PhenoCaB: a new approach to model spring phenology of boreal conifers

Fabrizio Cartenì, Lorena Balducci, Alain Dupont, Emiliano Salucci, Stefano Mazzoleni and Annie Deslauriers

**PHENOLOGY 2022│ 20 - 24 June 2022│Avignon, France**

Introduction

Phenology = timing of seasonal life cycles

Traditional phenological models

- **Statistical models**
(based on historical series of phenological events in relation to climatic factors)

- **Process-based models**
(relate phenological processes to environmental driving factors)

- **Physiological models**
(relate phenology to carbon balance, hormonal status etc.)
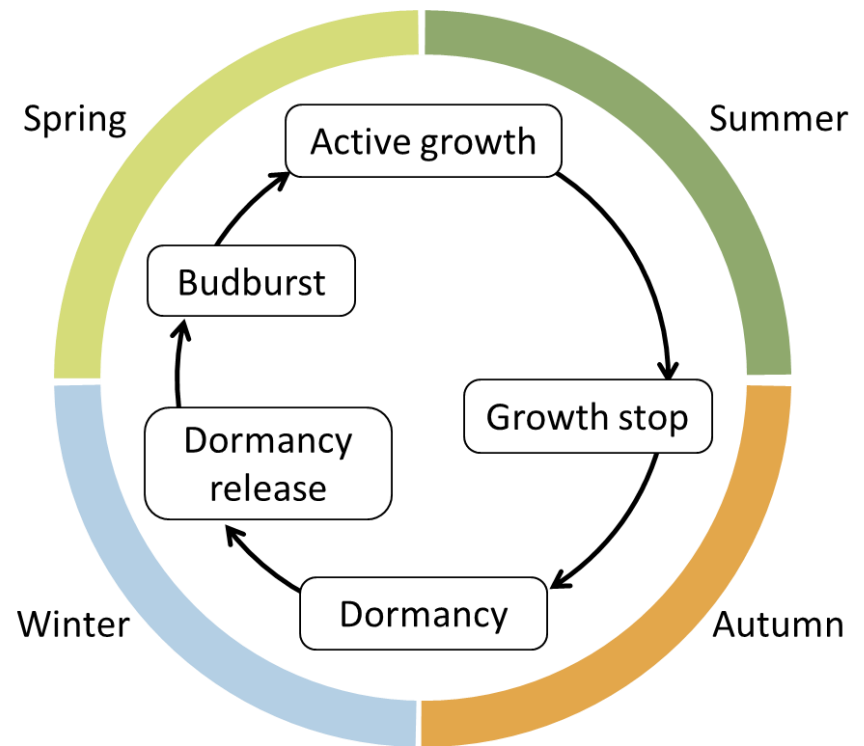
Introduction

Traditional phenological models

- ### Process-based models
(relate phenological processes to environmental driving factors)

State of development
of phase *n*

Critical state for the
completion of phase *n*

$$S_{n,t_n} = \sum_{t=t_{n-1}}^{t=t_n} R_{n,t}(Z) = S_n^*$$

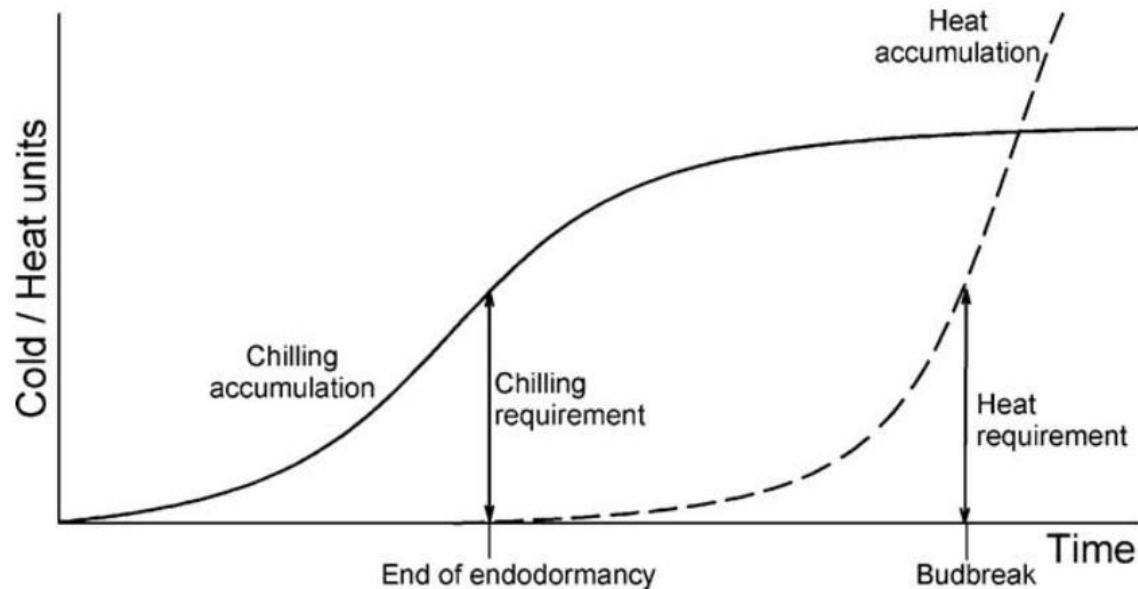Rate of development
of phase *n*

Environmental
variable

Introduction

Traditional phenological models

- ## Process-based models
(relate phenological processes to environmental driving factors)

e.g. temperature sums for dormancy break

Luedeling et al. (2009) Agricultural and Forest Meteorology, 149:1854–1864

Introduction

Traditional phenological models

Main limitations:

- unrelated to plant growth and physiological status
- calibration not applicable to different sites (implicitly considers stand demography, soil etc.) and future scenarios simulations

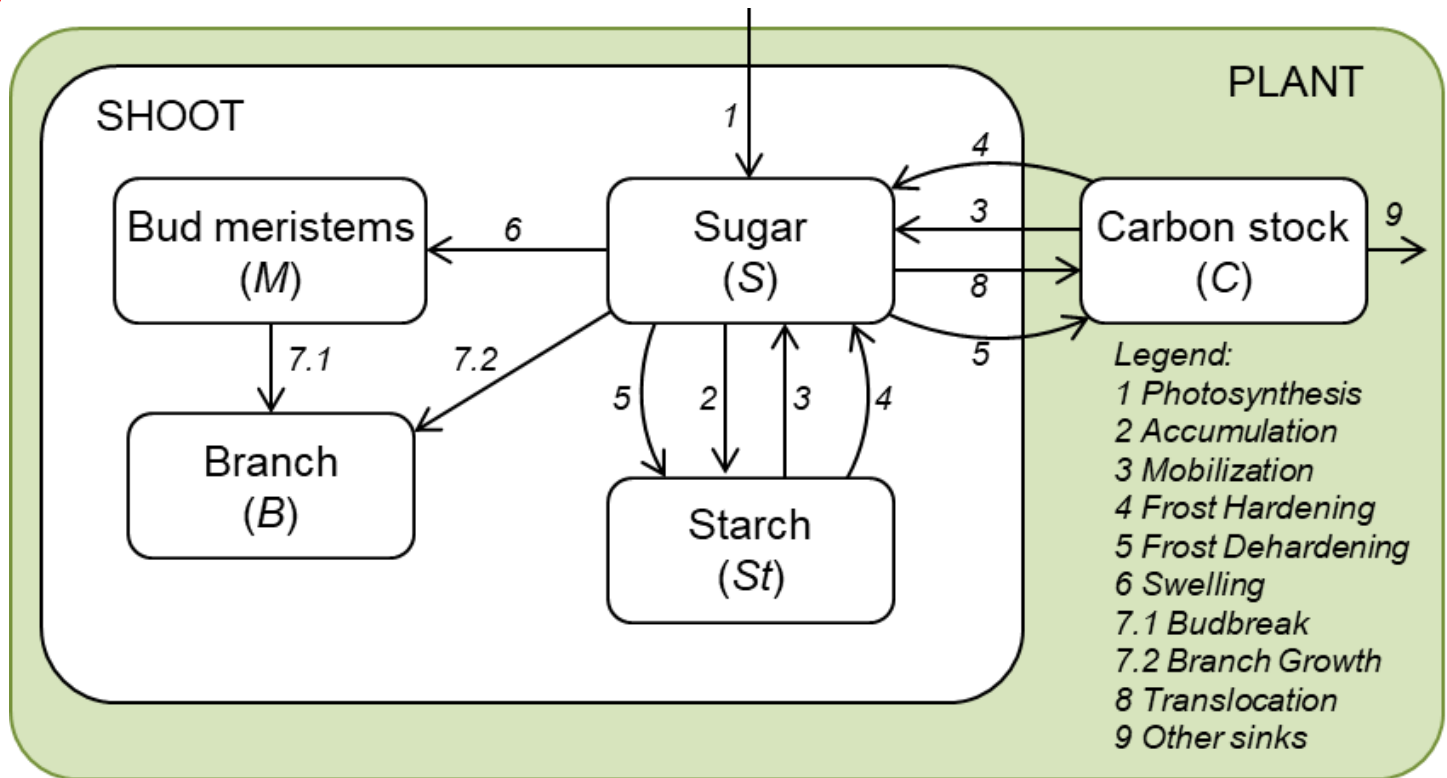Main advantage:

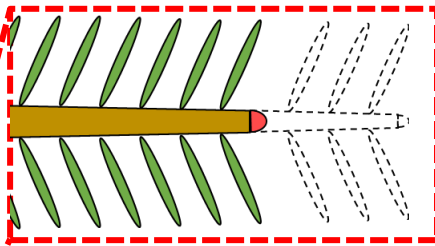- simple formulation and easy calibration

Aim: develop a physiologically-based model

- Coupling phenology to carbon allocation and nutritional status of plants
- Test the effect of climate change and biotic stressors
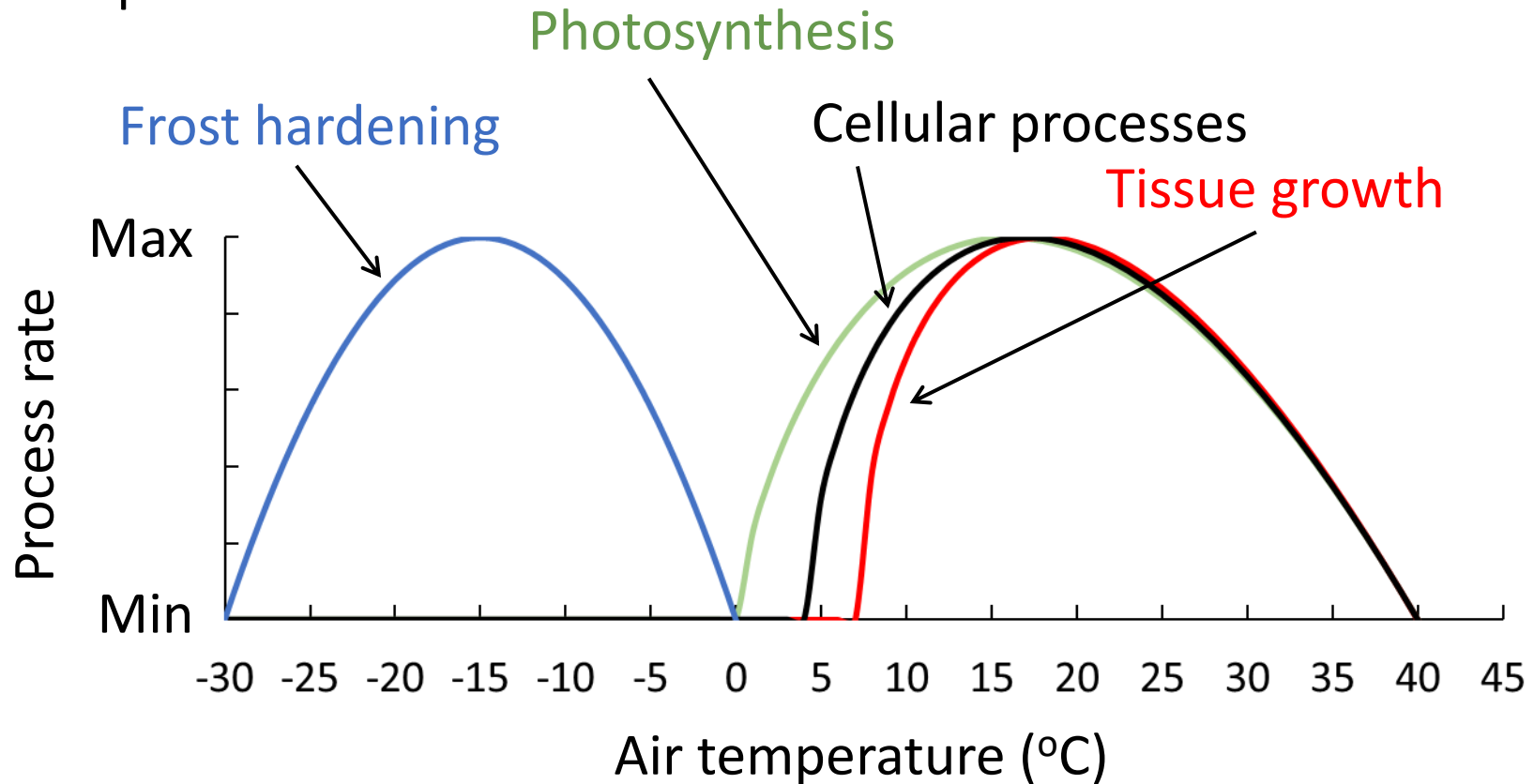
Model description

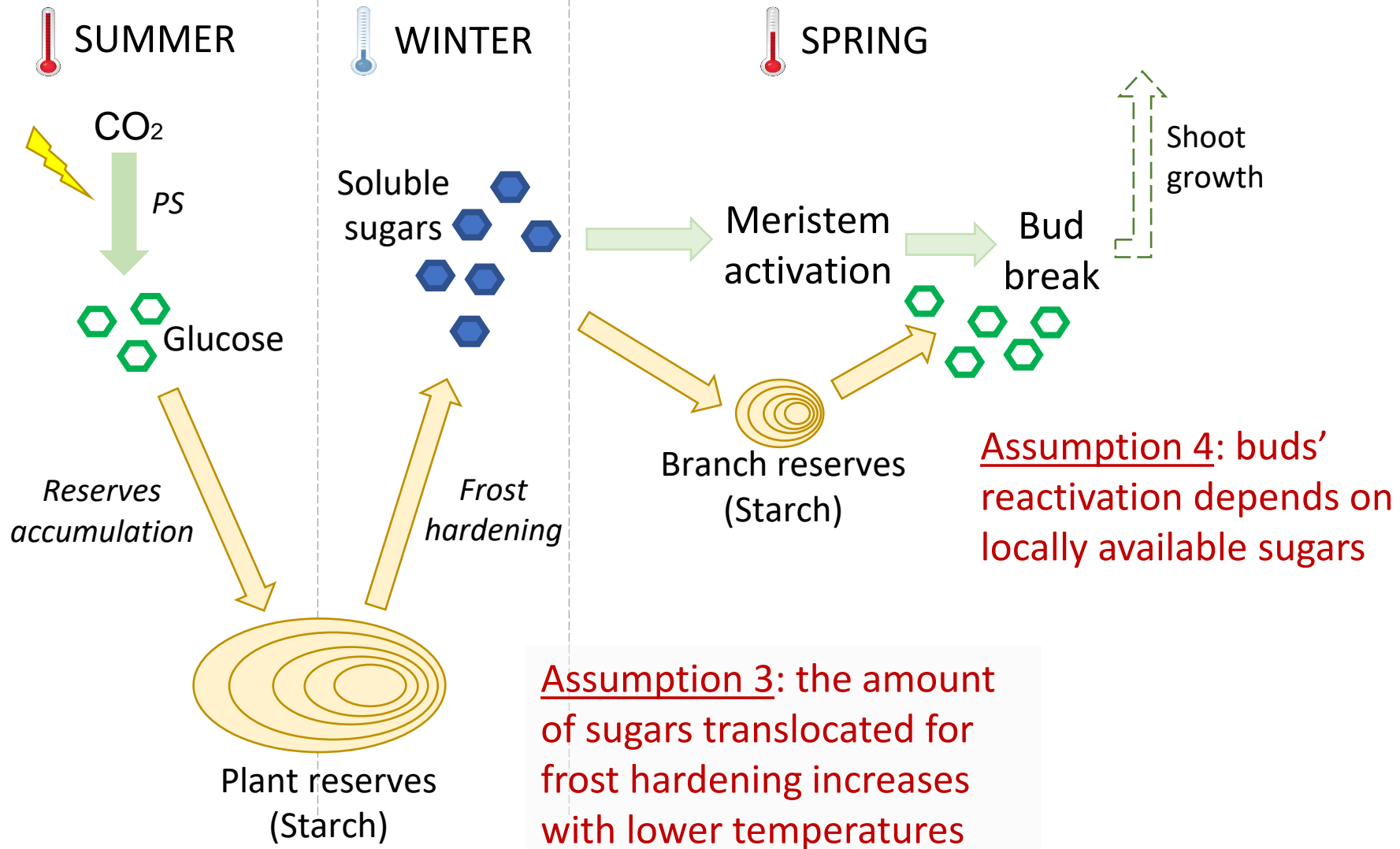Assumption 1: shoot tip represents the whole plant

PLANT

SHOOT

Bud meristems (M)

Sugar (S)

Carbon stock (C)

Branch (B)

Starch (St)

Legend:
1 Photosynthesis
2 Accumulation
3 Mobilization
4 Frost Hardening
5 Frost Dehardening
6 Swelling
7.1 Budbreak
7.2 Branch Growth
8 Translocation
9 Other sinks

Model description

Assumption 2: plant processes have different responses to temperature

Model description

SUMMER

WINTER

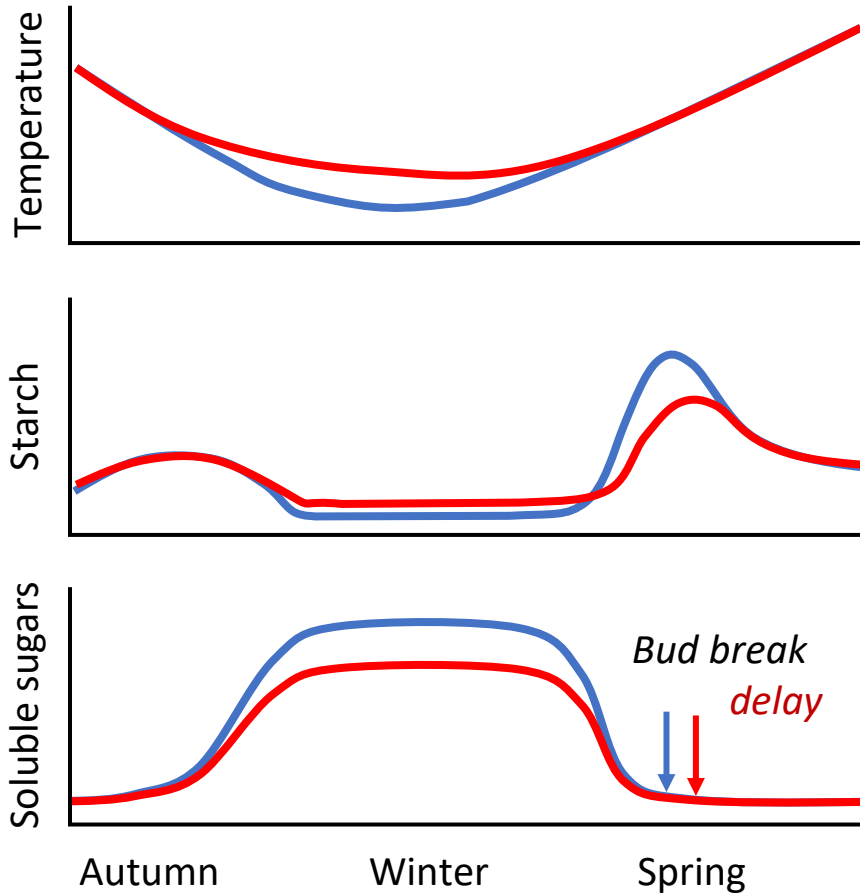SPRING

CO_2

PS

Glucose

Reserves accumulation

Plant reserves (Starch)

Soluble sugars

Frost hardening

Meristem activation

Bud break

Shoot growth

Branch reserves (Starch)

Assumption 4: buds' reactivation depends on locally available sugars

Assumption 3: the amount of sugars translocated for frost hardening increases with lower temperatures

Model description

Effect of temperature on bud phenology

Effect of **warmer winter** temperature
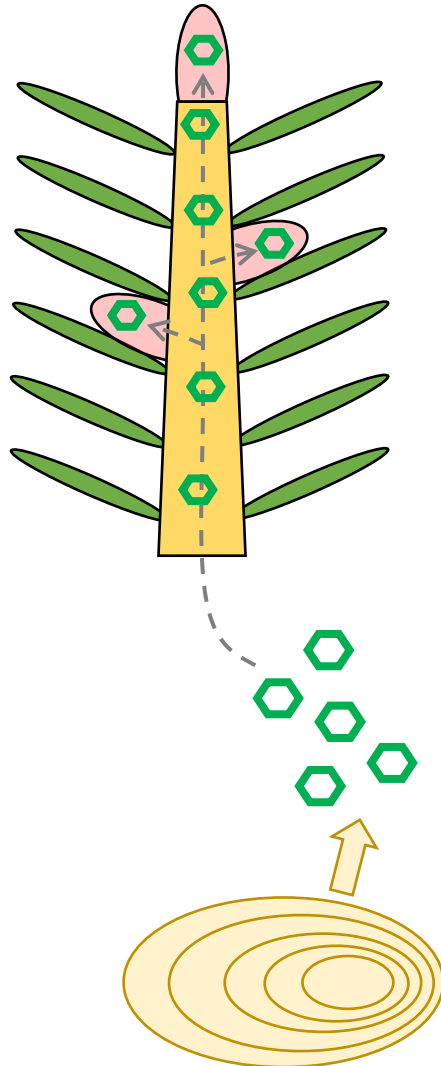
Effect of **warmer spring** temperature

Temperature

Starch

Soluble sugars

Bud break
delay

Bud break
advance

Autumn   Winter   Spring

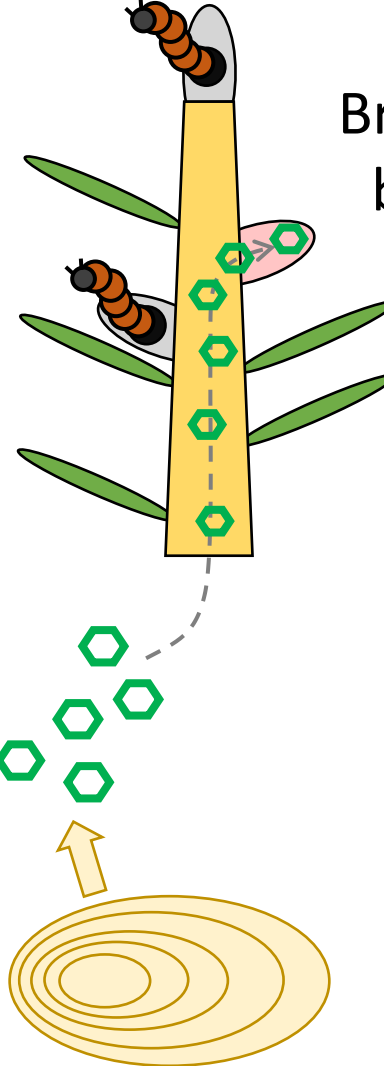Autumn   Winter   Spring

Effect of defoliation on bud phenology

Healthy branch

Branch attacked by budworms
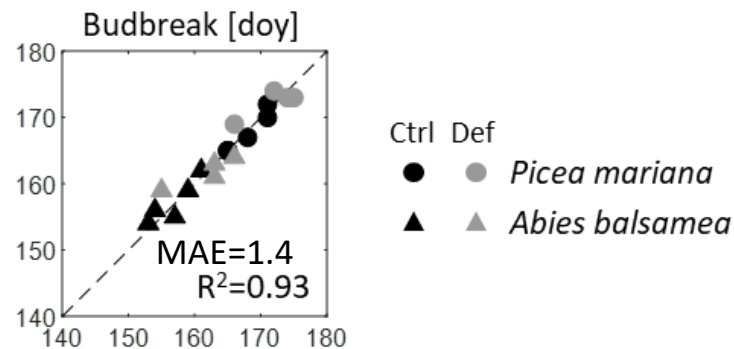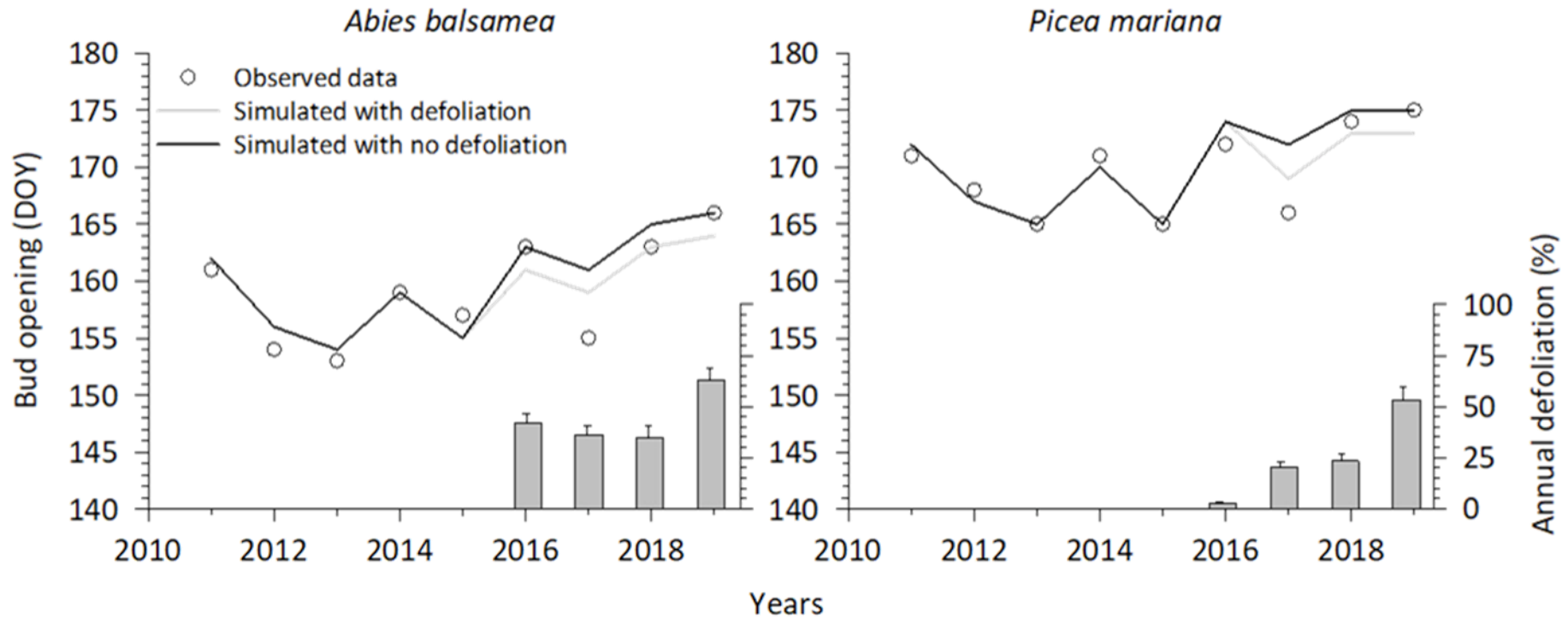
Sucrose

Starch

Experimental datasets
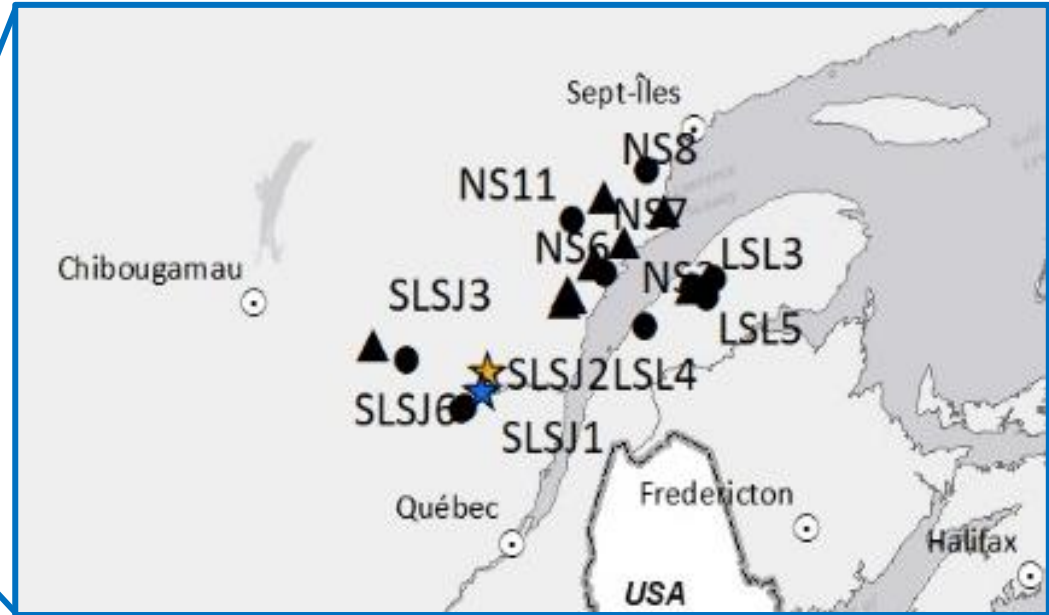
CALIBRATION

⭐ Long-term field site (Balsam fir, Black spruce)
(6 trees x 9 years)

VALIDATION

▲● SOPFIM monitoring program (Balsam fir, Black spruce)
(877 records over 20 sites and 11 years)
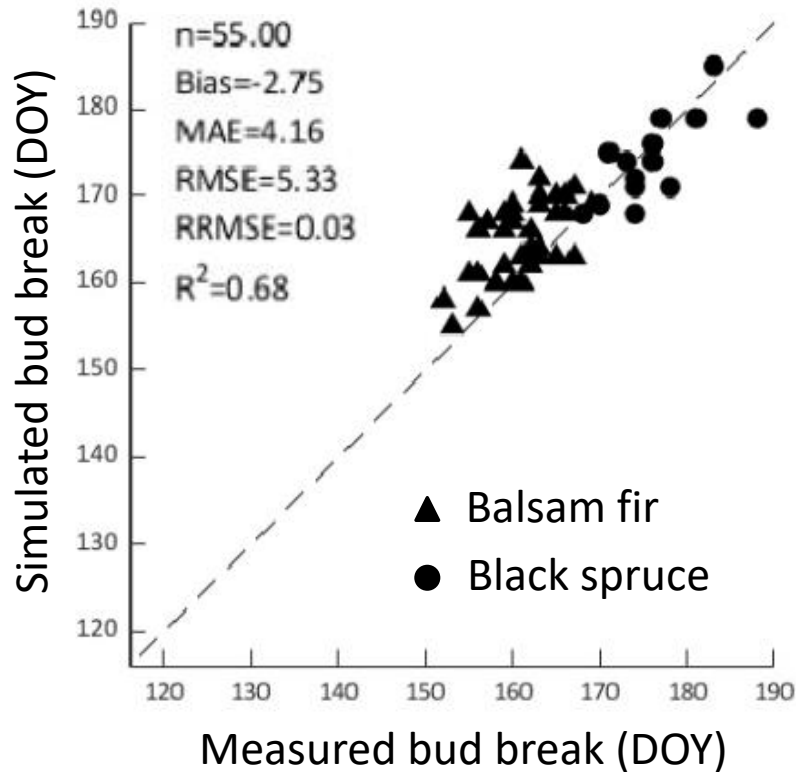
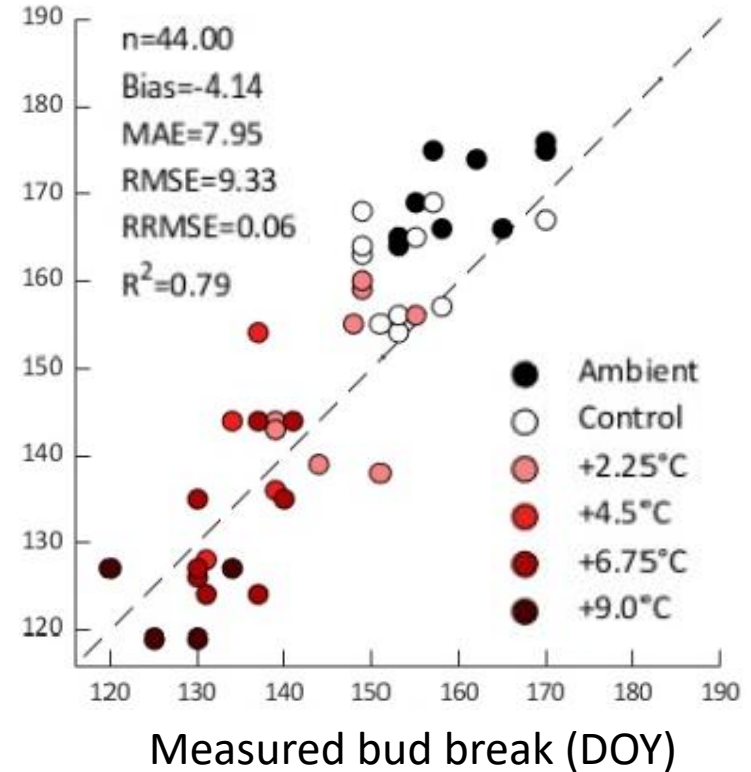⬠ SPRUCE experiment (Black spruce)
(11 plots for 5 years)
https://mnspruce.ornl.gov

Results - calibration

Results - validation

Quebec (Canada) SOPFIM dataset

n=55.00
Bias=-2.75
MAE=4.16
RMSE=5.33
RRMSE=0.03
R^2=0.68

▲ Balsam fir
● Black spruce

Simulated bud break (DOY)
Measured bud break (DOY)

Minnesota (USA) SPRUCE dataset

n=44.00
Bias=-4.14
MAE=7.95
RMSE=9.33
RRMSE=0.06
R^2=0.79

● Ambient
○ Control
● +2.25°C
● +4.5°C
● +6.75°C
● +9.0°C

Measured bud break (DOY)

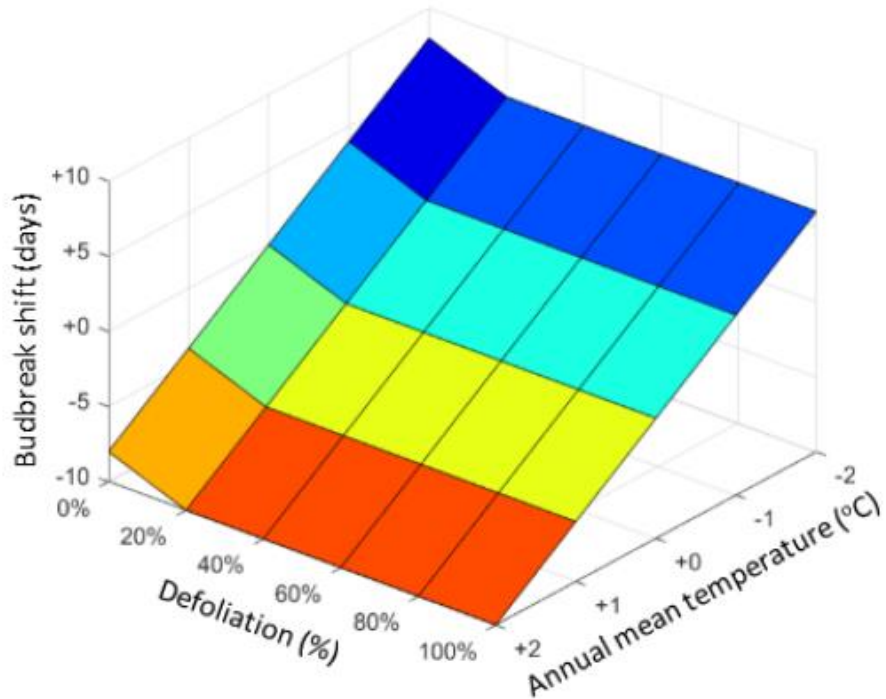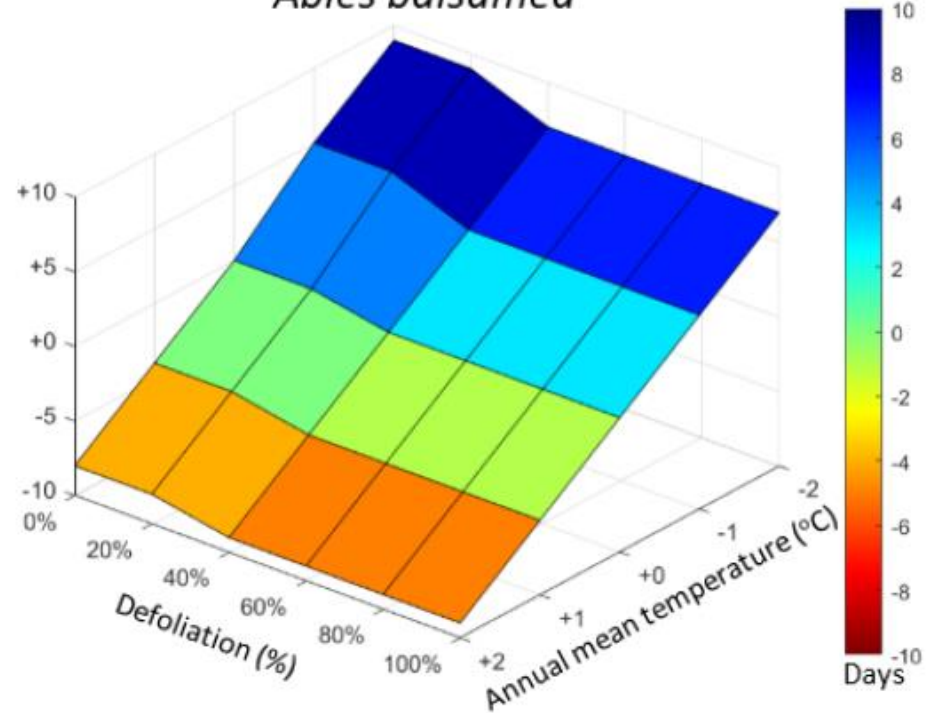# Results

Theoretical simulations

Conclusions

- Provides physiological basis for the effect of temperature on winter and spring phenology

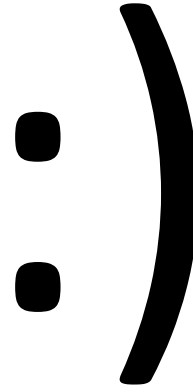- Weak effect of defoliation (requires further testing)

WEAK POINTS:

- complex equations

- too many parameters (difficult calibration)

STRONG POINTS:

- good overall performance

- site-independent calibration

Thank you

:)

Organizations that funded the development of the phenology model: