Supplementary Material

1. Smoothing time series tests

Since the MODIS data sets already have a maximum value composite (MVC) for noise removal, we only proceeded with the interpolation, filtering, and daily interpolation steps (Figure S1). The Sentinel-2 data was submitted to two different treatments to assess initial noise removal. One of the methods evaluated was Best Index Slope Extraction (BISE) [49] to remove noisy data from the time series using the R Phenex package [82]. This algorithm searches from the first date of the NDVI time series and accepts an increase in NDVI if the rate of change is less than a threshold called the growth factor. A decrease in NDVI will only be accepted if there is no NDVI observation in a predefined time period, called the slippage period, which has a value greater than 20% of the difference between the first low value and the previous high value [82]. In addition, we tested an 8-day MVC for Sentinel – 2A to verify the effect of composition alongside the raw data and filters tested (Figure S1).
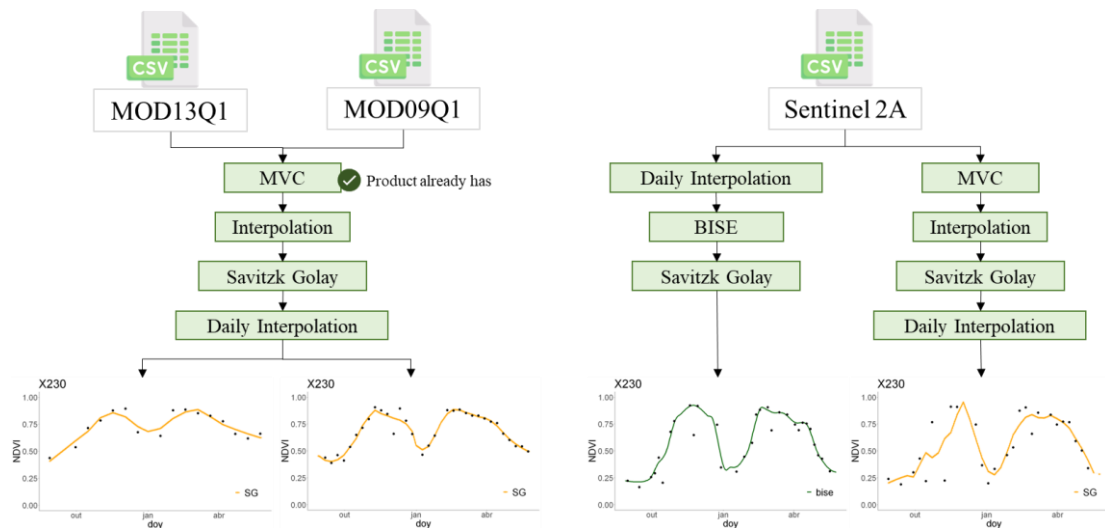

Figure S1 – Noise removal and time series fitting steps for each dataset used.

A greater improvement was observed in the raw dataset from the Sentinel-2 satellite. It can be seen that several outliers were removed from the time series, both using BISE and MVC. Both profiles obtained for Sentinel - 2A are similar, showing that,

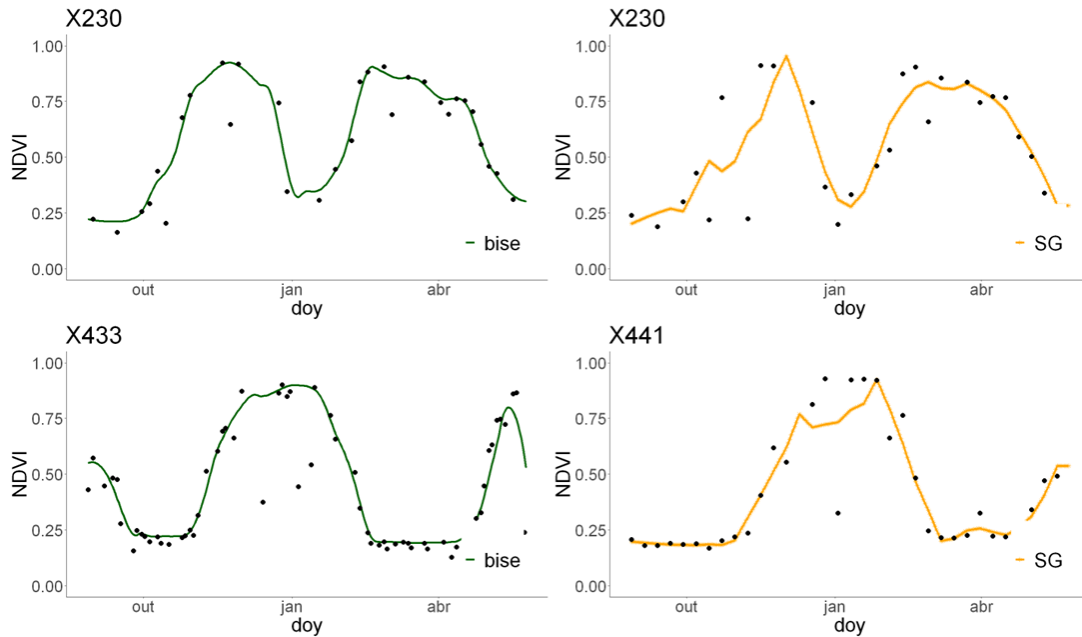besides being an easier algorithm to implement, BISE has enormous capacity to filter noisy data (Figure S2).

Figure S2 – NDVI profile for S2 (right) and S2 composition (left). NDVI profile after outlier removal using BISE + Savitzk Golay (green) or MVC + Savitzk Golay (yellow).

2. Parameter calibration

To perform the calibration, we randomly selected 200 time-series within the dataset to be tested. From these, we performed an extensive search testing different values for the main parameter of each package. For the CP, GB, PF, PX and TM packages, thresholds between 0.1 and 0.5 with intervals of 0.5 and 0.1 were tested. For the DT package, which has a different methodology, the methods of first and median for Start of Season (SOS) and last and median for End of Season (EOS) were used.

A fixed period of 10 days was subtracted from the detected SOS dates to match the sowing date (SD). Finally, we compared the results of the extensive search with the observed field data.

With the parameter calibration of each package, it is possible to see that there are large differences between the values tested, especially when evaluating the estimates of SD. Generally, a pattern can be observed for the SD estimates where the smallest differences from field data were those with lower parameter values between 10% and 25% (Figures S3 and S4). However, for the harvest dates (HD) estimates, the best results depend on each package and data source used.
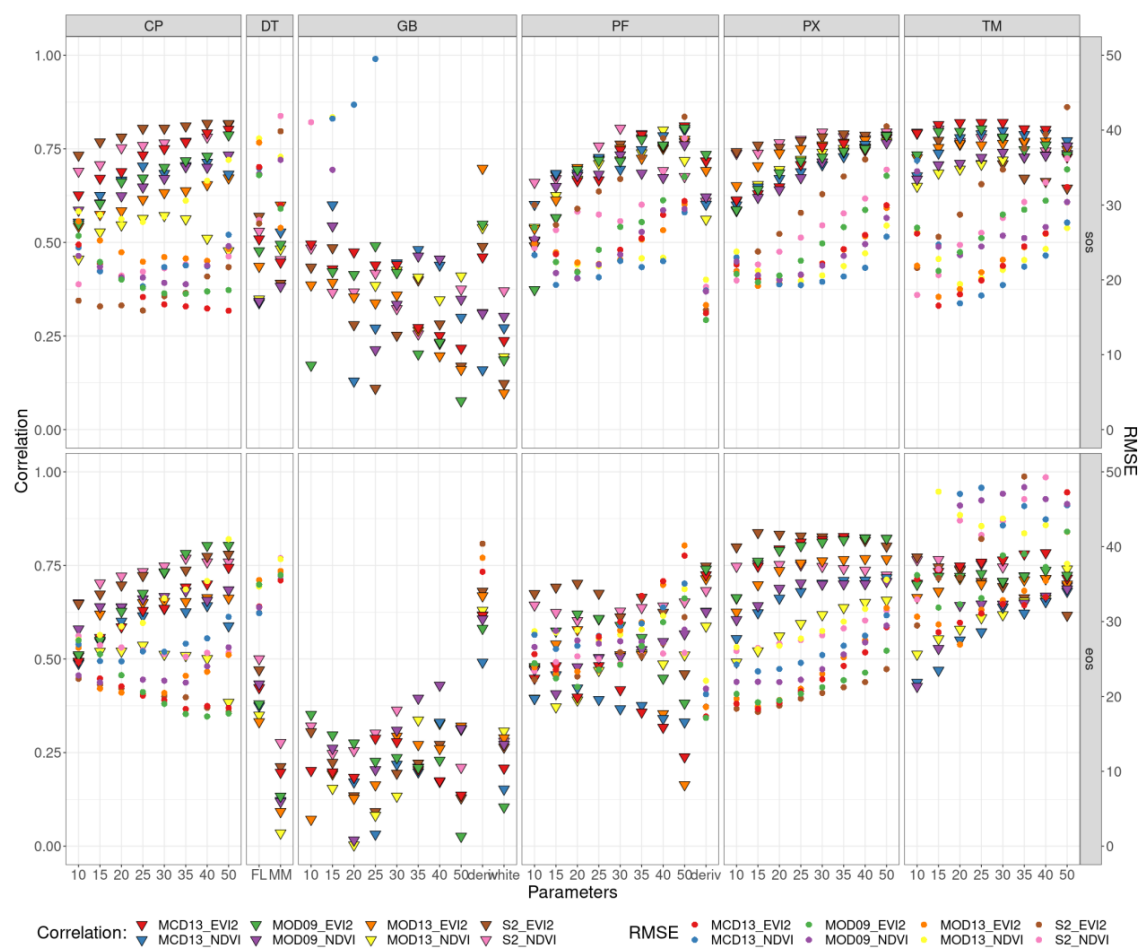
Figure S3 – Correlation coefficient between the data observed in the field and SD and HD estimates for the different parameters of each tested. CP (CropPhenology), DT (DEA tools), PF (phenofit), PX (Phenex) and TM (TIMESAT).
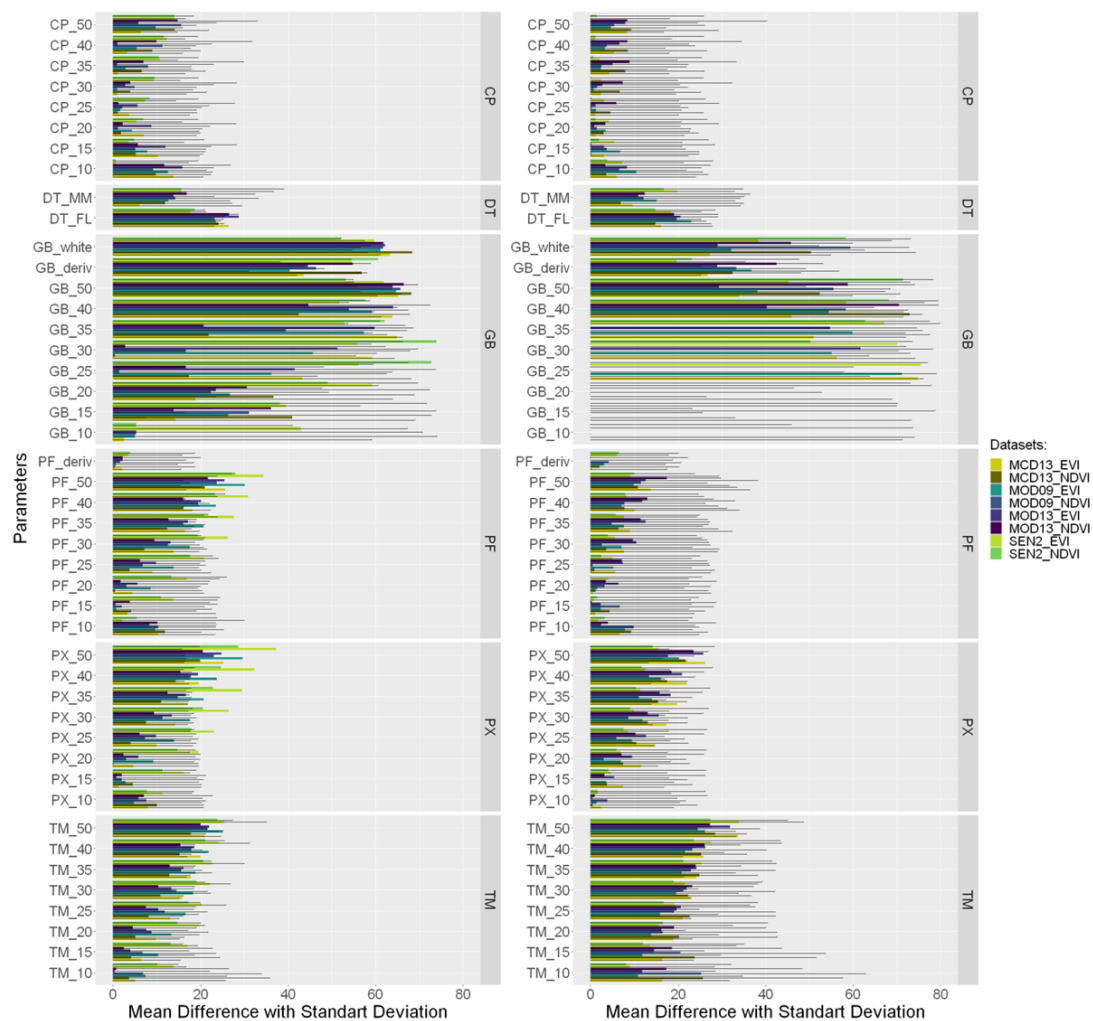
Figure S4 – Mean difference and standard deviation between the observed SD (left) and HD (right) field data and the different estimates made using different parameters for the packages. CP (CropPhenology), DT (DEA tools), PF (phenofit), PX (Phenex) and TM (TIMESAT).

3. Method validation and analysis

Table S1 – Correlation coefficient, RMSE (days), bias (%) and standard deviation (days) for all estimates, where CP (CropPhenology), DT (DEA tools), GB (greenbrown), PF (phenofit), PX (Phenex) and TM (TIMESAT).

Pkg	VI	DS	Sowing Date			Harvest Date		
			R	RMSE	Bias	R	RMSE	Bias
CP	EVI2	MCD13	**0,73**	**17,47**	-5,84	0,64	19,66	-1,93
		MOD09	0,70	**17,92**	4,59	**0,71**	18,09	**-0,47**
		MOD13	0,66	20,61	-8,58	0,56	22,50	**0,44**
		S2	**0,71**	**17,10**	2,30	**0,71**	19,03	1,14
	NDVI	MCD13	0,64	19,97	1,11	0,58	25,64	-3,22
		MOD09	0,63	22,30	11,57	0,65	24,21	-1,77
		MOD13	0,57	24,75	**-0,13**	**0,47**	31,16	-1,98
		S2	0,69	18,35	2,96	0,70	24,92	**0,77**
DT	EVI2	MCD13	**0,43**	31,41	8,06	**0,39**	31,97	8,73
		MOD09	0,54	29,76	**20,58**	**0,32**	35,24	12,06
		MOD13	0,54	27,98	**23,36**	**0,28**	35,31	10,94
		S2	0,56	26,52	**-27,62**	**0,42**	30,82	9,94
		MCD13	**0,46**	33,64	17,14	**0,37**	30,84	8,09

Region	VI	DS	R	RMSE	Bias	R	RMSE	Bias
GB	NDVI	MOD09	**0,43**	34,69	**22,01**	**0,40**	30,97	9,49
		MOD13	**0,48**	34,64	**28,21**	**0,29**	35,17	10,28
		S2	0,52	27,01	**-27,65**	**0,47**	30,13	8,22
	EVI2	MCD13	0,50	**57,57**	**68,85**	0,65	37,57	-14,31
		MOD09	**0,46**	**52,31**	**67,51**	0,65	**59,64**	-18,30
		MOD13	0,63	**58,56**	**68,11**	0,64	36,91	-13,76
		S2	0,53	**65,49**	**87,53**	**0,72**	32,39	-8,77
	NDVI	MCD13	**0,25**	**78,15**	**87,45**	**0,47**	**62,61**	-18,90
		MOD09	**0,35**	**64,13**	**73,84**	0,56	**58,12**	-17,19
		MOD13	0,51	**73,39**	**78,16**	0,57	**66,08**	**-20,39**
		S2	**0,33**	**79,41**	**95,78**	0,66	**50,97**	-12,05
PF	EVI2	MCD13	0,70	**15,95**	-4,29	0,70	**17,24**	**0,05**
		MOD09	**0,71**	**15,25**	**-0,17**	**0,71**	**16,66**	1,32
		MOD13	0,68	**16,77**	-4,13	0,68	18,20	**0,06**
		S2	0,70	**16,02**	3,91	0,70	18,21	2,60
	NDVI	MCD13	0,60	**17,92**	-1,09	0,61	19,39	1,03
		MOD09	0,63	**17,73**	1,84	0,63	19,62	1,97
		MOD13	0,56	19,90	-1,99	0,55	21,53	**0,65**
		S2	0,57	19,47	6,90	0,60	21,40	3,52
PX	EVI2	MCD13	0,67	18,23	1,42	**0,71**	19,16	-3,67
		MOD09	0,64	18,83	6,85	**0,72**	18,05	-1,53
		MOD13	**0,73**	**17,44**	2,37	0,62	21,00	-1,89
		S2	**0,76**	20,94	**20,27**	**0,75**	**17,67**	**-0,18**
	NDVI	MCD13	0,62	19,82	-6,19	0,58	22,42	-1,23
		MOD09	0,61	19,66	**-0,96**	0,65	21,94	**-0,58**
		MOD13	0,67	18,60	-2,66	0,48	28,31	**-0,90**
		S2	**0,74**	19,96	15,18	0,70	24,37	0,33
TM	EVI2	MCD13	**0,80**	**16,13**	10,37	**0,76**	27,60	-9,07
		MOD09	**0,76**	19,98	15,51	**0,73**	29,67	-6,75
		MOD13	**0,79**	**17,89**	7,89	0,68	31,71	-8,60
		S2	**0,80**	22,22	**23,09**	**0,74**	31,77	-4,17
	NDVI	MCD13	**0,76**	18,25	4,94	0,62	**42,94**	-9,36
		MOD09	**0,71**	19,55	11,18	0,67	**41,79**	-7,71
		MOD13	**0,74**	**16,17**	2,47	0,62	**42,17**	-8,92
		S2	**0,80**	18,46	17,56	**0,73**	37,48	-4,22

Blue: Best estimates (R>0.75, RMSE<18, Bias<1, sd<18). Red: Worst estimates (SD: R<0.5, RMSE>40, Bias>20, sd>40). Pkg = Package, VI = Vegetation Index, DS = Data Source, R = correlation coefficient, sd = standard deviation.
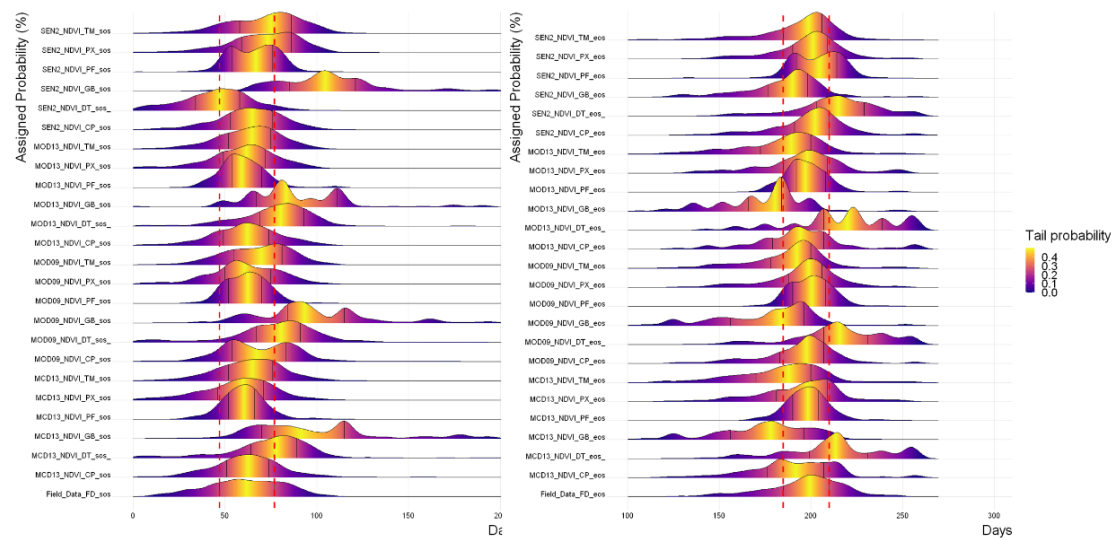
Figure S5 – Distribution of each tested dataset. Black lines indicate first and third quantiles. Red lines indicate the quantiles from field data.
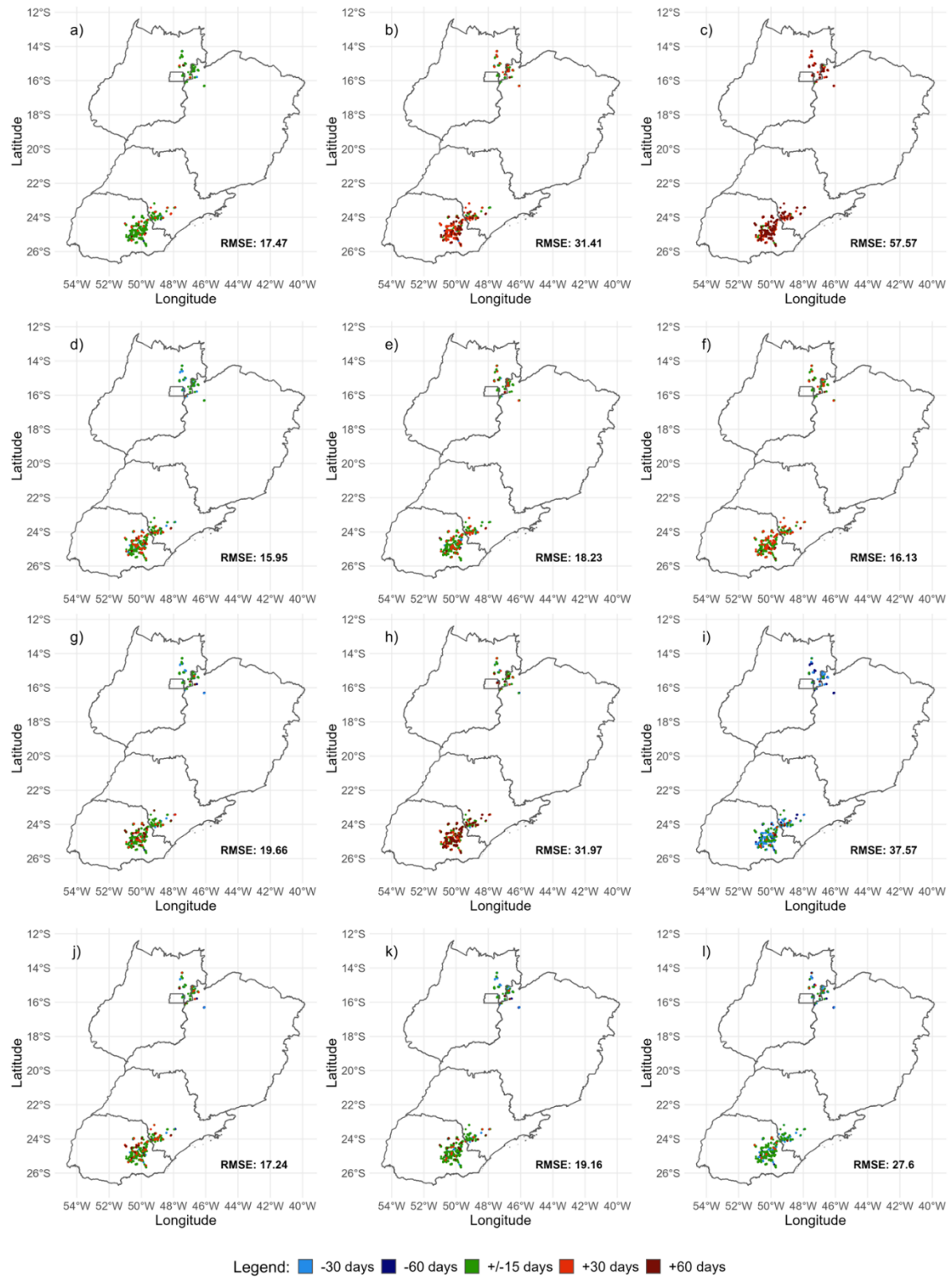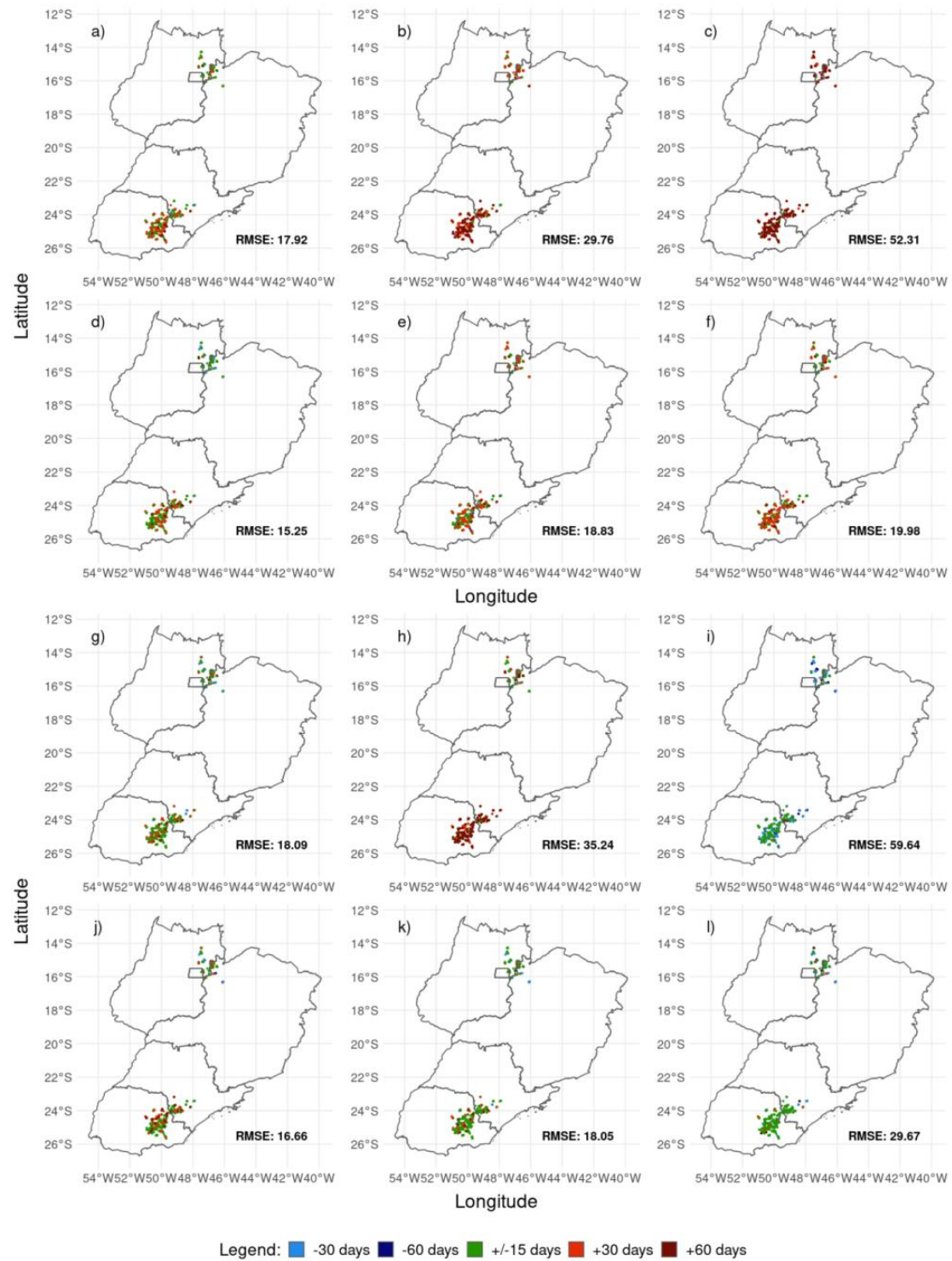
Figure S6 - Spatial pattern of the difference between observed and estimated sowing date (a,b,c,d,e, f) and harvest dates (g,h,i,j,k, l) estimated by the different packages tested for MCD13 EVI2. Where, CropPhenology (a, g), DEA tools (b,h), greenbrown (c,i), phenofit (d,j), Phenex (e,k) and TIMESAT (f,l). Root meant square error (RMSE) is in days.
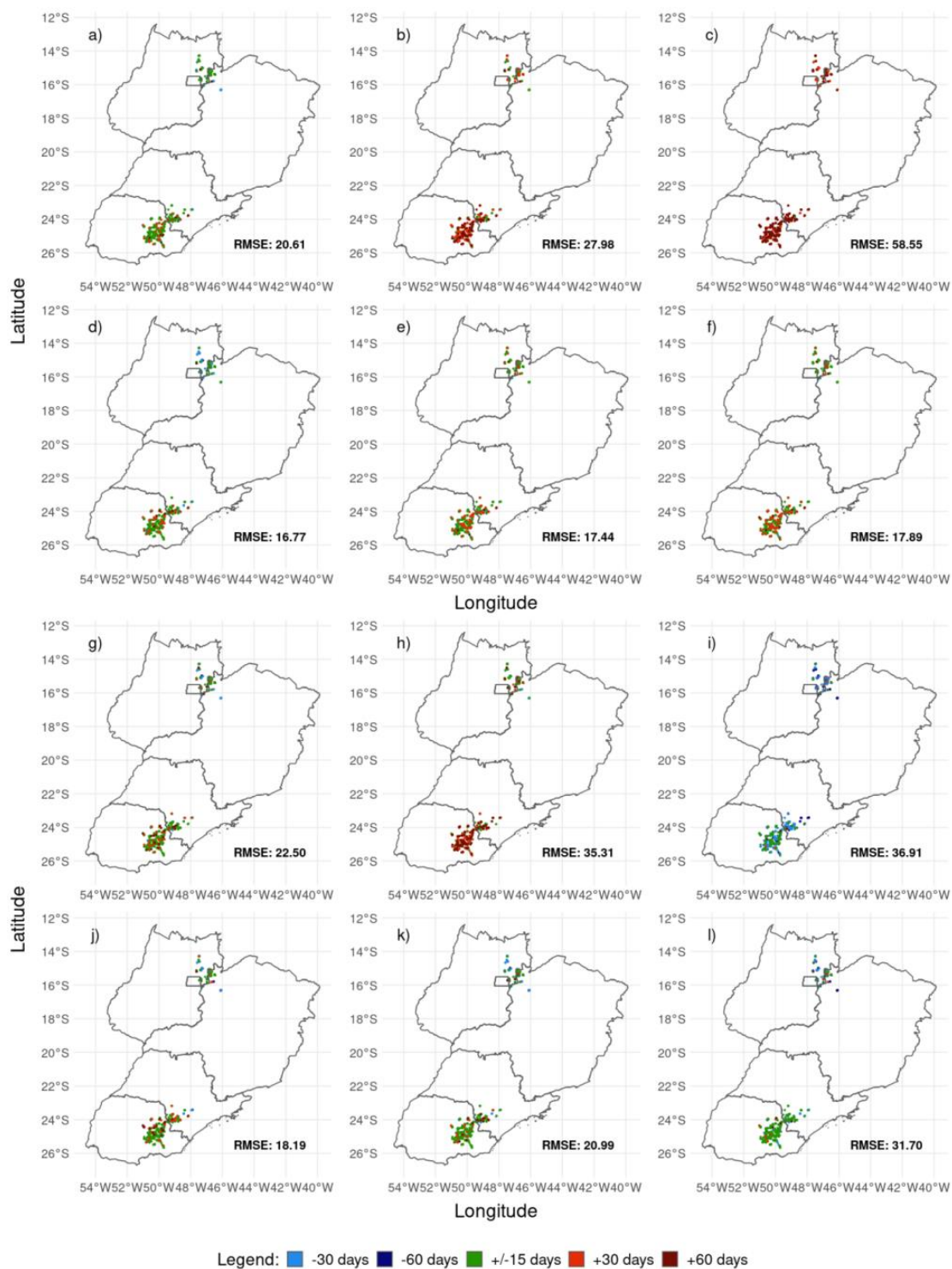
Figure S7 - Spatial pattern of the difference between observed and estimated sowing date (a,b,c,d,e, f) and harvest dates (g,h,i,j,k, l) estimated by the different packages tested for MOD09 EVI2. Where, CropPhenology (a, g), DEA tools (b,h), greenbrown (c,i), phenofit (d,j), Phenex (e,k) and TIMESAT (f,l). Root meant square error (RMSE) is in days.
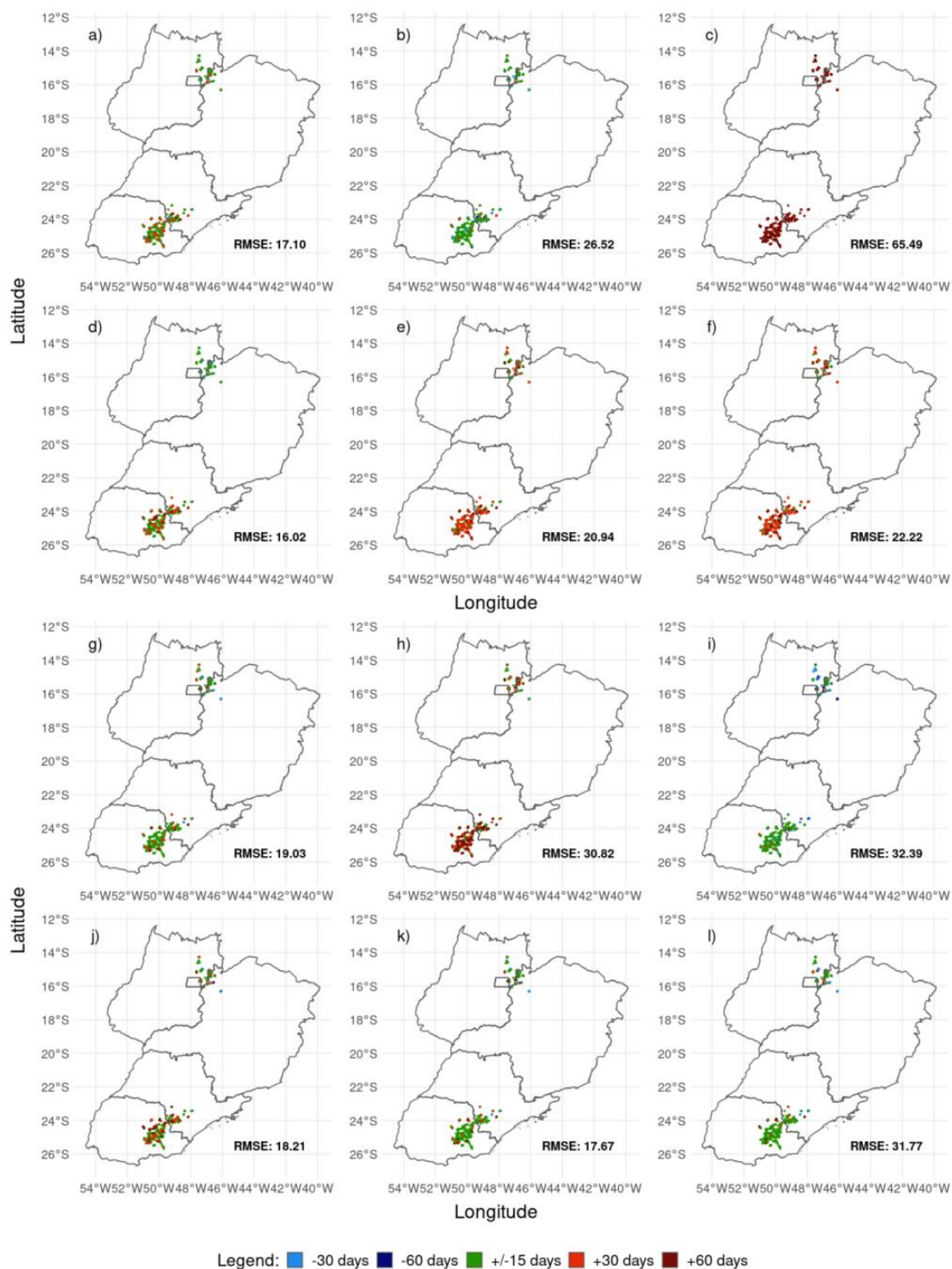
Figure S8 - Spatial pattern of the difference between observed and estimated sowing date (a,b,c,d,e, f) and harvest dates (g,h,i,j,k, l) estimated by the different packages tested for MOD13 EVI2. Where, CropPhenology (a, g), DEA tools (b,h), greenbrown (c,i), phenofit (d,j), Phenex (e,k) and TIMESAT (f,l). Root meant square error (RMSE) is in days.

Figure S9 - Spatial pattern of the difference between observed and estimated sowing date (a,b,c,d,e, f) and harvest dates (g,h,i,j,k, l) estimated by the different packages tested for Sentinel-2 EVI2. Where, CropPhenology (a, g), DEA tools (b,h), greenbrown (c,i), phenofit (d,j), Phenex (e,k) and TIMESAT (f,l). Root meant square error (RMSE) is in days.
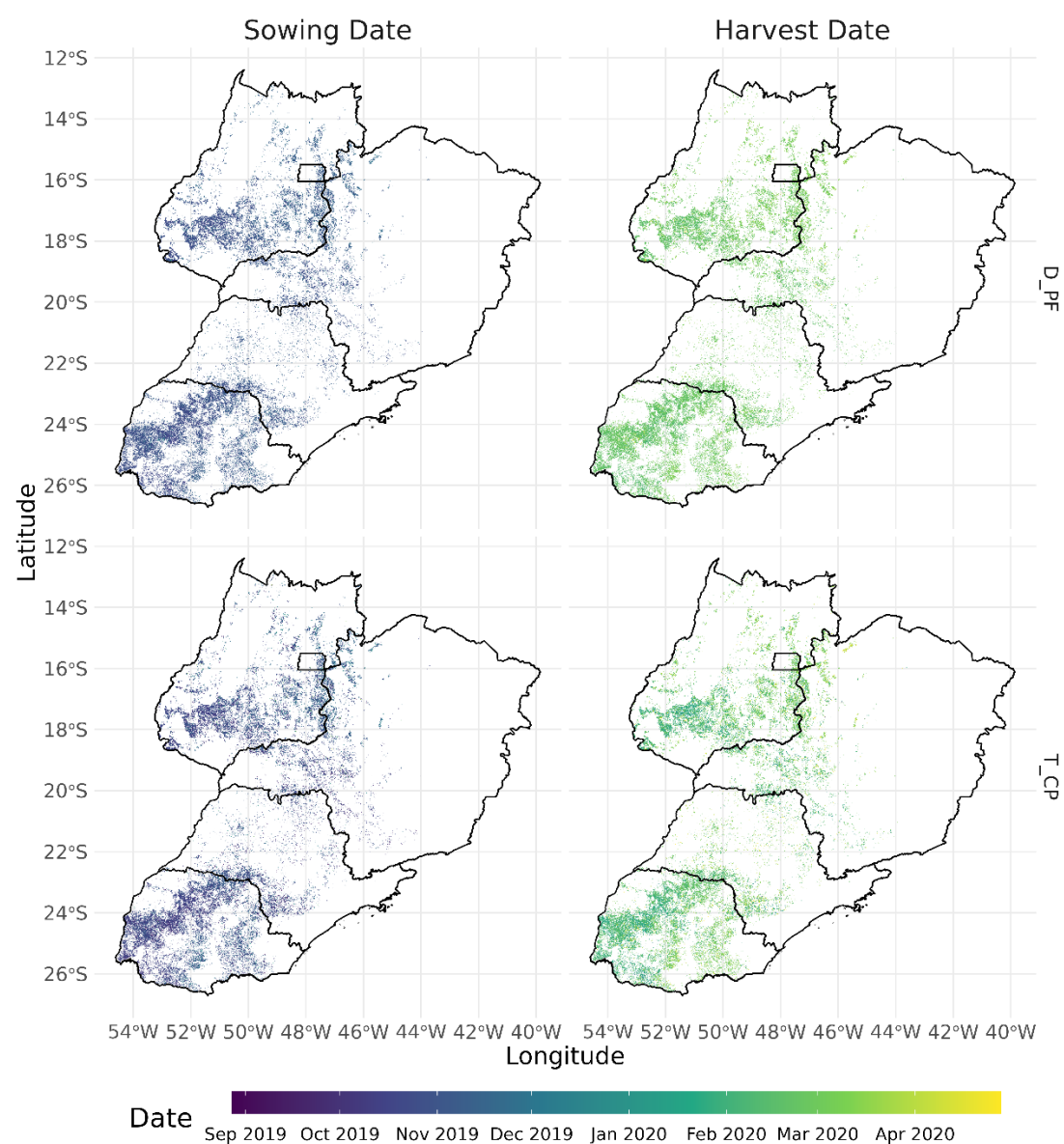
Figure S10 – Sowing and harvest dates estimates made using the CropPhenology (T_CP, threshold method) and phenofit (D_PF, derivative method) packages.
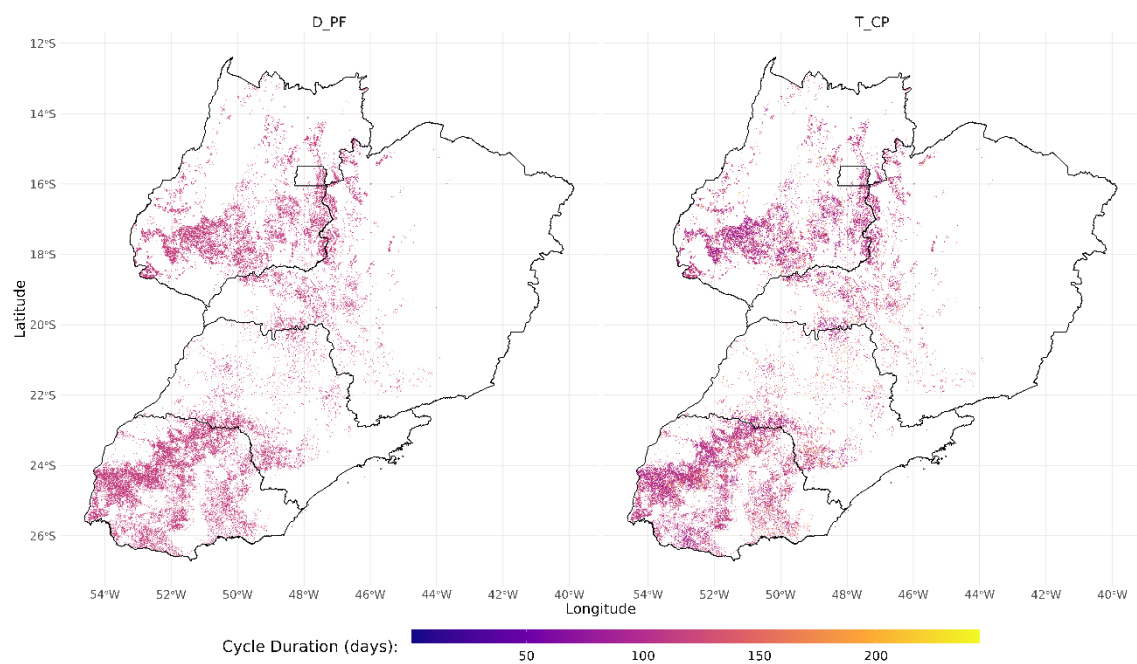
Figure S11 – Cycle duration estimated using the CropPhenology (T_CP, threshold method) and phenofit (D_PF, derivative method) packages.