Distribution of Lightning activity and NO_2 columns by satellite observations over Tibetan Plateau and estimation of lightning-generated NO_X in China

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ABSTRACT: As a significant natural source of NO_X, lightning produced NO_X (LNO_X) controls the formation of tropospheric ozone and has impact on the oxidizing capacity of the troposphere. It is worth exploring for a better understanding of the relationship between lightning activities and LNO_X in troposphere. Compared with other areas of China, it is found that the selected region of Tibetan Plateau is an ideal area to study LNO_X. In this paper, we analyze monthly means satellite data of Tibetan Plateau, which are obtained through Lightning Imaging Sensor (LIS) and The Global Ozone Monitoring Experiment 2(GOME-2). The results indicate that the spatial and temporal distribution of lightning density and tropospheric NO_2 are quite in agreement, and the correlation coefficient between them is 0.84 by linear fitting. LNO_X production in China is evaluated to 0.15(0.03~0.38)Tg(N)/y which is based on Beirle's estimation method. The result is helpful to better recognize the important role of lightning on climate change in China.

INTRODUCTION

Nitrogen oxides (NO_X) are important trace gases in atmosphere. Thunderstorm lightning has been considered a major source of nitrogen oxides. Recently, the estimations of global LNO_X production still have high uncertainty, due to the different selected methods and parameters. The results of LNO_X production in China is rarely been studied, which is range from 0.016 to 0.38 Tg(N)/y based on lightning data combined with ground observation and theory calculation[Zhou et al. 2002; Sun et al. 2004]. While satellite data, with long time series and global coverage, can provide a new approach to study LNO_X [Schumann and Huntrieser 2007]. Through this way, we can avoid the complexity of selecting physical parameters in theoretical method and the specificity of extrapolation in situ observation. In order to reduce the uncertainty, we should focus on a region with high lightning activities but low anthropogenic sources of NO_X. Compared with other areas of China, it is found that the Tibetan Plateau is sparsely populated with industry underdeveloped, so anthropogenic sources have little influence on tropospheric NO_X over

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the region, meanwhile the lightning frequency there is also much more than surrounding areas. All of these show that Tibetan Plateau is an ideal area to study the relationship between lightning and NO_X. In this paper, we use LIS&GOME-2 monthly means satellite data of Tibetan Plateau to analyze the distribution and correlation of lightning density and tropospheric NO_2 vertical column densities (VCD) over Tibetan Plateau, then take a rough estimation of LNO_X production in China.

DATA

The lightning data in this paper was chosen from the latest OTD/LIS 2.3 version grid data providing by Global Hydrology Resource Center (GHRC). The total time scale is 17 years, we selected the last three years data which was observed by LIS (Lightning Image Sensor). LIS was carried by Tropical Rainfall Measure Mission (TRMM) platform, launched in 1997. The TRMM orbits the earth with an inclination of 35°, thus allowing LIS to detect lightning activity in the tropical regions all around the world. The sensor detects and locates rapid changes in the brightness of the clouds as they are illuminated by lightning discharges. It uses narrow band optical filtering to select an oxygen triplet line generated by atmospheric lightning centered at 777.4nm. From space, total lightning including cloud-to-ground, intracloud, and cloud-to-cloud discharges are visible through LIS. Its latitude band is ±35°, and then up to ±39° since the satellite was boosted from 350 to 402km [Cecil et al. 2012].

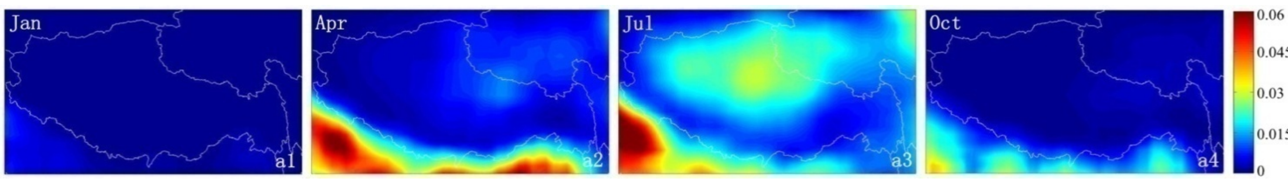
The Global Ozone Monitoring Experiment GOME-2 on board the METOP-satellite was launched in Oct, 2006, with an inclination of 98.8°. The instrument was selected in part as a result of the experience accumulated during a number of years of operations and data analysis from GOME. The more advanced GOM-2 is set to make a significant contribution towards climate and atmospheric research, whilst providing near real-time data, improving polarization measuring capability, increasing maximum swath width and so on. In this paper, we select the monthly mean data on the website of Tropospheric Emission Monitoring Internet Service TEMIS. The values given are the residual of subtracting two large numbers (the total slant column, and stratospheric slant NO_2 column) and the result of averaging and gridding mostly-clear retrievals [Boersma et al. 2004].

In order to analyze the spatial and temporal distribution and annual changing trend of lightning density and tropospheric NO_2 over Tibetan Plateau, we choose the area of 26°-37°N, 78°-100°E, data period from January 2009 to February 2009.

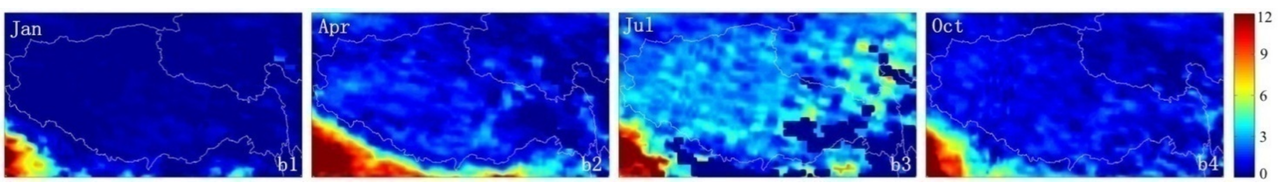
THE LIGHTNING DENSITY AND TROPOSPHERIC NO_2 IN TIBETAN PLATEAU

The spatial and temporal distribution

Anthropogenic emissions are found to be the dominant source of NO_X over China with important implications for nitrogen control by many researchers[Lin 2012]. Rapid development of economy promotes the industry burning and car exhaust, especially in densely populated areas such as eastern China. So we select Tibetan Plateau where has lower industry development. Through processing LIS and GOME-2 data, the distribution of lightning density and NO_2VCD over Tibetan Plateau of Jan, Apr, Jul, and Oct in 2010 were showed in Fig 1. Jan, Apr, Jul, Oct present for different seasons. In Fig 1(a), lightning activity of Tibetan Plateau shows obviously seasonal characteristic, summer is the most frequent period of thunderstorm, the maximum value is in the middle of Tibetan Plateau where located in the southern foot of Tanggula mountain. In spring, the value in eastern is higher than in western. From Fig 1(b), NO_2VCD in this region also presents the distribution of higher in summer and lower in winter. The peak value area of NO_2 concentration is nearly in accordance with lightning density, higher in summer generally. While many previous researches have shown that, in eastern China, the maximum value of NO_2 concentration usually appears in winter, minimum value occurs in summer. Because in eastern China, the source of tropospheric NO_2 is dominantly driven by anthropogenic emissions [6], these emissions don't present seasonal varying pattern. And the meteorological factor in winter is adverse to atmospheric diffusion, so that the pollutants can be retained for a long time in troposphere. However, in western China, such as Tibetan Plateau, the effect of human emissions, for example, fossil burning, car exhaust and so on is quite a few, the maximum value appears in summer indicates that nature source makes the main contribution to troposhperic NO_2 in western China.



(a)



(b)

Fig 1 Distribution of lightning density (a) and NO_2VCD (b) over Tibetan Plateau of Jan, Apr, Jul, Oct in 2010

In the southwest margin of Tibetan Plateau, both lightning density and NO_2VCD in Indian peninsula and Nepal have a high value in the whole year with a small variation. On one hand, the climate in Indian peninsula is greatly different from Tibet. The south of plateau is affected by southwest monsoon from the Indian Ocean with abundant rainfall and frequent lightning activity. Trough the separation of Himalayas Mountains, the north of plateau is cool and dry. On the other hand, the south area of Himalayas Mountains has a dense population, which makes the tropospheric NO_X source more complicated.

The annual variation and correlation

The tropospheric NO_2 of the central region of Tibetan Plateau is little affected by other source. By comparing Fig1(a)(b), we find that the NO_2 concentration has a good corresponding relation with lightning density, so we study this area further. Fig 2 shows their time sequence change of 38 months between January 2009 and February 2012. The result indicates that the monthly average value of tropospheric NO_2 and lightning density present the nearly same trend, which is the highest in summer and the lowest in winter. It confirmed that the tropospheric nitrogen oxide in this area is hardly influenced by human source.

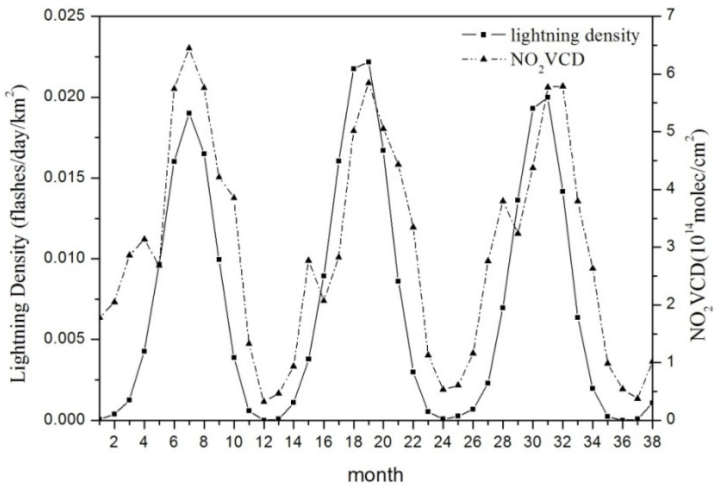


Fig 2 Annual trends of lightning density and NO_2VCD

In addition, we find that there is a different singular point in every spring, respectively in May 2009, April 2010 and May 2011. This phenomenon may caused by atmospheric circulation over Tibetan Plateau during spring. Other studies show that, Hadley circulation is located between equator and 30°N(S), which is the important part of the vertical meridian circulation. It rises in equatorial convergence zone and sinking in subtropical meridian circulation [Oort 1996]. But in the east Asia continent during the late spring and early summer (from April to June), the melting snow over Tibetan Plateau has became endothermic and made the soil temperature increased. The Tibetan Plateau becomes a huge heat source which is much higher than the south of plateau. With the increase of heating effect, Hadley circulation gradually disappeared and forming a monsoon circulation in opposite direction [Qian et al. 2001]. The change of vertical circulation may affect the trace gases in troposphere, decrease the tropospheric NO_2 concentration. Research on this aspect is not yet mature, we need a longer time series NO_2VCD and lightning density data combine atmospheric chemical transfer model for further study.

As shown in Fig 3, we study the correlation between tropospheric NO_2VCD and lightning in middle Tibetan Plateau by using linear fitting. The correlation coefficient reaches 0.84. Two linear fits are performed, using (a) all data points for three years and (b) only those with a lightning activity of more than 0.001flashes/day/km^2. And the resulting slopes are(a)210 (b)147, the errors are about 25.5(all units 10^{14}moles·cm^{-2}/(flashes·day^{-1}·km^{-2})=10^{24}molec/(flashes·day^{-1})).

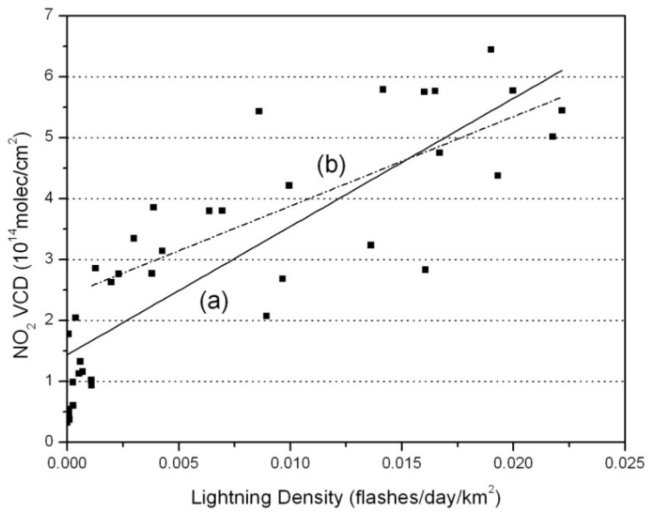


Fig 3 Correlation of lightning density and NO_2VCD for central Tibetan Plateau

(full line a for all data points, dotted line b for data with more than 0.001flashes/day/km^2)

Estimation of LNO_X production in China

We use the correlation and the Beirle's method for giving a rough estimation of LNO_X in China [Beirle et al. 2004b]. Trough the method, firstly, we obtain the daily NO_X emissions as in (1):

$$P_{day} = CF \times NO_2VCD / (\tau \times f_{NO_2}) \qquad (1)$$

Where CF is correction factor to correct the visibility of trace gases in the troposphere depends on the vertical profile and cloud cover. Here we select 1.5(1-2) [Velders et al. 2001]. The factor of f_{NO_2} is 0.4(0.4-0.8), which is presented for the ratio of NO_2 to NO_X [Ziereis et al. 2000]. The lifetime τ determines the accumulation of NO_2 in the atmosphere, and we select 4(2-6) days in this paper [Jaeglé et al. 1998]. Through this way, we calculate a daily NO_X production of 0.94(0.2-2.5)×NO_2VCD. Combined with the linear fitting results, the LNO_X production is 3.9(0.8~9.7)kg[N]/flash. After processing the LIS data, we obtain a nearly total number of 3.8×10^7flashes/y, and the LNO_X production in China of 0.15(0.03~0.38)Tg(N)/y.

CONCLUSION

Satellite data have certain advantages due to its long-time observation and large detection range. Through the analysis in China, we find that the Tibetan Plateau is a reasonable area for study LNO_X. The resulting rough estimation still needs further correction, because of the uncertainties which is brought by the influence of other sources. The future will hold better estimates through the ongoing collection of data and the chemical transfer model.

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