Modeling the growth and quality of grape berry in changing environments

Zhanwu Dai[1], Junqi Zhu, Michel Génard, Philippe Vivin, Nathalie Ollat, Eric Gomès, Stefano Poni, Serge Delrot

Rami Albasha[2], Christian Fournier, Christophe Pradal, Jorge Prieto, Gaëtan Louarn, Michaël Chelle, Eric Lebon

[1]UMR 1287 EGFV
ISVV Bordeaux, France
zhanwu.dai@inra.fr

[2]UMR 759 LEPSE
INRA Montpellier, France
Rami.albasha@inra.fr



Berry quality, a complex trait, is essential to wine quality…

Chemical Composition

Sugars (Glucose&Fructose)

Acids (Malate&Tartrate)

Secondary metabolites (phenolics&volatile compounds)

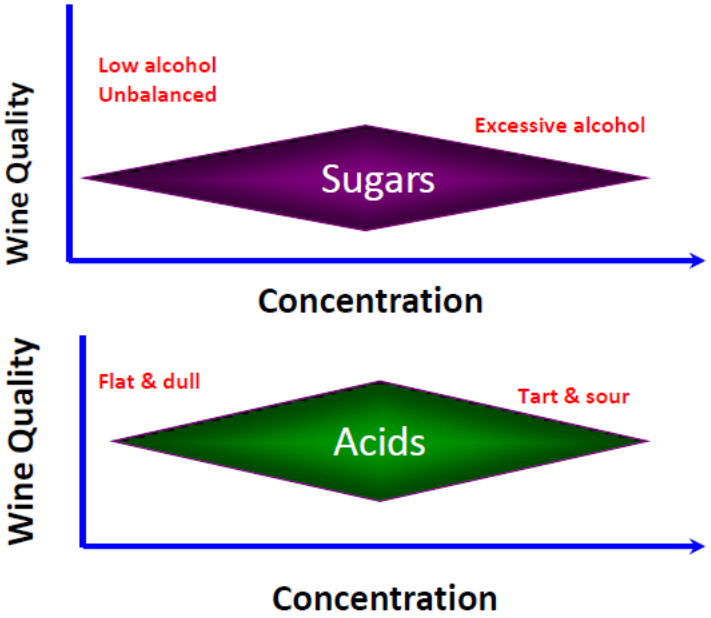
Wine Quality

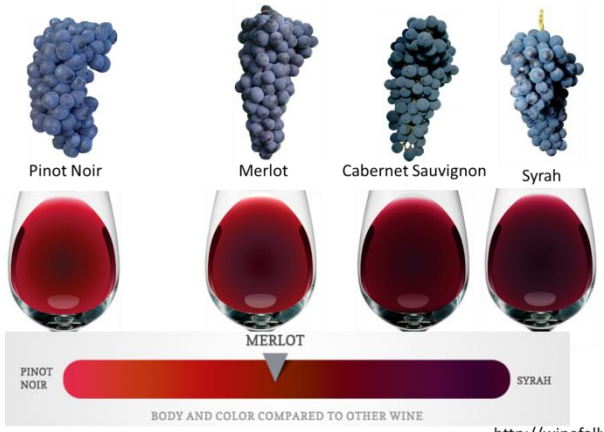
Alcohol content

Flavors

Aromas

Color



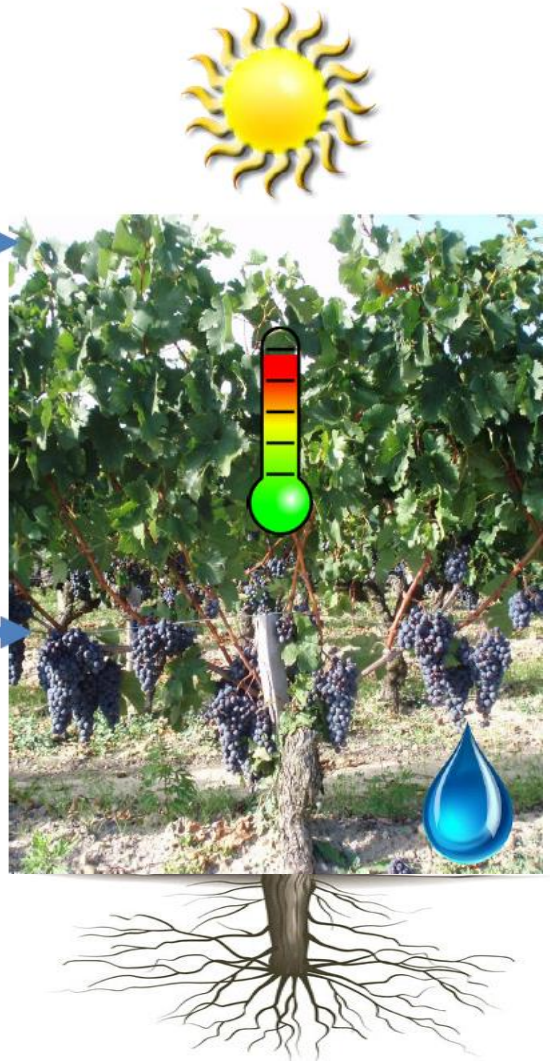


http://winefolly.com/

Berry quality is a result of interaction environment x genotype

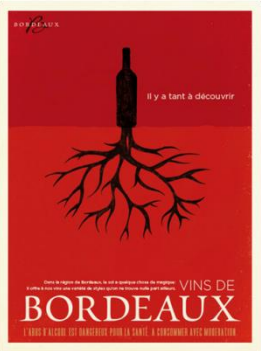
Environment
Soil
Climate (T,Light,RH)
« terroir »and « vintage »

Viticultural practices
Variety selection
Rootstock selection
Fruit load
Canopy management
Pruning
Irrigation / Fertilisation



Plant processes

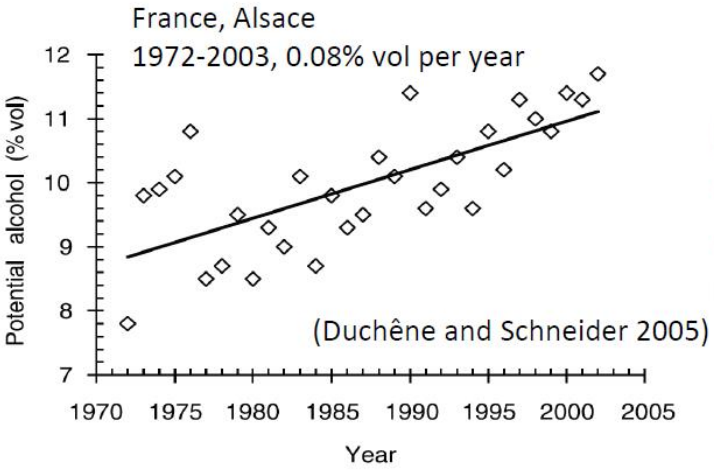
Photosynthesis
Transpiration
Plant water use
Berry growth & composition
Source-sink balance
C allocation to fruits
Soil N nutrition
Vine development
Root morphology
…

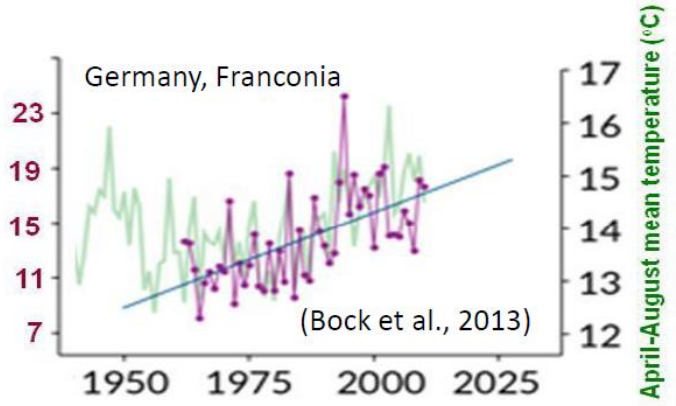


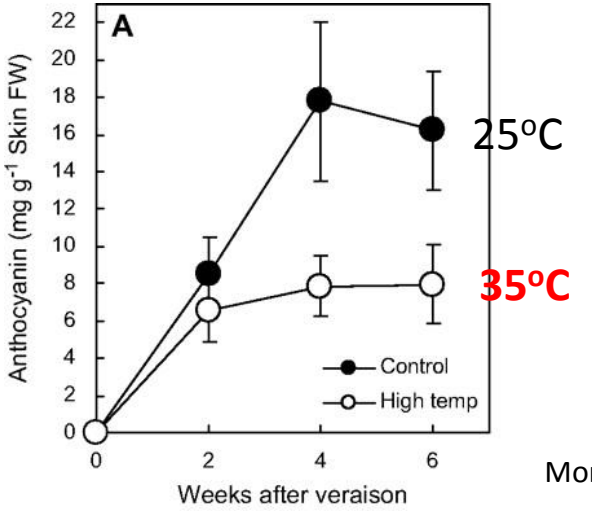
Climate change is modifying berry (wine) quality

Climate change will, depending on the region, increase:

- Atmospheric CO_2; - Temperature: 1,5 to 2°C by 2050; - Drought



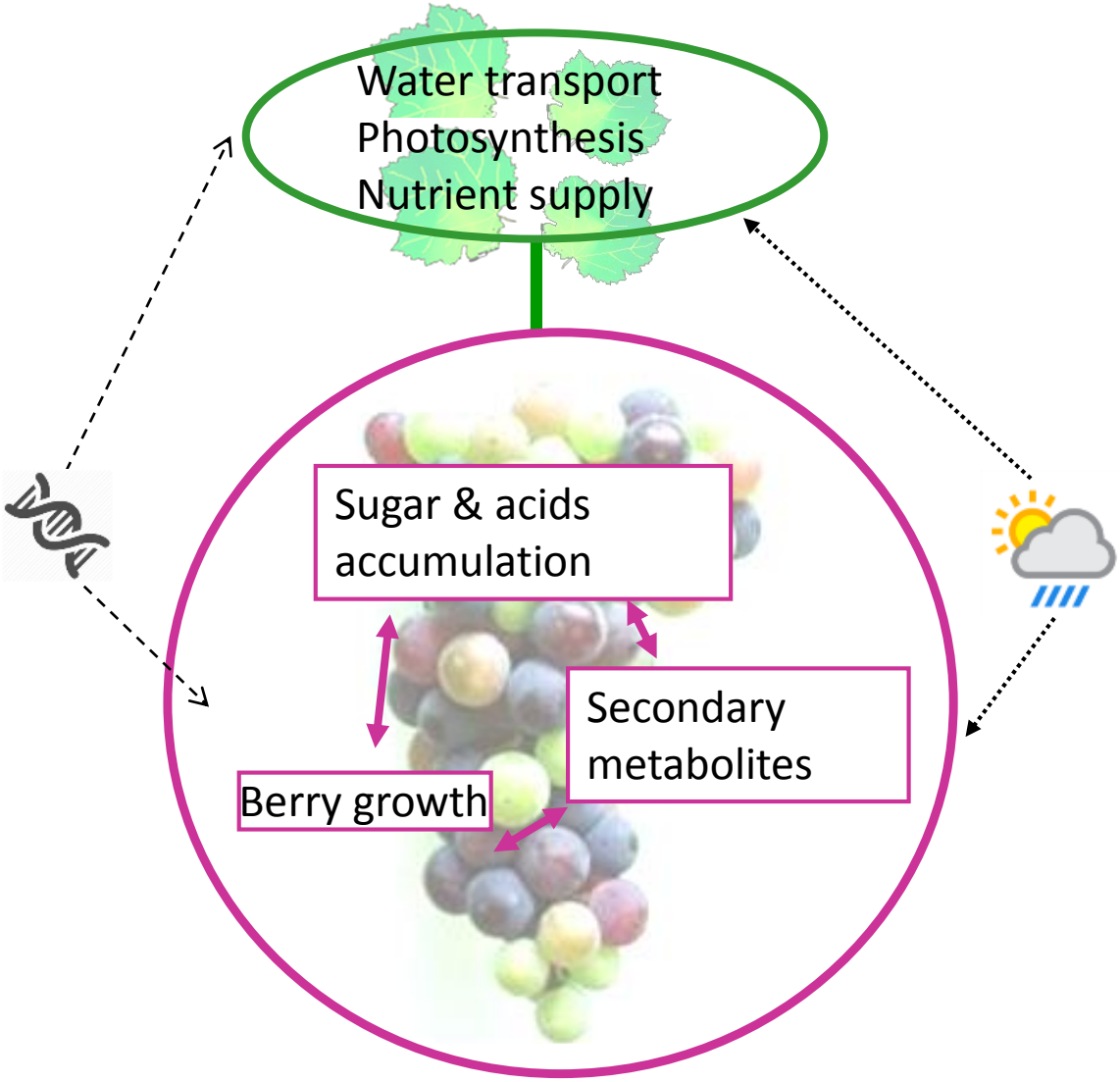




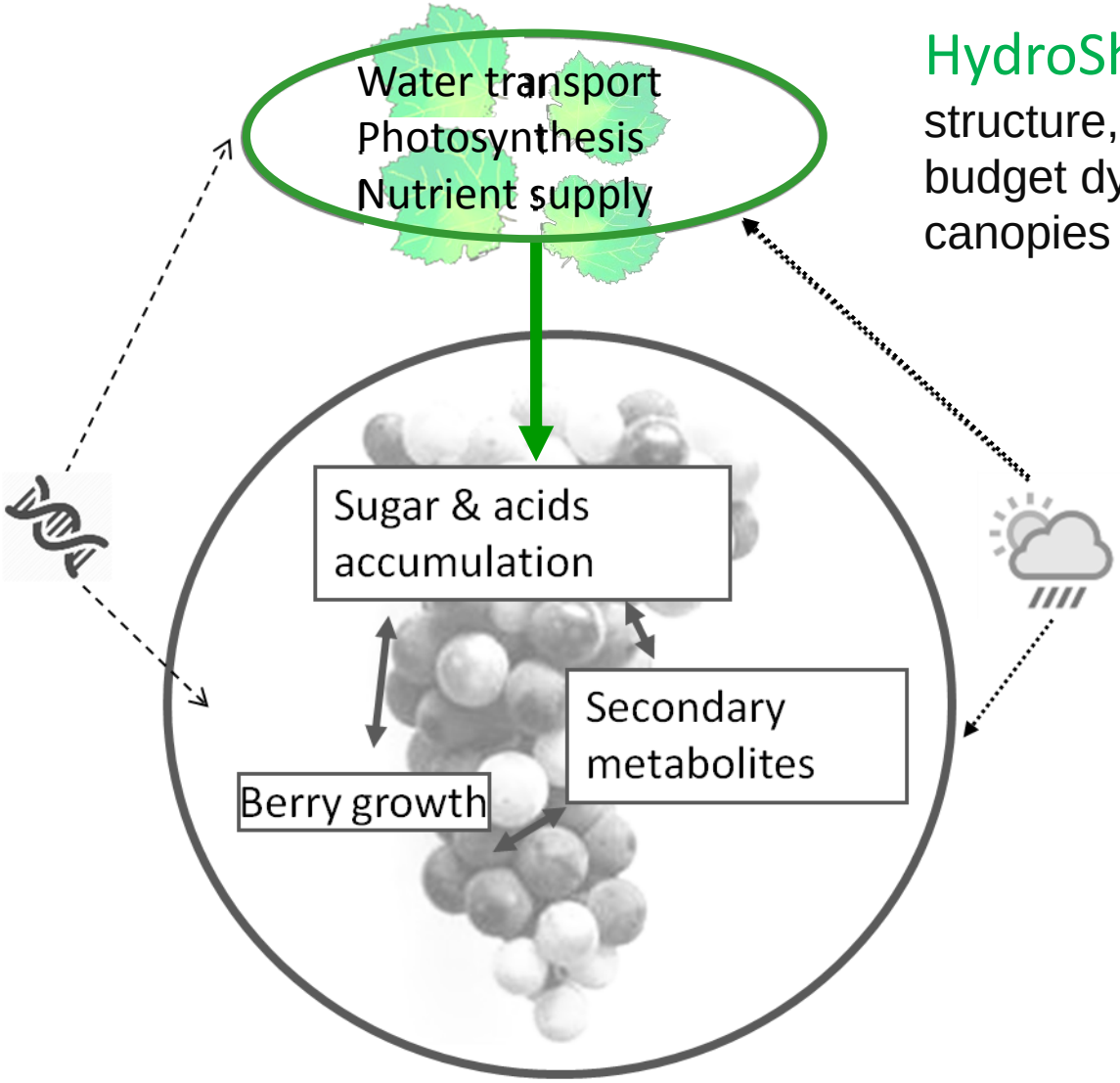
Mori et al., 2007

Need for a **holistic approach** to tackle phenotypic traits under changing environments

Integrative models for berry quality under climate change



Integrative models for berry quality under climate change

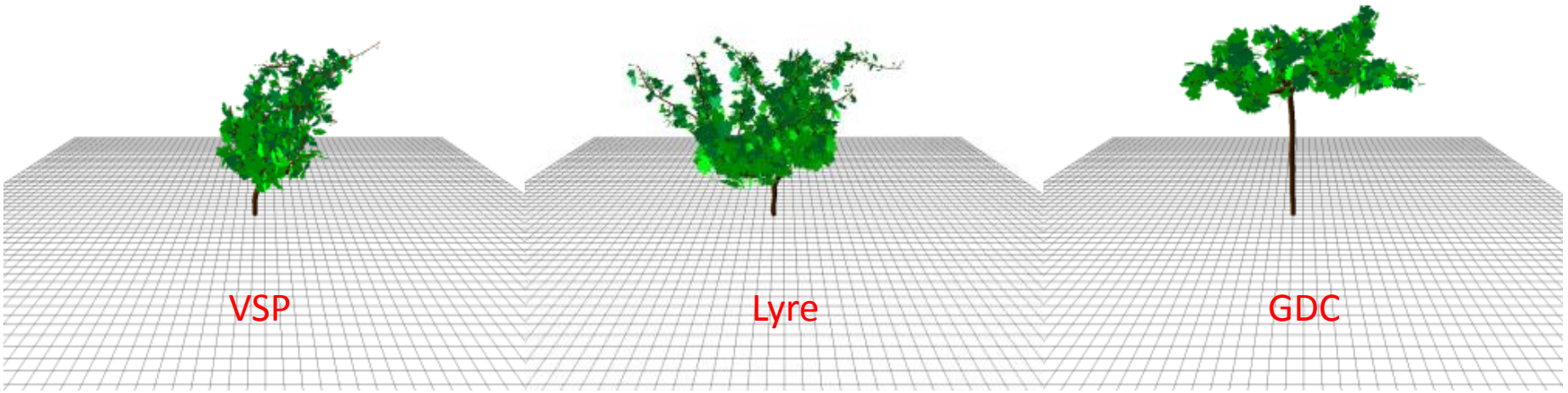


HydroShoot: Simulating hydraulic structure, gas exchange and energy budget dynamics of complex plants canopies under water deficit.

Integrative models for berry quality under climate change

HydroShoot:

How to account for complex canopies on water use efficiency?



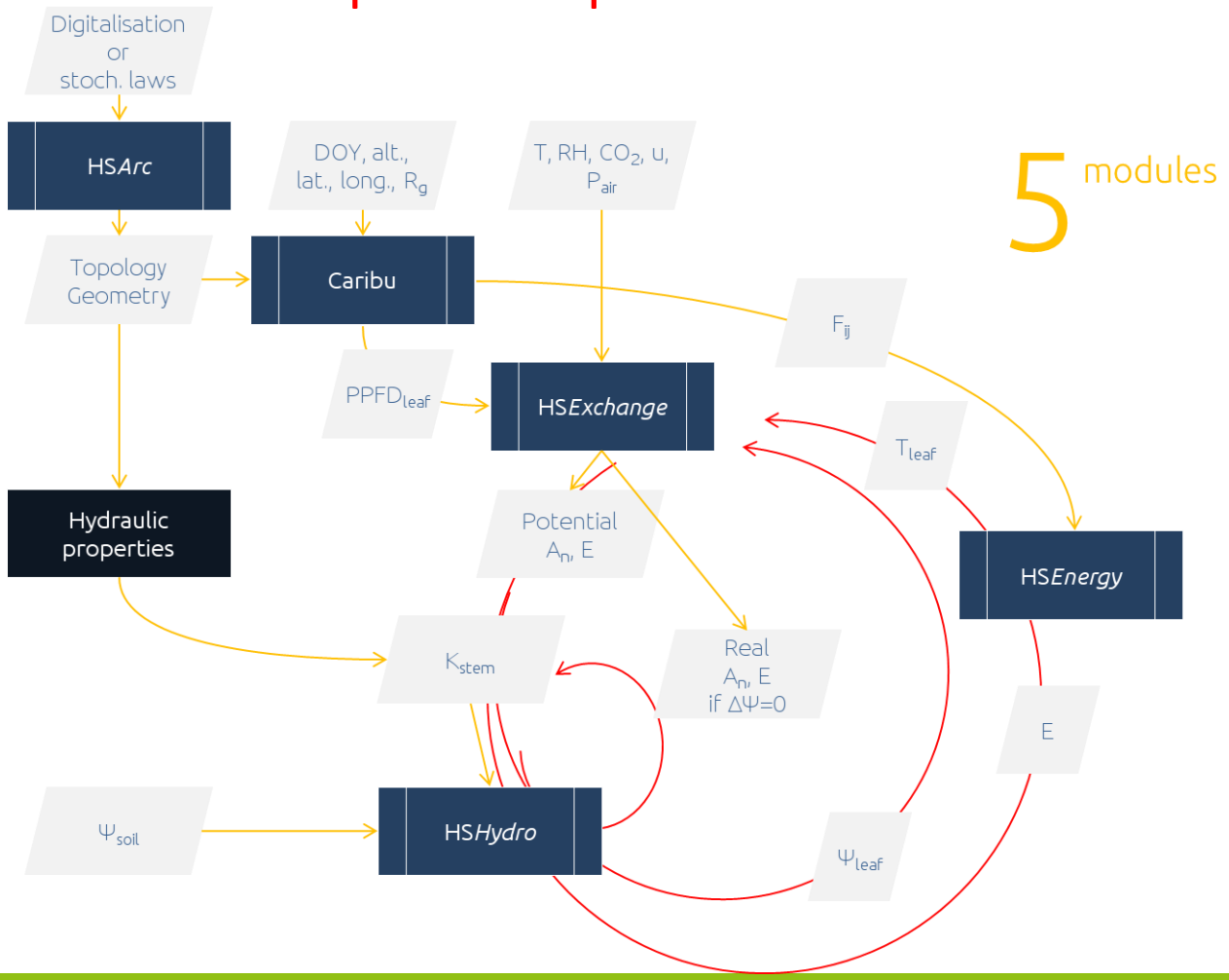
3 tools: **Light** interception,
water distribution
temperature

of **individual leafs**

Integrative models for berry quality under climate change

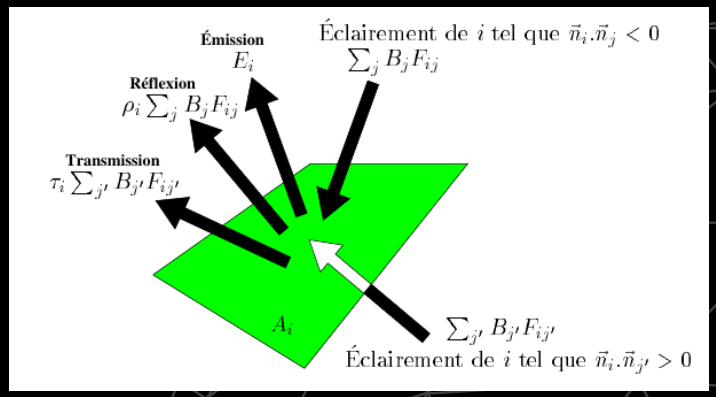
HydroShoot:

How to account for complex canopies on water use efficiency?



Integrative models for berry quality under climate change

- **Caribu** model (Chelle et al., 1998) to simulate plant organs' irradiance using Z-buffer and nested radiosity methods.

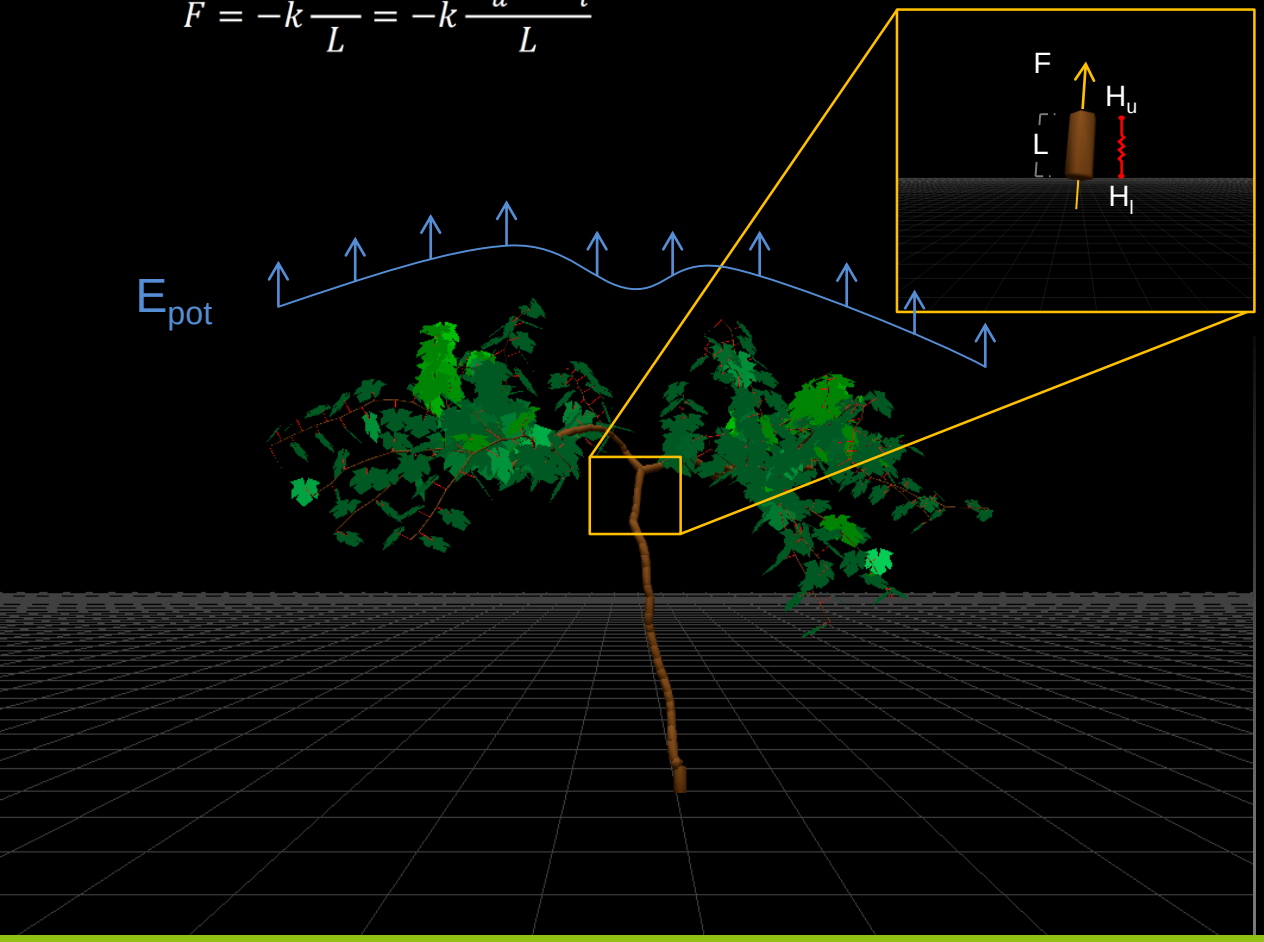


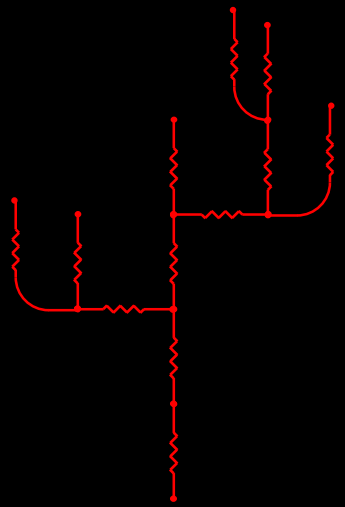
(Chelle et al., 1998)

Integrative models for berry quality under climate change

- Electrical circuit analogy (van den Honert, 1948)

$$F = -k\frac{\Delta H}{L} = -k\frac{H_u - H_l}{L}$$

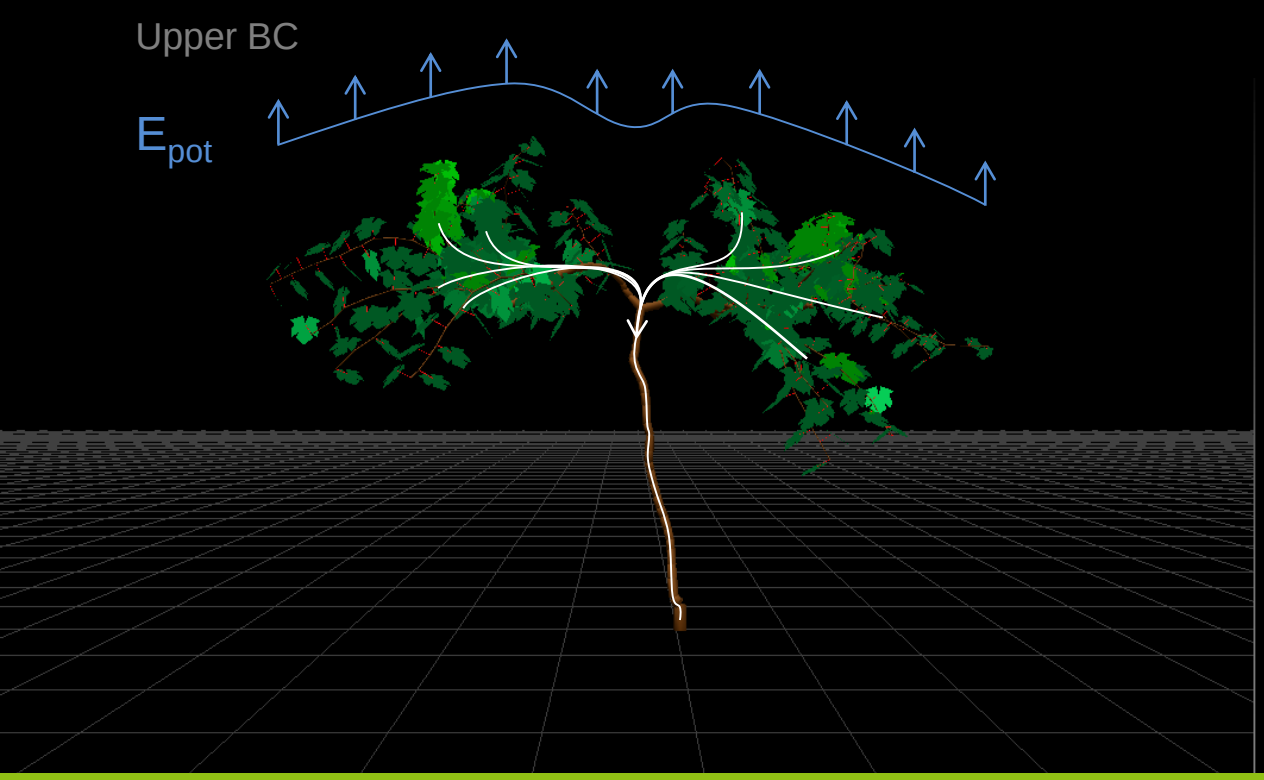


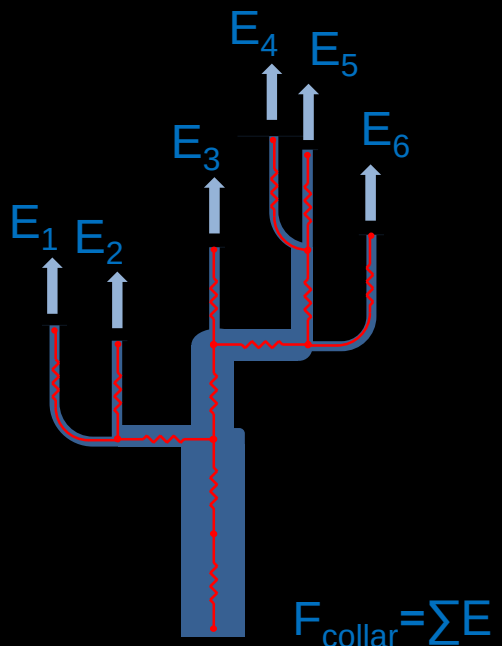


Integrative models for berry quality under climate change

- Electrical circuit analogy (van den Honert, 1948)
- K = cst $\longrightarrow$ 2 iterations following topological paths

1. Get down: F_{collar}

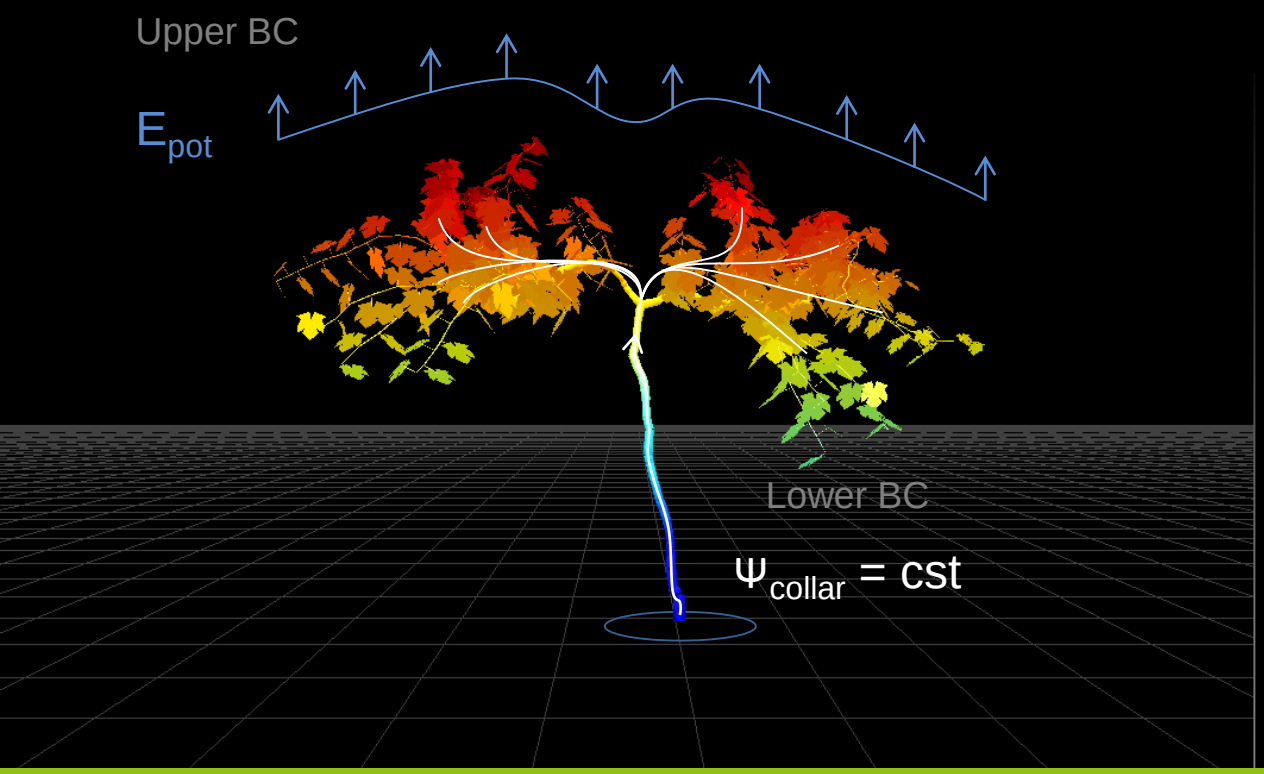


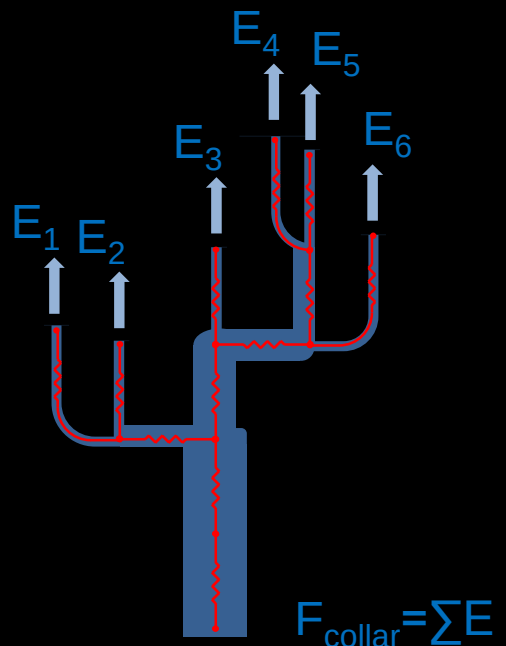


Integrative models for berry quality under climate change

- Electrical circuit analogy (van den Honert, 1948)
- K = cst ⟶ 2 iterations following topological paths

1. Get down: F_{collar}
2. Get up: Ψ_{xylem} at each organ





Integrative models for berry quality under climate change

- Leaf temperature at energy equilibrium (Gutschick, 2016)

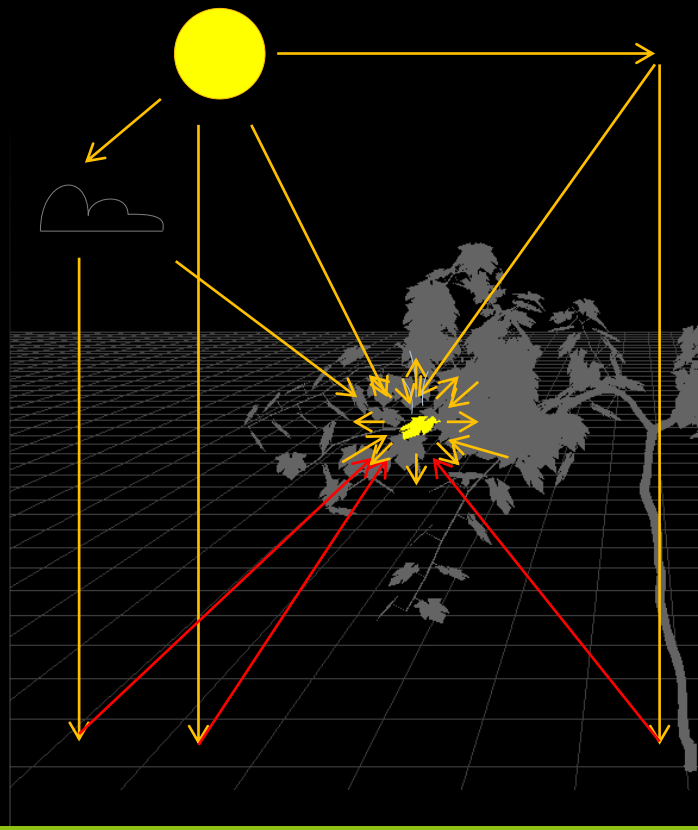
  + in the visible and near IR bands (shortwave irradiance)

  + in the thermal IR band (longwave irradiance)

  - in the thermal IR band

  - accompanying transpiration

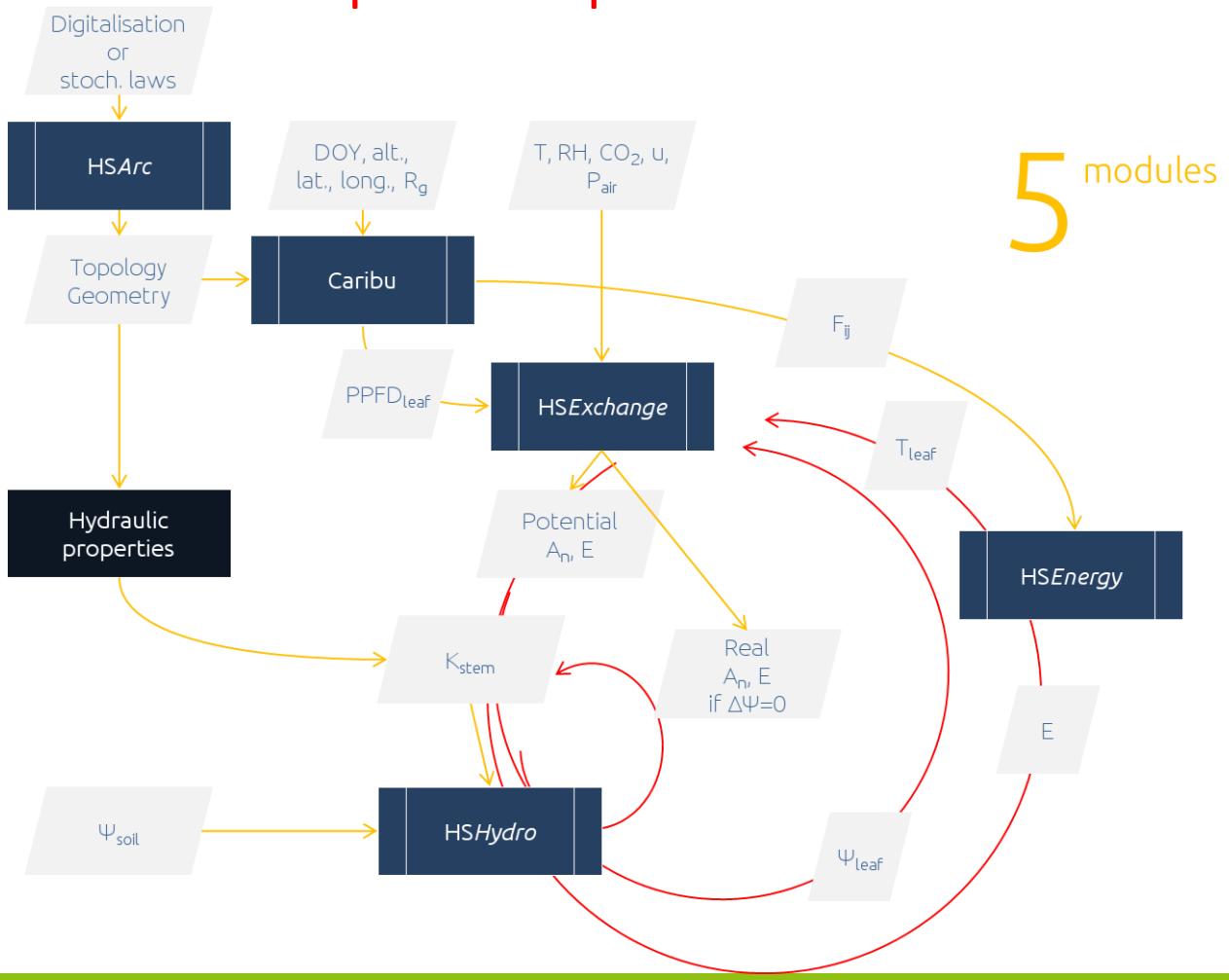
  - due to heat convection



Integrative models for berry quality under climate change

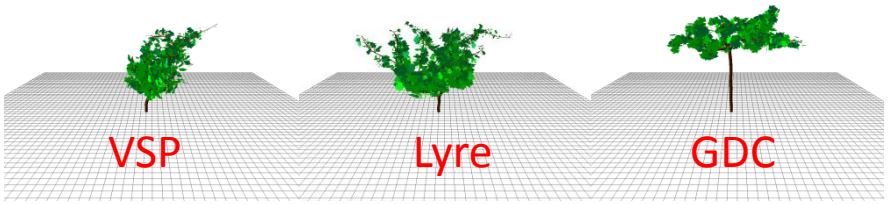
HydroShoot:

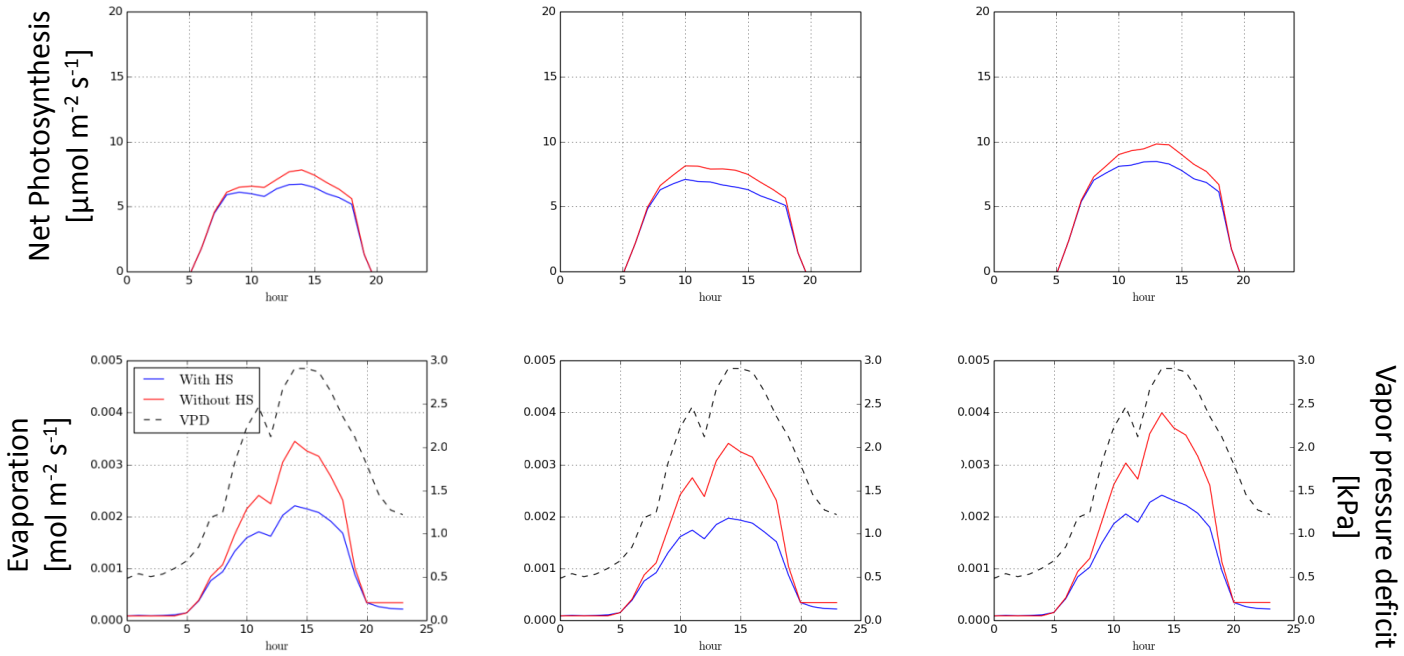
How to account for complex canopies on water use efficiency?



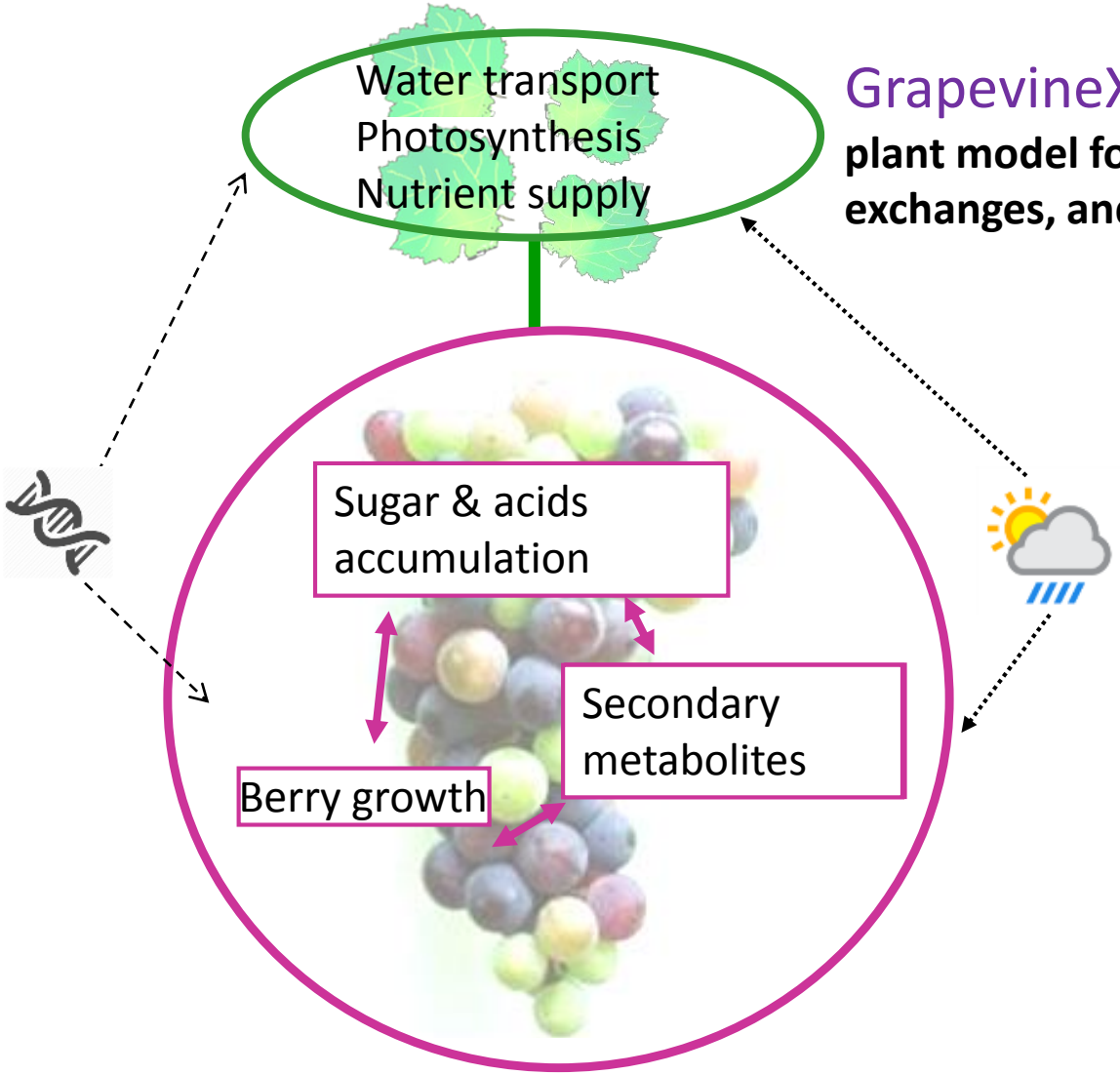
Integrative models for berry quality under climate change

HydroShoot: capture the effect of canopy structure on gas-exchange processes





Integrative models for berry quality under climate change



GrapevineXL: **A functional-structural plant model for water transport, leaf gas exchanges, and berry growth**

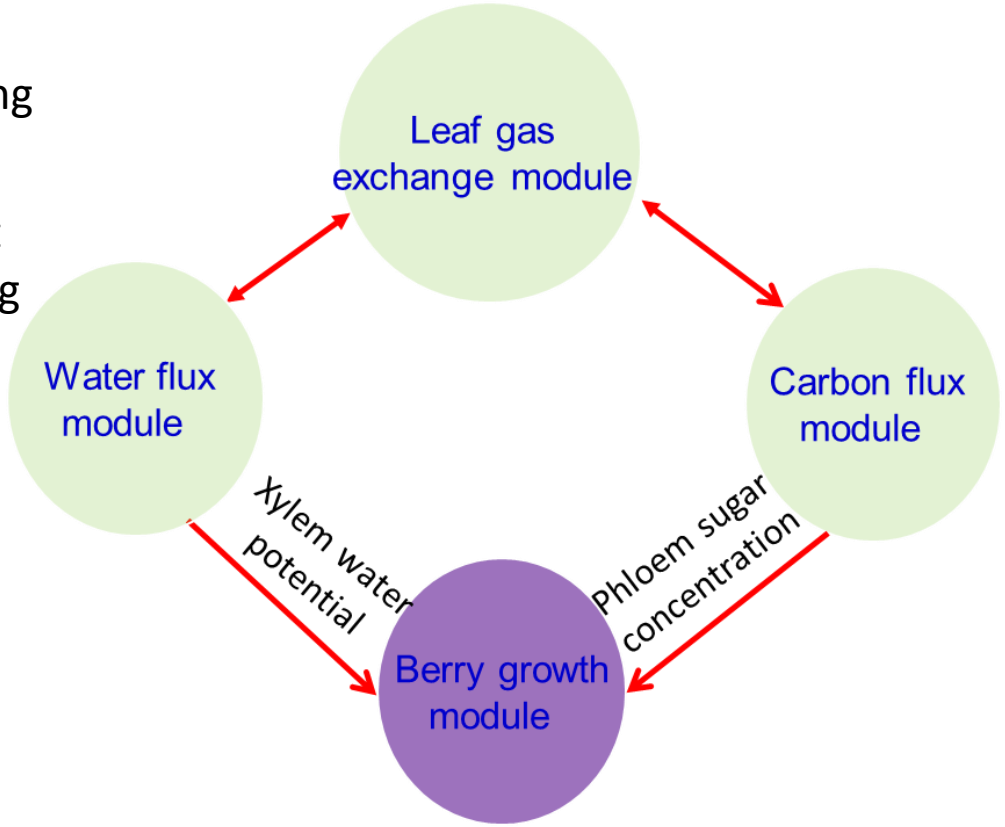
GrapevineXL :
A functional-structural plant model for water transport, leaf gas exchanges, and berry growth

Leaf: Pn, E, C unloading

Stem: water transport
carbon buffering

Berry: C, H_2O balance

Root: water uptake

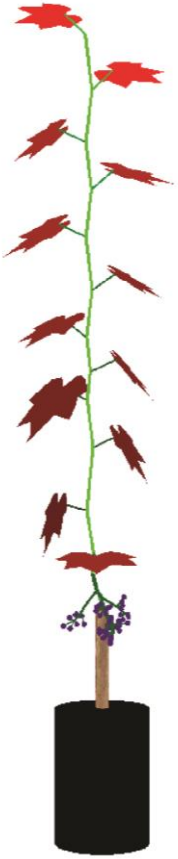


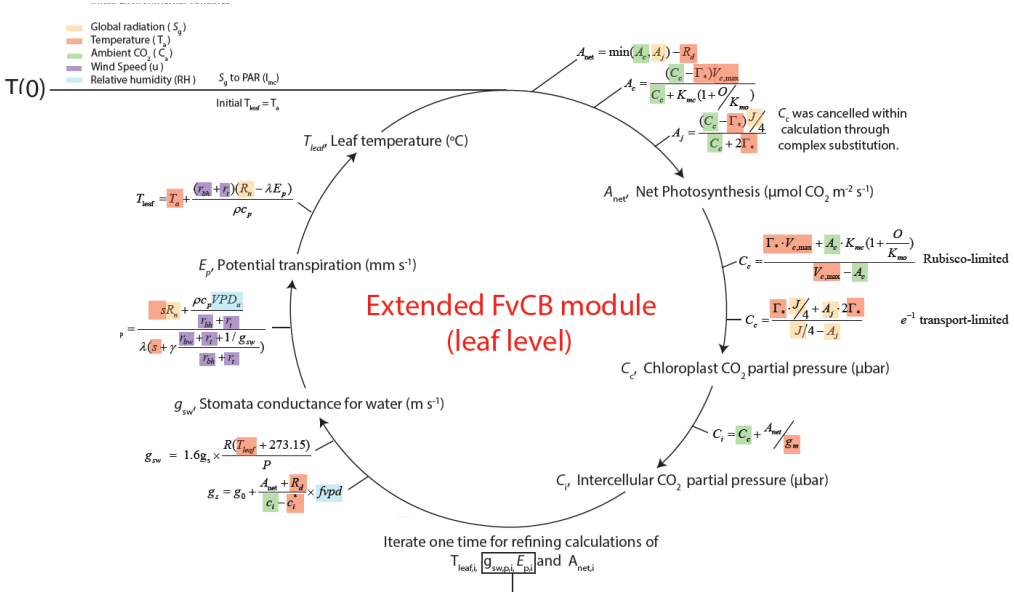
Zhu et al., submitted

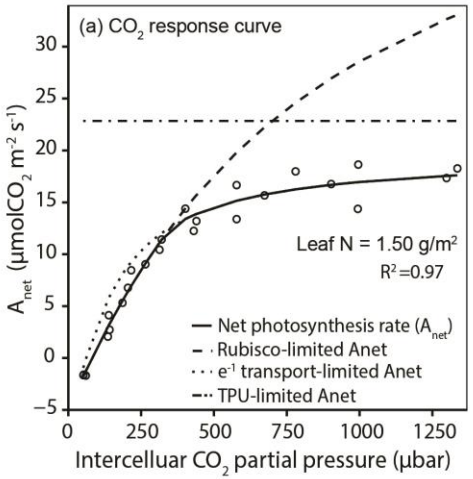
GroIMP

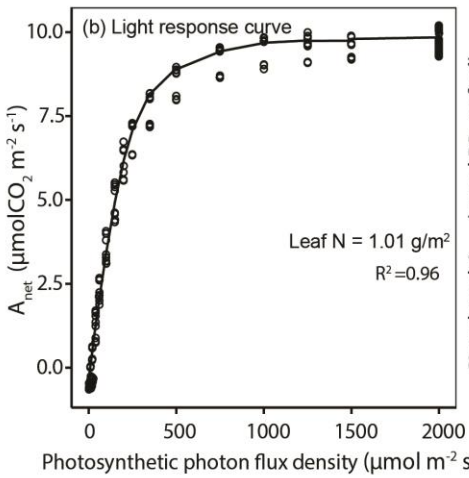
Leaf gas exchange module: an extended Farquhar-von-Caemmerer-Berry module

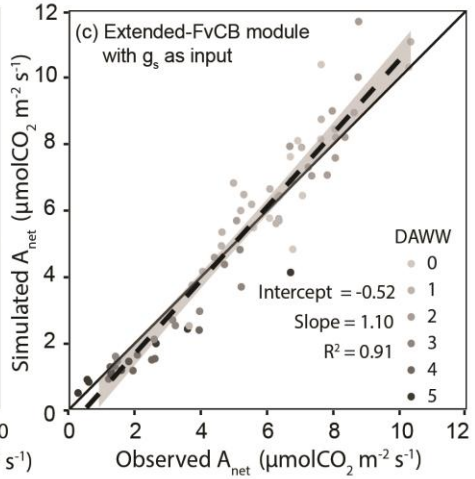
(b) Net photosynthesis





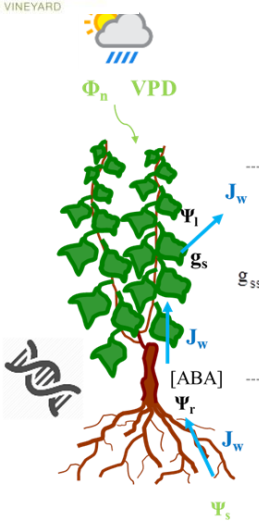






Zhu et al., submitted

Water flux module: Tardieu–Davies model



$$J_w = \frac{s(\Phi_n - G) + \rho_a c_p VPD g_a}{\lambda[s + (\gamma g_a / g_s)]} \quad (1)$$

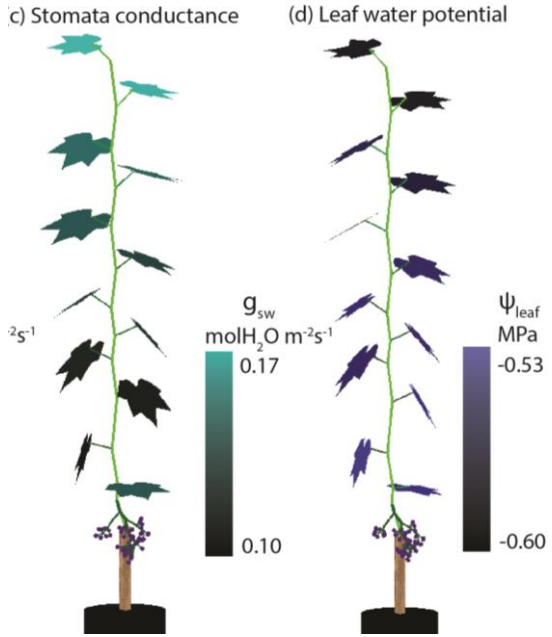
$$J_w = \frac{\Psi_r - \Psi_l}{R_p} \quad (2)$$

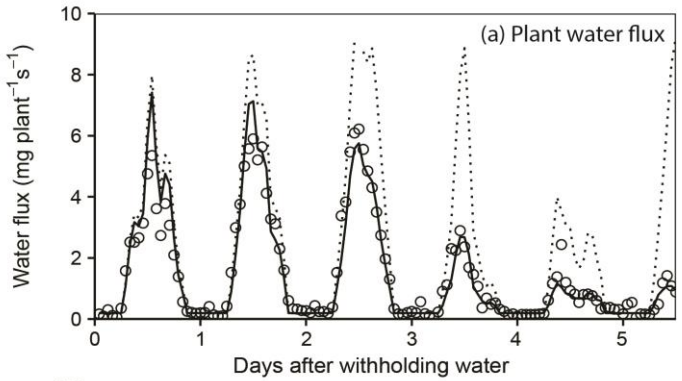
$$g_{ssat} = g_{smin} + \alpha \exp([ABA]\beta \exp(\delta\Psi_l)) \quad (3)$$

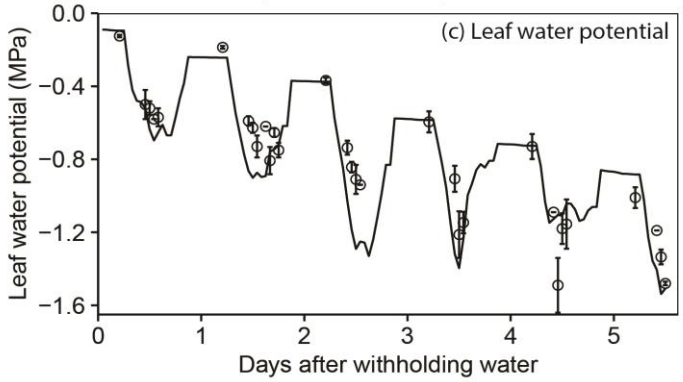
$$[ABA] = \frac{-P_{aba.1}\Psi_r}{J_w + P_{aba.2}} \quad (4)$$

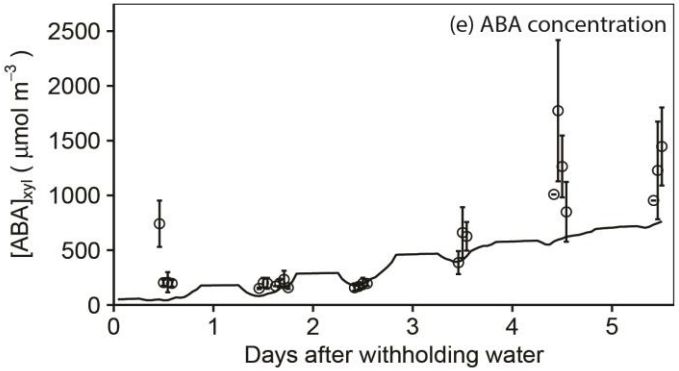
$$J_w = \frac{\Psi_s - \Psi_r}{R_{sp}} \quad (5)$$

$$R_{sp} = \frac{\ln(d^2/r^2)}{4\pi k s(\theta) RLA} \quad (6)$$



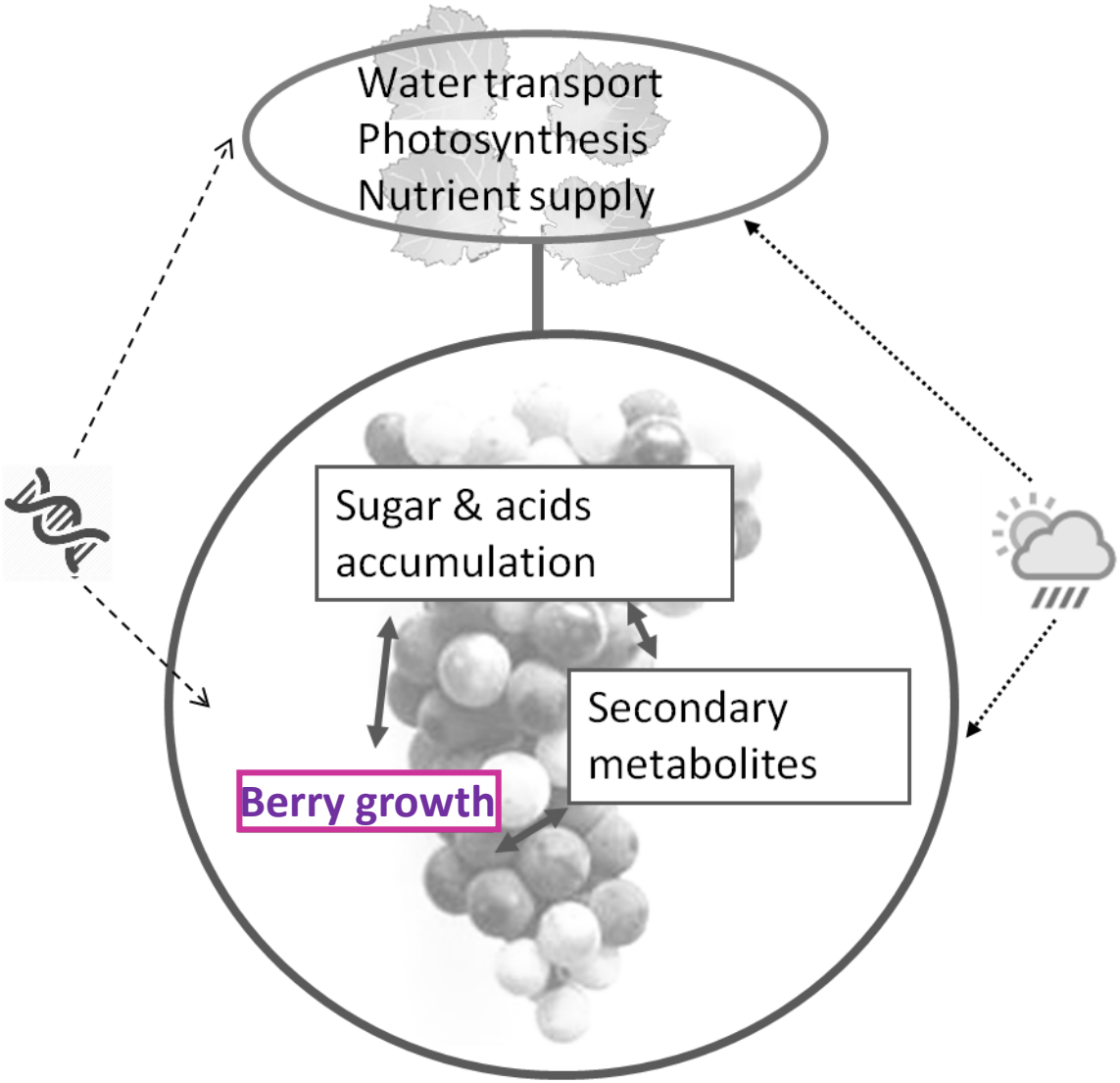




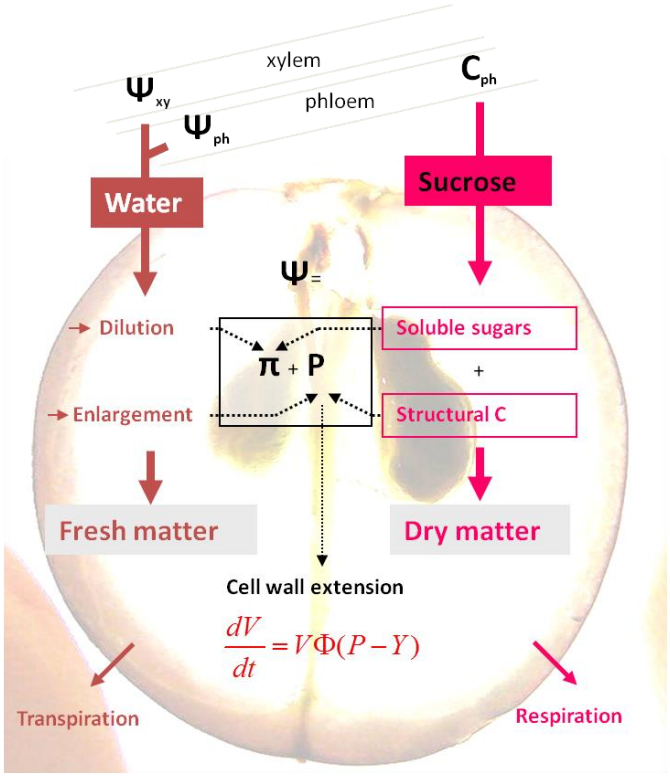


Zhu et al., submitted

Integrative models for berry quality under climate change

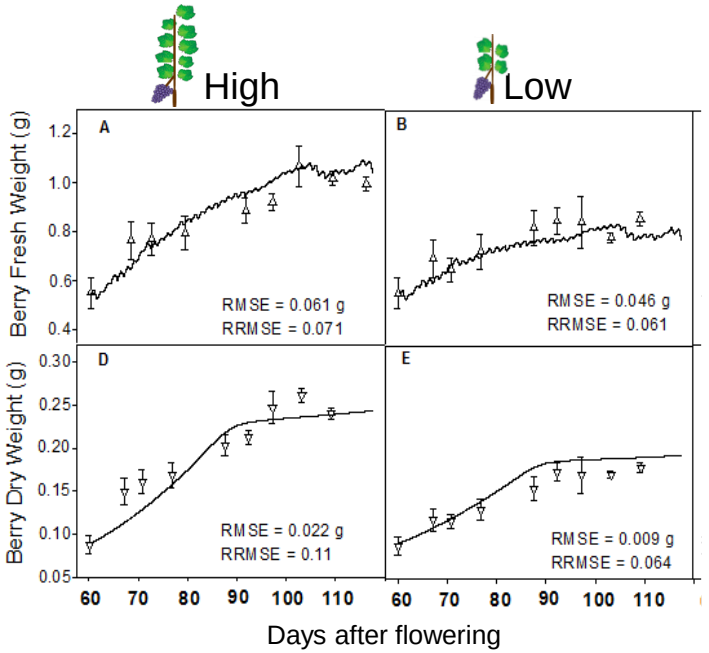


Berry growth : a biophysical fruit model

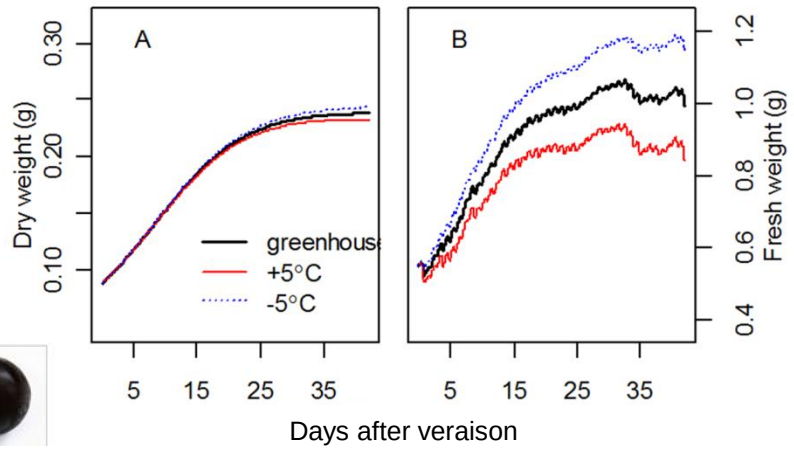


Fishman and Génard (1998)

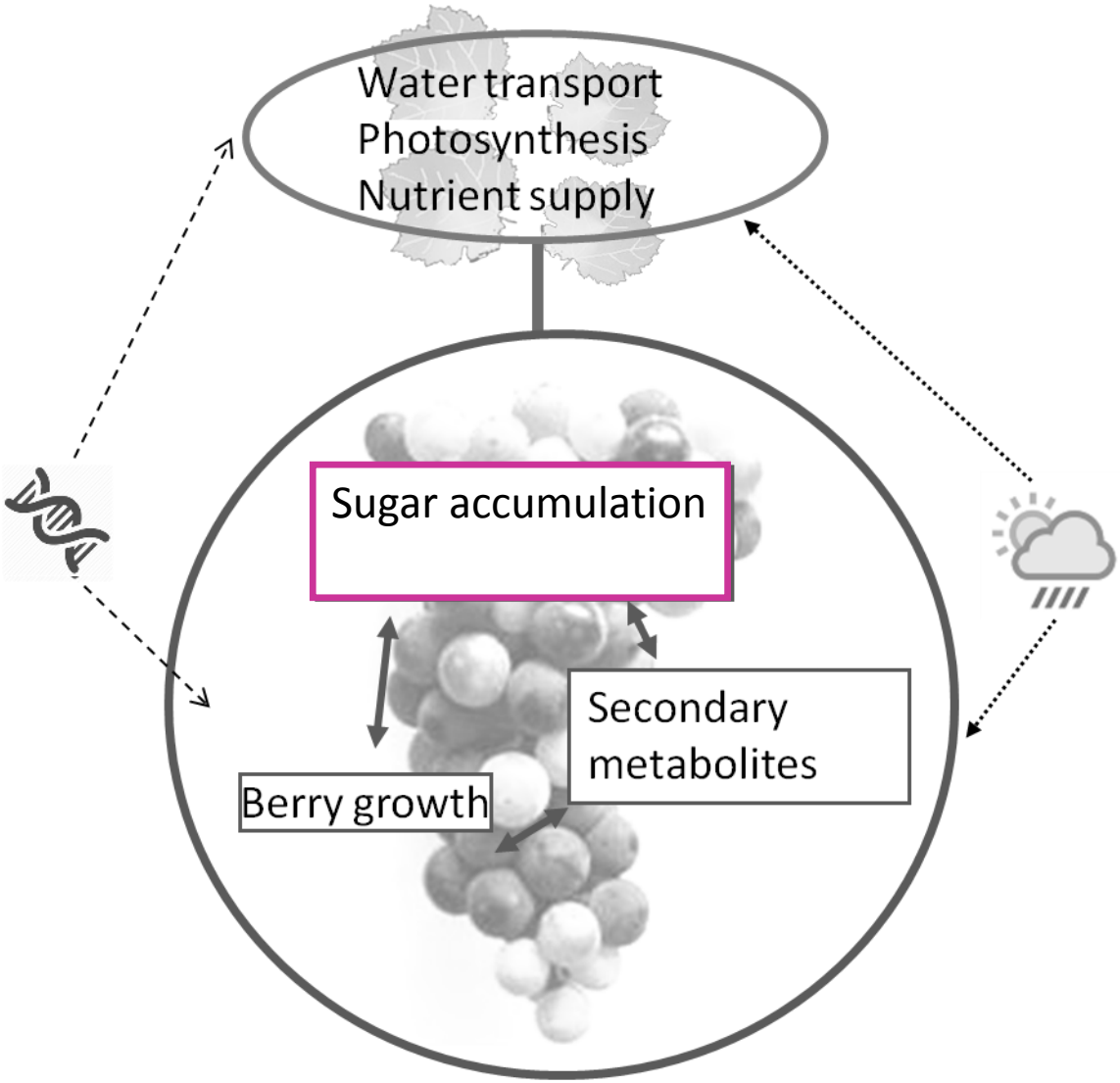
Effect of leaf-to-fruit ratio



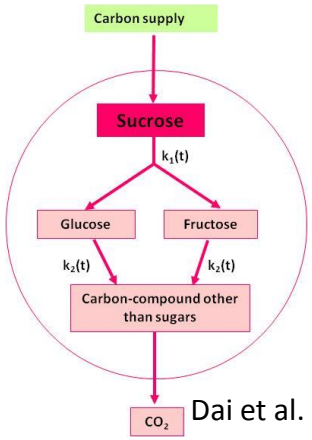
Effect of temperature



Integrative models for berry quality under climate change



Sugar concentration: a simplified process-based model



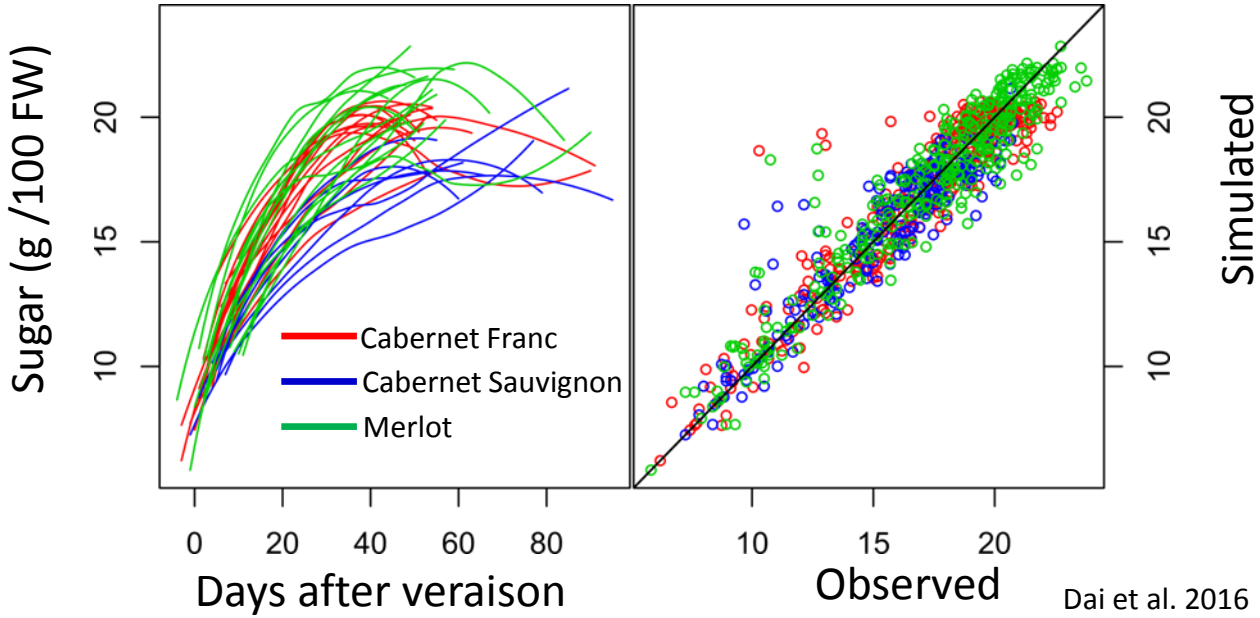
Dai et al. 2009

$$\frac{dsucre}{dt} = \underbrace{\frac{100\gamma_{PS}}{\gamma_c \cdot \gamma_{PF} \cdot PF} \cdot \frac{dPS}{dt}}_{\text{Sugar Import}} - \underbrace{K(t)\, sucre}_{\text{Sugar Metabolism}} - \underbrace{\frac{sucre}{PF} \cdot \frac{dPF}{dt}}_{\text{Water Dilution}}$$

[Sugar]

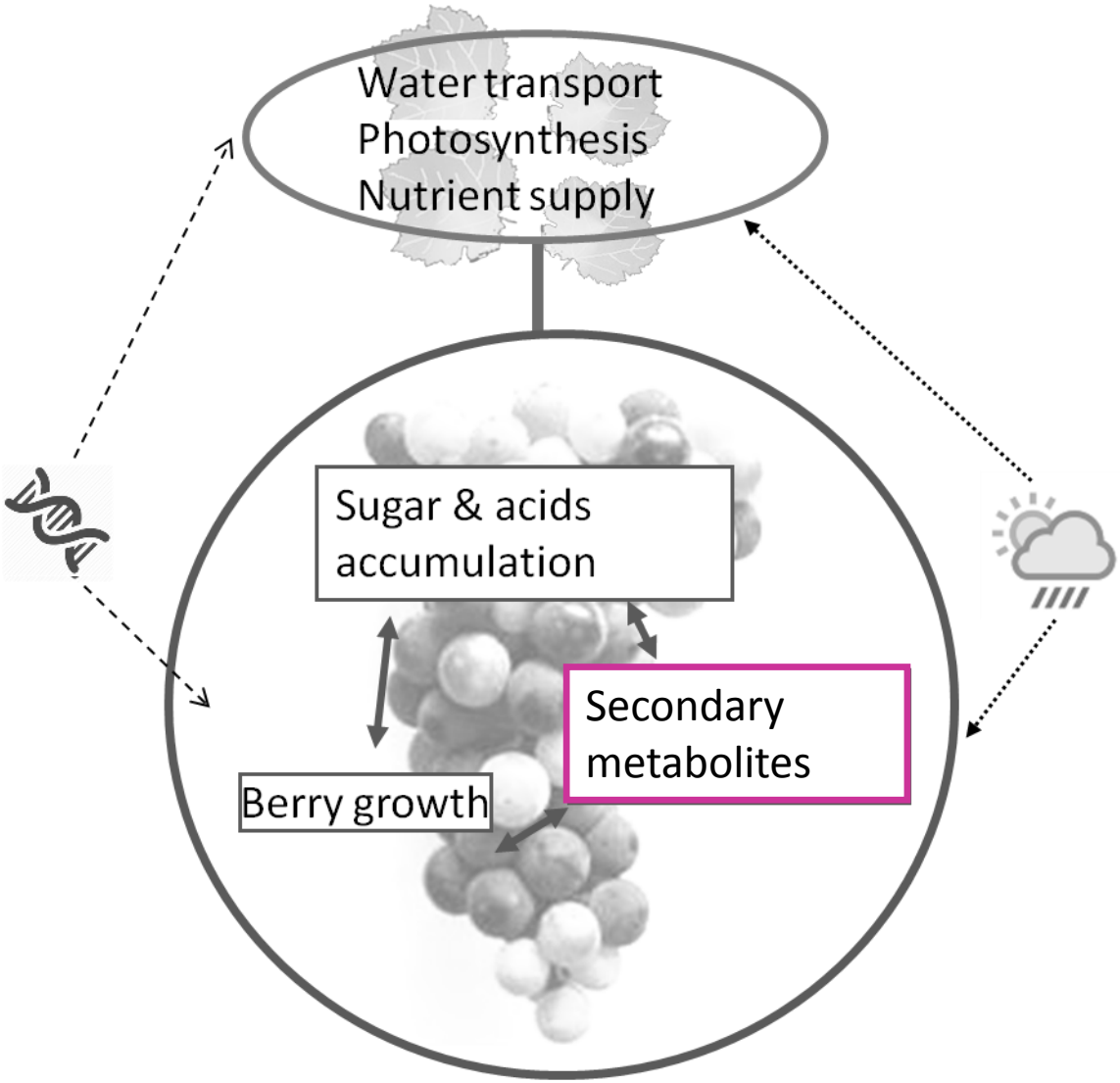
$$K(t) = k \frac{dPS}{dt} \frac{1}{PS}$$

Model validated on 3 cultivars over 15 years (1996-2010)



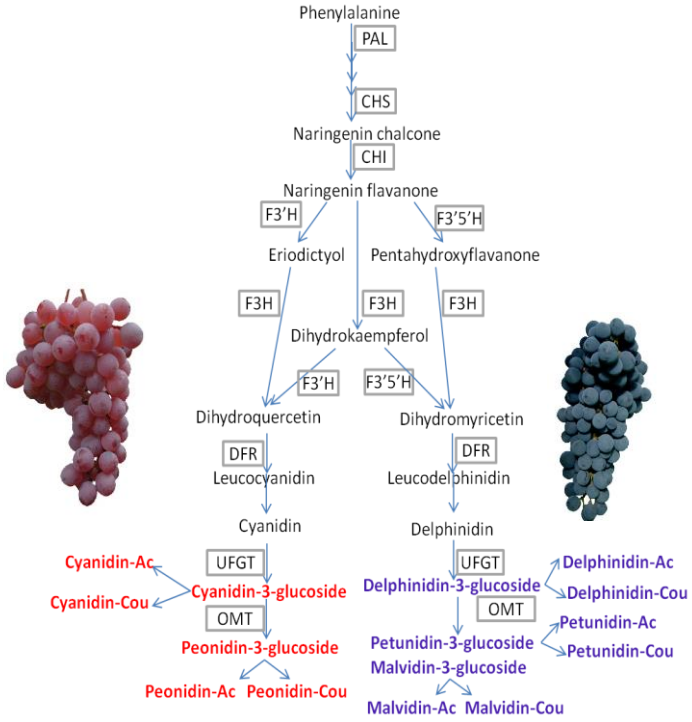
Dai et al. 2016

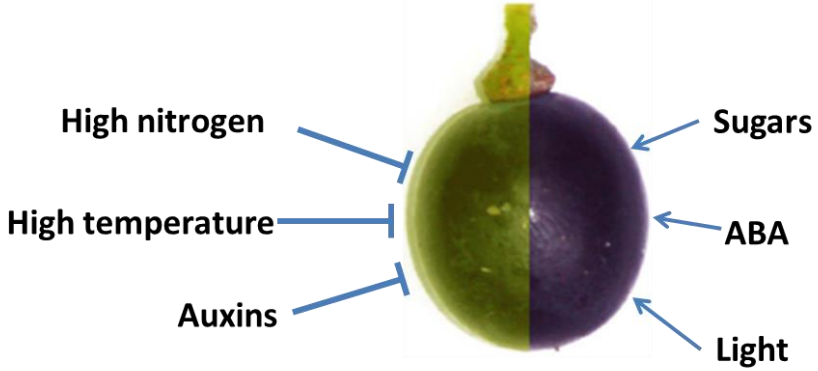
Integrative models for berry quality under climate change



Color pigments: a process-based model for anthocyanin composition

- Wide variation in total anthocyanin content and composition;

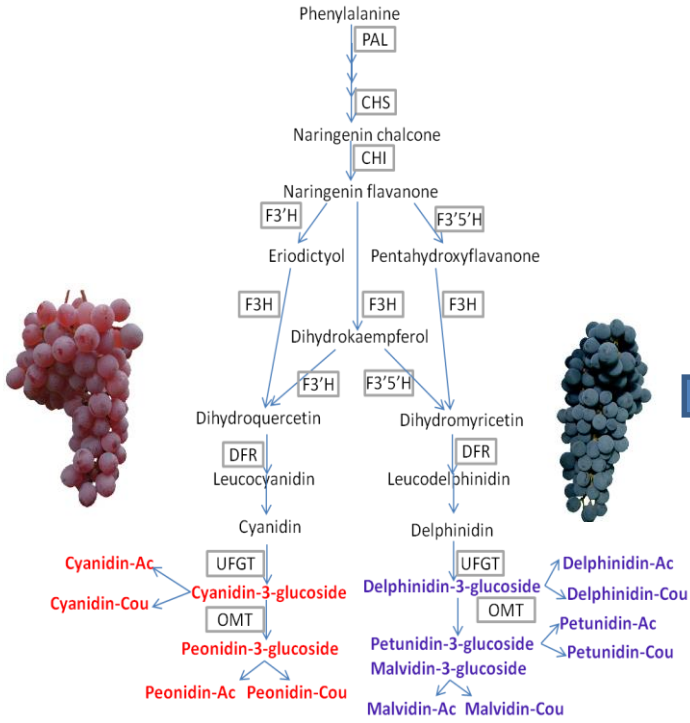


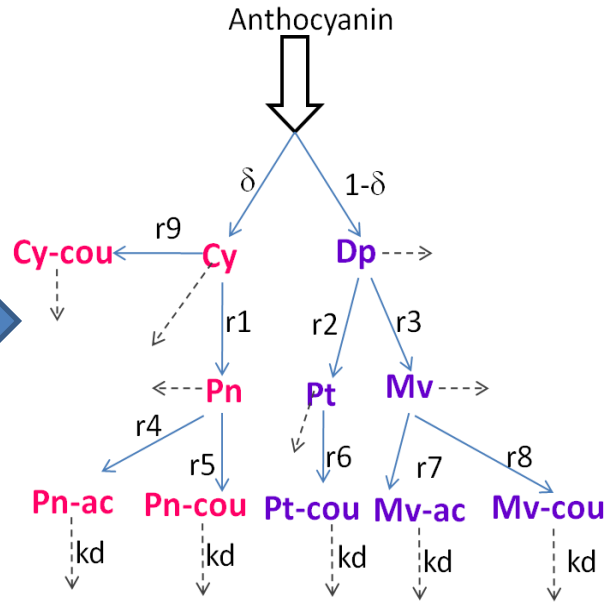


adapted from Böttcher and Davies, 2012

Color pigments: a process-based model for anthocyanin composition

- Wide variation in total anthocyanin content and composition;





$$\frac{dTA}{dt} = \frac{dTAobs}{dt} + kdTA$$

$$\frac{dCy}{dt} = \delta\frac{dTA}{dt} - (r1 + r9 + kd)Cy$$

$$\frac{dDp}{dt} = (1-\delta)\frac{dTA}{dt} - (r2 + r3 + kd)Cy$$

$$\frac{dPn}{dt} = r1Cy - (r4 + r5 + kd)Pn$$

$$\frac{dPt}{dt} = r2Dp - (r6 + kd)Pt$$

$$\frac{dMv}{dt} = r3Dp - (r7 + r8 + kd)Mv$$

$$\frac{dPn\_ac}{dt} = r4Pn - kdPn\_ac$$

$$\frac{dPn_{cou}}{dt} = r5Pn - kdPn_{cou}$$

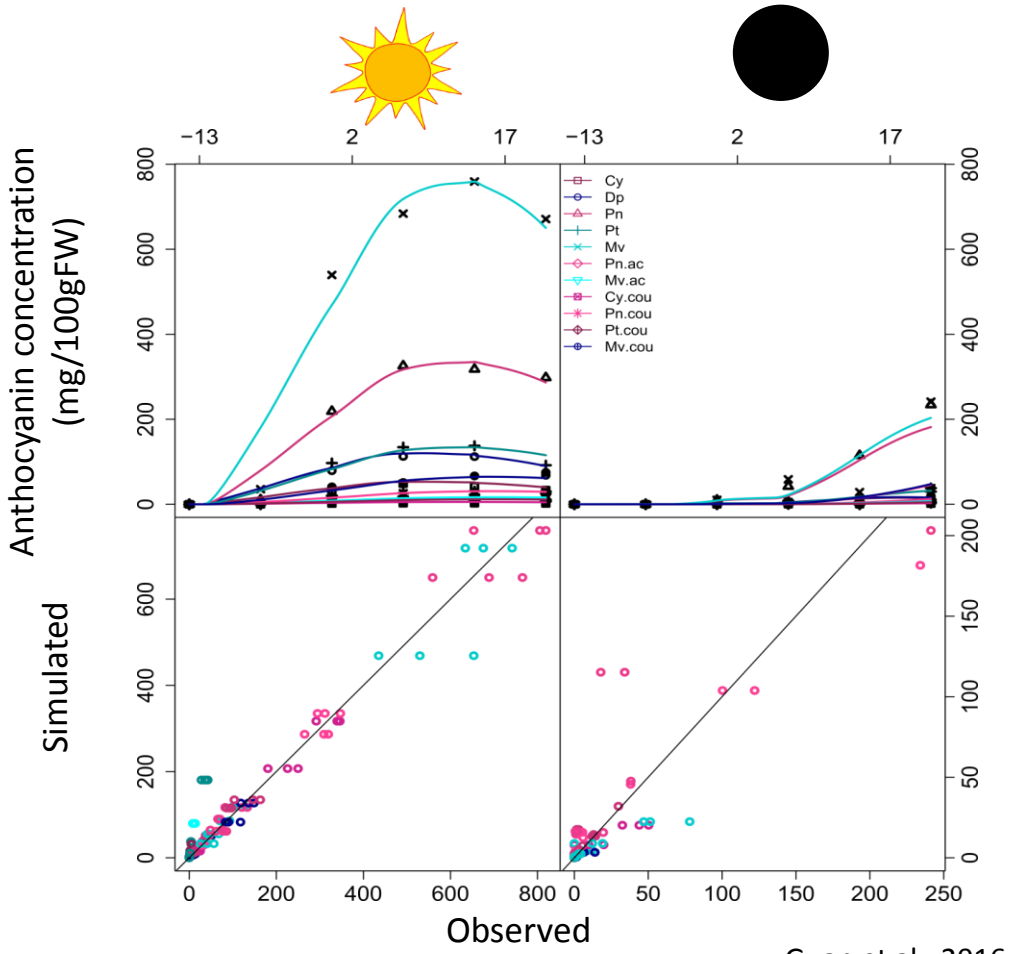
$$\frac{dPt_{\_cou}}{dt} = r6Pt - kdP\_cou$$

$$\frac{dMv_{\_ac}}{dt} = r7Mv - kdMv_{\_ac}$$

$$\frac{dMv\_cou}{dt} = r8Mv - kdMv\_cou$$

$$\frac{dCy\_cou}{dt} = r9Cy - kdCy\_cou$$

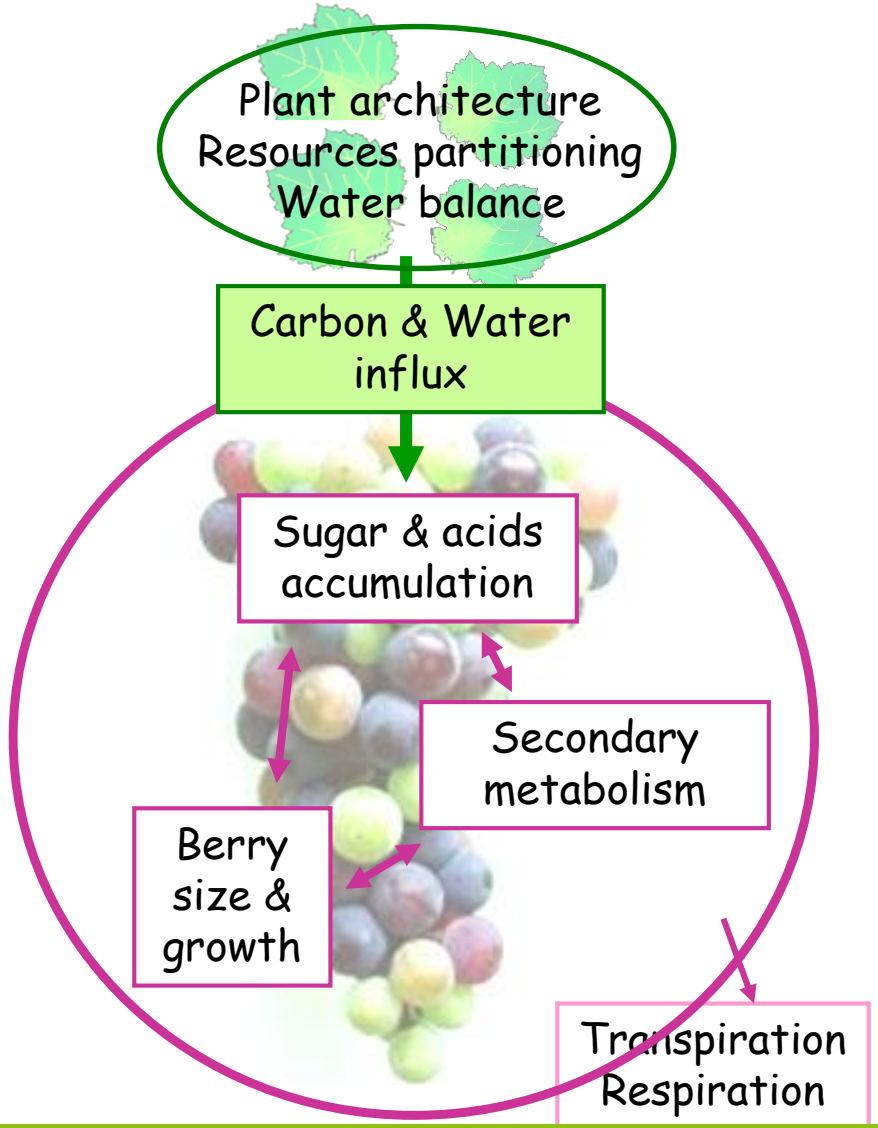
Color pigments: a process-based model for anthocyanin composition



Guan et al., 2016

- The model can simulate anthocyanin composition under various genotype x environment combinations;
- Model parameters can be considered as dissected traits

Conclusion and Perspectives



❑Fruit level: models developed for simulating berry growth, sugars and anthocyanin;

❑Whole-plant level: two functional-structurals model developed for water transport, leaf gas exchange, carbon allocation, and berry growth.

❑**Fruit level:**

- Develop new fruit-centered models cover other chemical compounds: organic acids, amino acids, flovonols, stilbene, aromas…
- Update existing models to kinetic models integrating gene expression, enzyme activity and metabolite concentration;

❑**Whole-plant level:**

- Connect HydroShoot with GrapevineXL
- Integrate berry metabolism modules
- Develop shoot growth module…

Thank you for your attention!