Journal of the Meteorological Society of Japan, Vol. 93, No. 4, pp. 505−508, 2015
DOI:10.2151/jmsj.2015-028

NOTES AND CORRESPONDENCE

Reply to the Comments of F. Fujibe on "Anthropogenic Heat Release: Estimation of Global Distribution and Possible Climate Effect" by Chen, B. et al.

Bing CHEN

The State Key Laboratory of Remote Sensing Science, Institute of Remote Sensing and Digital Earth, Chinese Academy of Sciences, Beijing, China
The State Key Laboratory of Numerical Modeling for Atmospheric Sciences and Geophysical Fluid Dynamics (LASG), Institute of Atmospheric Physics, Chinese Academy of Sciences, Beijing, China

Jian-Qi ZHAO

The State Key Laboratory of Numerical Modeling for Atmospheric Sciences and Geophysical Fluid Dynamics (LASG), Institute of Atmospheric Physics, Chinese Academy of Sciences, Beijing, China

Liang-Fu CHEN

The State Key Laboratory of Remote Sensing Science, Institute of Remote Sensing and Digital Earth, Chinese Academy of Sciences, Beijing, China

and

Guang-Yu SHI

The State Key Laboratory of Numerical Modeling for Atmospheric Sciences and Geophysical Fluid Dynamics (LASG), Institute of Atmospheric Physics, Chinese Academy of Sciences, Beijing, China

(Manuscript received 16 December 2014, in final form 28 April 2015)

Keywords Anthropogenic Heat Release (AHR); DMSP/OLS data; global distribution; climate change

Modern human society is based on vast consumption of energy resource. These resources such as fossil, nuclear, solar, and wind energies that are consumed will eventually turn into anthropogenic heat release (AHR) in the atmosphere, breaking the energy balance of the Earth–atmosphere system. Previous research on climate change focused on the climatic effect of greenhouse gases and aerosols, while the anthropogenic heat produced in the energy consumption process is usually ignored. Chen et al. (2014) (hereafter, C14) explored the possible climatic effect of AHR by applying the Defense Meteorological Satellite Program's Operational Linescan System (DMSP/OLS) data. AHR distribution is difficult to be

Corresponding author: Liang-Fu Chen, The State Key Laboratory of Remote Sensing Science, Institute of Remote Sensing and Digital Earth, Chinese Academy of Sciences, Beijing 100101, China
E-mail: chenlf@mail.iap.ac.cn

accurately measured at regional scale and even more difficult for large-scale regions. The application of the DMSP/OLS data to estimate the global grid distribution of AHR can solve the difficulty in estimating the large-scale high-precision grid distribution of AHR for climate models. Flanner (2009) estimated the global distribution of AHR based on the population density, and showed that the flux of AHR is 8.1 and 48 W m^{-2} in Tokyo and New York, respectively, at 0.5° × 0.5° resolution. Fujibe (2015) (hereafter, F15) commented that C14's result of AHR estimation in 2009 is unrealistically large. F15 also stated that regionally averaged heat fluxes are sufficiently large (approximately 1 W m^{-2}) in Western Europe and eastern USA according to Flanner (2009). From the 2009 statistics by British Petroleum (2014) (hereafter, BP), the mean AHR fluxes are 1.12 W m^{-2} for UK, 1.15 W m^{-2} for Germany, 0.74 W m^{-2} for Italy, 1.68 W m^{-2} for Japan, 0.31 W m^{-2} for USA, 0.29 W m^{-2} for China, and 3.19 W m^{-2} for South Korea. In fact, the global land mean AHR flux is approximately 0.10 W m^{-2}. The actual scale for "regionally averaged" should be quantified because in the concentrated regions, the AHR flux is much larger than the average level. From the statistics by the National Bureau of Statistics of China (http://www.stats.gov.cn/tjsj/ndsj/), the annual mean AHR fluxes in 2008 are more than 4 W m^{-2} for Beijing, more than 5 W m^{-2} for Tianjin, morethan 16 W m^{-2} for Shanghai, and more than 100 W m^{-2} for Macau (Chen et al. 2011). AHR is geographically concentrated and distributed, fundamentally correlating to the economic activities. AHR concentrated in the economically developed areas is much larger than the average value, reaching a large value that could affect regional climate, while in deserted areas, AHR flux is probably zero. During the daytime in central Tokyo, AHR flux exceeds 400 W m^{-2} with a maximum of 1590 W m^{-2} in winter (Ichinose et al. 1999). But in a larger scale, the mean flux of AHR may not appear so large. Therefore, the scale in the grid of AHR is essential for the research where the maximum value is larger for a smaller grid in a specific region. The results of the global distribution of AHR in C14 with the grid resolution 0.1° × 0.1° appear slightly different from Flanner's results (Flanner 2009), while they could be consistent with the energy consumption statistics.

F15's comment on C14 focuses on "AHR should be estimated to be constant as long as the sum of lights (SOL) is unchanged. We can therefore conclude that the rapid increase of AHR described by C14 is unreliable." F15's comment insists that if the SOL is unchanged, AHR should be the same. The SOL is the total sum of lights of a country (http://ngdc.noaa.gov/eog/dmsp/download_national_trend.html), which means that AHR could be changed if the SOL is unchanged. In some regions, AHR increases, while in others it decreases, but the SOL could be the same. The detailed analysis of the results of AHR by applying the DMSP/OLS data are as follows.

Table 1. Linear correlation between the AHR flux and the mean SOL of the main countries (including South Korea, Italy, Germany, UK, Japan, France, Spain, USA, India, and China) by six satellites from 1992 to 2012.

Satellite	R
F10	0.86
F12	0.85
F14	0.83
F15	0.81
F16	0.79
F18	0.72

The DMSP/OLS data are closely associated with economic development levels and energy consumption. In general, the areas where the value of the DMSP/OLS data is large are often developed and crowded regions with more energy consumption and anthropogenic heat emissions (Chen et al. 2012; Chen and Shi 2012). In C14, the global grid distribution of AHR from 1992 to 2009 was estimated using the DMSP/OLS data and applied in a global climate model to study the global climatic effect of AHR. The energy consumption statistics of the countries provided by BP and the stable light data from the DMSP/OLS Night-time Lights version 4 Time Series (http://ngdc.noaa.gov/eog/dmsp/downloadV4composites.html) were applied to the research. For the analysis presented in this study, continuous stable light data from 1992 to 2012 from DMSP satellites included the following six satellites: F10 (1992–1994), F12 (1994–1999), F14 (1997–2003), F15 (2000–2007), F16 (2004–2009), and F18 (2010–2012).

The AHR flux Q_a in various regions could be obtained by the equation: $Q_a = \frac{\text{energy consumption [J]}}{\text{time [s]} \cdot \text{area [m}^2\text{]}}$. The mean AHR flux for the main countries including South Korea, Italy, Germany, UK, Japan, France, Spain, USA, India, and China from 1992 to 2012 was obtained from the statistics of energy consumption by BP. The data of "National trends with inter-calibrated DMSP stable light" (http://ngdc.noaa.gov/eog/dmsp/download_national_trend.html)—the sum of the DMSP/OLS data for a nation—provide the

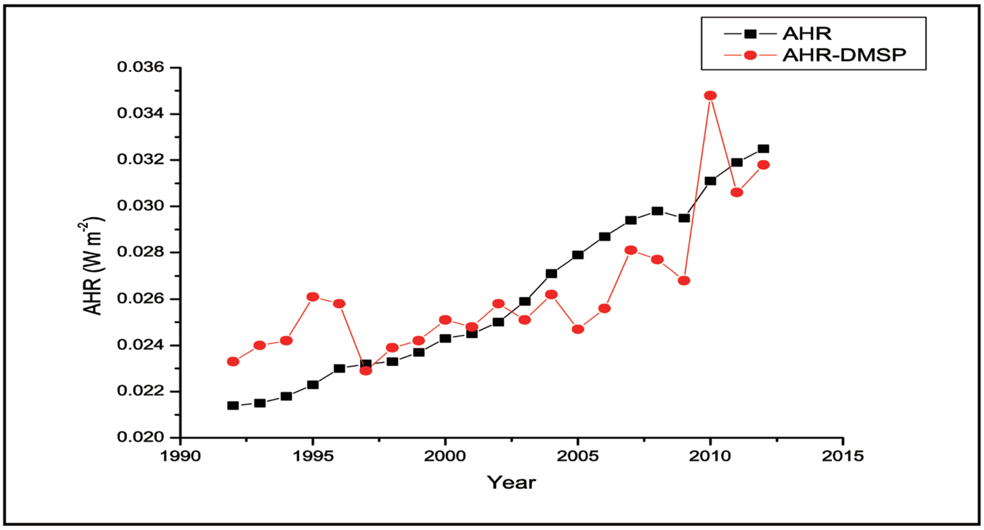

Fig. 1. Global mean AHR statistically obtained from BP (black) and estimated global mean AHR from DMSP/OLS (red) between 1992 and 2012.

annual records of the SOL in each country since 1992. Considering the possible difference in the sensors of different satellites, the relationship between the mean AHR flux and the mean SOL were analyzed separately. Table 1 lists the correlation coefficient (R) produced by the linear regression between the stable light data from six satellites and the AHR flux data.

As shown in Table 1, a close positive correlation is found between AHR and mean SOL. The results indicate that the DMSP/OLS data are closely correlated with the AHR flux, which means that the regions where the DMSP/OLS data are large are probably populated and developed regions with more energy consumption and anthropogenic heat. Figure 1 shows the global mean AHR statistically obtained from BP (BP, 2014) and the fitting results by the DMSP/OLS data from 1992 to 2012. The fitting results are almost consistent with the global mean AHR, and the correlation coefficient is 0.81. From Fig. 1, we can see that since the results of the DMSP/OLS data are almost consistent with global energy consumption, the results of energy consumption statistics and fitting results are almost the same. The error in the results obtained by the DMSP/OLS data is generally within 12 %.

The results suggest that since the DMSP/OLS data are almost consistent with global energy consumption and AHR, the results appear quite reliable on the global scale.

Figure 2 shows the discrepancy of the global distribution of AHR between 2009 (Fig. 3 in C14) and 2000 (Fig. 2 in C14) by the DMSP/OLS data.

From Fig. 2, AHR in Europe, South Asia, South America, and East Asia generally increases between 2000 and 2009. The increasing trend is more noticeable in East China, India, and European countries, while the decreasing trend is found in the regions including the Central and Eastern part of USA, East Russia, and Central India. In addition, the changing trend appears insignificant in some countries such as USA, South Korea, Japan, Germany, and Spain. AHR increased in some regions of these countries, while it decreased in the others. In other words, this is the probable reason the SOL slightly varies in some countries. This variation is consistent with the fact that the energy consumption in these regions is found to slightly vary. Further, there is no denying that some mistakes may occur in Fig. 3 of C14, for example, the increasing trend should not be so obvious. The possible cause for this is that some mistakes occur in displaying colors with the same color bar in Figs. 2 and 3 of C14. It may be the main comment that F15 focused on.

Due to the high-precision grid and unique ability to detect low levels of visible and near-infrared radiance at night, the DMSP/OLS data provide an effective way to estimate large-scale and high-resolution distribution of AHR. In particular, the result of the global distribution of AHR by applying the DMSP/OLS data is generally consistent with energy consumption statistics, but errors occur inevitably. This method

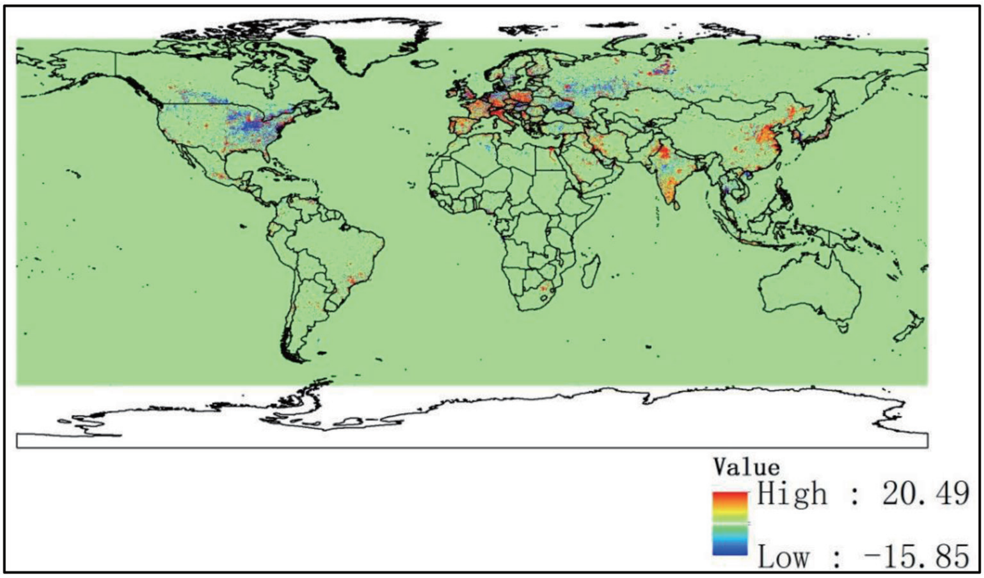

Fig. 2. Discrepancy of the global distribution of AHR between 2009 and 2000 by the DMSP/OLS data (resolution: 0.1° × 0.1°, unit: W m^{-2}).

provides a new way to obtain credible large-scale continuous high-precision grid distribution of AHR, which is necessary for the research of AHR in climate models.

Acknowledgments

This study was supported by China Postdoctoral Science Foundation (Grant No. 2013M541077); the Key Program of the National Natural Science Foundation of China (Grant No. 41130528); National Natural Science Foundation of China (Grant No. 4150050215, 41305004, and 41271542); The Chinese Academy of Sciences Strategic Prior Research Program (Grant No. XDA05040204); The National Basic Research Development Program of China (Grant No. 2011CB9520 01); and Open Project for 2014 of the State Key Laboratory of Numerical Modeling for Atmospheric Sciences and Geophysical Fluid Dynamics (LASG), Institute of Atmospheric Physics, Chinese Academy of Sciences. The mean SOL for all the countries was obtained using Arc GIS.

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