SUPPLEMENTARY MATERIAL

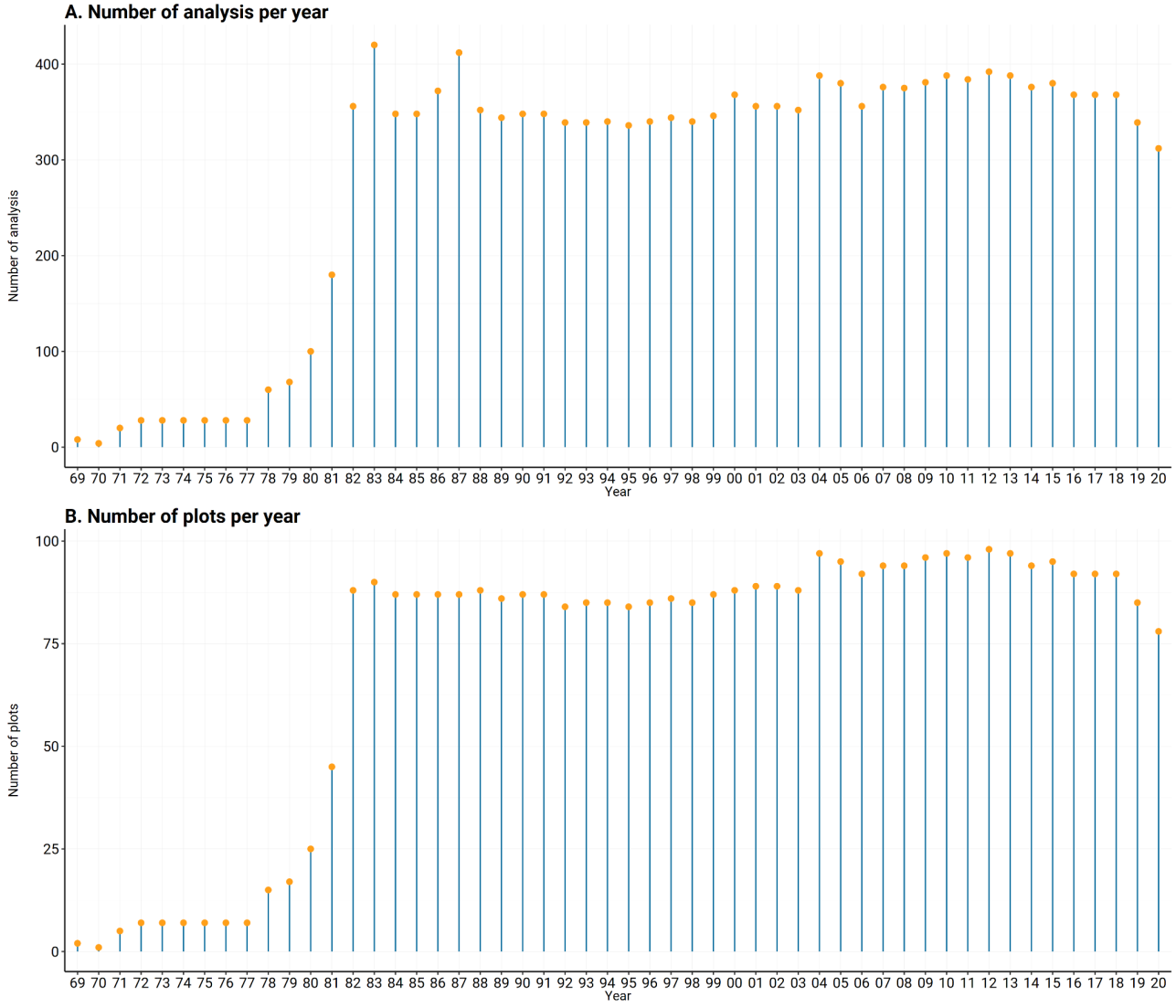


Figure 1SM. Overview of the Grenache maturity database.

A) Number of grape analyses per year; B) Number of plots sampled per year

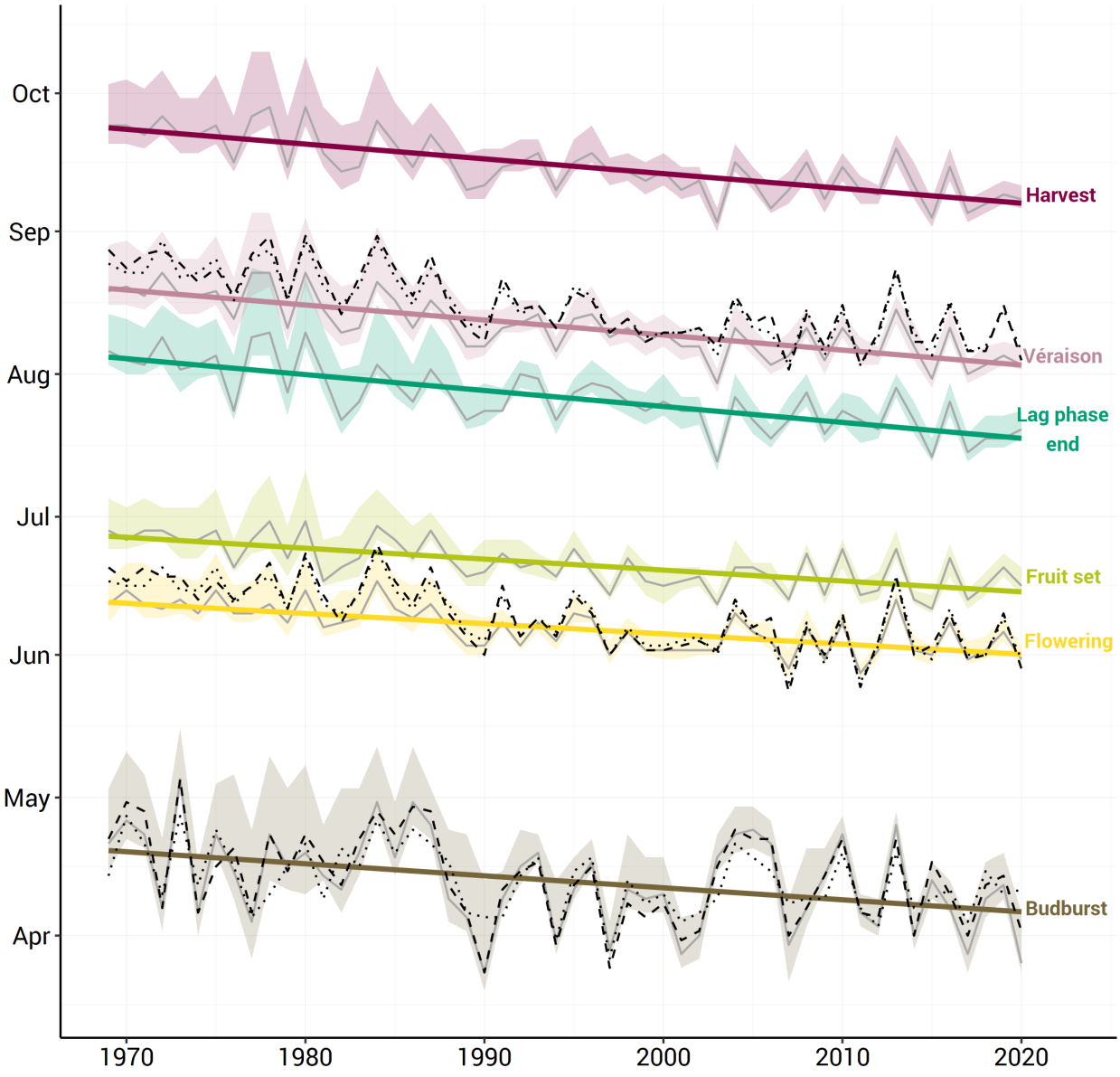
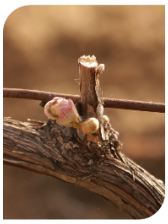


Figure 2SM. Comparison of process-based phenological models.

Bold lines are linear regressions for phenological stages calculated for each SAFRAN grid cell. The shaded area represents the interval between the 1st and the 9th decile. Grey line is the median of the model used in this study. Dotted line is Morales *et al.* (2020) model, dashed line is BRIN model (García de Cortázar-Atauri *et al.*, 2009a).

Process-based phenological models








Budbreak *Flowering* *Fruit set* *Lag-phase end* *Veraison* *Harvest*

Model name T0 = starting day of model GDD (Growing Day Degree) = Temperature threshold used for model calculation	GDD5 model T0 = Jan 1st GDD = 5°C	GFV model T0 = March 1st GDD = 0°C	T0 = GFV Flowering GDD = 10°C	T0 = GFV Flowering GDD = 10°C	GFV model T0 = March 1st GDD = 0°C	T0 = GFV Veraison
	Grenache Budbreak = 321.3°C	Grenache Flowering = 1269°C	Grenache Fruit set = 133°C	Grenache Lag-phase end = 600°C	Grenache Veraison = 2750°C	Grenache Harvest =Veraison + 35 days
Reference	García de Cortázar-Atauri *et al*., 2009a	Parker *et al*., 2011, 2013	García de Cortázar-Atauri *et al*., 2009a	Ojeda *et al*, 1999 García de Cortázar-Atauri *et al*., 2009a	*Parker et al. (2011)*	

Figure 3SM. Stages and phenological models used in the study.

Table 1SM. Summary of regressions

		Slope ±95 % CI (P-value) *** p<0.001; ** p<0.01; * p<0.05		Increase or decrease over 50 years	
Simulated phenology		***days / year evolution***		***days over 50 years evolution***	
Budburst	*BBCH 07 date*	-0.315 ± 0.02 ***		-15,8	
Flowering	*BBCH 65 date*	-0.236 ± 0.01 ***		-11,8	
Fruit set	*BBCH 71 date*	-0.267 ± 0.01 ***		-13,4	
Lag phase end	*BBCH 77 date*	-0.389 ± 0.01 ***		-19,4	
Véraison	*BBCH 85 date*	-0.365 ± 0.01 ***		-18,3	
Harvest	*BBCH 85 + 35 days*	-0.365 ± 0.01 ***		-18,3	
Climatics		***value / year evolution***		***value over 50 years evolution***	
	per period	**Bud-Flow**	**Flow-Harv**	**Bud-Flow**	**Flow-Harv**
mint	*minimal daily temperature (°C)*	+0.013 ± 0.00 ***	+0.062 ± 0.00 ***	+0,67	+3,1
maxt	*maximal daily temperature (°C)*	+0.017 ± 0.00 ***	+0.058 ± 0.00 ***	+0,83	+2,9
meant	*mean daily temperature (°C)*	+0.012 ± 0.00 ***	+0.059 ± 0.00 ***	+0,62	+2,95
ranget	*thermal amplitude (°C)*	+0.003 ± 0.00 *	-0.0036 ± 0.0015 *	+0,17	-0,18
sumsorad	*cumulated daily radiation (J/cm²)*	+387.8 ± 21.5 ***	+459.4 ± 15.8 ***	+19387	+22972
sumwd	*sum of water deficit (ETP-rainfall)*	-1.25 ± 0.11 ***	-3.47 ± 0.18 ***	-63	-173
rainsum	*rain cumulation (mm)*	-0.323 ± 0.09 ***	-1.024 ± 0.13 ***	-16	-51
raifreq	*frequency (%) of rainy days (>0mm)*	+0.027 ± 0.00 *	+0.002 ± 0.01	+1,4	+0,1
phalen	*phase length (number of days)*	+0.079 ± 0.012 ***	-0.129 ± 0.01 ***	+4,0	-6,4
cdaystmin	*number of cold days (<0°C)*	+0.0006 ± 0.00 **	not computed	+0,03	
cfreqtmin	*frequency (%) of cold days (<0°C)*	+0.0008 ± 0.00 *	not computed	+0,04	
hwindfreq	*frequency (%) of windy days (>5.28m/s)*	-0.034 ± 0.02 *	-0.095 ± 0.02 ***	-1,7	-4,8
wetfreq	*frequency (%) of wet days (relative humidity>60%)*	-0.204 ± 0.02 ***	-0.6675 ± 0.02 ***	-10,2	-33,4
hsdays	*number of heat stress days (tmax>35°C)*	not computed	+0.076 ± 0.02 ***		+3,8
xhsdays	*number of heat stress days (tmax>40°C)*	not computed	+0.002 ± 0.00 ***		+0,1
hsfreq	*frequency (%) of heat stress days (tmax>35°C)*	not computed	+0.079 ± 0.01 ***		+4,0
Maturity		***value at harvest / year evolution***		***value at harvest over 50 years evolution***	
Alcohol	*%vol.*	+0.052 ± 0.002 ***		2,6	
Total Acidity	*g H_2SO_4/L*	-0.026 ± 0.001 ***		-1,3	
pH		+0.006 ± 0.000 ***		+0,28	
200-berry weight	*g*	-1.72 ± 0.08 ***		-86	

All the climate variables are from the SAFRAN MétéoFrance Database. ETP = daily evapotranspiration (mm) calculated with the FAO formula (Allen *et al*., 1998); Date = the day of the year of the simulated phenological stage (DOY). Empty cells mean that indicators were not calculated because they were not relevant.

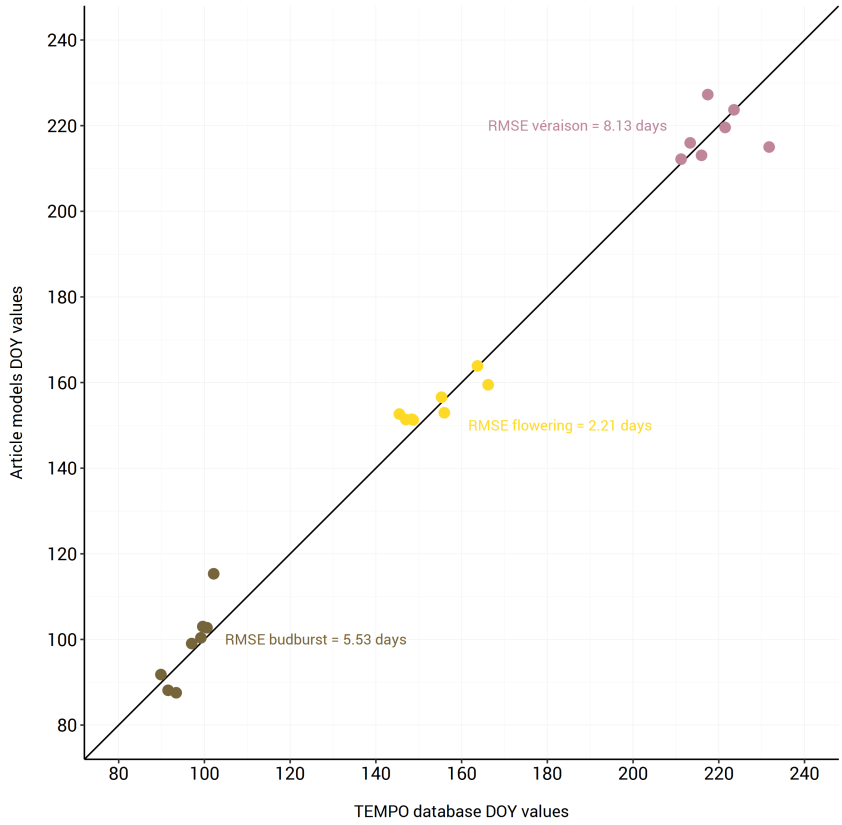


Figure 4SM. Phenological stages calculated using process-based models vs observed dates database: Root Mean Square Error calculation

Real dates of phenological stages used to do the comparison are from the TEMPO database (https://data.pheno.fr/). These data were not used for the original model calibration. The data extracted from the TEMPO portal cover the period 2013-2020 and comprise the stages of budburst (349 observations of BBCH 7 and 9), flowering (1569 observations of BBCH 61-67) and véraison (1069 observations of BBCH 85). From the TEMPO portal, it was not possible to characterise the variety (only *Vitis vinifera* could be identified). In order to evaluate the process-based model, the mean phenological stages for each year was calculated using the simulated date from the study (averaging all the data from the grids) and the observed data from the TEMPO portal (averaging all the data from the same area). This figure compares these means values (simulated and observed data) for each year. The results show that the model has a high capacity to represent the different years for all the stages. As expected, the model provides a very good result for flowering, a less favourable result for véraison, and a very good result for budburst (better than in previous articles exploring budburst models).

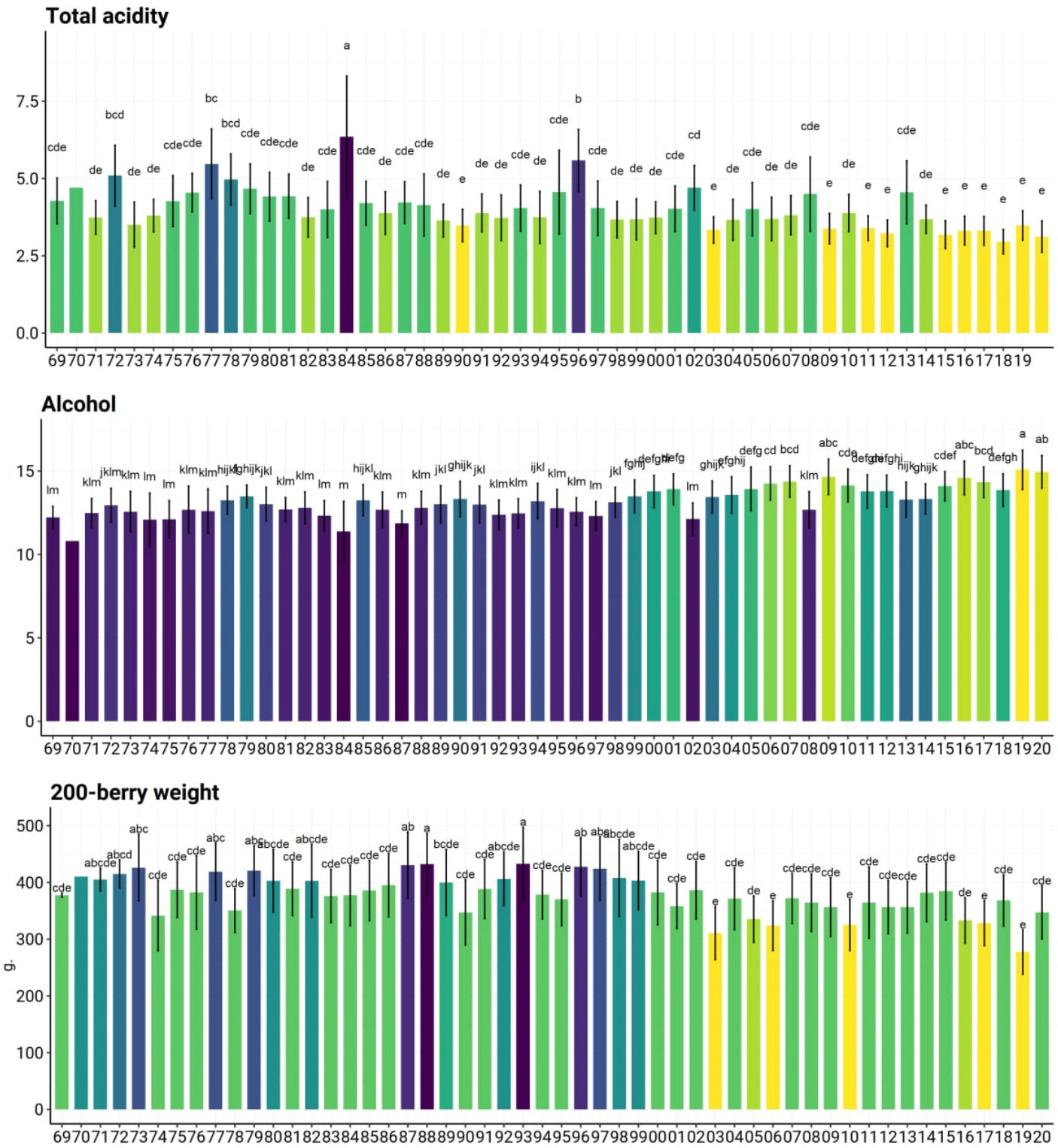


Figure 5SM. Grenache maturity values at harvest

Multiple comparison of years by calculating the means of Least Significant Difference and grouping of years. Alpha = 0.05, p-adjust = Bonferroni

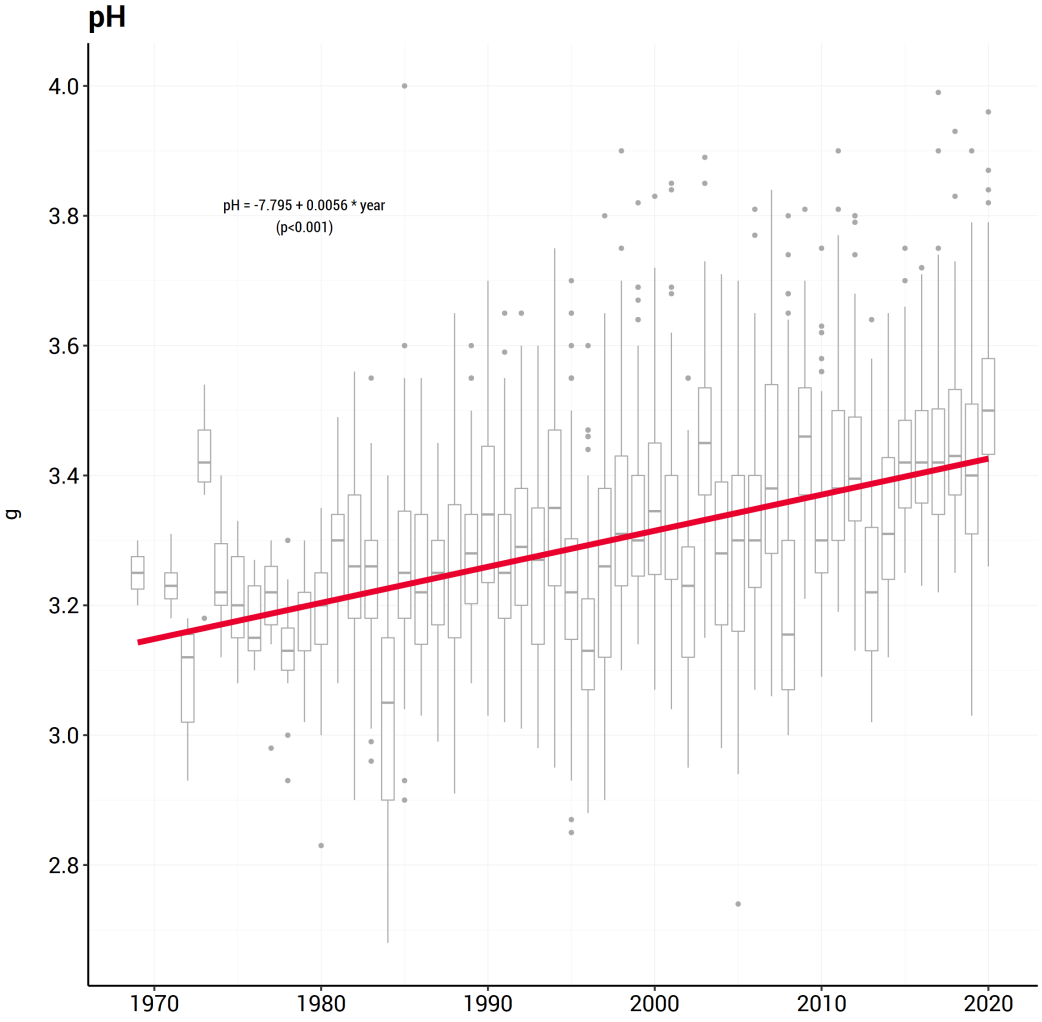


Figure 6SM. Changes in pH for Grenache in the southern Rhône valley from 1969 to 2020

Box-plots show the distribution of the data: the line in the middle of the box is the median value of the dataset, the box delimits 25 and 75 % quantiles. The grey dots are outlier values. The red line represents the linear regression applied to the whole maturity-at-harvest pH dataset.

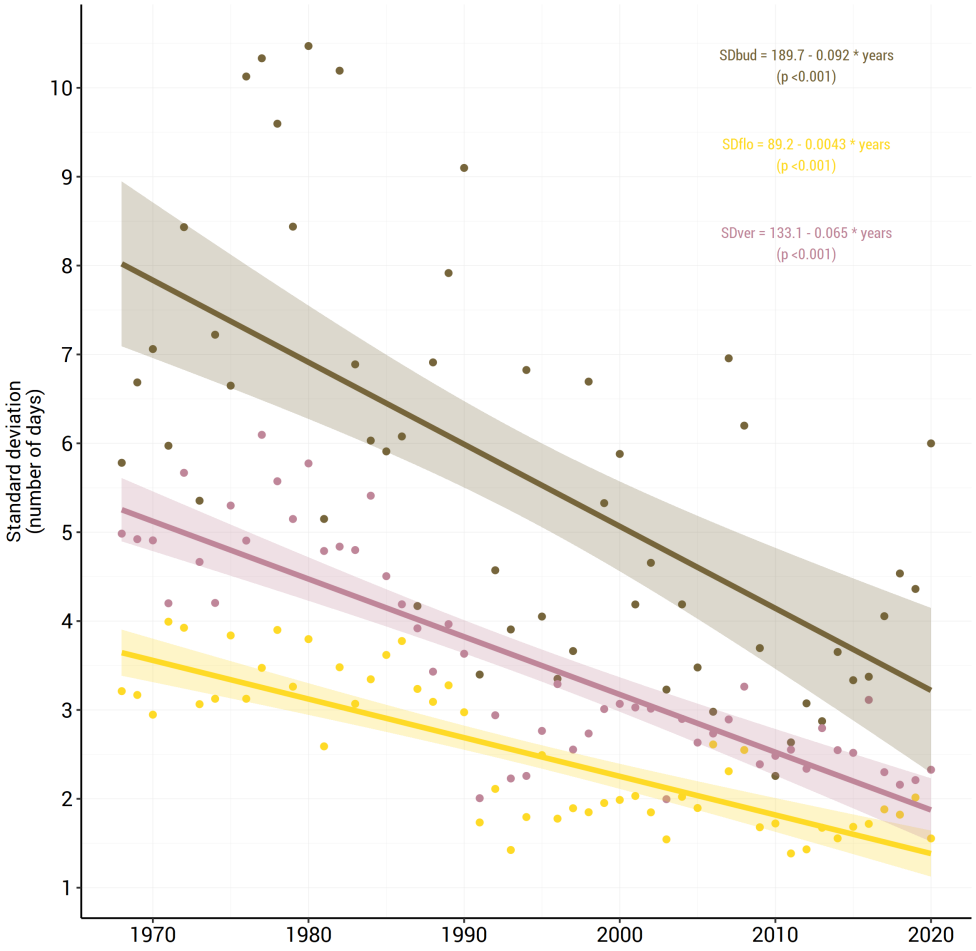


Figure 7SM. Calculated main stages Budburst, Flowering, Véraison: standard deviation between spatial cells

The dates (day-of-year) of the stages calculated for each grid cell are aggregated according to year and the standard deviation was calculated. A significant decrease in date differences between grid cells can be observed for budbreak, flowering and véraison.

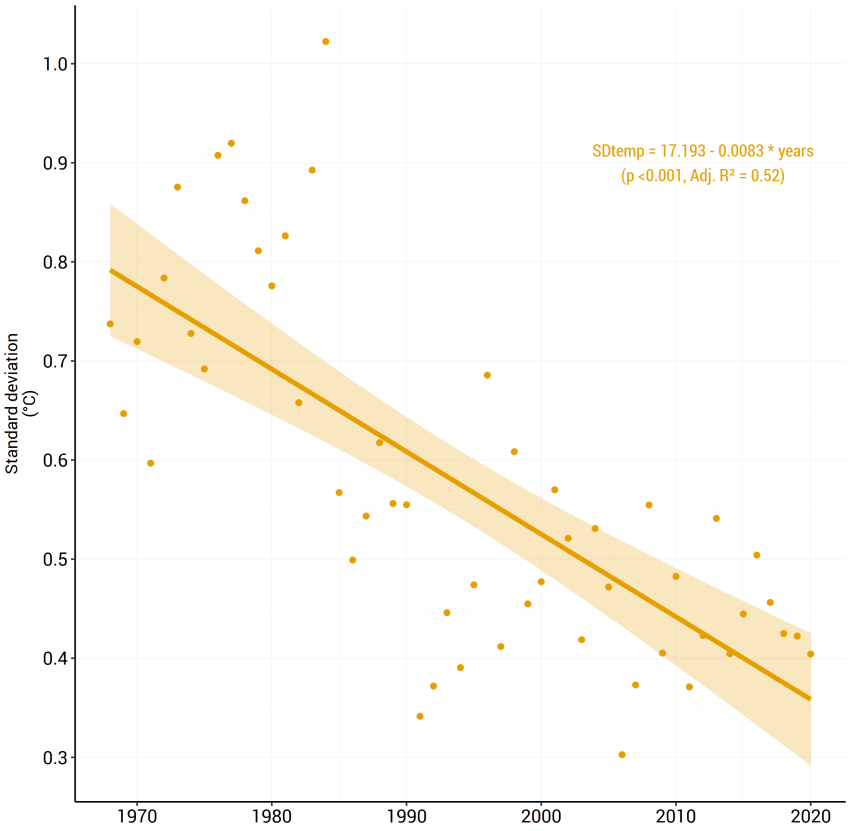


Figure 8SM. Mean temperature during the flowering-to-harvest phase: standard deviation between spatial cells

The mean temperatures (°C) of the flowering-to-harvest phase for each grid cell were aggregated according to year and the standard deviation was calculated. A significant decrease in temperature differences between grid cells can be observed.

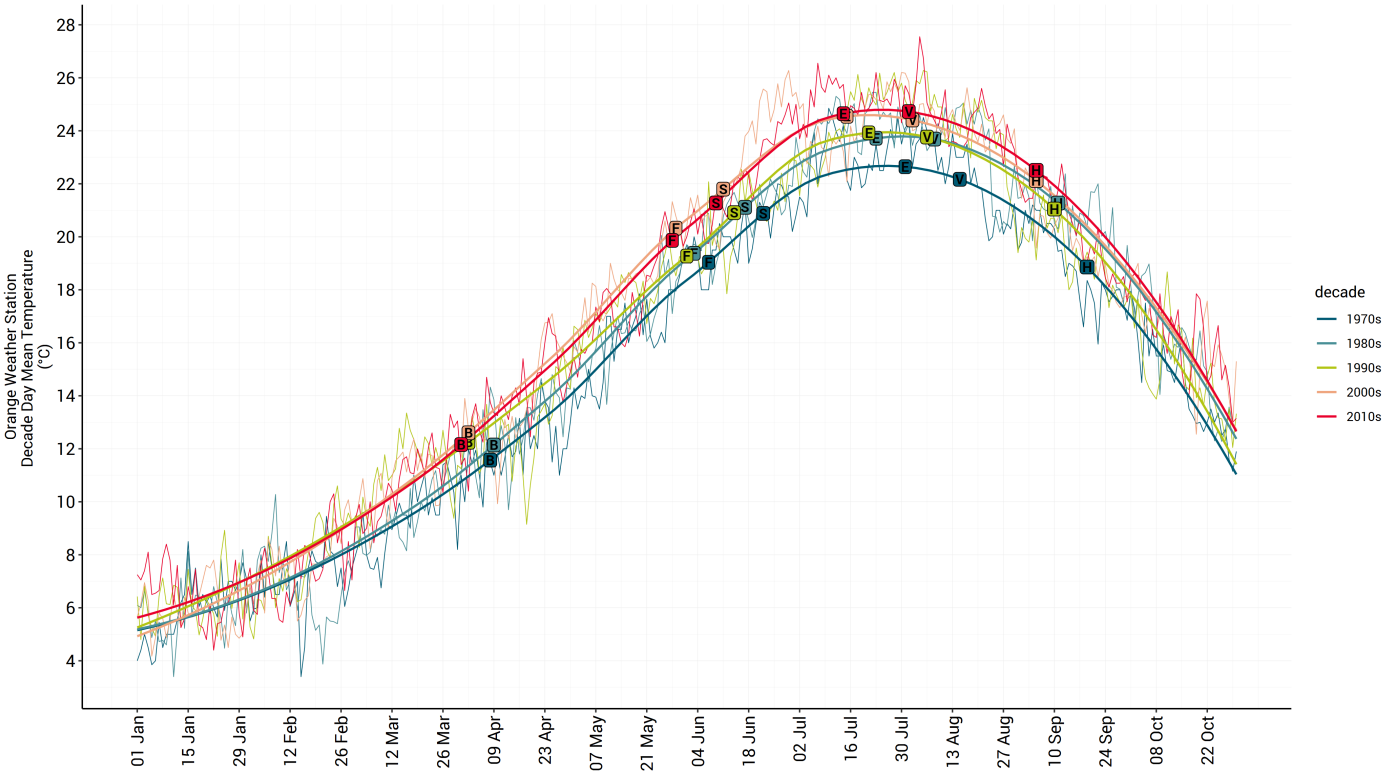


Figure 9SM. Mean temperatures per decade in Orange, France, 1969-2020. Orange-Caritat station (data from Climatik - AgroClim – INRAE)

The daily mean temperatures of the Orange weather station are aggregated according to decade. The thin curves correspond to the raw values of the aggregations obtained (decade fay mean temperature), the thicker curves correspond to the values smoothed by local polynomial regression (loess, with span = 1). Initials indicate the calculated dates for the main phenological stages (decade mean). B = Burdburst; F = Flowering; S = Fruit set; E = End of lag phase of herbaceous berry growth; V = Véraison; H = Harvest

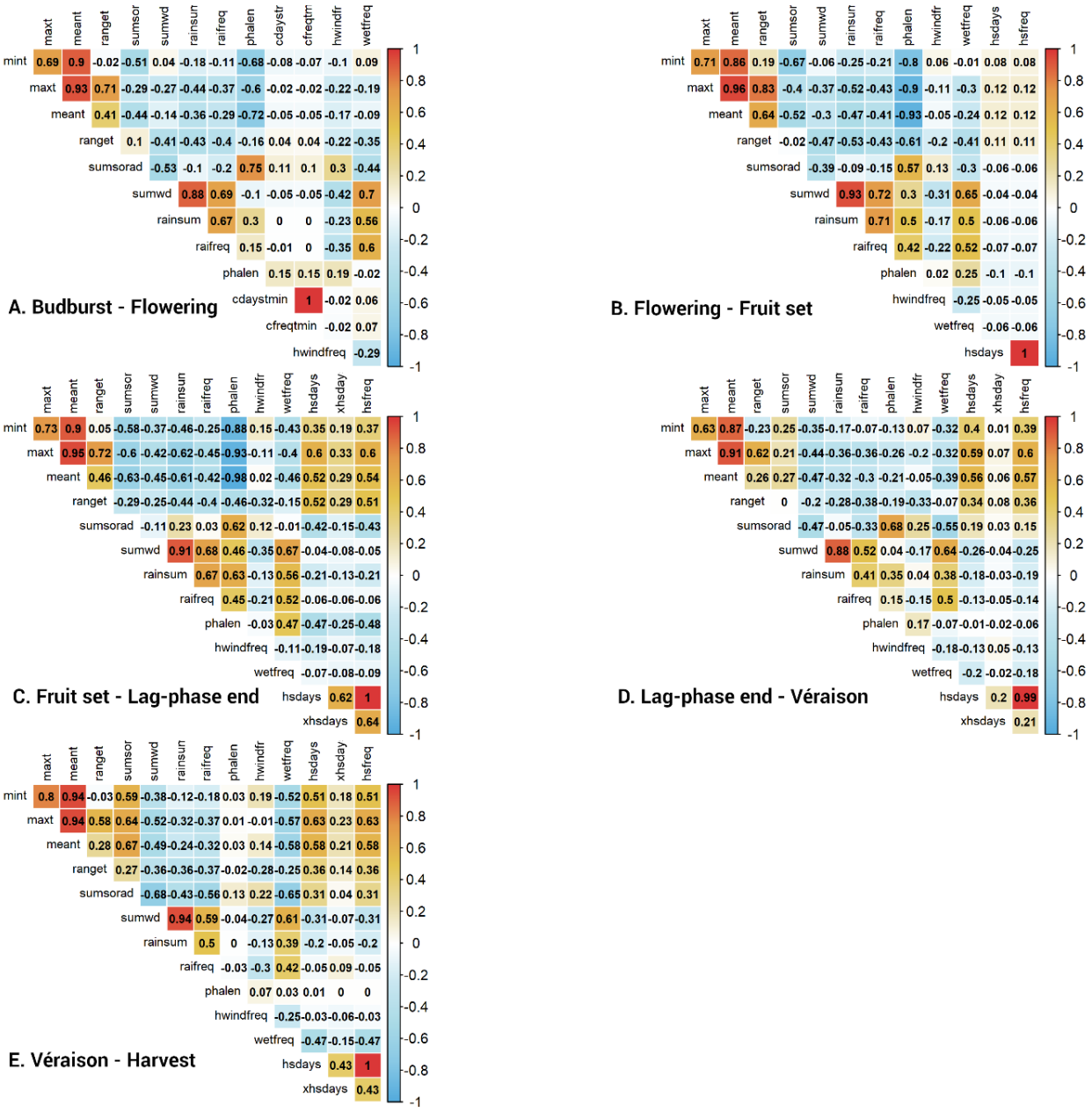


Figure 10SM. Correlations between ecoclimatic indicators at different phenological phases

Matrices of Pearson's correlations coefficients of the ecoclimatic indicators at different phenological stages were computed to examine the relationships between each ecoclimatic indicator. For this, the values to be correlated were centered. For all correlations p-values < 0.001. mint = minimal daily temperature (°C); maxt = maximal daily temperature (°C); meant = mean daily temperature (°C); ranget = thermal amplitude (°C); sumsorad = cumulated daily radiation (J/cm²); sumwd = sum of water deficit (ETP-rainfall); rainsum = rain cumulation (mm); raifreq = frequency (%) of rainy days (> 0mm); phalen = phase length (number of days); cdaystmin = number of cold days (< 0 °C); cfreqtmin = frequency (%) of cold days (< 0 °C); hwindfreq = frequency (%) of windy days (> 5.28 m/s); wetfreq = frequency (%) of wet days (relative humidity > 60 %); hsdays = number of heat stress days (tmax > 35°C); xhsdays = number of heat stress days (tmax > 40 °C);hsfreq =f requency (%) of heat stress days (tmax > 35 °C)