The spatial distribution of remote sensed SO2 in China and its relationship with energy consumption

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Abstract. The spatial distribution of SO2 in China was analyzed using OMI-Level3 SO2 PBL (planetary boundary layer) column concentration data of 2013. At the same time, the total value of energy consumption per unit area and coal energy consumption per unit area were analyzed and compared with SO2 distribution. Results show that SO2 distribute unevenly in whole China, and even at the provincial level, SO2 concentration difference was obvious. The spatial distribution of SO2 in China displays characteristics of two highest plates as the center, sub-high regions radiate from center, as well as “The east higher than the west, and the north higher than the south”. Energy consumption per unit area and coal consumption per unit area also distribute unevenly, and the two distributions have similar characteristics but different details. The higher similar spatial distributions of SO2 and energy consumption (especially coal consumption) imply the firm connection of SO2 pollution and coal consumption. SO2 pollution in China remains acute, and the control on coal consumption remains important and emergent in recent years.

1. Introduction
Sulphur dioxide (SO2) is one important gaseous pollutant in the troposphere [1], which not only impacts air quality, but also human health and environment through the forms of acid rain or fine particle [2-3]. The source of atmospheric SO2 includes anthropogenic and natural ones. The burning of fossil fuels in human activity is the main source of SO2 [4-5]. Especially in China, as economic development and fossil fuel consumption increasing, monitoring and research of SO2 are necessary. Most traditional research used data from SO2 monitoring stations, which confine the scale of study time and space [6-7]. China is a vast country, and regional difference exists in many affects, including economy, energy consumption and SO2 distribution. Therefore, this article analyses the spatial distribution of SO2 in China and its relationship with energy consumption using the remote sensed and statistical data.

2. Data Processing and Method

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2.1 Data source and processing

At present, remote sensed SO$_2$ data are mostly from GOME, SCIAMACHY, OMI, GOME-2, and OMPS. Many researches [8-9] suggest retrieving concentration of trace gases by using OMI data achieved higher precision. The data used in this study mainly include OMI-Level3 SO$_2$ PBL (planetary boundary layer) column concentration data with $0.25^\circ \times 0.25^\circ$ spatial resolution of 2013, which were downloaded from NASA website (http://acdarm.gesdisc.eosdis.nasa.gov/). SO$_2$ column concentration of planetary boundary layer is closely related to human activities. And OMI-Level 3 SO$_2$ PBL data are filtered from OMI-Level 2 SO$_2$ PBL column concentration data according to observation angel, abnormal row and other conditions.

Energy consumption data of provinces in China (given the difficulty in data acquisition, Hong Kong, Macao, Taiwan, and Tibet were not included) of 2013 used in the study area were from China energy statistical yearbook. China and provinces boundary vector data are downloaded from National Geometrics Centre of China.

2.2 Method

In order to quantitatively analyze the distributions of SO$_2$ concentration, energy consumption and coal consumption, this article introduced spatial correlation matrix of Geoinformatics to measure the correlation. Spatial correlation matrix is used to calculate the correlation coefficient of data which have the same space range [10], formula is shown in formula 1, the value range is [-1,1]. While 1 represent completely correlation, -1 represent completely negative correlation.

$$\text{Corr}_{ij} = \frac{1}{(n-1)\sigma_i \sigma_j} \sum_{k=1}^{n} (v_{ik} - \mu_i)(v_{jk} - \mu_j)$$

$\text{Corr}_{ij}$$—$the correlation coefficient of the distributions of SO$_2$ concentration and energy consumption (coal consumption), $i$—the distributions of SO$_2$, $j$—the distributions of energy consumption (coal consumption), $\mu$——mean value of raster data, $n$——number of pixels, $v_{ik}$—$the k$ th pixel value of $i$ layer, $v_{jk}$—$the k$ th pixel value of $j$ layer; $\sigma$——standard deviations of data layer.

3. Results and discussions

The spatial distribution of remote sensed SO$_2$ column concentration of China in 2013 was shown in Figure 1, where the SO$_2$ concentration of China can be divided into five levels. The highest SO$_2$ concentration area is located in two plates. One is the middle and lower reaches of the Yellow River Basin area, including the east of Shanxi, the south of Hebei, Tianjin, the north of Henan, Shandong and the north of Jiangsu. The other part is the Sichuan Basin area, including the southeast of Sichuan, the west of Chongqing and Guizhou. SO$_2$ concentrations in these areas were mostly higher than 0.6 DU. The radiation zones of the two plates in the first level and Pearl River Delta region constituted the second level of SO$_2$ concentration. Heilongjiang, the west of Jilin, the north of Liaoning, the east of Inner Mongolia, the southeast of Gansu, the east of Hunan, the south of Hubei, most part of Jiangxi, and the north of Guangdong concentrated in the third level. The forth level included Yunnan, Fujian, the north of Xinjiang and the west of Sichuan. Besides all above areas, the rest areas fall in the fifth level, which mostly located in the northwest of China.

Figure 2 and 3 show the spatial distributions of energy consumption per unit area and coal consumption per unit area of China in 2013, respectively. As shown in the Figures, just like SO$_2$ distribution, energy consumption per unit area and coal consumption per unit area distributed unevenly. The two distributions have similar characteristics but different details. The high energy consumption per unit area zones focus on Bohai Bay Economic Region (Beijing, Hebei, Tianjin, Liaoning), east coast region (Jiangsu, Zhejiang, Shanghai) and Guangdong. The sub-high region including Shanxi, Henan, Ningxia, followed by Shaanxi, Hubei, Anhui, Guizhou, Hunan, Jilin and Fujian. The rest provinces have relatively low energy consumption per unit area.

Comparing with distribution of energy consumption, coal consumption’s high regions focused on the Yellow River Basin area and east coast regions, including Shanxi, Hebei, Tianjin, Henan, Shan-
dong, Jiangsu and Shanghai. Beijing, Liaoning, Anhui, Zhejiang, Ningxia and Guangdong composed the sub-high region. The third high coal consumption per unit area region located in Shanxi, Chongqing and Guizhou, followed by Hubei, Hunan and Jiangxi. The rest provinces constituted the low value zone.

Table 1 gives the correlation coefficient calculated result of the distribution of SO$_2$ and the spatial distribution of energy consumption and coal consumption. The correlation coefficient of SO$_2$ and energy consumption is 0.6578, while the coefficient with coal consumption reached 0.8707. It is easy to conclude that the spatial distribution of SO$_2$ does have connection with the spatial distribution of energy consumption and coal consumption, showing higher similarity with coal consumption per unit area.

Table 1. The correlation coefficient of distribution of SO$_2$ and energy consumption

|     | energy consumption per unit area | coal consumption per unit area |
|-----|----------------------------------|-------------------------------|
| SO$_2$ | 0.6578                             | 0.8707                           |

It’s worth noting that some provinces’ coal consumption distribution and average SO$_2$ distribution appear inconsistent, especially reflected in Zhejiang and Sichuan. Zhejiang belongs to the high region

Figure 1. The spatial distribution of remote sensed SO$_2$ column concentration of China in 2013.

Figure 2. The spatial distribution of energy consumption per unit area of China in 2013.

Figure 3. The spatial distribution of coal consumption per unit area of China in 2013.

Figure 4. The overlapped distributions of provincial average SO$_2$ concentration and coal consumption per unit area of China in 2013.
of coal consumption per unit area while belong to the fourth level of provincial average SO$_2$
concentration. The southeast of Sichuan located in one of the highest SO$_2$ concentration plate while its
provincial average SO$_2$ concentration declined markedly, only was 0.21DU. The inconformity
mainly and directly caused by the non-uniformity of SO$_2$ concentration distribution has been ignored
in provincial scale. If the influence could be eliminated, consistency of SO$_2$ concentration distribution
and coal consumption per unit area distribution would be higher, though at present they have shown
high similarities.

4. Conclusion
In this paper, the spatial distribution of SO$_2$ in China was analyzed using OMI-Level3 SO$_2$ PBL
(planetary boundary layer) column concentration data of 2013. SO$_2$ distributes unevenly in whole
China, even at the provincial level, and SO$_2$ concentration difference was obvious. SO$_2$ concentration
of China can be divided into five levels, the highest SO$_2$ concentration area located in the middle and
lower reaches of the Yellow River Basin area and Sichuan Basin area, where SO$_2$ concentration were
mostly higher than 0.6 DU. The radiation zone of the first level region and Pearl River Delta region
constituted the second level of SO$_2$ concentration. In summary, the spatial distribution of SO$_2$ in China
displays characteristic of "two highest plates as the center, sub-high regions radiate from center; and
the east being higher than the west, the north being higher than the south". Energy consumption per
unit area and coal consumption per unit area also distributed unevenly, and the two distributions have
similar characteristics but different details. The spatial distribution of SO$_2$ do has connection with the
spatial distribution of energy consumption and coal consumption, and show higher similarity with coal
consumption per unit area. SO$_2$ pollution in China remains acute, and the control of coal consumption
remains important and emergent in recent years.

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