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BUDBURST OF EUROPEAN BEECH IN VENTOUX FOREST: A MODELLING APPROACH OF TRADE-OFF BETWEEN CARBON INPUT AND FROST RISKS

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1. Introduction

Phenology consists in the study of cyclical biological events, such as flowering, budburst, breeding, and dispersion. These phenological observations can be interpreted with respect to climatic conditions. For vegetation, it is an important adaptive trait since it determines duration and timing of the growing season as well as the period of reproduction (Chuine et al., 2000) and is also shown to be a major determinant of plant species ranges. Change of phenology is one of the most easily observed responses to climatic change (Parmesan & Yohe, 2003). As budbreak determines the length of growing season for deciduous species, it is also an important factor determining their carbon budget. Davi et al. (2006) showed that for deciduous species, the length of the leafy period might increase by 38 days from 1960 to 2100 (early budburst contributing for 55% and delayed leaf fall for 45% of this increase).
Fagus sylvatica budburst is late in plain and is quite early in high altitudes while its growth is negatively affected from earlier budburst due to late frost. This behaviour is probably due to the necessity to increase as more as possible the vegetation length.
In this presentation, we first compared beech budburst with other species, within plains using a French database and along an altitudinal gradient. Then, the variations of budburst with altitude were discussed from an adaptative perspective using simulations obtained from a process based model.

Material and Methods

The French database RENECOFOR
The RENECOFOR-network was created by the French National Forest Board (Office National des Forêts, ONF) in 1992 in order to complete the existing French forest health monitoring activities. In each plot, phenological observations were performed once a week on 36 trees representative of the plot in terms of species, age and structure. Budburst date was defined as the date when 50% of the trees have the buds open over at least 20% of the crown of each tree. To compare *Fagus* with other species, 1186 budburst dates were analysed for six deciduous species from 1997 to 2005.

The altitudinal gradient
The altitudinal gradient was studied on Mont Ventoux (44°11'N; 5°17'E), a mountain located at the south-western of the Alps (1909m). In 1850, it was almost entirely deforested due to pastoral and forest over-exploitation. The decrease of grazing combined with the reforestation efforts undertaken in the 20th century using pines made it possible for post-pioneers (*Sorbus aria*, *Acer opalus*) and shade-tolerant species (*Abies alba* Mill. and *Fagus sylvatica* L.) to gradually recolonize the planted stands. Climate is typical of low altitude mountains with Mediterranean influences with 9.25°C mean annual temperature and 1068 mm mean annual

rainfall at 1000 m. Two gradients were further studied: 4 stands on the north face and 4 stands on south face (respectively at 890m, 1115m, 1410m, 1530m gathering 90 beeches).

Measures
A notation of bud development was carried out for each tree every week (14 times in 2006 and 18 times in 2007) by distinguishing the bottom and the top of the canopy. Six marks were used to quantify accurately budburst dynamics. The position, altitude, diameter and height of each tree were recorded. Temperature and relative humidity were recorded using eight mini meteorological stations Prosensor V2 (U23-001 ±0.2°C; ±2.5% RH). All the stations were put at 1.5 m from the ground in a cleared stand inside a case protecting the sensors against direct radiation and overheating.

CASTANEA Model
CASTANEA is a physiological process-based model simulating the carbon and the water balance in forest stands. The main simulated output variables are the canopy photosynthesis, maintenance and growth respiration, organs growth, soil heterotrophic respiration, transpiration, and evapotranspiration. Phenological stages (budburst, end of leaf growth, and start of leaf yellowing) and leaf growth depend on degree days (i.e. heat amount accumulated). Budburst is simulated following the equation 1-3:

(1) $$R_{frcBB} = \begin{cases} T & \text{if } T > T_1 \quad \textit{and} \quad N > Nstart \\ 0 & \text{if } T \le T_1 \quad \textit{or} \quad N < Nstart \end{cases}$$

where R_{frcBB} is the rate of forcing for bud break, T the mean daily temperature, T the base temperature, N the day of year and N_{START} the date of onset of rest.

(2) $$S_{frcBB} = \sum_{N_{START}}^{N} R_{frcBB} \qquad \text{if} \qquad S_{frcBB} < F_{critBB}$$

(3) $$N_{BB} = N \qquad \text{if} \qquad S_{frcBB} = F_{critBB}$$

with S_{frcBB} the state of forcing, F_{critBB} the critical value of state of forcing for the transition from quiescence to the active period and N_{BB} the day when bud break occurred. Effects of frost are taken into account when Tmin is below -3°C (Dittmar et al. 2006). Complete description and validation of the model were given in Dufrêne et al. (2005).

Results and discussion

Renecofor data base
In plain, *Fagus* budburst occurs later (Julian day 114) than other deciduous species (110, 107, 112, 107, 110 respectively for *Betula*, *Carpinus*, *Castanea*, *Corylus* and *Quercus*). Correlation coefficient (Coef) between average temperature from January to March and average budburst date is higher for *Fagus* (r=-0.5) than for *Quercus* (r=-0.32). Furthermore, *Fagus* is the only species for which Coef is higher with April temperature (r=-0.58) than with average temperature since January. This last result shows the importance of frost on beech phenology.

Altitudinal gradient
Budburst occurs later in high altitudes (Fig. 1a) and later in 2006 than in 2007. Estimated state of forcing (with N_{START}=74 and T_1=0) is the same between 2006 and 2007, but change between North and South faces and with altitudes (Figure 1b). These observations could be the result of adaptation to altitude and exposition. Indeed these changes allow to maximize the carbon gain by increasing vegetation length (early budburst), but avoiding frost damages that occur Tmin is below -3°C (Fig 2).

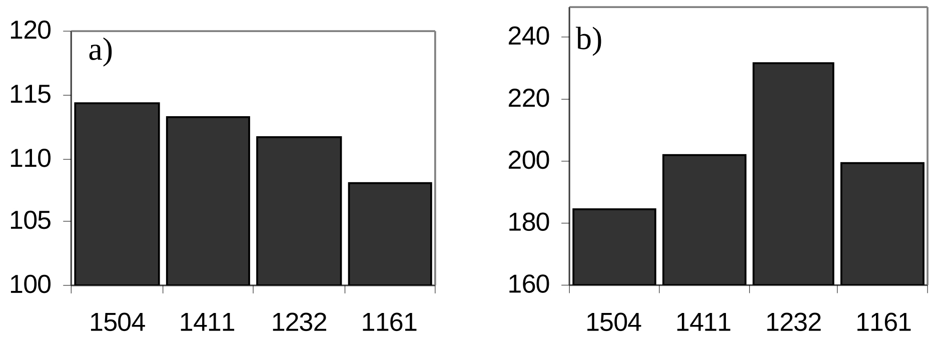

Figure 1: a) Mean date of budburst and b) estimated state of forcing (°C) in function of altitude

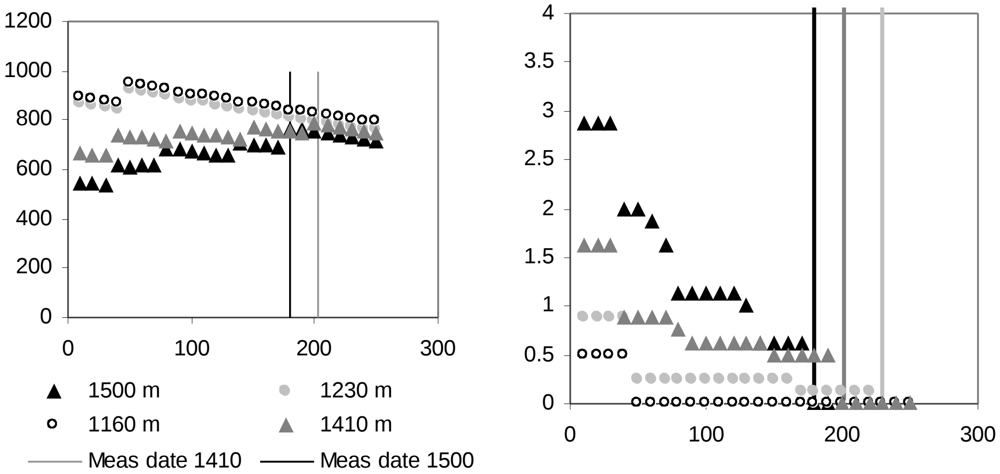

Figure 2: Sensitivity of a) GPP-R (g_C m^{-2} y^{-1}) b) number of days with Tmin<-3°C to simulated state of forcing (°C) in average from 2000 to 2007. Vertical bars indicate the measured state of forcing on four altitudes.

To conclude, state of forcing of Beech budburst appears to be adapted to the elevation with a date of budburst selected to avoid frost damages. This result is consistent with the fact that budburst date is mainly determinate by April temperature (high correlation in the French database and delayed NSTART of Julian Day 74).

References

Chuine I et al. 2000. J. Ecol., 88, 1 :12.
Davi, H. et al. 2006. Agricultural and Forest Meteorology, 141, 35-56.
Dittmar, C., et al. 2006. Eur. J. For. Res. 125: 249-259.
Dufrêne et al. 2005. Ecological modelling. 185(2-4), 407-436.
Parmesan C, et al. 2003. Nature 421: 37–42.