Supplementary Material

S1. MCWLA-Rice Parameters

Table S1. Description and prior intervals for the 17 parameters incorporated in the MCWLA-Rice model.

Function module		Crop parameter	Description	Interval
Phenology Component	VGP	At	Sensitivity of the developmental rate to air temperature	0.18–0.22
		Th	Air temperature at which DVR is half of the maximum rate at the optimum temperature	13.92–15.92
		DVI*	Value of DVI at which the crop becomes sensitive to photoperiod	0.74–1.14
		Gv	Minimum number of days required from transplanting to heading	33.98–37.98
		Lc	Critical day length	12.4–14.4
	RGP	Kl	Sensitivity of the developmental rate to day length	0.71–1.11
		Tcr	Empirical parameter for DVR when DVI > 1	12.0–18.0
Biomass Component		Ygp	Yield gap parameter	0.6–0.99
		Rrl	Relative growth of root depth and LAI	1.0–2.0
		Sle	Scaling factor for absorbed photosynthetically active radiation ecosystem versus leaf scale	0.4–0.6
		Ttmax	Maximum transpiration rate	3.0–7.0
		Gm	Empirical parameter in calculating atmospheric demand water	3.0–7.0
		Rm25	Maintenance respiration at 25 °C	0.33–0.73
		Mr	Empirical parameter in calculating maintenance respiration	40.0–60.0
		Ag	Growth respiration parameter	0.15–0.55
		Ccool	Curvature factor of spikelet sterility due to low temperature	1.0–2.5
		Chot	Curvature factor of spikelet sterility due to high temperature	12.5–18.5

S2. Climate cycles during calibration period

Considering that a crop model should capture weather-related temporal variability and trends, it is necessary to investigate whether a climate cycle (or in other words, adequate climate scenarios) existed during our calibration period. Actually, according to Chinese Agro-meteorological disaster dataset (from National Meteorological Information Center), we calculated the average disaster times for experiment stations during the period from 2000 to 2009 (Figure S1 in the response letter). We found that the disaster times per experimental station repeatedly rose and fell. For example, the average disaster times increased from three at year 2000, reached 10 at 2002, and then decreased to four at 2003. The similar changes also happened from 2004 to 2008. Hence, we concluded that climate cycles existed during our calibration process, which could improve the simulation ability of crop models under various climate scenarios. On other side, literatures about ecological model calibration always conduct the similar length of calibration period. For example, Ng et al. [1] calibrated SWAT during the period from 2002 to 2008 in Salt Creek watershed, USA. Chen at al. [2] used data from 2001 to 2008 to calibrated MCWLA-Wheat in North Plain of China.

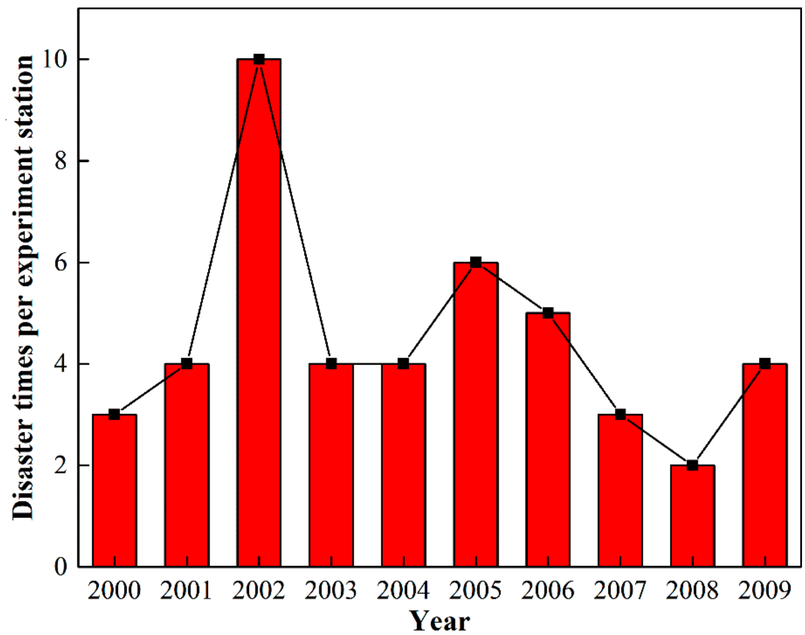

Figure S1. The disaster times per experiment station during the period from 2000 to 2009.

References

1. Ng, T.L.; Eheart, J.W.; Cai, X.; Miguez, F. Modeling Miscanthus in the soil and water assessment tool (SWAT) to simulate its water quality effects as a bioenergy crop. *ENVIRON SCI TECHNOL*. **2010**, *44(18)*, 7138-7144.

2. Chen, Y.; Zhang, Z.; Tao, F. Improving regional winter wheat yield estimation through assimilation of phenology and leaf area index from remote sensing data. *EUR J AGRON*. **2018**, *101*, 163-173.

S3. Raw LAI data and time profile smoothed by wavelet analysis

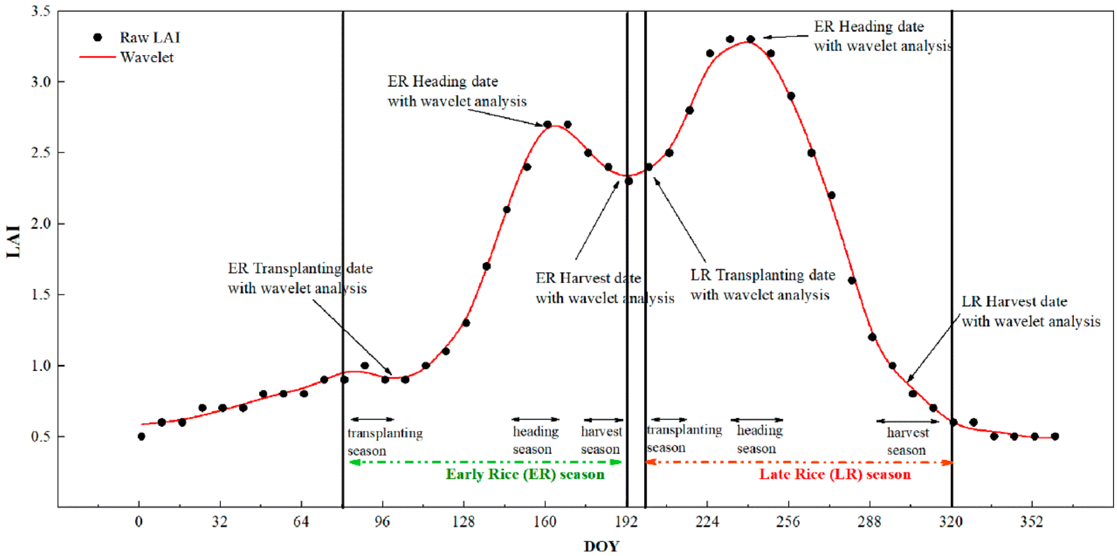

Figure S2. Raw remotely-sensed LAI data and time profiles smoothed using the wavelet method for a typical double-rice pixel

S4. Remotely-retrieved grid phenology dates

Grid phenology dates at 0.25° × 0.25° scale were retrieved using the wavelet methods described in Section 2.3 for double rice in the study area. Through comparing with ground observed phenology dates from six agro-meteorological experimental stations across study area (details in Figure 1d in Section 2.1), Figure C.1 indicated that the retrieved phenology dates were almost identical to the observation. Especially, all errors between the retrieved and the observed harvest date of early rice, transplanting date and heading date of late rice were within 16 days, although some errors were higher than 16 days for transplanting and heading date of early rice, and harvest date of late rice (Figure S3). Statistically, the average RMSE of early rice was 7.5 days for transplanting date, 5.3 for both heading date and harvest date; the RMSE of late rice was 5.9 days for transplanting date, 5.5 days for heading date, and 7.7 days for harvest date (Table S2). Such results reflected the interactions between natural factors and human managements in the double-cropping rice rotation system: 1) The early rice harvest and late rice transplanting were within a specific period to ensure adequate temperature and sunlight accumulation for the double rice rotation system, which were characterized by a short interval between the two local peaks (heading dates of early rice and late rice) in a LAI time series for double-cropping rice (Figure S2). 2) The two local peaks accounted for heading dates in double copping seasons, and often were conductive to estimate other phenology dates (Figure S2). 3) Compared with them, the retrieval of early rice transplanting and late rice harvest had less accuracy because of the huge differences in human agricultural management factors, such as rice varieties, level of agricultural mechanization, and so on. Nevertheless, the average of all RMSEs was 6.3 days, which was good enough for MCWLA-Rice calibration in our research.

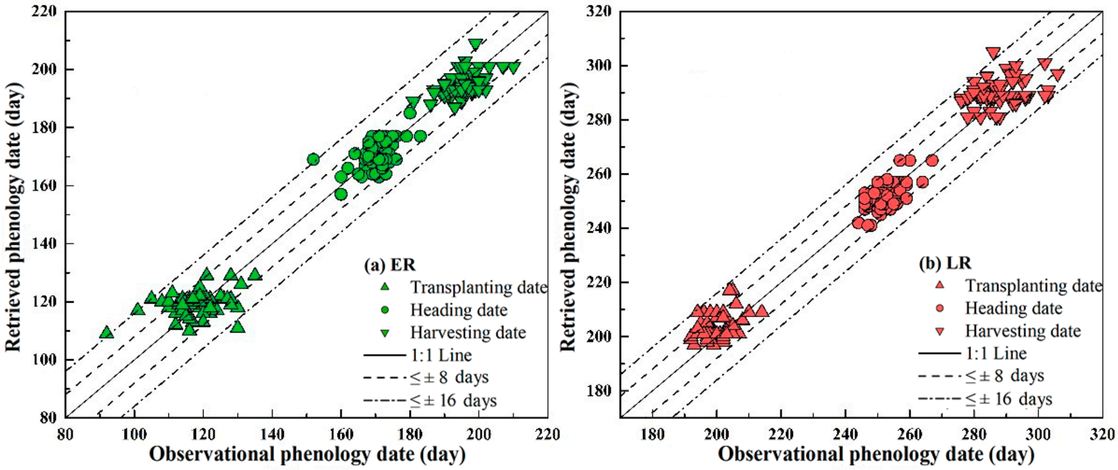

Figure S3. One-to-one comparison between observed and remotely-retrieved phenology dates at the pixel scale: (**a**) Early rice (ER); and (**b**) late rice (LR).

Table S2. RMSE between the observed and remotely-estimated phenology dates at the pixel scale.

		Average	RMSE ≤ 8 days (%)	8 days < RMSE ≤ 16 days (%)	RMSE > 16 days (%)
Early rice	Transplanting	7.5	86.86	10.15	2.99
	Heading	5.3	95.65	2.90	1.45
	Harvest	5.3	95.70	4.30	0.00
Late rice	Transplanting	5.9	86.96	13.04	0.00
	Heading	5.5	92.75	7.25	0.00
	Harvest	7.7	73.91	24.64	1.45
Average		6.3	88.64	10.38	0.98

S5. Parameters' contribution to calibration results

To investigate which parameters contributed most to calibration results, we analyzed the average improvement of each parameter (Figure S4). The larger improvements indicated that the corresponding parameters were more sensitive variables and more possible to affect the calibration results. We found that the improvement of 10th and 15th parameter for early rice and that of the 8th, 10th, and 13th parameter for late rice were significantly larger than others. More interestingly, all above parameters belong to yield component of MCWLA-Rice according to Supplementary S1. Therefore, we could conclude that parameters of yield component contributed most to calibration results, especially the 10th parameter.

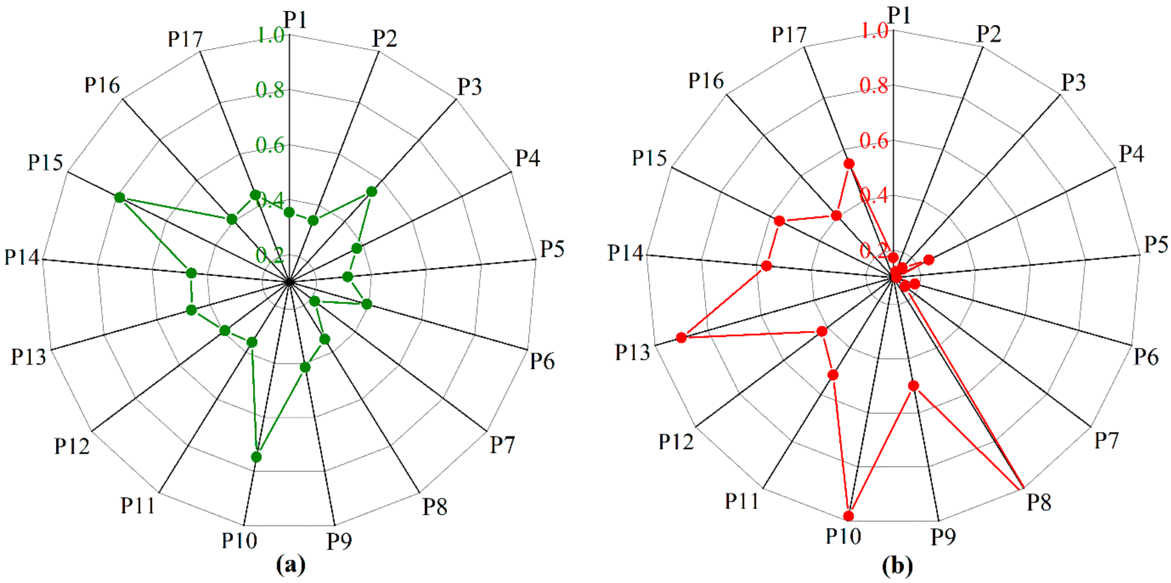

Figure S4. The improvement of crop parameters after calibration for (**a**) early rice and (**b**) late rice.