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Evaluation of long-term tropospheric NO_2 columns and the effect of different ecosystem in Yangtze River Delta

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Abstract

The spatial and temporal characters of tropospheric NO_2 column over Yangtze River Delta (YZD) are analyzed using monthly averaged tropospheric NO_2 column densities from GOME (1996-2002) and SCIAMACHY (2003-2010) measurements. In addition, with the NO_2 column densities data and the land cover maps of YZD, the characters of NO_2 concentration over different ecosystem have been analyzed. The results indicated that the tropospheric NO_2 column densities in YZD increased distinctly from 1996 to 2010 and it showed distinct regional and seasonal variation characteristics. It has the highest concentration in winter while lowest in summer. It also presents zonal distribution and decreasing along the Yangtze River from eastern to western. Under the influence of the urbanization process, the highest NO_2 column densities appeared at cities and metropolis which are located in the Shanghai, Nanjing as well as Hangzhou. Moreover the lowest column densities appeared at the forest areas which are in the south and west of Zhejiang province. The sharp increasing of appeared in water bodies, followed urban area and water bodies. The lowest increasing of NO_2 column appeared in grassland. Furthermore, we inferred the ground-level NO_2 concentration from the GOME and SCIAMACHY data in this paper. We compared with the dry plus of N deposition which inferred from the remote sensing data and the mass concentration of N dry deposition from the control experiments, they performed significant correlation ($P<0.001$), and have the high R value (R^2=0.86).

Keywords: Tropospheric NO_2 column densities; temporal and spatial dynamics; Land cover; Yangtze River Delta; N deposition

1. Introduction

Nitrogen dioxide (NO_2) is one of relatively stable nitrogen oxides in atmosphere. Nitrogen oxides are play a key role in the photo-chemically which induced catalytic production of ozone[1], and results in summer smog, acid rain and has increased levels of tropospheric ozone globally[1, 2]. NOx has significant natural sources (e.g. lighting and soil emissions) [3] and anthropogenic (e.g. biomass burning, fossil fuel combustion) sources[1, 3, 4]. With the expanding economy, Emissions from fossil fuel combustion and biomass burning reduce the NO_x [2] and has significantly increased air pollution.

There is a significant influence to tropospheric NO_2 concentration because of the human activity and land cover change near ground. As a result of NO_x source distribution and the relatively short NO_2 chemical lifetime, the tropospheric NO_2 columns observed from space are dominated by the NO_2 amount in the boundary layer. The NO_2

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columns retrieved from space can be used to prefer the currently estimates of NO_x emissions [5]. Urban areas as an intensity human activity contain many sources which emissions from automobiles, fossil fuel combustion and power plant and so on. The increasing emission of automobile has a significant influence in air pollution [2]. However, tropospheric NO_2 columns are the main come from the atmospheric diffusion and natural emissions over forest and grass land where there is little human activity[1]. Emissions from soil of cropland because of the plenty of N fertilizer and biomass burning in these areas have enhanced the concentration of tropospheric NO_2.

The tropospheric NO_2 increasing in anthropogenic emissions would come back to the terrestrial and marine ecosystems through the way of dry and wet deposition. As an important nutrition and acid source for ecosystems, the sharply change of NO_2 concentration has been of consequence for the productivity and stability of terrestrial and marine ecosystems[6, 7]. The ecosystems which are short of Nutrition would increase the primary productivity, biomass and the fund of soil organic carbon with the deposition of Nitrogen. However, it is harmful for the nitrification ecosystems with the deposition of nitrogen. It also can hasten the nitrogen loss of terrestrial ecosystems and eutrophication in water bodies[8]. Thus, it has significant meaning to study the characteristic of tropospheric NO_2 over different land covers.

In recent years using the satellite data, the column densities, vertical profiles at times and emission inventories are researched. Tropospheric NO_2 columns retrieved from GOME satellite measurements have been used to analyze the spatial and temporal patterns of NOx columns[9, 10]. Boersma K, et al. study Error of the system analysis for tropospheric NO_2 retrieval from satellite[11]. The quality of SCIAMACHY NO_2 data retrieved by KNMI/BIRA has previously been validated by Heue KP et al. and Gloudemans A, et al.[12, 13]. Tropospheric NO_2 columns retrieved from SCIAMACHY have been used to provide top-down estimates of surface NOx emissions via inverse modeling, to examine specific sources, to infer NOx lifetimes, and to estimate surface NO_2 concentrations. These analyses, however, are affected by large discrepancies among contemporary tropospheric NO_2 retrievals [11-13]. Tropospheric NO_2 columns retrieved from SCIAMACHY satellite measurements have been used to evaluate chemical transport models[14], to examine spatial and temporal patterns of NOx emissions. It is important for confidence in the accuracy and reliability of these analyses to assess the quality data which retrieval from GOEM and SCIAMACHY satellite measurement in the large scale regions over all seasons. Jagele,L studied the NOx seasonal changes in spatial and temporal distribution from biomass burning using GOME satellite data[15]. Boersma, K studied NO_2 in the troposphere spatial and temporal distribution resulting from lightning using GOME data and model simulation[16]. Richter, A studied the global trends of tropospheric NO_2 using GOME and SCIAMACHY data from 1996 to 2004, the results showed that the regions of eastern China and Hong Kong had significant growth[5]. Vanders, GJM Using data from 1996 to 2005 also found that the concentration of NO_2 of some industrial development in eastern China region has significantly increased[17]. Uno, I compared the tropospheric NO_2 results of GOME data used in 1996-2003 and the CTM simulation[18]. Han, K Using three-dimensional chemical transport model analyze the NO_2 emissions in East Asia and chemical transport mechanism, and compared the result with the GOME data[19].

Due to the different emission sources, tropospheric NO_2 has significantly different characteristics over different regional environment and surface vegetation[19]. Using the fourteen years of available GOME and SCIAMACHY data (GOME: 1996-2002; SCIAMACHY: 2003-2010), the spatial and temporal trends of tropospheric NO_2 column densities in YZD regions have been taken to investigate in general. In this study, we also analyzed the validation of tropospheric NO_2 columns over different land covers of YZD which derived from the product of UMD and EUROPE300 and analyzed the ecological effect of tropospheric NO_2 deposition over different ecosystems.

2. Materials and methods

2.1 GOME and SCIAMACHY Tropospheric NO_2 Columns

The tropospheric NO_2 column densities involved in this paper were level 2 products of version 1.10 of KNMI(Royal Dutch Meteorological Institute, the Netherlands), and were download from the website of the tropospheric Emission Monitoring Internet Service(TEMIS) , which is part of the Data User Program (DUP) of the European Space Agency (ESA) (http://www.temis.nl/airpollution/nO2.html). The tropospheric NO_2 column data were retrieved by GOME (Global Ozone Monitoring Experiment)[8, 9] and SCIAMACHY (Scanning Imaging Absorption spectroMeter for Atmospheric Chartography)[10]. The ground scene of GOME typically has a footprint of 320×40 km^2. With an across-track swath of 960 km, global coverage at the equator is achieved within three days[5]. SCIAMACHY have a resolution of 30× 60 km^2. The total across-track footprint provides global coverage once in every six days at the equator and more frequently at higher latitudes[11]. The algorithm and retrieval error of the NO_2

column densities from GOME and SCIAMACHY have been studied by many researchers: for details, see Boersma, K[11, 16], Richter, A and Richter, A[10] and Martin, RV[9].

Using the tools of matrix calculation, we translate the original NO_2 column densities data which are HDF format into point data which are SHP format. Then these point data were interpolated into raster format data, which spatial resolution are 0.08333 degree. The purposes of interpolation are to fill the area where data were missing and to analysis the regional transformation of the tropospheric NO_2 columns. At last, we clipped the NO_2 columns using the Yangtze River Delta region (YZD), and obtain the monthly average NO_2 data of YZD during 1996-2009a.

2.2 Validations of tropospheric NO_2 columns from satellite

Blond pointed that NO_2 surface measurements performed in urban areas cannot be used for the validation of the SCIAMACHY NO_2 tropospheric columns with a relatively low spatial resolution. They also show that for rural areas, there is a direct relationship between the measured NO_2 surface concentrations and SCIAMACHY total columns[20]. As a result, we chose the Lin'an air pollution background station (LAS, WMO station) which located in south-western rural area of Hangzhou city in Zhejiang Province. As one of three regional background stations in China (Lin'an, Shangdianzi and Waliguan), LAS is also the only monitoring atmosphere site and present key role in researching the air pollution of YZD. LAS has been monitoring the background atmosphere condition of YZD from July, 2005. In our study, the measured data of LAS has been covered from august of 2005 to June of 2009.

In contrast to in LAS data which measure the NO_2 concentration near the ground, the remote sensing data from GOME and SCIAMACHY, after correction for vertical sensitivity, yield the column amount integrated over the troposphere. With the exception of aircraft and lightning, the sources of nitrogen oxides are located close to the surface. As a result of this NOx source distribution and the relatively short NO_2 chemical lifetime, the tropospheric NO_2 columns observed from space are dominated by the NO_2 amount in the boundary layer. We compared the monthly surface NO_2 concentration of SDZ in Beijing and tropospheric NO_2 Columns from January 2007 to April 2009. The NO_2 concentration of LA is the surface average value of the site data during 30 days, while tropospheric NO_2 columns from GOME and SCIAMACHY are the average value of time point, and it is the information of total troposphere column. The tropospheric NO_2 columns have been from the near ground NOx emissions. Though there are different spatial and temporal scales of the data from measurement and remote sensing, they have been certain comparability[4] .

The comparison indicated that there is finer similarity between satellite measurements and ground based observations (Fig. 1) during January 2007 to April 2009.

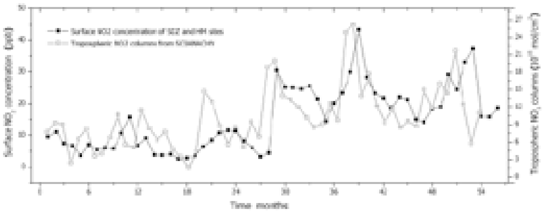

Fig. 1 The comparison between tropospheric NO_2 columns and the near ground NO_2

We analyzed the correlation between tropospheric NO_2 columns and near ground concentration on the LA site in Zhejiang province from January 2007 to April 2009 (Fig. 2). With the scatter plots of the surface NO_2 and the tropospheric columns, the regression analysis parameters are given in the figure 2, and it shows better correlation coefficient (R^2 = 0.86, and P<0.001). Therefore the NO_2 columns retrieved from GOME and SCIAMACHY can be used to analyze the spatial and temporal distribution characterization of tropospheric NO_2 at YZD.

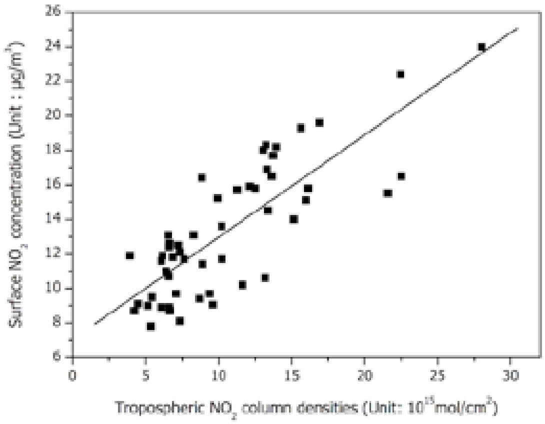

Fig. 2 The analysis of relationship between the column densities of tropospheric NO_2 and the concentration of surface NO_2

2.3 NO_2 dry deposition Retrievals

Dry deposition refers to the deposition rate of nitrogen as a gas or aerosol in a dry atmosphere, a process that depends on the surface and aerodynamic resistances. It is not only one of the main processes to remove pollutants of atmosphere, but also the efficient way to take the nutrients nitrogen into ecological system from the atmosphere. So the study of dry deposition has been of great significance on the environment and ecology. Dry deposition can thus be estimated if the atmospheric concentrations, the roughness and the wind speed are known. However, deposition of larger aerosols may also occur by sedimentation and impaction. At first, researchers can obtain the dry deposition velocity based on the field or laboratory measurement. Then they developed many models to simulate the deposition process [21, 22], and got the spatial and temporal distribution of Nr deposition in certain precision. But due to the lack of reliable regional ground gas concentration and sedimentation velocity data, models simulation also has contained a great deal of limitations. The ratio of dry to total deposition varies markedly over different ecosystem, but is usually between 1:1.7 and 1:2[23], equal or more than wet deposition of Nr.

Remote sensing can monitor the concentration of nitrogen oxides distribution over the global in a long time since 1995 [9]. And it provided a new method to study tropospheric NO_2 distribution and chemical changes based on these satellite data. The dry deposition flux was calculated as the product of the sedimentation velocity and the surface NO_2 concentration [24] in this study:

$$F(N_d) = V_i(N) \times C_i(N) \quad (1)$$

Here,
$F(N_d)$ dry deposition flux of NO_2;
$V_i(N)$ sedimentation velocity of NO_2 over the i ecosystem;
$C_i(N)$ surface NO_2 concentration over the i ecosystem.

The dry deposition velocity of NO_2 were used in this study resulted from zhang, Y[24], which combined the site-specific gradient meteorological data and a big-leaf model to simulate the distribution of dry deposition velocities for the main types of land use present in China. The surface NO_2 concentrations are retrieval from tropospheric NO_2 column of GOME and SCIAMACHY.

2.3.1 Inferring surface NO_2 concentration from GOME and SCIAMACHY

We estimate ground-level NO_2 concentrations from GOME and SCIMACHY for calculating the NO_2 dry deposition flux. We follow the approach of empirical formula between ground-level NO_2 and tropospheric NO_2 vertical columns in LAS (2.2).

The ground-level NO_2 is inferred from the equation as follow:

$$Y = 0.591 \times 10^{-15} \times X + 7.041 \quad (2)$$

The Y denotes the ground-level NO_2 concentrations. The symbol X represents the vertical densities NO_2 of troposphere. Equation (2) implicitly assumes that the tropospheric NO_2 column is dominated by the emission of the ground. This assumption didn't consider the effect of atmospheric transmission.

2.3.2 The reference data of N Dry depositions

In order to verify the flux of the dry deposition using empirical formula, we collected the real NO_2 dry deposition flux through consulting the published literature [25-31] and the results are shown in table 1.

Table 1 NO_2 dry deposition flux in different sites

Sites	Lat *(N, degree)*	Lon *(E, degree)*	Time *(a)*	dry deposition *(Unit：kg/hm²·a)*	References
Nanjing (Jiangsu)	32.18	118.71	2005	43.83	Deng，2009[25]
CEF (Beijing)	39.95	116.30	2007	53.3	Shen，2009[26]
QZ (Hebei)	36.87	115.02	2007	57.4	Shen，2009[26]
Longyan(Fujian)	25.10	117.03	2004	3.89	Chen，2006[27]
Zhangzhou(Fujian)	24.51	117.65	2004	5.64	Chen，2006[27]
Xiamen Univ. (Fujian)	24.44	118.10	2004	4.99	Chen，2006[27]
Forest of Yintan(Jiangxi)	28.25	116.92	2004	6.58	Fan，2007[28]
Cropland of Guanzhong(Shanxi)	35.33	109.96	1996	16.3	Li，1999[29]
Yangling(Shanxi)	34.27	108.08	2006	1.5	Wang，2008[30]
Luochuan(Shanxi)	35.76	109.43	2006	1.2	Wang，2008[30]
Caijiatang of shaoshan (Hunan)	27.87	112.91	2001	28.9	Xiang，2006[31]

2. 4 Land cover change maps

There are two maps of land cover change in YZD to analysis the distribution of NO_2 column in different land cover. The UMD data, for indicating the land cover of 1996-2000, was classified into 14 types land covers through NDVI which synthesized 10 days of AVHRR data during 1992-1993 using data mining decision tree. The overall accuracy of this data is 66.9% and the spatial resolution is 1 km. The EUROPE300 data, for indicating the land cover of 2001-2010, was classified into 23 types land covers through ENVISAT/MERIS data during 2004-2006. The method of this product is three steps: first, they divided the globe land into 22 ecological climate zones; then, the globe map was classified using multiple iterative clustering methods; at last, they chose the 3,000 sites to validate the result of classification. The overall accuracy of this data is 73% and the spatial resolution is 300 m. According to Chinese national land resources classification system, we take combination the original 14 categories into six land cover types: water bodies, forest, grass land, cropland, urban area and unused land. The result is as shown in Figure 3.

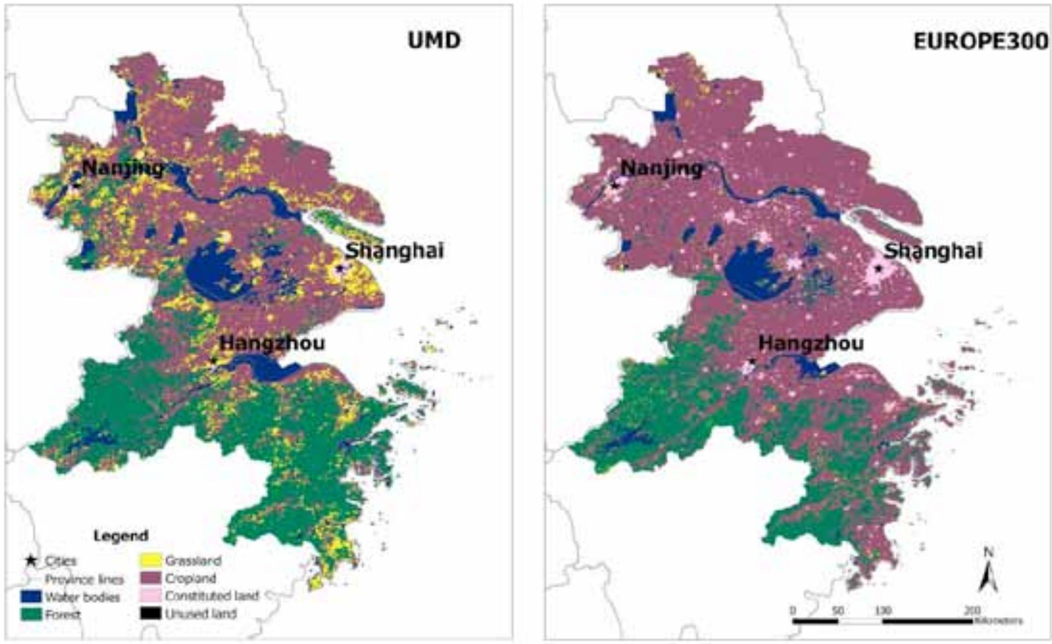

Fig. 3 Land cover maps of YZD during 1996-2010. The left one is derived from the UMD product for indicating the land cover of 1996-2000 in YZD region; the right one is derived from the EUROPE 300 products of 2006 for indicating the land cover of 2001-2010 in YZD region.

3. Results and discussion

3.1 General distribution of NO_2 column densities over the YZD

Using the fifteen years of available GOME and SCIAMACHY data (GOME: 1996-2002; SCIAMACHY: 2003-2010), the spatial and temporal trends of tropospheric NO_2 column densities in YZD have been taken to investigate in general.

To illustrate the spatial distribution of NO_2, the averages of the tropospheric NO_2 column densities derived using SCAMACHY measurements from January to December 2008 are shown in Figure 4 A for the ZD. The result indicate that the highest tropospheric NO_2 column densities are widespread across the Yangtze River, from Shanghai to the metropolitan regions which are located in south of Jiangsu province. While there is also higher NO_2 concentration appeared in Hangzhou bay which have the biggest metropolitan area in Zhejiang province.

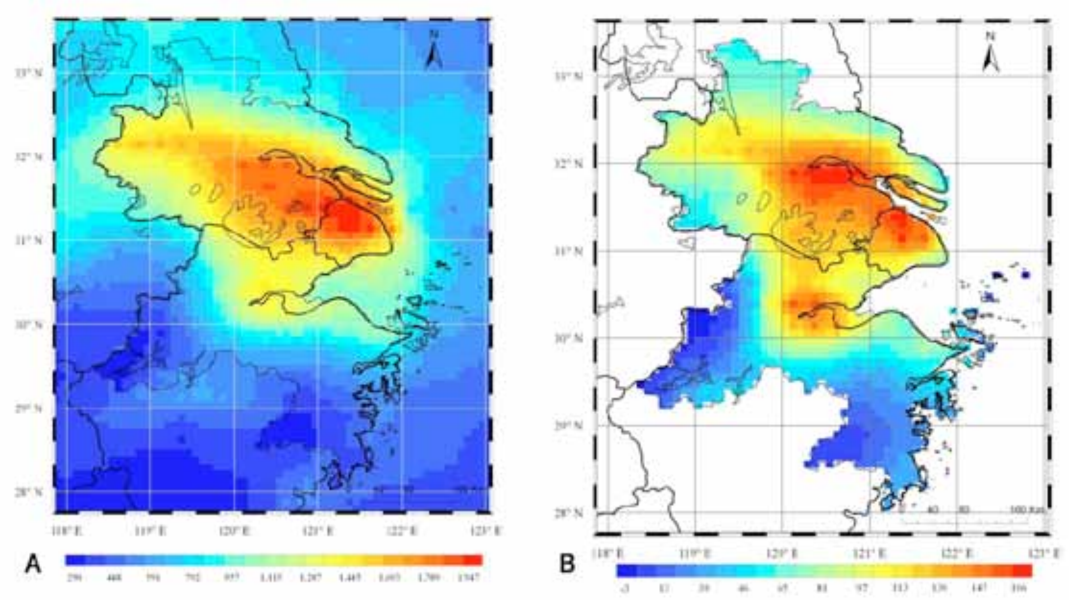

Fig. 4 Spatial variation of tropospheric NO_2 over YZD region. A is the tropospheric NO_2 vertical columns derived from SCIAMACHY and averaged between January and December 2008 for YZD; B is the average annual changes in tropospheric NO_2 as observed by GOME and SCIAMACHY from 1996 to 2010. The gradient obtained from a linear regression of the annual averages of troposheric NO_2 column densities, retrieved from 1996 to 2010 is shown. Reductions in NO_2 are observed over the YZD, while large increase are evident over shanghai, Nanjing and Hangzhou regions.

Using the fifteen years of available GOME and SCIAMACHY data, the other approach has been taken to investigate possible trends. In a spatial view, a straight line has been fitted to the annual averages of tropospheric NO_2 from 1996 to 2010. The resulting slopes are shown in Figure 4 B. In most regions of the YZD region, the NO_2 columns have changed significantly over these 15 years. However, two exceptions are obvious from the graph: NO_2 columns in metropolitan area which contain Shanghai, Nanjing and Hangzhou cities, increased strongly while they decreased in West and South-Eastern of Zhejiang province. There are also some indications of increasing NO_2 in the Hangzhou-Jiaxing-Huzhou plain regions and the south of Jiangsu province. Clearly, assuming a linear trend is a simplification, but the overall pattern should be correct. These observations are broadly consistent with a trend of large increases over east of china from 1996 to 2004[5].

The biggest surprise is the strong increase in the NO_2 over the YZD, and this is investigated in more detail in Figure 5, where monthly averages are plotted over the whole region of YZD. Clearly, NO_2 columns increased throughout the observations, mainly in winter but also in summer. The data also show the large seasonality of the NO_2 columns which is due to variations in emissions. However there are some different characteristics between the seasonality of satellite data from GOME and from SCIAMACHY. The trend was obviously concluded that it has the highest value in winter and lowest in summer according to the satellite data from GOME. But this character has been showed few distinctly according to SCIAMACHY data.

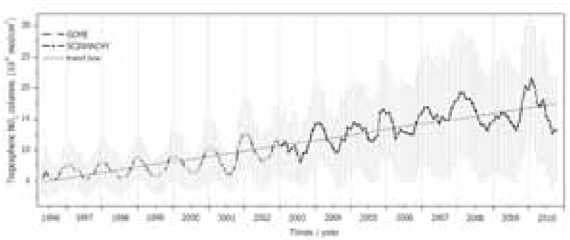

Fig. 5 Time series of satellite observed monthly tropospheric NO_2 column densities during 1996-2010 over YZD (unit: 10^{15}moleculecm^{-2})

3.2 The characterization of tropospheric NO_2 column densities over different ecosystem in YZD

Due to the different regional environment and emission sources, tropospheric NO_2 has significantly different characteristics over different land covers[9]. In this study, we analyzed the variation of tropospheric NO_2 columns over different land covers of YZD which derived from the product of UMD and EUROPE 300.

Figure 6 is the variety trends and the growth rate of NO_2 columns over five land covers. An obvious increasing trend has appeared in all the land covers. According to the NO_2 columns of different land covers, the highest value appeared in the urban area, water bodies and cropland while the lowest value showed over forest and grass land (figure 6 A). The temporal development of the NO_2 column is shown in figure 6 B relative to the value measured in 1996. It is evident from these time series that the changes depicted in figure 6 A are systematic and not dominated by year-to-year variations, in particular over water bodies and forest. There has the fastest increasing amount of NO_2 column over water bodies during 1996-2010, then the urban area, crop land and forest.

The anthropogenic emissions are the main source of tropospheric NO_2 column densities over urban area and crop land. As a contrast, the validation of NO_2 columns is lower value and unobvious anural changes over grass land and forest because of the natural emission of these regions.

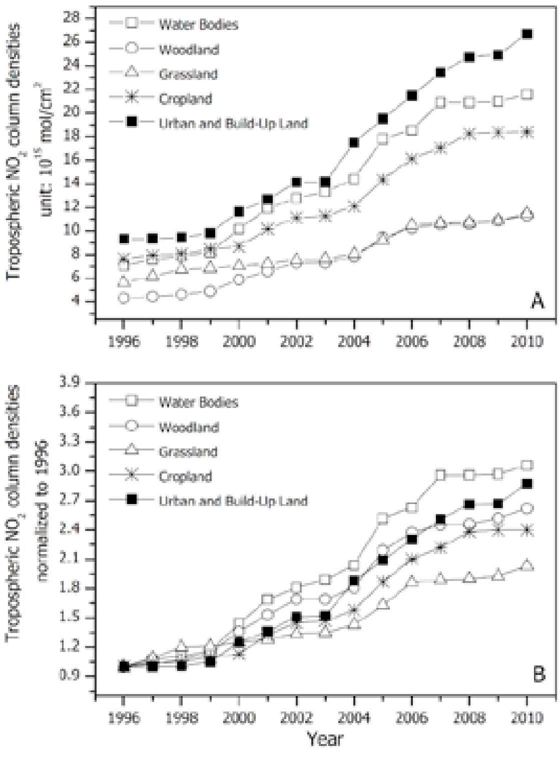

Fig. 6 (A) It is the temporal evolution of tropospheric NO_2 column densities from GOME and SCIAMACHY for different ecosystems in YZD. (B) The mean annual NO_2 column densities normalized to 1996 for the different ecosystems including water bodies, forest, grassland, cropland, and urban area, which are defined in Fig. 3.

The statistical analysis was used to study the characteristic of troposperic NO_2 column over different land covers during 1996-2010. The result is shown in table 2 and figure 7. At first, amount of the NO_2 column characterized the average densities of NO_2 in troposphere. There is the highest column density of NO_2 in urban area, and then the second is cropland according to table 2. While there are lowest values over water bodies and forest. In addition, the standard variance statistics characterization of NO_2 column indicate the differentiation of NO_2 column densities in spatial. So there is the largest differentiate of NO_2 column in forest (Table 2). And the order of differentiate is grass land, crop land, water bodies and urban area by size. The third, statistical histogram is reflected the grade distribution of NO_2 column densities. Figure 7 indicated that the NO_2 column has the obviously ‘upper shift’ trend amount the five land covers, especially over urban area and water bodies.

Table 2 Tropospheric NO_2 column densities statistic features over different land coverage

Land coverage	STD	Mean	DMA*
Water bodies	2.90	14.27	3.06
Forest	5.10	7.76	-3.46
Grass land	4.44	8.43	-2.79
Cropland	4.01	12.53	1.32
Urban area	2.74	16.59	5.37

*DMA: Difference between the Mean values and the Average value of Yangtze region

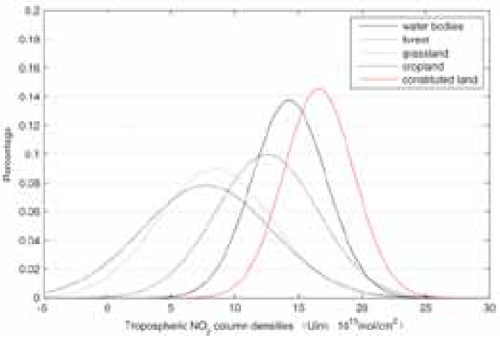

Fig. 7 Tropospheric NO_2 columns statistic curve over different land coverage

To interpret the observed behavior of NO_2 column, the following potential reasons, which might explain an increase of the observed NO_2 columns over different land covers, should be considered. There are a number of population and human activities intensity in urban area and crop land, as a result of a large emission amount in these regions. There are little human activities in forest and grass land, as a result of transmission instead of emission amount of NO_2 column. There is the specific character over water bodies. Although the emission of NO_2 is less the others in water, they are almost located surrounding the human activities indent area such as Taihu Lake in YZD. NO_2 column of Transmission is the main source of water bodies. Then there is plenty of water vapor over there, it can prolong the lifetime of NO_2 in troposphere. As a result there also prefer the high value of NO_2 column over water bodies in YZD region.

3.3 Comparison of tropospheric NO_2 column and the flux of NO_2 dry deposition

We compared the tropospheric NO_2 column and the flux of NO_2 dry deposition at this section. The flux of NO_2 dry deposition was collected from the reference literatures which have been published in jurists or magazines. These data have precise coordinates and temporal information. So we elected the tropospheric NO_2 column according to the same coordinates and time, and then carried on the comparison and analysis.

The result is shown as figure 8, and it indicated that there is a significant correlation ($P<0.0001$, $R^2=0.925$) between tropospheric NO_2 and flux of NO_2 dry deposition. However, the discrete phenomena appeared in the high value points because of the lack of flux NO_2 dry deposition data. Overall, it can be used to calculate the NO_2 dry deposition using the satellite data.

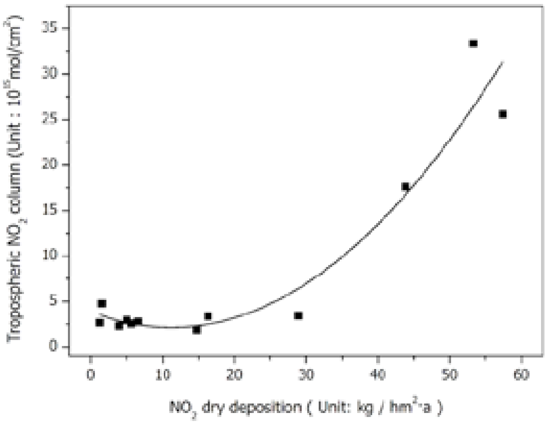

Fig. 8 The analysis of relationship between the column densities of tropospheric NO_2 and the flux of NO_2 dry deposition

3.4 Flux of NO_2 dry deposition over different land covers in YZD

There are the similarity trends of NO_2 dry deposition over different land covers. The amounts of NO_2 dry deposition have increased steadily during 1996 to 2010, which appeared increased significantly in 2005(Fig.9). However, there also performed distinctly on quantities of NO_2 dry deposition over per land cover. Through there is the high value of NO_2 column on water bodies, the amount of NO_2 dry deposition is smallest among these land covers. It is the highest dry deposition amount of NO_2 over crop land, then the grass land and forest.

As a result of wet deposition and precipitation are directly related, the nitrogen wet deposition plays a dominated role in the total amount of nitrogen deposition in YZD region. But the dry deposition flux of nitrogen has also the same quantity as the nitrogen wet deposition and cannot be underestimated. Some researches indicated that the dry deposition of nitrogen occupied 20-40 percent of total deposition amount[23]. As a nutrient source of terrestrial ecosystem, atmospheric nitrogen deposition has significant effects on the ecosystem of agriculture, forest and water bodies in YZD region. However, the related conclusions have not been given and this is the next step of our research target.

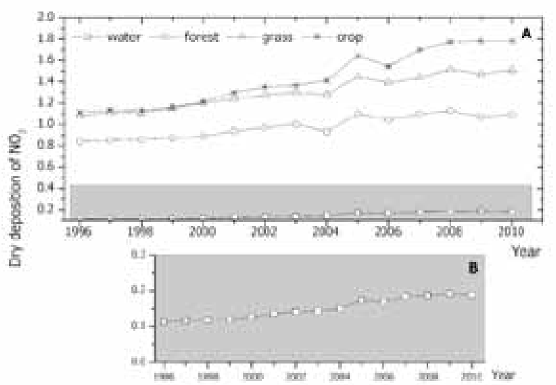

Fig. 9 The trend of the flux NO_2 dry deposition over different land covers. A is the fluxes of NO_2 dry deposition over four land covers: forest, water, grass and crop land; B is the flux of NO_2 dry deposition over water.

4. Conclusions

Using the fourteen years of available GOME and SCIAMACHY data (GOME: 1996-2002; SCIAMACHY: 2003-2009), the spatial and temporal trends of tropospheric NO_2 column densities in YZD region have been taken to investigate in general. In this study, we analyzed the variation of tropospheric NO_2 columns over different land covers of YZD which derived from the products of UMD and EUROPE 300. At last, we try to estimate the amount of NO_2 nitrogen dry deposition using satellite data over different land covers.

(1) The result indicate that the highest tropospheric NO_2 column densities are widespread across the Yangtze River, from Shanghai to the metropolitan regions which are located in south of Jiangsu province. In most regions of the YZD region, the NO_2 columns have increased significantly over these 15 years. In spatial, NO_2 columns in metropolitan area which contain Shanghai, Nanjing and Hangzhou cities, increased strongly while they decreased in West and South-Eastern of Zhejiang province. A pronounced seasonal variation and a significant increase from year to year are observed, most notably in the winter values. The highest value of NO_2 columns appeared in winter and lowest value in summer during the period of 1996 to 2010.

(2) NO_2 columns in metropolitan area which contain shanghai, Nanjing and Hangzhou regions, increased strongly while the value decreased in the middle part of YZD. These observations are broadly consistent with a trend of large increases over urban area of YZD from 1996 to 2010.

There are the lowest values of NO_2 column over forest and grass land. It has the same trend of NO_2 column over forest and grass land and distinctly variation on the high value of NO_2 column over urban, water bodies and crop land. There are also different rate of increase over five land covers. It has a maximum growth rate of NO_2 column over water bodies, followed by the urban area, forest and crop land, while a minimum over grass land.

(3) There is the highest column density of NO_2 in urban area, and then the second is cropland. While there are lowest values over water bodies and forest. So there is the largest differentiate of NO_2 column in forest. And the order of differentiate is grass land, crop land, water bodies and urban area by size. The NO_2 column has the obviously ‘upper shift’ trend amount the five land covers, especially over urban area and water bodies.

(4) There are the similarity trends of NO_2 dry deposition over different land covers. The amounts of NO_2 dry deposition have increased steadily during 1996 to 2010, which appeared increased significantly in 2005. Through there is the high value of NO_2 column on water bodies, the amount of NO_2 dry deposition is smallest among these land covers. It is the highest dry deposition amount of NO_2 over crop land, then the grass land and forest.

The characterization of NO_2 column was preliminary analyzed in this paper as well as the amount of NO_2 dry deposition over different land covers. Further work will focus on the sources of NO_2 column over different land covers as well as the ecological effect of NO_2 deposition to terrestrial ecosystem.

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