INTEGRATED PROTECTION IN VITICULTURE

Grapevine Phenology of cv. *Touriga Franca* and *Touriga Nacional* in the Douro Wine Region: Modelling and Climate Change Projections

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Study area and datasets

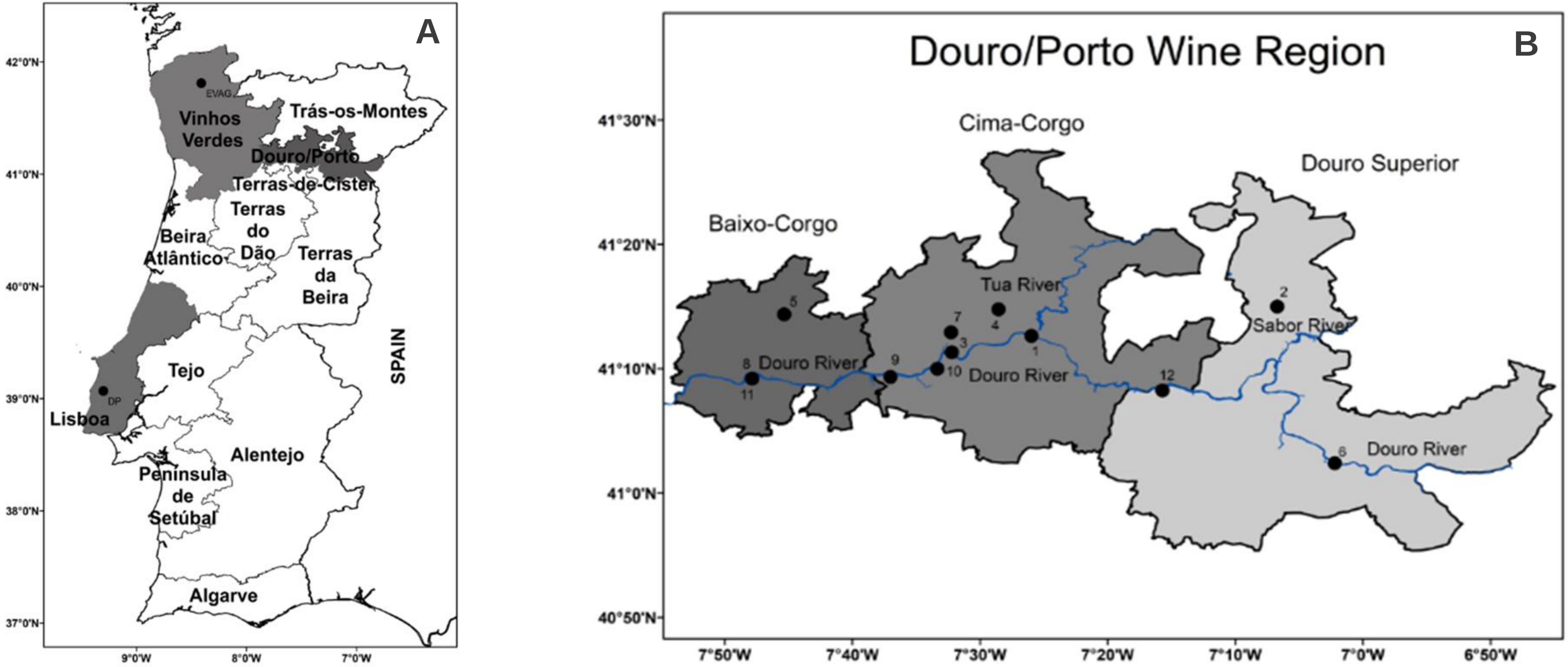


Figure 1: (A) Map of mainland Portugal with wine regions´s boundaries; (B) Douro/Porto Wine Region its sub-regions.

Study area and datasets

Wine Region	Grapevine variety (cv)	Available time period		
		Budburst	Flowering	Veraison
Douro/ Porto	Touriga Franca	2014 - 2017	2014 - 2017	2014 - 2017
Douro/ Porto	Touriga Nacional	2014 - 2017	2014 - 2017	2014 - 2017
Lisboa	Touriga Franca	1995 - 2014	1995 - 2014	1995 - 2014
Lisboa	Touriga Nacional	1990 - 2000 2006 - 2014	1990 - 2000 2006 - 2014	1990 - 2000 2006 - 2014
Vinhos - Verdes	Touriga Franca	2005 - 2009	2005 - 2009	2005 - 2009
Vinhos - Verdes	Touriga Nacional	2005 - 2009	2005 - 2009	2005 - 2009

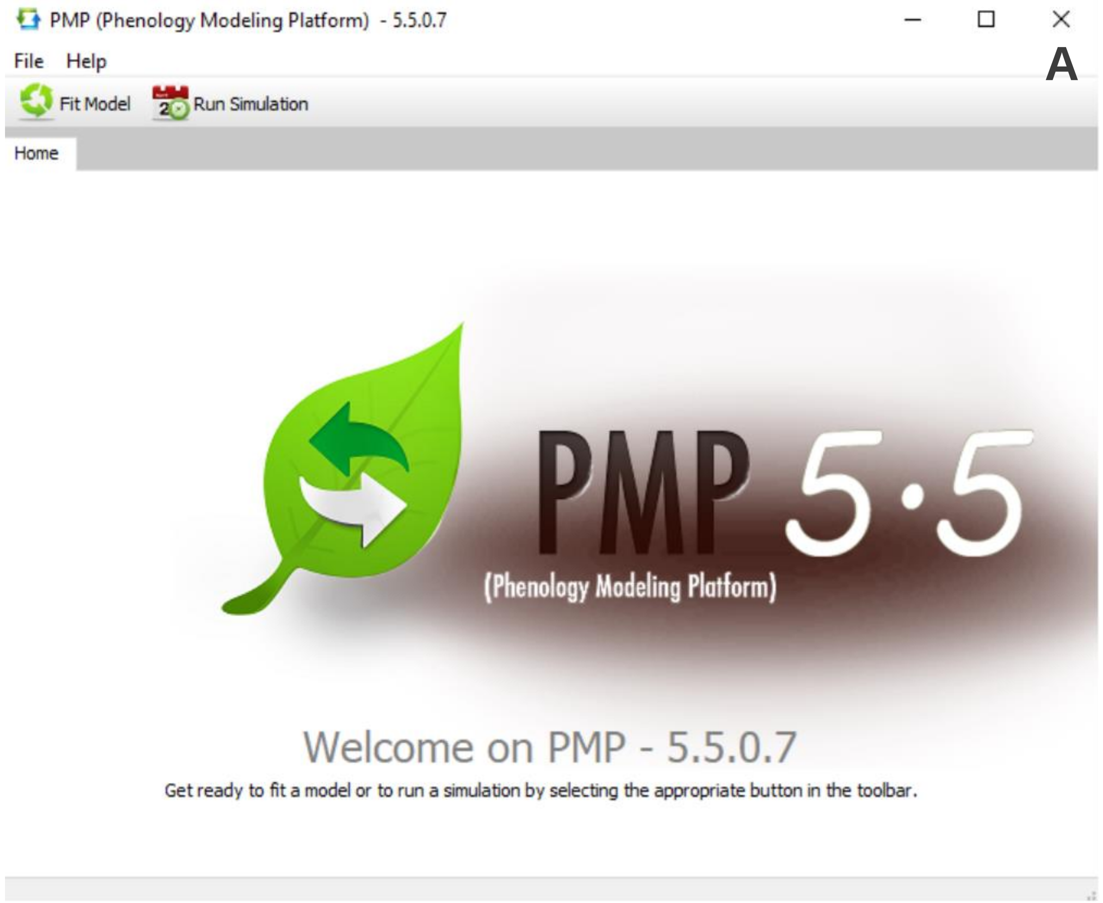
Figure 2: Phenological states data used (budburst, flowering and veraison dates) by wine region (Douro, Lisboa and Vinhos-Verdes).

Phenological models

Model name	Reference	Starting date
Bidabe	Bidabe (1967)	1^{st} August year before
Chuine	Chuine (2000)	1^{st} August year before
Growing Degree Days (GDD)	de Reaumur (1753)	1^{st} January
Richardson	Richardson (1974)	1^{st} January
Sigmoid	Hänninen (1990)	1^{st} January
Smoothed Utah (SU)	Bonhomme et al. (2010)	1^{st} August year before
Wang	Wang and Engel (1998)	1^{st} January

Figure 3: Phenological models selected and based on previous studies.Two main groups of phenological models used: chilling models (Bidabe, Chuine, and Smoothed Utah), used to simulate the dormancy phase; and the forcing models (GDD, Richardson, Sigmoid, and Wang) applied to simulate thermal accumulation during the three phenophases: budburst, flowering, and veraison.

Modelling tools and performance verification



B

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}(O_i - P_i)^2}{n}},$$

$$EF = 1 - \frac{\sum_{i=1}^{n}(O_i - P_i)^2}{\sum_{i=1}^{n}(O_i - \overline{O_i})^2},$$

$$AIC = n \times \ln\left(\frac{\sum_{i=1}^{n}(O_i - P_i)^2}{n}\right) + 2k + \left(\frac{2k(k+1)}{n-k-1}\right)$$

Figure 4: (A) The Phenological Modelling Platform, was used to test and calibrate different phenological models applied to grapevines; (B) The model performance is assessed by four metrics: RMSE, EF, AIC and R^2

Future climate projections

GCM	RCM	Abbreviation
CNRM-CERFACS-CNRM-CM5	SMHI- RCA4	CNRMSMHI
MPI-M-MPI-ESM-LR	CLMcom-CCLM4-8-17	MPICLM

Figure 5: For the simulations under future climates, were used daily time series generated by a two-member ensemble of climate model chains, produced within the framework of the EURO-CORDEX (Coordinated Downscaling Experiment—European Domain) project and to apply the previously calibrated phenology models.

Results

✓ **Model performance verification (Cv. *Touriga Franca*)**

Phenophase	Model	Description	Model performance			
	With dormancy		RMSEP	EF	R^2	AIC
Dormancy - Budburst	Bidabe + Wang	Q_{10}=0.9 T_m=5.5, T_M=34.3, T_{opt}=14.7	6.4	0.36	0.62	185.1
	Bidabe + Sigmoid	Q_{10}=1.0 d= –22.4, e=7.4	6.5	0.35	0.58	186.5
	SU + Sigmoid	T_{m1}= –13.4, T_{opt}= 29.2, T_{n2}= 44.6, min= –0.5 d= –39.9, e=7.5	6.2	0.41	0.64	187.4
	SU + GDD	T_{m1}= –2.8, T_{opt} = 29.2, T_{n2}= 36.6, min= –0.3 T_b=0	6.5	0.35	0.59	190.1
	SU + Wang	T_{m1}= –32.2, T_{opt}= 29.3, T_{n2}= 35.7, min= –0.3 T_m= 5.3, T_M= 34.8, T_{opt}= 15.1	6.4	0.37	0.63	190.4
	Chuine + Sigmoid	a= 0.3, b= –21.1, c= –2.5 d= –40, e= 7.5	6.4	0.38	0.57	192.3
	Bidabe + Richardson	Q_{10}= 0.9 T_{low}= 0.2, T_{high}= 43.2	6.5	0.35	0.54	201.4
	Without dormancy					
	Sigmoid	d= –40, e= 7.5	6.4	0.38	0.61	181.6

Figure 6:The results show that for Dormency-Budburst, the RMSEP is of 6–7 days for *Touriga Franca*. The EF varies from 0.35 to 0.41. The corresponding coefficient of determination (R^2) show values ranging from 0.54 to 0.64.

Phenophase	Model	Description	Model performance			
			RMSEP	EF	R^2	AIC
Budburst - Flowering	GDD	T_b =6.6	5.1	0.69	0.85	159.1
	Sigmoid	d= –0.2, e=16.9	5.1	0.70	0.86	159.4
	Richardson	T_{low}=6.5, T_{high} =36.9	5.1	0.69	0.85	161.1
	Wang	T_m=0, T_M =40	5.1	0.69	0.86	161.9
	Richardson	T_{low}=5, T_{high} =25	5.2	0.68	0.84	162.6
	Richardson	T_{low}=5, T_{high}=20	5.3	0.67	0.83	164.1
	GDD	T_b=0	5.9	0.60	0.78	171.1
	Wang	T_m=0, T_M=31.6, T_{opt}=25.5	5.6	0.62	0.87	172.3
Flowering - Veraison	Sigmoid	d= –0.5, e=13.0	4.3	0.83	0.92	141.1
	Richardson	T_{low}=0.0, T_{high} =21.5	4.2	0.83	0.91	142.1
	Wang	T_m=0, T_M =40	4.2	0.84	0.92	142.6
	Wang	T_m=0, T_M=40, T_{opt}=25	4.2	0.84	0.92	143.1
	Wang	T_m=0, T_M=40, T_{opt}=26	4.2	0.83	0.91	144.2
	Richardson	T_{low}=5, T_{high}=20	4.3	0.82	0.91	144.9
	Wang	T_m=0, T_M=36.6, T_{opt}=25.6	4.4	0.82	0.91	148.9
	GDD	T_b=0	5.1	0.76	0.90	157.6

Figure 7: In the case of Budburst-Flowering, the RMSEP is of 5–6 days (*Touriga Franca*) less one day than for the Dormency-Budburst phase. The EF also presents much higher values than in the previous phenophase, between 0.60 to 0.70. Among the three phenophases, the best results are achieved for Flowering-Veraison, with RMSEP of 4–5 days. The EF varies from 0.76 to 0.84.

✓ Model performance verification (Cv. *Touriga Nacional*)

Phenophase	Model	Description	Model performance			
	With dormancy		RMSEP	EF	R^2	AIC
Dormancy - Budburst	Bidabe + GDD	Q_{10}= 0.9 T_b= 0	7.8	0.18	0.43	190.5
	Bidabe + Wang	Q_{10}= 0.7 T_m= –36.7, T_M= 34, T_{opt}= 18	7.7	0.20	0.44	193.7
	Bidabe + Richardson	Q_{10}= 0.9 T_{low}= 0, T_{high}= 37.3	7.8	0.18	0.42	193.9
	SU + Sigmoid	T_{m1}= –34.1, T_{opt}= 29.9, T_{n2}= 43, min= –0.2 d= –39.7, e=7.5	7.6	0.23	0.48	196.0
	SU + GDD	T_{m1}= –31.1, T_{opt}= 29.5, T_{n2}= 32.1, min= –0.1 T_b= 0	8.0	0.15	0.41	197.8
	Bidabe + Sigmoid	Q_{10}= 1 d= –38.3, e= 7.5	7.8	0.19	0.41	197.9
	SU + Wang	T_{m1}= –31.1, T_{opt}= 30, T_{n2}= 32.2, min= –0.4 T_m= –16.1, T_M= 25.1, T_{opt}= 16.4	7.9	0.17	0.42	201.0
	Without dormancy					
	Sigmoid	d= –40, e= 7.5	7.2	0.20	0.42	190.9

Figure 8:The results show that for Dormency-Budburst, the RMSEP is of almost 8 days for *Touriga Nacional*. The EF varies from 0.15 to 0.23. The corresponding coefficient of determination (R^2) show values ranging from 0.41 to 0.48.

Phenophase	Model	Description	Model performance			
			RMSEP	EF	R^2	AIC
Budburst - Flowering	GDD	T_b=7.0	5.4	0.68	0.83	169.6
	Sigmoid	d= –0.3, e=14.4	5.4	0.69	0.84	170.5
	Richardson	T_{low}=7.0, T_{high}=20.8	5.4	0.69	0.83	171.1
	Wang	T_m=0, T_M=40	5.3	0.69	0.83	172.5
	Richardson	T_{low}=5, T_{high}=25	5.7	0.67	0.82	173.6
	Richardson	T_{low}=5, T_{high}=20	5.8	0.67	0.82	173.7
	Wang	T_m=0, T_M=26.5, T_{opt}=21.8	5.3	0.66	0.84	177.3
	GDD	T_b=0	6.8	0.61	0.78	180.1
Flowering - Veraison	Sigmoid	d= –0.4, e=14.4	6.0	0.85	0.93	151.3
	Richardson	T_{low}=0.1, T_{high}=23.7	5.6	0.86	0.93	151.6
	GDD	T_b=0	5.6	0.85	0.92	154.8
	Wang	T_m=0, T_M=40	5.7	0.86	0.93	155.7
	Wang	T_m=0, T_M=40, T_{opt}=25	6.2	0.85	0.91	161.0
	Richardson	T_{low}=5, T_{high}=20	6.1	0.83	0.92	161.7
	Richardson	T_{low}=5, T_{high}=25	5.9	0.83	0.91	161.8
	Wang	T_m=0, T_M=43.2, T_{opt}=29.9	5.9	0.83	0.91	164.9

Figure 9: In the case of Budburst-Flowering, the RMSEP is of 5–6 days (*Touriga Nacional*). The EF also presents much higher values than in the previous phenophase, between 0.61 to 0.69. Among the three phenophases, the best results are achieved for Flowering-Veraison, with RMSEP of 5-6 days. The EF varies from 0.83 to 0.86.

✓ **Average of two climate models (CNRMSMHI e MPICLM) on the *cv. Touriga Franca***

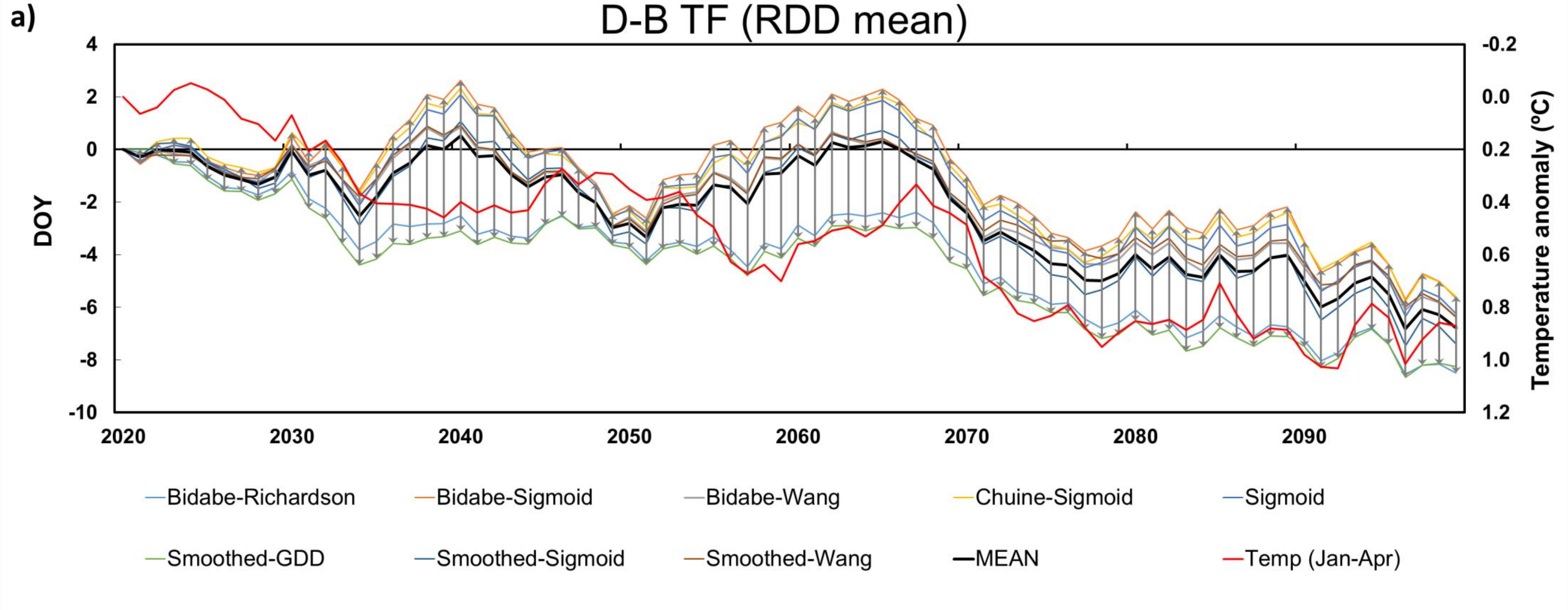


Figure 10: In the case of Dormency-Budburst for *Touriga Franca*, a mean anticipation of 6 days is expected from 2020 to 2100, with important inter-decadal variability, without a clear trend until 2070, followed by a more pronounced long-term decrease from 2070 to 2100.

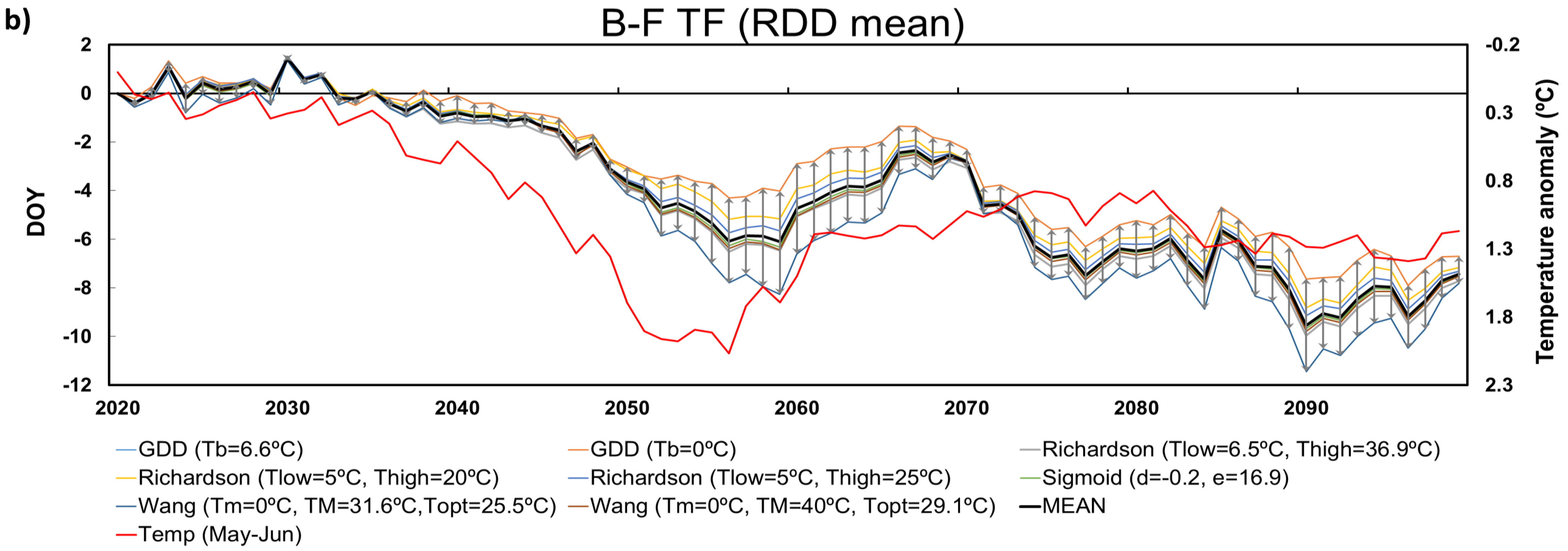


Figure 11: For Budburst-Flowering in *Touriga Franca*, a clear anticipation is expected after 2040, despite the delay in the period of 2060–2070, which can be attributed to a cooler period in the future climate.

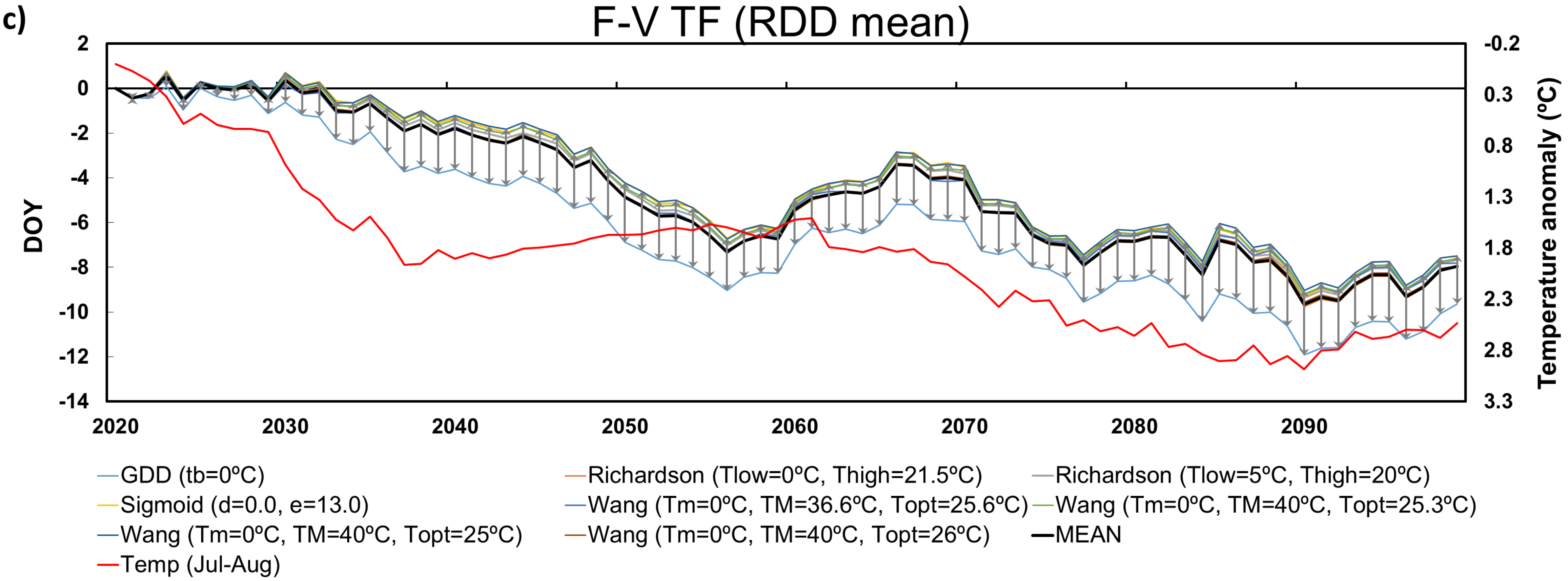


Figure 12: For Flowering-Veraison, an anticipation of 8–10 days over the full period is projected, with analogous temporal variability to Budburst-Flowering.

✓ **Average of two climate models (CNRMSMHI e MPICLM) on the *cv. Touriga Nacional***

a)

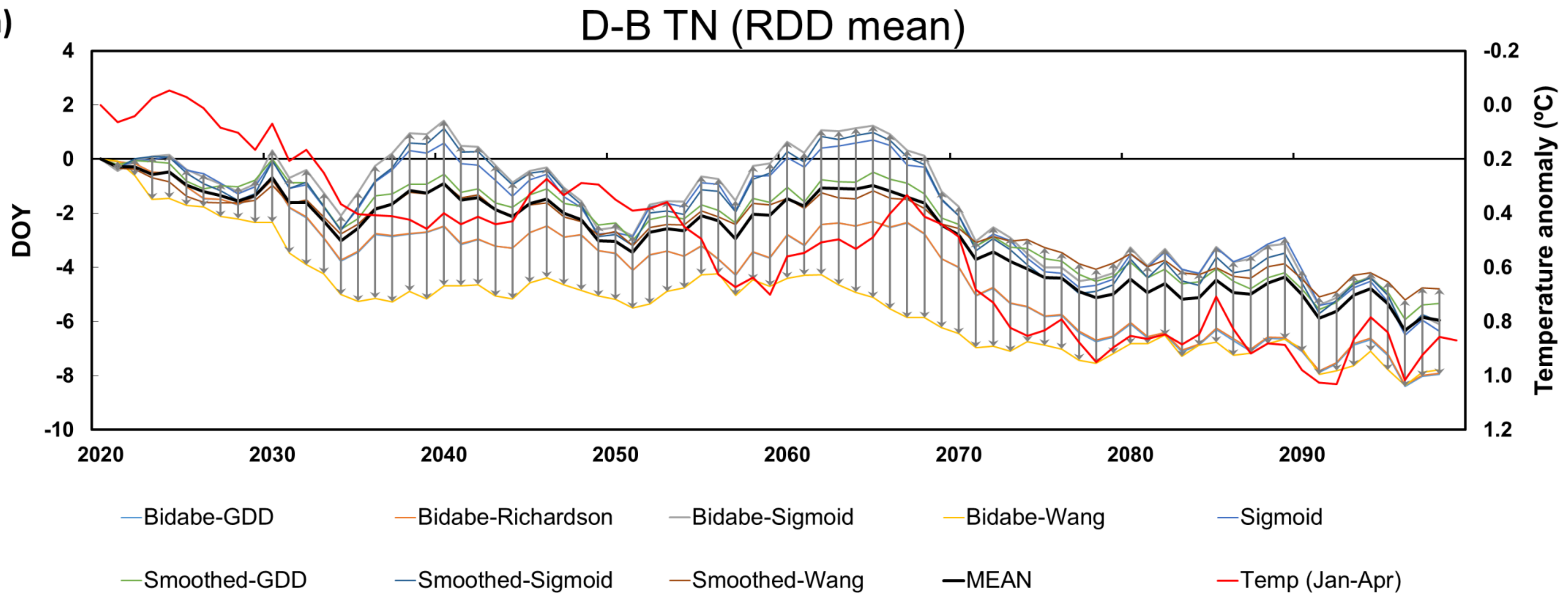


Figure 13: Similar considerations can be made for *Touriga Nacional*. The models Smoothed-GDD and Smoothed-Wang are the closest to the mean.

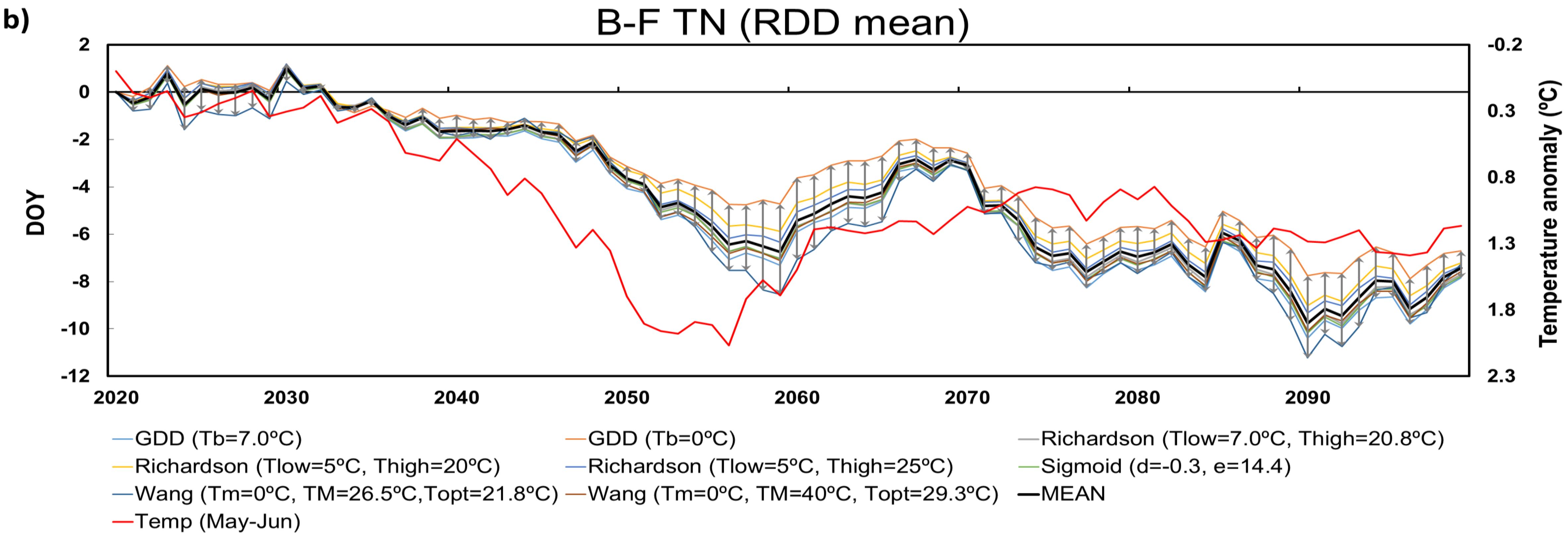


Figure 14: For Budburst-Flowering, the Richardson and the Sigmoid are models show the most central behaviour.

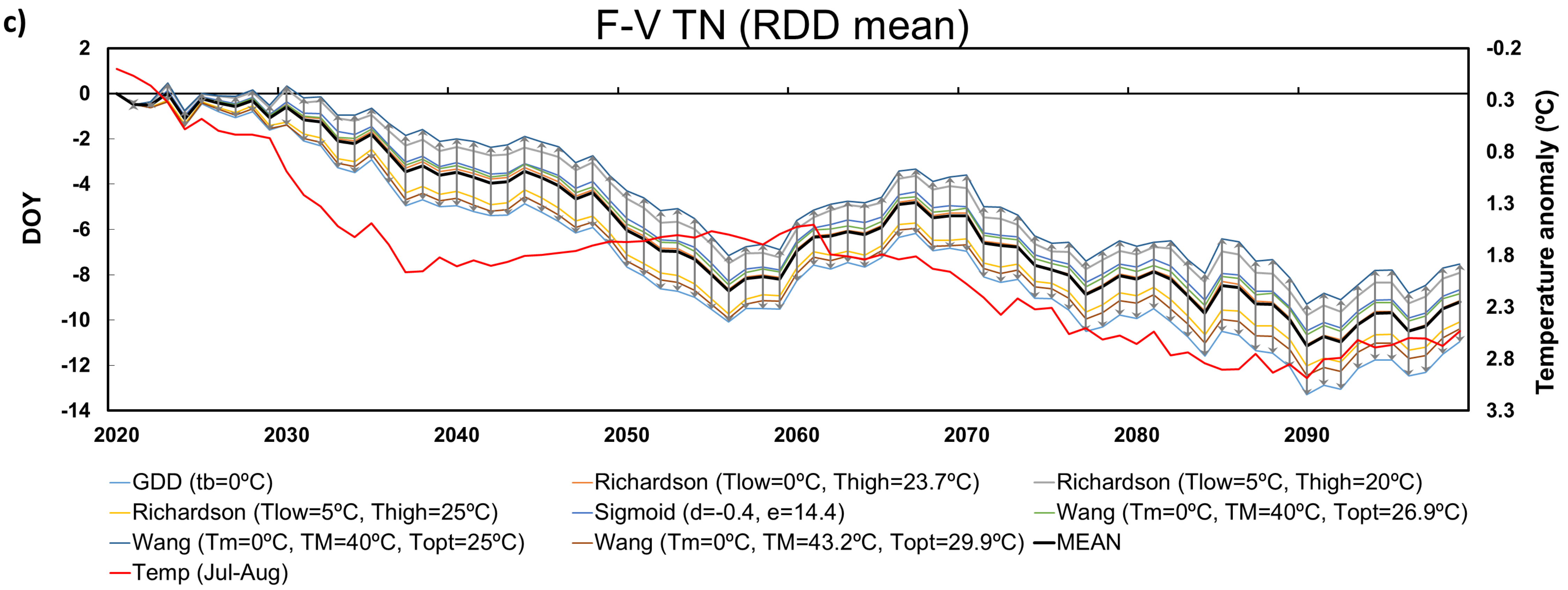


Figure 15: The anticipation of veraison for *Touriga Nacional* is more pronounced than for *Touriga Franca* (8 to 12 days).

Conclusions

- ✓ **The accurate prediction phenological timings promotes best practices and the timely implementation of suitable measures.**

- ✓ **The identification of the best phenological models (a set of eight models per phenophase), thus warranting their application both in an operational mode (real-time monitoring and short-term prediction) and in future climate change projections (long-term prediction).**

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