

Supplementary materials for manuscript "PhenoRice: a method for automatic extraction of spatio-temporal information on rice crops using satellite data time series"

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Analysis of factors affecting Phenorice's crop detection

Table S 1: Sites characteristics vs detection accuracy

Case study	Target homogeneity*	Time series quality during rice seasons**	Contrast with surrounding environment	OA [%]	PA [%]
IT	High	High	Medium	80	70
IND	Low	Medium	Low	71	60
PHL-DS	High	High	High	80	75
PHL-WS	Medium-high	Low	Low	80	60

Table S1 summarizes the characteristics of the three sites and their effect on detection accuracy. In summary, PhenoRice detection performance is related to target homogeneity, data quality and contrast with the surrounding environment. The results during the wet season in the tropics are comparable to the other less challenging situations, demonstrating that the method can be used in a tropical context which reflects much of the world's rice growing areas. Site fragmentation, as expected, is an important factor in reducing algorithm detection capability.

* Opposite of fragmentation; ** Function of cloud contamination

Characteristics of rice cropping systems analysed and field data available for the production of HR reference maps

Table S 2: Characteristics of the datasets used for validation of the HR maps used as reference

Site	Thematic layer	Monitoring / Validation sites	Information collected	Time window of field surveys (Start – End)	Number and frequency of the observations	Farm/Field size	Method used for production of reference HR map	Reference
ITA	Crop establishment dates map	6 areas of about 2 x 2 Km: Rice fields: 1200 Non-rice fields: 291	Field status; Photos; Soil/water (Classes: dry soil, wet soil, partially flooded and fully flooded); Crop stages (Classes: absent, BBCH 11-15; BBCH 16-29)	05/04/2013 – 07/07/2013	Average of 8 observations (Weekly time step) from start of flooding to maximum tillering	Avg. farm size: 50 ha Avg. field size: 3.3 ha (Min 0.7 – Max 7.4 ha)	Map produced by GIS analysis exploiting available field boundaries and observation - Output: 10 m spatial resolution	Ranghetti et al. 2016
	Rice map		Map derived from annual official declarations provided by farmers					ERSAF, 2013 Regione Piemonte, 2011
PHL	Crop establishment dates map	DS: 33 monitored paddy fields; WS: 33 monitored paddy fields	Field status; Photos; Weather conditions; Soil/Water (Classes: plowed, harrowed, levelled, flooded*, saturated); Crop establishment*; Growth stage *Actual dates of flooding and transplanting were acquired through interviews with farmers.	DS: 6/12/2012 – 13/04/2013 WS: 02/05/2013 – 23/09/2013	DS: 7 visits every 16 days WS: 6 visits every 11 days (In correspondence with SAR acquisitions)	Avg. farm size: 1.94 ha Avg. rice area per farm: WS: 1.22 ha DS: 1.32 ha	SAR multitemporal processing - Output: DS: 30m spatial resolution WS: 18.5m spatial resolution	Asilo et al. (2014)
	Rice map	253 validation sites Rice: 194 Non-rice: 59	Cultivated crop					
IND	Crop establishment dates map	20 monitored paddy fields	Field status; Photos; Weather conditions; Plant height; Water depth; Crop stage; Leaf Area Index	16/08/2013 – 23/12/2013	8 visits every 16 days (In correspondence with SAR acquisitions)	Avg. farm size (by district): Ariyalur: 0.58 ha; Nagapattinam: 0.86 ha; Thanjavur: 0.72 ha; Thiruvapur: 0.92 ha	SAR multitemporal processing - Output 3m spatial resolution map	Pazhanivelan et al. (2015); Nelson et al. (2014)
	Rice map	102 validation sites Rice: 60; Non-rice: 42	Cultivated crop					

Analysis of factors affecting Phenorice's crop detection

Detection rate as a function of rice presence

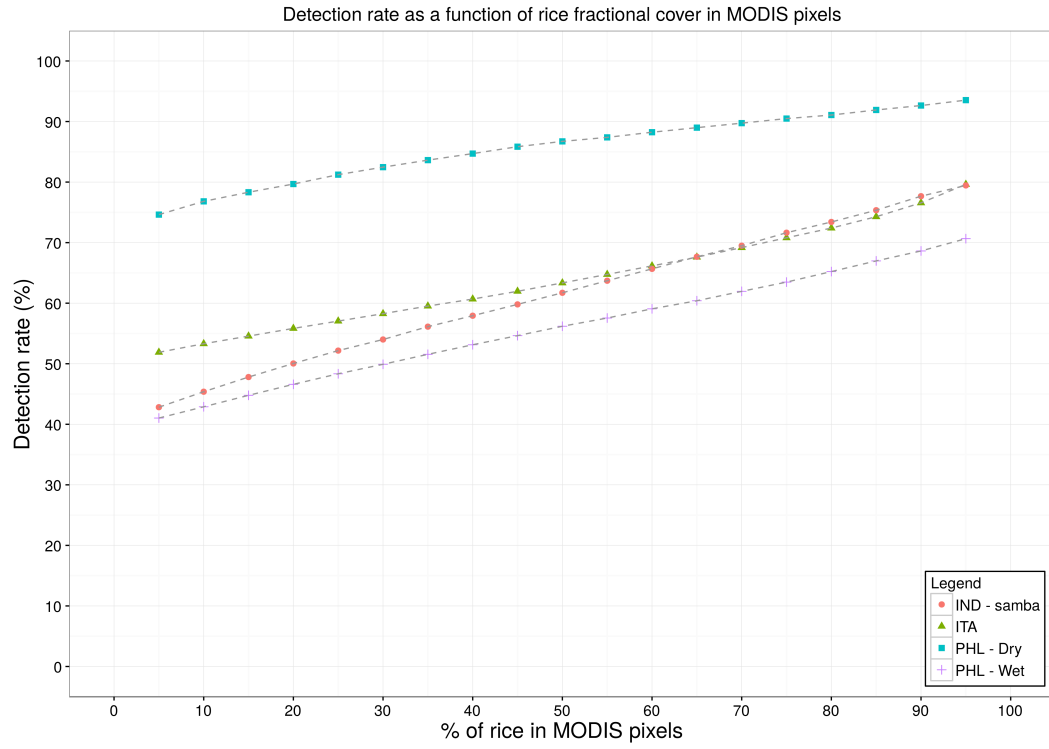


Figure S 1: Detection rate vs percentage of rice surface in MODIS pixels for ITA, IND, PHL-WS and PHL-DS. Points represent the ratio between the number of pixels detected by PhenoRice as rice, and the total number of MODIS pixels with a rice fractional cover above a certain percentage (i.e., producer's accuracy).

Target fragmentation in the different sites and its relationships with detection accuracy

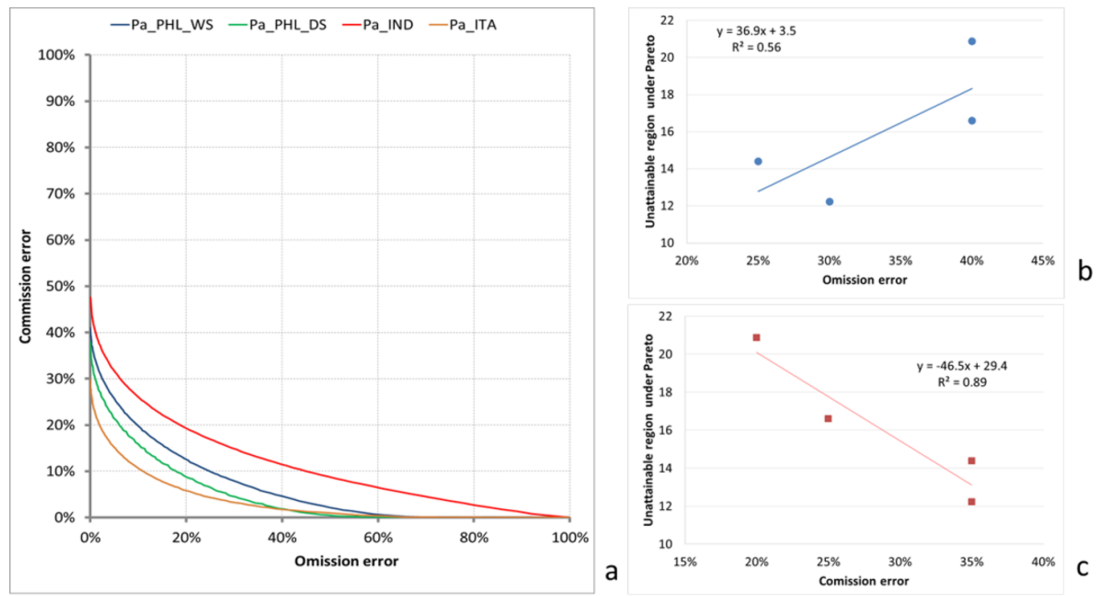


Figure S 2: a) Pareto Boundary in the Commission Error (CE) – Omission Error (OE) space for PHL-WS, PHL-DS, IND and ITA. The region under the Pareto Boundary is the unattainable accuracy region due to low resolution bias as a function of MODIS data resolution and target fragmentation (Boschetti et al., 2004). b,c) relation between omission and commission errors and "unattainable area under the curve".

Cloud contamination in the different sites and seasons

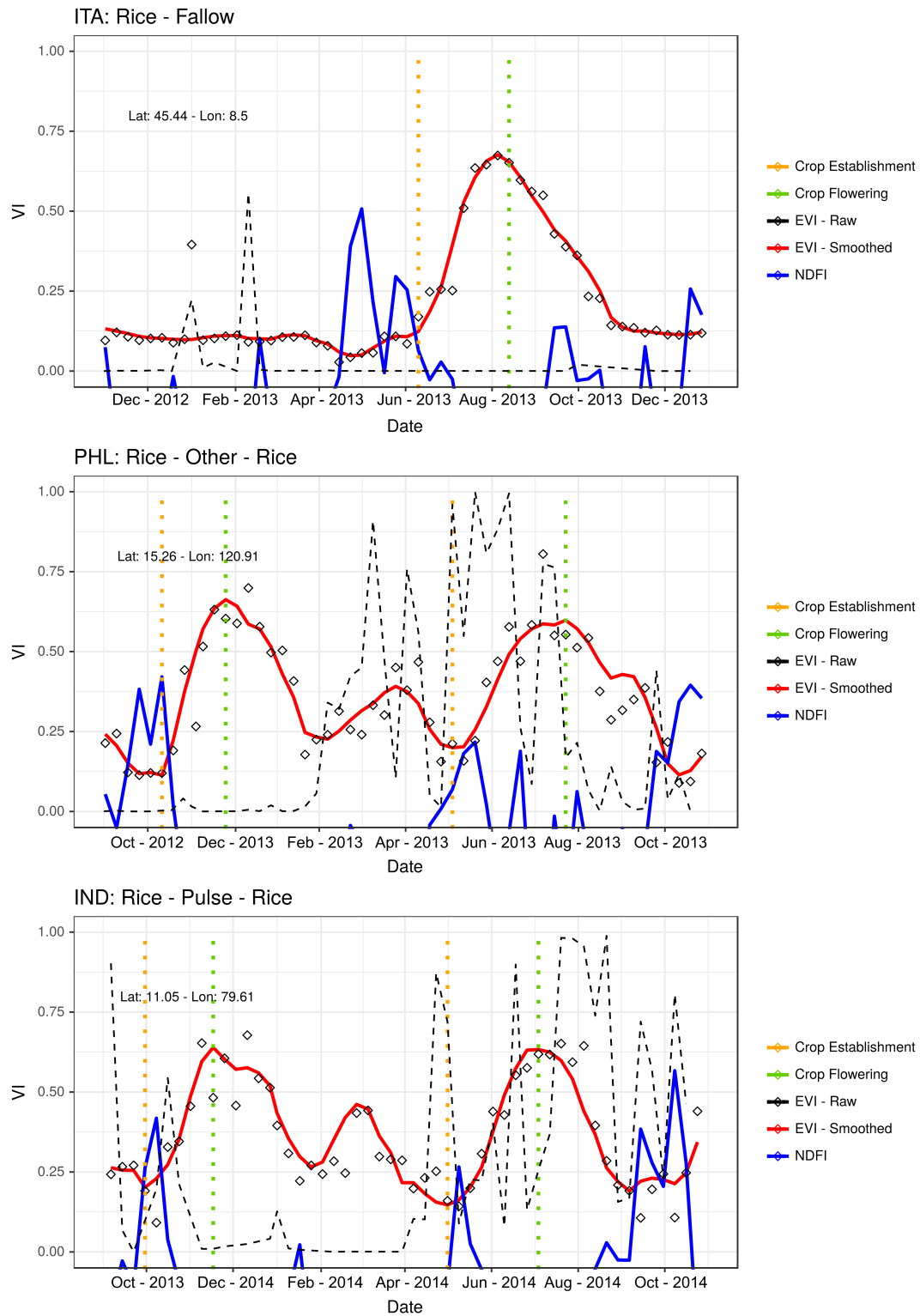


Figure S 3: Analysis of cloud contamination in the different sites (Top panel ITA, centre panel PHL and bottom panel IND year 2014) and seasons (in the tropics, the dry season is from November to April and the wet season is from June to October). The black dashed line represent the fraction of cloud contaminated pixels for the entire analysed area for the different dates of composite.

Figures S1, S2 and S3 shows different aspect to be considered in the interpretation and assessment of PhenoRice results and algorithm performance. Figure S1 shows how the algorithm provides similar results in relation to rice presence in the pixel for PHL-WS, ITA and IND. PHL-DS (blue dots) shows a better detection rate for lower rice presence due to a stronger contrast between flooded fields and the surrounding landscape in dry season. Figure S2 supports the interpretation on how algorithm performance is related to target fragmentation (panels b and c). The IND case study is more challenging, showing a larger unattainable region under the Pareto boundary, where omission errors higher than 80% are still part of the optimal achievable accuracy. The other sites have a comparable fragmentation level, as shown by the Pareto curves. The rice cultivated area in PHL-DS (which relies on medium and large scale irrigation) is more compact and less fragmented than PHL-WS (which is a mixture of rainfed and irrigated area). The unattainable area under the Pareto curves is correlated with the obtained omission (Figure S2b) and commission errors (panel c), confirming the impact of target fragmentation on achievable accuracy. Figure S3 indicates the timing, duration and pervasiveness of cloud contamination in the different test sites and seasons. As expected, the ITA case study, where rice is grown in the summer in a temperate climate, and the PHL-WS, where rice is grown in the tropical monsoon season, represent the best and worst condition respectively. Cloud contamination is not so strong during the dry season in the tropics, (IND and PHL-DS).

Comparing crop establishment date maps (MODIS against very high resolution) for PHL-DS and WS

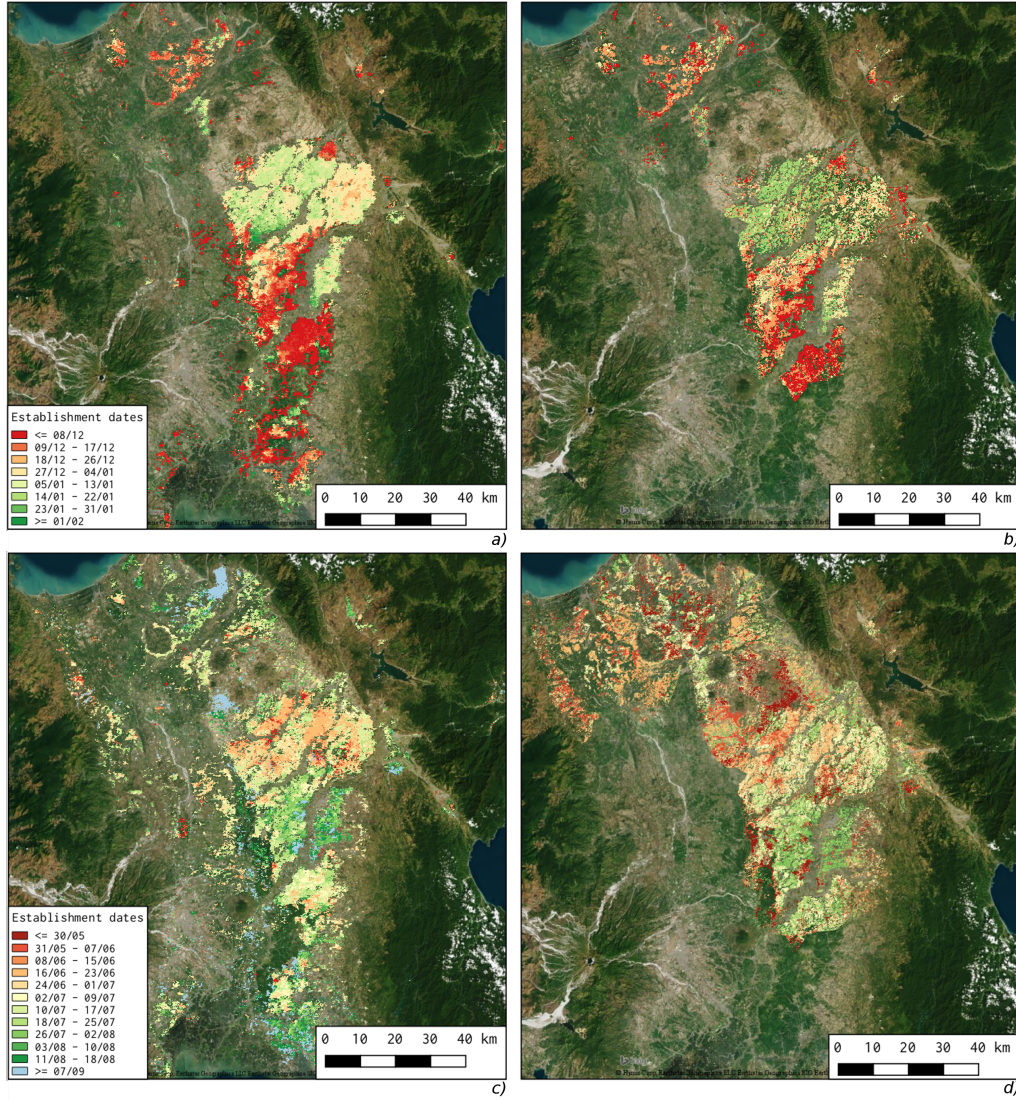


Figure S 4: Visual comparison between crop establishment maps derived by PhenoRice from MODIS data (a and c) in the PHL study site, and those derived from VHR SAR data (b and d). Top and bottom panels correspond to the DS and WS seasons, respectively

Analysis of the relation between date of crop establishment, flowering and length of vegetative and reproductive phases

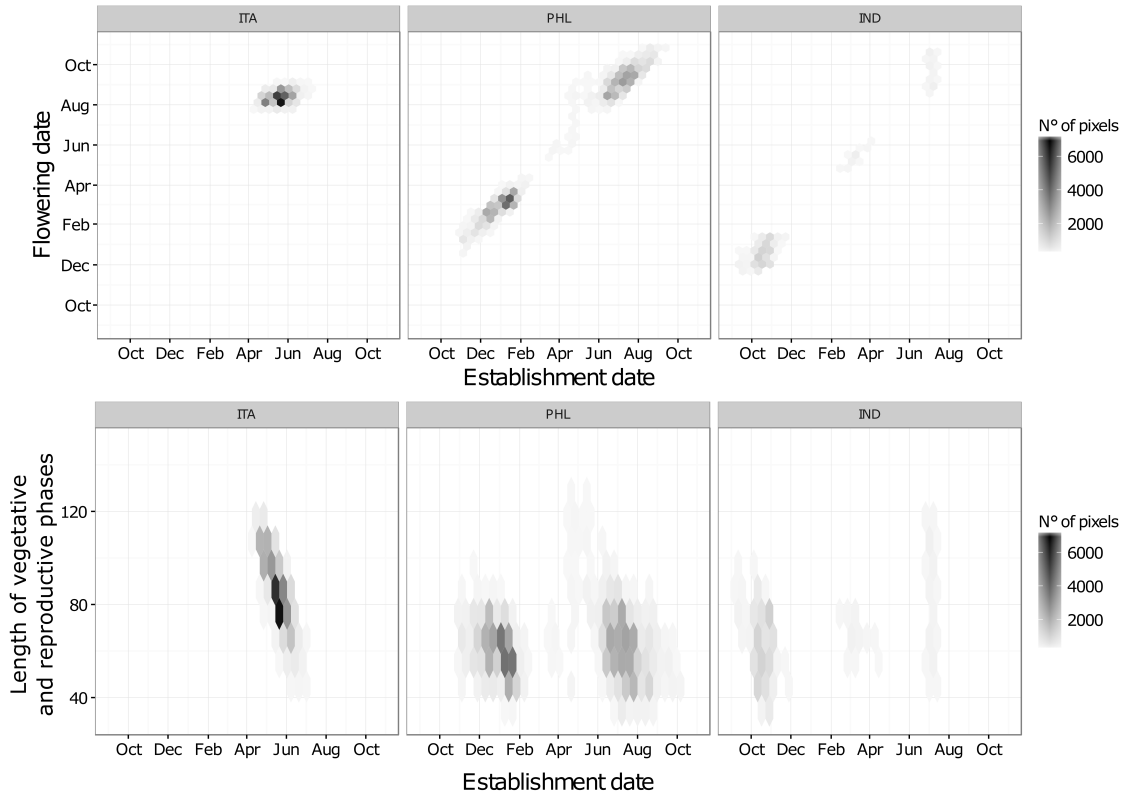


Figure S 5: Relationship between crop establishment dates, flowering dates and length of vegetative season in the three case studies (The shade of grey of the different hexagons depends on the number of MODIS pixels for which the estimated establishment and flowering dates (or establishment and length of season) couples fall in the area of the hexagon).

Figure S5 shows a visual analysis of the relationship between PhenoRice estimates of flowering dates vs. crop establishment dates (top panel), and of length of vegetative phase vs crop establishment dates (bottom panel). IND and PHL are tropical cropping systems and are characterised by multiple seasons and a wide spread of crop establishment dates due to climatic conditions being favourable for rice cultivation almost all year, so that sowing is mostly influenced by water availability and management choices (e.g. crop rotation). This means that flowering dates are well correlated with crop establishment dates while there is little relationship between crop establishment dates and the length of the vegetative season. On the other hand, flowering dates in ITA are concentrated in a short period, irrespective of the crop establishment date while a strong correlation exists between crop establishment and length of the vegetative season. This is because varieties with both medium and long growth durations are sown in Mediterranean countries. In Italy traditional long cycle varieties are established in April, while shorter cycle varieties are sown later due to the relatively short favourable period for rice cultivation. Both variety groups reach maturity at the same time in mid-summer, leading to the observed correlation between sowing date and vegetative phase length. PhenoRice outputs are able to highlight the different characteristics of each agro-ecosystem.

Examples of interannual analyses of crop establishment and flowering dates – the case of Northern Italy

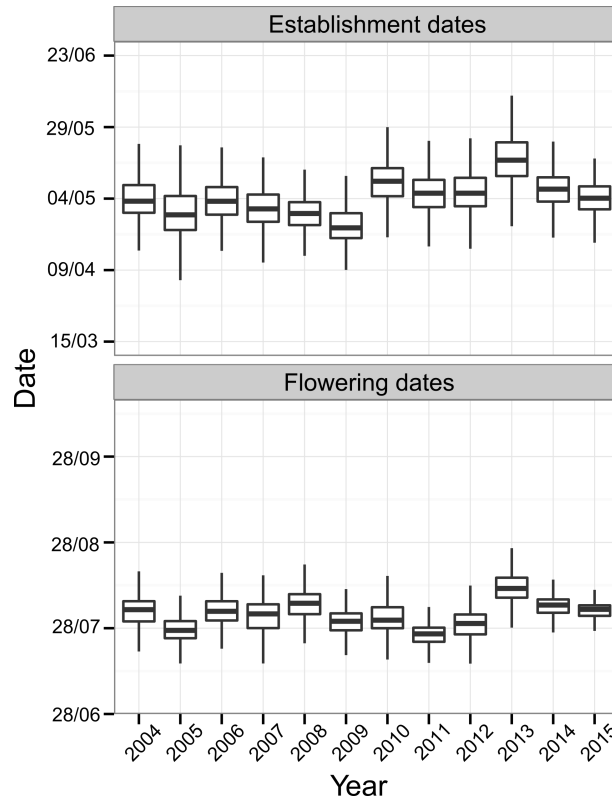


Figure S 6: Statistical distribution of crop establishment (sowing – top panel) and flowering (bottom panel) dates estimated by PhenoRice for the period 2004-2015 in the north of Italy.

Figure 6 shows box-plots representing the statistical distribution of crop establishment and flowering dates for the Italian study area derived by applying the PhenoRice algorithm on the 2004-2015 period in the framework of the ERMES project. (<http://www.ermes-fp7space.eu/en/result-ach/ermes-first-results-phenological-mapping/>). Sowing dates estimates were found to be reasonable according to local knowledge about common agro-practices. The slight delay of sowing depicted on the last years (from end of april/beginning of may to mid of may) is in agreement with recent changes in cultivated varieties and management practices, with short cycle, high yielding varieties that sown later in the season on the increase. It is also interesting to notice how year 2013 shows an anomalous delay in sowing dates. This result is in agreement with the agronomic report for the season, which was characterised by atypically strong and continuous rain events in spring (Camera di Commercio di Pavia, 2013). In this condition, farmers had to postpone field preparation for sowing. These results confirm the potential of PhenoRice for district level interannual analysis to monitor changes in agro-practices and critical anomalous events.