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Introduction to special section on 'East Asia Climate and Environment'

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ABSTRACT

Activities within the collaborative project East Asia Climate and Environment focus on the impact on the composition of chemically active greenhouse compounds from the rapidly growing emissions in Asia. Estimates of emissions (past and future) are discussed in light of the demand for energy in the different sectors. The impact includes regional scale contributions through short-lived climate compounds like particles and ozone, while global scale contributions are demonstrated through changes in oxidation capacity affecting compounds like CH_4. One key issue is the important and increasing contribution from China to atmospheric chemical changes.

1. Background

A collaborative project with East Asia Climate and Environment (EACE) as topic was initiated in 1997 in a meeting held at the State University of New York at Albany with participating scientists from Taiwan, China, Norway and the United States. Over the years, several EACE workshops have been organized to discuss research progress and to stimulate interaction among the participants. Two special issues were published in Terrestrial Atmosphere and Oceans (TAO): in 2001 on 'the Environmental impacts of aircraft emissions' and in 2007 on 'Climate–Chemistry Interactions: Atmospheric Ozone, Aerosols and Clouds over East Asia'.

The topics of EACE are the atmospheric chemically and radiatively active constituents (e.g. O_3 and aerosols), their distribution and changes due to large increases in emission of pollutants in SE Asia in recent decades. The most recent workshop, the Eighth EACE workshop, 'Atmospheric Composition: Chemistry-Climate Interaction', was held 10–12 November 2008 in Taipei.

While many types of aerosols (black carbon, primary organic carbons and dust) are primary compounds, ozone and some key aerosol types (sulphate, secondary organic compounds) are secondary compounds formed in the atmosphere. The distribution of these secondary compounds is firstly determined by the emissions of primary compounds, e.g. NO_x, VOC and SO_2, but it is also sensitive to the oxidation potential of the atmosphere (e.g. OH distribution) and to the state of the climate system (e.g. temperature, moisture, wind and clouds). Ozone and aerosols are well-recognized pollutants and they have sufficiently short lifetimes (days, weeks) in the troposphere to show large spatial and temporal variations depending on the distribution of pollution emissions. SE Asia stands out as a key region due to the large emission increases. Although many of the processes affecting pollution and climate are known, the interactions in the system are not well understood and remain a key topic for research.

The purpose of this *Tellus-B* special section is to document findings of topics and issues closely relevant to the climate and environment over East Asia with focus on the chemistry-climate interaction involving atmospheric O_3, aerosols and clouds presented at the 7th EACE workshop in Oslo in June 2007. Studies of composition change and climate impact and air quality are triggered by the large and rapidly increasing demand for energy and the concurrent increases in emissions in SE Asia. In the following we will give a background presentation for the studies reported in this issue.

2. Energy use and contributions from different sectors in China

Changes in pollutant and climate compound emissions are closely linked to economic development and energy use. Since China carried out its economic reform and opening policies in the late 1970s, China has sustained high economic development

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in the past decades. The annual GDP growth rates were between 5 and 14%, with an average rate of about 10% between 1980 and 2006 (National Bureau of Statistic of China, 2006, http://www.stats.gov.cn/tjsj/ndsj/2006/indexch.htm). Concurrent with the rapid economic development, China's energy consumption has increased dramatically during this period. China is now the second largest energy consumer in the world accounting for approximately 15% of the world's total energy in 2005 (World Energy Outlook, 2007). Between 2000 and 2006, the primary energy consumption increased by 55%. The increase in coal consumption was particularly large, 74%, mainly due to demand from the electricity industry.

China has a unique energy structure dominated by coal. China has abundant coal and hydropower resources but little oil and gas. The estimated coal reserve in 2004 was 20% of the world's total reserve, ranking second in the world, while the oil reserve are small only 1.4% of the world's total reserve. Natural gas reserves are even smaller, standing at only 1.2% of the world's total reserve and ranking 17th in 2004. China has large economic exploitable hydropower but most of this is difficult to utilize because of technological, environmental, and ecological reasons. The hydropower represents about 16% of the total generated electricity in 2005. Renewable energy sources such as wind, solar, geothermal and tidal water are increasing but still at the stage of initiation. The total renewable energy, of which most are biogenic fuel, accounts for 13% of the total primary energy consumption in China (World Energy Outlook, 2007). The industry has been the largest consumer of energy in China, and it will continue to be so in coming years. It accounted for more than 40% of the end-use energy consumption in China in 2005, while residential use accounted for 30%. Although the transport sector contributes moderately, it is a fast growing sector, for example, its share increased from 5% in 1980 to 11% in 2005. The contributions from other sectors are small.

Industry and household, which are major contributors for anthropogenic emissions, have large potential for energy saving by improved efficiencies. Efforts have been made during recent years to improve energy efficiency. In 2005, China's 11th Five-Year Plan sets an ambitious target for energy-efficiency improvement of 20%, or 4.36% each year from 2006 to 2010. However, the efficiency was improved only by 1.3% in 2006 indicating that more measures are needed to meet the target in coming years.

3. Emissions in China

The development in the transport sector illustrates the challenges China is facing: Vehicle exhaust emissions are becoming increasingly serious in China. The number of motor vehicles in China increased by 60 times between 1980 and 2005, from 1.8 to 107 million. Note that the economy of China increased only 34 times during the same period (National Bureau

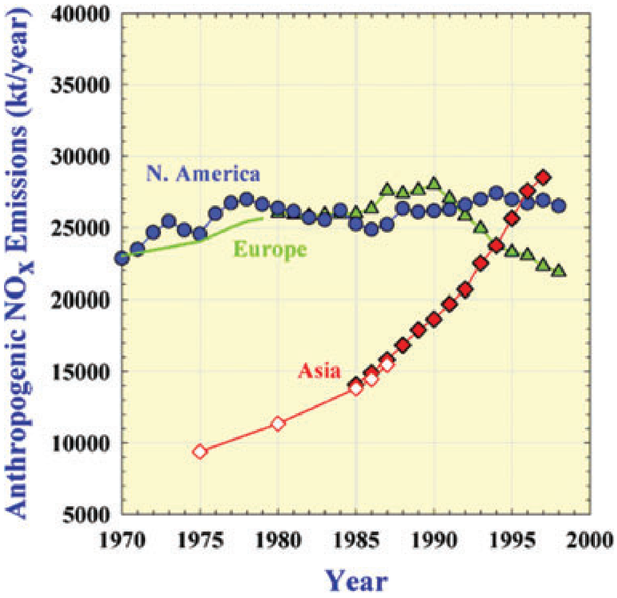

Fig. 1. Changes in anthropogenic NO_x emissions in North America (United States and Canada), Europe (including Russia and the Middle East) and Asia (east, southeast and south Asia) (Akimoto, 2003).

of Statistic of China, 2007, http://www.stats.gov.cn/tjsj/ndsj/2007/indexch.htm).

With more than 60% of the energy consumption covered by utilization of coal, coal combustion related emissions are a major concern for air pollution in China with SO_2 as dominant air pollutant. Vehicle emissions represent another important source of air pollution, with large increases over the last two to three decades: Emissions of CO, NMVOC, SO_2 and particulate matter (PM_{10}) increased 14–16% yearly between 1980 and 2005 (Cai and Xie, 2007).

The increasing contribution from Asia (mainly China) to global emissions is illustrated in Fig. 1 where the time history of NO_x emissions for different regions is given. While emissions during the last decade have levelled off or even decreased in the main emission regions in developed countries (Europe and North America), the emissions continued to increase in Asia (Akimoto, 2003; Streets et al., 2003). The large increase in NO_x emissions in China is found to strongly enhance ozone (Zhang et al., 2007) and affect global methane trends due to changes in the atmospheric oxidation potential and thereby methane lifetime (Dalsøren et al., 2009).

Significant improvements in construction of emission inventories were made for China during recent years. Emission data are becoming available on regional, provincial and municipal scales. Ohara et al. (2007) compared the different recent emission inventories with data updated for year 2000. Emission inventories have also been further developed with significant revisions: TRACE-P emission inventories by Streets et al. (2006) suggested an increase in CO emissions of 36%; Kim et al. (2006)

suggested 20–75% reduction in NH_3 emissions. Furthermore, Streets et al. (2007) suggested that the VOC emissions were underestimated by studying ozone production and distribution in Beijing. Wei et al. (2008) conducted a NMHC emission inventory for China for year 2005. Chinese emission factors are introduced and the emissions are distributed on the provincial level with income as an index. Coal and biofuels are widely used in Chinese household, and an inventory for anthropogenic mercury emissions in China from 1980 to 2000 were presented by Streets et al. (2005). An inventory for black carbon and organic carbon emission from China for year 2000 was developed by Cao et al. (2006). A vehicular emission inventory was compiled by Cai and Xie (2007) for China from 1980 to 2005. Emission factors for the majority of vehicles in China are comparable to those for Europe, since the dominant vehicle manufacturing technologies in China are based on European technologies. Vehicle emission regulations implemented in China have been almost the same as those executed in Europe.

Biogenic emissions of VOCs, which are more pronounced in South and East China than in other parts of the country, were reported in several studies with significant spread among the estimates. Geron et al. (2006) studied the biogenic VOC emissions in Yunnan province, and made estimates of the emission factors and emissions from different components. This biogenic VOC emission inventory gave much higher values than the previous study by Steiner et al. (2002).

The relative contribution of Asian emissions to global emission has become significant and is expected to continue to grow rapidly. The Asian contribution to global emissions of SO_2 and NO_x increased from about 30 and 20%, respectively in the beginning of the 1990s to 50 and 35% in 2005 (Cofala et al., 2007).

4. Future emission trends

China's long-term social and economic development goal is to reach a GDP of USD 3.7 trillion (constant 1995 USD) by 2020, which would quadruple per capita GDP of 2000 (Yang, 2008). To achieve this goal, the GDP would increase at a rate of 7.2% per annum between 2000 and 2020. At the same time, the Chinese government plans to lessen the nation's rate of energy consumption with a goal of only doubling energy consumption between 2000 and 2020, yielding an increase at a rate of about 3.6% per year. Statistical data, however, show that energy use has been growing much faster. During the period 1995–2050, the total energy consumption in China is predicted to increase from 981 to 3638 MtC with the share of industry in the total energy consumption falling from 72.2 to 42.8%, while the share of transportation will rise to 17.3% (Chen, 2005). The significant decrease in the relative contribution of the industry sector will be due to energy efficiency improvement and structural adjustment of both industrial branches and products. It is clear that coal will continue to be the major energy resource and electricity fuel in China in the future, although China has been the world's fastest-growing oil consumer during the past 2 yr.

The effect of introducing new energy sources and implementation of stricter environmental regulations are likely to have strong impact on emissions. A study by Tang et al. (2007) in Pearl River Delta on the vehicle emissions showed that the emissions of different C_2–C_{10} NMHC species changed between 2001 and 2006, which have implications for the atmospheric oxidation potential.

Recently, integrated estimates of emissions for Asia have been made available. As an example, the Japanese Regional Emission Inventory in Asia (REAS; Ohara et al., 2007) presented emissions of several pollutants for the period 1980–2020 and also made comparisons with previous studies, which dealt with particular pollutants (e.g. SO2, NO_x). The GAINS-Asia model has also been updated with projections based on RAINS-Asia (see Amann et al., 2008)

5. Impact on atmospheric composition

The concentration of particulate matter in many Chinese cities represents a major health concern. Inhalable particle matters have become the principal type of air pollution in Beijing, which arouse worldwide attention (Zhang et al., 2007). Streets and Aunan (2006) studied the black carbon contribution from households in China. In addition, the increased CO, NO_x and VOC emissions play important roles in enhanced surface O_3 levels and enhanced health risk, as well as damage to vegetation. Increased concentration of NO_x in the troposphere over China was observed from space (Richter et al., 2005). NO_x, CO and VOCs also affect OH concentrations, and thereby the oxidation potential of the atmosphere (Dalsøren and Isaksen, 2006). The methane loss is particularly sensitive to abundance and changes of OH at low latitudes. In the study by Dalsøren and Isaksen (2006) it is calculated that SE Asia contributes 15.9% of the global methane loss in 2001. Over the period 1990–2001 they found a noticeable increase in OH levels and corresponding methane loss in the region (Table 1). As seen in Table 1 the development is SE Asia is quite different from other major emission regions similar to those also highlighted in Fig. 1. Continued emission increase in this region with a shift towards a lower CO/NO_x emission ratio, representative of fossil fuel combustion sources, is likely to have important implications for the global methane budget. This is discussed further in the study by Dalsøren et al. (2009) in this special section.

The rapid increase in Asian emissions may result in enhanced background levels and occasional pollutant episodes of the more long-lived pollutants in other world regions due to intercontinental transport. Eastward transport from Asia to the west and equatorial Pacific, North America and Europe (Fiore et al., 2002; Li et al., 2002; Martin et al., 2002; Jaffe et al., 2003; Wild et al., 2003; Liang et al., 2004; Price et al., 2004; Zhang et al., 2008) is important as well as westward transport in the middle

Table 1. Trends in non-biomass burning anthropogenic emissions of CO and NO_x, CTM calculated trends in tropospheric OH and CH_4 removal (Dalsøren and Isaksen, 2006)

Region	Change CO emissions % 1990–2001 energy, industry, transport	Change NO_x emissions % 1990–2001 energy, industry, transport	OH change% yr^{-1}	CH4 loss ($k \times$ OH $\times$ CH_4) change% yr^{-1}
Northern America	3.9	1.6	0.04	0.30
Northern Europe	−51.0	−39.6	−0.63	−0.60
Southeast Asia	14.8	61.3	0.27	0.83
Global	−0.3	8.6	0.08	0.50

troposphere during the summer monsoon (Li et al., 2001) and to the Indian Ocean during the dry monsoon season (Lelieveld et al., 2001).

Increasing attentions have been paid to species related to photochemical production from biogenic and anthropogenic emissions. Wei et al. (2007) studied the ozone production and influence from biogenic emissions in Pearl River Delta, south China. Wang et al. (2008) studied the impact of biogenic emissions of VOC and NO_x on tropospheric ozone over eastern China, and they concluded that the biogenic VOCs can contribute up to 30 ppbv to ozone concentration locally. On regional scale, Wei et al. (2008) showed that evaporation is the largest contributor (38%) for anthropogenic VOCs emissions in China, followed by combustion (30%) and transportation (28%). This pattern is expected to change with the fast increase in the vehicle fleets in China. Few observational data exist on the trends in NO_x concentrations. Due to its short lifetime, the distribution of NO_x displays large spatial and temporal fluctuations, which makes it difficult to perform trend analysis.

6. Conclusions

One of the remarkable developments in emissions in Asia is the rapid growth in the transport sector. Both ship traffic and land based transport show more rapid growth than in most other areas. It has been observed in the United States and in Europe that at a certain income level there is a strong increase in car ownership. Recently, several developing countries reached such income levels, and a rapid increase in traffic-related emissions and worsening of air quality, especially in mega cities, occurred. The willingness to accept measures to improve local air quality has also grown with improved economy. It is therefore likely that there will be regulations in emissions of pollutants in the future. Although transportation in Asia is one of the fastest growing sectors, the rate of future increase in emissions will depend largely on the compliance with regulations.

Although recent economic setbacks have reduced current yearly growth rate in China to 6–7%, it is believed that future increases in energy use will make China a major contributor to global pollution emissions, in spite of the introduction of environmental legislation, specifically targeting the transport sector in urban areas and the power plant sector. The importance of Asian emissions is illustrated by the fact that the Asian contribution to the global emissions of SO2 and NO*x* increased respectively from about 30 and 20% in the beginning of the 1990s to 50 and 35% in 2005 (Cofala et al., 2007).

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