Spatiotemporal characteristics of ultraviolet solar radiation in China

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ABSTRACT
UV radiation plays an important role in climate change and photochemical reactions, and in Ecosystem Research. In this study, the authors presented study results of China’s National Basic Research Program Study on the climatic characteristics and reconstruction method of UV radiation in China. The spatiotemporal variation of UV radiation in China has been discussed, and then an efficient modeling method has been established to obtain history UV radiation data to analyse the variation trends of UV radiation in China. Finally, the influence of aerosol, cloud, ozone, and water vapor on UV radiation has been discussed.

1. Introduction
Ultraviolet (UV) radiation is a key parameter in the study of atmospheric photochemistry (Dickerson et al. 1997; Ferrero et al. 2006; Thomas, Swaminatha, and Lucas 2012). UV radiation can drive most photochemical radical reactions in the photochemistry process in the troposphere; for example, the solar spectra between 190 and 350 nm can lead to hydrogen peroxide photolysis, nitrous acid photolysis occurs between 310 and 396 nm, the spectra from 301 to 356 nm cause formaldehyde photolysis, and the spectra from 202 to 422 nm mainly result in nitrogen dioxide photolysis (Zhou 1996; Deng et al. 2012).

UV radiation is an essential parameter for the research field of climate change and for the evolution of the ecological system (Grants and Heisler 1997; Cañada et al. 2000). In China, measurements of UV radiation on a national scale have been conducted since August 2004. Thus, long-term measurements of UV radiation are rare, and datasets are only available for some locations. Unfortunately, only rich measurements and long-term data series on UV radiation can be used to determine the climate variation characteristics of UV radiation and the influence of UV radiation on ecological processes. In brief, UV radiation plays an important role in climate change and the study of photochemical processes (Calbó, Pages, and Gonzalez 2005; de Outer, Slaper, and Tax 2005; Hu, Wang, and Liu 2007).

Because studies on the climate variation characteristics of UV radiation over China have been insufficient, observations on a national scale are urgently needed to establish an efficient model for reconstructing long-term UV radiation data over China and enrich the knowledgebase on aerosol–radiation interactions in China. In 2013, China’s National Basic Research Program funded a project entitled ‘Study on the Climatic Characteristics and Reconstruction methods of UV Radiation in China’ that was led by Prof. HU Bo, the director of the Sub-Centre of Atmosphere Science of the Chinese Ecosystem Research Network (CERN). The aims of this project were to investigate the distribution and variation characteristics of UV radiation, develop reconstruction methods for modeling historical UV radiation data, and quantify the impact of aerosols on UV radiation in China. There were many atmospheric chemistry and environmental scientists involved in the project. The results have contributed to an improved knowledgebase on UV radiation and aerosol–radiation interactions.

2. Major achievements
To determine the spatiotemporal variation of UV radiation in China, observations from 2004 to 2015 at 44 radiation stations belonging to CERN were used. After strict quality...
control, these data were used to analyze the spatial variance and long-term variation properties of UV radiation over China. A detailed description of the dataset can be found in Liu et al. (2017b). Next, a reconstruction method was developed to estimate the historical UV radiation based on an atmospheric radiation model, and then the variation trends of UV radiation were discussed. In addition, the influences of aerosol, cloud, ozone, and water vapor content on UV radiation were also quantified (Liu et al. 2017b).

2.1 Spatial and temporal variation characteristics of observed UV radiation over China

The spatial distribution and temporal variation of UV radiation were discussed based on observations made at stations belonging to CERN. The multi-annual mean UV radiation was 0.55 MJ m$^{-2}$ d$^{-1}$, and the highest value (20.46 MJ m$^{-2}$ d$^{-1}$) occurred at Lhasa station. The highest radiation appeared over the Tibetan Plateau region, while the lowest values were observed in the southwest region. There was a decreasing trend of UV radiation from south to northwest of 100°E; however, the latitudinal variation characteristics east of 100°E were contrary to those in West China (Wang et al. 2014; Liu et al. 2017a). In most climate regions, the UV radiation presented a negative variation trend from 2005 to 2015, and the decreasing trend of UV radiation was approximately $-0.740$ KJ m$^{-2}$ d$^{-1}$ yr$^{-1}$. The ratio of UV to global radiation was lowest in the Yellow River area and increased to the north and south of this area. The distribution of the ratio of UV radiation to solar radiation was consistent with the water vapor content and opposite that of the clearness index. In terms of temporal change, the ratio increased from February, the highest value of the ratio appeared in summer (June and July), and the ratio decreased from August in most areas of China. The yearly variation in the ratio of UV radiation to solar radiation presented an opposite trend to the clearness index.

2.2 Long-term variation in UV radiation over China

A semi-empirical reconstruction model for UV radiation was developed to obtain historical UV radiation data to investigate the temporal variation characteristics and spatial distribution over China (Zhang et al. 2014; Liu et al. 2017b). Following previous studies, we divided the stations into eight regions and then used the in-situ data to develop an estimation model suitable for each subregion. The model involves the clearness index and the cosine of the solar zenith angle, and the method is suitable for all atmospheric conditions. Results indicated that the model can be widely used in calculating historical UV radiation.

A historical dataset of daily UV radiation, spanning 1961 to 2014, from 724 routine weather stations belonging to the China Meteorological Administration, was obtained via the aforementioned method. Based on this reconstructed dataset, the spatial distribution and temporal variation of UV radiation were discussed. Meridionally, increasing trends were found from eastern China to western China. Latitudinally, there was an increasing trend from south to north. The daily UV radiation presented a decreasing trend from 1961 to 2014 throughout China, except over the Tibetan Plateau region (Liu et al. 2016, 2017a). There was a decreasing linear trend from the early 1960s to the late 1980s, which then tapered off and reached a steadily low level from the 1990s throughout China.

2.3 Quantification of the factors impacting UV radiation

The extinction effects of aerosol optical depth (AOD), ozone, clouds, and water vapor content on UV radiation were calculated (Liu et al. 2017b). The attenuation of cloud to UV radiation was highest, with an attenuation ratio of approximately 18.13%; however, ozone exerted the lowest attenuation effect, which contributed 1.12%. Aerosol and water vapor extinguished 7.59% and 6.20% of the UV radiation, respectively, during the transmission of UV radiation through the atmosphere. The spatial distribution of the attenuation effects of AOD, ozone, and cloud on UV radiation were similar to the various characteristics of AOD, ozone, and cloud (Liu et al. 2017b). However, the attenuation effect of water vapor on UV radiation presented an inconsistent distribution compared with that of relative humidity, perhaps because relative humidity relies on the interaction between temperature and water content.

These results provide information for research on aerosol–radiation and cloud–radiation interactions in China. At the same time, the methods developed and results obtained are useful for assessing the effects of UV radiation on local air quality.

3. Future studies

Studying the variation in UV radiation and quantifying the effects of aerosol, cloud, ozone, and water vapor on UV radiation has improved the level of understanding with respect to the spatiotemporal variation and the degree of influence of aerosol and clouds on UV radiation over China. Follow-up research on UV radiation should focus on modeling the influence of UV radiation on ozone production and the concentration of secondary aerosols, and then quantifying the relationship between UV radiation and ozone, as well as between UV radiation and secondary aerosols.
Disclosure statement

No potential conflict of interest was reported by the authors.

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References

Calbó, J., D. Pages, and J. A. Gonzalez. 2005. “Empirical Studies of Cloud Effects on UV Radiation: A Review.” Reviews of Geophysics 43: RG2002. doi:10.1029/2004RG000155.

Cañada, J., G. Pedrós, A. López, and J. V. Boscá. 2000. “Influences of the Clearness Index for the Whole Spectrum and of the Relative Optical Air Mass on UV Solar Irradiance for Two Locations in the Mediterranean Area, Valencia and Cordoba.” Journal of Geophysical Research 105: 4659–4766. doi:10.1029/1999JD901106.

de Outer, P. N., H. Slaper, and R. Tax. 2005. “UV Radiation in the Netherlands: Assessing Long-Term Variability and Trends in Relation to Ozone and Clouds.” Journal of Geophysical Research 110: D02203.

Deng, X., X. Zhou, X. Tie, D. Wu, F. Li, H. Tan, and T. Den. 2012. “Attenuation of Ultraviolet Radiation Reaching the Surface Due to Atmospheric Aerosols in Guangzhou.” Chinese Science Bulletin 57: 27592766. doi:10.1007/s11434-012-5172-5.

Dickerson, R., S. Kondragunta, G. Stenchikov, K. Civerolo, B. Doddridge, and B. Holben. 1997. “The Impact of Aerosols on Solar Ultraviolet Radiation and Photochemical Smog.” Science 278: 827–830. doi:10.1126/science.278.5339.827.

Ferrero, E., M. Éóry, G. Ferreyra, I. Schloss, H. Zagarese, M. Vernet, and F. Momo. 2006. “Vertical Mixing and Ecological Effects of Ultraviolet Radiation in Planktonic Communities.” Photochemistry and Photobiology 82 (4): 898. doi:10.1562/2005-11-23-ra-736.

Grants, R. H., and G. M. Heisler. 1997. “Obscured Overcast Sky Radiance Distributions for Ultraviolet and Photosynthetically Active Radiation.” Journal of Applied Meteorology 36: 1336–1345. doi:10.1175/1520-0450(1997)036<1336:OOSRDF>2.0.CO;2.

Hu, B., Y. S. Wang, and G. R. Liu. 2007. “Ultraviolet Radiation Spatiotemporal Characteristics Derived from the Ground-Based Measurements Taken in China.” Atmospheric Environment 41: 5707–5718. doi:10.1016/j.atmosenv.2007.02.044.

Liu, H., B. Hu, Y. S. Wang, G. Liu, L. Tang, D. Ji, Y. Bai, et al. 2017a. “Two Ultraviolet Radiation Datasets that Cover China.” Advances in Atmospheric Sciences 34 (7): 805–815. doi:10.1007/s00376-017-6293-1.

Liu, H., B. Hu, L. Zhang, Y. S. Wang, and P. F. Tian. 2016. “Spatiotemporal Characteristics of Ultraviolet Radiation in Recent 54 Years from Measurements and Reconstructions over the Tibetan Plateau.” Journal of Geophysical Research 121: 7673–7690. doi:10.1002/2015JD024378.

Liu, H., B. Hu, L. Zhang, X. J. Zhao, K. Z. Shang, Y. S. Wang, and J. Wang. 2017b. “Ultraviolet Radiation over China: Spatial Distribution and Trends.” Renewable and Sustainable Energy Reviews 76: 1371–1383. doi:10.1016/j.rser.2017.03.102.

Thomas, P., A. Swaminatha, and R. Lucas. 2012. “Climate Change and Health with an Emphasis on Interactions with Ultraviolet Radiation: A Review.” Global Change Biology 18 (8): 2392–2405. doi:10.1111/j.1365-2486.2012.02706.x.

Wang, L. C., W. Gong, L. Feng, A. W. Lin, and B. Hu. 2014. “Long-Term Variations of UV Radiation in China from Measurements and Model Reconstructions.” Energy 78: 928–938. doi:10.1016/j.energy.2014.10.090.

Zhang, X., B. Hu, Y. Wang, and J. Lu. 2014. “Reconstruction of Daily Ultraviolet Radiation for Nine Observation Stations in China.” Journal of Atmospheric Chemistry 71: 303–319. doi:10.1007/s10874-015-9296-2.

Zhou, X. 1996. Variation of Atmospheric Ozone and Its Climatic & Environmental Impact in China (I) (In Chinese). Beijing: Meteorological Press.