AIR QUALITY MEASUREMENTS DURING THE 2008 OLYMPIC GAMES FROM THE GOME-2 INSTRUMENT ON METOP

N. Hao[1], P. Valks[1], M. Rix[1], I. De Smedt[2], M. Van. Roozendael[2], D. Loyoal[1], W. Zimmer[1], S.Emmadi[1]

[1] *DLR, Munchner Strasse 20, Wessling, Germany: nan.hao@dlr.de*
[2] *BIRA-IASB, Belgium: Michel.VanRoozendael@aeronomie.be*

ABSTRACT

The Chinese government has implemented strict controls to reduce the emissions of air pollutants from industries, vehicles and construction sites during the Beijing Olympic Games. We use operational GOME-2 tropospheric NO_2 and SO_2 products and pre-operational formaldehyde (HCHO) products developed at the German Aerospace Centre, in the framework of EUMETSAT´s Satellite Application Facility on Ozone and Atmospheric Chemistry Monitoring (O3M-SAF) to assess the effectiveness of these controls and to study the impact on pollutants over Beijing and neighboring provinces.

Preliminary analysis indicates a reduction in NO_2 concentrations from July to September compared to 2007 over Beijing and surrounding areas. Abnormal decreases of NO_2 in October, November, and December 2008 were found and possible reasons were discussed. Changes in SO_2 concentrations during emission control period are not so apparent because SO_2 is a longer lived gas and more likely to be transported from other regions. However, the decline of SO_2 started before and lasted beyond the Olympic season, especially in winter with highest SO_2 pollution. The change of formaldehyde (HCHO) concentration was also invested by GOME-2 during the Olympic period.

1. INTRODUCTION

Beijing is one of the world's largest mega-cities with more than 17 million residents and more than 3 million vehicles. The dense traffic, construction, industry, coal-fired power plants and city's geography result in severe air pollution in Beijing. To improve air quality during the Beijing Olympic Games, systematic long- and short-term measures were implemented before and during the Olympic Games including introducing strict vehicular emissions standards, removing one-half cars (about 1.5 million cars) off the road from July 20 to September 20 through an odd/even plate number rule, closing or relocating pollution emitting factories and freezing construction activities. Since surrounding areas can contribute significantly to Beijing's air pollution [1,2], emission controls on large industrial sources were also applied in surrounding provinces such as Hebei, Shanxi, and Shandong province and in Tijian city. Traffic reduction measures similar to Beijing's were implemented in Tianjing. Tab. 1 summarizes the detailed air pollution control measures adapted by the Beijing Municipal Environmental Protection Bureau (EPB) at different stages before, during and after the Olympics.

We will show here that reduction in NO_2, SO_2 and HCHO over Beijing and surrounding provinces is observed from GOME-2 during the Olympic period. To evaluate the current status (post-Olympics) of air pollutants in Beijing, and if the control measures implemented during Olympics were still effective, we did research till June 2009.

2. GOME-2 instrument and O3M-SAF

The Global Ozone Monitoring Equipment -2 (GOME-2) on the MetOp-A satellite, launched in October 2006, is part of the EUMETSAT Polar System (EPS) with three polar-orbiting operational MetOp satellites. MetOp-A is flying on a sunsynchronous orbit and has an equator crossing time of 9:30 local time [3]. Further MetOp satellites are to be launched in 2012 and 2016. They will provide a continuous time series of trace gas measurements until 2020. GOME-2 is a nadir scanning UV-VIS spectrometer that measures the Earth's backscattered radiance and extraterrestrial solar irradiance in the ultraviolet and visible part of the spectrum (240 - 790 nm). The advanced GOME-2 observes four times smaller ground pixels (80 km x 40 km) than GOME on ERS-2, and provides a global coverage within about one day.

The operational GOME-2 tropospheric NO_2, total SO_2 and pre-operational HCHO products are provided by the German Aerospace Center (DLR) in the framework of EUMETSAT's Satellite Application Facility on Ozone and Atmospheric Chemistry Monitoring (O3M-SAF). The focus of the O3M-SAF is to process, archive, validate and disseminate atmospheric data products of ozone, various trace gases, aerosols and surface ultraviolet radiation. The operational level 1-to-2 processing of the trace gases product is performed at DLR with UPAS (Universal Processor for Atmospheric Spectrometers), a new generation system for the processing of operational trace gas and cloud property products in near-real time and off-line [4]. DLR needs less than 15 minutes for acquiring the input data, retrieving the trace gas total columns and disseminating

the resulting products, which means the level 2 near-real time trace gases products are delivered via EUMETCast to the end-users approximately 2 hours after sensing (1 hour and 45 min are needed for the delivery of level 1). The German National Remote Sensing Data Library stores the GOME-2 O_3, NO_2 and SO_2 data for enabling the long-term monitoring of global change, and data reprocessing (http://wdc.dlr.de/sensors/gome2) [5].

3. GOME-2 Tropospheric NO_2, HCHO AND Total SO_2 Retrieval and comparison to ground-based data

3.1 Tropospheric NO_2

Total NO_2 is routinely retrieved with the GOME Data Processor (GDP) version 4.3 using Differential Optical Absorption Spectroscopy (DOAS) method [6] in 425-450 nm wavelength regions. An additional algorithm is applied to retrieve the tropospheric NO_2 column for polluted conditions. After subtracting the estimated stratospheric component from the total column, the tropospheric NO_2 column is determined using an air mass factor based on monthly climatological NO_2 profiles from the MOZART-2 model [7].
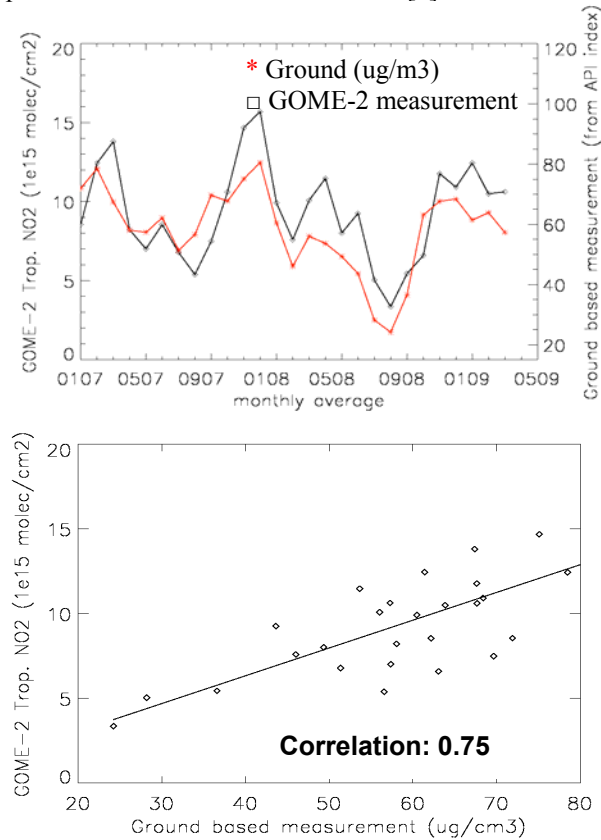

Figure 1 NO_2 comparisons between GOME-2 and API index over Beijing

The air pollution index (API index) is a simple and generalized ways to describe the air quality in city. The API normally depends on the three pollutants SO_2, NO_2,

particulate matters measured in several monitoring station in a city. Beijing NO_2 API index use the average of 27 monitoring stations in Beijing. The API index data come from website http://www.bjee.org.cn/api/index.php. Fig 1 shows the monthly average NO_2 comparison between GOME-2 and NO_2 API index over Beijing. We can clearly see that these two measurement results have the similar variation trend and good correlation.

3.2 HCHO

Total HCHO is generated from GOME-2 using the DOAS technique[6] which consists in two steps (1) a spectral fit (328.5 – 346 nm) to derive effective slant columns (2) a conversion of slant columns into vertical columns using air mass factors determined from radiative transport model taking into account the cloud fraction, the cloud height and the ground albedo. Vertical profile shapes of HCHO are provided by the global CTM IMAGES[8].

3.3 SO_2

SO_2 columns are retrieved from GOME-2 UV backscatter measurements of sunlight in a two-step procedure [9]. In a first step, slant column densities (SCD) of SO_2 are determined using the DOAS method [6] in the wavelength region between 315 – 326 nm. In a second step, the corrected slant column densities of SO_2 are converted to vertical column densities (VCD) through division by an appropriate air mass factor. The detail retrievals are reported elsewhere [10].

Similar as NO_2, we did the comparison between GOME-2 and SO_2 API index over Beijing. Considering these two measurements have different spatial resolution and different time period, the results are impressing as shown in Fig 2 and the correlation coefficient is 0.8.
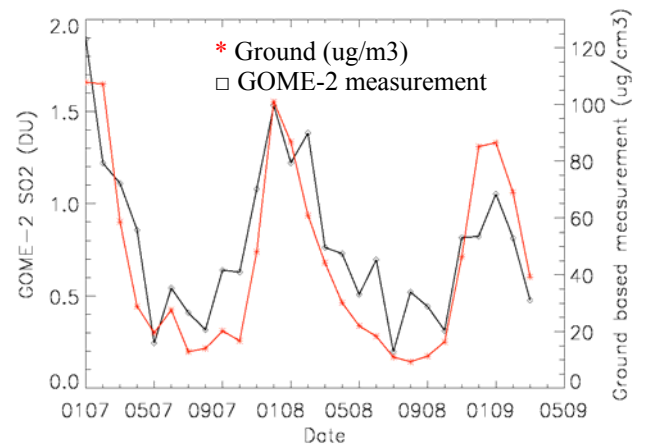

Figure 2 SO_2 comparisons between GOME-2 and API index over Beijing.

4. Seasonal variation of NO$_2$, HCHO and SO$_2$ over China

4.1 NO$_2$ seasonal variation

NO$_2$ maximum is expected in the winter because the lifetime of NOx is longer in the winter [11]. Fig.3 shows GOME-2 monthly average of tropospheric NO$_2$ over the east and west of China from January, 2007 to June 2009. It can be seen that in the east of China the expected seasonal NO$_2$ maximum in winter is found, but in the west of China a NO$_2$ maximum during summertime is found. The different source of tropospheric NO$_2$ in the east and west of China result in this different seasonal variation. Increased anthropogenic emissions with the variability in meteorological conditions and chemistry during wintertime lead to maximum NO$_2$ in east of China. As there is nearly no anthropogenic activity in west of China, natural emissions such as soil emissions and lighting are the main source of tropospheric NO$_2$, which increase because of high temperature and more lighting in summertime.

4.2 HCHO seasonal variation

As shown in Fig 4, the HCHO over east of China presents a strong seasonal variation primarily related to the oxidation of biogenic VOCs emitted during the summer season. Over Thailand (south of China), the HCHO maximum occurs between February and April.

4.3 SO$_2$ seasonal variation

Fig 5 illustrates that a maximum SO$_2$ is found during winter in east of China due to increased heating, chemistry and meteorological conditions. The lower SO$_2$ pollution levels in the summer reflect an increase in frequency and amount of precipitation. For example, Beijing gets around 75% of its total rainfall between June and August.
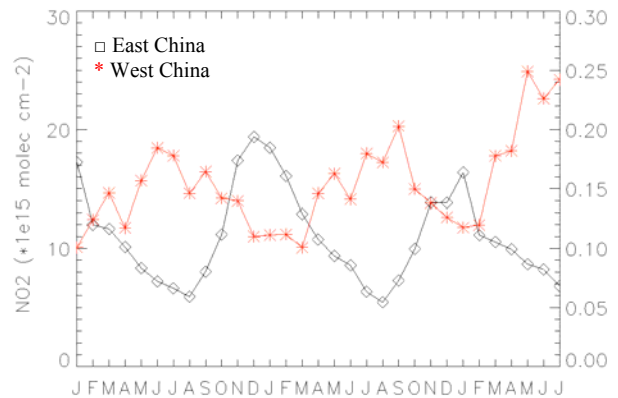

Figure 3 Monthly variations of tropospheric NO$_2$ over the east and west of China (from Jan.2007 to Jun.2009)
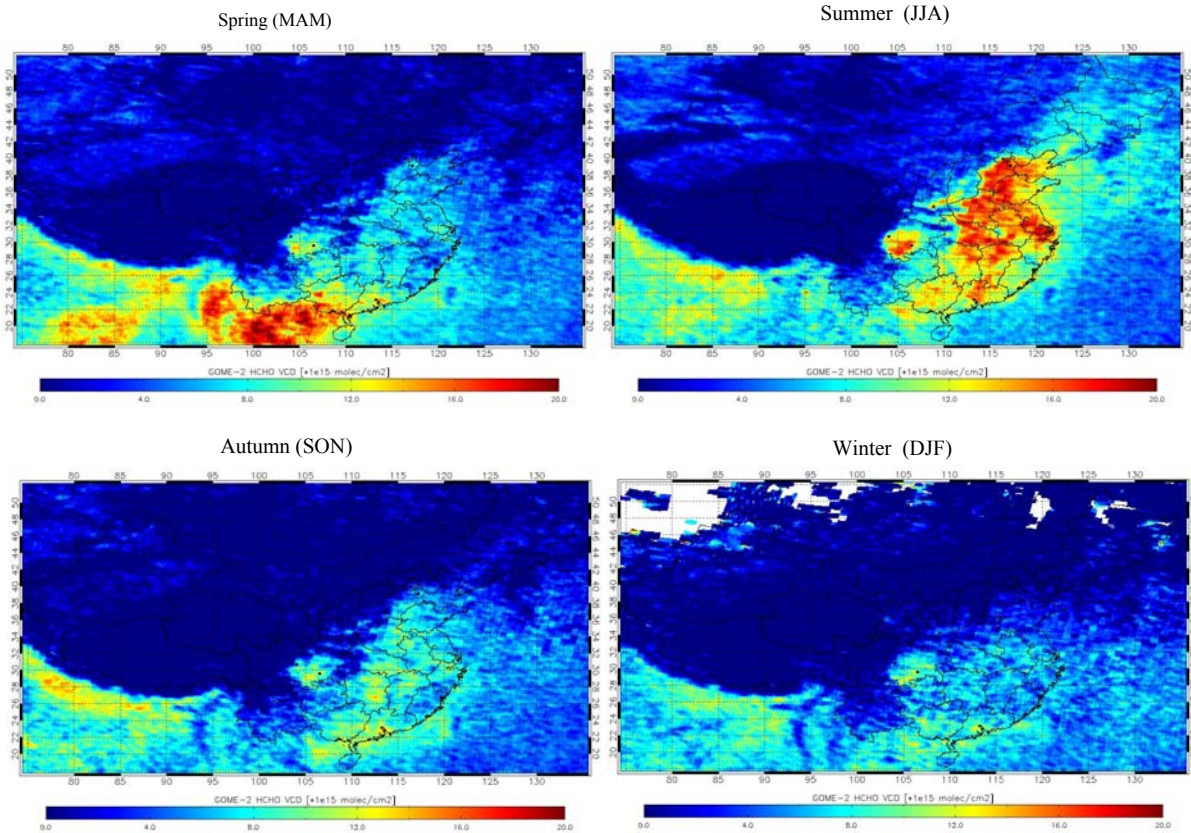

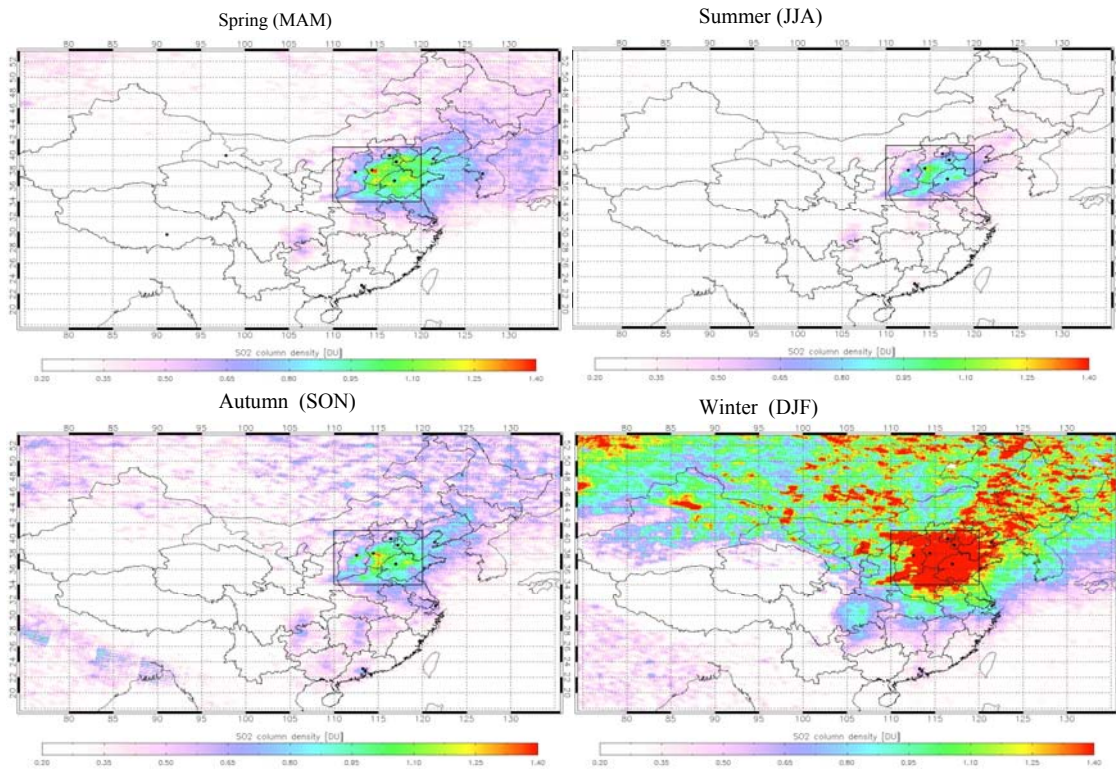Figure 4 Seasonal variation of HCHO over China

Figure 5 Seasonal variation of SO_2 over China

5. Air quality improvement during the Olympic

5.1 Change of NO_2

As summarized in the introduction, all the short term emission control measures were applied in August, 2008. Therefore, in order to evaluate the effects of the emission controls, most of the analysis below will focus on pollutant concentrations in this period. We processed operational O3MSAF tropospheric NO_2 columns in these boxes (as shown in Fig. 6) during Olympic Period (Aug, 2007 and 2008) and no emission control period (from Jan. to Jun. 2007,2008 and 2009). Fig 7 shows that tropospheric NO_2 decreased about 38% over Beijing and about 25% over Tianjin during Olympic period. In the Beijing surrounding areas such as Hebei, Shanxi and Shandong Province, NO_2 also decreased from 2% to 22%. However, it is hardly to see any consistent and clearly decrease of NO_2 over Beijing and surrounding areas during no emission control period. This proves that emission control did play an important role in NO_2 reduction during Olympic period. Of course, meteorological effect also contributed to this decrease. Some researchers from KNMI [12] and

Tsinghua University [13] used the chemistry transport model to divide the meteorological effect and emission control effect to the decrease of NO_2. Their conclusions approved with us that emission control measures contribute to the decrease of NO_2 over Beijing and surrounding areas.
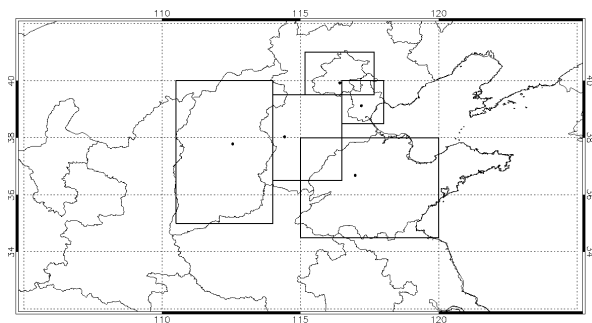

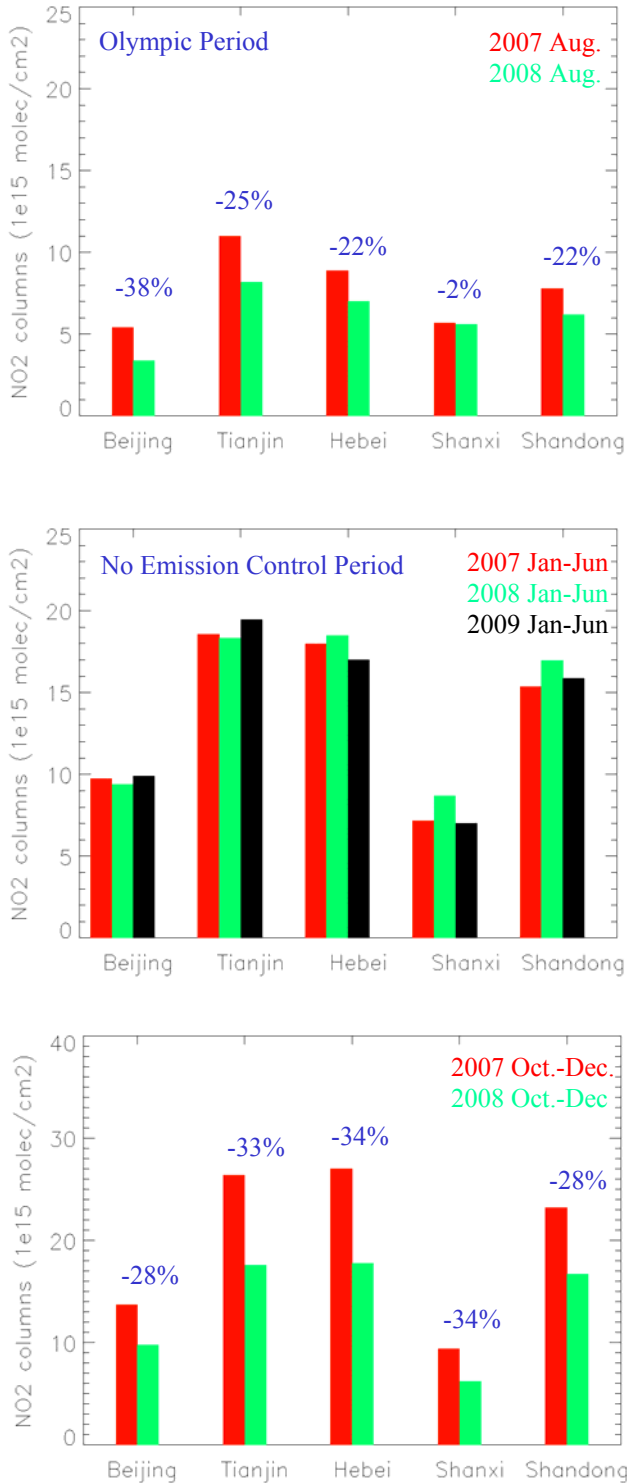Figure 6 Five boxes represent Beijing, Tianjin, HeBei, Shanxi and Shandong Province.

Figure 7 Change of NO$_2$ during Olympic period, no emission control period and post-Olympic period over China

To check the NO$_2$ pollution after Olympics, we analysed the data from October to December, 2008. The abnormal decreases of NO$_2$ in all areas during this period are shown in Fig 7. The possible reason is down turn in the economy and energy production during this period in China. The meteorological effect is not so strong as in summer because there are few rains. Similar trends for PM10 concentrations in Beijing were reported in the paper [14]. More work are needed for this phenomenon.

5.2 Change of HCHO
One of the sources of HCHO is from fossil combustion especially over East China. As shown in Fig 8, HCHO from July to September in 2008 decreased in Beijing and Tianjin comparison to 2007 because of emission control.

5.3 Change of SO2
Fig 9 shows that SO$_2$ concentrations over Beijing decreased though to a lesser extent than the traffic related pollutants such as NO$_2$. As mentioned before, the highest SO$_2$ pollution occurs in winter over East China. Therefore, we researched the change of SO$_2$ from January to February in the last three years. Clear decrease of SO2 over Beijing and other regions in winter (from Jan. to Feb.) can be found in Fig 10. This phenomenon is related to installation of desulphurization equipment in coal-fired power station and boilers in China and shut down small coal-fired boilers which were started from 2007.

6 CONCLUSIONS
Seasonal variations of tropospheric NO$_2$, HCHO and total SO$_2$ over China can be detected by GOME-2. The comparisons of GOME-2 tropospheric NO$_2$ and SO$_2$ to ground-based data show the good correlation. In this study, we conclude that emission control measures were successful in improving air quality over Beijing and surrounding areas. NO$_2$, SO$_2$ and HCHO reductions during Olympic Games were observed by GOME-2. It showed that about 38% reductions of tropospheric NO$_2$ over Beijing in August compared to 2007. Abnormal NO$_2$ decrease during post-Olympic period (Oct – Dec. 2008) was possible related to down turn in economy and energy production and 20% traffic reduction and more research are needed. The install of desulphurization equipments in power plants and boilers contribute to three years decrease of SO$_2$ over east China in winter. All the analysis in this paper based on the operational O3MSAF trace-gas column products.

7. REFERENCES

1. Streets, D. G., Fu, J. H. S., Jang, C. J., Hao, J. M., He, K. B., Tang,X. Y., Zhang, Y. H., Wang, Z. F., Li, Z. P., Zhang, Q., Wang, L.T., Wang, B. Y., and Yu, C.(2007) Air quality during the 2008 Beijing Olympic Games, Atmos. Environ., 41(3), 480–4922.

2. Wang, Y., McElroy, M. B., Munger, J. W., Hao, J., Ma, H., Nielsen, C. P., and Chen, Y. (2008)Variations of O3 and CO in summertime at a rural site near Beijing, Atmos. Chem. Phys., 8, 6355–6363, http://www.atmos-chem-phys.net/8/6355/2008/.

3. J. Callies, E. Corpaccioli, M. Eisinger, A. Hahne, A. Lefebvre. (2000) "GOME-2 – MetOp's Second Generation Sensor for Operational Ozone Monitoring," ESA Bulletin, No. 102

4. Y. Livschitz, D. Loyola (2003) Design Document for the GOME-2 Universal Processor for Atmospheric Spectrometers, SAF/O3M/DLR/DD/001, Issue 2.0.

5. D. Loyola, W. Zimmer, S. Kiemle, P. Valks, T. Ruppert (2008) Product User Manual for GOME Total Columns of Ozone, Minor Trace Gases, and Cloud Properties, Doc. No: DLR/GOME/PUM/01, Iss./Rev.: 2/A, Available: http://wdc.dlr.de/sensors/gome2/

6. Platt, U., and J. Stutz (2008), Differential Optical Absorption Spectroscopy: Principles and Applications, Springer, Heidelberg, Germany.

7. Nüß, H., A. Richter, P. Valks and J. Burrows (2005), Improvement of the NO2 total column retrieval for GOME-2, O3M SAF Visiting Scientist Activity, Draft Final Report, IUP University of Bremen, Dec.2005.

8. Mueller, J-F., and T. Stavrakou (2005) Inversion of CO and NOx emissions using the adjoint of the IMAGES model, Atmos. Chem. Phys. 5, 1157-1186.

9. P. Valks, D. Loyola, N.Hao, M.Rix, and S. Slijkhuis (2008) Algorithm Theoretical Basis Document for GOME-2 Total Column Products of Ozone, Minor Trace Gases and Cloud Properties (GDP 4.2 for O3M-SAF OTO and NTO), DLR/GOME-2/ATBD/Iss./Rev.: 1/D, Available: http://wdc.dlr.de/sensors/gome2/

10. M. Rix, P. Valks, N. Hao, J. van Geffen, C. Clerbaux, L. Clarisse, P.-F. Coheur, D. G. Loyola R., T. Erbertseder, W. Zimmer and S. Emmadi (2009) Satellite monitoring of volcanic sulfur dioxide emissions for early warning of volcanic hazards. Journal of Selected Topics in Earth Observations and Remote Sensing. In press.

11. Beirle S, Platt U, Wenig M and Wagner T (2003) Weekly cycle of NO2 by GOME measurements: a signature of anthropogenic sources. Atmos. Chem. Phys., 3, 2225-2232.

12. Mijling, B., R. J. van der A, K. F. Boersma, M. Van Roozendael, I. De Smedt, and H. M. Kelder (2009), Reductions of NO2 detected from space during the 2008 Beijing Olympic Games, Geophys. Res. Lett., 36, L13801, doi:10.1029/2009GL038943.

13. Y.Wang, J.Hao, M.B.McElory, J.W.Munger, H.Ma, D.Chen and C.P.Nielsen (2009), Ozone air quality during the 2008 Beijing Olympics: effectiveness of emission restriction, Atmos. Chem. Phys., 9, 5237-5251.

14. WenTao Wang, Toby Primbs, ShuTao and Staci L. Massey Simonich (2009), Atmospheric Particulate Matter Pollution during the 2008 Olympics, Environ. Sci. Technol., 43, 5314-5320.

Table 1. Stating dates of different air pollution control measures before, during and after Olympic Games

|	
1 Jan 2008	Introduce new vehicular emission standard (Euro IV)
Before	Relocating heavy industrial polluters, install desulfurization facility
	The use of natural gas for power generation increased 15%
23 Jun 2008	50% of government cars were not allowed driving on road (~210,000 cars)
20 July 2008	Starting the full scale control
	The odd/even plate number rule for traffic control(~1.5-2 million cars)
	Stricter control on vehicles entering in Beijing
	Reduce and stop production at some factories surrounding Beijing
8 Aug 2008	Extra 20% of governmental cars were not allowed driving on road
20 Sep 2008	Lifting regulations adapted from July 20
Present	Control 20% of private cars based on the last digital of plate number (~700,000 cars)

2007 Jul.-Sep. 2008 Jul.-Sep.
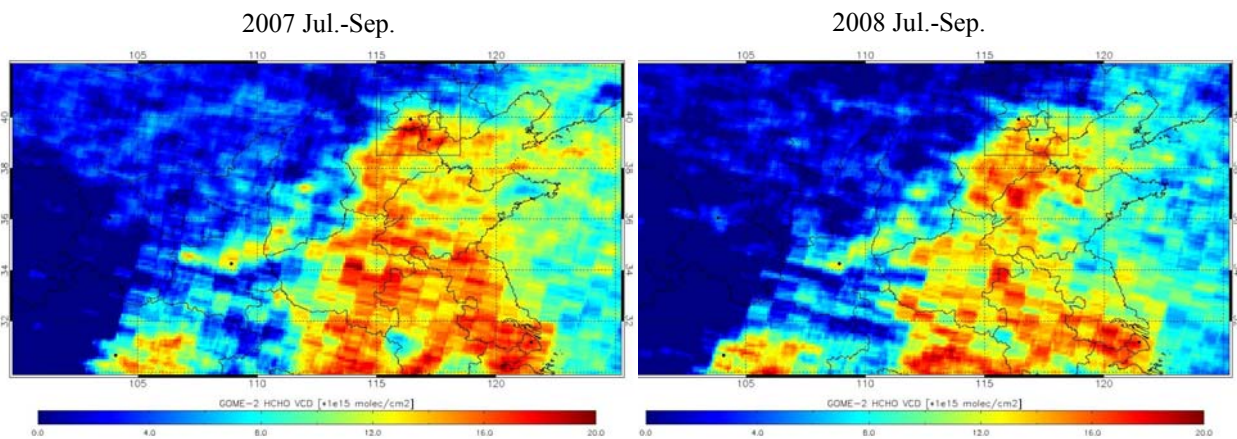
Figure 8 Change of HCHO during emission control period
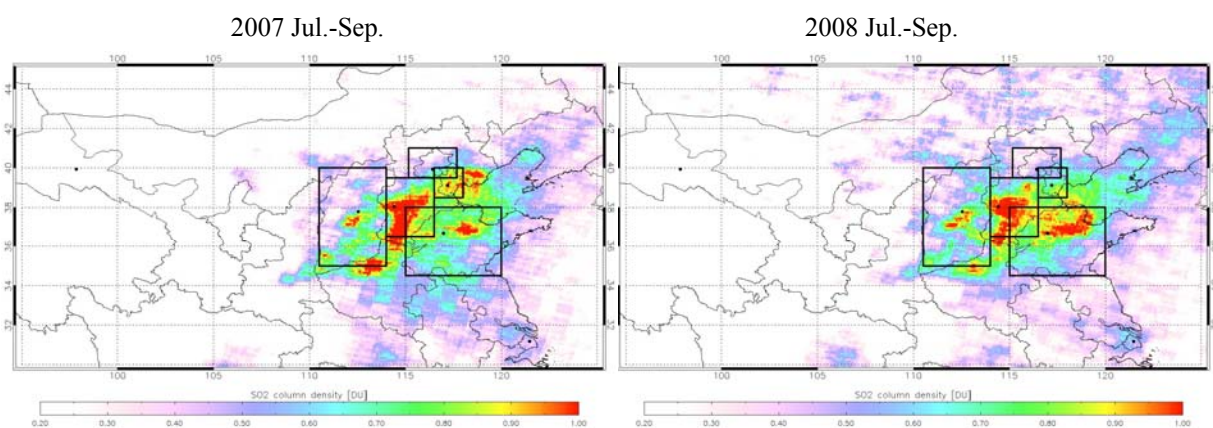
2007 Jul.-Sep. 2008 Jul.-Sep.
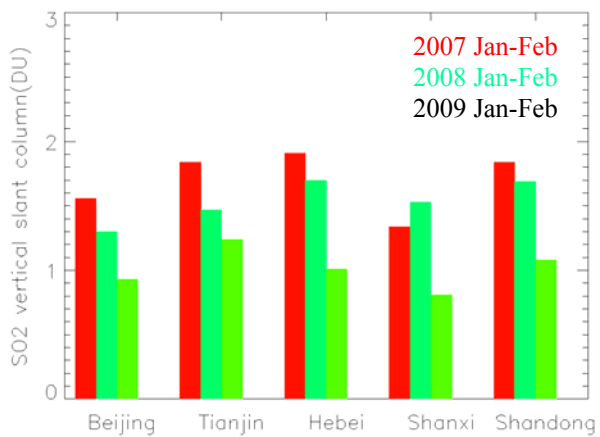

Figure 9 Change of SO$_2$ during emission control period

Figure 10 Decrease of SO$_2$ in winter over China

7