APPENDIX

Impact of long-term (1764-2017) air temperature on phenology of cereals and vines in two locations of northern Italy

Davide Cammarano,[1] Francesca Becherini,[2] Luisa Leolini,[3] Dario Camuffo,[4] Marco Moriondo,[5] Antonio della Valle,[4] Roberto Ferrise[3]

[1]Department of Agroecology, Aarhus University, iClimate, Centre for Circular Bioeconomy (CBIO), Tjele, Denmark; [2]National Research Council (CNR), Institute of Polar Sciences (ISP), Venice Mestre, Italy; [3]Department of Agriculture, Food, Environment and Forestry, University of Florence (DAGRI), Florence, Italy; [4]National Research Council of Italy (CNR), Institute of Atmospheric Sciences and Climate (IASC), Padua, Italy; [5]National Research Council (CNR), Institute of Bio-Economy (IBE), Florence, Italy

The grapevine varieties had different CU and FU requirements for the endo-dormancy release, budbreak, flowering and veraison stages (Fila 2012). A period of exposure to effective CU accumulation is needed for satisfying the variety-specific chilling requirement. This period ranges from 6 days for Cabernet Sauvignon to 21 days for Glera resulting in a 90% of the effective CU accumulated from -2.2°C to 7.7°C for Glera and Merlot and from 4.0°C to 6.8°C for Chardonnay and Cabernet Sauvignon (Table S2). After endo-dormancy release, the thermal requirement at the maximum effective forcing accumulation is reached on average with 537 Σ°C for budbreak, 1258 Σ°C for flowering and 2944 Σ°C for veraison with Merlot (4560 Σ°C) and Cabernet Sauvignon (5157 Σ°C) showing the lowest and highest thermal requirement during all phenological phases, respectively. The minimum and maximum temperature thresholds for forcing accumulation were defined by the 5% (T_b) and the 95% (T_{cutoff}) of the effective forcing unit accumulation. The base and cut off temperatures for all varieties ranged from the minimum of Chardonnay (T_b = 1.4°C; T_{cutoff} = 30.8°C) to the maximum of Merlot (T_b = 3.6°C; T_{cutoff}= 34.7°C; Table S2).

Table S1. Crop thermal requirements adopted. $Vern_{Tmin}$, EDD_{Tmin} : minimum effective temperature for vernalization and endodormancy; $Vern_{Tmax}$, EDD_{Tmax} : maximum effective temperature for vernalization and endodormancy; # days: number of days with effective temperatures for satisfying crop cold requirements; T_{base}, T_{cutoff}: minimum and maximum temperature for accumulating growing degree days (GDD); Cumulated GDD for bud break ($GDD_{budbreak}$), flowering ($GDD_{flowering}$), veraison ($GDD_{veraison}$), maturity ($GDD_{maturity}$)

CEREALS	**Thermal requirements for vernalization**			**Thermal requirements for crop development**			
	$Vern_{Tmin}$ (°C)	*$Vern_{Tmax}$ (°C)*	*# days*	*T_{base} (°C)*	*T_{cutoff} (°C)*	*$GDD_{flowering}$ (Σ°Cd)*	*$GDD_{maturity}$ (Σ°Cd)*
Maize (FAO 500)				10.0	30.0	780	1400
Spring wheat				3.0	30.0	900	1500
Winter wheat	3.0	10.0	50.0	0.0	30.0	900	1500

GRAPEVINE	**Thermal requirements for endodormancy**			**Thermal requirements for crop development**				
	EDD_{Tmin} (°C)	*EDD_{Tmax} (°C)*	*# days*	*T_{base} (°C)*	*T_{cutoff} (°C)*	*$GDD_{budbreak}$ (Σ°Cd)*	*$GDD_{flowering}$ (Σ°Cd)*	*$GDD_{veraison}$ (Σ°Cd)*
Cabernet-Sauvignon	4.56	6.82	6.9	2.0	32.4	678	1387	3092
Merlot	-0.2	7.15	12.2	3.6	34.7	493	1173	2894
Chardonnay	4.02	6.53	13.8	1.4	30.8	534	1263	2848
Glera	-2.21	7.69	20.8	2.8	33.6	442	1210	2942

Table S2. Parameterization of the UNICHILL model obtained by Fila (2012) and based on field and forced cuttings observations of four different grapevine varieties.

Varieties	**a_c**	**b_c**	**c_c**	**b_f**	**c_f**	**C_{req}**	**F_b**	**F_f**	**F_v**
Glera	1.441	-14.719	-2.369	-0.191	18.216	20.776	12.122	33.209	80.744
Chardonnay	1.525	-5.317	3.531	-0.200	16.090	13.752	16.603	39.261	88.512
Merlot	0.927	7.400	7.464	-0.189	19.155	12.224	12.853	30.605	75.517
Cabernet S.	6.790	17.241	6.962	-0.194	17.187	6.853	19.734	40.341	89.928

a_c,b_c,c_c,b_f and c_f are the empirical parameters of the UNICHILL model; C_{req} is the chilling requirement for endo-dormancy release; F_b, F_f and F_v are the forcing requirements for the occurrence of budbreak, flowering and veraison stages, respectively.

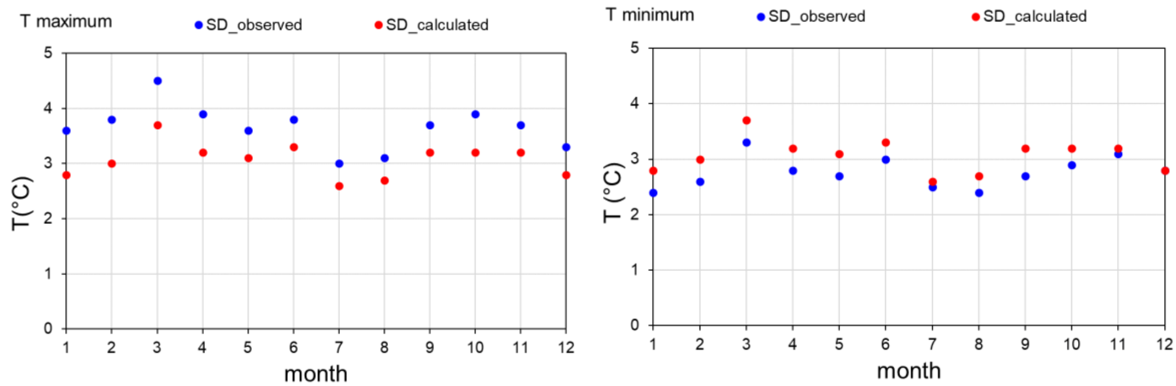

Figure S1. Monthly SD differences for the observed and calculated data for Tmax and for Tmin.

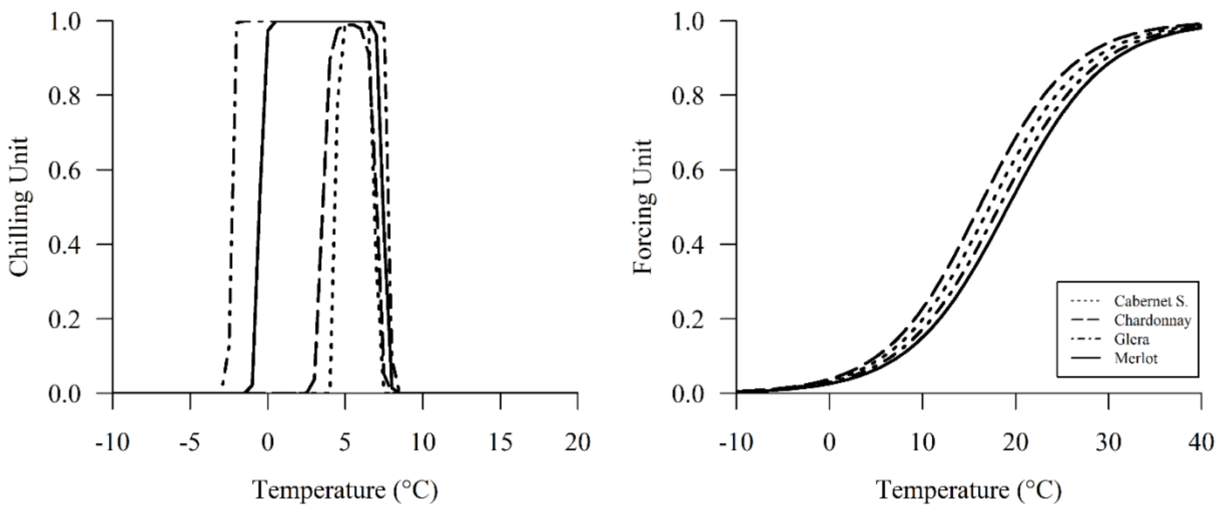

Figure S2. Chilling and Forcing units functions of the UNICHILL model using the calibration B proposed by Fila (2012) for four grapevine varieties (Cabernet S., Chardonnay, Glera and Merlot).

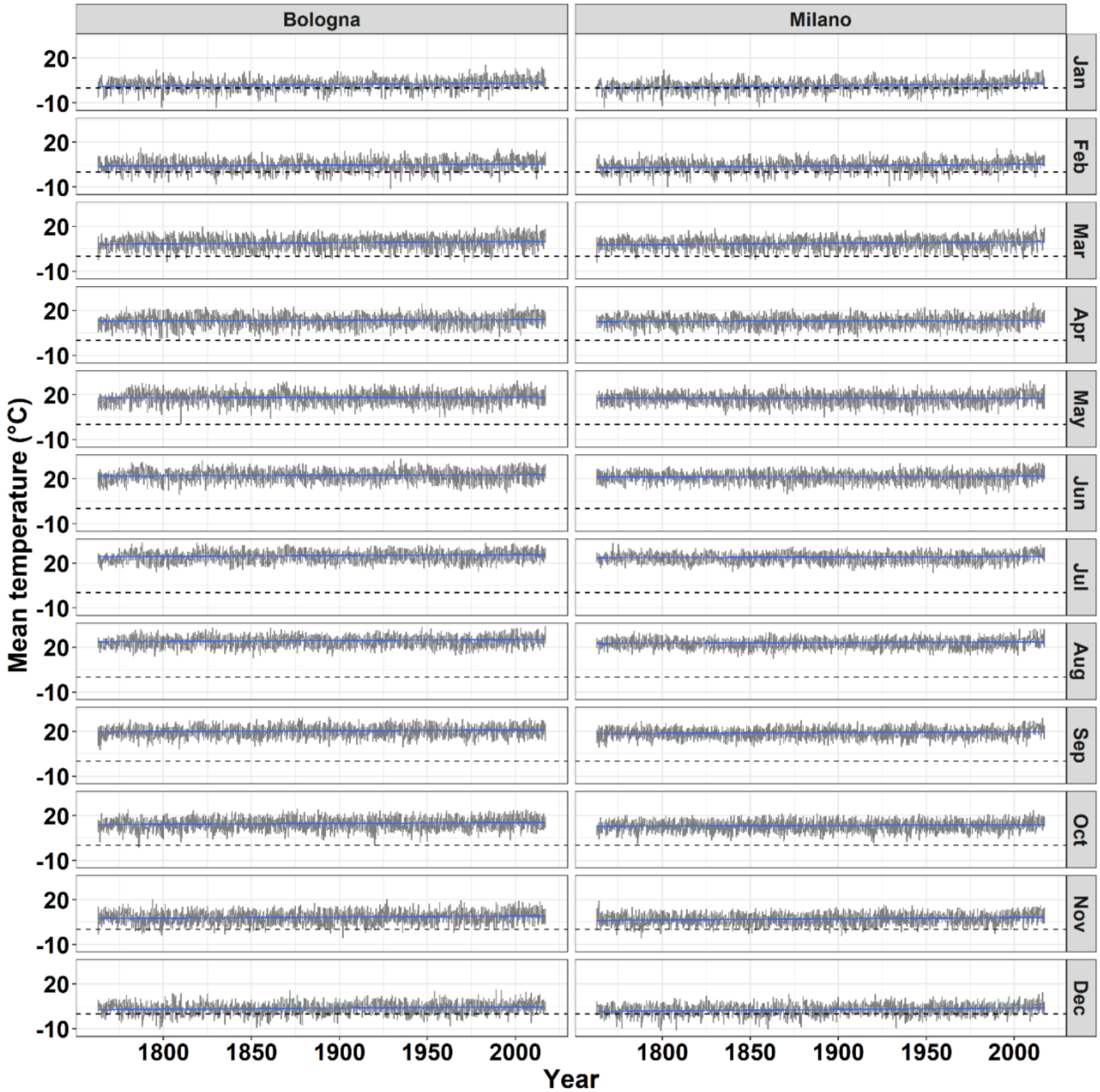

Figure S3. Monthly mean air temperature (°C) recorded in Bologna and Milano from 1763 to 2017.

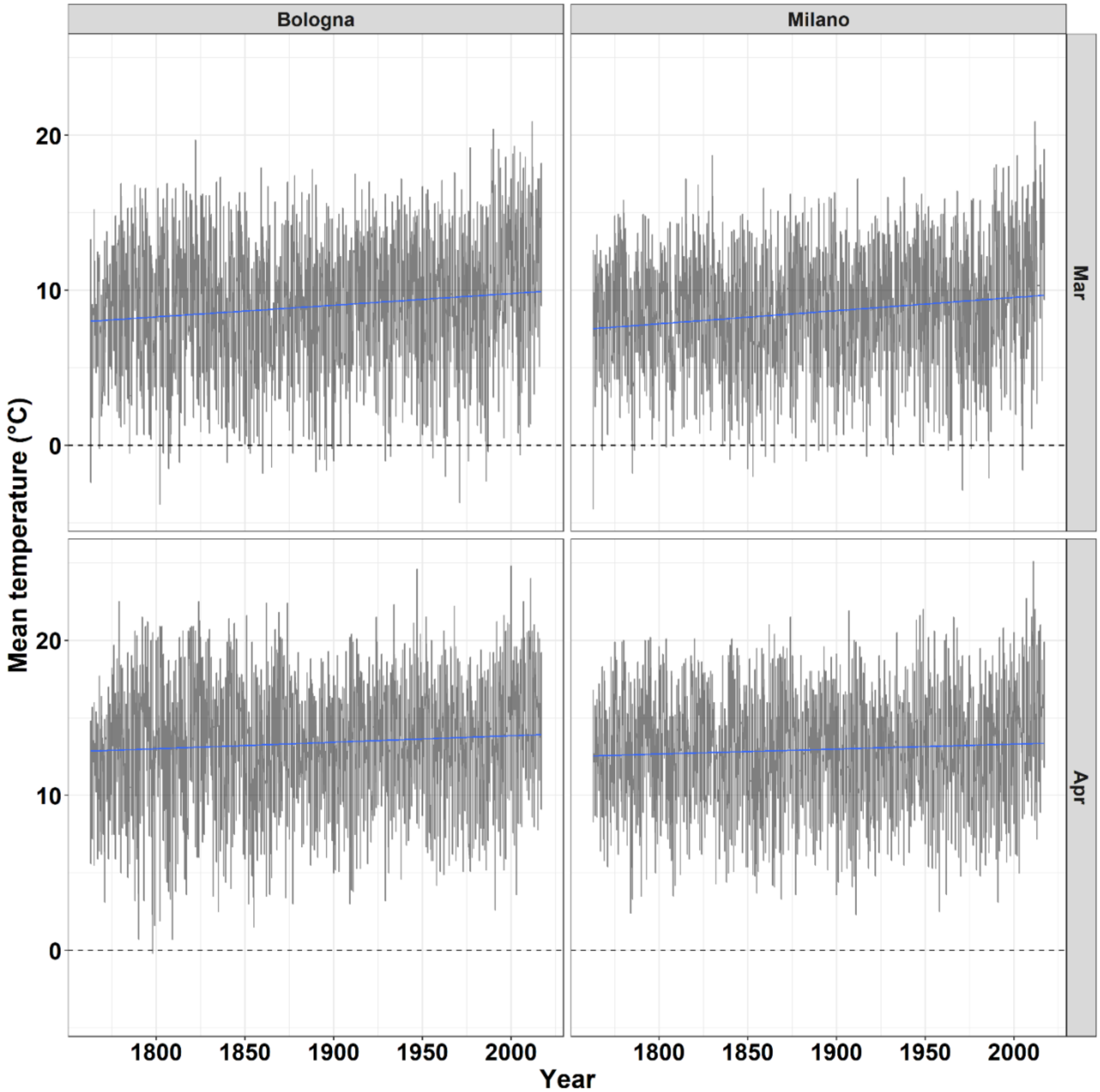

Figure S4. Monthly mean air temperature (°C) recorded in Bologna and Milano from 1763 to 2017 for the months of March and April, corresponding to a period in which wheat development transition to reproductive stage.

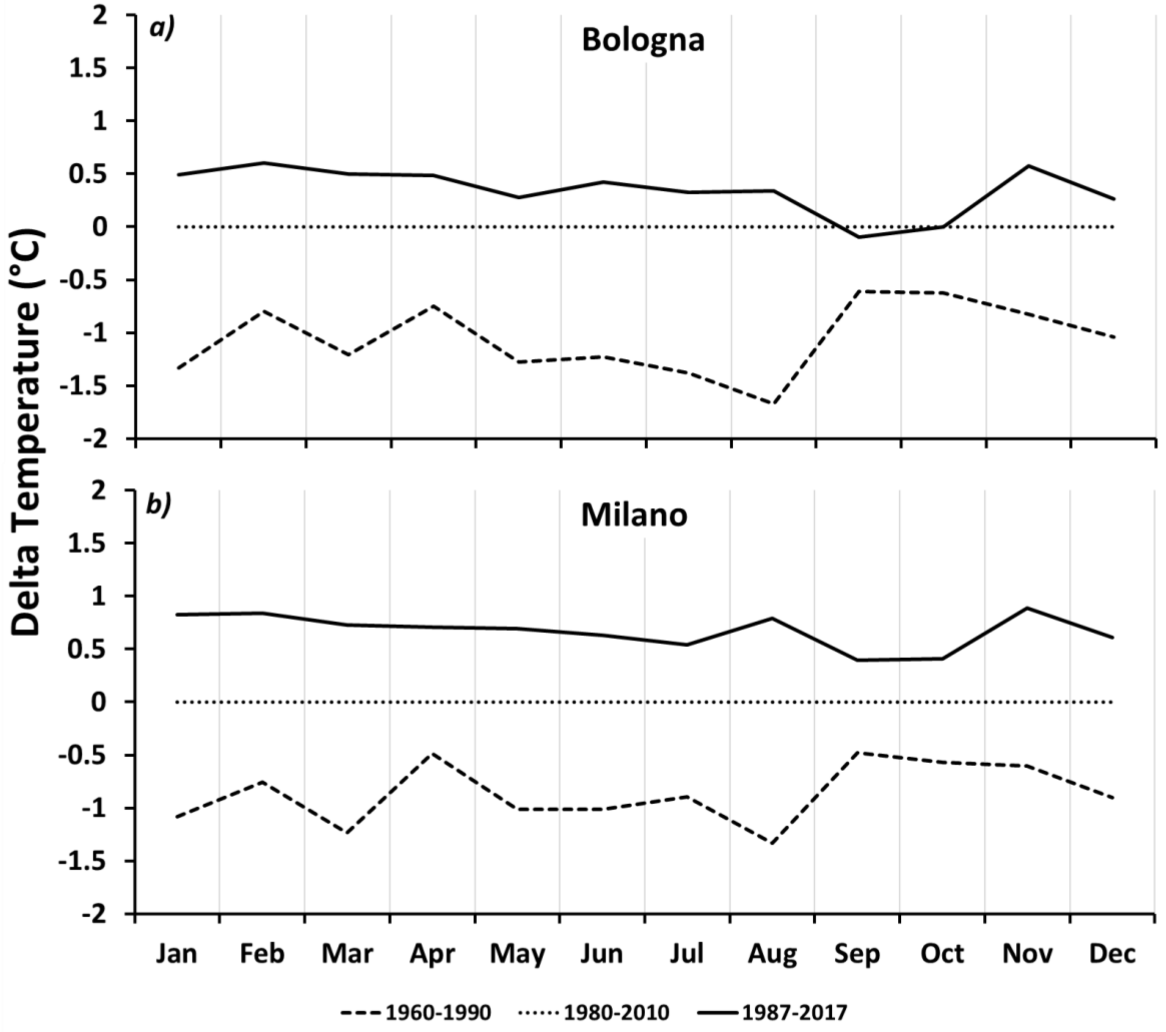

Figure S5. Difference in air temperature of two different 30-years period (1960-1990, and 1987-2017) and the 1980-2010 for (***a***) Bologna, and (***b***) Milano.

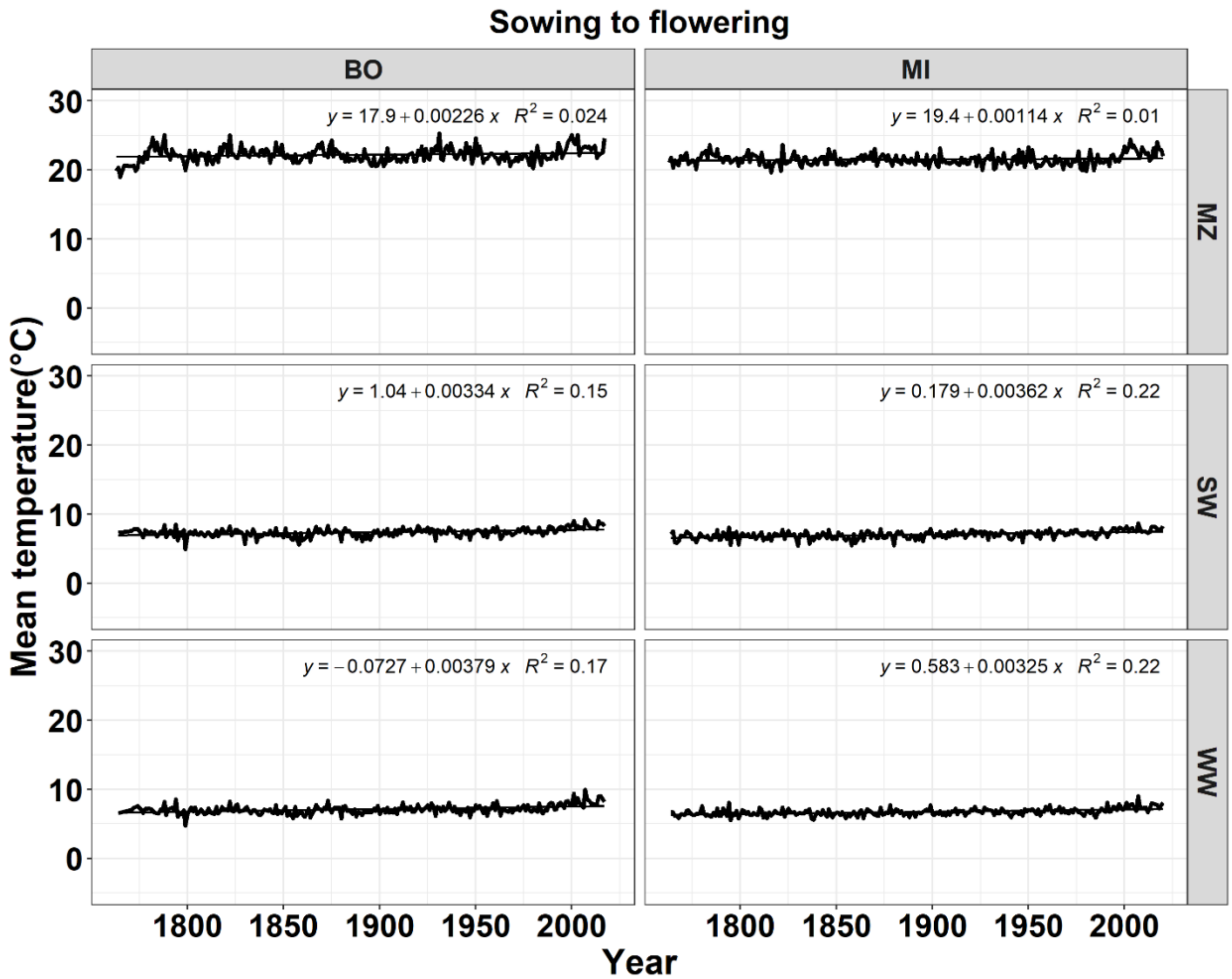

Figure S6. Time series of the mean air temperature between sowing to flowering for Maize (MZ), Spring wheat (SW), and Winter wheat (WW) for Bologna and Milano from 1763 to 2017.

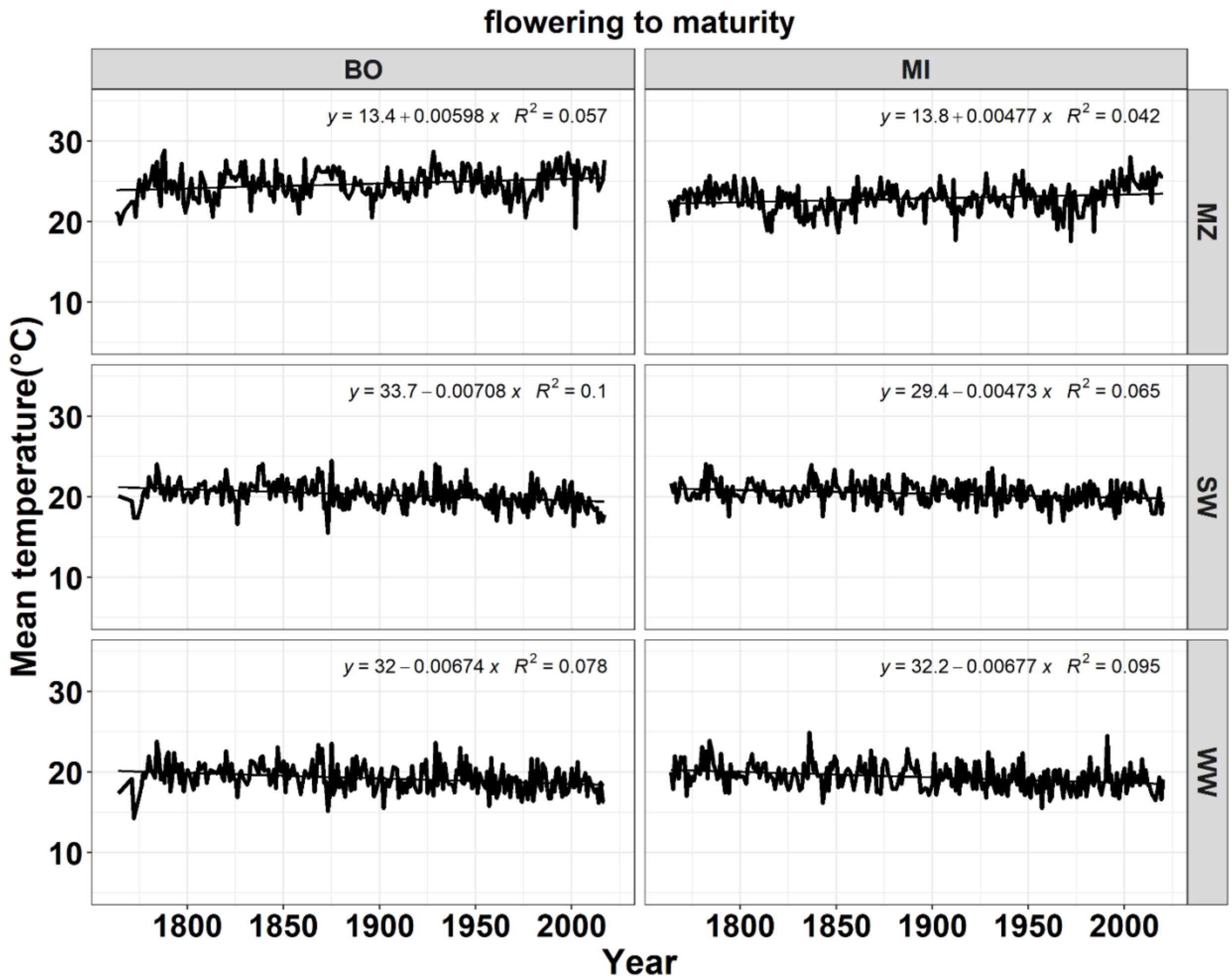

Figure S7. Time series of the mean air temperature between flowering to maturity for Maize (MZ), Spring wheat (SW), and Winter wheat (WW) for Bologna and Milano from 1763 to 2017.

References:

Fila G (2012) Mathematical Models for the Analysis of the Spatio-Temporal Variability of Vine Phenology University of Padova