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Long-term variations of ultraviolet radiation in China from measurements and model reconstructions

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ABSTRACT

Measurements of ultraviolet (UV) radiation at 38 stations from Chinese Ecosystem Research Network during 2006–2012 were used for reconstructing the historical UV levels in China for the first time. UV models were introduced by analyzing the dependence of UV irradiation on clearness index (K_t) and cosine of solar zenith angle under any sky conditions in each station. Mean bias error (MBE), mean-absolute bias error (MABE) and root-mean-square error (RMSE) were used for assessing the model performance; relative differences between UV estimates and measurements were generally lower than 10% at most stations, which indicated that our all-sky UV models can produce acceptable estimates in China. Long-term UV values during 1961–2012 were then reconstructed for investigating the spatio-temporal characteristics of UV radiation in China based on daily global solar radiation (G) at 115 meteorological stations from China Meteorological Administration. Annual mean daily UV radiation ranged from 0.55 MJ m^{-2} d^{-1} to 0.65 MJ m^{-2} d^{-1} with average value being about 0.61 MJ m^{-2} d^{-1}. It was also discovered that UV radiation decreased slightly at about −2.72 kJ m^{-2} d^{-1} per decade during the study period and there was an increasing trend since 1991 (0.7 kJ m^{-2} d^{-1} per year).

1. Introduction

Solar UV (ultraviolet) radiation reaching the Earth's surface has received considerable attention in recent years from scientific community and the general population for its photochemical and biological effects on the biosphere [1–3]. Although comprising only a small fraction of total radiant solar energy, UV radiation plays important roles in solar energy application and global climate change [4–6], for example, UV radiation directly affects the photosynthetic uptake of atmospheric carbon dioxide, ecosystem stability and global biogeochemical cycles [7]. UV radiation also has the capacity to cause direct and immediate harm to virtually all living organisms (sunburn, skin cancer and cataracts) [8–10]. Therefore, a clear knowledge of UV variability in time and space has high priority in scientific research, which will contribute a lot to many studies, such as air pollution, Energy Budget and the Earth's climate system [11–13].

Due to great difficulties in conducting accurate measurements and proper quality control, monitoring of the UV radiation has been a challenging task, which has led to the development of ground-based measurement programs to provide long-term records of its levels [14–16]. However, UV observations are still very few in the world and their records are relatively short [17–19]. UV levels have to be estimated through either empirical/semiphysical methods or satellite-based observations [20–22], for example, Bilbao et al. [10] developed a semi-empirical method for estimating solar erythemal UV irradiance in Spain; Herman [23] analyzed the global UV levels during 1979–2008 using satellite data. It is known that stratospheric ozone, clouds, aerosol scattering and absorption and surface albedo highly affected the UV variability, which makes the accurate estimation very difficult to obtain [24–27]. It is also

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reported that many studies are focused only on clear sky conditions [28,29], the estimation models should be recalibrated to account for local geographical and atmospheric conditions [30–33]. Satellite estimates of surface UV radiation provide global coverage, but the sampling frequency is typically only once per day with a coarse spatial resolution that represents average conditions over large areas [23,34]. Thus, more experimental studies related to UV radiation observation and modeling are still needed [35,36].

UV observations started only in the 1990s and the reconstructions for the past 50 years have gained scientific interest with respect to the well known evolution of ozone layer and the general variation of climate [37–39]. Though our earlier study Hu et al. [31] studied the interannual variations of UV radiation in Beijing since 1960; Wang et al. [19] analyzed the UV radiation at Wuhan, China from measurements and modeling for the past 50 years, there are relatively less studies focusing on analyzing the long-term variations of UV radiation in China at national scale. Chinese Ecosystem Research Network (CERN) has been set up since August 2004 [40,41], the observations of UV radiation can be used for accurately analyzing the radiation properties across the whole country; for example, Hu et al. [40] has preliminarily analyzed the spatial-temporal characteristics of UV radiation in China using one year's observation. However, there is no more information about how UV radiation evolved during 1961–2012 in China, which necessitates reconstructing UV levels in China based on nationwide CERN observations.

The main objectives of this study is to introduce non-linear statistical models for estimating hourly/daily UV radiation by investigating the relationship between UV radiation and cosine of solar zenith angle and clearness index (Kt) based on measurements at 38 CERN stations in China during 2006–2012. Hourly/daily UV radiation from 1961 to 2012 were then reconstructed based on global solar radiation (*G*) observations at 115 meteorological stations from China Meteorological Administration (CMA) for revealing the long-term trends of UV radiation in China. The possible reasons for the interannual variations of UV radiation in China will also be discussed.

Table 1
Annual mean daily values of UV and F_{UV} at 38 CERN sites in China.

Station	Longitude	Latitude	UV (MJ m^{-2})	F_{UV} (%)
AKS	89°49′E	40°37′N	0.672	3.55
ALS	101°01′E	24°32′N	0.648	4.90
AS	109°19′E	36°51′N	0.579	4.03
BJF	115°26′E	40°00′N	0.438	5.00
CL	80°43′E	37°00′N	0.595	3.52
CS	120°41′E	31°32′N	0.518	4.53
DYW	114°31′E	22°31′N	0.619	4.50
DHS	112°32′E	23°10′N	0.51	4.07
DH	114°23′E	30°33′N	0.511	4.22
EES	110°11′E	39°29′N	0.628	3.92
FQ	114°24′E	35°00′N	0.471	3.69
FK	87°55′E	44°17′N	0.633	4.00
GGS	102°00′E	29°33′N	0.486	4.84
HB	101°19′E	37°37′N	0.701	4.12
HL	126°38′E	47°26′N	0.505	3.61
HS	112°32′E	22°41′N	0.536	4.41
HJ	108°20′E	24°44′N	0.48	4.61
HT	109°35′E	26°47′N	0.513	4.77
JZW	119°56′E	35°43′N	0.523	3.90
LS	91°20′E	29°40′N	0.906	4.33
LZ	99°35′E	39°04′N	0.675	3.88
LC	114°41′E	37°53′N	0.461	3.32
MX	103°54′E	31°42′N	0.528	4.61
NM	120°42′E	43°55′N	0.614	3.84
NMG	116°42′E	43°38′N	0.703	4.39
QZY	115°04′E	26°45′N	0.535	4.52
SJ	133°31′E	47°35′N	0.558	4.17
SYA	109°28′E	18°13′N	0.767	4.59
SPT	104°57′E	37°27′N	0.604	3.74
SYG	123°24′E	41°31′N	0.515	3.76
TH	120°13′E	31°24′N	0.535	4.22
TY	111°27′E	28°55′N	0.508	4.55
XSBN	101°16′E	21°54′N	0.671	4.53
YTI	105°27′E	31°16′N	0.442	4.46
YTN	116°55′E	28°15′N	0.544	4.46
YC	116°22′E	36°40′N	0.48	3.42
CBS	128°28′E	42°24′N	0.538	3.88
CW	107°40′E	35°12′N	0.549	3.72

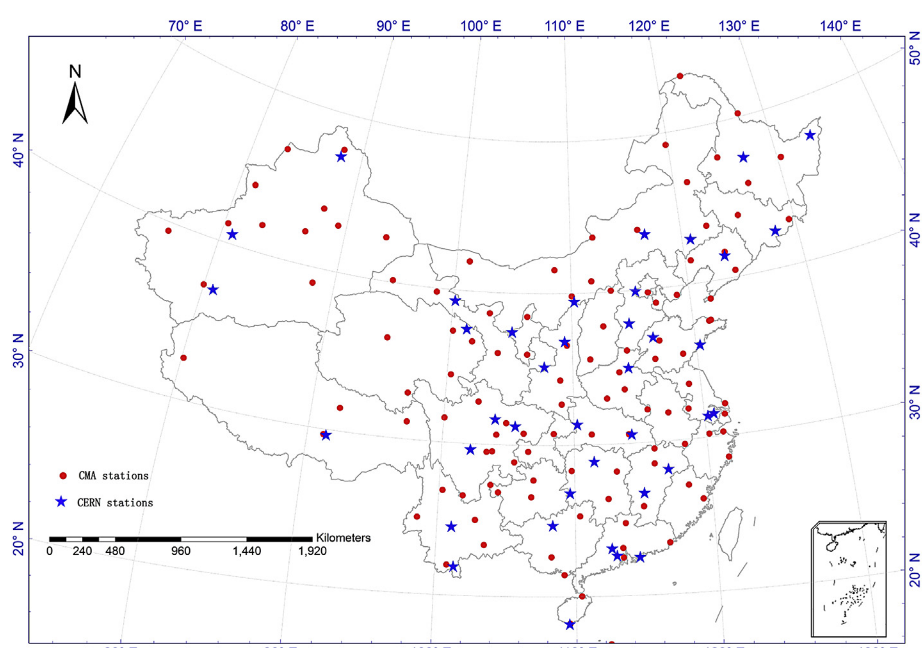

Fig. 1. Spatial distribution of UV radiation observation stations of CERN and *G* stations of CMA in China.