AIR QUALITY MONITORING AND FORECASTING IN CHINA

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ABSTRACT

For the last decade the industrial activity of China has been growing at rapid pace, bringing economic wealth to its 1300 million inhabitants, but also generating an unprecedented level of air pollution. This deteriorates the air quality of the densely populated and industrialized areas such as Beijing, Shanghai and the Pearl River Delta, and increases the background pollution levels world-wide [1]. The AMFIC project aims at monitoring and forecasting the air quality in China by using satellite observations and model simulations, together with ground observations in China. The combination of these instruments and tools offers a unique possibility to investigate trends in air pollution and the effectiveness of air quality policy.

1. OVERVIEW OF THE AMFIC PROJECT

Within the AMFIC project the NO_2 concentration in the troposphere of China is one of the trace gases that is monitored using satellite measurements. The combined measurement series of the satellite instruments GOME and SCIAMACHY almost span a decade, which allows for a trend analysis of NO_2 concentrations. It can be concluded that the 10 years long NO_2 dataset can be used for significant trend analysis in most parts of China. The largest trend is found in Eastern China, where the economic growth is one of the fastest of the world. The fastest growing city with respect to both economy and tropospheric NO_2 is Shanghai, which had a yearly increase of tropospheric NO_2 of about 29% since 1996.

Other air pollutants that are routinely monitored over China by satellite are sulphur dioxide (SO_2), formaldehyde (CH_2O) and aerosols. High SO_2 concentrations reveal the regions of coal mining, industry and power plants in China. CH_2O is emitted by rice fields, biomass burning and to some extent by industrial activities. Aerosols are an indication of traffic, industry, wild fires or desert dust. Algorithms for satellite retrieval of aerosols have been developed and optimized for the situation over China. The algorithm has been used to produce satellite-derived aerosol information over China for a period of 8 months in 2008. The results show the high aerosol concentrations over the Eastern part of China associated with population density and industrial activities.

For a three year period an archive of carbon monoxide (CO) and methane (CH_4) data has been produced. For this an improved algorithm has been developed for the retrieval of CO and CH_4 from SCIAMACHY (on ENVISAT) nadir spectra. They have been compared with other data sets to assess their quality (e.g., with ground-based Fourier Transform Spectroscopy (FTS) retrievals, global model data sets of methane, and independent satellite data such as MOPITT CO).

Extensive validation activities have been performed using local ground observation in China. The feedback from these validation studies received by the retrieval teams have improved the retrieval algorithms in many cases.

The air quality in West China is modelled and forecasted with regional chemical transport models, adapted to the Chinese domain. It models the trace gas concentrations in the troposphere and the boundary model at a grid of 0.25 degree resolution. By using meteorological forecast data the model generates daily air quality forecasts up to five days ahead. The result for East China and for the greater urban areas of Beijing, Shanghai, Hong Kong, Shenyang, Qingdao and Seoul are published on a English-Chinese bilingual website (see Fig. 1).

The daily model output is also used as boundary condition for higher resolution model of Beijing and Shenyang by the Flemish Institute VITO and the street level model of Beijing by Cambridge Environmental Research Consultants (CERC).

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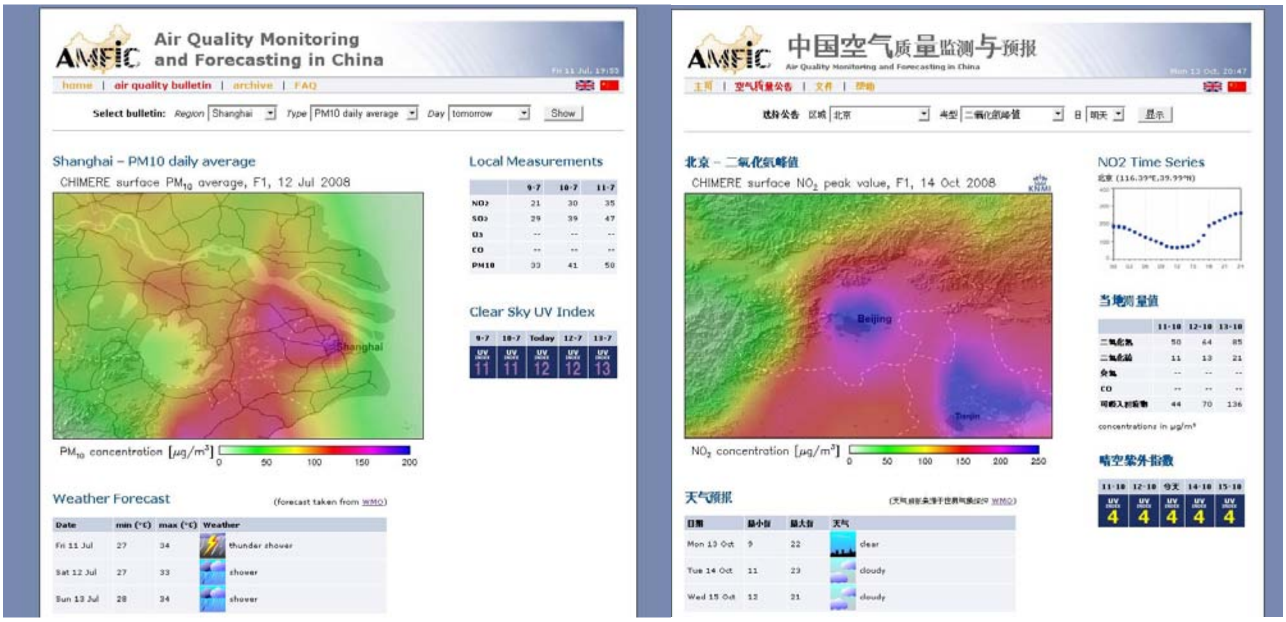

Figure 1. Examples of the AMFIC air quality bulletin.

Embedded in the Chimere model the Aurora model is operational to model the air quality for the regions of Beijing and Shenyang with a resolution of up to 1 km resolution. For these model runs a new emission database had to be constructed using local emission inventories. Both the Chimere and Aurora models were already operational during the Olympic Games and gave specific information for the cities with Olympic activities

The project results, i.e. satellite observations, model results and validation reports are made available via the web-site. Some dedicated pages have been made for the Olympic Games and Paralympics in 2008.

The following sections describe the use of satellite instruments to monitor air quality, the implementation of an operational air quality model for China, and the use of both satellite observations and model simulations to estimate the effect of the air quality measures during the 2008 Beijing Olympic Games.

2. OBSERVING AIR QUALITY FROM SPACE

Ground measurements of air quality in China are often sparse and inaccessible, which make satellite observations the obvious tool to monitor country-wide pollution levels on a daily basis and to observe concentration trends on longer time scales. The Ozone Monitoring Instrument (OMI) is a nadir looking solar backscatter spectrometer, which measures in the ultraviolet and visible wavelength range to infer trace gases, such as ozone and nitrogen dioxide (NO_2). Since it was launched in 2004 onboard NASA's EOS-Aura satellite it observes the Earth's atmosphere at a spatial resolution of about 20 km. In October 2006 a comparable instrument, GOME-2, was launched onboard the MetOp-A satellite. GOME-2 measures at a wider spectral range, but at a lower spatial resolution of about 40 km. Both instruments have near-daily global coverage.

Trace gas columns are retrieved from the depth of typical absorption structures in the atmospheric reflectance spectrum. Radiative transfer calculations are used to relate the measured absorption to a vertical column concentration, taking into account the viewing angle and atmospheric conditions, such as clouds, surface reflectance and the vertical profile of the trace gas. For nitrogen dioxide, the main interest for air quality monitoring is its amount in the troposphere. To separate the tropospheric column from the total column a data assimilation scheme is applied that provides the stratospheric column. Subtraction from the total column provides the tropospheric column.

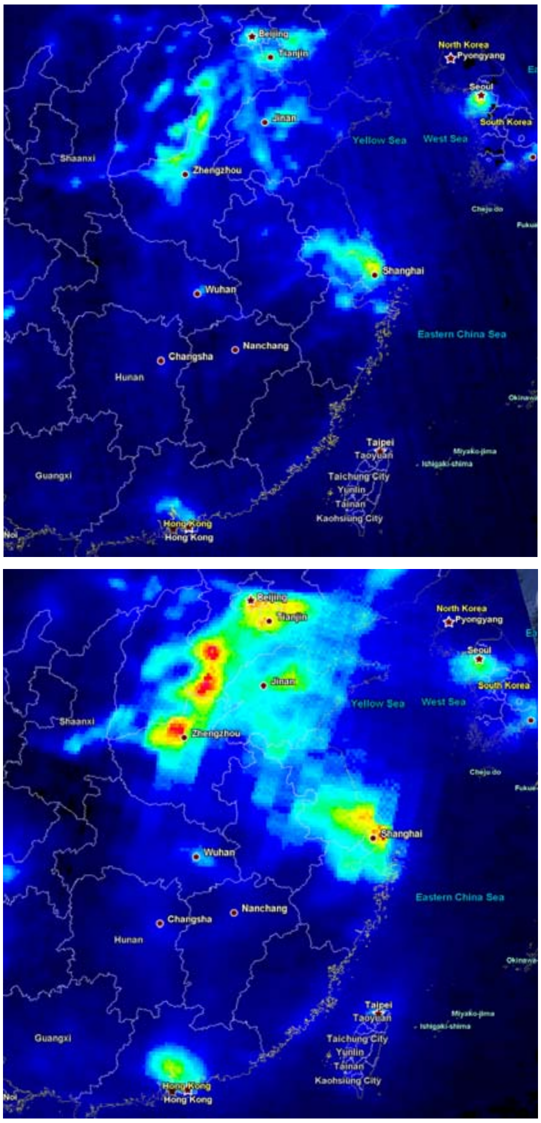

Figure 2. Observations of the average tropospheric NO_2 over East China in May-June 2009 by OMI (top) and GOME-2 (bottom). Hotspots of human activity are clearly visible. Note the higher spatial resolution of the OMI instrument. Due to the diurnal cycle of NO_2, GOME-2 observes a stronger signal than OMI.

The satellite instruments have a fixed overpass time: GOME-2 measures in the morning (9:30 local time) and OMI measures in the afternoon (at 13:30 local time). This allows us to probe the diurnal cycle of nitrogen dioxide (Fig. 2). Besides the diurnal cycle also weekly and seasonal cycles are monitored. This variability in the amount of nitrogen dioxide is due to chemical conversions depending on sunlight (photo-dissociation) and to time-dependent emissions of nitrogen dioxide and related species.

Nitrogen dioxide has significant natural sources (e.g. soil emissions, wildfires and lightning), but in populated areas NO_2 sources are predominantly anthropogenic (e.g. fuel combustion and human-induced biomass burning). By monitoring the concentration of nitrogen dioxide over several years, information on the trend of the emission sources can be determined. For the period 1996-2006, a time series has been constructed by combining the observations of GOME (launched in 1995) with SCIAMACHY (launched in 2002; almost same overpass time) of the daily global nitrogen dioxide concentrations [2]. The monthly NO_2 columns for these ten years have been fitted with a linear function superposed on an annual seasonal cycle on a grid with a spatial resolution of 1x1 degree. Western-Europe and the East coast of the US show slightly negative trends due to emission regulations (Fig. 3), but positive trends are found for Asian cities with a strong economical growth like Teheran (Iran), Novosibirsk (Russia) and especially for the booming cities in the East of China.

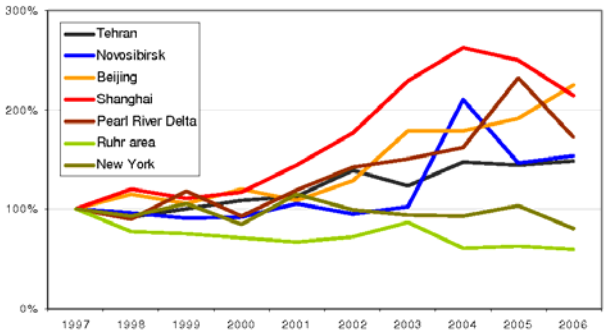

Figure 3. Trends of tropospheric NO_2 columns for different urban areas, taken from 10 years of SCIAMACHY data. 1997 is taken as the reference year.

3. MODELLING AIR QUALITY IN CHINA

For a better interpretation of satellite measured air pollution and for the conversion of measured column data to emission rates, an appropriate model is required which is able to simulate pollutant concentrations. CHIMERE is a regional chemistry transport model which is successfully used in Europe for air quality forecasts on urban to continental scales. For the AMFIC project (Air quality Monitoring and Forecasting in China) we implemented CHIMERE on a 0.25x0.25 degree resolution over East China, enclosing all important populated and industrialized areas. The model simulates the evolution of 44 gaseous species and aerosols in 8 atmospheric layers in the troposphere up to 500 hPa. The meteorological data needed for calculating the transport, deposition and the chemistry of the species is taken from the European Centre for Medium-Range Weather Forecasts (ECMWF).

The sparse available ground measurements from China makes model validation complicated, but not impossible

[3]. Fig. 4 shows comparisons of CHIMERE simulations with daily averaged measured surface concentrations of NO_2 published by the Beijing Environmental Protection Bureau (BJEPB), and PM_{10} (particulate matter of 10 microns or less in diameter) surface concentrations measured by the British Broadcasting Company (BBC) at 13:00 local time. Both comparisons illustrate the capability of CHIMERE of capturing the day-to-day variability of pollutant concentrations.

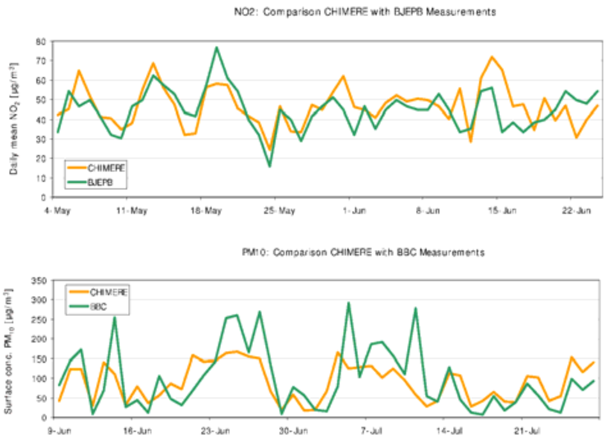

Figure 4. (Top) Comparison of the daily-averaged surface concentrations of NO_2 from CHIMERE over Beijing with the measured concentrations published by BJEPB for the period 4 May to 30 June 2008. (Bottom) Comparison of the surface concentrations of PM_{10} from CHIMERE at 13:00 local time with measurements done by the BBC before and during the Olympic Games. Measurements were done at midday in the city center.

By using meteorological forecast data, the model is able to generate daily air quality forecasts up to five days ahead. The result for East China and for the greater urban areas of Beijing, Shanghai, Hong Kong, Shenyang, Qingdao and Seoul are published on a English-Chinese bilingual website. The daily model output is also used as boundary condition for a higher resolution model of Beijing and Shenyang by the Flemish Institute for Technical Research (VITO) and the street level model of Beijing by Cambridge Environmental Research Consultants (CERC). On request of the Dutch National Olympic Committee, during the 2008 Beijing Olympic Games a dedicated website was made available by KNMI to inform the athletes on the forecasted air quality and meteorology at all Olympic venues.

4. NITROGEN DIOXIDE REDUCTION DURING THE 2008 BEIJING OLYMPIC GAMES

Heavy air pollution in Beijing, mainly originating from dense traffic, construction activities, industry, and coal-fired power plants, is a major concern for local authorities. To prevent high levels of air pollution during the Beijing Olympic Games (8-24 August 2008) and the Paralympics (6-17 September 2008), important measures inside and outside the city have been taken, including the temporarily shut down of polluting industry, the suspension of construction activities, and traffic restrictions. Traffic within the ring roads was restricted to cars with even number plates on even days and with odd numbers on odd days, 300.000 high-emission vehicles were banned from the city's roads, and the use of governmental and commercial vehicles was restricted (see Fig. 5).

Figure 5. Morning traffic flow on the East 4th Ring Road in Beijing during the restrictions on Friday 19 September (top), and after the restrictions on Monday 22 September (bottom). Source: China Daily

To study the effect of the air quality measures on tropospheric nitrogen dioxide concentrations, we compare the NO_2 observations over the Beijing area by OMI and GOME-2 before and during the Olympic Games. We take advantage of the high spatial resolution and daily global coverage of OMI, and the stronger anthropogenic nitrogen dioxide signal (due to its earlier overpass in the day) of GOME-2 [4]. As can be seen in Fig. 6, the nitrogen dioxide concentration over Beijing during the Olympic Games is significantly less than before. This, however, can partly be explained by favorable meteorological conditions during this period: predominant northerly winds bring in clean air masses from the sparsely populated mountain areas, and more precipitation on more rainy days washes out the air pollution over the city. By comparing the satellite observations with CHIMERE simulations based on pre-Olympic nitrogen dioxide emission estimates, we compensate for these atypical meteorological conditions [5]. Differences between observation and simulation can only be explained by changes in anthropogenic emissions.

The model results are interpolated to the time and the footprint of the satellite observation. For the pre-Olympic reference period (2 May to 30 June 2008) we see good agreement between simulations and observations for the Beijing area. When the air quality measures are enforced, the observations drop with respect to the simulations, which are based on an unchanged emission scenario. During the Beijing Olympic Games, the GOME-2 and OMI columns show a reduction of 59%–69% with respect to pre-Olympic values. Fig. 6 shows the geographic extent of the concentration reductions as observed by GOME-2. In the pre-Olympic period both satellite and model show high concentrations in the populated and industrialized areas. During the Olympic period, the satellite observes decreased nitrogen dioxide concentrations for Beijing, whereas the other cities continue to show high concentrations.

Highest concentration reductions are found in and around Beijing and the industrial areas in the south and south-east (60%–70%). The surrounding cities of Tianjin and Shijiazhuang show smaller reductions of about 30% and 20%, respectively. In the two months after the Olympic Games the nitrogen dioxide concentrations are still reduced with 40%, mainly due to the prolonged air quality measures and the reduced economic activity. One year afterwards, however, nitrogen dioxide levels have returned to their high pre-Olympic values.

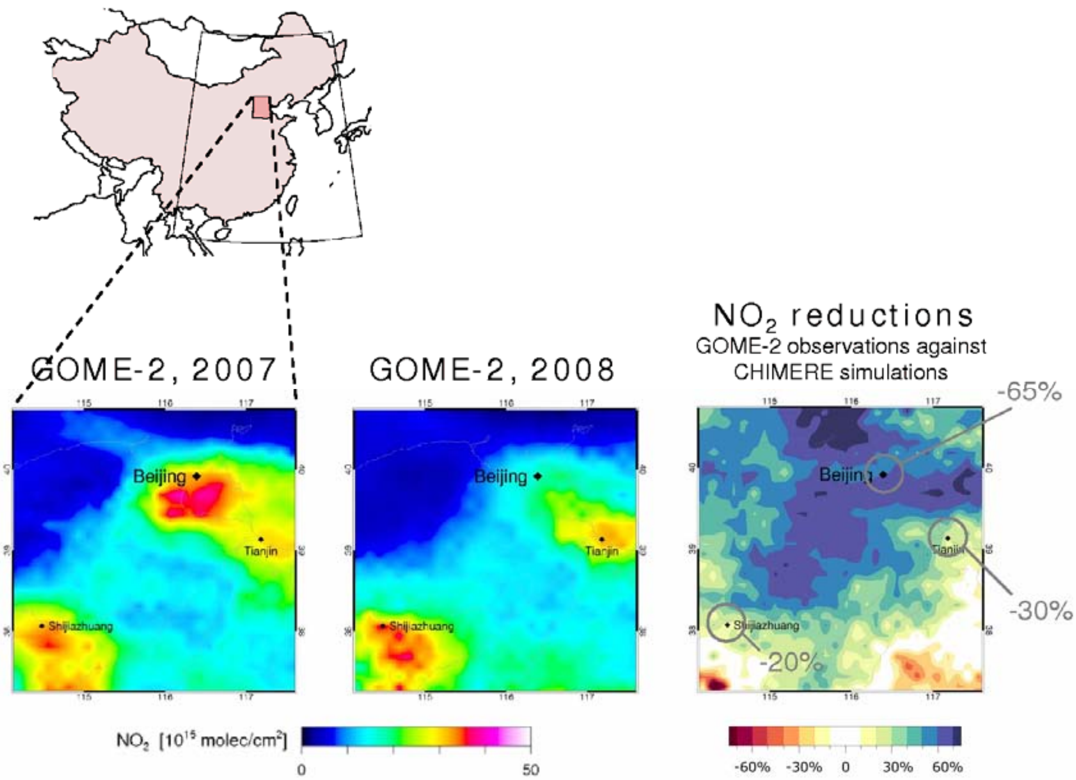

Figure 6 Observations of the tropospheric NO_2 columns by GOME-2 over the Beijing area during the Olympic period (middle panel) and the corresponding period one year before (left panel). The right panel shows the associated concentration reduction, when compared with the model results: the air quality measures were especially effective in the area around Beijing; the cities of Tianjin and Shijiazhuang showed smaller reductions in air pollution.

5. CONCLUSION

Satellite observation of tropospheric columns of nitrogen dioxide are extremely useful to analyze air pollution levels world-wide. The long-term data record from 1995 onwards shows strongly increasing pollution levels in China and slowly decreasing levels in Western Europe and Eastern USA. Observed trends can be attributed to economic growth and emission reduction measures.

On a shorter time scale, the effect of emission reductions during the Beijing Olympic Games of 2008 have been studied. By comparing satellite observations with air quality model results, we find a reduction of approximately 65% above Beijing during the Olympic period, showing the (temporary) success of the Chinese air pollution control efforts.

Future research will concentrate on improved methods to couple tropospheric pollutant concentrations observed by satellites to their underlying emission sources [6]. The trend and variability of emissions inferred from long-term satellite observations will give a better understanding of the effectiveness of air quality policies.

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