## Supplementary Materials in the Manuscript

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| Zone | Apr. | May. | Jun. | Jul. | Agu. | Sep. |
|------|------|------|------|------|------|------|
| Ι    |      |      | ф    | *    |      |      |
| Π    |      |      |      | Ъ    | ÷    |      |
| III  |      | ф    |      | ģ    | 8    |      |
| IV   |      | ф    |      | ą    | R.   |      |

**Figure S1.** The typical growing cycles of maize in each agro-ecological zone. (♀ represents V3 stage, ❀ represents silking stage).

|            | 0.        | .5 1.5 2.5 3.      | 5 5          | 00 800 1100         |              | -2.0 -1.0 0.0                         | 0 2                | 21 23 25 23        | 7                  | 100 130 16         | 0                   | 8 12 16             |                     |          |
|------------|-----------|--------------------|--------------|---------------------|--------------|---------------------------------------|--------------------|--------------------|--------------------|--------------------|---------------------|---------------------|---------------------|----------|
| 5          | Yield     | <b>***</b><br>0.34 | 0.57         | <b>***</b><br>-0.40 | ***<br>-0.35 | -0.015                                | ***<br>0.30        | *<br>0.14          | ***<br>-0.27       | <b>***</b><br>0.23 | -0.12               | -0.089              | <b>***</b><br>0.26  | 000 8000 |
| 0.5 2.0 3. |           |                    | 0.79*        | -0.87*              | -0.80        | <b>**</b><br>-0.17                    | 0.026              | <b>**</b><br>-0.19 | ***<br>-0.41       | ***<br>0.26        | <b>*</b><br>-0.15   | ***<br>-0.27        | <b>***</b><br>0.34  |          |
| 0          |           | ×.                 |              | -0.85               | -0.79        | ***<br>-0.24                          | 0.028              | ***<br>-0.30       | ***<br>-0.43       | ***<br>0.38        | <b>***</b><br>-0.22 | <b>***</b><br>-0.33 | 0.45 <sup>***</sup> | 25 0.50  |
| 006 00     |           | ****               | ***          | ALL A               | 0.86         | ***<br>0.21                           | 0.04               | ***<br>0.37        | <b>***</b><br>0.37 | ***<br>-0.32       | <b>**</b><br>0.16   | ***<br>0.26         | ***<br>-0.39        |          |
| 6          |           |                    |              |                     | KDD          | <b>*</b><br>0.15                      | 0.049              | ***<br>0.35        | ***<br>0.28        | ***<br>-0.22       | **<br>0.16          | ***<br>0.28         | ***<br>-0.29        |          |
| -2.0 -0.5  | 00000     | °°°°               |              | 8000                |              | FDD                                   | <b>***</b><br>0.28 | <b>***</b><br>0.34 | 0.12               | -0.943             | -0.039              | -0.021              | -0.089              |          |
| 4          |           |                    |              |                     |              |                                       | Tinin              | 0.83*              | -0.015             | <b>**</b><br>0.18  | <b>***</b><br>-0.22 | -0.061              | <b>*</b><br>0.13    | 10 14    |
| 24 2       |           |                    |              |                     |              | • • • • • • •                         |                    | Tmax               | 0.11               | 0.033              | <b>*</b><br>-0.15   | 0.027               | -0.039              |          |
|            |           |                    |              |                     |              | <del></del>                           |                    |                    | Pdsi               | ***<br>-0.31       | <b>**</b><br>0.17   | 0.078               | ***<br>-0.36        | 6 2 2    |
| 100 140    |           |                    |              |                     |              | • • • • • • • • • • • •               |                    |                    |                    | P                  | -0.81               | -0.59<br>+0.59      | 0.95*               |          |
|            |           | <b>Se</b> i        |              |                     |              | <u>مە</u> پ،                          |                    |                    |                    | <b>`</b>           |                     | 0.73**              | -0.78               | - 04     |
| 8 12 18    |           |                    |              | ÷.                  | ×.           |                                       |                    |                    |                    | ÷.                 |                     |                     | -0.65               |          |
|            |           |                    |              |                     |              | · · · · · · · · · · · · · · · · · · · |                    |                    |                    |                    | 8.000               |                     |                     | 06 0.14  |
|            | 2000 6000 | 0.                 | 25 0.40 0.55 |                     | 0 40 80      |                                       | 10 14              |                    | -6 -2 24           |                    | 40 80 12            | o 0                 | 0.06 0.10 0.14      | 0        |

**Figure S2.** The correlations between transient variables (i.e., satellite data and climate variables) and yield in zone I. Each dot in the scatterplot represents a single county-year record. Single asterisk (\*), double asterisks (\*\*) and triple asterisks (\*\*\*) denote statistical significance levels of p-value<0.05, p-value <0.01 and p-value <0.001, respectively; "NS" indicates significance levels above 0.05.



Figure S3. The correlations between transient variables (i.e., satellite data and climate variables) and yield in zone II.

|           | 0             | .5 1.5 2.5 3.5      | :                   | 200 400 600         | -3                                     | 8.0 -1.5 0.0        | 0                   | 18 22 26 30  |                     | 0.05 0.08 0.1      | 11                  | 15 20 25 30         | )                |              |
|-----------|---------------|---------------------|---------------------|---------------------|--|---------------------|---------------------|--|---------------------|--------------------|---------------------|---------------------|------------------|--------------|
| 10        | Yield         | <b>***</b><br>-0.40 | <b>***</b><br>-0.30 | <b>***</b><br>0.27  | <b>***</b><br>0.24                     | -0.01               | <b>***</b><br>-0.17 | <b>***</b><br>-0.18  | -6.051              | <b>**</b><br>-0.14 | <b>***</b><br>-0.32 | <b>***</b><br>-0.19 | -0.083           |              |
| 5 2.0 3/  |               | SIF                 | 0.71**              | -0.59               | ***<br>-0.52                           | 0.12                | ***<br>0.26         | ***<br>0.22  | <b>***</b><br>0.32  | 0.044              | 0.52                | ***<br>0.28         | 0.12             | - 8          |
| 0         |               |                     | EVA                 | <b>***</b><br>-0.45 | <b>***</b><br>-0.63                    | **<br>0.16          | <b>***</b><br>0.36  | <b>***</b><br>0.30   | <b>***</b><br>0.43  | **<br>0.13         | <b>***</b><br>0.46  | ***<br>0.35         | ***<br>0.25      | 0.3 0.5      |
| 00 200    |               |                     |                     | GDD                 | <b>0.68</b>                            | • **<br>-0.14       | <b>***</b><br>-0.43 | <b>***</b><br>-0.32  | <b>***</b><br>-0.31 | 0.042              | -0.65               | <b>***</b><br>-0.49 | -0.015           |              |
| 0         |               |                     |                     |                     | KDD                                    | <b>***</b><br>-0.17 | ***<br>-0.26        | <b>**</b><br>-0.16   | <b>***</b><br>-0.42 | 0.027              | <b>***</b><br>-0.52 | <b>***</b><br>-0.28 | -0.051           | 09 00 00     |
| 0 - 10    |               |                     |                     |                     |  | FDD                 | ***<br>0.18         | <b>**</b><br>0.16  | <b>**</b><br>0.16   | 0.097              | ***<br>0.18         | <b>**</b><br>0.16   | <b>*</b><br>0.11 |              |
| ę         | *             |                     | ÷ <b>ra</b>         |                     | <b>.</b>                               | , <u> </u>          | Train               | 0.97*  | <b>***</b><br>0.26  | 0.69**             | <b>***</b><br>0.44  | 0.98*               | 0.75**           | - 8          |
| 18 24 30  | <b>.</b>      |                     |                     |                     |  | ~                   | STATES              | Tmax   | ***<br>0.17         | 0.78**             | ***<br>0.36         | 0.95*               | 0.77**           |              |
|           |               |                     |                     |                     | ************************************** |                     |                     |  | Pdsi                | *<br>0.11          | 0.61                | ***<br>0.17         | -62057           | <br><br>     |
| 0.05 0.09 |               |                     |                     |                     |  |                     | , P                 | , P  |                     | Pet                | ***<br>0.18         | 0.58                | 0.70**           |              |
|           |               |                     | . 🏓                 |                     | <b>.</b>                               | <u> </u>            |                     | <b></b>  | . <b>19</b>         |                    |                     | ***<br>0.40         | 0.037            | 1400<br>1400 |
| 15 25     | <b>.</b>      |                     | . <b></b>           |                     |  |                     |                     | and the second sec |                     |                    |                     | Vap                 | 0.72**           | -            |
|           |               |                     |                     | <b>.</b>            |  | ~                   |                     | , store  |                     | <b>.</b>           |                     | Ì                   | A pd             | 90 120       |
| 20        | 000 5000 8000 |                     | 0.3 0.5             |                     | 0 20 40 60                             |                     | 10 15 20 2          | 5  | -6 -2 0 2           |                    | 600 1200            |                     | 90 110 130       |              |

**Figure S4.** The correlations between transient variables (i.e., satellite data and climate variables) and yield in zone III.

|          |               | 0.0 1.0 2.0 | )           | 600 1000 14                             | 00 -                | 2.0 -1.0 0.0    | 0 1                                      | 5 20 25 30          | )                  | 100 130 160  |                        | 6 8 10              |                     |
|----------|---------------|-------------|-------------|---|---------------------|-----------------|--|---------------------|--------------------|--|------------------------|---------------------|---------------------|
|          | Yie           | -0.15       | ***<br>0.35 | <b>***</b><br>0.50                      | ***<br>0.22         | -0.082          | ***<br>0.21                              | ***<br>0.36         | <b>***</b><br>0.21 | ***<br>0.49  | <b>***</b><br>-0.41    | <b>***</b><br>-0.36 | ***<br>0.43         |
| 0 1.5    |               | SIF         | ***<br>0.23 | ***<br>-0.46                            | <b>***</b><br>-0.50 | 0.026           | -0.13                                    | <b>***</b><br>-0.27 | -0.035             | <b>***</b><br>-0.43  | <b>***</b><br>0.51     | 0.53                | <b>***</b><br>-0.39 |
| 0        |               |             |             | ***<br>0.33                             | -0.07               | -62013          | <b>***</b><br>0.42                       | <b>***</b><br>0.46  | ***<br>0.28        | <b>***</b><br>0.43   | <b>***</b><br>-0.39    | 0.029               | 0.46                |
| 300 1200 |               |             |             |   | 0.74                | -0.089          | 0.68                                     | 0.79*               | ***<br>0.23        | 0.93*  | -0.86                  | <b>***</b><br>-0.33 | 0.87*               |
| Ű        |               |             |             |   | KDD                 | -0.11           | ***<br>0.49                              | ***<br>0.53         | <b>*</b><br>0.12   | 0.68   | -0.57<br>-0.57         | <b>**</b><br>-0.19  | 0.58                |
| 2.0 -0.5 | ° 8°          | °.°         | °°8         | ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~ | 89                  | FDD             | 0.017                                    | 0.056               | 0.044              | -0.052   | 0.071                  | 0.06                | -0.072              |
| Ĩ        |               |             |             |   |                     |                 | Tania                                    | 0.96                | <b>***</b><br>0.28 | 0.79**   | -0.71**                | ***<br>0.34         | 0.88*               |
| 22       |               |             |             |   |                     |                 | - 5-4-5-5-5-5-5-5-5-5-5-5-5-5-5-5-5-5-5- |                     | <b>***</b><br>0.29 | 0.88   | -0.82                  | <b>*</b><br>0.13    | 0.96*               |
| -        |               |             |             | ÷.                                      |                     | ,               |  | <b>S</b>            | Rdşi               | ***<br>0.25  | <b>**</b><br>-0.19     | 0.023               | ***<br>0.29         |
| 00 140   |               |             |             |   |                     |                 |  | . <u>\$</u>         |                    | Per  | -0.87*                 | <b>***</b><br>-0.25 | 0.94*               |
|          |               | <b>.</b>    |             |   | Š.                  | . <u>.</u> , ., |  | ÷.                  |                    |  | Pre                    | <b>***</b><br>0.30  | -0.91*              |
| 6 10     | * <b>**</b> * |             |             | <b>.</b>                                |                     | ·               | <u>, and a</u>                           | <b>.</b>            |                    | ¥.   | **                     | Van                 | <b>*</b><br>-0.13   |
|          |               |             |             |   |                     |                 |  | -                   |                    | and the second s |                        |                     |                     |
|          | 4000 8000     |             | 030 045     |   | 0 40 80 140         |                 | 4 8 12 16                                |                     | 4 0 2 4            |  | 1 1 1 1 1 1<br>1 40 80 | 0                   | 05 0 15             |

Figure S5. The correlations between transient variables (i.e., satellite data and climate variables) and yield in zone IV



**Figure S6.** The spatial patterns of the recorded yield (**a**) and predicted yield using EVI for RF (**b**), XGBoost (**c**) and LSTM (**d**).



Figure S7. The spatial patterns of the relative errors for RF (a), XGBoost (b) and LSTM (c).

Table S1 An overview of the collected datasets in this study.

| Category           | Variables   | Spatial<br>Resolution | Temporal<br>Resolution | Time<br>Coverage | Source  |  |  |
|--------------------|---|-----------------------|------------------------|------------------|---|--|--|
| Maize yield and    | Maize yield   | County                | Year                   | 2001-2015        | Agricultural Statistical Yearbook   |  |  |
| planting area      | Planting area   | 1 km                  | Year                   | 2001-2015        | ChinaCropPhen dataset (Luo et al., 2019)  |  |  |
| Satellite data     | EVI   | 1 km                  | 16-day                 | 2001-2015        | MOD13A2 EVI product (Collection 6)  |  |  |
|                    | SIF   | 0.05°                 | 4-day                  | 2001-2015        | CSIF datasets (Zhang et al., 2018)  |  |  |
|                    | LST (KDD, GDD, FDD)   | 1 km                  | Daily                  | 2001-2015        | MOD11A1 product (Version 6)   |  |  |
|                    | Climate data (Tmin, Tmax, Pre,<br>Pdsi, Pet, Vap, Vpd)                    | 4 km                  | Monthly                | 2001-2015        | TerraClimate datasets   |  |  |
| Environmental data | Soil properties (SCLAY, SSILT,<br>SSAND, S_OC, S_PH, S_CEC,<br>SREF_BULK) | 1 km                  | -                      | -                | Soil particle-size distribution dataset (Shangguan et al., 2012)                            |  |  |
|                    | Irrigation ratio  | County                | -                      | -                | Science and Technology Innovation Project of Improving Food<br>Yield and Efficiency Project |  |  |

## References

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- 3. Shangguan, W., Dai, Y., Liu, B., Ye, A., & Yuan, H. A soil particle-size distribution dataset for regional land and climate modelling in china. *GEODERMA*. 2012, 171-172(none), 0-91.

**Table S2** The mean of predicted *RMSE* and *R*<sup>2</sup> for two combinations of inputs (i.e., "SIF +Environment" and "EVI +Environment") and four methods (i.e., LASSO, RF, XGBoost and LSTM) from 2011-2015 in each agro-ecological zone.

| Zone | LASSO |         |       | RF           | XGBoost      | LSTM         |  |  |
|------|-------|---------|-------|--------------|--------------|--------------|--|--|
|      |       | RMSE    | $R^2$ | $RMSE$ $R^2$ | $RMSE$ $R^2$ | RMSE $R^2$   |  |  |
| Ι    |       |         |       |              |              |              |  |  |
|      | SIF   | 1513.49 | 0.35  | 1061.99 0.68 | 1073.68 0.67 | 1115.47 0.65 |  |  |
|      | EVI   | 1591.26 | 0.28  | 1108.51 0.65 | 1093.17 0.66 | 1130.01 0.64 |  |  |

| т |  |
|---|--|
|   |  |
|   |  |
| - |  |

|     | SIF | 1103.82 | 0.22 | 615.11 | 0.75 | 602.47 | 0.77 | 667.41 | 0.73 |
|-----|-----|---------|------|--------|------|--------|------|--------|------|
|     | EVI | 1107.75 | 0.21 | 651.26 | 0.72 | 647.74 | 0.72 | 679.47 | 0.72 |
| III |     |         |      |        |      |        |      |        |      |
|     | SIF | 951.61  | 0.31 | 601.78 | 0.72 | 577.54 | 0.75 | 594.11 | 0.73 |
|     | EVI | 934.91  | 0.33 | 572.47 | 0.75 | 559.41 | 0.76 | 596.43 | 0.73 |
| IV  |     |         |      |        |      |        |      |        |      |
|     | SIF | 1468.31 | 0.33 | 691.56 | 0.85 | 653.52 | 0.86 | 844.99 | 0.78 |
|     | EVI | 1520.52 | 0.29 | 736.20 | 0.83 | 681.08 | 0.85 | 839.68 | 0.79 |