Satellite-derived $PM_{2.5}$ (Annual Average) from MODIS (version 7)

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May 2018

1. Algorithm

Two steps were required to build this satellite $PM_{2.5}$ data set. First, spectral data from the two Moderate Resolution Imaging Spectroradiometer (MODIS) instruments (collection 6), aboard the National Aeronautics and Space Administration (NASA) Earth Observing System (EOS) satellites Terra and Aqua, were used to build Aerosol Optical Depth (AOD) data at a resolution of 1 km (Li et al., 2005). Second, an observational data driven algorithm, which took the ground-observed visibility and relative humidity data as inputs, was developed to derive the ground-level $PM_{2.5}$ concentration from the AOD (Lin et al., 2015, 2018). For more details of the algorithm and data for AOD and $PM_{2.5}$, please see the following references.

Reference:

Li, C., Lau, A.K.H., Mao, J., and Chu, D.A. (2005). Retrieval, validation, and application of the 1-km aerosol optical depth from MODIS measurements over Hong Kong. IEEE Trans. Geosci. Remote Sens. *43*, 2650–2658. (AOD Algorithm)

Lin, C.Q., Li, Y., Yuan, Z.B., Lau, A.K.H., Li, C.C., and Fung, J.C.H. (2015). Using satellite remote sensing data to estimate the high-resolution distribution of ground-level PM2.5. Remote Sens. Environ. *156*, 117–128. (PM2.5 Algorithm)

Lin, C.Q., Liu, G., Lau, A.K.H., Li, Y., Li, C.C., Fung, J.C.H., and Lao, X.Q. (2018). High-resolution satellite remote sensing of provincial PM2.5 trends in China from 2001 to 2015. Atmos. Environ. *180*, 110–116. (PM2.5 Data)

2. Data download

The data can be downloaded from http://envf.ust.hk/dataview/aod2pm/current. A download link will be sent to the user's E-mail after the user registered an account from "Data Download Request". We created annual averages of the satellite-derived $PM_{2.5}$ concentrations ($\mu g/m^3$) in China at a spatial resolution of 0.03°×0.03° for download. The current version of satellite-derived $PM_{2.5}$ was denoted as version 7. The downloaded data are in netcdf format, which contain variables of "Longitude", "Latitude", and "pm25". The variable "Longitude" is a one-dimension array with 833 numbers, which vary from 100.015°E to 124.975°E with an interval of 0.03°. The variable "Latitude" is a one-dimension array with 800 numbers, which vary from 41.985°N to 18.015°N with an interval of -0.03°. The variable "pm25" is a two-dimension array with a shape of 800×833, for which the first dimension is associated with latitude and the second dimension is associated with longitude. The upper-left corner of "pm25" array is associated with the location of 100.015°E and 41.985°N. The lower-right corner of "pm25" array is associated with the location of 124.975°E and 18.015°N. The value in "pm25" array at the location of (x°E, y°N) represents the spatial average $PM_{2.5}$ concentration in the 0.03°×0.03° grid, which has longitude ranging from (x-0.015)°E to (x+0.015)°E and latitude ranging from (y-0.015)°N to (y+0.015)°N.

3. Acknowledgement

We acknowledge the National Aeronautics and Space Administration (NASA) for providing the satellite data and the World Meteorological Organization (WMO) for providing the

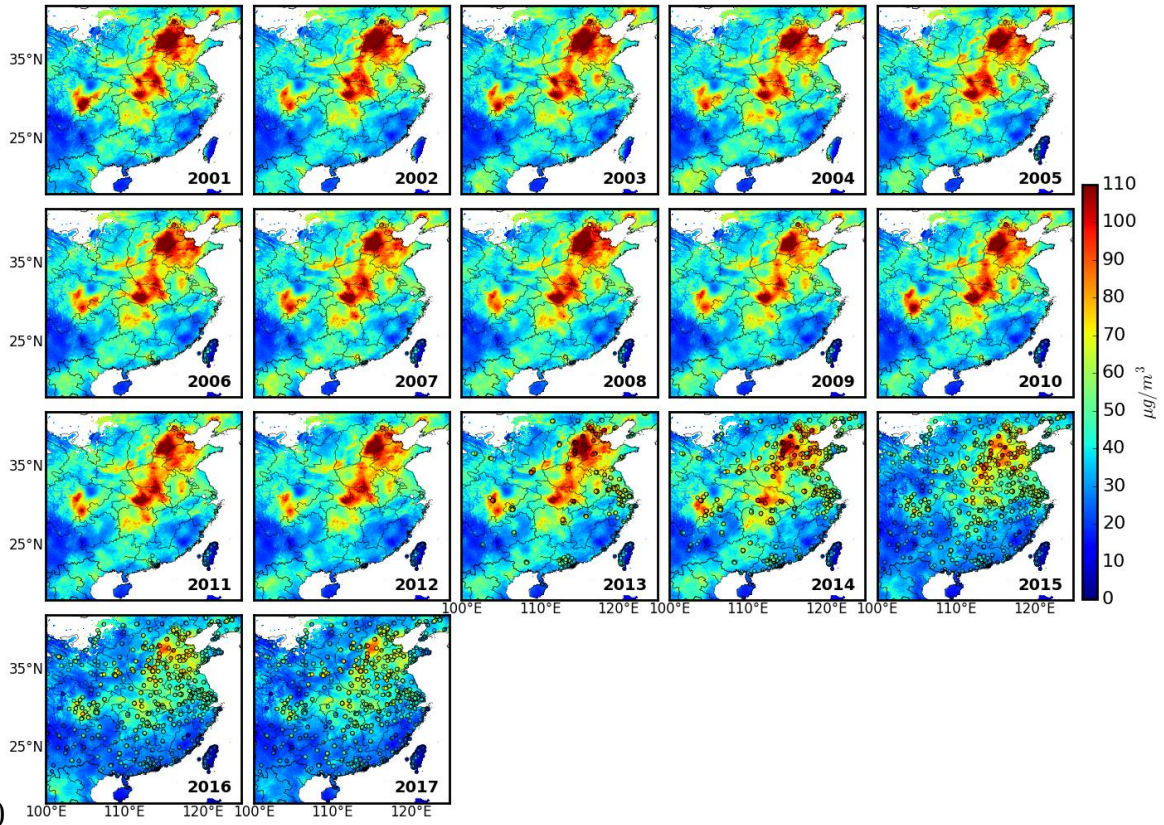
ground meteorological data. We also thank the Ministry of Environmental Protection of China, the Hong Kong Environmental Protection Department (HK EPD), and the Taiwan Environmental Protection Administration for provision of air-quality monitoring data.

4. Use of data

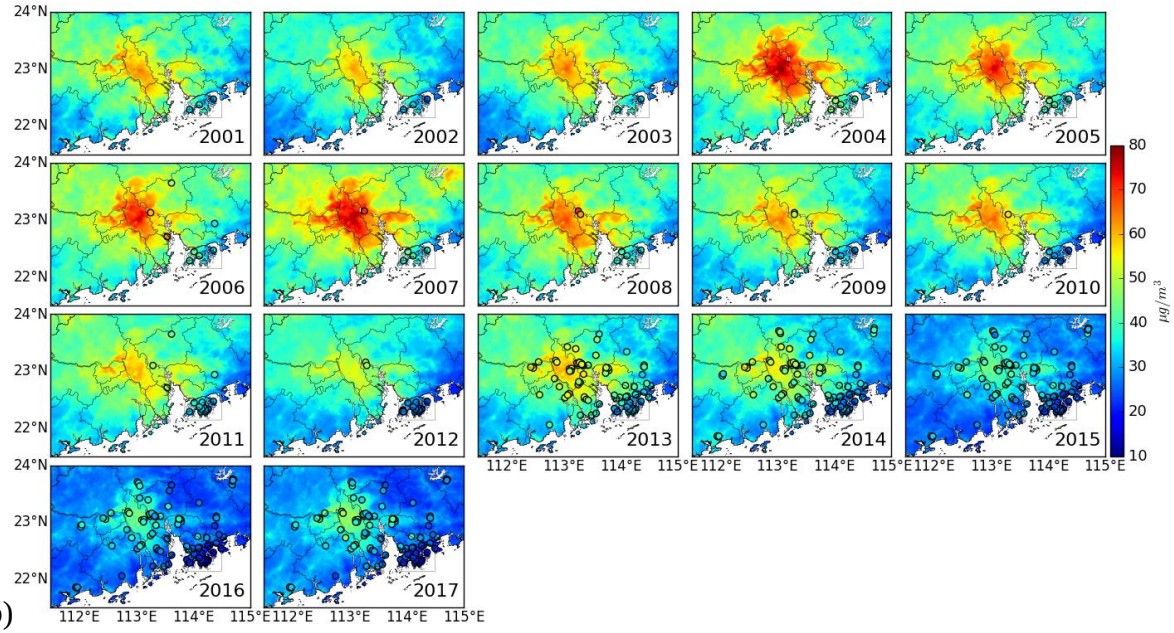
If you use this data, please acknowledge that the $PM_{2.5}$ data are obtained from the Institute for the Environment of the Hong Kong University of Science and Technology.

5. Supplementary verification

The following figures show the spatial distributions of annual averages of the satellite-derived $PM_{2.5}$ and the available ground observations in (a) China and (b) the Pearl River Delta (PRD) region from 2001 to 2017 [2001-2017 data information and usage: Lu et al. (2019), Analysis of the adverse health effects of $PM_{2.5}$ from 2001 to 2017 in China and the role of urbanization in aggravating the health burden, Science of the Total Environment].



(a)



(b)

Figure 1. Spatial distributions of annual averages of the satellite-derived $PM_{2.5}$ concentrations and the available ground observations in (a) China and (b) the PRD region from 2001 to 2017.

The following figure shows the inter-annual variations of the $PM_{2.5}$ concentrations from 2001 to 2017 in a few metropolises, including Beijing, Shanghai, Guangzhou, Hong Kong, and Taipei. The solid lines represent satellite observations. The dashed lines represent the averages of the available ground observations from sources including the national network, U.S. embassy, and the publications. The dotted lines represent ground observations from the U.S. embassy.

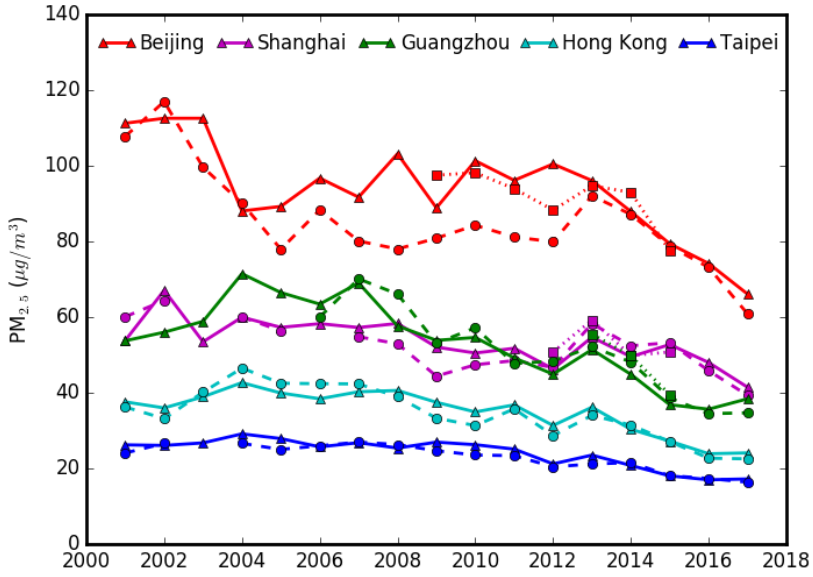


Figure 2. Inter-annual variations of the satellite-retrieved (solid lines) and ground-observed (dashed lines) $PM_{2.5}$ concentrations in Beijing, Shanghai, Guangzhou, Hong Kong, and Taipei. The ground observations of $PM_{2.5}$ concentrations from the U.S. embassy in Beijing, Shanghai, and Guangzhou are also plotted by the dotted lines.

Since the data sets were initially built on a spatial resolution of 0.01°×0.01°, we compared the accuracies of the two data sets at different resolutions. The following figures (a) and (b) show the spatial distributions of satellite-derived $PM_{2.5}$ in China at resolutions of 0.03°×0.03° and 0.01°×0.01°, respectively. The following figures (c) and (d) show the verifications of the satellite-derived $PM_{2.5}$ at resolutions of 0.03°×0.03° and 0.01°×0.01° in China from 2001 to 2017, respectively. The statistical metrics include correlation coefficient, root mean square error, mean error, mean absolute error, mean percentage error, mean absolute percentage error. Mean biases of the two data sets are similar and within 20%.

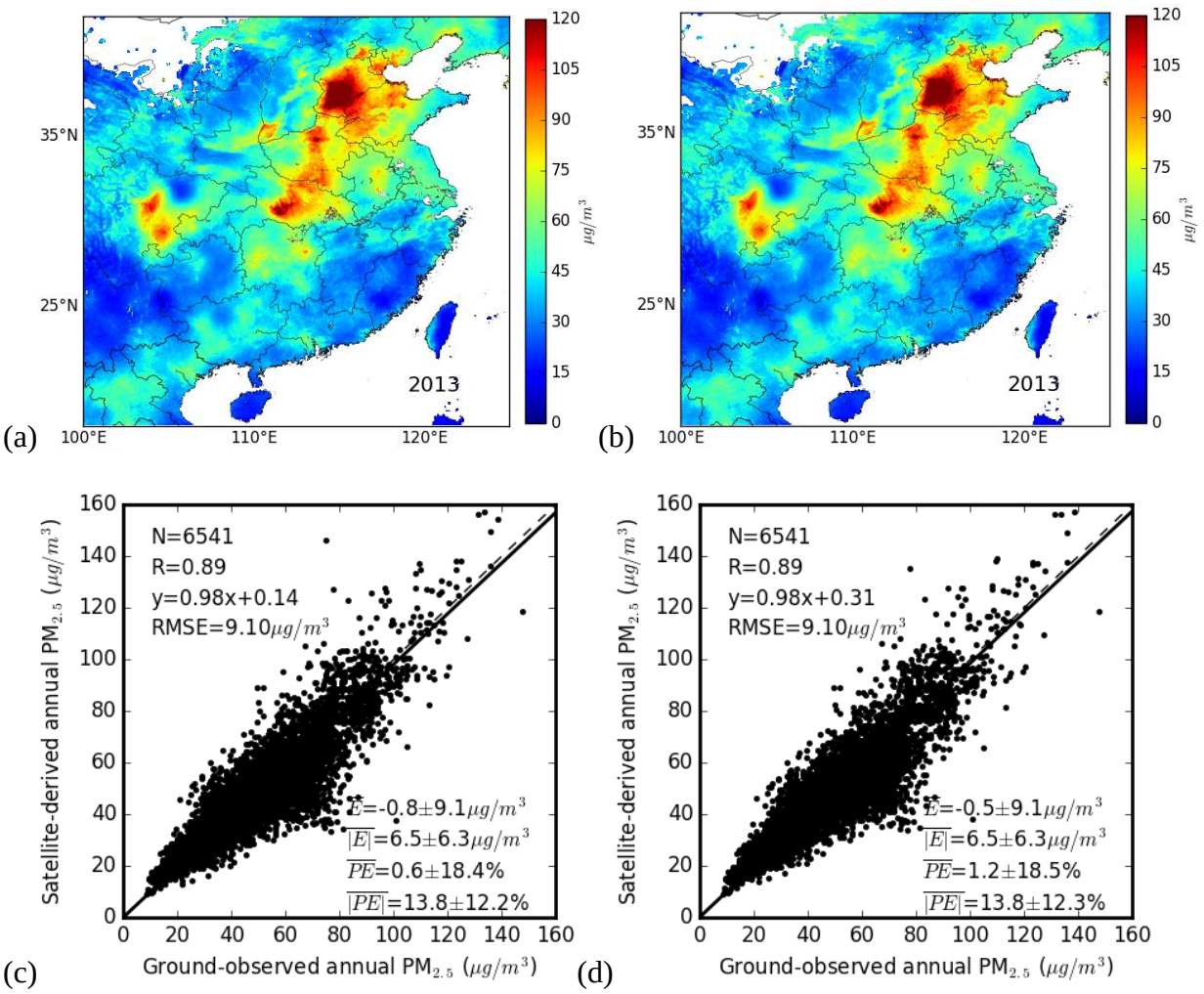


Figure 3. Spatial distributions of the satellite-derived $PM_{2.5}$ in China at resolutions of (a) 0.03°×0.03° and (b) 0.01°×0.01°. Verifications of the satellite-derived $PM_{2.5}$ at resolutions of (c) 0.03°×0.03° and (d) 0.01°×0.01° in China from 2001 to 2017.

The following figures (a) and (b) show the spatial distributions of satellite-derived $PM_{2.5}$ in the PRD at resolutions of 0.03°×0.03° and 0.01°×0.01°, respectively. The following figures (c) and (d) show the verifications of the satellite-derived $PM_{2.5}$ at resolutions of 0.03°×0.03° and 0.01°×0.01° in the PRD from 2001 to 2017, respectively.

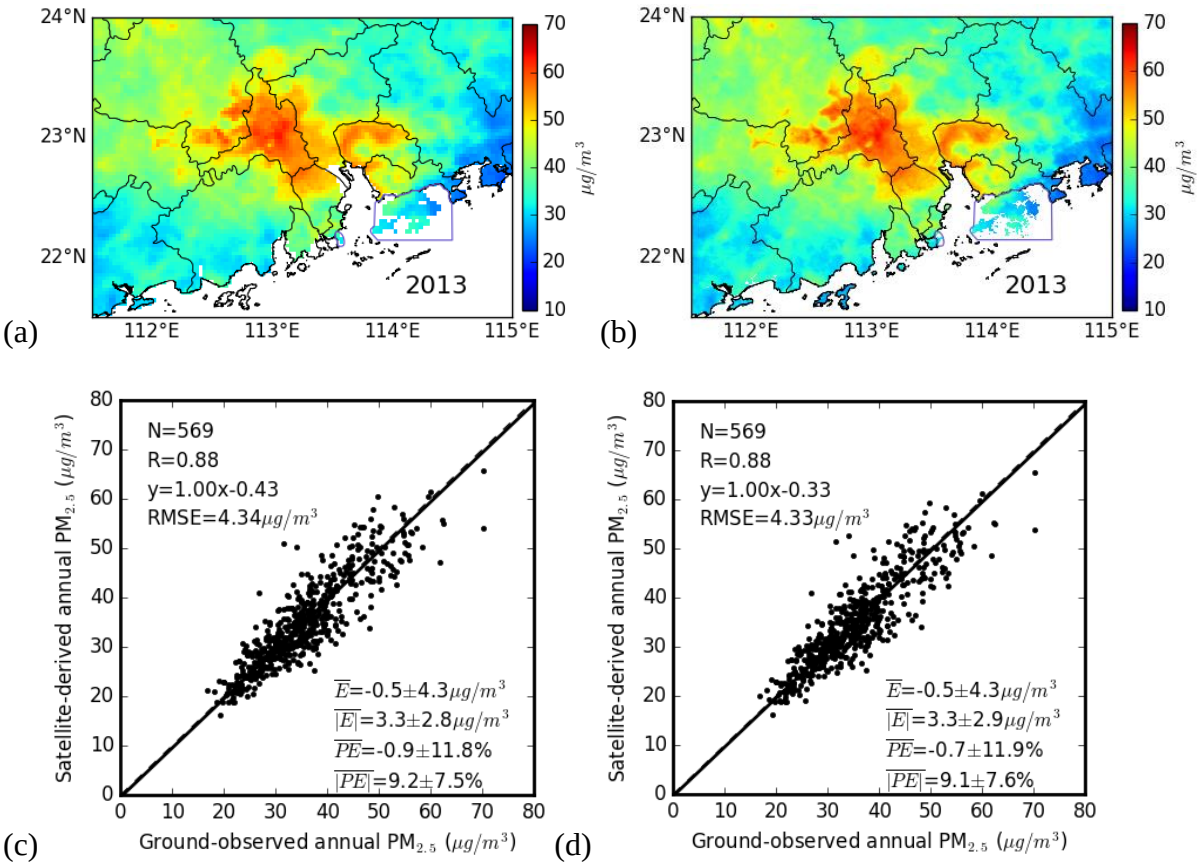


Figure 4. Spatial distributions of the satellite-derived $PM_{2.5}$ in the PRD at resolutions of (a) 0.03°×0.03° and (b) 0.01°×0.01°. Verifications of the satellite-derived $PM_{2.5}$ at resolutions of (c) 0.03°×0.03° and (d) 0.01°×0.01° in the PRD from 2001 to 2017.

The following figures (a) and (b) show the spatial distributions of satellite-derived $PM_{2.5}$ in Hong Kong at resolutions of 0.03°×0.03° and 0.01°×0.01°, respectively. The following figures (c) and (d) show the verifications of the satellite-derived $PM_{2.5}$ at resolutions of 0.03°×0.03° and 0.01°×0.01° in Hong Kong from 2001 to 2017, respectively.

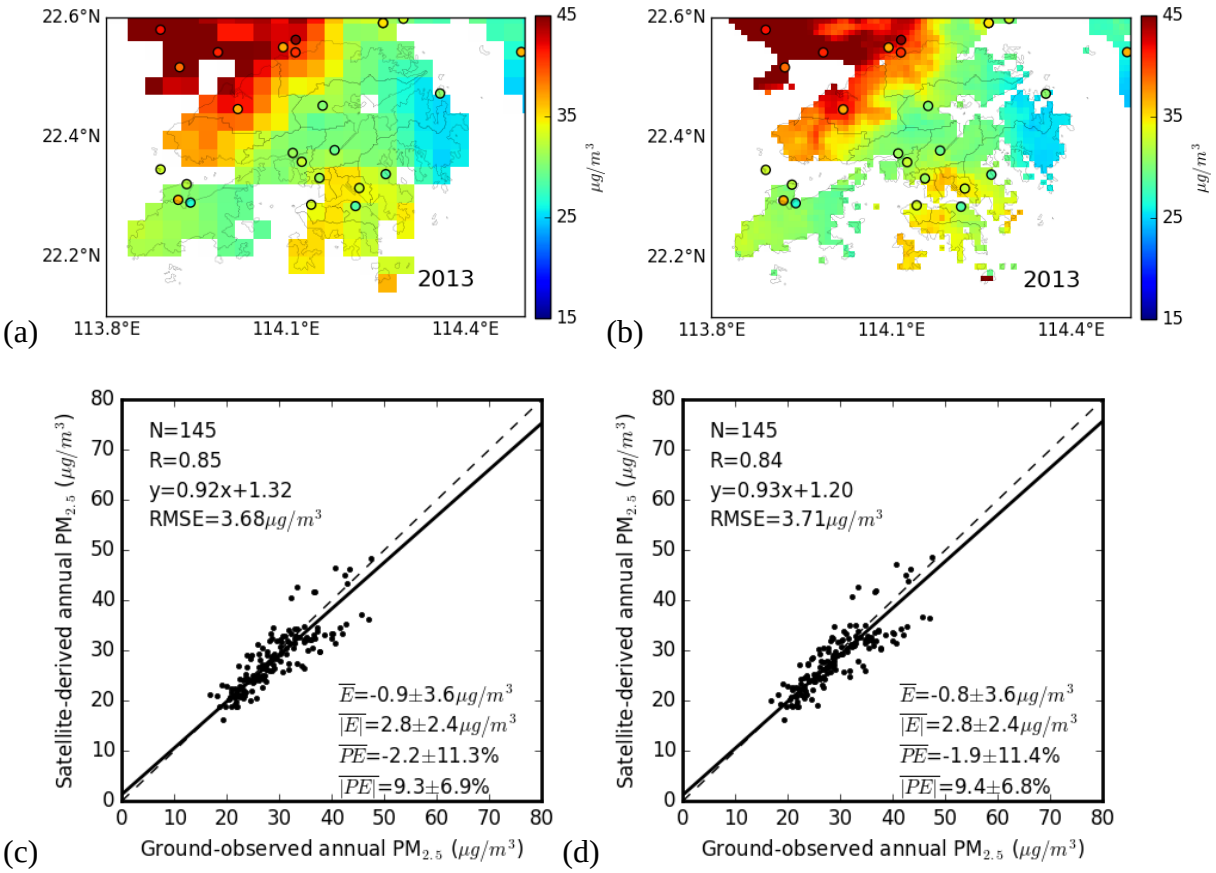


Figure 5. Spatial distributions of satellite-derived $PM_{2.5}$ in Hong Kong at resolutions of (a) 0.03°×0.03° and (b) 0.01°×0.01°. Verifications of the satellite-derived $PM_{2.5}$ at resolutions of (c) 0.03°×0.03° and (d) 0.01°×0.01° in Hong Kong from 2001 to 2017.