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Modelling interannual variation in the spring and autumn land surface phenology of the European forest

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Table S1. Random Forest models for interannual variation in spring phenology on the basis of different predictor combinations considering different temporal windows prior to the phenological event. Temperature and precipitation predictors were derived from the European Climate Assessment & Dataset (Haylock et al. 2008), and the DAL and SIS (w/m^2) predictors from Meteosat satellite sensors (Müller and Trentmann 2013; Posselt et al. 2011; Posselt et al. 2012). TX, TN and TG: maximum, minimum and average temperature, respectively; PP: precipitation; SIS: surface incoming shortwave radiation; DAL: surface radiation daylight; GDD: growing degree days; CHIL: chilling requirements; FF, LF and PF: first, last and period of freeze, respectively. Prefix M and C represent the mean and cumulated functions. Suffix 30 and 90 refers to the number of days considered in the computation of the predictors.

Models														Ps-R^2	RMSE
GDD030	MTG30	MTX30	MTN30	CRR30	MRR30	CSIS30	MSIS30	CDAL30	MDAL30	CHIL	FF	LF	PF	0.78	0.61
GDD030	MTG90	MTX90	MTN90	CRR30	MRR90	CSIS30	MSIS90	CDAL30	MDAL90	CHIL	FF	LF	PF	0.81	0.57
GDD530	MTG30	MTX30	MTN30	CRR30	MRR30	CSIS30	MSIS30	CDAL30	MDAL30	CHIL	FF	LF	PF	0.78	0.61
GDD530	MTG90	MTX90	MTN90	CRR30	MRR90	CSIS30	MSIS90	CDAL30	MDAL90	CHIL	FF	LF	PF	0.81	0.58
GDD090	MTG30	MTX30	MTN30	CRR90	MRR30	CSIS90	MSIS30	CDAL90	MDAL30	CHIL	FF	LF	PF	0.81	0.57
GDD090	MTG90	MTX90	MTN90	CRR90	MRR90	CSIS90	MSIS90	CDAL90	MDAL90	CHIL	FF	LF	PF	0.80	0.59
GDD590	MTG30	MTX30	MTN30	CRR90	MRR30	CSIS90	MSIS30	CDAL90	MDAL30	CHIL	FF	LF	PF	0.81	0.57
GDD590	MTG90	MTX90	MTN90	CRR90	MRR90	CSIS90	MSIS90	CDAL90	MDAL90	CHIL	FF	LF	PF	0.79	0.59
GDD030	MTG30	MTX30	MTN30	CRR30	MRR30	CSIS30	MSIS30	CDAL30	MDAL30					0.74	0.66
GDD030	MTG90	MTX90	MTN90	CRR30	MRR90	CSIS30	MSIS90	CDAL30	MDAL90					0.81	0.66
GDD530	MTG30	MTX30	MTN30	CRR30	MRR30	CSIS30	MSIS30	CDAL30	MDAL30					0.75	0.65
GDD530	MTG90	MTX90	MTN90	CRR30	MRR90	CSIS30	MSIS90	CDAL30	MDAL90					0.81	0.58
GDD090	MTG90	MTX90	MTN90	CRR90	MRR90	CSIS90	MSIS90	CDAL90	MDAL90					0.79	0.60
GDD090	MTG30	MTX30	MTN30	CRR90	MRR30	CSIS90	MSIS30	CDAL90	MDAL30					0.80	0.58
GDD590	MTG90	MTX90	MTN90	CRR90	MRR90	CSIS90	MSIS90	CDAL90	MDAL90					0.79	0.61
GDD590	MTG30	MTX30	MTN30	CRR90	MRR30	CSIS90	MSIS30	CDAL90	MDAL30					0.79	0.60
GDD030	MTG30	MTX30	MTN30	CRR30	MRR30	CHIL90	FF	LF	PF					0.72	0.69
GDD030	MTG90	MTX90	MTN90	CRR30	MRR90	CHIL90	FF	LF	PF					0.77	0.63
GDD530	MTG30	MTX30	MTN30	CRR30	MRR30	CHIL90	FF	LF	PF					0.74	0.67
GDD530	MTG90	MTX90	MTN90	CRR30	MRR90	CHIL90	FF	LF	PF					0.77	0.63
GDD090	MTG30	MTX30	MTN30	CRR90	MRR30	CHIL90	FF	LF	PF					0.76	0.65
GDD090	MTG90	MTX90	MTN90	CRR90	MRR90	CHIL90	FF	LF	PF					0.73	0.68
GDD590	MTG30	MTX30	MTN30	CRR90	MRR30	CHIL90	FF	LF	PF					0.76	0.65
GDD590	MTG90	MTX90	MTN90	CRR90	MRR90	CHIL90	FF	LF	PF					0.73	0.68
GDD030	MTG30	MTX30	MTN30	CSIS30	MSIS30	CDAL3	MDAL3							0.72	0.69
GDD030	MTG90	MTX90	MTN90	CSIS30	MSIS90	CDAL3	MDAL9							0.78	0.62
GDD530	MTG30	MTX30	MTN30	CSIS30	MSIS30	CDAL3	MDAL3							0.73	0.68
GDD530	MTG90	MTX90	MTN90	CSIS30	MSIS90	CDAL3	MDAL9							0.77	0.62
GDD090	MTG90	MTX90	MTN90	CSIS90	MSIS90	CDAL9	MDAL9							0.77	0.63
GDD090	MTG30	MTX30	MTN30	CSIS90	MSIS30	CDAL9	MDAL3							0.77	0.63
GDD590	MTG90	MTX90	MTN90	CSIS90	MSIS90	CDAL9	MDAL9							0.77	0.63
GDD590	MTG30	MTX30	MTN30	CSIS90	MSIS30	CDAL9	MDAL3							0.76	0.65
GDD030	MTG30	MTX30	MTN30	CHIL90	FF	LF	PF							0.71	0.71
GDD030	MTG90	MTX90	MTN90	CHIL90	FF	LF	PF							0.73	0.68
GDD530	MTG30	MTX30	MTN30	CHIL90	FF	LF	PF							0.72	0.70
GDD530	MTG90	MTX90	MTN90	CHIL90	FF	LF	PF							0.72	0.69
GDD090	MTG30	MTX30	MTN30	CHIL90	FF	LF	PF							0.72	0.69
GDD090	MTG90	MTX90	MTN90	CHIL90	FF	LF	PF							0.70	0.72
GDD590	MTG30	MTX30	MTN30	CHIL90	FF	LF	PF							0.71	0.70
GDD590	MTG90	MTX90	MTN90	CHIL90	FF	LF	PF							0.70	0.71
GDD030	MTG30	MTX30	MTN30	CRR30	MRR30									0.66	0.77

GDD030	MTG90	MTX90	MTN90	CRR30	MRR90	0.75	0.65
GDD530	MTG30	MTX30	MTN30	CRR30	MRR30	0.68	0.75
GDD530	MTG90	MTX90	MTN90	CRR30	MRR90	0.75	0.65
GDD090	MTG90	MTX90	MTN90	CRR90	MRR90	0.69	0.73
GDD090	MTG30	MTX30	MTN30	CRR90	MRR30	0.73	0.68
GDD590	MTG90	MTX90	MTN90	CRR90	MRR90	0.70	0.72
GDD590	MTG30	MTX30	MTN30	CRR90	MRR30	0.73	0.68

Table S2. Random Forest models for interannual variation in autumn phenology on the basis of different predictor combinations considering different temporal windows prior to the phenological event. Temperature and precipitation predictors were derived from the European Climate Assessment & Dataset (Haylock et al. 2008), and the DAL and SIS (w/m^2) predictors from Meteosat satellite sensors (Müller and Trentmann 2013; Posselt et al. 2011; Posselt et al. 2012). TX, TN and TG: maximum, minimum and average temperature, respectively; PP: precipitation; SIS: surface incoming shortwave radiation; DAL: surface radiation daylight; GDD: growing degree days; CHIL: chilling requirements; FF, LF and PF: first, last and period of freeze, respectively. Prefix M and C represent the mean and cumulated functions. Suffix 30 and 90 refers to the number of days considered in the computation of the predictors.

Models												Ps-R^2	RMSE
GDD030	MTG30	MTX30	MTN30	CHIL30	FF	CRR30	MRR30	CSIS30	MSIS30	CDAL30	MDAL30	0.58	1.05
GDD030	MTG90	MTX90	MTN90	CHIL30	FF	CRR30	MRR90	CSIS30	MSIS90	CDAL30	MDAL90	0.61	1.01
GDD530	MTG30	MTX30	MTN30	CHIL30	FF	CRR30	MRR30	CSIS30	MSIS30	CDAL30	MDAL30	0.57	1.05
GDD530	MTG90	MTX90	MTN90	CHIL30	FF	CRR30	MRR90	CSIS30	MSIS90	CDAL30	MDAL90	0.61	1.01
GDD090	MTG30	MTX30	MTN30	CHIL90	FF	CRR90	MRR30	CSIS90	MSIS30	CDAL90	MDAL30	0.58	1.04
GDD090	MTG90	MTX90	MTN90	CHIL90	FF	CRR90	MRR90	CSIS90	MSIS90	CDAL90	MDAL90	0.60	1.02
GDD590	MTG30	MTX30	MTN30	CHIL90	FF	CRR90	MRR30	CSIS90	MSIS30	CDAL90	MDAL30	0.59	1.03
GDD590	MTG90	MTX90	MTN90	CHIL90	FF	CRR90	MRR90	CSIS90	MSIS90	CDAL90	MDAL90	0.61	1.00
GDD030	MTG30	MTX30	MTN30	CHIL30	FF	CRR30	MRR30					0.54	1.09
GDD030	MTG90	MTX90	MTN90	CHIL30	FF	CRR30	MRR90					0.57	1.06
GDD530	MTG30	MTX30	MTN30	CHIL30	FF	CRR30	MRR30					0.54	1.09
GDD530	MTG90	MTX90	MTN90	CHIL30	FF	CRR30	MRR90					0.57	1.06
GDD090	MTG30	MTX30	MTN30	CHIL90	FF	CRR90	MRR30					0.54	1.09
GDD090	MTG90	MTX90	MTN90	CHIL90	FF	CRR90	MRR90					0.53	1.10
GDD590	MTG30	MTX30	MTN30	CHIL90	FF	CRR90	MRR30					0.55	1.08
GDD590	MTG90	MTX90	MTN90	CHIL90	FF	CRR90	MRR90					0.55	1.08
GDD030	MTG30	MTX30	MTN30	CHIL30	FF							0.54	1.10
GDD030	MTG90	MTX90	MTN90	CHIL30	FF							0.56	1.07
GDD530	MTG30	MTX30	MTN30	CHIL30	FF							0.53	1.10
GDD530	MTG90	MTX90	MTN90	CHIL30	FF							0.56	1.07
GDD090	MTG30	MTX30	MTN30	CHIL90	FF							0.52	1.11
GDD090	MTG90	MTX90	MTN90	CHIL90	FF							0.52	1.12
GDD590	MTG30	MTX30	MTN30	CHIL90	FF							0.52	1.11
GDD590	MTG90	MTX90	MTN90	CHIL90	FF							0.54	1.09
GDD030	MTG30	MTX30	MTN30	CHIL30								0.48	1.16
GDD030	MTG90	MTX90	MTN90	CHIL30								0.49	1.14
GDD530	MTG30	MTX30	MTN30	CHIL30								0.48	1.16
GDD530	MTG90	MTX90	MTN90	CHIL30								0.49	1.14
GDD090	MTG30	MTX30	MTN30	CHIL90								0.49	1.15
GDD090	MTG90	MTX90	MTN90	CHIL90								0.45	1.19
GDD590	MTG30	MTX30	MTN30	CHIL90								0.48	1.16
GDD590	MTG90	MTX90	MTN90	CHIL90								0.47	1.17
GDD030	MTG30	MTX30	MTN30									0.41	1.23
GDD030	MTG90	MTX90	MTN90									0.38	1.27
GDD530	MTG30	MTX30	MTN30									0.41	1.24
GDD530	MTG90	MTX90	MTN90									0.37	1.28
GDD090	MTG30	MTX30	MTN30									0.43	1.22
GDD090	MTG90	MTX90	MTN90									0.37	1.28
GDD590	MTG30	MTX30	MTN30									0.42	1.23
GDD590	MTG90	MTX90	MTN90									0.40	1.25

Table S3. Random Forest models for interannual variation in autumn phenology considering spring interannual variation as a predictor and different temporal windows prior to the phenological event. Temperature and precipitation predictors were derived from the European Climate Assessment & Dataset (Haylock et al. 2008), and the DAL and SIS (w/m^2) predictors from Meteosat satellite sensors (Müller and Trentmann 2013; Posselt et al. 2011; Posselt et al. 2012). OGA: Z-score value in onset on greenness, legacy effect of an advanced or delayed spring. TX, TN and TG: maximum, minimum and average temperature, respectively; PP: precipitation; SIS: surface incoming shortwave radiation; DAL: surface radiation daylight; GDD: growing degree days; CHIL: chilling requirements; FF, LF and PF: first, last and period of freeze, respectively. Prefix M and C represent the mean and cumulated functions. Suffix 30 and 90 refers to the number of days considered in the computation of the predictors.

						Models							Ps-R^2	RMSE
OGA	GDD030	MTG30	MTX30	MTN30	CHIL30	FF	CRR30	MRR30	CSIS30	MSIS30	CDAL30	MDAL30	0.58	1.04
OGA	GDD030	MTG90	MTX90	MTN90	CHIL30	FF	CRR30	MRR90	CSIS30	MSIS90	CDAL30	MDAL90	0.61	1.01
OGA	GDD530	MTG30	MTX30	MTN30	CHIL30	FF	CRR30	MRR30	CSIS30	MSIS30	CDAL30	MDAL30	0.58	1.04
OGA	GDD530	MTG90	MTX90	MTN90	CHIL30	FF	CRR30	MRR90	CSIS30	MSIS90	CDAL30	MDAL90	0.61	1.01
OGA	GDD090	MTG30	MTX30	MTN30	CHIL90	FF	CRR90	MRR30	CSIS90	MSIS30	CDAL90	MDAL30	0.59	1.03
OGA	GDD090	MTG90	MTX90	MTN90	CHIL90	FF	CRR90	MRR90	CSIS90	MSIS90	CDAL90	MDAL90	0.60	1.02
OGA	GDD590	MTG30	MTX30	MTN30	CHIL90	FF	CRR90	MRR30	CSIS90	MSIS30	CDAL90	MDAL30	0.60	1.02
OGA	GDD590	MTG90	MTX90	MTN90	CHIL90	FF	CRR90	MRR90	CSIS90	MSIS90	CDAL90	MDAL90	0.61	1.00
OGA	GDD030	MTG30	MTX30	MTN30	CHIL30	FF	CRR30	MRR30					0.55	1.08
OGA	GDD030	MTG90	MTX90	MTN90	CHIL30	FF	CRR30	MRR90					0.57	1.05
OGA	GDD530	MTG30	MTX30	MTN30	CHIL30	FF	CRR30	MRR30					0.54	1.09
OGA	GDD530	MTG90	MTX90	MTN90	CHIL30	FF	CRR30	MRR90					0.57	1.05
OGA	GDD090	MTG30	MTX30	MTN30	CHIL90	FF	CRR90	MRR30					0.55	1.08
OGA	GDD090	MTG90	MTX90	MTN90	CHIL90	FF	CRR90	MRR90					0.53	1.10
OGA	GDD590	MTG30	MTX30	MTN30	CHIL90	FF	CRR90	MRR30					0.56	1.07
OGA	GDD590	MTG90	MTX90	MTN90	CHIL90	FF	CRR90	MRR90					0.55	1.08
OGA	GDD030	MTG30	MTX30	MTN30	CHIL30	FF							0.55	1.08
OGA	GDD030	MTG90	MTX90	MTN90	CHIL30	FF							0.56	1.07
OGA	GDD530	MTG30	MTX30	MTN30	CHIL30	FF							0.54	1.09
OGA	GDD530	MTG90	MTX90	MTN90	CHIL30	FF							0.56	1.06
OGA	GDD090	MTG30	MTX30	MTN30	CHIL90	FF							0.54	1.09
OGA	GDD090	MTG90	MTX90	MTN90	CHIL90	FF							0.52	1.11
OGA	GDD590	MTG30	MTX30	MTN30	CHIL90	FF							0.53	1.10
OGA	GDD590	MTG90	MTX90	MTN90	CHIL90	FF							0.55	1.08
OGA	GDD030	MTG30	MTX30	MTN30	CHIL30								0.50	1.14
OGA	GDD030	MTG90	MTX90	MTN90	CHIL30								0.51	1.12
OGA	GDD530	MTG30	MTX30	MTN30	CHIL30								0.50	1.14
OGA	GDD530	MTG90	MTX90	MTN90	CHIL30								0.51	1.12
OGA	GDD090	MTG30	MTX30	MTN30	CHIL90								0.51	1.12
OGA	GDD090	MTG90	MTX90	MTN90	CHIL90								0.48	1.15
OGA	GDD590	MTG30	MTX30	MTN30	CHIL90								0.51	1.13
OGA	GDD590	MTG90	MTX90	MTN90	CHIL90								0.51	1.13
OGA	GDD030	MTG30	MTX30	MTN30									0.42	1.23
OGA	GDD030	MTG90	MTX90	MTN90									0.41	1.24
OGA	GDD530	MTG30	MTX30	MTN30									0.42	1.22
OGA	GDD530	MTG90	MTX90	MTN90									0.40	1.24
OGA	GDD090	MTG30	MTX30	MTN30									0.44	1.20
OGA	GDD090	MTG90	MTX90	MTN90									0.39	1.26
OGA	GDD590	MTG30	MTX30	MTN30									0.43	1.21
OGA	GDD590	MTG90	MTX90	MTN90									0.42	1.22

Table S4. Details of spring and autumn multivariate least squares linear regressions. TN and TG: minimum and average temperature, respectively; SIS: surface incoming shortwave radiation; GDD: growing degree days; CHIL: chilling requirements; FF: first freeze. Prefix M and C represent the mean and cumulated functions. Suffix 30 and 90 refers to the number of days considered in the computation of the predictors.

Model	R^2	Std. error	Significance
$OG_{Z\text{-}score}$=-3.79E-01-4.98E-04*MTN30-4.04E-04*CSIS90+4.42E-04*MTG30-7.33E-05*GDD090+1.34E-02*CHIL90+1.24E-04*MSIS30	0.36	1.05	6.15E-184
$EOS_{Z\text{-}score}$=4.85E-03+3.76E-04*FF+1.16E-03*CHIL30+4.54E-05*MTN90+4.28E-06*MTX90+8.68E-07*GDD030-6.31E-08*MSIS90	0.25	1.40	1.31E-91

Figure S1. Z-score values of the onset on greenness (OG) date estimates over the European forest for the 2003–2011 period. The z-score values for a given year were computed as the difference from the multi-year mean, normalized by the standard deviation across years.

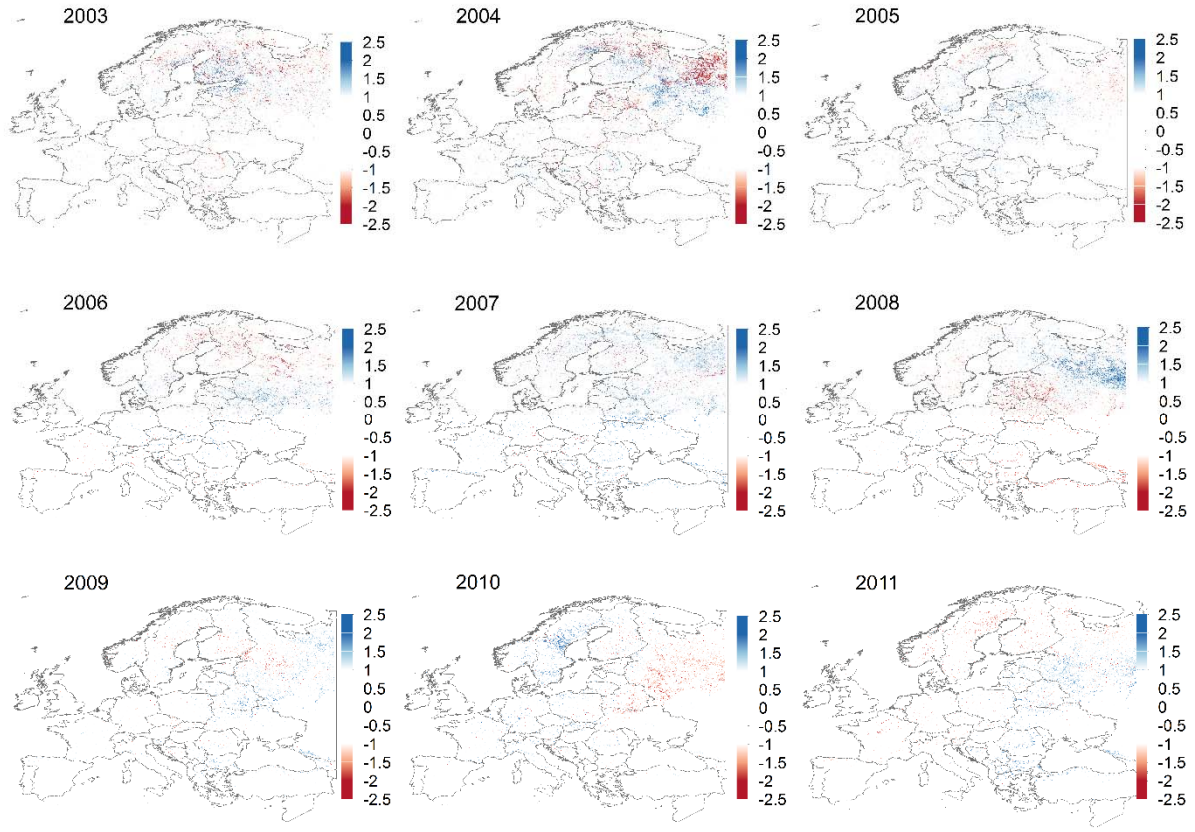


Figure S2. Z-score values of the end of senescence date estimates over the European forest for the 2003–2011 period. The z-score values for a given year were computed as the difference from the multi-year mean, normalized by the standard deviation across years.

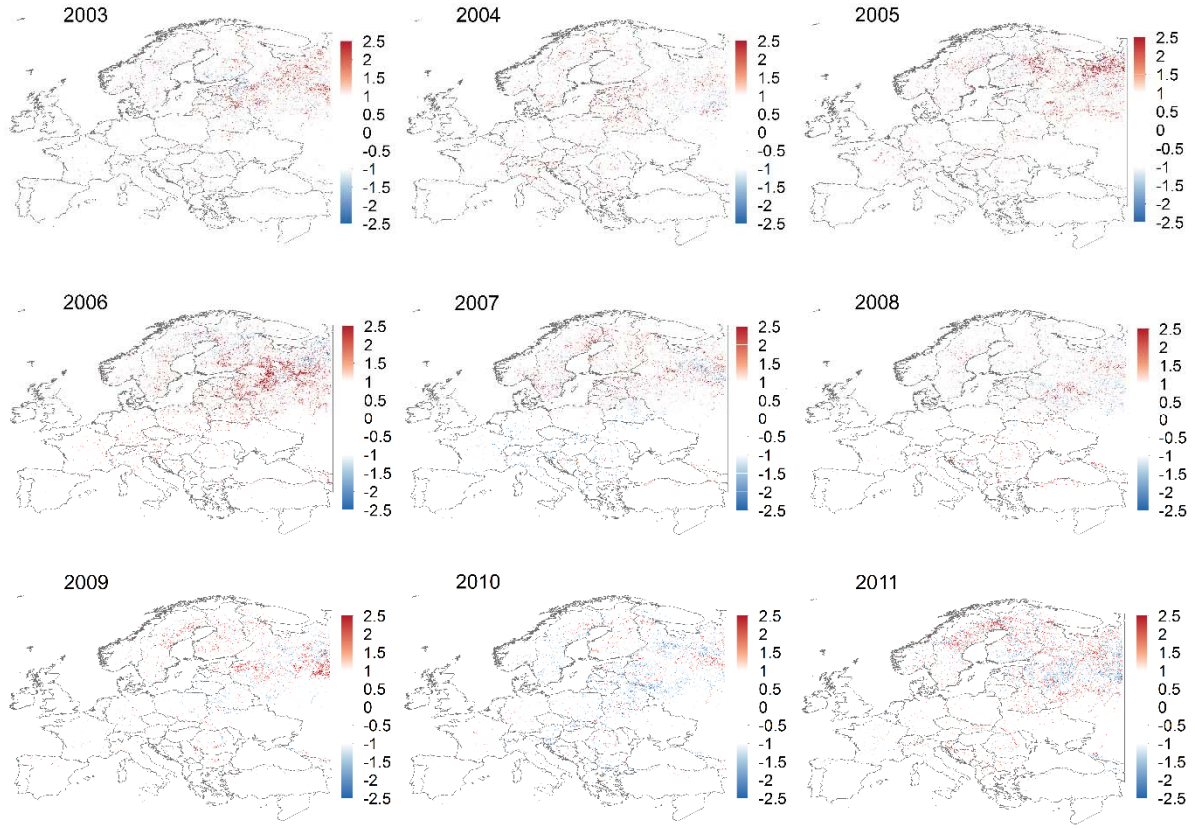


Figure S3. Relative errors between observed interannual variation in onset on greenness and the predictions of the selected Random forest model based on an independent test.

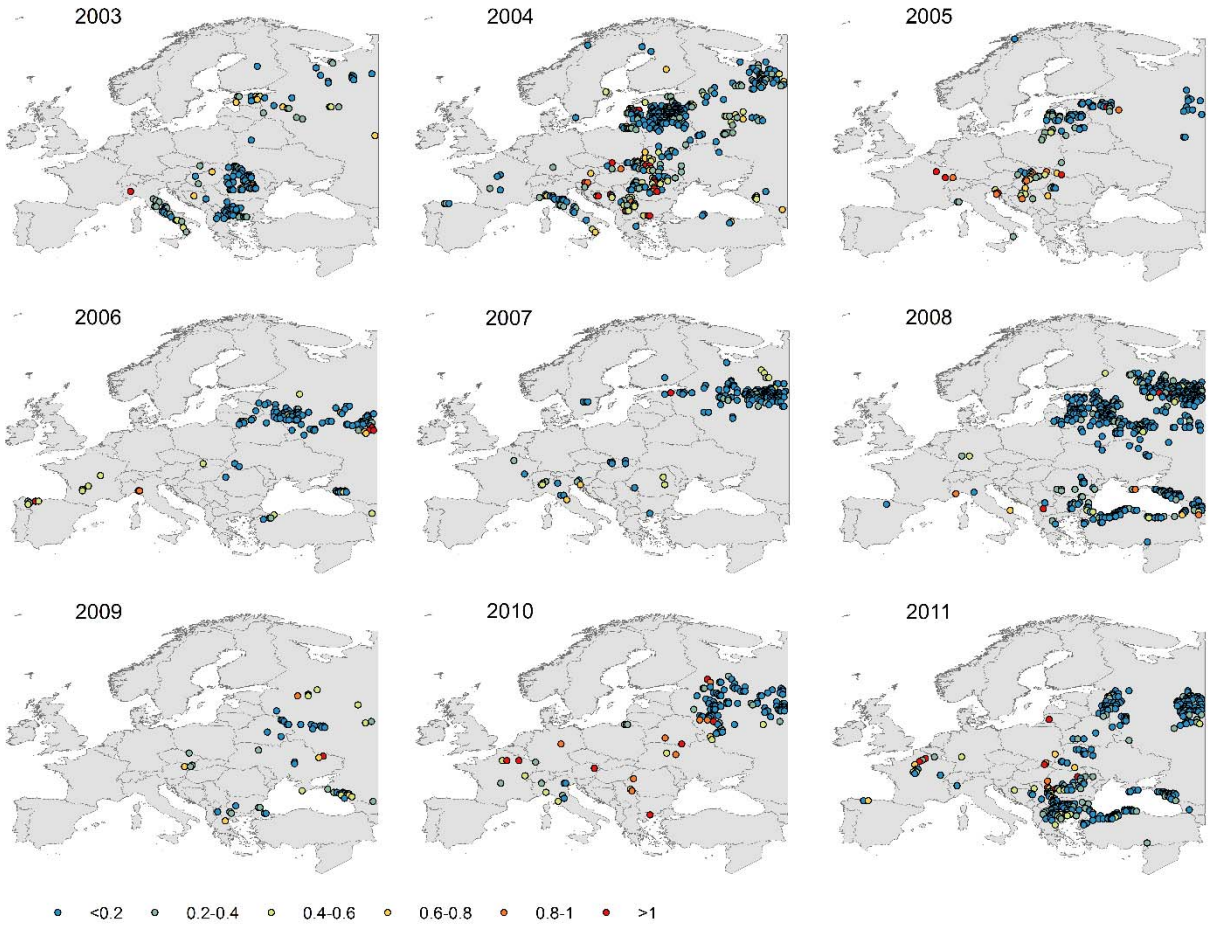


Figure S4. Relative errors between observed interannual variation in onset on greenness and the predictions of the multivariate linear regression model based on an independent test.

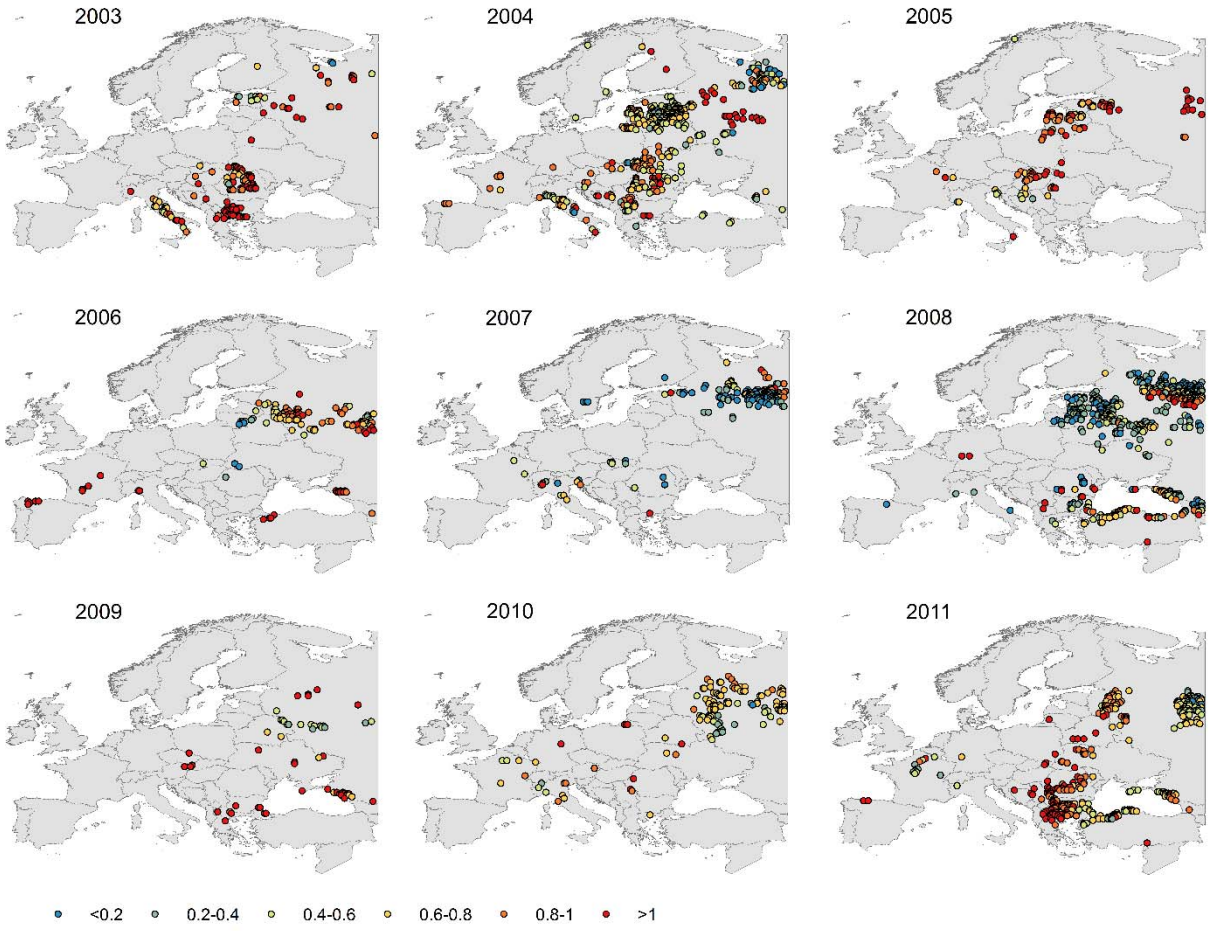


Figure S5. Relative errors between observed interannual variation in end of senescence and the predictions of the selected Random forest model based on an independent test.

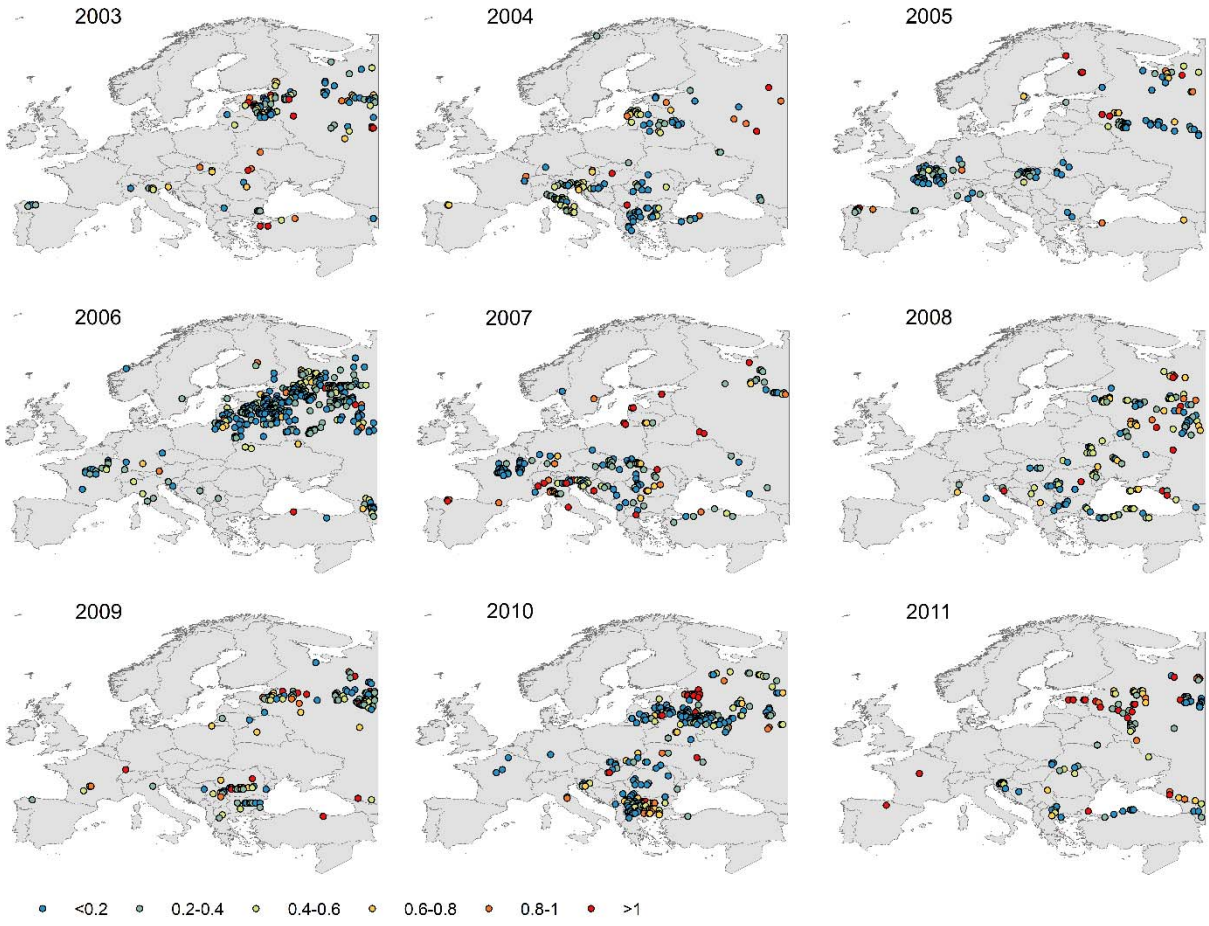
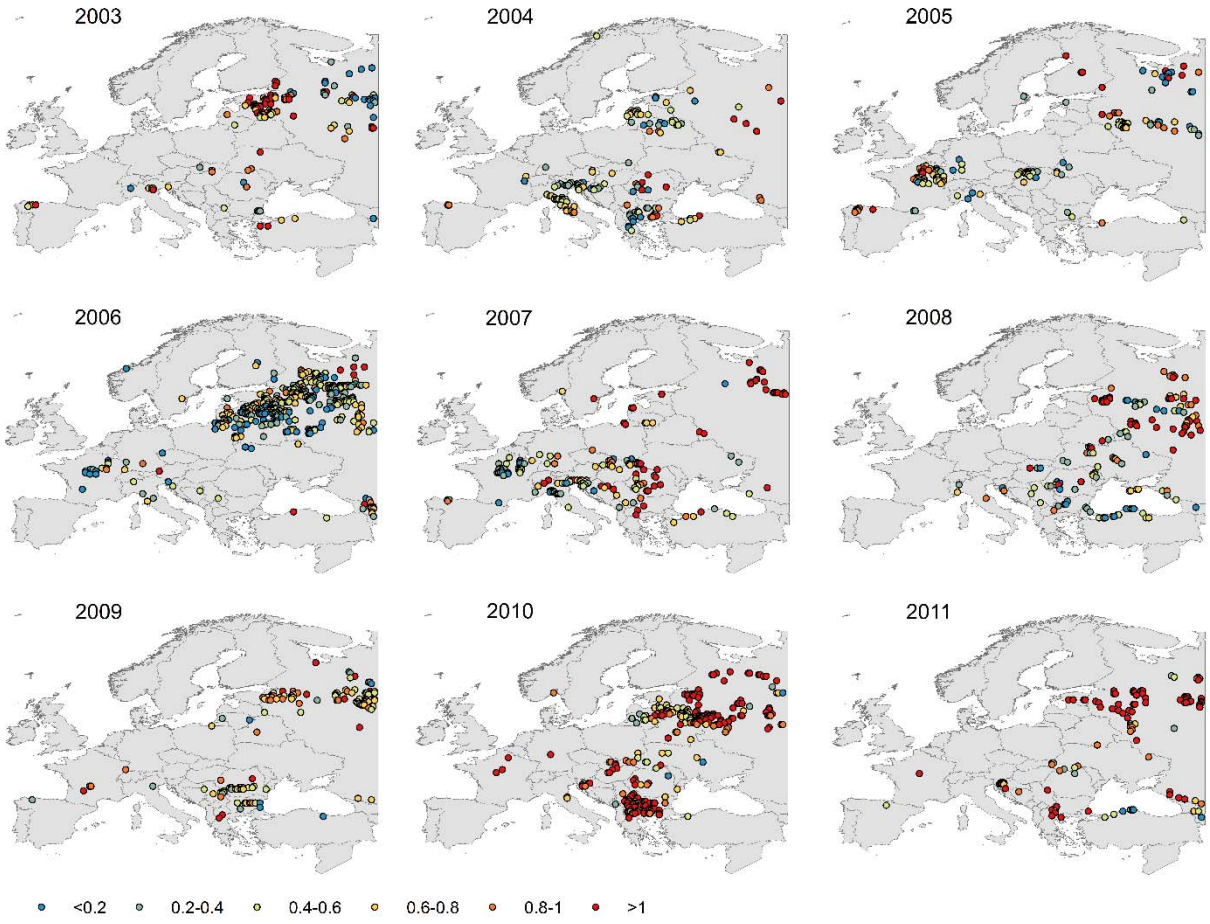


Figure S6. Relative errors between observed interannual variation in end of senescence and the predictions of the selected Random forest model based on an independent test.



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