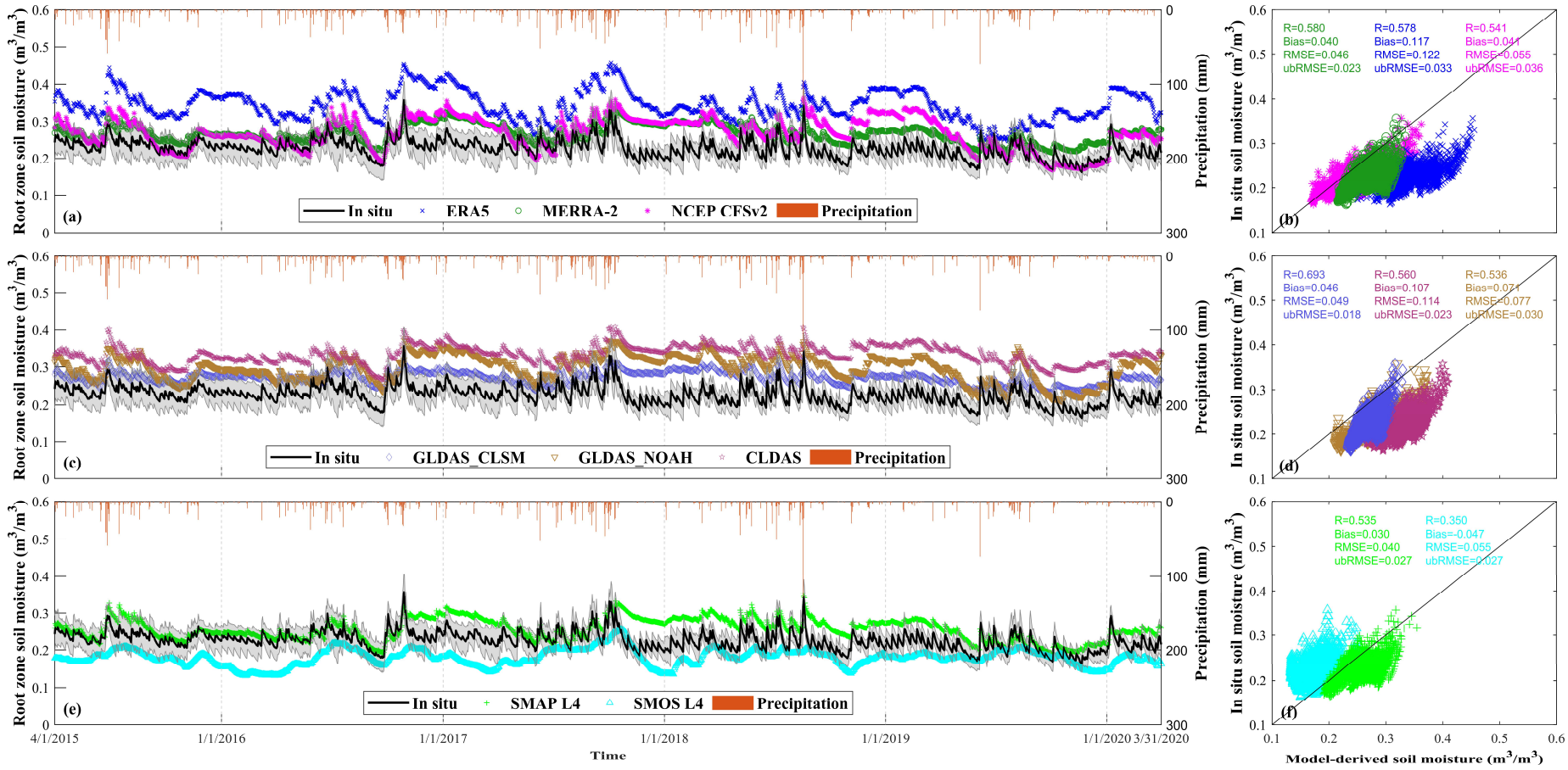


Fig. S1 Stations-averaged RZSM (0-100 cm) comparison between model-derived RZSM and in situ soil moisture observations spanning the period from April 1, 2015 to March 31, 2020, including the time series (left panel) and scatterplots (right panel). The gray-shaded areas in the left panel represent the standard deviation of *in situ* stations observations within the HRB.

**Calculation of seasonal anomaly**

Soil moisture products can show large differences at different timescales (e.g. subseasonal, mean seasonal and interannual) (Draper and Reichle, 2015; Gruber et al., 2020). To avoid seasonal effects, the soil moisture products are typically decomposed into different frequency components (e.g., the raw soil moisture and monthly soil moisture anomaly). In this study, the monthly anomaly time series of the RZSM are calculated based on the moving average decomposition method. The difference from the mean is divided by the standard deviation for a moving average window of five weeks (Rüdiger et al., 2009; Albergel et al., 2012). The moving window F is defined as follows for each RZSM estimate or observation on day (t), F=[t-17:t+17]. If at least five measurements are available in this period, the moving average and the standard deviation of the root zone soil moisture are calculated. The anomaly is given by the following equation:

$$RZSM_{anomaly}(t) = \frac{RZSM(t) - \overline{RZSM(F)}}{stdev(RZSM(F))} \quad \text{(S1)}$$

where $RZSM(t)$, $RZSM_{anomaly}(t)$ and stdev, denote the raw RZSM, the seasonal anomaly of RZSM at day *t*, and standard deviation, respectively. Equation (S1) is applied to gridded and *in situ* RZSM for comparison.

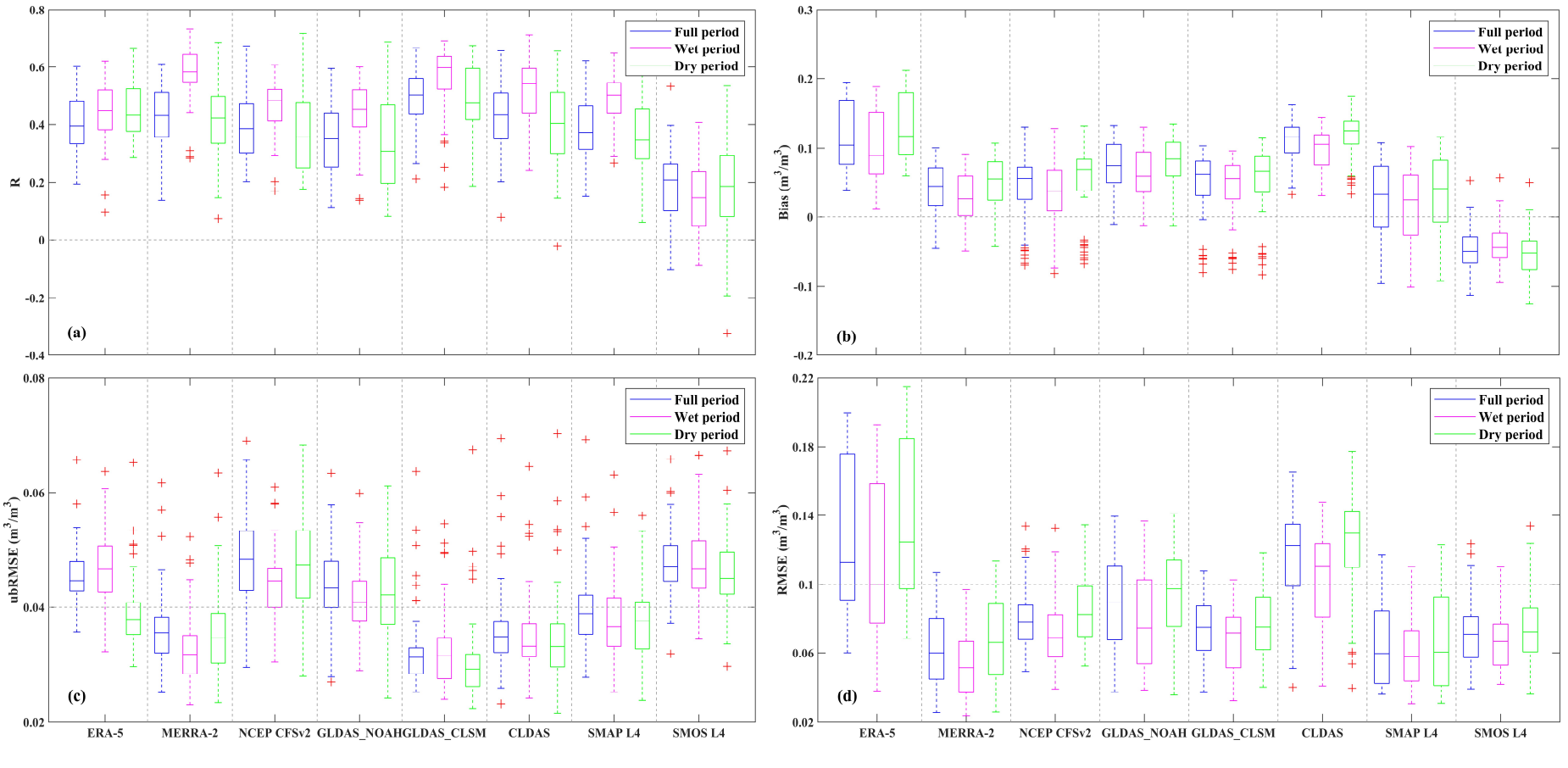


Fig. S2 Single-station RZSM comparison between model-derived RZSM and in situ soil moisture observations for different periods, including the Full period (from 1 April 2015 to 31 March 2020), Wet period (from June to September) and Dry period (from October to May). Each outlier "+" represents an *in situ* station. The five horizontal lines of the box plot represent the minimum, 25$^{th}$ percentile, 50$^{th}$ percentile, 75$^{th}$ percentile and maximum from bottom to top, respectively.

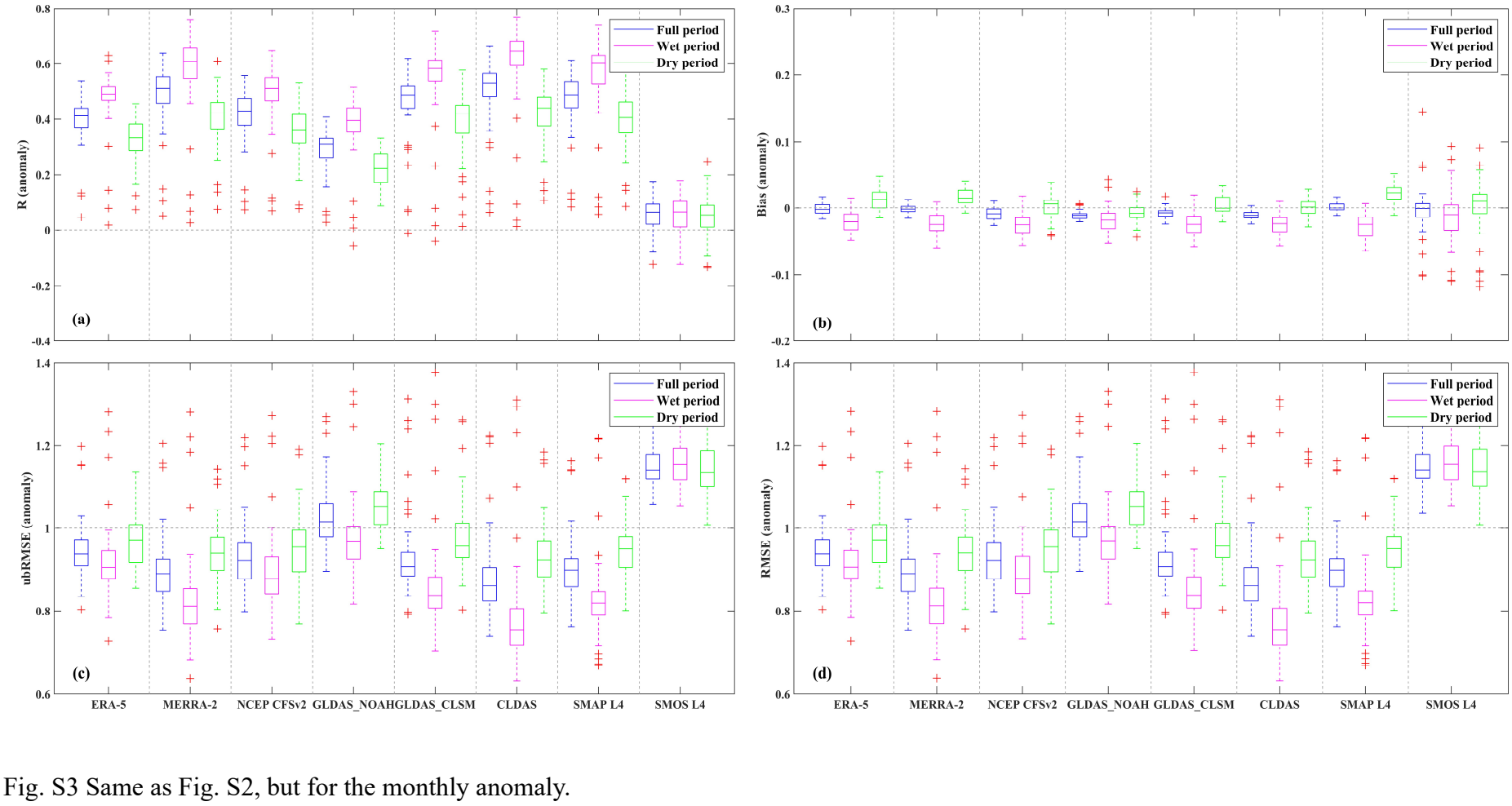


Fig. S3 Same as Fig. S2, but for the monthly anomaly.

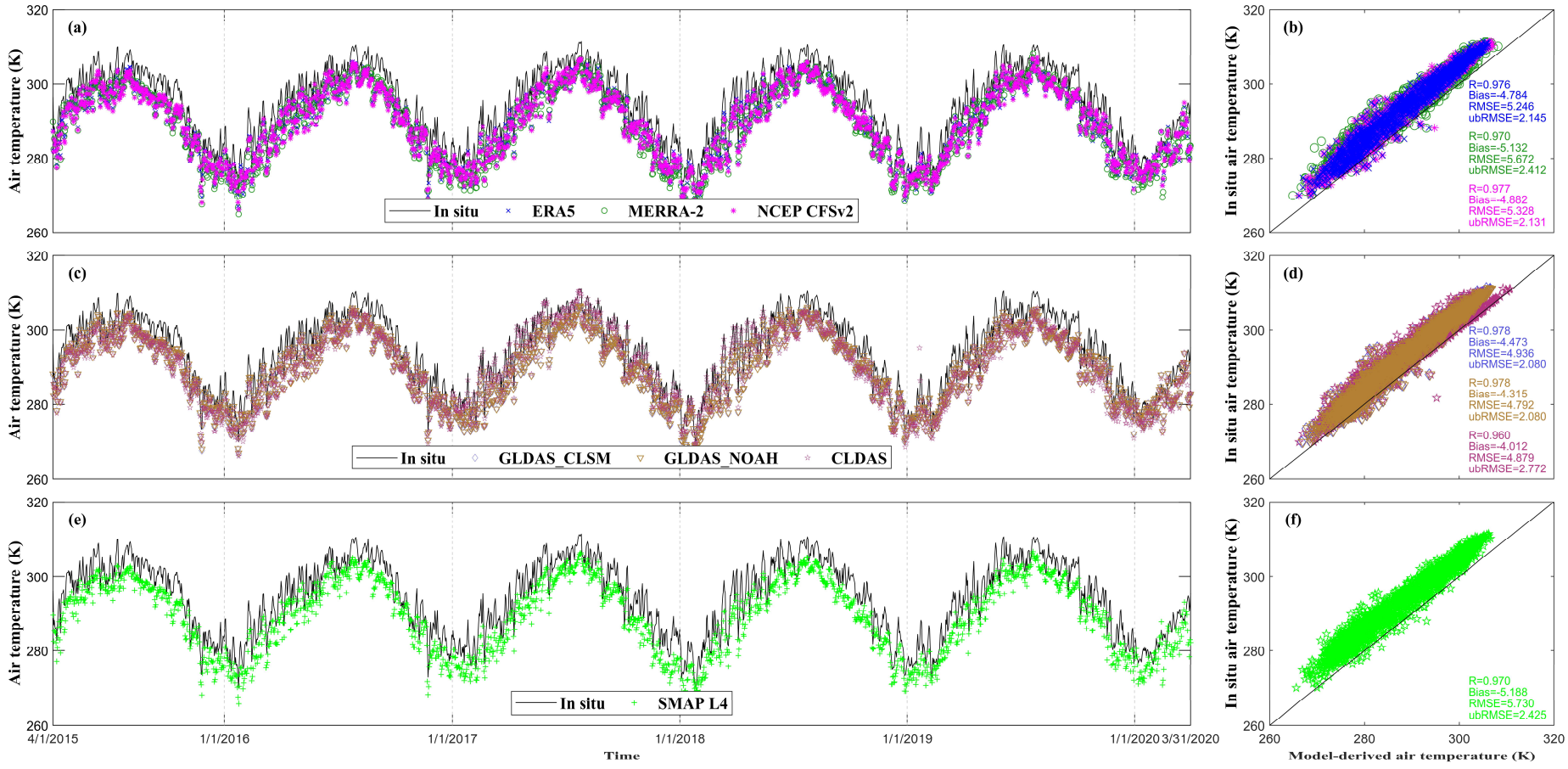


Fig. S4 Stations-averaged air temperature comparison between modeled air temperature and CMA air temperature dataset spanning the period from April 1, 2015 to March 31, 2020, including the time series (left panel) and scatterplots (right panel). ERA5, MERRA-2, NCEP CFSv2, GLDAS_CLSM, GLDAS_NOAH, CLDAS and CMA products provide the air temperature datasets at the 2-m screen level. SMAP L4 product provides the air temperature at center height of the lowest atmospheric model layer.

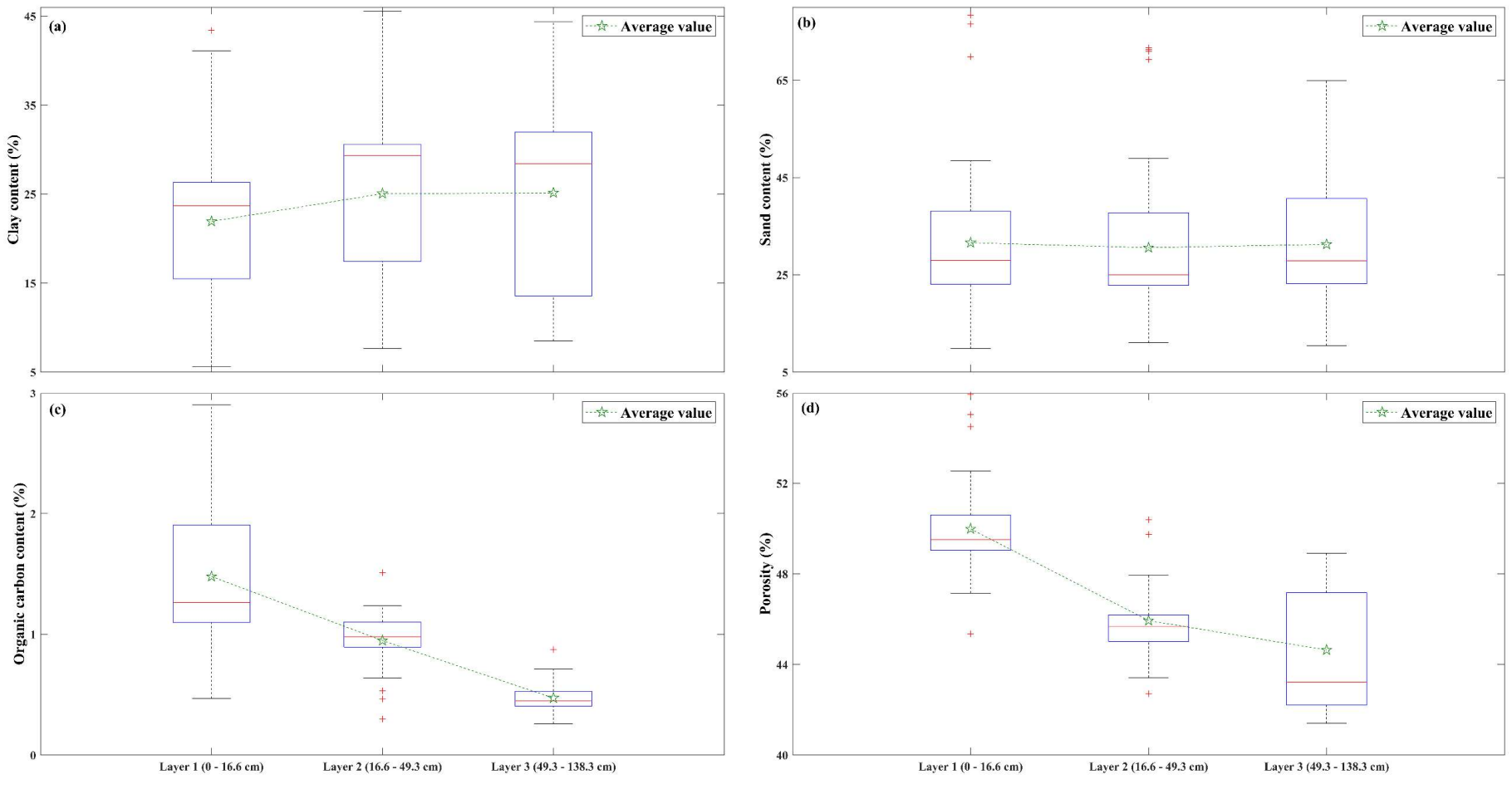


Fig. S5 Soil properties (clay and sand content, organic carbon content and porosity) of three soil layers (Layer1 (0-16.6 cm): plough layer; Layer 2 (16.6-49.3 cm): black soil layer; Layer3 (49.3-138.3 cm): lime concretion layer) HRB at different stations.

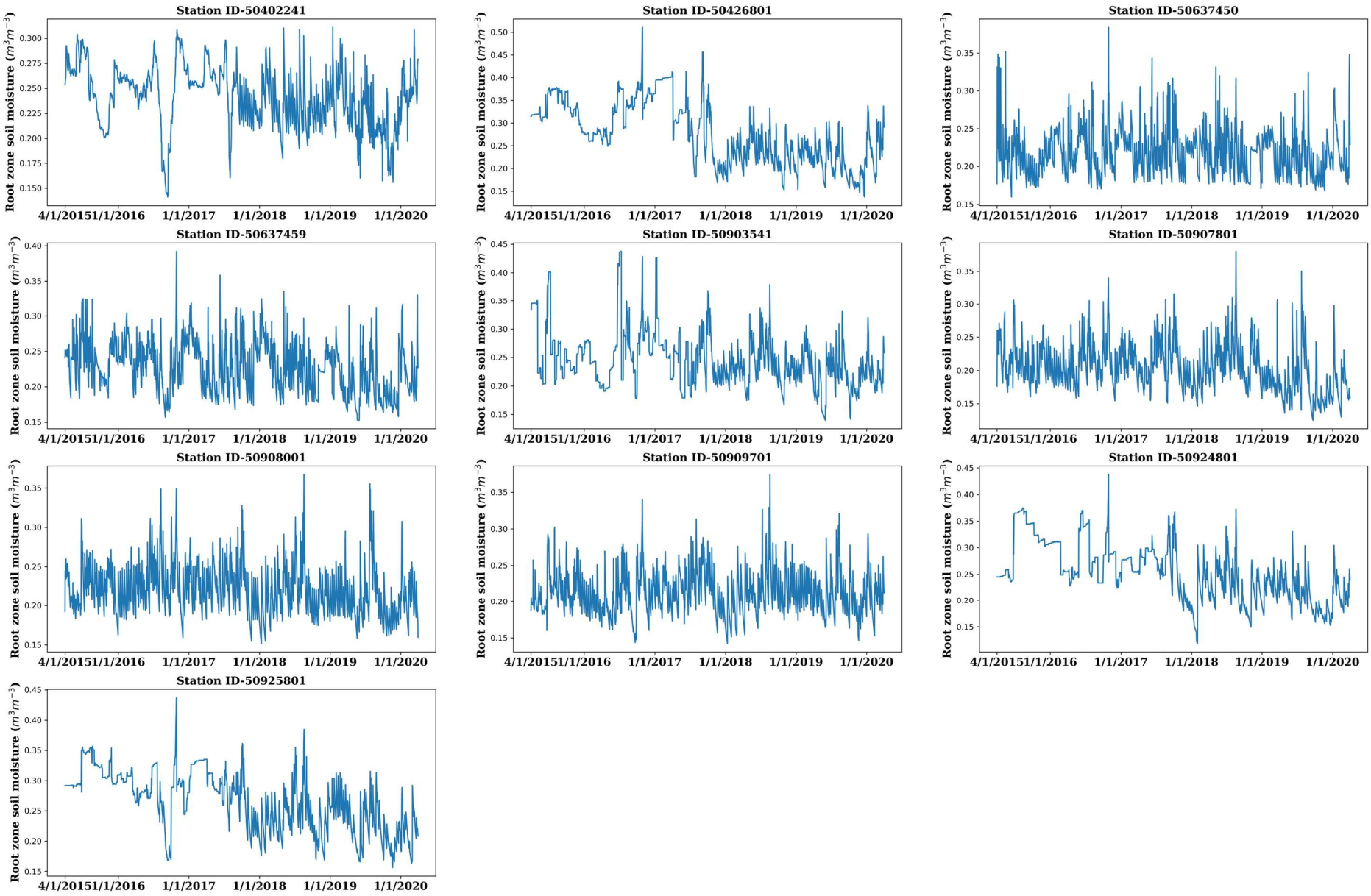


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Fig. S6 Time series of root zone soil moisture over the Huai river basin from 1 April 2015 to 31 March 2020. Measurements from the 10 *in situ* stations are available at https://doi.org/10.6084/m9.figshare.23497502.

Table. S1 Statistical metrics of eight RZSM products validated by *in situ* measurements (0-100 cm) at each station from 1 April 2015 to 31 March 2020. Mean score values and their standard deviation (brackets) are given for all seasons, wet season, and dry season.

| Dataset | Period | *In situ* validation (raw) | | | *In situ* validation (anomaly) | | |
|---|---|---|---|---|---|---|---|
| | | R | ubRMSE ($m^3\ m^{-3}$) | Bias ($m^3\ m^{-3}$) | R | ubRMSE (-) | Bias (-) |
| ERA-5 | All | 0.40 (0.10) | 0.045 (0.005) | 0.104 (0.047) | 0.41 (0.08) | 0.94 (0.07) | -0.00 (0.01) |
| | Wet | 0.45 (0.10) | 0.047 (0.006) | 0.089 (0.048) | 0.49 (0.11) | 0.91 (0.09) | -0.02 (0.02) |
| | Dry | 0.43 (0.10) | 0.038 (0.006) | 0.117 (0.046) | 0.33 (0.08) | 0.97 (0.06) | 0.01 (0.01) |
| MERRA-2 | All | 0.43 (0.10) | 0.036 (0.007) | 0.044 (0.036) | 0.51(0.11) | 0.89 (0.09) | -0.00 (0.01) |
| | Wet | 0.58 (0.09) | 0.032 (0.006) | 0.026 (0.035) | 0.61 (0.14) | 0.81 (0.12) | -0.03 (0.02) |
| | Dry | 0.42 (0.12) | 0.035 (0.008) | 0.055 (0.038) | 0.42 (0.10) | 0.94 (0.07) | 0.02 (0.01) |
| NCEP CFSv2 | All | 0.39 (0.11) | 0.048 (0.008) | 0.056 (0.052) | 0.43 (0.10) | 0.92(0.08) | -0.01 (0.01) |
| | Wet | 0.48 (0.09) | 0.045 (0.006) | 0.038 (0.051) | 0.51 (0.12) | 0.88 (0.10) | -0.03 (0.02) |
| | Dry | 0.36 (0.14) | 0.047 (0.010) | 0.069 (0.053) | 0.36 (0.09) | 0.96 (0.08) | 0.01 (0.02) |
| GLDAS_NOA | All | 0.35 (0.12) | 0.043 (0.007) | 0.075 (0.038) | 0.31 (0.08) | 1.02 (0.07) | -0.01 (0.01) |
| | Wet | 0.45 (0.11) | 0.041 (0.006) | 0.059 (0.040) | 0.40 (0.11) | 0.97 (0.11) | -0.02 (0.02) |
| | Dry | 0.31 (0.15) | 0.042 (0.008) | 0.084 (0.038) | 0.22 (0.06) | 1.05 (0.06) | -0.01 (0.01) |
| GLDAS_CLS | All | **0.50** (0.09) | **0.031** (0.007) | 0.061 (0.051) | 0.49 (0.12) | 0.91 (0.10) | -0.01 (0.01) |
| | Wet | **0.60** (0.11) | **0.031** (0.007) | 0.055 (0.050) | 0.58 (0.15) | 0.84 (0.13) | -0.03 (0.02) |
| | Dry | **0.47** (0.12) | **0.029** (0.007) | 0.067 (0.052) | 0.42 (0.11) | 0.96 (0.086) | **0.00** (0.01) |
| CLDAS | All | 0.44 (0.12) | 0.035 (0.008) | 0.116 (0.032) | **0.53** (0.12) | **0.86** (0.10) | -0.01 (0.01) |
| | Wet | 0.54 (0.11) | 0.033 (0.007) | 0.105 (0.032) | **0.65** (0.16) | **0.76** (0.14) | -0.02 (0.02) |
| | Dry | 0.40 (0.14) | 0.033 (0.009) | 0.125 (0.033) | **0.44** (0.10) | **0.93** (0.08) | 0.00 (0.01) |
| SMAP L4 | All | 0.37 (0.10) | 0.039 (0.007) | **0.033** (0.049) | 0.49 (0.11) | 0.90 (0.08) | **0.00** (0.01) |
| | Wet | 0.50 (0.08) | 0.037 (0.007) | **0.025** (0.049) | 0.60 (0.14) | 0.81 (0.11) | -0.02 (0.02) |
| | Dry | 0.35 (0.12) | 0.038 (0.008) | **0.041** (0.049) | 0.41 (0.09) | 0.95 (0.07) | 0.02 (0.01) |
| SMOS L4 | All | 0.21 (0.13) | 0.048 (0.007) | -0.050 (0.030) | 0.06 (0.06) | 1.14 (0.05) | -0.00 (0.03) |
| | Wet | 0.15 (0.13) | 0.047 (0.007) | -0.045 (0.030) | 0.07 (0.07) | 1.16 (0.06) | **-0.01** (0.05) |
| | Dry | 0.19 (0.16) | 0.045 (0.007) | -0.053 (0.032) | 0.05 (0.08) | 1.14 (0.06) | 0.01 (0.04) |

Note: Bold values denote the optimal values for each period. Data points used in this study at each station are 1827.

Table. S2 Distribution of Huai River Basin in situ stations and observed points at each station from April 1, 2015 to March 31, 2020.

| Station ID | Station Name | Longitude (E) | Latitude (N) | Elevation (m) | Time series length of the study period (day) | Number of soil moisture observations | Number of missing soil moisture observations |
|---|---|---|---|---|---|---|---|
| 50402241 | Taolaoba | 117.164 | 32.184 | 48 | 1827 | 1809 | 18 |
| 50403609 | Chahua | 116.022 | 33.033 | 39 | 1827 | 1804 | 23 |
| 50403809 | Hanting | 116.319 | 33.021 | 28 | 1827 | 1807 | 20 |
| 50420400 | Songji | 115.271 | 32.815 | 39 | 1827 | 1802 | 25 |
| 50421000 | Funan | 115.571 | 32.637 | 33 | 1827 | 1776 | 51 |
| 50421800 | Santa | 115.697 | 32.808 | 33 | 1827 | 1776 | 51 |
| 50423201 | Yaoli | 116.172 | 31.823 | 58 | 1827 | 1752 | 75 |
| 50424701 | Guanting | 116.851 | 31.797 | 51 | 1827 | 1808 | 19 |
| 50426001 | Zhuangmu | 117.112 | 32.363 | 27 | 1827 | 1812 | 15 |
| 50426072 | Guiji | 116.623 | 32.778 | 23 | 1827 | 1807 | 20 |
| 50426801 | Xiaji | 116.540 | 32.654 | 25 | 1827 | 1809 | 18 |
| 50429700 | Shuangfu | 115.569 | 33.342 | 37 | 1827 | 1775 | 52 |
| 50430100 | Fentai | 115.727 | 33.455 | 35 | 1827 | 1776 | 51 |
| 50430117 | Santang | 115.829 | 33.314 | 32 | 1827 | 1801 | 26 |
| 50430709 | Lixin | 116.209 | 33.143 | 28 | 1827 | 1780 | 47 |
| 50601600 | Jieshou | 115.359 | 33.265 | 42 | 1827 | 1776 | 51 |
| 50609001 | Yangqiao | 115.392 | 33.017 | 28 | 1827 | 1775 | 52 |
| 50634550 | Guangwu | 115.334 | 33.374 | 42 | 1827 | 1802 | 25 |
| 50636750 | Huangling | 115.134 | 33.041 | 37 | 1827 | 1776 | 51 |

| Station ID | Station Name | Longitude (E) | Latitude (N) | Elevation (m) | Time series length of the study period (day) | Number of soil moisture observations | Number of missing soil moisture observations |
|---|---|---|---|---|---|---|---|
| 50637371 | Quanyang | 115.437 | 33.112 | 35 | 1827 | 1801 | 26 |
| 50637413 | Kanheliu | 115.852 | 33.099 | 33 | 1827 | 1775 | 52 |
| 50637427 | Kouziji | 116.087 | 32.844 | 26 | 1827 | 1776 | 51 |
| 50637450 | Sanshilipu | 116.106 | 32.697 | 27 | 1827 | 1775 | 52 |
| 50637459 | Xiaqiao | 116.384 | 32.643 | 26 | 1827 | 1774 | 53 |
| 50700401 | Hengpaitou | 116.364 | 31.590 | 72 | 1827 | 1769 | 58 |
| 50701303 | Xianghongdianxiakuxi | 116.177 | 31.580 | 116 | 1827 | 1779 | 48 |
| 50725311 | Wangchenggang | 116.526 | 31.740 | 76 | 1827 | 1784 | 43 |
| 50830409 | Lumiao | 115.795 | 33.998 | 39 | 1827 | 1776 | 51 |
| 50830419 | Dasi | 115.873 | 33.802 | 42 | 1827 | 1778 | 49 |
| 50830439 | Youhe | 115.789 | 33.631 | 38 | 1827 | 1803 | 24 |
| 50830449 | Huagou | 116.063 | 33.510 | 33 | 1827 | 1811 | 16 |
| 50830480 | Dahu | 116.351 | 33.515 | 31 | 1827 | 1809 | 18 |
| 50830489 | Chenqiao | 116.561 | 33.094 | 25 | 1827 | 1777 | 50 |
| 50830601 | Heliu | 116.967 | 33.033 | 25 | 1827 | 1809 | 18 |
| 50900601 | Linhuanzha | 116.567 | 33.667 | 29 | 1827 | 1809 | 18 |
| 50901501 | Guzhenzha | 117.333 | 33.300 | 18 | 1827 | 1811 | 16 |
| 50903176 | Wudaogou | 117.341 | 33.156 | 21 | 1827 | 1808 | 19 |
| 50903421 | Hexiangzha | 117.183 | 33.000 | 18 | 1827 | 1806 | 21 |
| 50903600 | Tancheng | 116.557 | 33.441 | 29 | 1827 | 1804 | 23 |

| Station ID | Station Name | Longitude (E) | Latitude (N) | Elevation (m) | Time series length of the study period (day) | Number of soil moisture observations | Number of missing soil moisture observations |
|---|---|---|---|---|---|---|---|
| 50903541 | Xibakou | 117.867 | 33.150 | 11 | 1827 | 1809 | 18 |
| 50907801 | Xulouzha | 116.750 | 33.917 | 30 | 1827 | 1812 | 15 |
| 50908001 | Suxianzha | 117.083 | 33.667 | 28 | 1827 | 1811 | 16 |
| 50909701 | Gukouzha | 116.450 | 34.267 | 39 | 1827 | 1810 | 17 |
| 50912201 | Kuaitanggou | 117.550 | 33.750 | 20 | 1827 | 1810 | 17 |
| 50913201 | Yanglou | 116.783 | 34.317 | 39 | 1827 | 1809 | 18 |
| 50913901 | Langanji | 117.233 | 33.934 | 25 | 1827 | 1811 | 16 |
| 50922032 | Dulou | 116.850 | 34.200 | 37 | 1827 | 1811 | 16 |
| 50922072 | Xiangyang | 117.583 | 33.467 | 24 | 1827 | 1809 | 18 |
| 50922172 | Shuangdui | 116.900 | 33.417 | 25 | 1827 | 1811 | 16 |
| 50922232 | Shuoli | 116.900 | 34.033 | 32 | 1827 | 1812 | 15 |
| 50922332 | Huangmiao | 117.652 | 33.079 | 19 | 1827 | 1810 | 17 |
| 50924801 | Baoji | 117.113 | 33.158 | 22 | 1827 | 1807 | 20 |
| 50925801 | Dinghouying | 117.338 | 33.457 | 24 | 1827 | 1811 | 16 |
| 50931578 | Xuanmiao | 116.267 | 34.517 | 54 | 1827 | 1810 | 17 |
| 50932801 | Longhai | 116.350 | 34.400 | 45 | 1827 | 1811 | 16 |
| 50933001 | Zhangzhuangzhai | 116.600 | 34.117 | 37 | 1827 | 1811 | 16 |
| 50935201 | Sixian | 117.917 | 33.434 | 16 | 1827 | 1811 | 16 |
| 50938101 | Dazhuang | 117.867 | 33.667 | 20 | 1827 | 1812 | 15 |

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