High spatial resolution nighttime $PM_{2.5}$ datasets in the Beijing-Tianjin-Hebei region from 2015 to 2021 using VIIRS/DNB and deep learning model

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The spatial performance of the ten-fold site-based cross-validation used to estimate nighttime $PM_{2.5}$ concentration in the BTH region from 2015 to 2021 is shown in Figure S1. Although Chengde and Zhangjiakou showed poorer accuracy than the central and eastern BTH regions, the model performed better there. The poor performance of the model can be attributed to the absence of ground stations in these two cities. Figure 1 illustrates that compared with other cities, these two cities have higher altitudes, denser vegetation coverage, and fewer ground monitoring sites, which could result in the model's subpar performance in these regions. The site-based cross-validations with R^2 greater than 0.6 accounted for 32%, 24%, 28%, 32%, 32%, 52%, and 68% from 2015 to 2021. Although there was a slight decline in 2016 and 2017, the proportion of site-by-site R^2 was greater than 0.6, increasing annually.

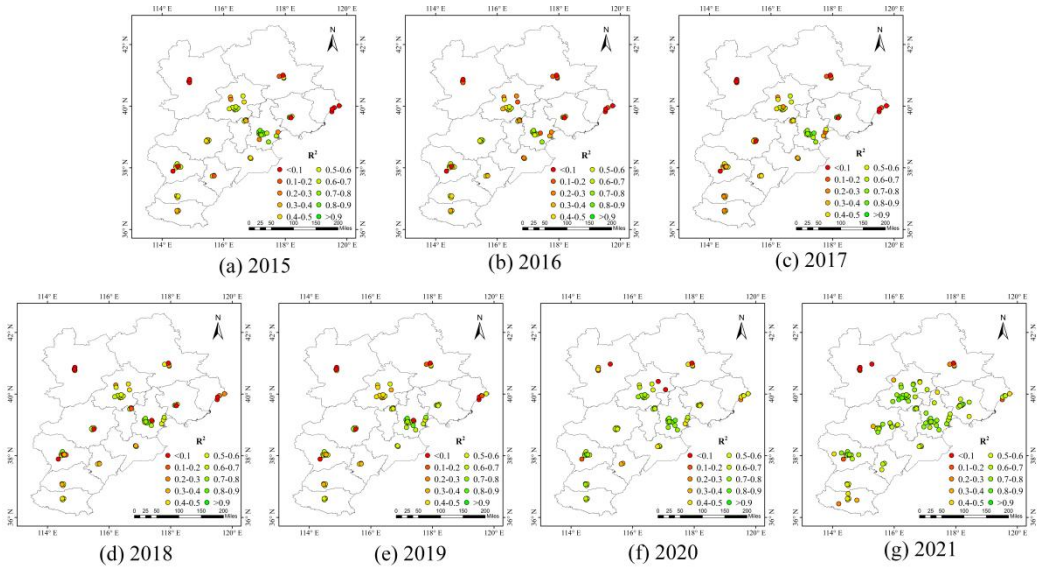

Figure S1. The spatial distribution of ten-fold site-based cross-validate R^2 (from 2015 to 2021).

From 2015 to 2021, the BTH region's nighttime $PM_{2.5}$ spatial estimation uncertainty is shown in Figure S2. As shown in Figure S2, the RMSE of nearly 90% of the sites was above 30 μg/m3 in 2015, 2016, and 2017, whereas the percentages of sites with an RMSE below 30 μg/m3 for 2018, 2019, 2020, and 2021 were 27%, 44%, 73%, and 87%, respectively. The annual increase in R^2 (Figure S1) and decrease in RMSE (Figure S2) indicate that the model has exhibited better performance in recent years as the air quality has improved.

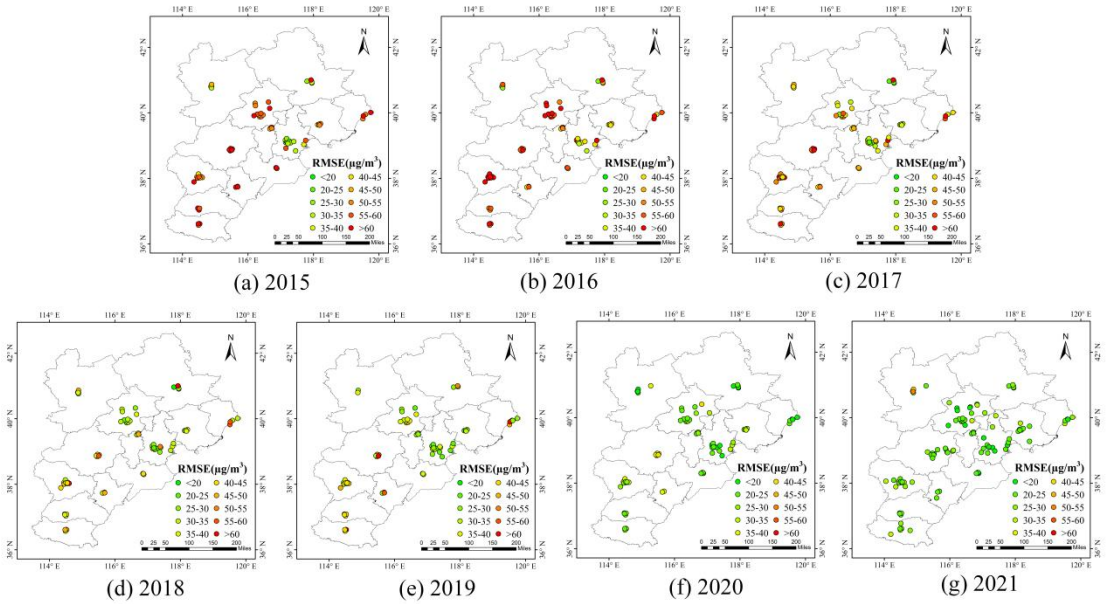

Figure S2. The spatial distribution of ten-fold site-based cross-validate RMSE (from 2015 to 2021).

Figures S3 and S4 show the spatial performance and uncertainty of the model based on the leave-one-city cross-validation method to estimate nighttime $PM_{2.5}$, for the BTH region from 2015 to 2021. The leave-one-city cross-validation method uses data from one city as validation data and the remaining data from the other 12 cities as training data. This process was repeated until all cities were used as validation sets.

The leave-one-city cross-validation results utilized in this investigation exhibited an unsatisfactory performance, as illustrated in Figures S3 and S4. The primary cause of the difference in performance between the day and night was the light source. Specifically, sunlight is used during the day, while the light sources for the night include ground light, moonlight, and other sources. However, the energy entering the satellite detector at night is weak and ranges between 10^{-5} and 10^{-6} of that in sunlight. Moreover, the radiation intensity of the ground light source is at least ten times greater than that of moonlight [39], making ground light the primary light source for the DNB. As the intensity of the ground light source varies owing to the different economic developments and population densities of each city, the leave-one-city cross-validation process performs poorly at night. Consequently, a localized model is required to better estimate nighttime $PM_{2.5}$ concentration.

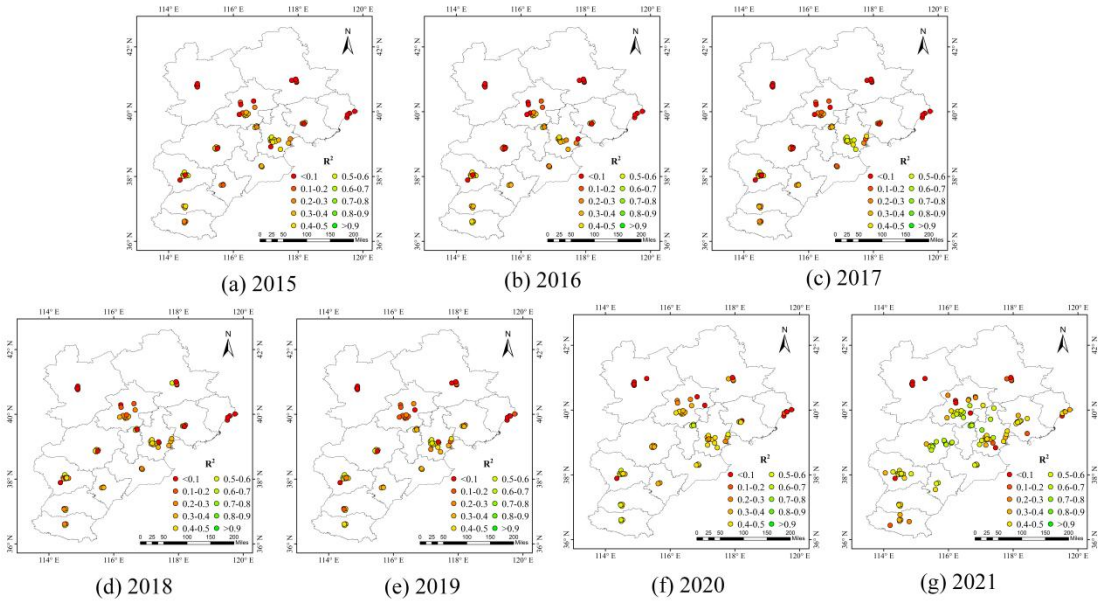

Figure S3. The measured and estimated $PM_{2.5}$ concentration between 2015 and 2021 were used to leave-one-city cross-validate the spatial distribution of R^2.

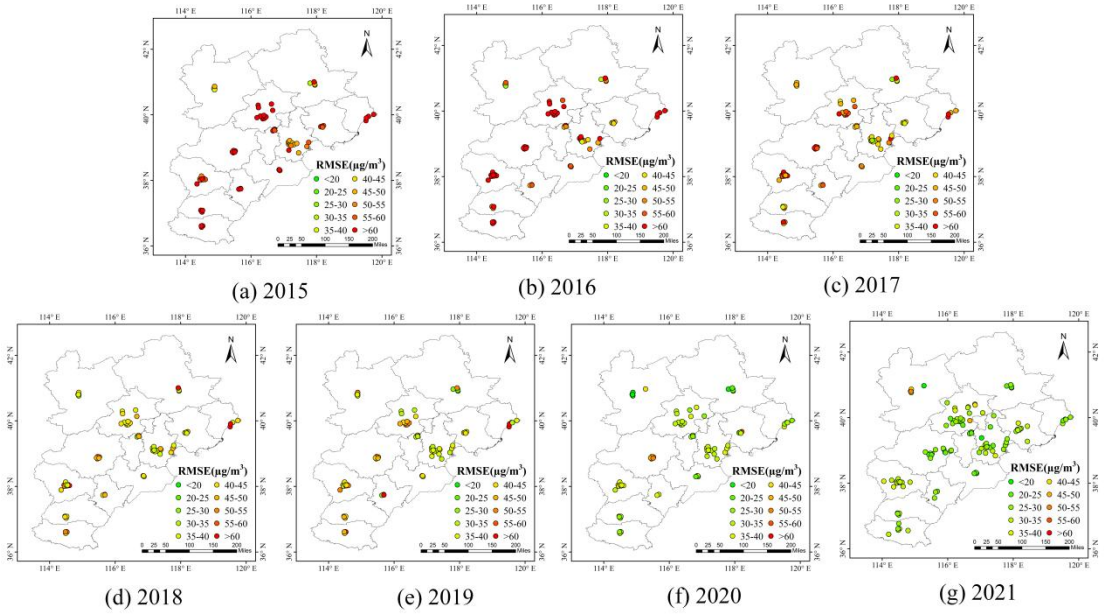

Figure S4. The measured and estimated $PM_{2.5}$ concentration between 2015 and 2021 were used to leave-one-city cross-validate the spatial distribution of RMSE.

References

39. Miller, S.D.; Turner, R.E. A dynamic lunar spectral irradiance data set for NPOESS/VIIRS day/night band nighttime environmental applications. *IEEE Transactions on Geoscience and Remote Sensing* **2009**, *47*, 2316-2329.