

ModExtreme - Workshop Montpellier -
September 10, 2015

Models of expansive growth as a function of temperature and water deficit with explicit genetic variability

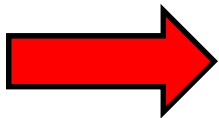
Boris Parent, François Tardieu

1) Models with genetic variability

Most crop models use a single set of parameters per species

Studies on climate change and extreme events:

- # genotypes in the future
- # genotypes depending on environment and climatic scenarios
- simulating virtual genotypes in virtual scenarios



We need models with explicit genetic variability

Introduction

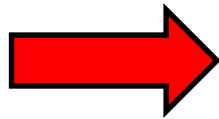
2) A level a simplification compatible with phenotyping

Phenotyped traits \sim Model parameters

We can now measure parameter values of hundreds of genotypes

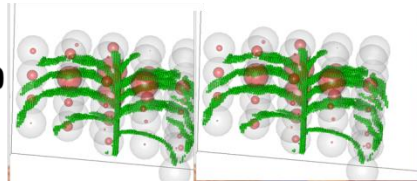
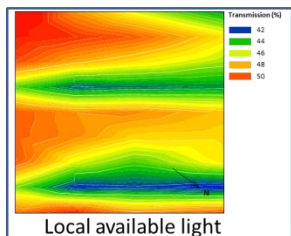
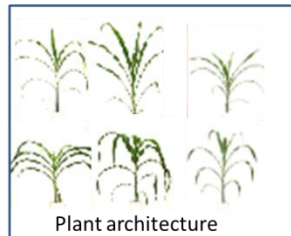
-Not always explicitly in models

-Some parameters impossible to measure



Adapt models to phenotyping ?

Adapt phenotyping methods to crop models ?



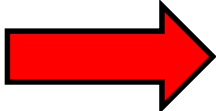
PHENOME
RESEARCH & INNOVATION
FPPN



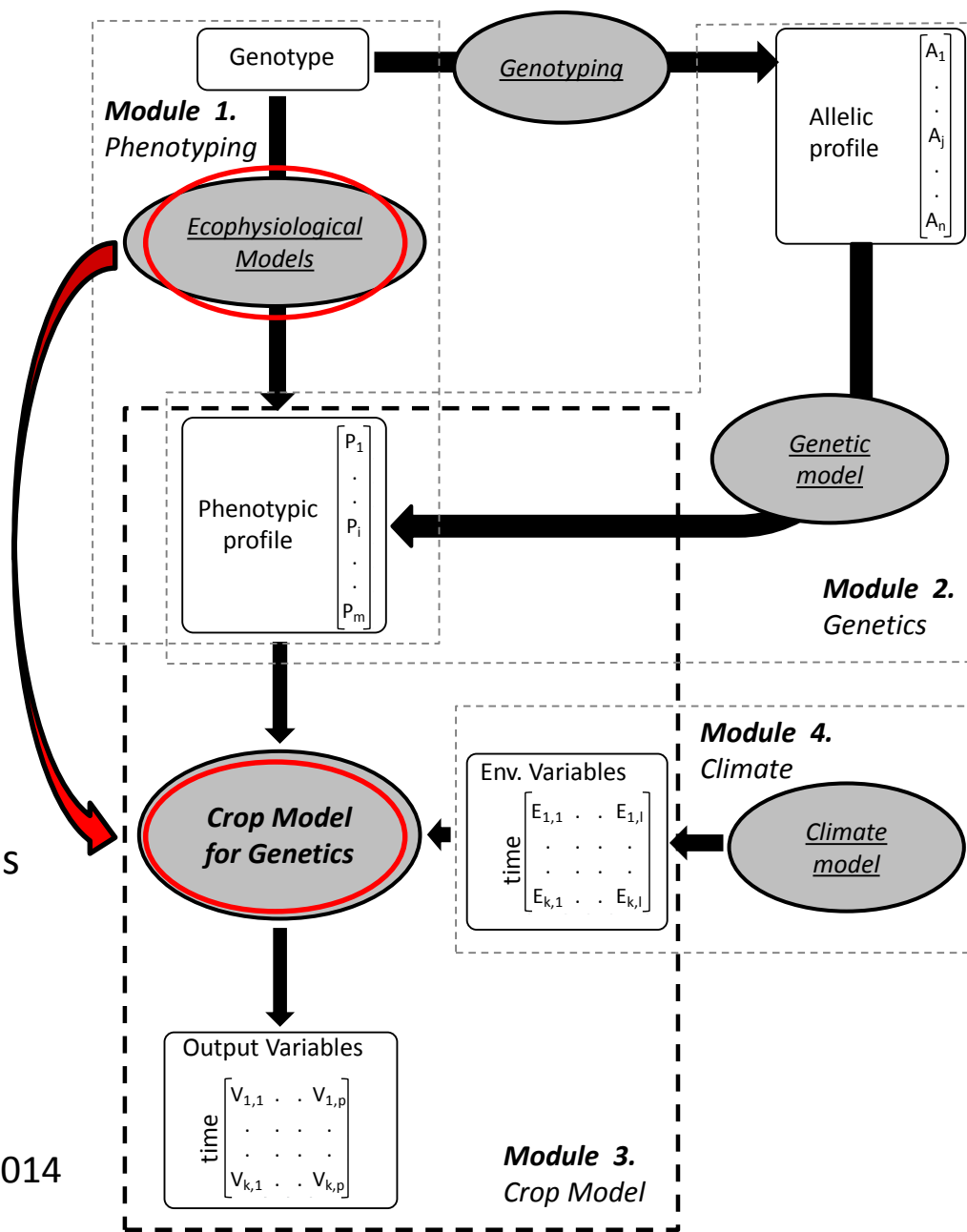
LI Cabrera C. Fournier



3) Coupling crop models with Ecophysiological models and genetic models

 Simulating which combination of traits / alleles improves performances in which environment / climatic scenario

Parent and Tardieu, JXB, 2014



Outline

Responses of Development / Expansive growth to Temperature

- # equations in crop models
- Model proposed in this project
- Reconciling the approaches

Responses of Water transfer / Expansive growth to soil water and evaporative demand

- Update of the Tardieu and Davies model (1993)
- Simplified model of expansive growth with easily phenotyped genotypic parameters

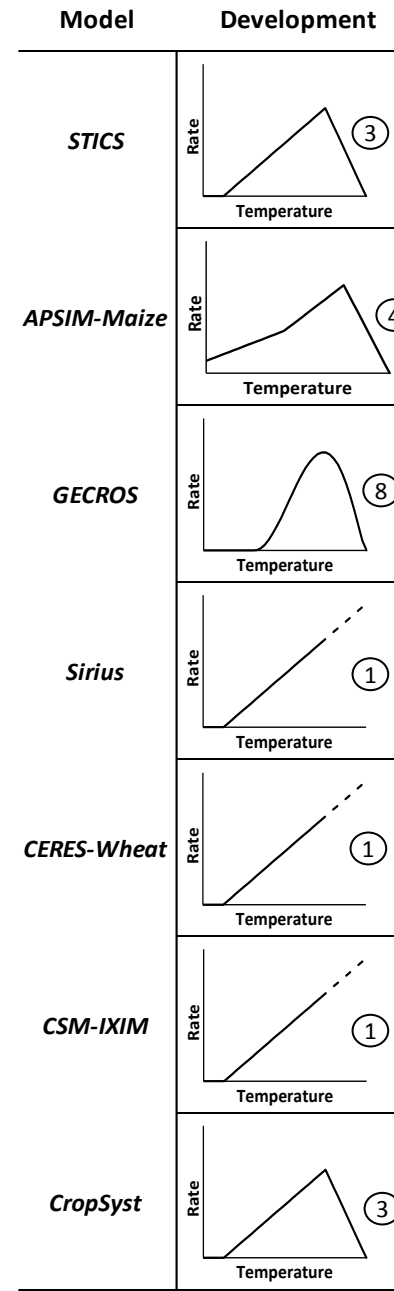
Conclusion

Responses to temperature

Diversity of formalisms in crop models

equations

between development and growth



Responses to temperature

Diversity of formalisms in crop models

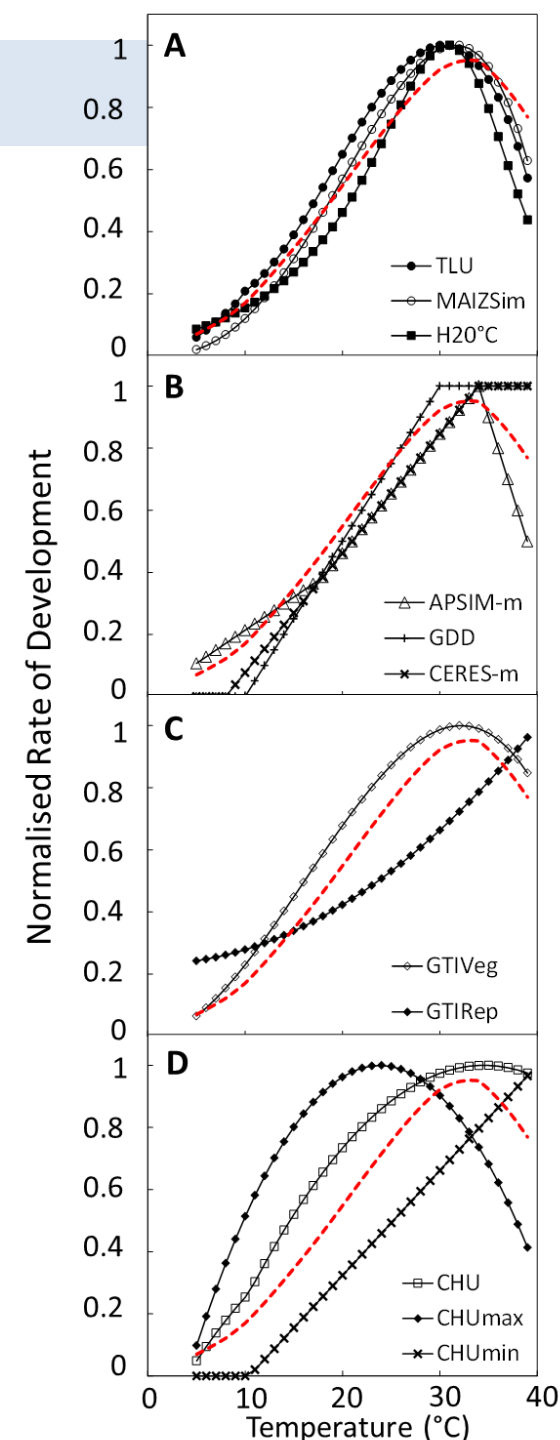
equations

between development and growth

between development stages

between day and night

even within species



Responses to temperature

The proposed model:

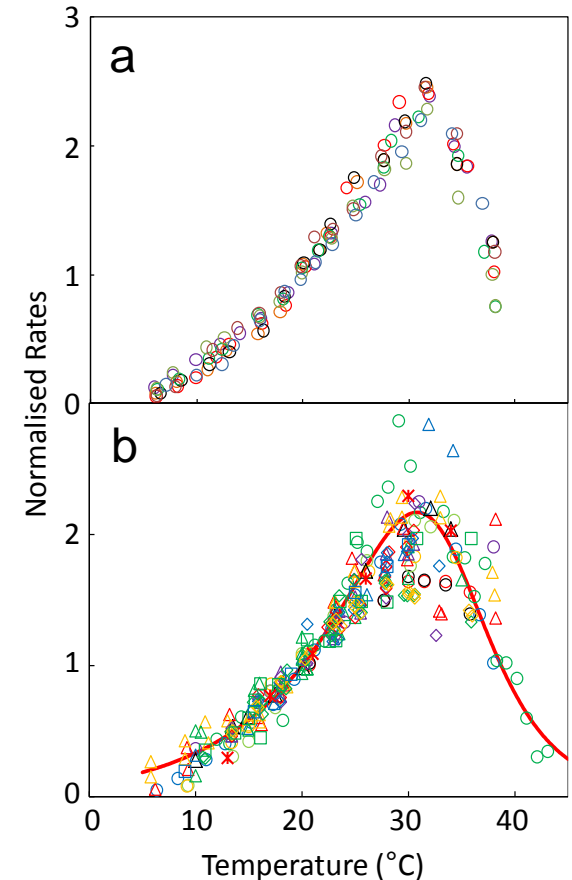
$$F(T) = \frac{A T e^{\left(\frac{-\Delta H_A^\ddagger}{RT} \right)}}{1 + \left[e^{\left(\frac{-\Delta H_A^\ddagger}{RT} \right)} \right]^\alpha \left(1 - \frac{T}{T_0} \right)}$$

Parent and Tardieu, NewPhyt, 2012

Another one in the jungle of temperature models ?

Or a simplifying approach ?

- 2 parameters
- Large range of temperatures
- Parameters with a biochemical meaning (for comparative studies)
- No variation observed between developmental processes
- No variation observed within species



Responses to temperature

The proposed model:

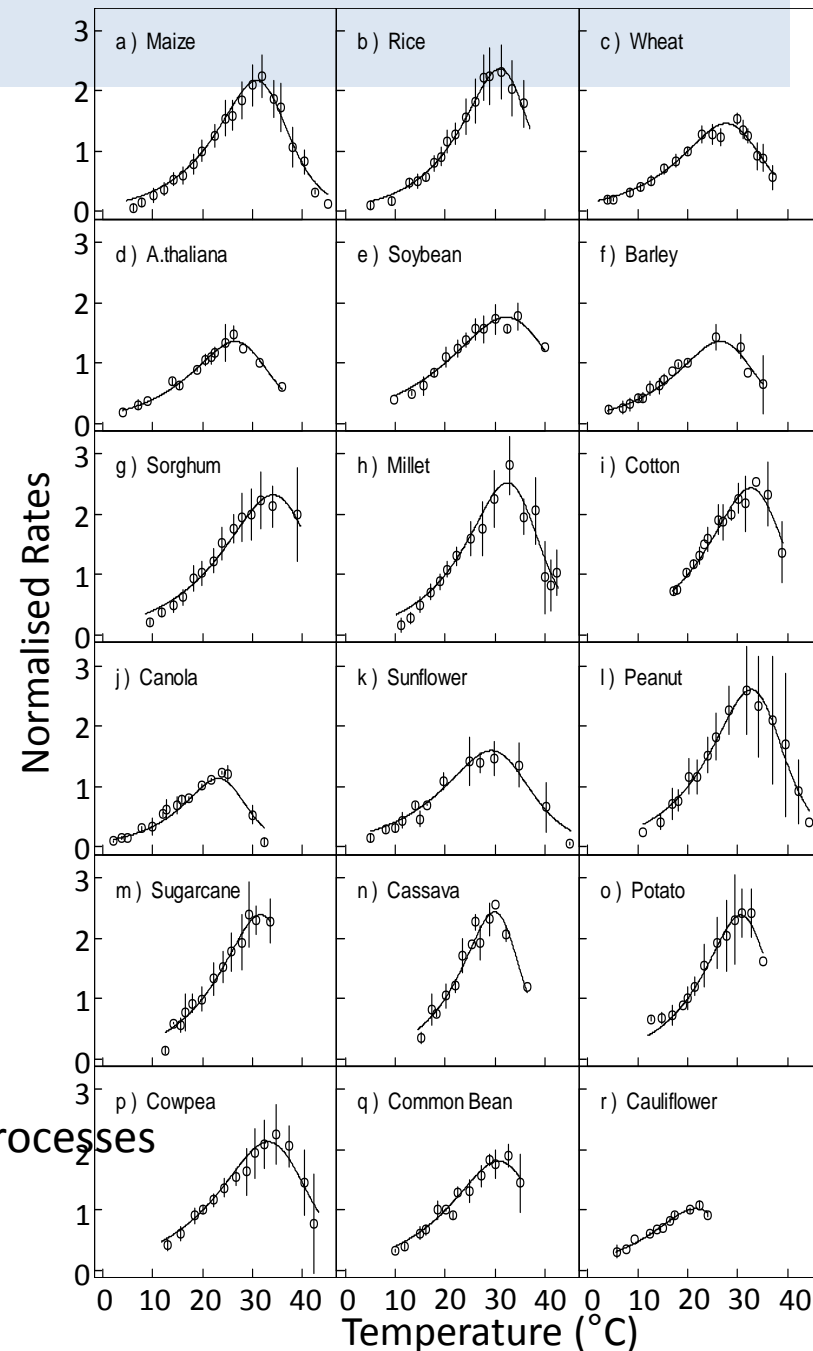
$$F(T) = \frac{A T e^{\left(\frac{-\Delta H_A^*}{RT} \right)}}{1 + \left[e^{\left(\frac{-\Delta H_A^*}{RT} \right)} \right]^{\alpha \left(1 - \frac{T}{T_0} \right)}}$$

Parent and Tardieu, NewPhyt, 2012

Another one in the jungle of temperature models ?





Or a simplifying approach ?

- 2 parameters
- Large range of temperatures
- Parameters with a biochemical meaning (for comparative studies)
- No variation observed between developmental processes
- No variation observed within species
- Parameter values in 18 species



Responses to temperature

Reconciling approaches

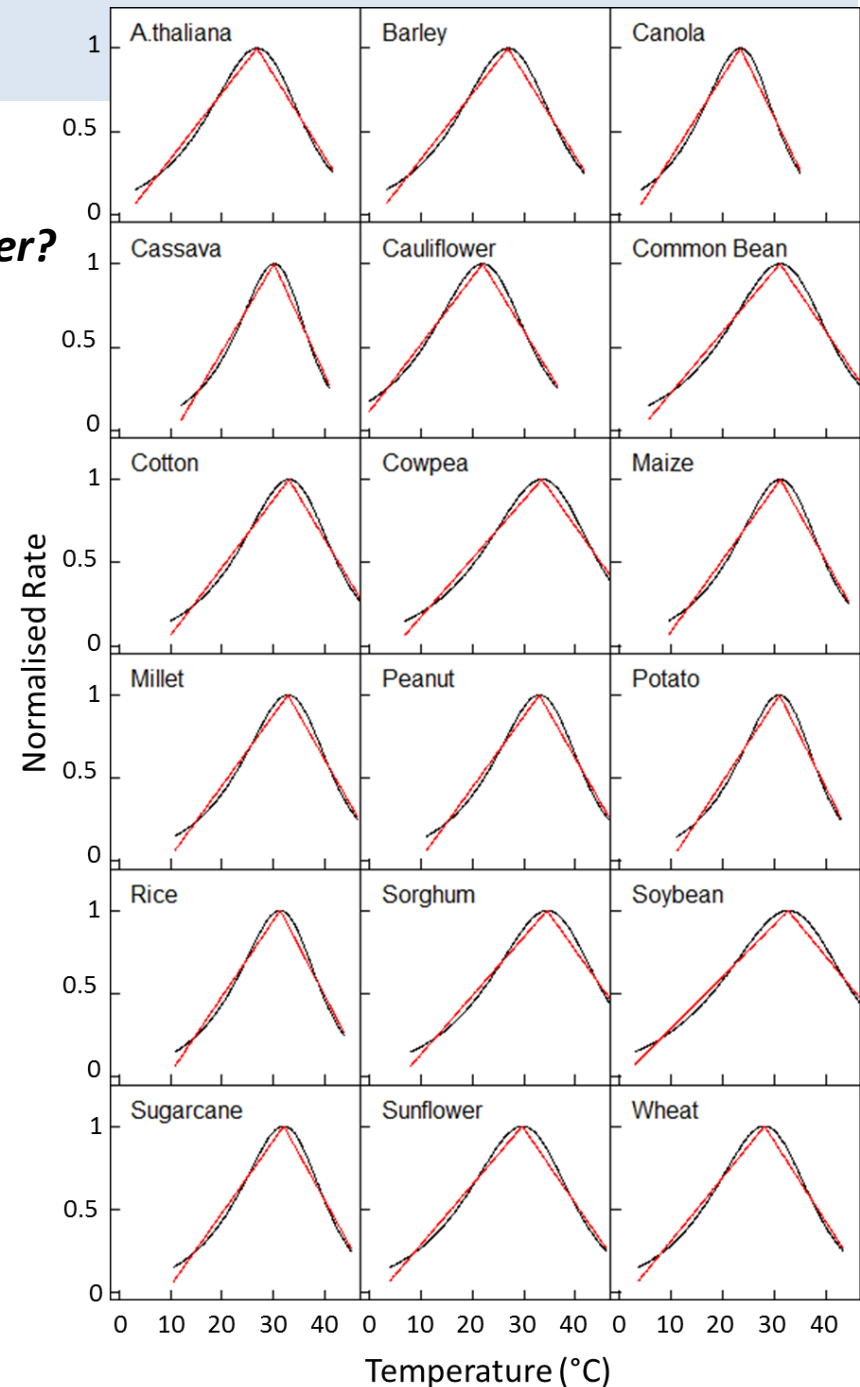
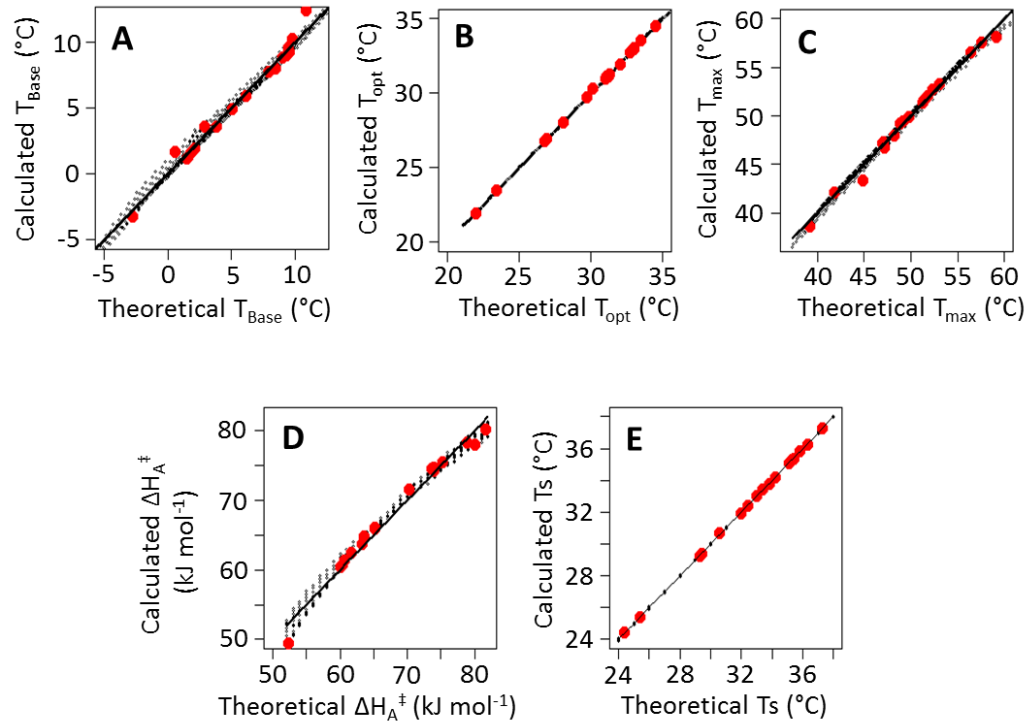
- # equations  *from one model to the other*
- # between development and growth  *Effect of evaporative demand ?*
- # between development stages  *Temperature range effect ?*
- # between day and night  *Temperature range effect ?
Min/max vs. hourly temperatures*

Responses to temperature

Reconciling approaches
can we go from one model to the other?

Ex : Non-linear PT12 ~ Bilinear model

Linear equations between parameters :



Responses to temperature

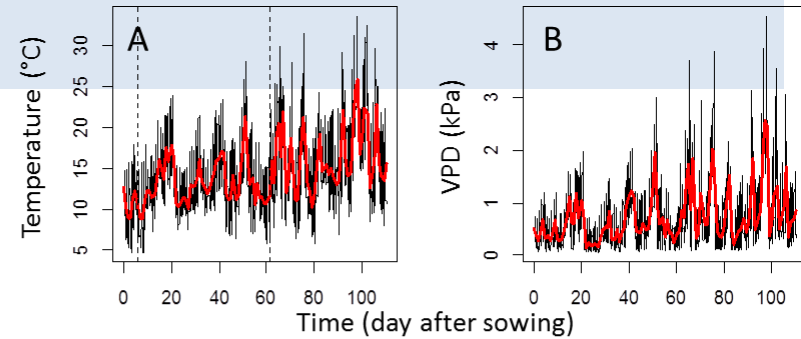
Reconciling approaches

Effect of temperature range

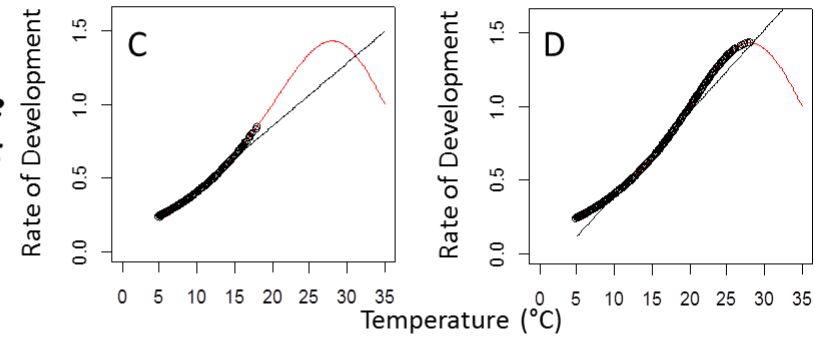
Ex : temperature range effect on wheat threshold temperature

$$-4^{\circ}\text{C} < T_{\text{base}} < 5^{\circ}\text{C}$$

Climate



Temperature range effect



Responses to temperature

Reconciling approaches

Effect of temperature range

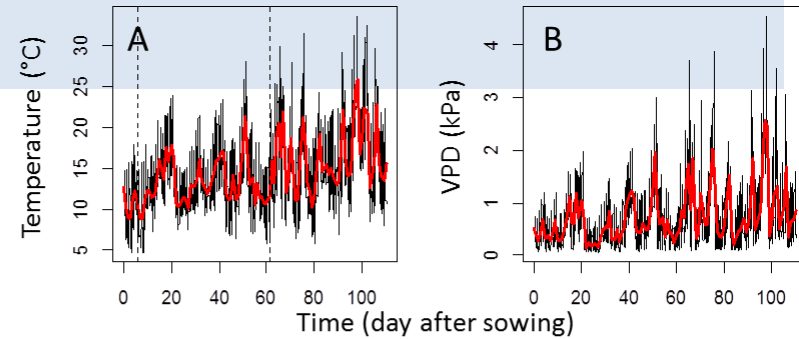
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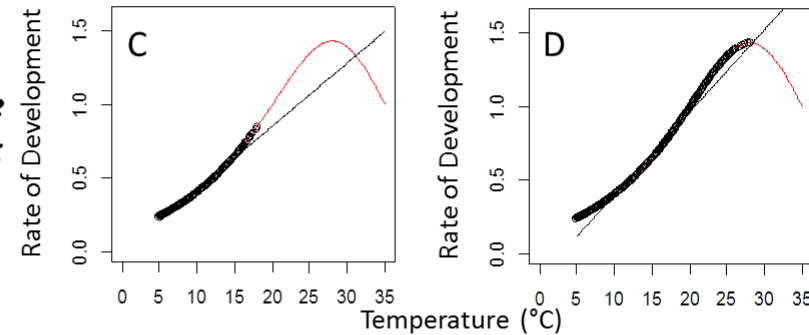
Effect of evaporative demand

Complete change in overall response

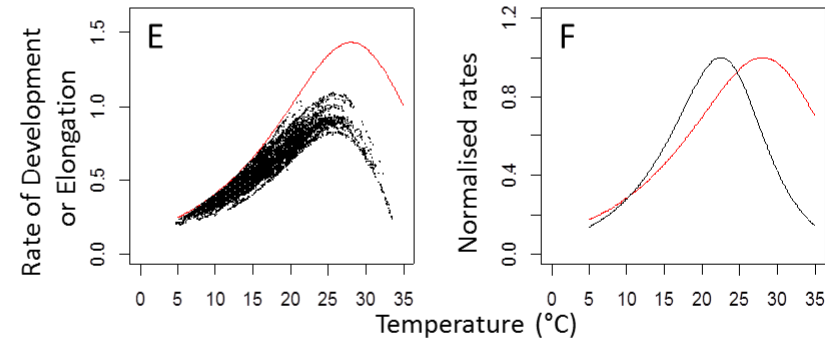
Climate



Temperature range effect



VPD effect



Responses to temperature

Reconciling approaches

Effect of temperature range

Ex : temperature range effect on wheat threshold temperature

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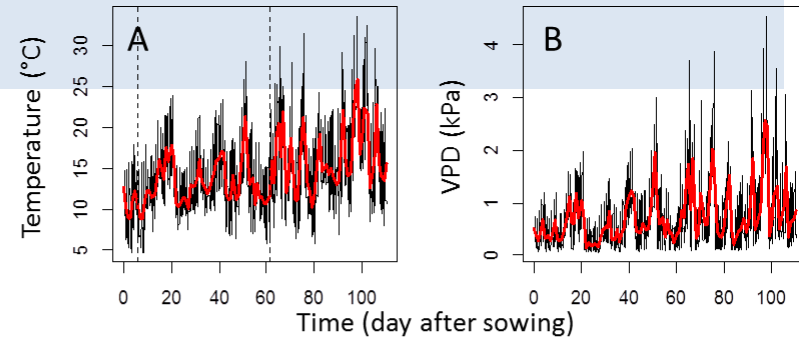
Effect of evaporative demand

Complete change in overall response

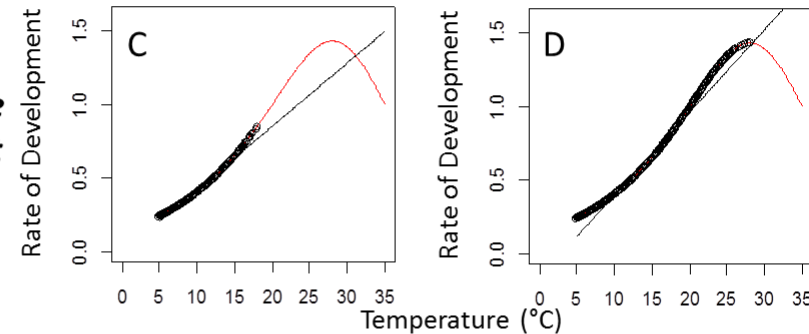
Effect of timestep

A shift by 4°C in temperature responses

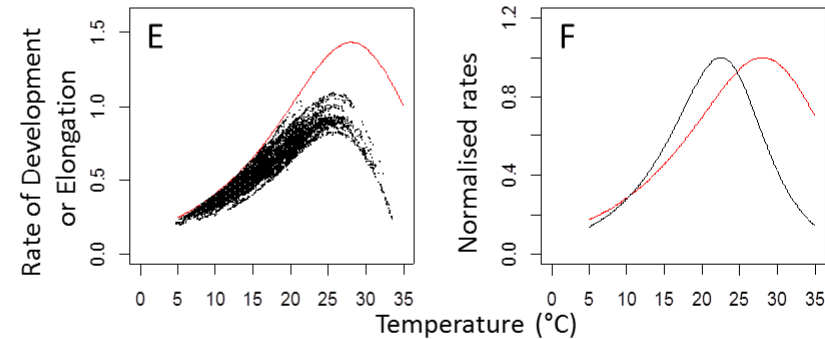
Climate



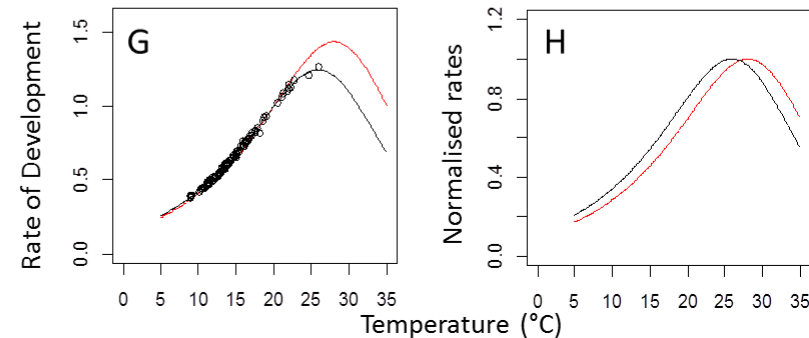
Temperature range effect



VPD effect







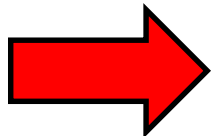
Timestep effect



Responses to temperature

Reconciling approaches

- # equations  *from one model to another*
- # between development and growth  *Effect of evaporative demand ?*
- # between development stages  *Temperature range effect ?*
- # between day and night  *Temperature range effect ?
Min/max vs. hourly temperatures*



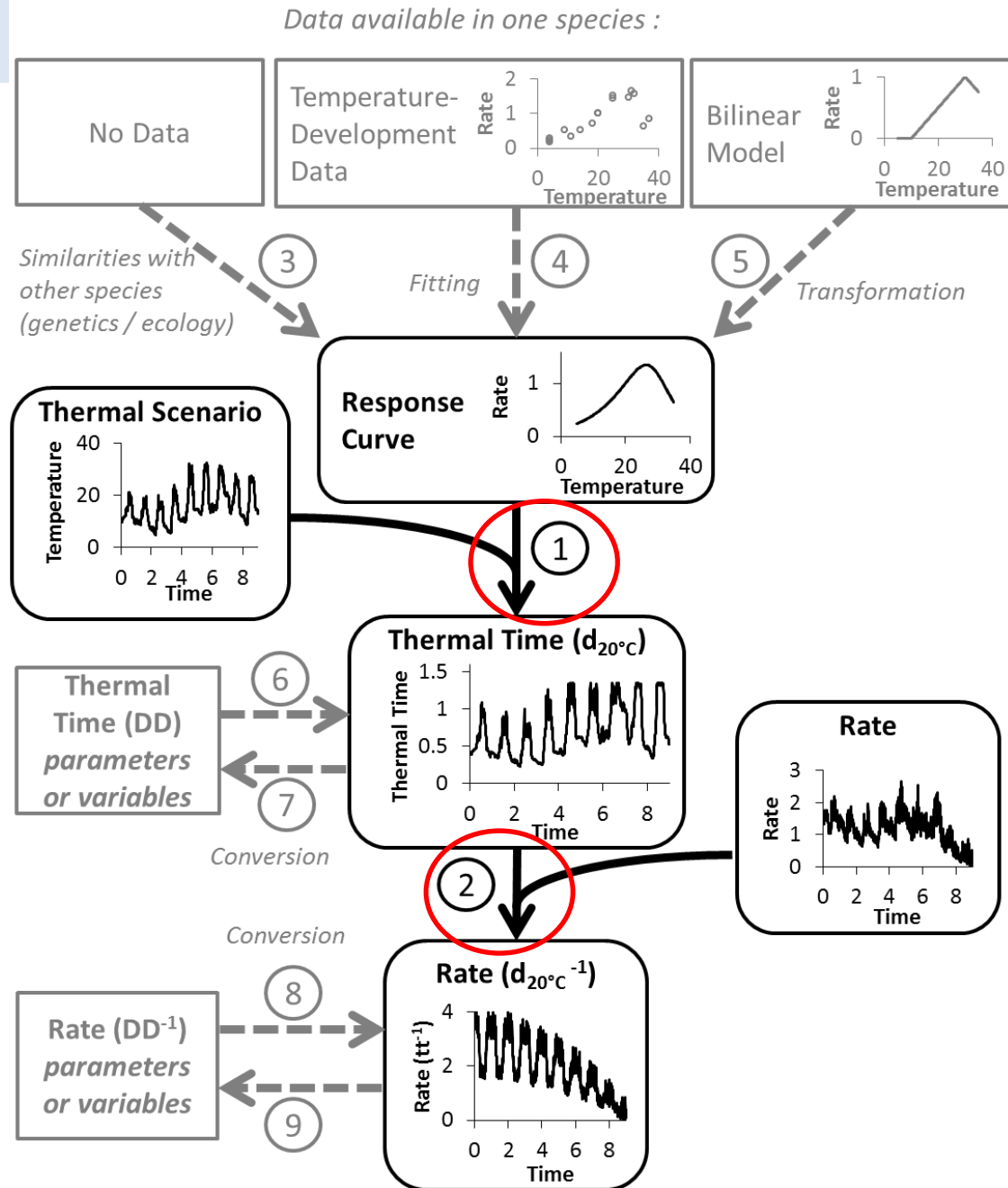
Differences between equations / parameter values
stage effects
day or night

could be artefacts from modelling strategies / simplifications

When considering all these aspects, one can calculate parameter values of one model the other.

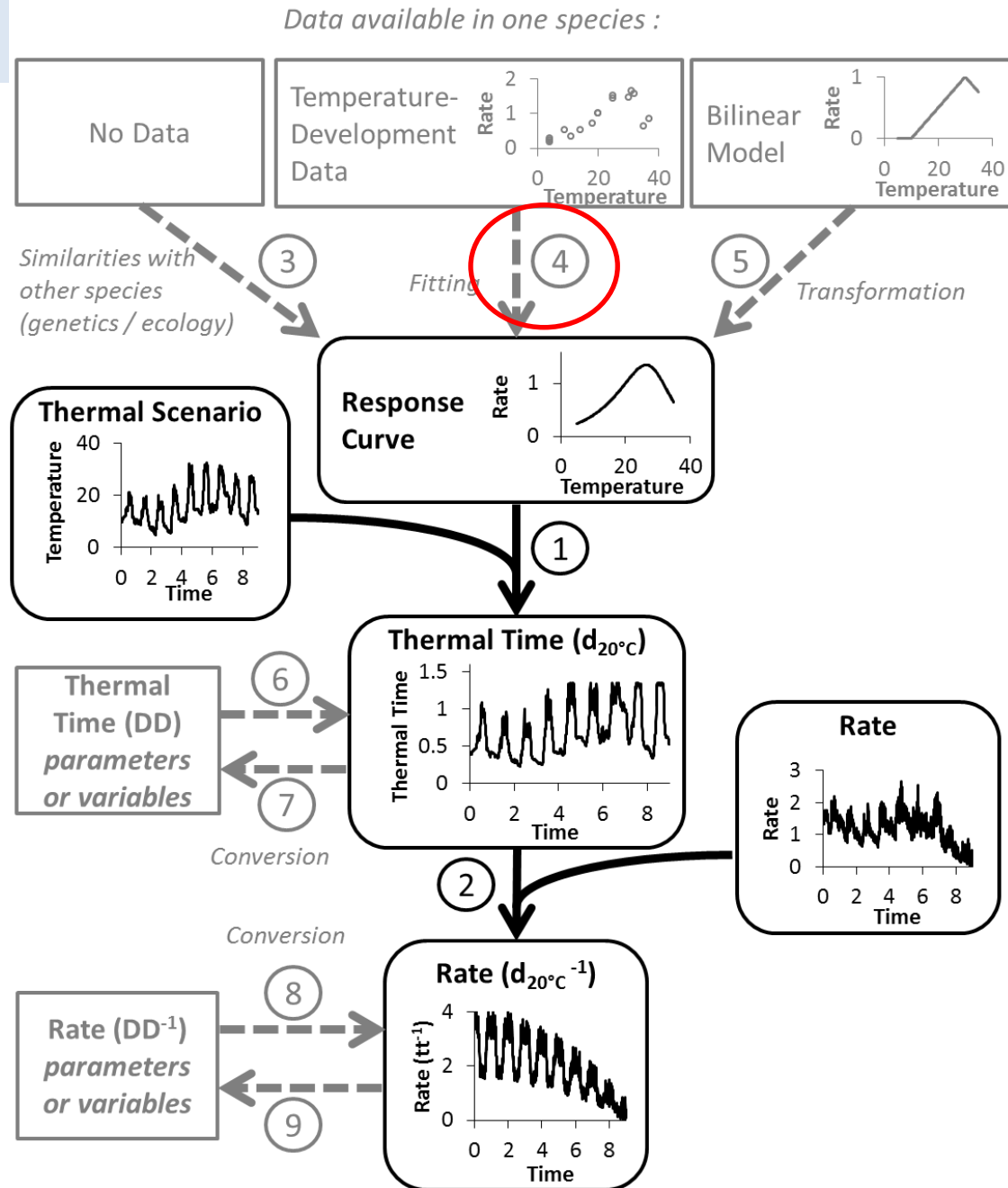
Responses to temperature

R scripts of thermal time and rate calculations



Responses to temperature

R scripts for fitting response curves



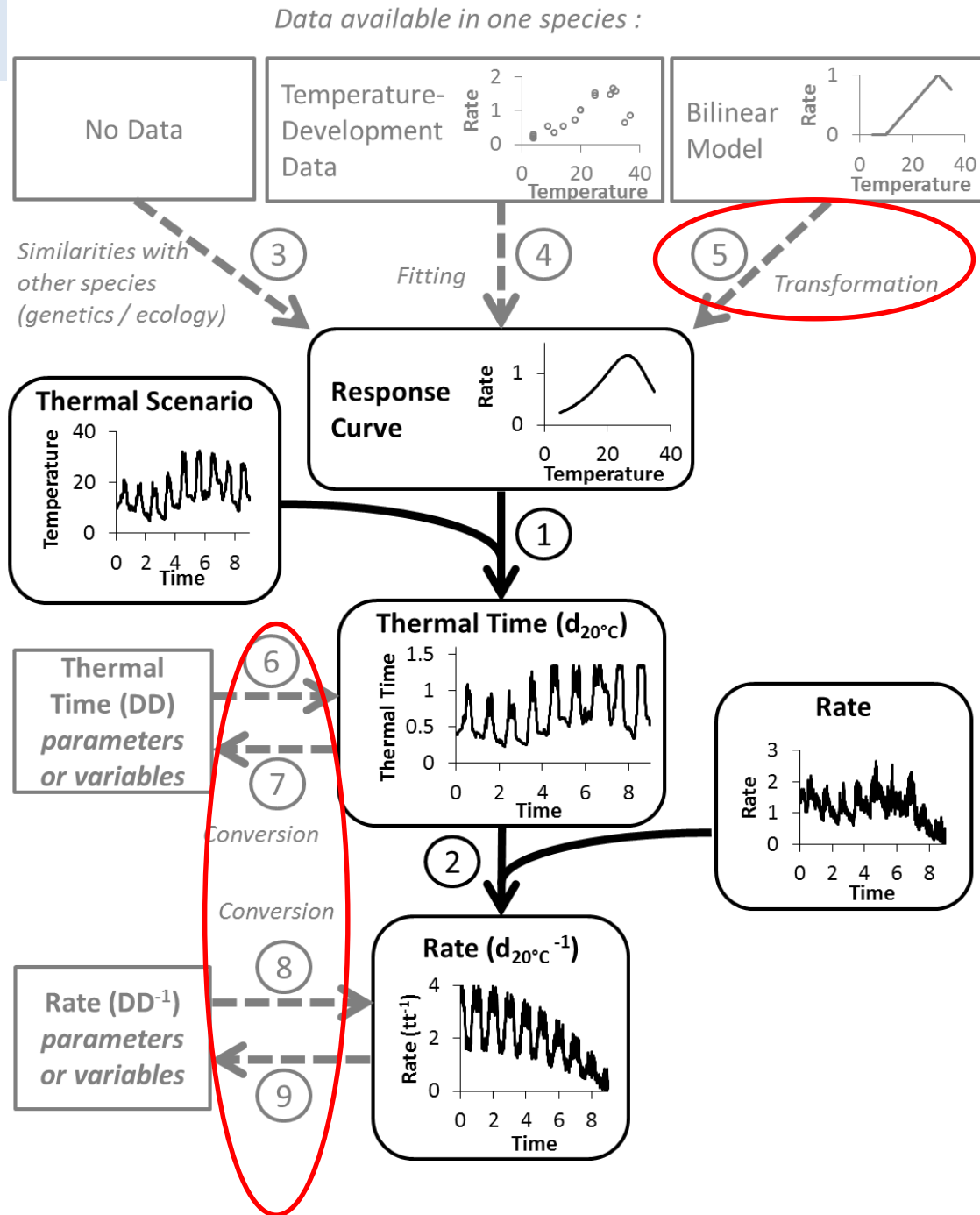
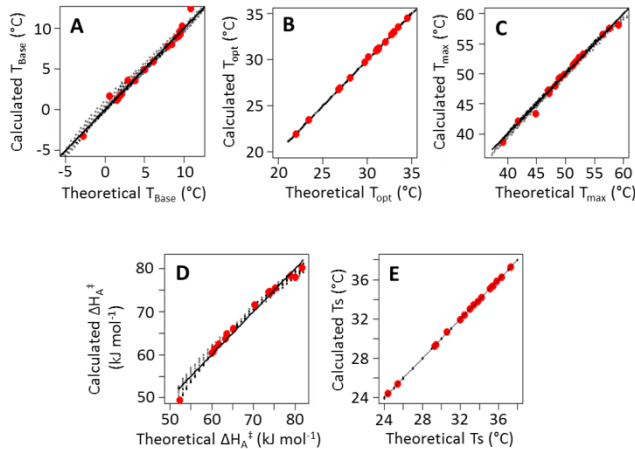
Responses to temperature

R scripts for converting

- parameter values
- thermal time values
- rate values

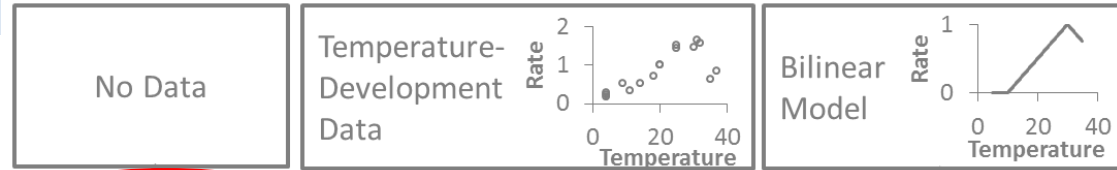
between

- linear / bilinear models
- non-linear model



Responses to temperature

Data available in one species :

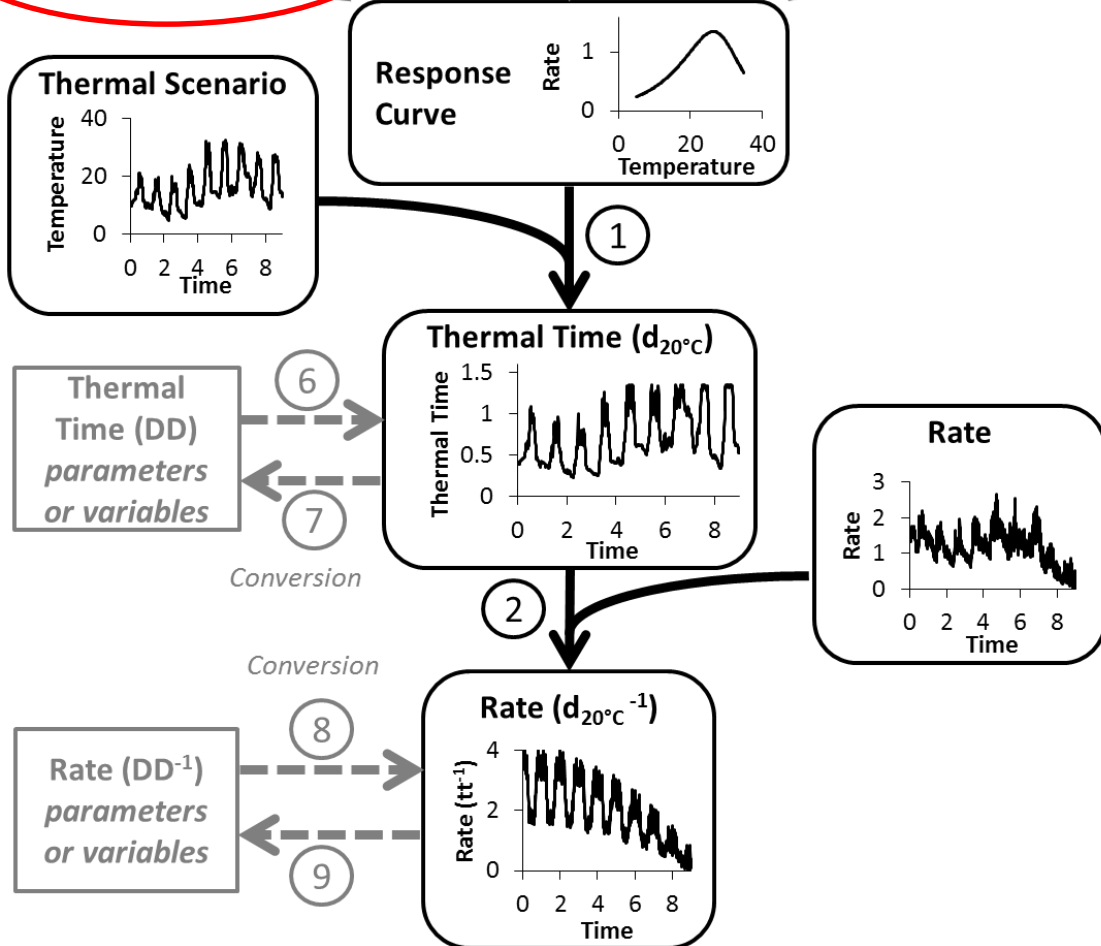
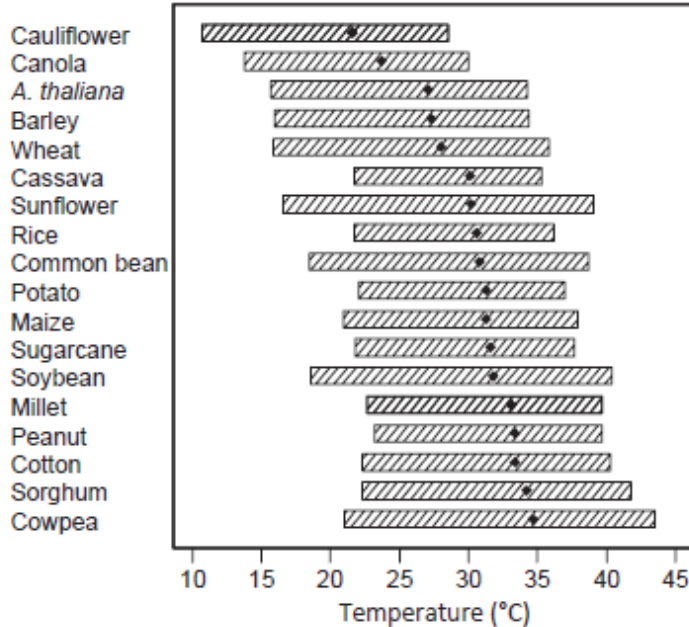


Similarities with other species (genetics / ecology)

Fitting

Transformation

Parameter values of 18 species from different origins

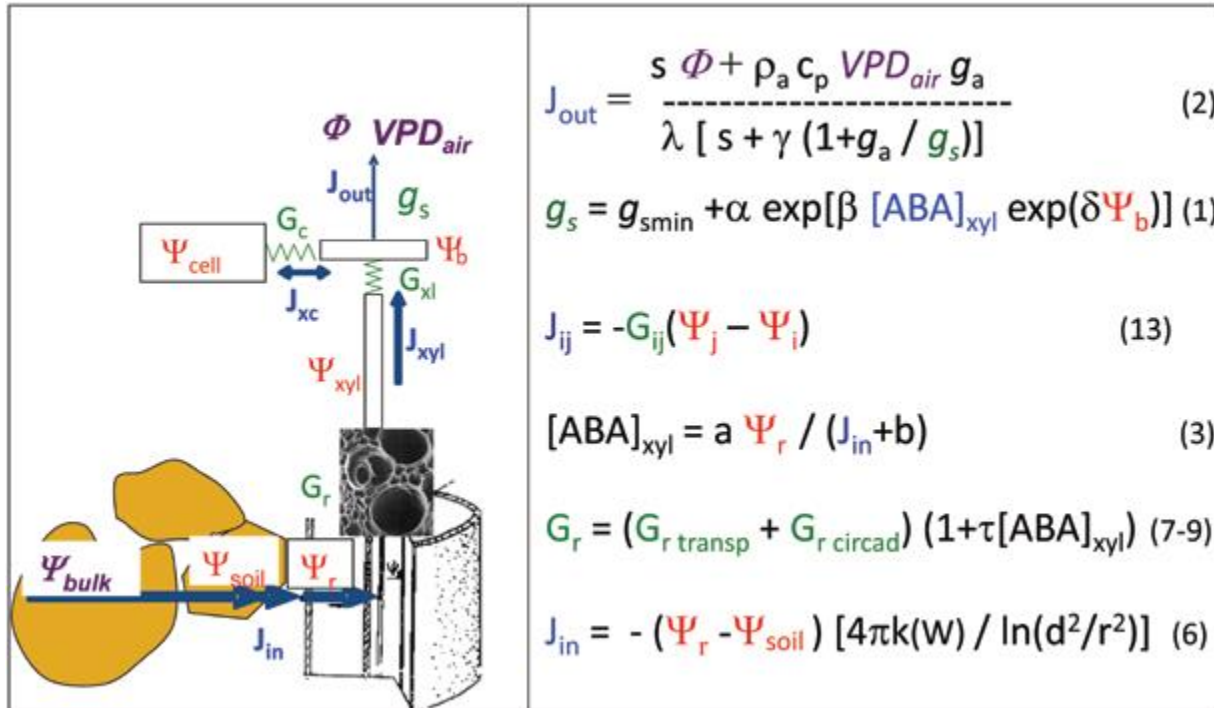


Responses to water deficit and evaporative demand

Updating the Tardieu and Davies (1993) model

A model of stomatal conductance, transpiration and circulations of water and ABA in the plant

-Updated and extended to more complex cases and to the simulation of expansive growth



Responses to water deficit and evaporative demand

Updating the Tardieu and Davies (1993) model

-Changes in tissue hydraulic conductance in the model

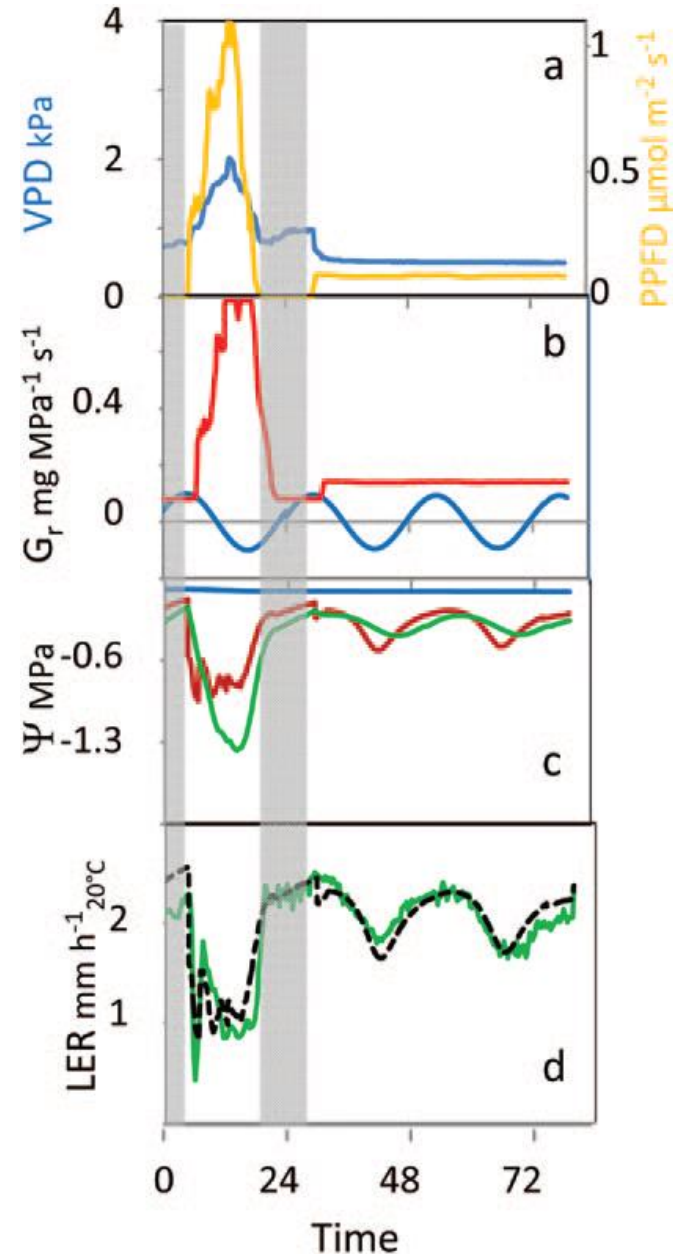
-Circadian Conductances

-Transpiration-dependant Conductances

-ABA-dependant Conductances

-Leaf expansion from xylem water potential and ABA

-Leaf has a capacitance

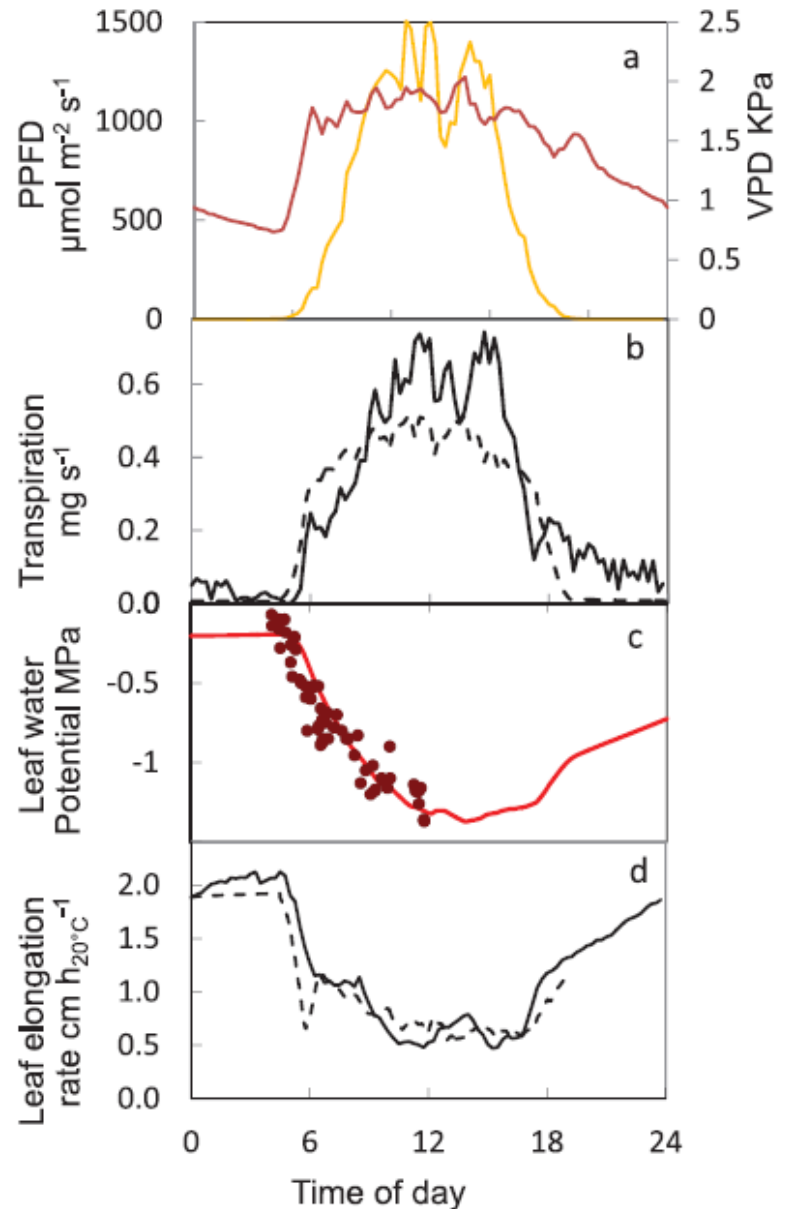
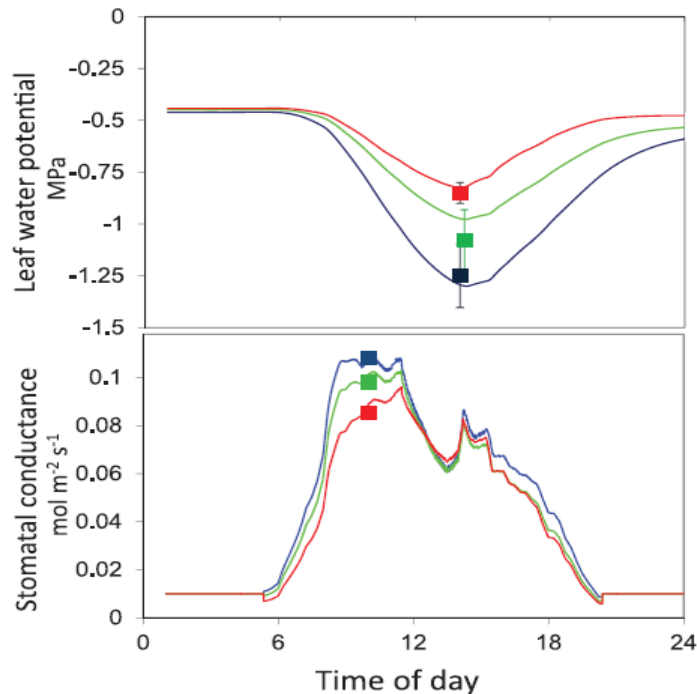


Responses to water deficit and evaporative demand

Updating the Tardieu and Davies (1993) model

Validated in different situations

- Simulates the rapid decrease of leaf growth in the early morning
- Simulates the behaviors of transgenic lines affected on ABA production

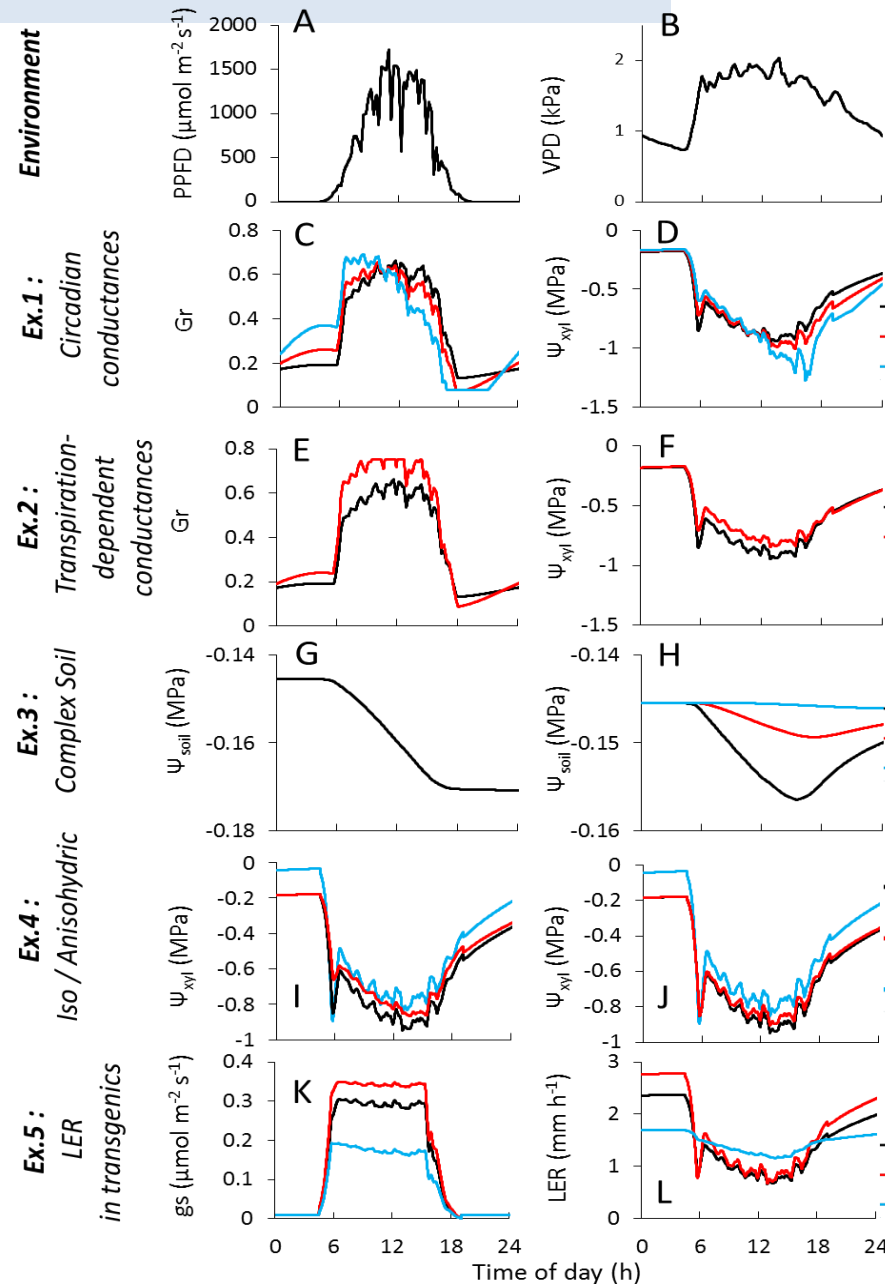


Responses to water deficit and evaporative demand

Updating the Tardieu and Davies (1993) model

Validated in different situations

- Simulates the rapid decrease of leaf growth in the early morning
- Simulates the behaviors of transgenic lines affected on ABA production
- Allows to simulate the effect of the genetic variability on hydraulic traits

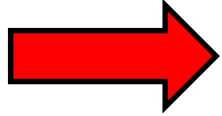


Responses to water deficit and evaporative demand

Updating the Tardieu and Davies (1993) model

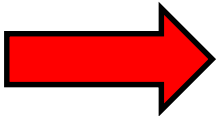
Could it be inserted in crop models ?

For research purposes ?



Upscaling research outputs (ex : studies on aquaporins, interaction with other factors which are not in this model)

For simulating yield ?



Simplifications are probably needed.
With less parameters

Responses to water deficit and evaporative demand

A simplified model of development and growth with easily phenotyped parameters

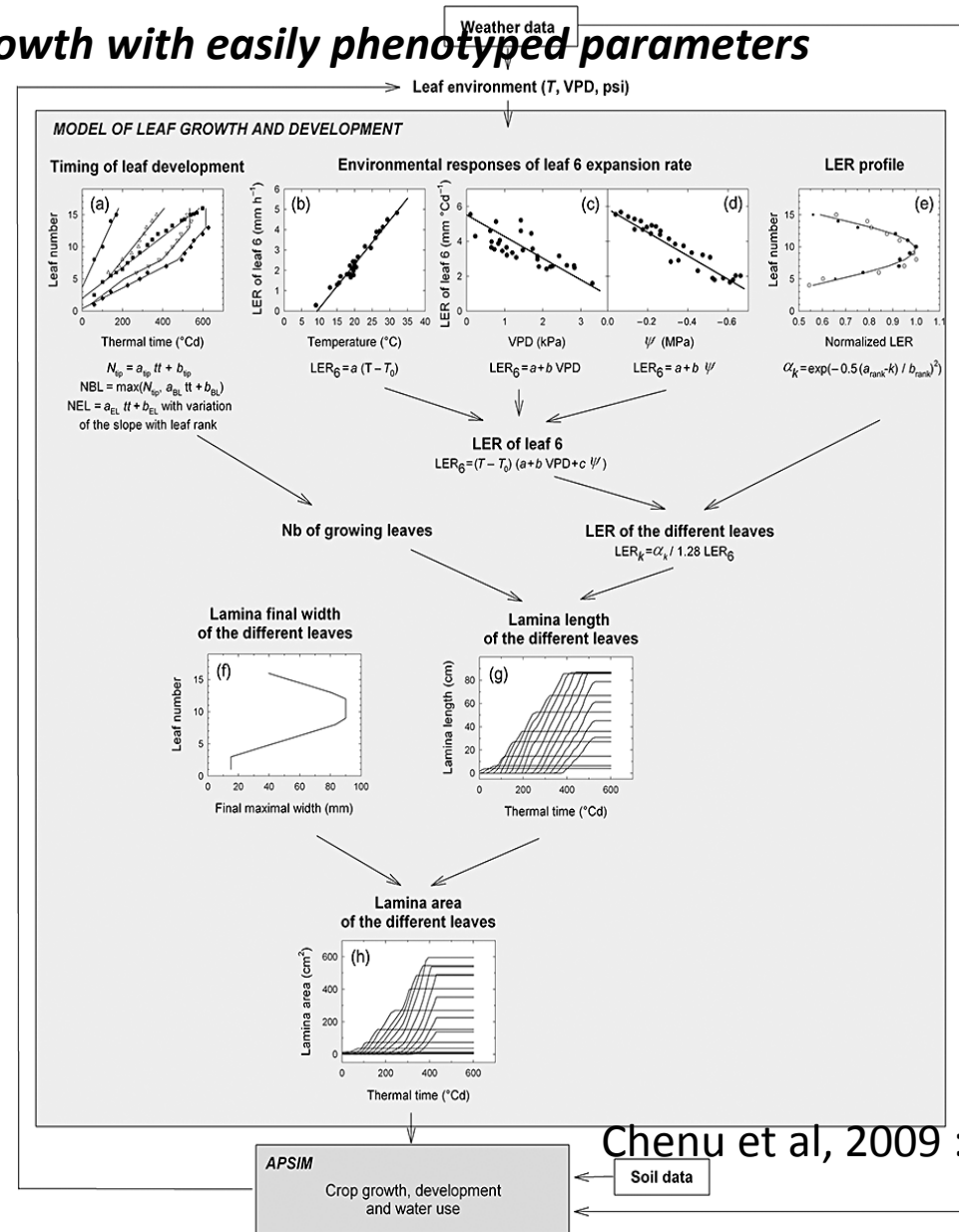
Combining:

- model of leaf development
- model of growth response to environmental conditions

environmental conditions

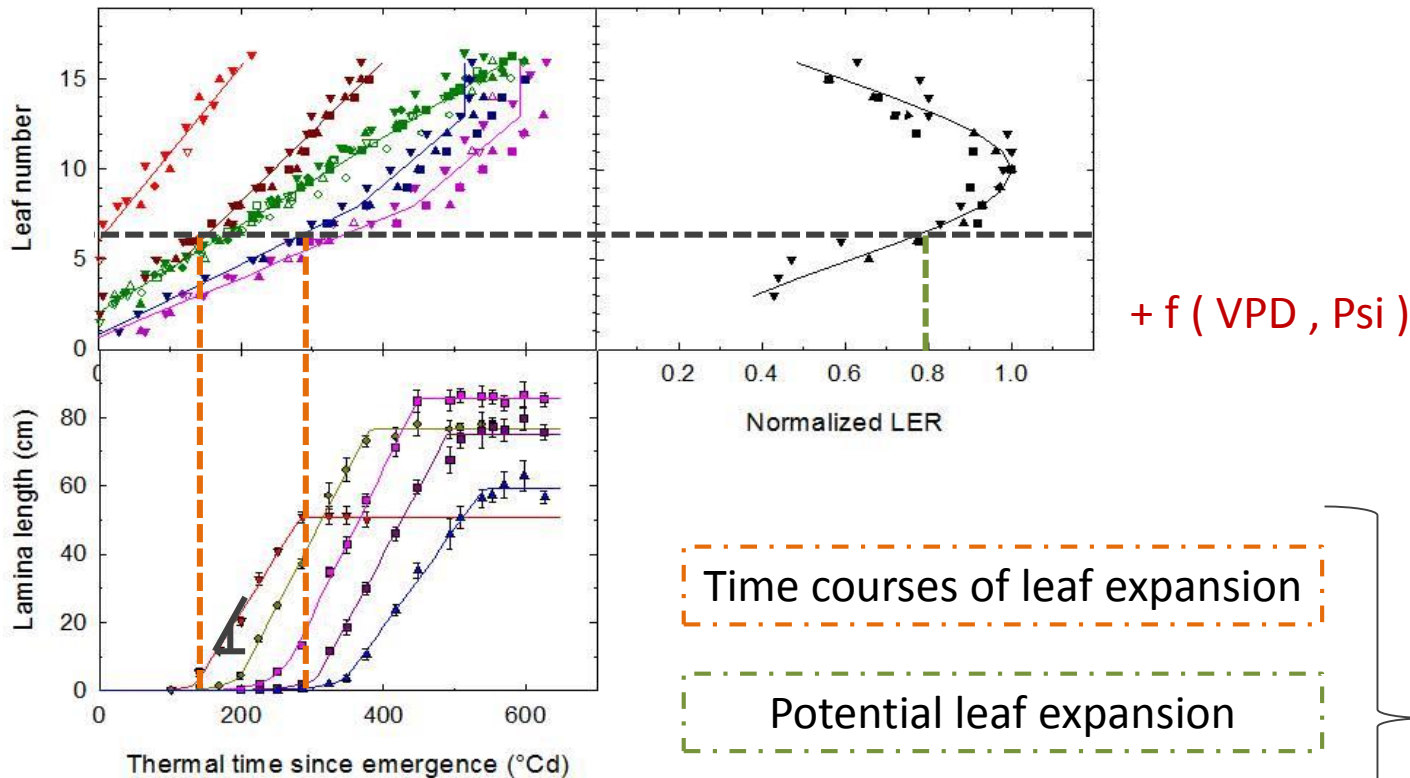
Problem:

- not adapted to genotypes with # leaf number
- still too many parameters (>20)



Responses to water deficit and evaporative demand

A simplified model of development and growth with easily phenotyped parameters



Time courses of leaf expansion

Potential leaf expansion

+ environmental effects

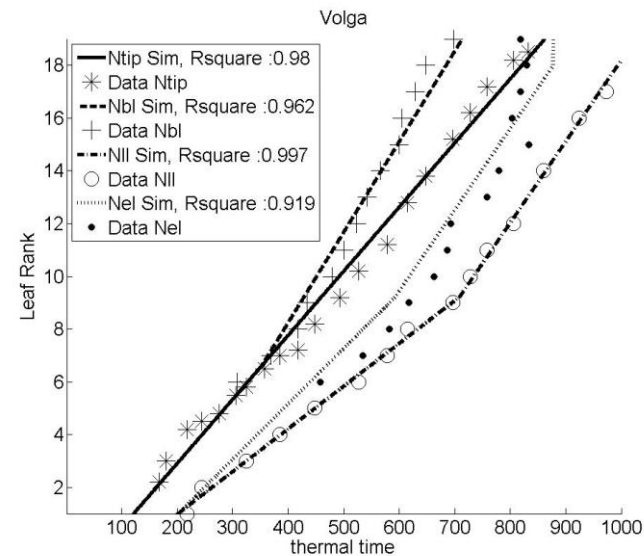
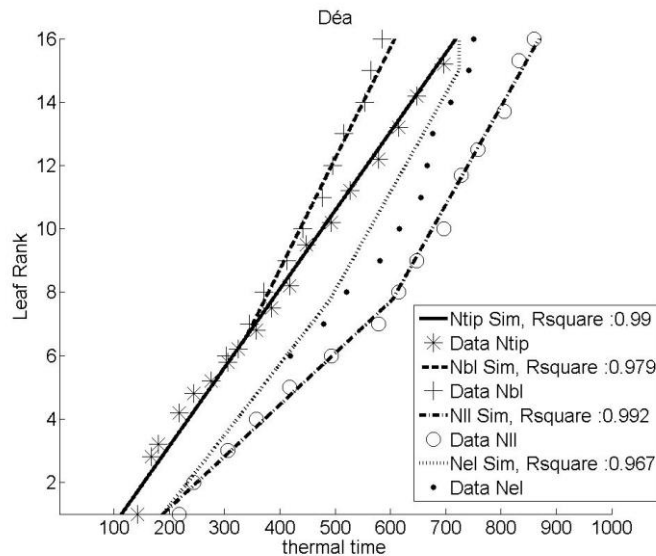
+ de 20 params

Sebastien Lacube



Responses to water deficit and evaporative demand

A simplified model of development and growth with easily phenotyped parameters



5 parameters with genotypic variations, easily measurable:

- Final number of leaves
- Phyllochron
- Thermal time for one leaf appearance
- Thermal time for one leaf ligulation
- Slope of ligulation for first leaves

*+ work on
leaf width
Transpiration effect*

Sebastien Lacube



Conclusion

Models of expansive growth as a function of temperature and water deficit with explicit genetic variability

Temperature response

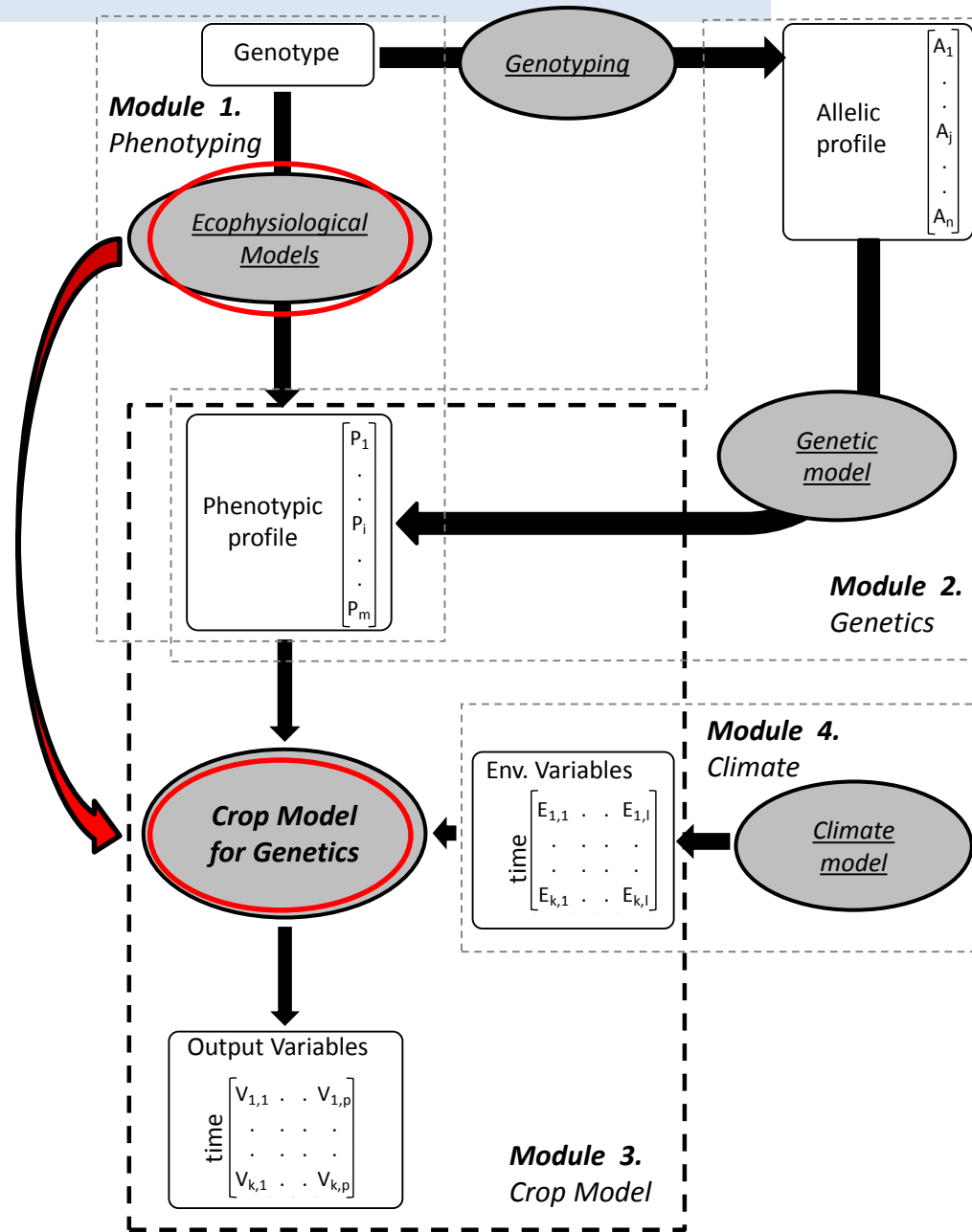
- simplifies the diversity observed in crop models
- R scripts, parameter values

Water transfer and leaf expansion

- diversity of stomatal control and hydraulic conductances
- R scripts, non inserted in crop models

Leaf development and expansion

- few parameters with a large genetic variability
- a module, will be inserted into crop models for testing (APSIM)



Acknowledgement

Temperature :

Yves Gibon

Olivier Turc

François Tardieu



Water transfer :

Thierry Simonneau

François Tardieu

Leaf expansion:

Sebastien Lacube

