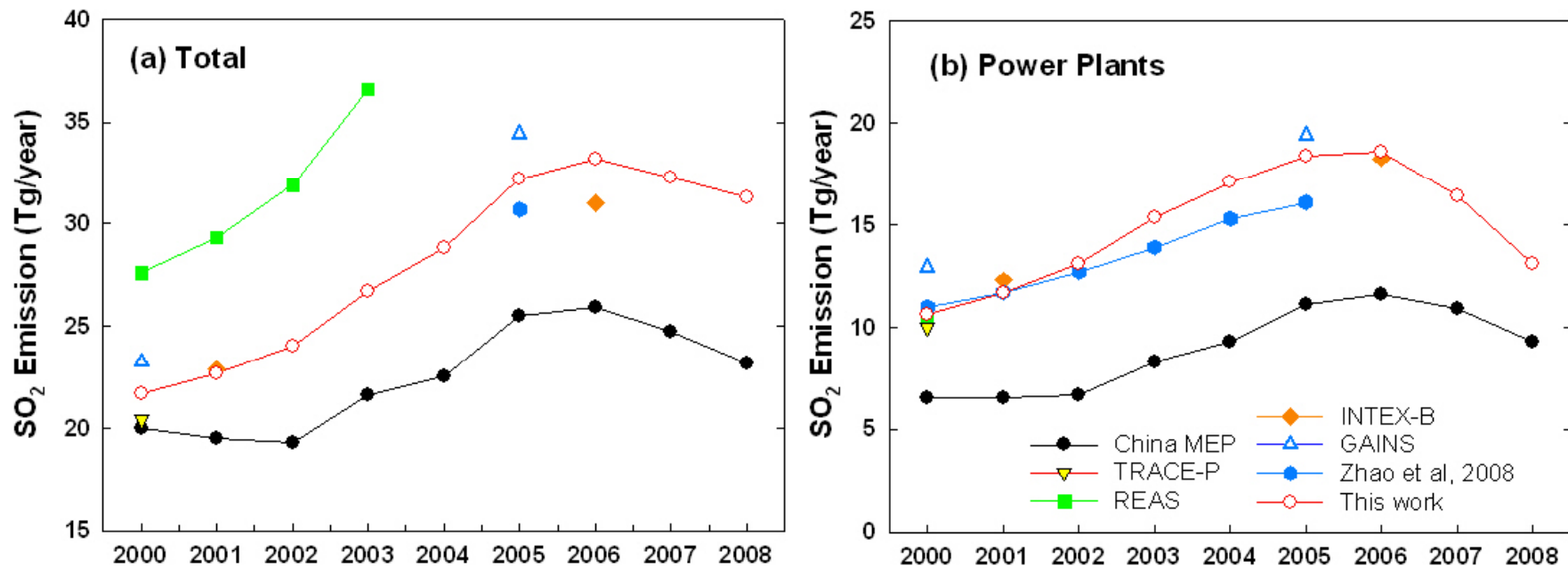
- The SO₂ emission in China increased by 53% from 2000 to 2006 with an AGR of 7.3%.
- The national SO₂ emission decreased after 2006 due to the application of pollution control technologies (e.g. FGD) and the phaseout of small highly emitted power generation units.
- Power plants are the main sources of SO₂ (> 50 %), and dominate the national SO₂ emission (R=0.95).
- The change of SO₂ emission is nationwide.
- However, the extent of the increase is different. From 2000 to 2006:
 - North China increased by 85%
 - South China increased by 28%

SO₂ emission in Japan and Korea after 2000



- The estimated SO₂ emission in Japan and South Korea shows a steady decrease trend after 2000.
- Although there is some variability of volcanic emission from 2000 to 2006, the variation is quite small ($\pm 8\%$ of the average value of 1.1 Tg per year), showing a small decreasing tendency during this period.

This work vs. previous studies

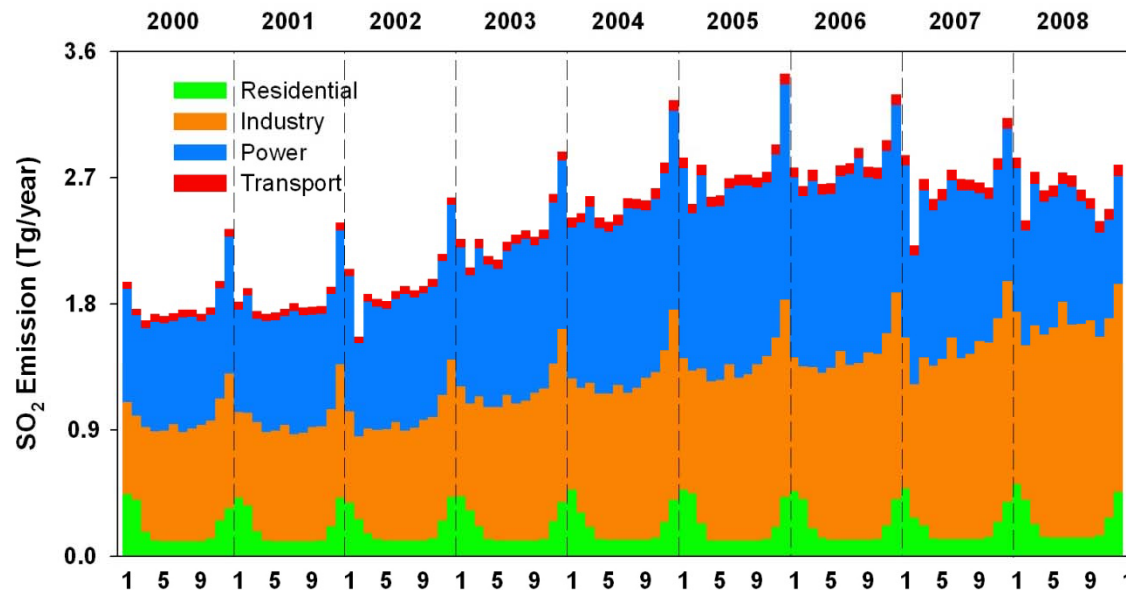


- Aikawa et al. compared the measured sulfate (SO_4^{2-}) concentration with CMAQ simulation at multiple sites over the East Asia Pacific Rim region.
- The SO_2 emissions: REAS and China MEP.
- The comparisons suggest that the REAS inventory overestimates, whereas the China MEP inventory underestimates the SO_2 emission from China.

Aikawa et al., 2010

SO₂ emission in China after 2000 --- Seasonality variations

- Month-specific SO₂ emissions during 2000-2008 are developed:
 - **Residential:** a dependence of stove operation on monthly mean temperatures
 - **Power:** monthly power generation
 - **Industry:** monthly industry GDP, H₂SO₄ and coke production
 - **Transport:** monthly volume of passenger and freight transported by ship, railway and aviation



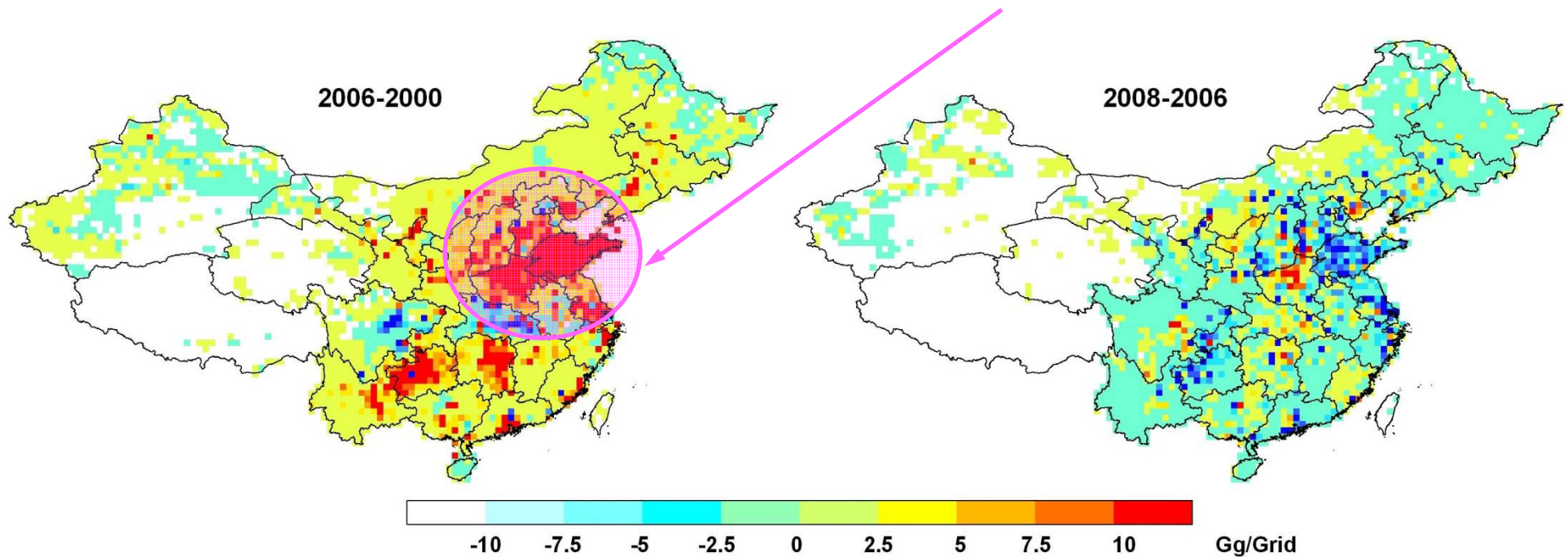
- weak seasonality variations
- high in December due to the increasing coal consumption in residential sector
- low in February since the reduced industrial activity during the Chinese Spring Festival holiday

SO₂ emission in China after 2000 --- Gridded emissions

■ Spatial proxies:

- **Year-specific:** total, urban and rural population, industrial GDP, crop land cover, and railroad and road network
- **Power plants:** bottom-up unit-based inventory

Since this area is to the windward of Japan and Korea, the dramatic change of SO₂ emission after 2000 may influence SO₂, SO₄²⁻ and AOD not only in China, but also in other parts of East Asia



Method and data sets

	Monitoring data	Satellite data
SO ₂	A variety of statistical yearbooks (China) Environmental Bulletins of a variety of provinces and cities (China) EANET (Japan and South Korea) NIES (Japan)	SCIAMACHY OMI
SO ₄ ²⁻	EANET (Japan and South Korea)	
Acid rain	A variety of statistical yearbooks (China)	
AOD		MODIS MISR
SSR	Subset of SSR observations reported by Wild et al. (2009) (East Aisa)	

For ease of comparison between the trends of multifarious data sets, the data sets are normalized based on the following equation:

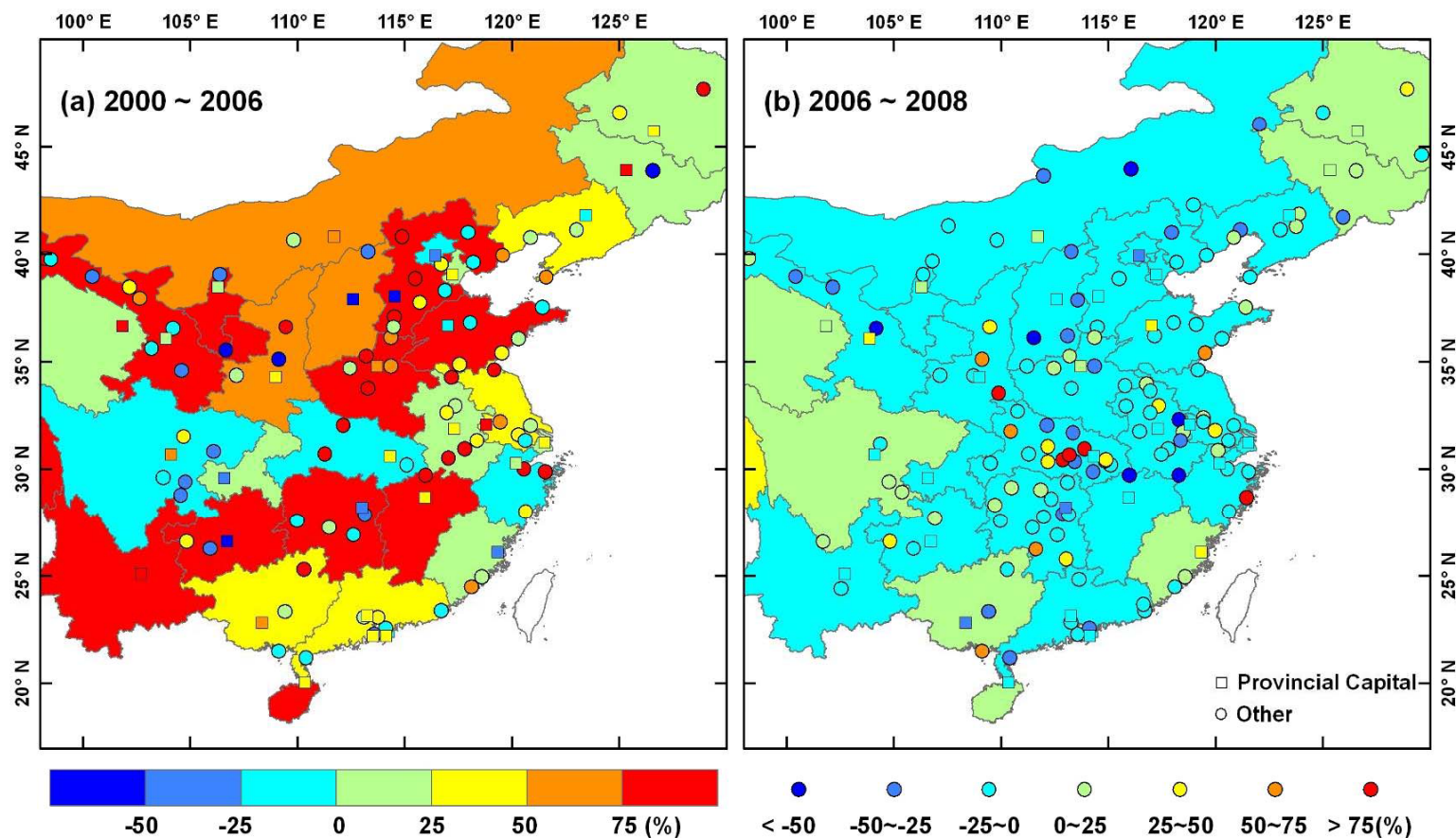
$$x'_{i,j} = \frac{(x_{i,j} - \bar{x}_j)}{\sigma_j}$$

Diagram illustrating the normalization equation:

- Normalized value** points to $x'_{i,j}$
- average value** points to $\bar{x}_j$
- standard deviation** points to σ_j

Comparison of SO_2 emission and sulfur related quantities

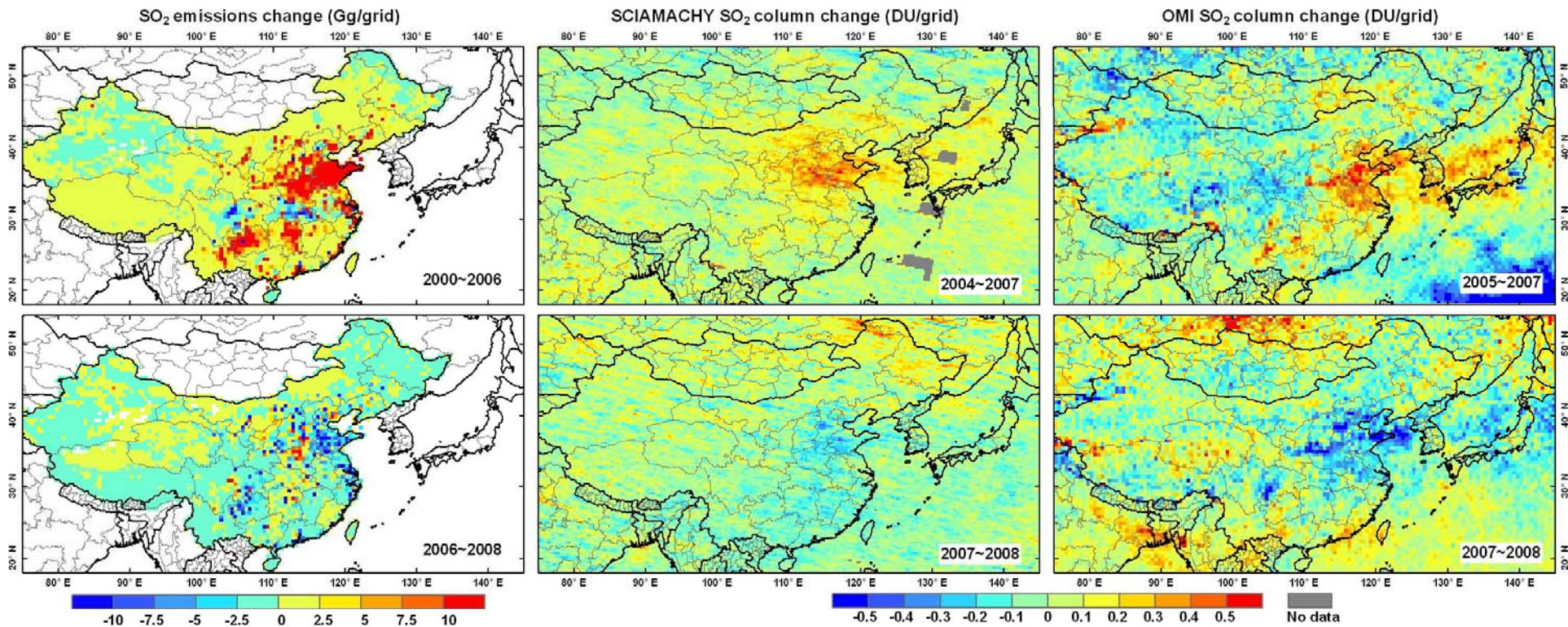
SO_2 emission vs. SO_2 concentration in China



The percentage change of SO_2 emission (provinces) and SO_2 concentrations (cities) in China.

Comparison of SO₂ emission and sulfur related quantities

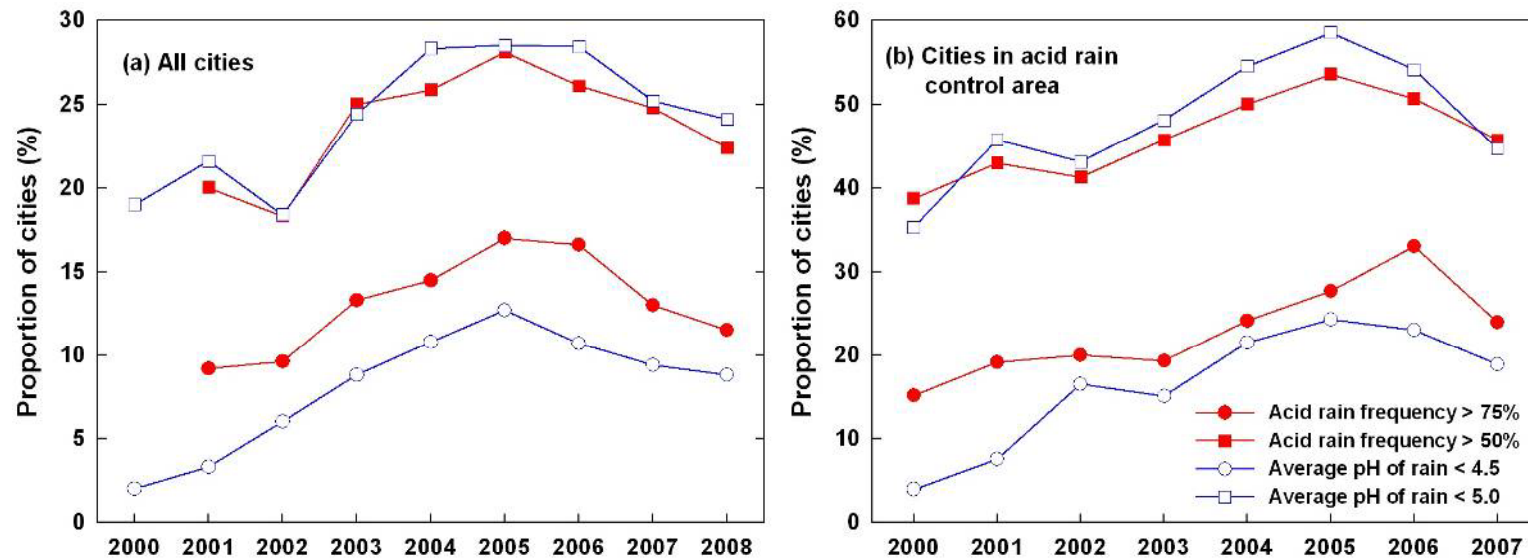
SO₂ emission vs. SO₂ satellite observations



- The changes of SO₂ columns before and after 2007 are observed by both the SCIAMACHY and the OMI instruments.

Comparison of SO₂ emission and sulfur related quantities

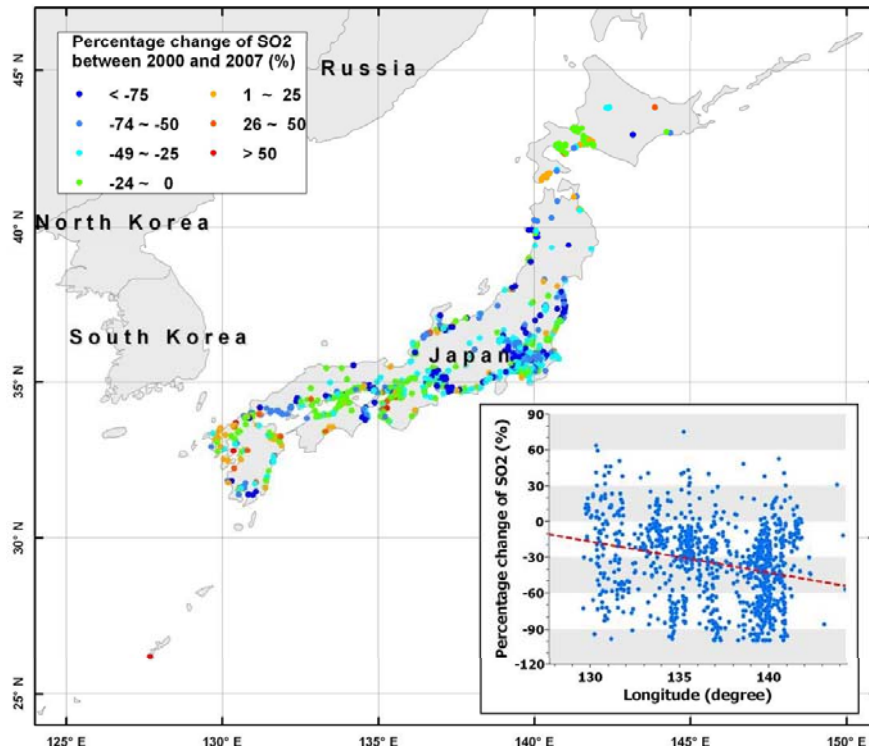
SO₂ emission vs. acid rain in China



- Although NO_x, PM, NH₃ and other acidifying species also contribute to the acidification, SO₂ emission is believed to be the major cause of the acid rain in China.
- The proportion of cities experiencing acid rain with a frequency of >50% and >75% was increasing between 2000 and 2005; meanwhile the proportion of cities experiencing moderate and heavy acid rain increased too.
- The acid rain problem in Chinese cities was alleviated after 2005.

Comparison of SO₂ emission and sulfur related quantities

SO₂ emission vs. SO₂ and SO₄²⁻ in Japan and Korea



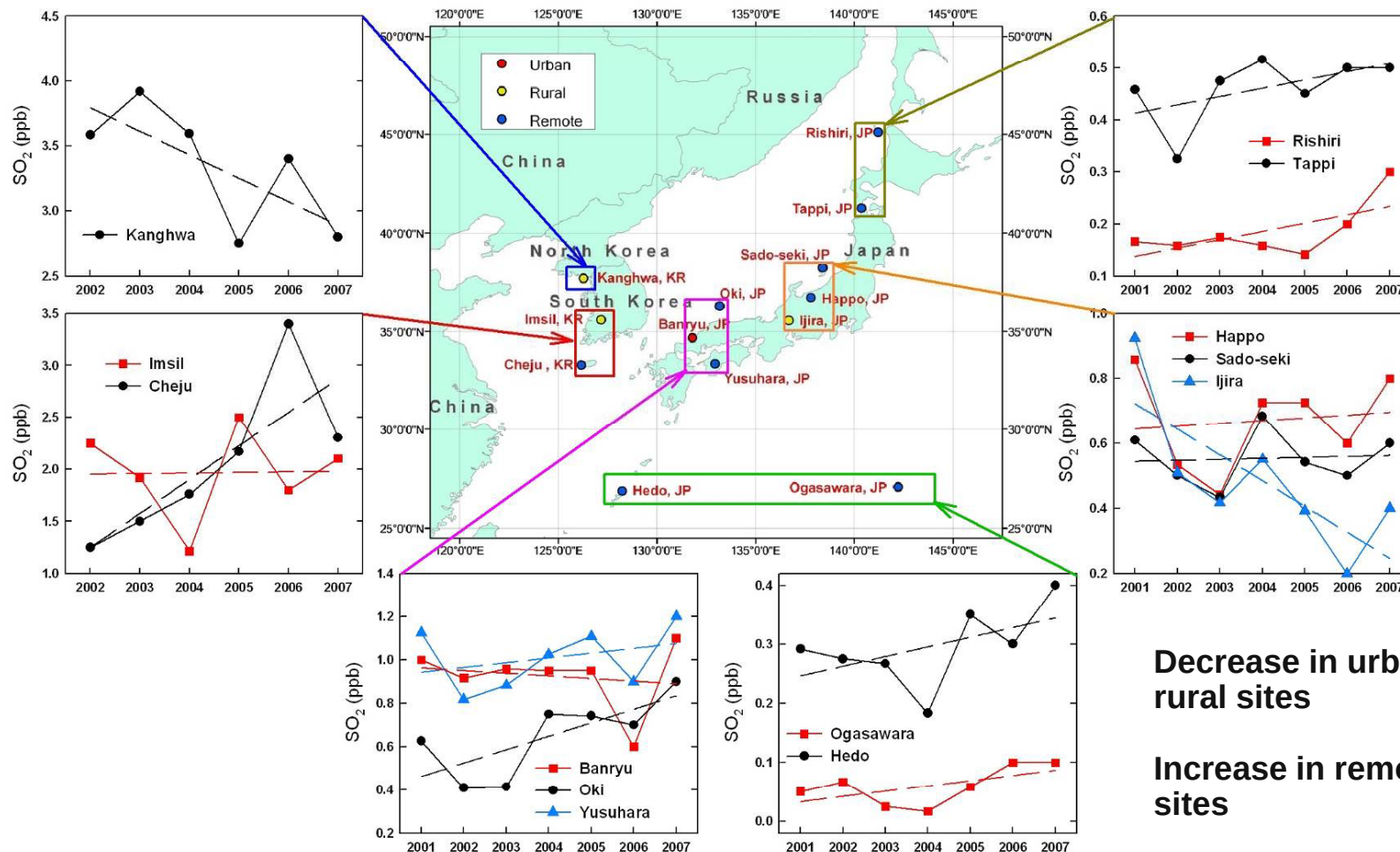
- Not like China, the SO₂ concentrations in most cities of Japan tend to continuously decrease after 2000.
- There is a longitudinal gradient in the percentage change of urban SO₂ concentration in Japan during 2000-2007.
- In spite of the relatively short lifetime of SO₂, the transport of increasing SO₂ from the Asian continent can partially counteracts the local reduction of SO₂ emission downwind, and even overrides it in some southwest areas of Japan.

*Percentage SO₂ changes during 2000-2007
Japan NIES sites*

Comparison of SO₂ emission and sulfur related quantities

SO₂ emission vs. SO₂ and SO₄²⁻ in Japan and Korea

Interannual SO₂ trends (EANET sites)



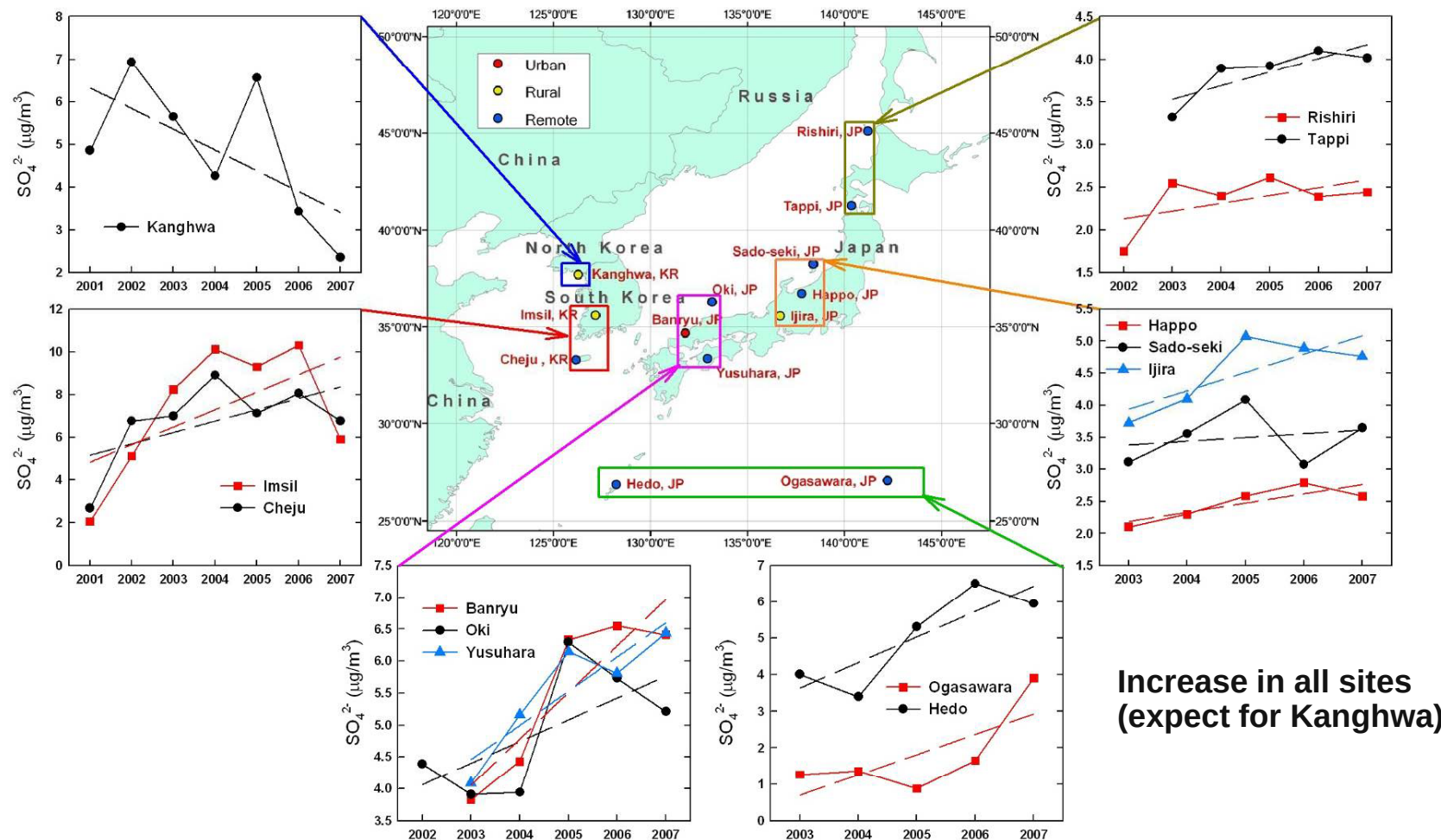
Decrease in urban and rural sites

Increase in remote sites

Comparison of SO_2 emission and sulfur related quantities

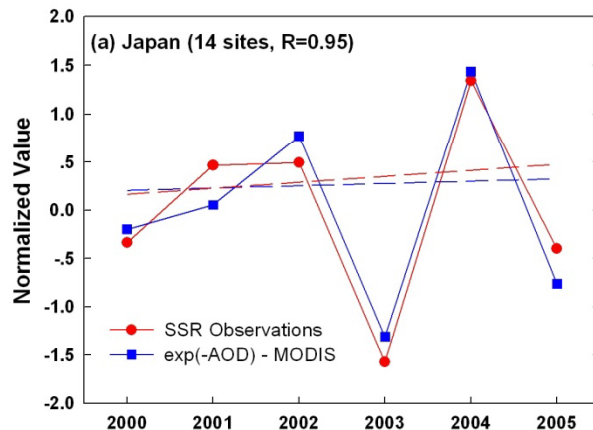
SO_2 emission vs. SO_2 and SO_4^{2-} in Japan and Korea

Interannual SO_4^{2-} trends (EANET sites)

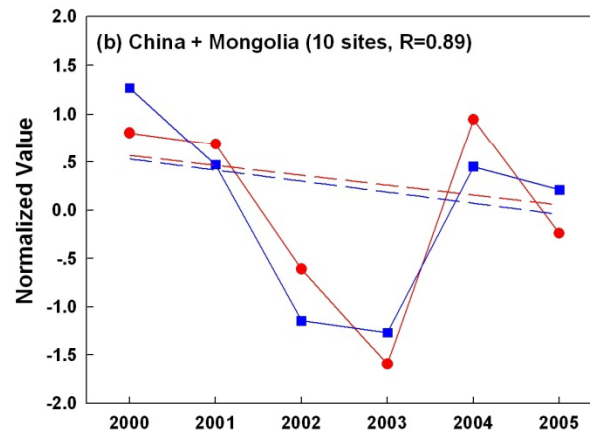


Comparison of SO_2 emission and sulfur related quantities

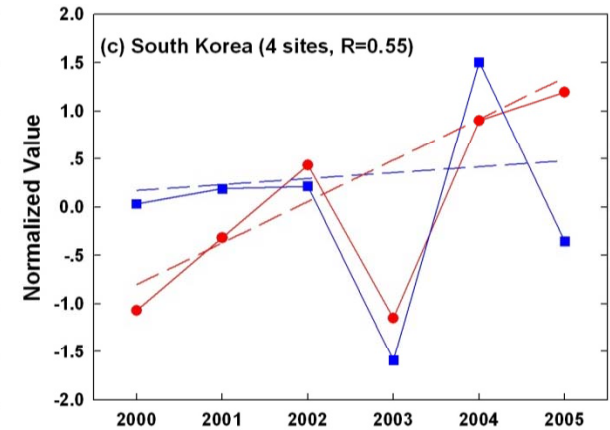
SO_2 emission vs. SSR in East Asia



Japan: Brightening



China & Mongolia: Dimming

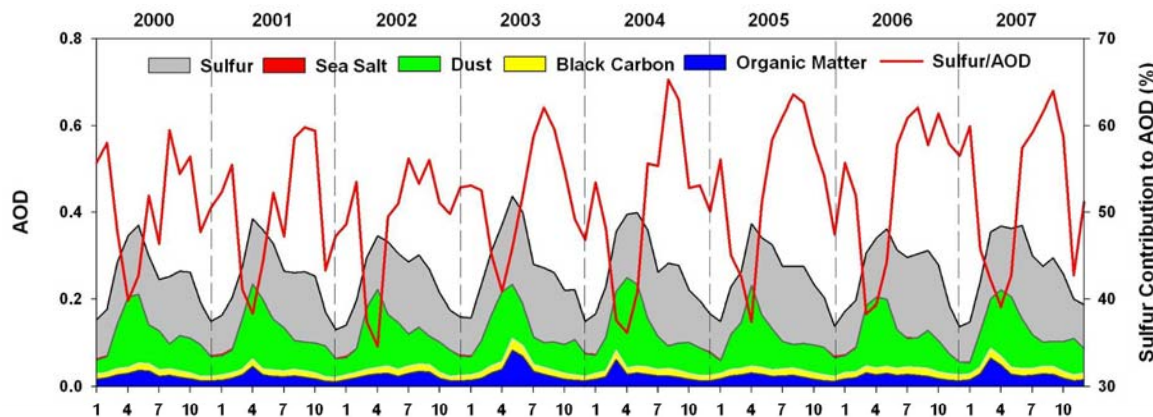
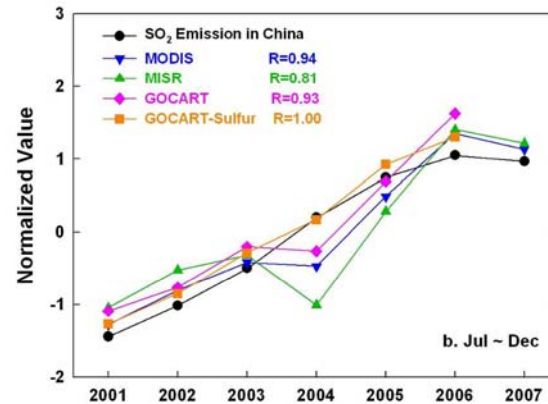
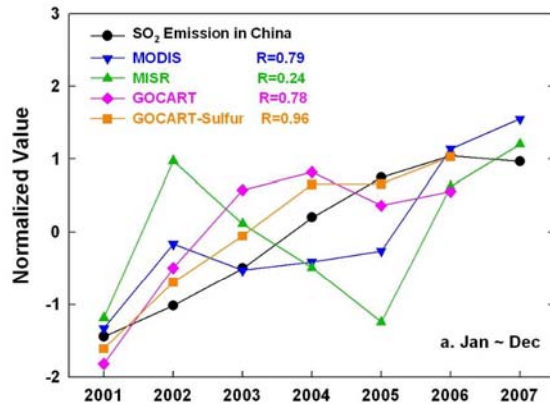


South Korea: Brightening

- The continuous dimming in China is consistent with the dramatic increase in SO_2 emission in East Asia after 2000.
- It further confirm the hypothesis that changes in AOD over time, particularly the regional transitions from dimming to brightening, are caused by the changing patterns of anthropogenic emissions of aerosols and aerosol precursors.

Comparison of SO_2 emission and sulfur related quantities

SO_2 emission vs. AOD in East Asia



- AOD trends: increase
- The contribution of sulfur to total AOD peaks in the second half year.
- AOD trends agree much better with SO_2 emission in China during the period of July to December, indicating the effect of emission in China on AOD is more pronounced during the second half of the year.

Summary

- Using a detailed technology-based methodology, we estimated the SO₂ emission in China increased by 53% from 2000 to 2006 with an annual growth rate of 7.3%.
- The growth of national SO₂ emission slowed down around 2005, and tends to decrease after 2006.
- Comparison of SO₂ emission and sulfur related data sets over East Asia.
 - The change of SO₂ emission in China after 2000 is generally in line with the change of SO₂ concentration and acid rain pH and frequency in China, as well as with the increasing trends of background SO₂ and sulfate concentration in East Asia.
 - The SO₂ concentrations in most cities of Japan tend to continuously decrease after 2000. A longitudinal gradient in the percentage change of urban SO₂ concentration in Japan is found during 2000-2007.
 - Both SSR measurements and satellite AOD products show that China and East Asia excluding Japan underwent a continuous dimming after 2000.



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Thank you for your attention!

Questions?

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