INRAE Occitanie-Montpellier - MISTEA

Weather generators and phenological models to study climate change impacts on grapevines and apples

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   - Estimation
   - Simulation

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   - Apple Model
   - With simulated TG (Apple)

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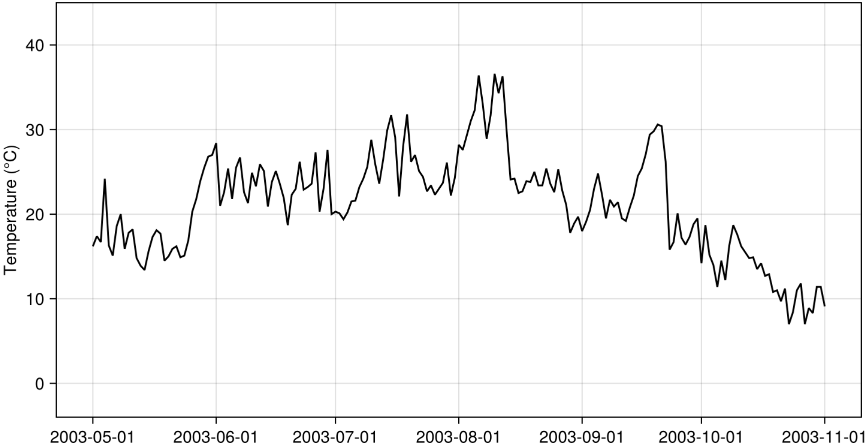
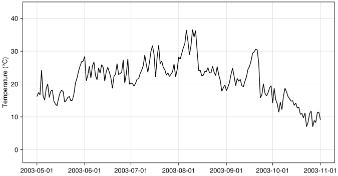
I. Stochastic weather generators



Recorded daily maximum temperature (TX) at Lille from 1st May 2003 to 1st November 2003 (source : ECA&D)

Weather data



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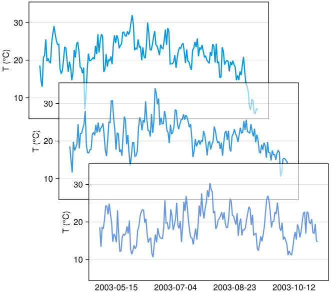
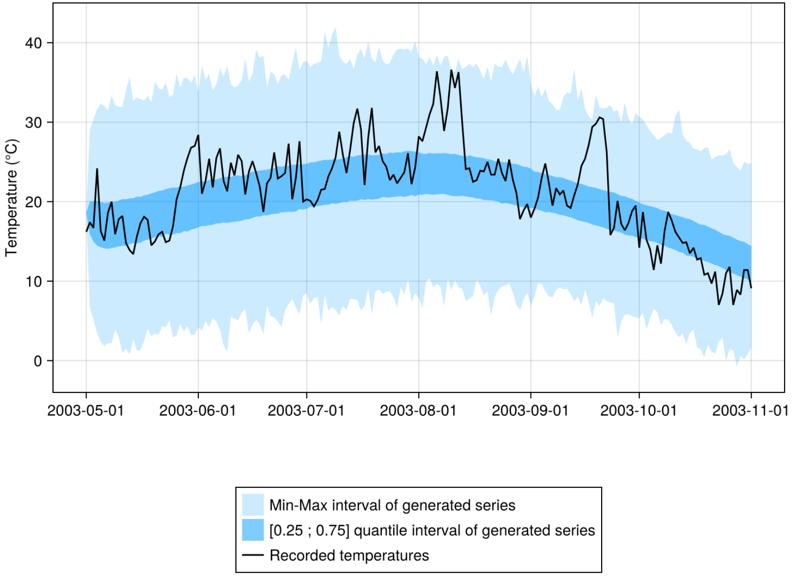
Stochastic Model

→

Simulations

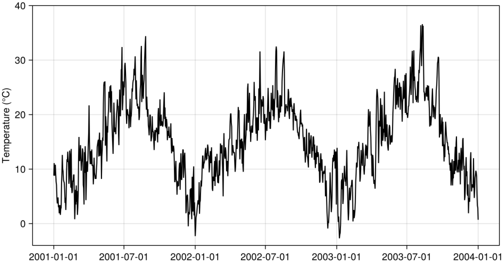


With 5000 simulations :

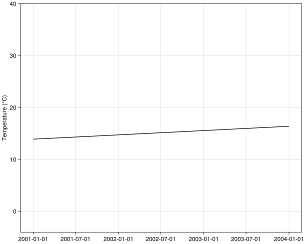


$Y_t = T_t + S_t + X_t$ where

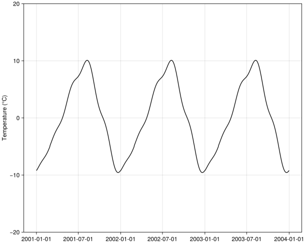
- T_t is the trend
- S_t is the seasonality
- X_t is the stochastic part



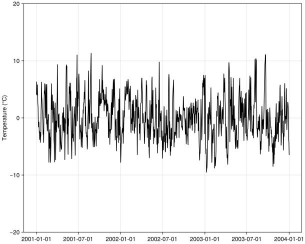
Y_t



T_t



S_t



X_t

- Trend : $T_t = \mu$ (for now)
- Seasonality :

$$S_t = \sum_{k=1}^{K} \alpha_k \cos(\omega k t) + \beta_k \sin(\omega k t)$$

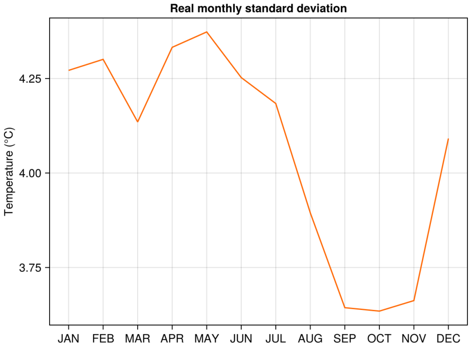
With $\omega = 2\pi/365.25$, α_k and β_k coefficients to estimate and K the order ($K = 5$ in our work).

I. Stochastic weather generators | Model

- Stochastic part $\sim$ AR(p) model :

$$X_t = \sum_{i=1}^{p} \phi_i X_{t-i} + \sigma \varepsilon_t$$

With $\varepsilon_t \overset{\text{iid}}{\sim} \mathcal{N}(0,1)$, ϕ_i and σ coefficients to estimate and p the order (we have chosen $p = 1$).
Problem : Some features change during a year :



Model with different parameters for each month :

$$X_t = \sum_{i=1}^{p} \phi_{i,m(t)} X_{t-i} + \sigma_{m(t)} \varepsilon_t$$

With $\varepsilon_t \overset{\text{iid}}{\sim} \mathcal{N}(0,1)$ and $m(t)$ the month of the date t.

$\rightarrow (p+1) \times 12$ parameters

1. **Ordinary Linear Square (OLS) regression** to estimate μ, α_k and β_k for $k = 1, \ldots, K$:

$$Y_t = \mu + \sum_{k=1}^{K} (\alpha_k \cos(\omega k t) + \beta_k \sin(\omega k t)) + X_t$$

With X_t the residuals.

2. **Maximum likelihood estimation** on these residuals to estimate $\phi_{i,j}$ and σ_j^2, for $i = 1, 2, \ldots, p$ and $j = 1, 2, \ldots, 12$:

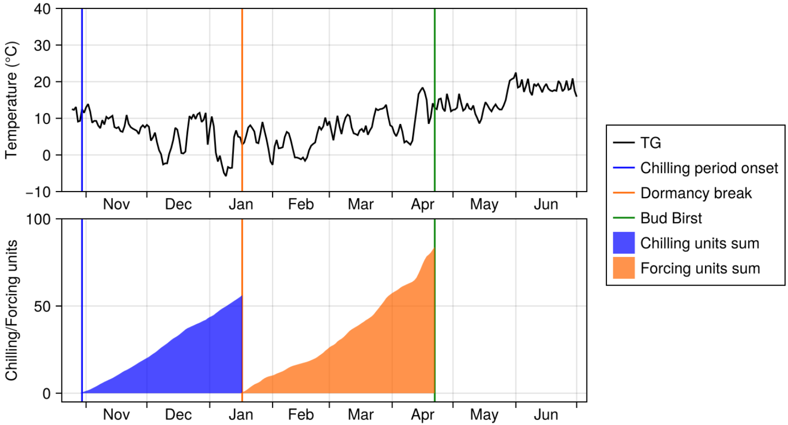
$$X_t = \sum_{i=1}^{p} \phi_{i,m(t)} X_{t-i} + \sigma_{m(t)} \varepsilon_t$$

I. Stochastic weather generators | Simulation

We have estimated $\hat{\mu}$, $\hat{\alpha}_k$ and $\hat{\beta}_k$ for $k = 1, \ldots, K$ and $\hat{\phi}_{i,j}$ and $\hat{\sigma}_j^2$, for $i = 1, 2, \ldots, p$, $j = 1, 2, \ldots, 12$. To simulate new temperatures series :

1. Initial conditions : $\hat{X}_1 = X_1, \hat{X}_2 = X_2, \ldots, \hat{X}_p = X_p$
2. For $t > p$:
   $$\hat{X}_t = \sum_{i=1}^{p} \hat{\phi}_{i,m(t)} \hat{X}_{t-i} + \hat{\sigma}_{m(t)} \varepsilon_t$$
   With $\varepsilon_t \sim \mathcal{N}(0, 1)$.
3. $$\hat{Y}_t = \hat{\mu} + \sum_{k=1}^{K} (\hat{\alpha}_k \cos(\omega k t) + \hat{\beta}_k \sin(\omega k t)) + \hat{X}_t$$

II. Phenological models



Apple phenology dates simulated for the 2002-2003 period in Lille, according to the parameters estimated in Legave and al. - 2013

Dormancy break date :

$$n_{db} = \min\{N, \sum_{n=CPO}^{N} C_U(n) > C_c\}$$

Budbirst date :

$$n_{bb} = \min\{N, \sum_{n=n_{db}}^{N} A_c(n) > G_{hc}\}$$

CPO : Chilling period onset
C_c, G_{hc} : Chilling and heating quantity required
C_U, A_c : Chilling and heating function

Chilling function :

$$C_U(n) = Q_{10c}^{-\frac{TX(n)}{10}} + Q_{10c}^{-\frac{TN(n)}{10}}$$

Heating function :

$$T^*(h,n) = \begin{cases} TN(n) + h\left(\frac{TX(n)-TN(n)}{12}\right) & \text{if } h \leq 12 \\ TX(n) - (h-12)\left(\frac{TX(n)-TN(n+1)}{12}\right) & \text{if } h > 12 \end{cases}$$

$$T(h,n) = \begin{cases} 0 & \text{if } T^*(h,n) < T_{0Bc} \\ T^*(h,n) - T_{0Bc} & \text{if } T_{0Bc} \leq T^*(h,n) \leq T_{MBc} \\ T_{MBc} - T_{0Bc} & \text{if } T_{MBc} < T^*(h,n) \end{cases}$$

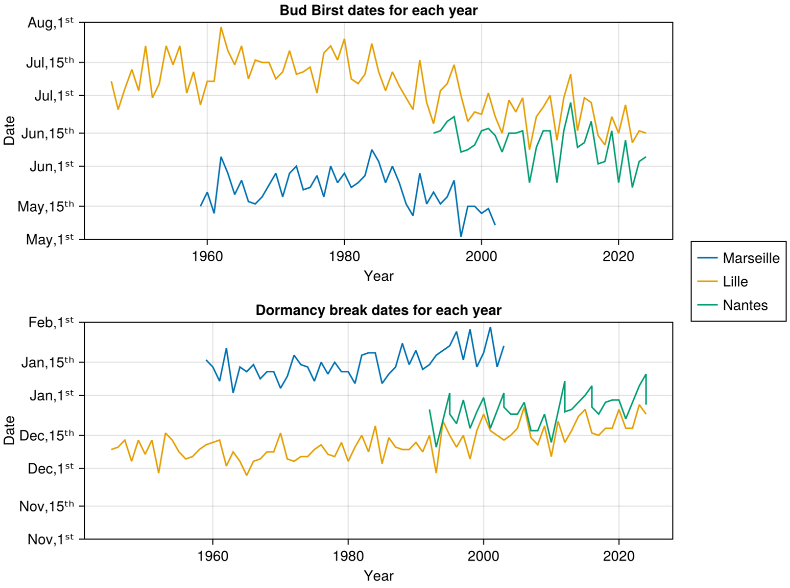
$$A_c(n) = \sum_{h=1}^{24} T(h,n)$$

Q_{10c} and T_{0Bc} are parameters and T_{MBc} is fixed at 25°C.

Parameters considered for our simulation :

- CPO : 1^{st} of August
- C_c : 119.0 (chilling units)
- G_{hc} : 13236°C
- Q_{10c} : 2.17
- T_{0Bc} : 8.19°C

II. Phenological models | Grapevine



Dormancy break date :

$$n_{db} = \min\{N, \sum_{n=CPO}^{N} F_c(TG(n)) > C\}$$

Budbirst date :

$$n_{bb} = \min\{N, \sum_{n=n_{db}}^{N} F_h(TG(n)) > H\}$$

CPO : Chilling period onset
C, H : Chilling and heating quantity required
F_c, F_h : Chilling and heating function

Parameters considered for our simulation :

- CPO : 30th of October
- C : 56.0 (chilling units)
- H : 83.58 (forcing units)
- F_c : Triangular chilling

$$F_c(T) = \begin{cases} 1 - (|T - T_c|/I_c) & \text{if } T \in (T_c - I_c, T_c + I_c) \\ 0 & \text{else} \end{cases}$$

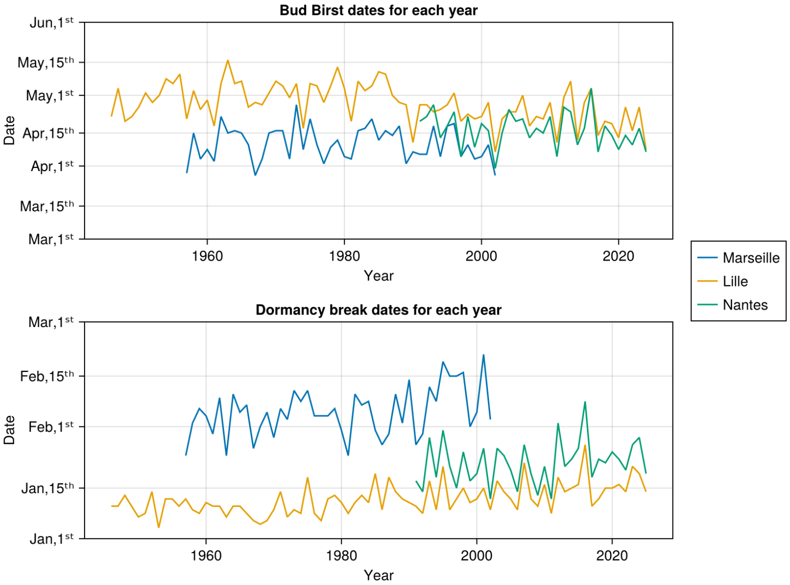
With $T_c = 1.1°\text{C}$ and $I_c = 20.°\text{C}$

- F_h : Exponential forcing

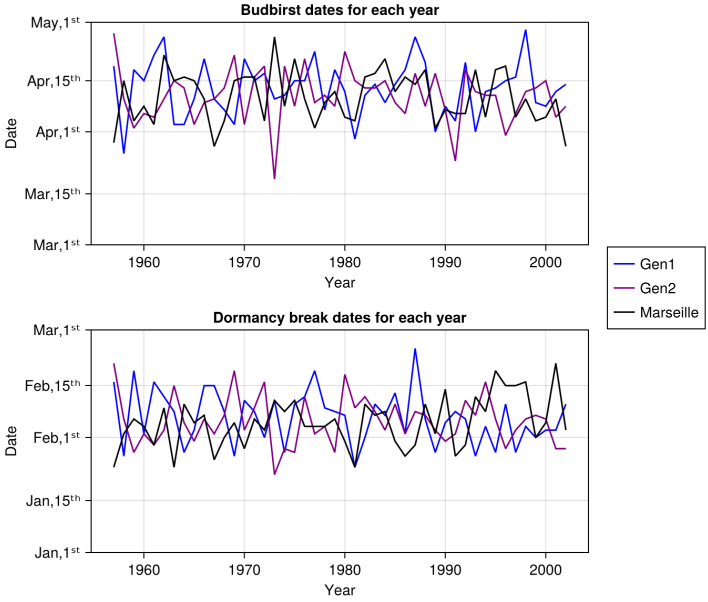
$$F_h(T) = \exp(T/T_h)$$

With $T_h = 9.0°\text{C}$

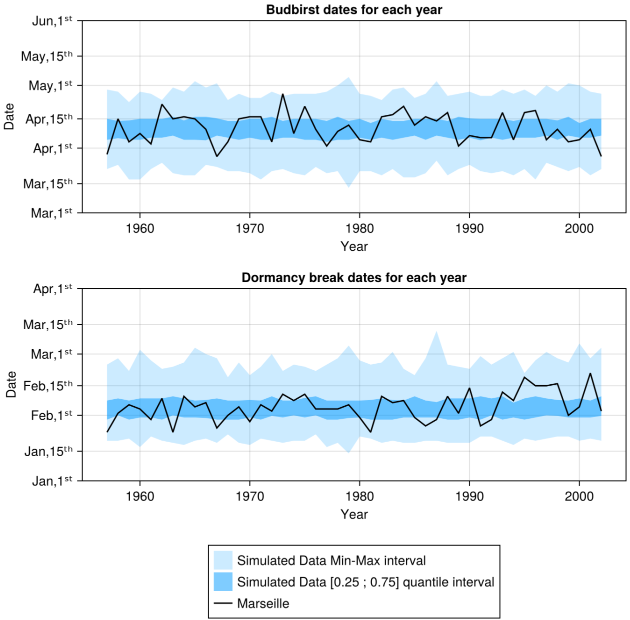
II. Phenological models | Apple



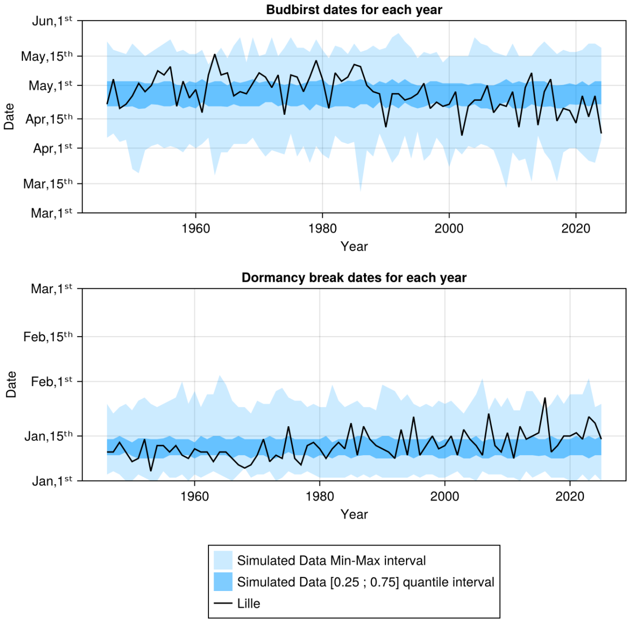
II. Phenological models | With simulated TG (Apple)



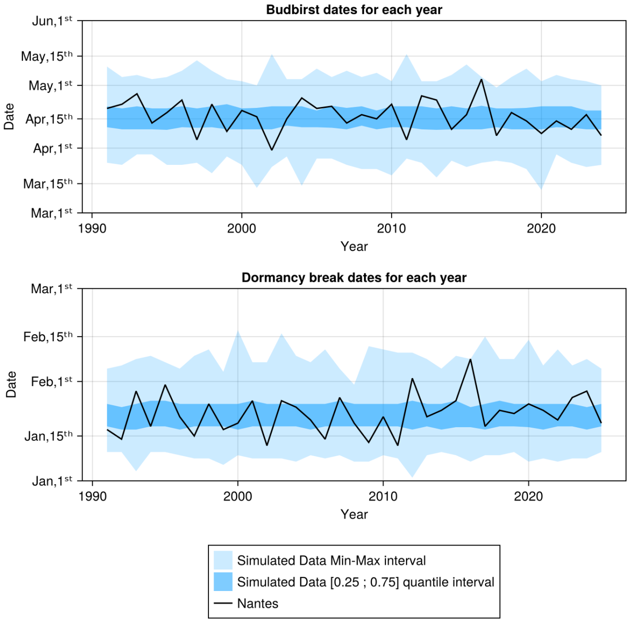
II. Phenological models | With simulated TG (Apple)



II. Phenological models | With simulated TG (Apple)



II. Phenological models | With simulated TG (Apple)



Conclusion

- We have studied and implemented a model that is able to generate temperature series but with a too simple modeling of the trend.
- We have implemented phenological models and applied them on stations from different climates in France, and we noticed that there is an evolution across the years since ≈ 1980.
- Finally, we have applied phenological on simulated series, and the results show that it is required to consider a better model for the trend if we want more realistic temperature series.

Thanks you !