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# Impacts of land cover changes on biogenic emission and its contribution to ozone and secondary organic aerosol in China

**Jinlong Ma et al.**

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**Table S1. WRF model physics schemes used in this study.**

| Physical mechanism | Scheme | Reference |
|---|---|---|
| Microphysics | Thompson scheme | (Thompson et al., 2008) |
| Long-wave radiation | RRTM scheme | (Iacono et al., 2008) |
| Short-wave radiation | Goddard short wave | (Chou and Suarez, 1999) |
| Land Surface | Thermal diffusion scheme | (Dudhia, 1996) |
| PBL Scheme | YSU scheme | (Hong, 2010;Hong et al., 2006) |
| Cumulus parameter | Grell-Freitas ensemble scheme | (Grell and Freitas, 2014) |

**Table S2. The sources of datasets.**

| Datasets | Year | Temporal Resolution | Spatial Resolution | Source |
|---|---|---|---|---|
| MODIS MCD12Q1 | 2001-2021 | Yearly | 500 m | Available at https://search.earthdata.nasa.gov/, last access: 10 April 2022 |
| C3S LC | 1992-2021 | Yearly | 300 m | Available at https://cds.climate.copernicus.eu/cdsapp#!/dataset/satellite-land-cover?tab=form, last access: 21 March 2022 |
| CGLS LC | 2015-2019 | Yearly | 100 m | Available at https://land.copernicus.eu/global/products/lc, last access: 15 April 2022 |
| MODIS MOD15 | 2000-2021 | 8 days | 500 m | Available at https://search.earthdata.nasa.gov/, last access: 10 April 2022 |
| GLASS | 2000-2021 | 8 days | 500 m | Available at http://www.glass.umd.edu/LAI/MODIS/, last access: 11 April 2022 |
| CGLS | 2014-2021 | 10 days | 300 m | Available at https://land.copernicus.eu/global/products/lai, last access: 10 April 2022 |

**Table S3. Indices used to evaluate model performance.**

| Index | Definition* | Remarks |
|---|---|---|
| Mean bias (MB) | $\frac{1}{N}\sum_{i=1}^{N}(M_i - O_i)$ | |
| Root mean square error (RMSE) | $\sqrt{\frac{1}{N}\sum_{i=1}^{N}(M_i - O_i)^2}$ | Reported as % |
| Gross Error (GE) | $\frac{1}{N}\sum_{i=1}^{N}\frac{\lvert M_i - O_i\rvert}{O_i}$ | Reported as % |
| Mean normalized bias (MNB) | $\frac{1}{N}\sum_{i=1}^{N}\frac{M_i - O_i}{O_i}$ | Reported as % |
| Mean normalized error (MNE) | $\frac{1}{N}\sum_{i=1}^{N}\frac{\lvert M_i - O_i\rvert}{O_i}$ | Reported as % |
| Mean fractional bias (MFB) | $\frac{2}{N}\sum_{i=1}^{N}\frac{(M_i - O_i)}{(M_i + O_i)}$ | Reported as % |
| Mean fractional error (MFE) | $\frac{2}{N}\sum_{i=1}^{N}\frac{\lvert M_i - O_i\rvert}{(M_i + O_i)}$ | Reported as % |

Note: * i represents the pairing of N observations O and predictions M by site and time.

**Table S4. Model performance of meteorological parameters temperature (T2), wind speed (WS), wind direction and relative humidity (RH) in each season and whole year in China. The values without meeting the benchmarks are bolded. (PRE is prediction; OBS is observation; MB is bias; GE is gross error; and RMSE is root mean square error).**

| | Statistics | Spring | Summer | Fall | Winter | Year | Benchmarks* |
|---|---|---|---|---|---|---|---|
| T2 (K) | OBS | 287.3 | 297.3 | 287.0 | 273.1 | 278.7 | |
| | PRE | 286.4 | 296.7 | 286.3 | 271.7 | 278.4 | |
| | MB | **-0.8** | **-0.6** | **-0.6** | **-1.4** | **-0.6** | ≤±0.5 |
| | GE | **2.6** | **2.3** | **2.4** | **3.2** | **2.4** | ≤2.0 |
| | RMSE | 3.7 | 3.2 | 3.2 | 4.3 | 3.3 | |
| WS ($ms^{-1}$) | OBS | 3.5 | 3.2 | 3.3 | 3.4 | 3.4 | |
| | PRE | 4.5 | 3.8 | 4.1 | 4.5 | 4.3 | |
| | MB | **0.9** | 0.5 | **0.8** | **1.1** | **0.9** | ≤±0.5 |
| | GE | 1.7 | 1.4 | 1.5 | 1.7 | 1.7 | ≤2.0 |
| | RMSE | **2.2** | 1.8 | 2.0 | **2.3** | **2.2** | ≤2.0 |
| WD (°) | OBS | 177.5 | 168.9 | 167.4 | 186.2 | 182.2 | |
| | PRE | 184.5 | 172.7 | 162.9 | 187.2 | 188.3 | |
| | MB | 6.9 | 3.8 | 3.7 | 1.0 | 6.1 | ≤±10 |
| | GE | **44.1** | **45.2** | **42.6** | **43.3** | **44.8** | ≤±30 |
| | RMSE | 61.1 | 62.1 | 59.3 | 59.8 | 61.7 | |
| RH (%) | OBS | 70.4 | 69.2 | 74.4 | 78.3 | 71.9 | |
| | PRE | 69.9 | 70.5 | 74.9 | 77.0 | 71.9 | |
| | MB | -0.5 | 1.2 | 0.6 | -1.2 | 0.0 | |
| | GE | 11.9 | 11.3 | 11.2 | 10.8 | 11.5 | |
| | RMSE | 15.6 | 14.7 | 14.6 | 14.3 | 15.1 | |

Note: * are benchmarks suggested by Emery et al. (2001).

**Table S5. Model performance on maximum daily average 1h (MDA1) $O_3$ and maximum daily average 8h (MDA8) $O_3$ in different cases in China and important regions. The values without meeting the criteria are bolded. There are 1381 stations shown as purple in Figure S1. (OBS is mean observation; PRE is mean prediction; MNB: mean normalized bias; MNE: mean normalized error; MFB: mean fractional bias; and MFE: mean fractional error). The unit for $O_3$ is ppb.**

| | | Statistics | C1 | C2 | C3 | C4 | C5 | Criteria* |
|---|---|---|---|---|---|---|---|---|
| MDA1 $O_3$ Cutoff 60 ppb | China | OBS | 67.92 | 67.92 | 67.92 | 67.92 | 67.92 | |
| | | PRE | 70.69 | 69.35 | 70.67 | 67.7 | 70.36 | |
| | | MNB | 0.05 | 0.04 | 0.05 | 0.02 | 0.05 | ≤±0.15 |
| | | MNE | 0.19 | 0.19 | 0.19 | 0.18 | 0.19 | ≤0.3 |
| | | MFB | 0.02 | 0.0 | 0.02 | -0.01 | 0.01 | |
| | | MFE | 0.18 | 0.18 | 0.18 | 0.18 | 0.19 | |
| | NCP | OBS | 69.12 | 69.12 | 69.12 | 69.12 | 69.12 | |
| | | PRE | 74.48 | 72.97 | 74.45 | 71.9 | 73.9 | |
| | | MNB | 0.08 | 0.07 | 0.08 | 0.05 | 0.08 | ≤±0.15 |
| | | MNE | 0.2 | 0.19 | 0.2 | 0.18 | 0.2 | ≤0.3 |
| | | MFB | 0.05 | 0.03 | 0.05 | 0.02 | 0.04 | |
| | | MFE | 0.18 | 0.18 | 0.18 | 0.17 | 0.18 | |
| | YRD | OBS | 69.12 | 69.12 | 69.12 | 69.12 | 69.12 | |
| | | PRE | 73.82 | 72.4 | 73.74 | 69.75 | 73.24 | |
| | | MNB | 0.08 | 0.06 | 0.08 | 0.03 | 0.07 | ≤±0.15 |
| | | MNE | 0.2 | 0.2 | 0.2 | 0.18 | 0.2 | ≤0.3 |
| | | MFB | 0.04 | 0.02 | 0.04 | 0.0 | 0.03 | |
| | | MFE | 0.19 | 0.19 | 0.19 | 0.18 | 0.19 | |
| | PRD | OBS | 72.1 | 72.1 | 72.1 | 72.1 | 72.1 | |
| | | PRE | 72.69 | 71.32 | 72.58 | 69.69 | 73.36 | |
| | | MNB | 0.03 | 0.01 | 0.02 | -0.01 | 0.03 | ≤±0.15 |
| | | MNE | 0.19 | 0.19 | 0.19 | 0.18 | 0.2 | ≤0.3 |
| | | MFB | -0.01 | -0.02 | -0.01 | -0.04 | -0.0 | |
| | | MFE | 0.19 | 0.19 | 0.19 | 0.18 | 0.19 | |
| | | OBS | 61.36 | 61.36 | 61.36 | 61.36 | 61.36 | |
| | | PRE | 63.68 | 62.27 | 63.65 | 60.16 | 63.27 | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | China | MNB | 0.04 | 0.02 | 0.04 | -0.01 | 0.04 | ≤±0.15 |
| | | MNE | 0.21 | 0.2 | 0.21 | 0.19 | 0.21 | ≤0.3 |
| | | MFB | 0.05 | 0.04 | 0.05 | 0.02 | 0.05 | |
| | | MFE | 0.16 | 0.15 | 0.16 | 0.14 | 0.16 | |
| | | OBS | 64.55 | 64.55 | 64.55 | 64.55 | 64.55 | |
| | | PRE | 68.3 | 66.81 | 68.26 | 65.75 | 67.85 | |
| | NCP | MNB | 0.06 | 0.04 | 0.06 | 0.03 | 0.06 | ≤±0.15 |
| | | MNE | 0.23 | 0.22 | 0.23 | 0.21 | 0.23 | ≤0.3 |
| | | MFB | 0.07 | 0.06 | 0.07 | 0.04 | 0.07 | |
| MDA8 $O_3$ | | MFE | 0.17 | 0.16 | 0.17 | 0.16 | 0.17 | |
| Cutoff | | OBS | 63.52 | 63.52 | 63.52 | 63.52 | 63.52 | |
| 60 ppb | | PRE | 69.0 | 67.29 | 68.91 | 63.73 | 68.02 | |
| | YRD | MNB | 0.08 | 0.06 | 0.08 | 0.01 | 0.07 | ≤±0.15 |
| | | MNE | 0.21 | 0.2 | 0.21 | 0.19 | 0.21 | ≤0.3 |
| | | MFB | 0.07 | 0.06 | 0.07 | 0.02 | 0.06 | |
| | | MFE | 0.17 | 0.17 | 0.17 | 0.15 | 0.17 | |
| | | OBS | 65.58 | 65.58 | 65.58 | 65.58 | 65.58 | |
| | | PRE | 61.74 | 60.19 | 61.65 | 58.35 | 62.22 | |
| | PRD | MNB | -0.04 | -0.06 | -0.04 | -0.09 | -0.03 | ≤±0.15 |
| | | MNE | 0.25 | 0.24 | 0.25 | 0.24 | 0.25 | ≤0.3 |
| | | MFB | 0.04 | 0.02 | 0.03 | 0.0 | 0.04 | |
| | | MFE | 0.14 | 0.14 | 0.14 | 0.13 | 0.14 | |

Note: * are criteria suggested by EPA (2007).

**Table S6. Model performance $PM_{2.5}$ pollutants in different cases in China and important regions. There are 1381 stations shown as purple in Figure S1.**

| | | Statistics | C1 | C2 | C3 | C4 | C5 | Criteria* |
|---|---|---|---|---|---|---|---|---|
| $PM_{2.5}$ ($\mu g\ m^{-3}$) | China | OBS | 41.51 | 41.51 | 41.51 | 41.51 | 41.51 | |
| | | PRE | 40.67 | 40.44 | 40.64 | 40.02 | 40.6 | |
| | | MNB | 0.27 | 0.27 | 0.27 | 0.25 | 0.27 | |
| | | MNE | 0.73 | 0.73 | 0.73 | 0.72 | 0.73 | |
| | | MFB | -0.11 | -0.11 | -0.11 | -0.13 | -0.11 | ≤±0.6 |
| | | MFE | 0.57 | 0.57 | 0.57 | 0.57 | 0.56 | ≤0.75 |
| | NCP | OBS | 48.92 | 48.92 | 48.92 | 48.92 | 48.92 | |
| | | PRE | 47.85 | 47.63 | 47.85 | 47.42 | 47.79 | |
| | | MNB | 0.31 | 0.31 | 0.31 | 0.3 | 0.31 | |
| | | MNE | 0.69 | 0.68 | 0.69 | 0.68 | 0.69 | |
| | | MFB | -0.03 | -0.03 | -0.03 | -0.04 | -0.03 | ≤±0.6 |
| | | MFE | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | ≤0.75 |
| | YRD | OBS | 43.67 | 43.67 | 43.67 | 43.67 | 43.67 | |
| | | PRE | 48.15 | 47.87 | 48.12 | 47.3 | 48.02 | |
| | | MNB | 0.36 | 0.36 | 0.36 | 0.34 | 0.36 | |
| | | MNE | 0.7 | 0.7 | 0.7 | 0.69 | 0.7 | |
| | | MFB | 0.01 | 0.01 | 0.01 | -0.01 | 0.01 | ≤±0.6 |
| | | MFE | 0.48 | 0.48 | 0.48 | 0.49 | 0.48 | ≤0.75 |
| | PRD | OBS | 32.85 | 32.85 | 32.85 | 32.85 | 32.85 | |
| | | PRE | 33.69 | 33.46 | 33.63 | 32.93 | 33.76 | |
| | | MNB | 0.28 | 0.27 | 0.28 | 0.25 | 0.28 | |
| | | MNE | 0.77 | 0.77 | 0.77 | 0.77 | 0.77 | |
| | | MFB | -0.12 | -0.13 | -0.12 | -0.15 | -0.12 | ≤±0.6 |
| | | MFE | 0.59 | 0.6 | 0.6 | 0.61 | 0.59 | ≤0.75 |

Note: * are criteria suggested by Boylan and Russell (2006).

**Table S7. Seasonal averaged temperature in important regions of China. Unit is ℃.**

| | Spring | Summer | Fall | Winter |
|---|---|---|---|---|
| NCP | 14.4 | 25.8 | 14.2 | -0.6 |
| YRD | 16.2 | 26.9 | 18.2 | 6.0 |
| PRD | 22.6 | 28.7 | 24.2 | 15.0 |

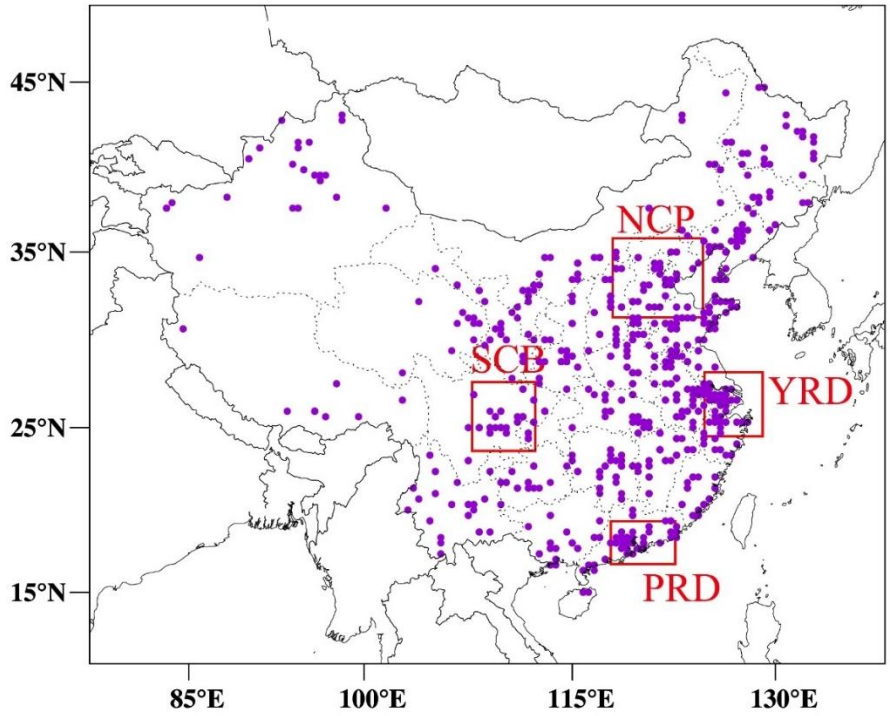


**Figure S1. Model domain with the key city clusters (North China Plain, NCP; Yangtze River Delta, YRD; Pearl River Delta, PRD; Sichuan Basin, SCB). Purple-filled circles show locations of air quality monitoring sites (1381 sites in total).**

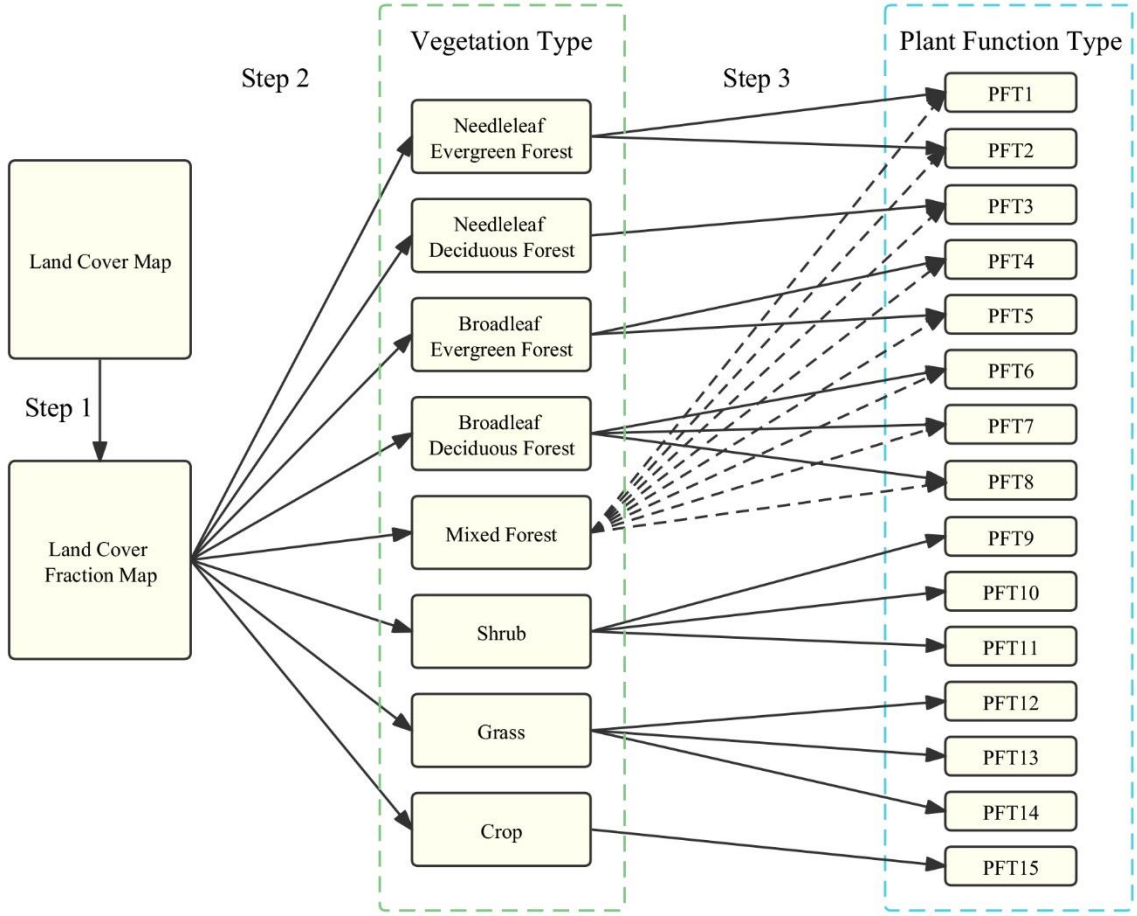


**Figure S2. The flow chart for making plant function type (PFT). The dashed line represents the complementary classification for PFT1 to PFT8.**

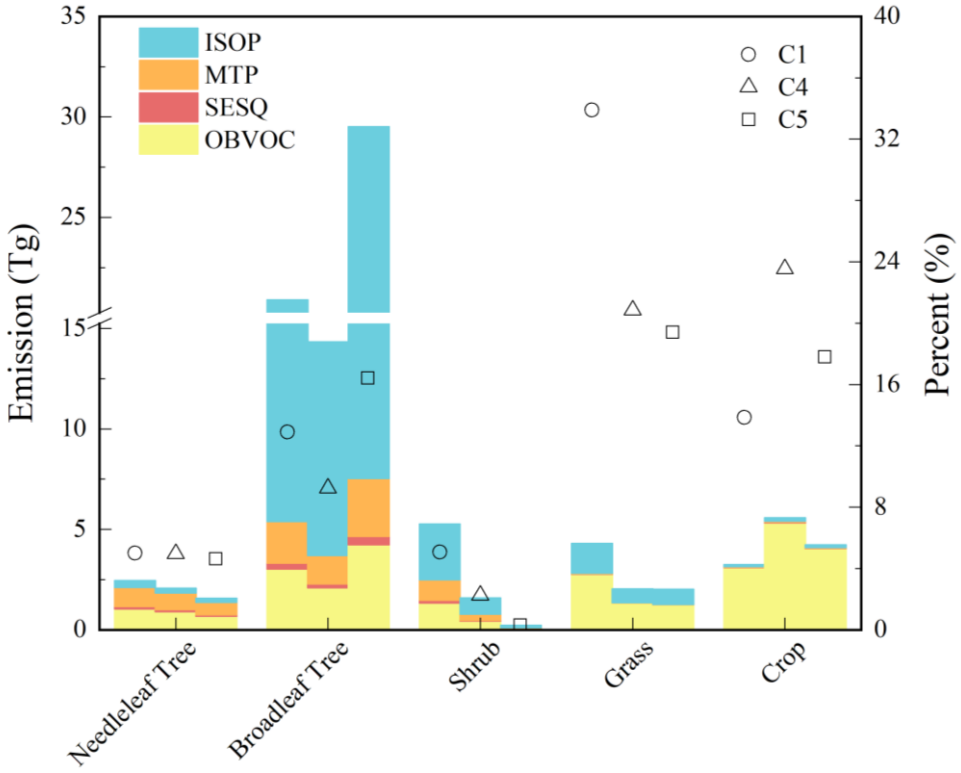


**Figure S3. The BVOC emissions and vegetation fractions of needleleaf tree, broadleaf tree, shrub, grass, and crop in the C1, C4 and C5. ISOP is isoprene, MTP is monoterpene, SESQ is sesquiterpene and OBVOC is other BVOCs.**

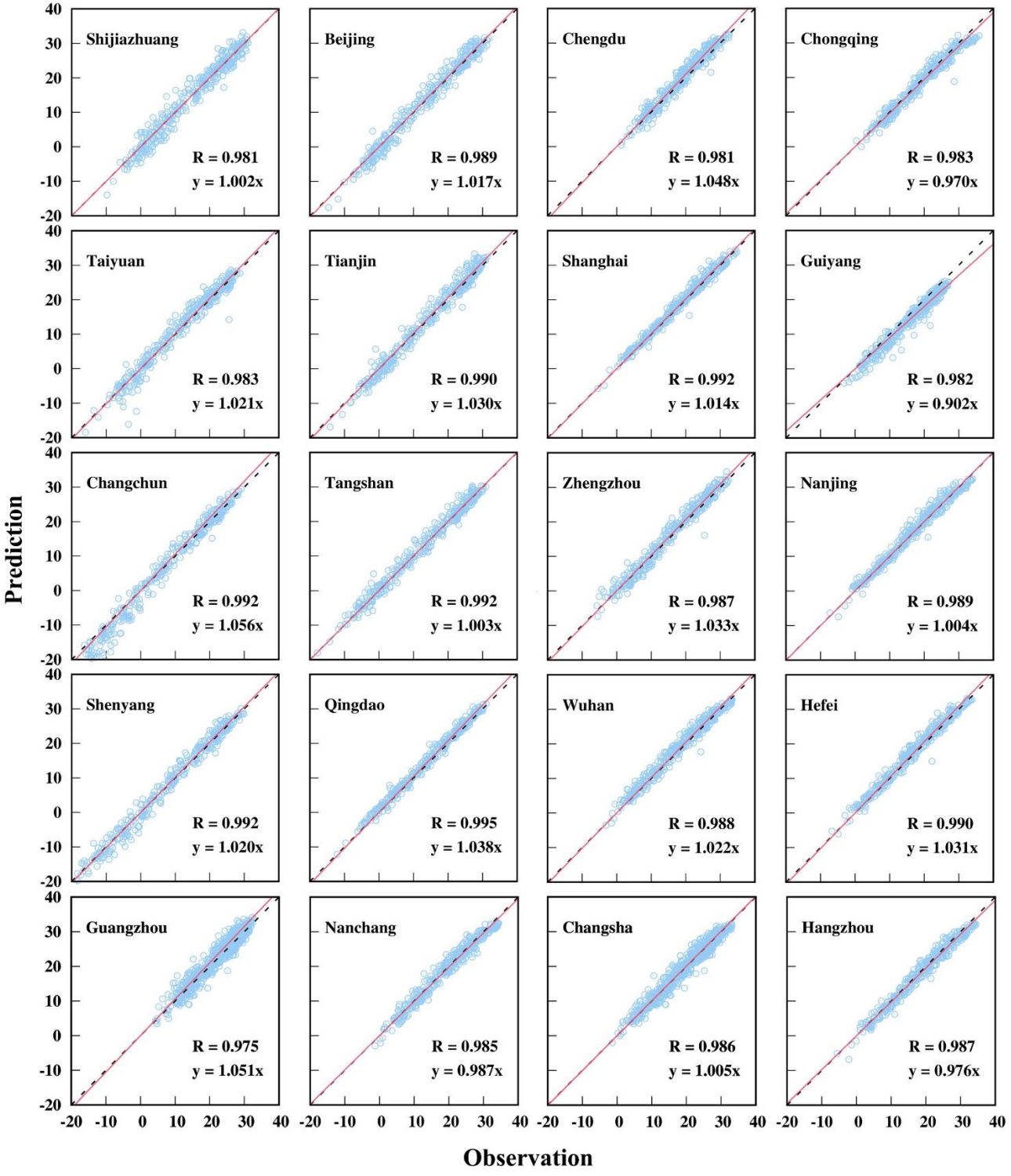


**Figure S4. Comparison of observed and predicted daily averaged 2m temperature in each city.**

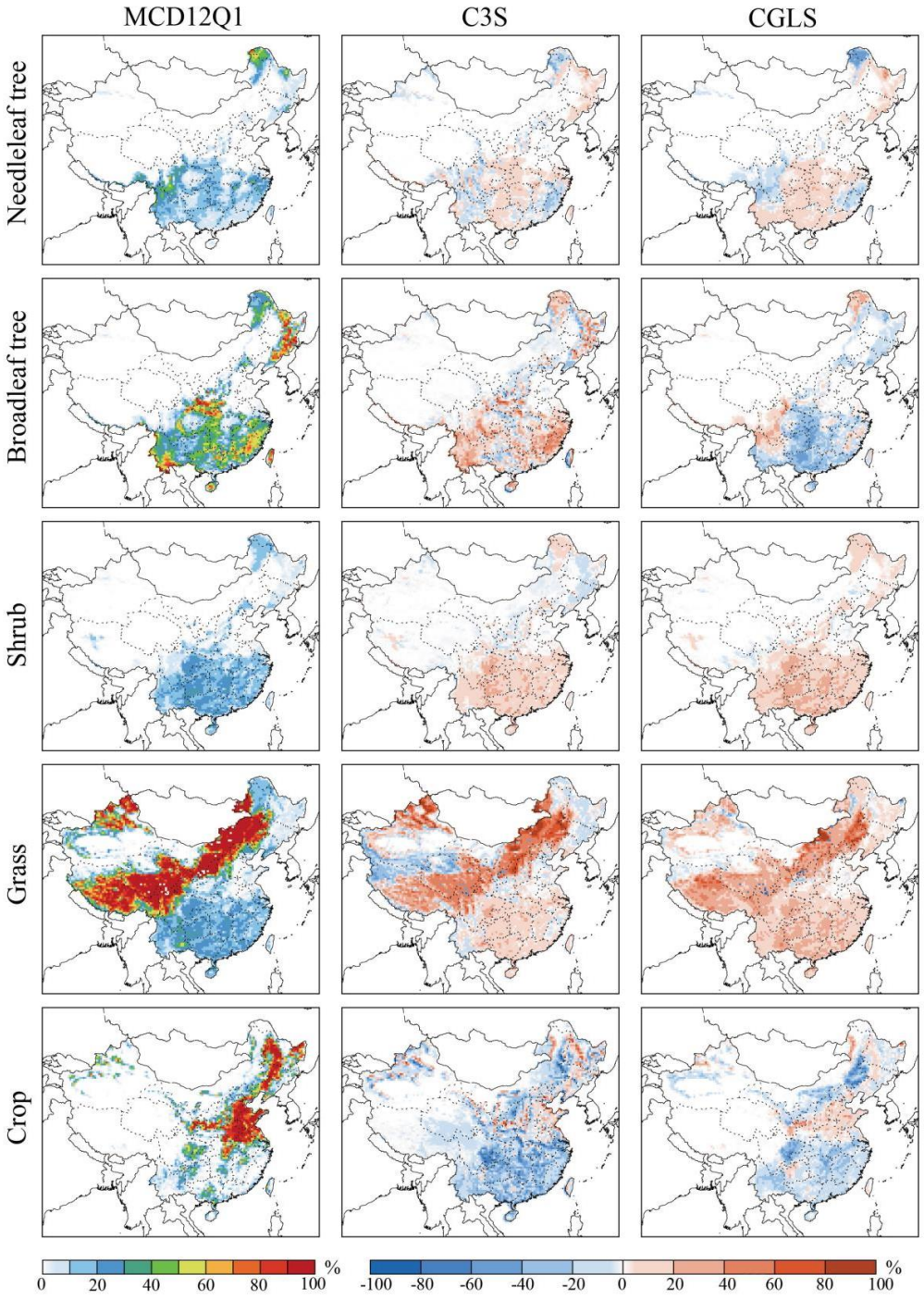


**Figure S5. The cover fraction of different PFTs in the MCD12Q1 product and the difference between the MCD12Q1 and the other satellite products for the year 2016.**

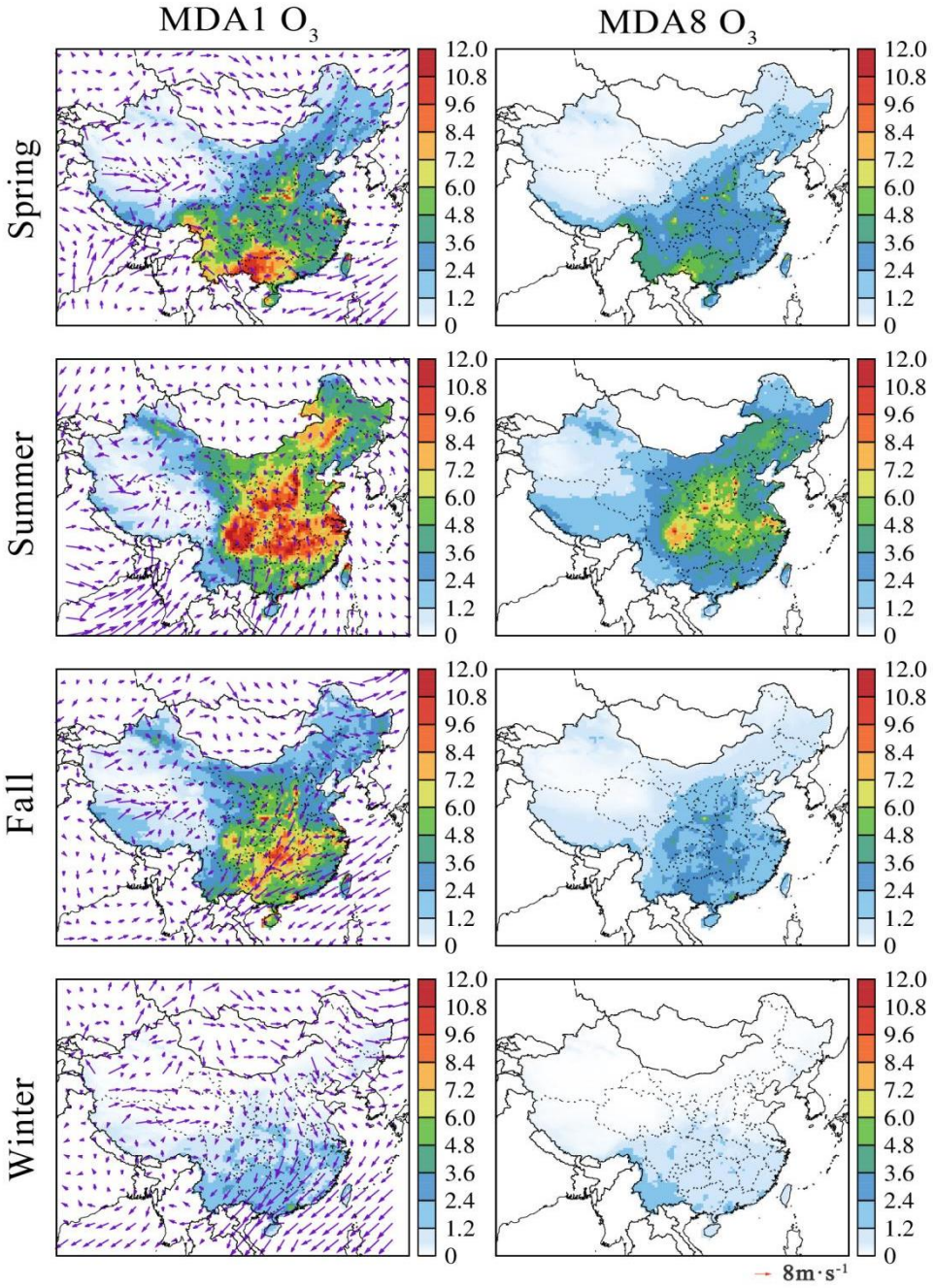


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**Figure S6. Seasonal spatial variation of predicted MDA1 $O_3$ and MDA8 $O_3$ formed by BVOCs and wind vectors. C1 is chosen as the input data to draw these maps. Unit is ppb.**

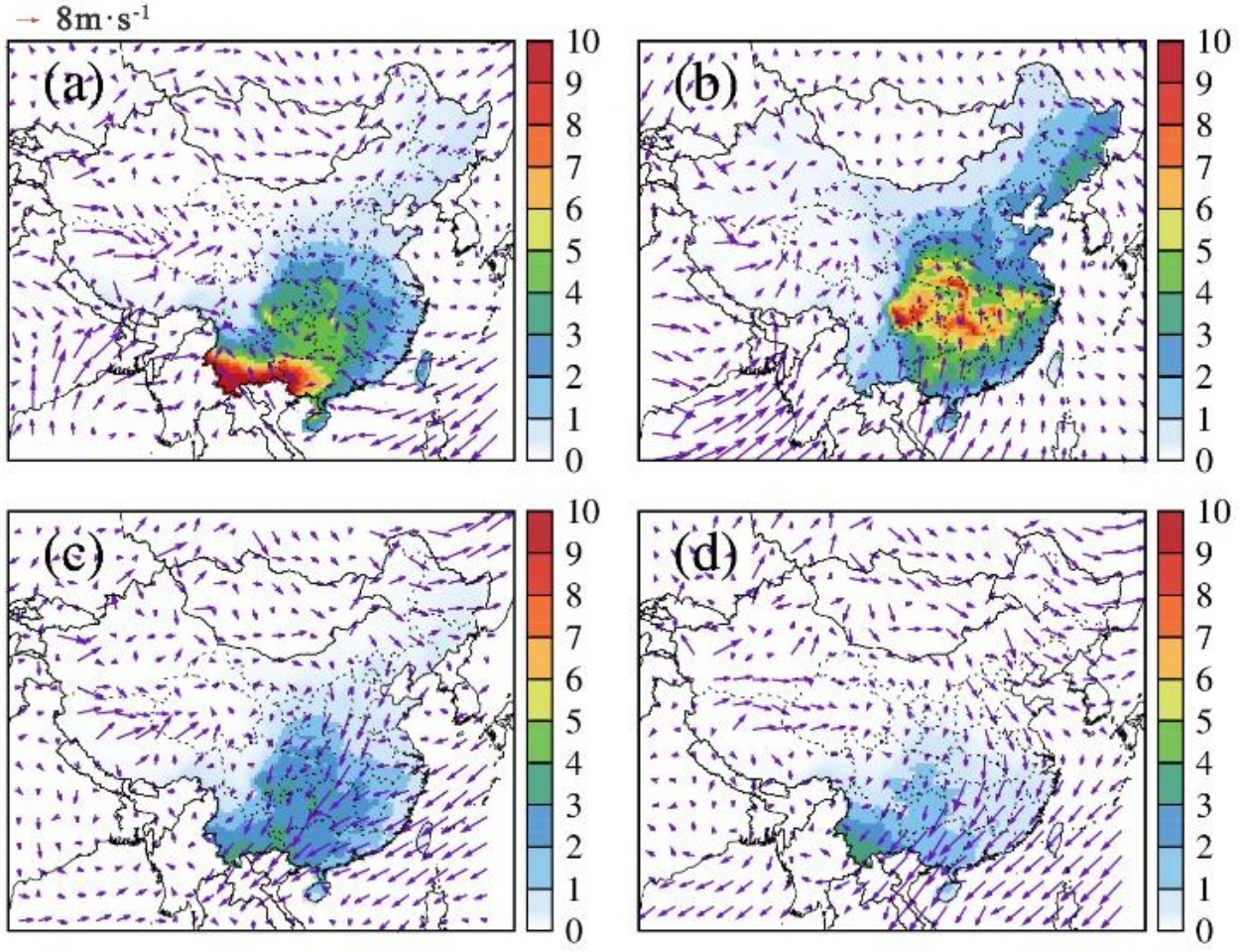


**Figure S7. Seasonal spatial variation of predicted SOA formed by BVOCs and wind vectors ((a) Spring, (b) Summer, (c) Fall, (d) Winter). C5 is chosen as the input data to draw these maps. Unit is μg $m^{-3}$.**

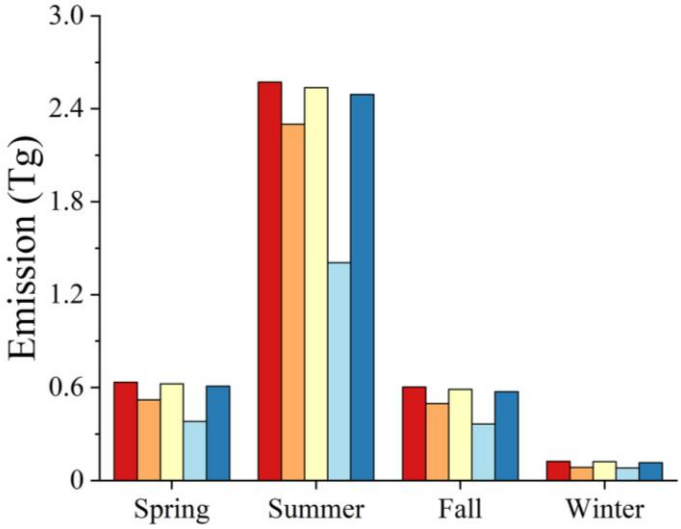


**Figure S8. Seasonal spatial variation of BVOCs in the YRD.**

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