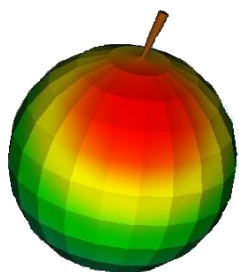




Déterminisme de la température des organismes

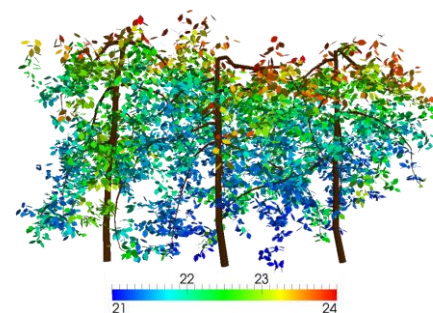
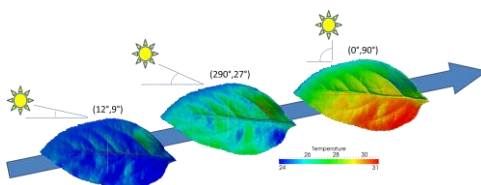
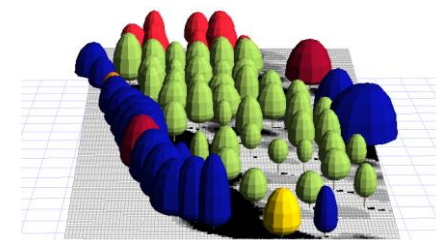
Lien avec les facteurs de l'environnement et variabilité spatiale



Marc Saudreau

UMR PIAF – Clermont-Ferrand

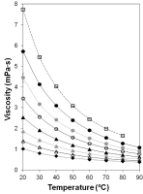
marc.saudreau@inrae.fr



Contexte – Température un facteur clef

Propriétés Physiques

- Masse volumique
- Pression
- Capacité calorifique
- Viscosité



(Cuecas, et al., Biophysical J., 2016)

Température

Fonctionnement des organismes

Activité Enzymatique

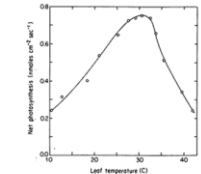
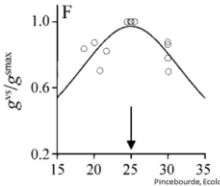


Fig. 6. Temperature dependence of photosynthesis. Measurements were made at 200 micromoles cm⁻² sec⁻¹ photosynthetically active radiation using leaves 3.6 × 0.1 cm in length in ambient air containing 320 µl CO₂ l⁻¹ and 8.8 µg H₂O cm⁻³. Nobel, Plant Physiol, 1976

Photosynthèse



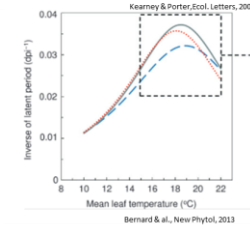
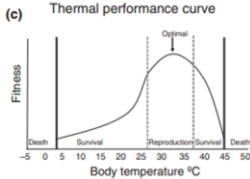
Conductance Stomatique

Pincebourde, Ecolo. Monog. 2006

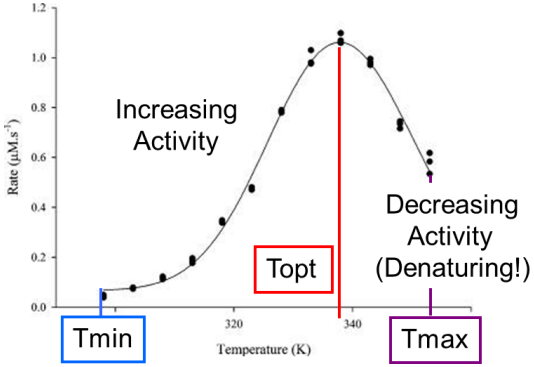
Insectes
Animaux

Plantes

Pathogènes



Bernard & al., New Phytol, 2013



Acid Phosphatase Activity
(Peterson, et al., BiochemJ, 2007)



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Séminaire TEMPO

4 Octobre 2023 / Saudreau

Contexte – Température un facteur clef



Degrés jour
Dose de froid ou chaud



$T \gg 1$
or
 $T \ll 0$

Développement - Phénologie

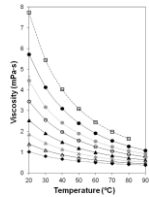
Lésions

Propriétés
Physiques

Température

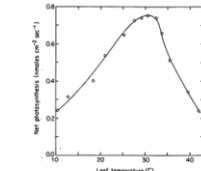
Activité métabolique

Masse volumique
Pression
Capacité calorifique
Viscosité



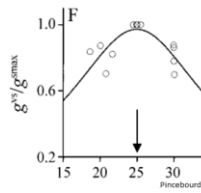
(Cuecas, et al., Biophysical J., 2016)

Fonctionnement des organismes



Photosynthèse

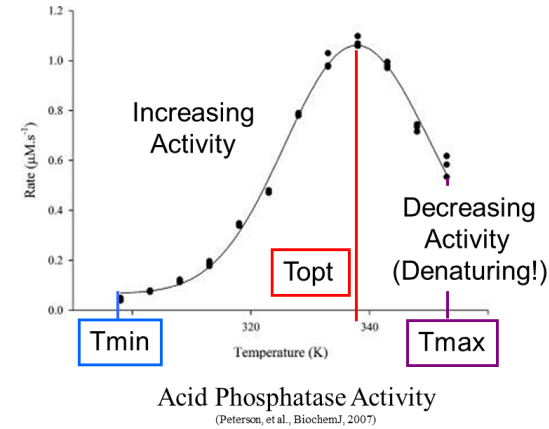
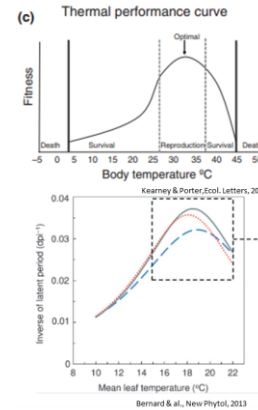
Fig. 6. Temperature dependence of photosynthesis. Measurements were made at 200 micromoles $\text{cm}^{-2} \text{sec}^{-1}$ photosynthetically active radiation using leaves 3.6 to 0.1 cm in length in ambient air containing 320 μl CO_2 , 1° and 8.8 μg H_2O cm^{-3} . Nobel, Plant Physiol, 1976



Conductance
Stomatique

Pincebourde, Ecolo. Monog. 2006

Insectes
Animaux
Plantes
Pathogènes



INRAE

Séminaire TEMPO

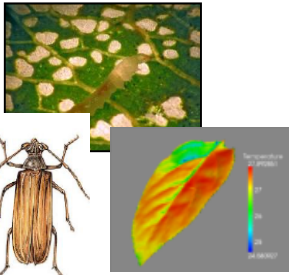
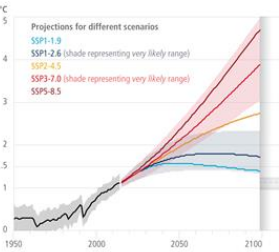
4 Octobre 2023 / Saudreau

Facteur clef du fonctionnement, développement et de la survie
Dépendance non linéaire à la température

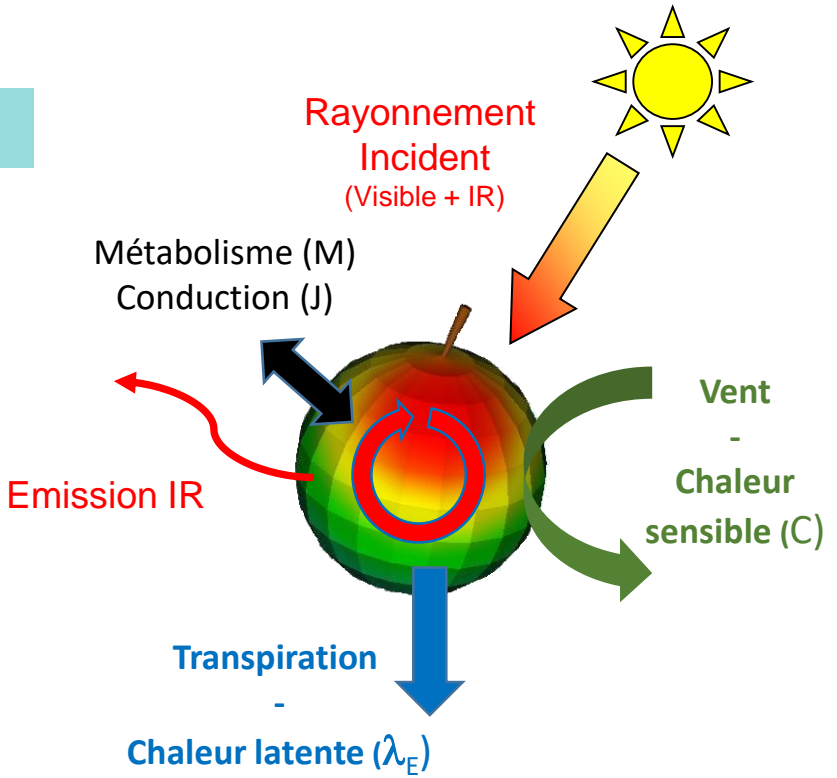
Contexte – Microhabitats thermiques

Climat

Organe



Climat



Bilan d'énergie

$$\frac{\partial T}{\partial t} = \text{Visible} + \text{IR}(T) + M(T) + J(T) \quad (\text{Sources})$$

$$- \text{IRe}(T) - C(T) - \lambda_E(T) \quad (\text{Pertes})$$

Température Organe

≠ Température d'air

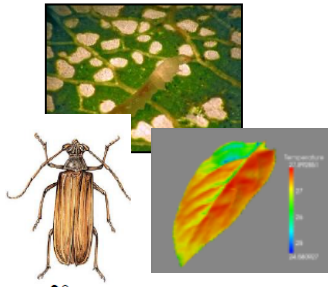
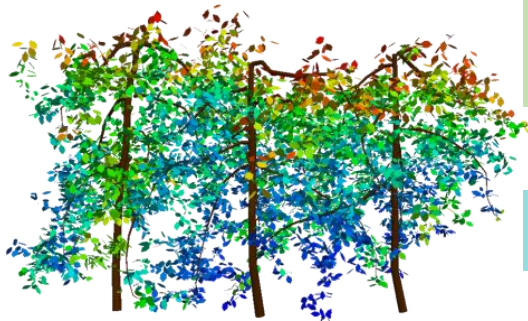
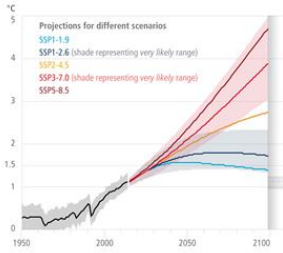
Contexte – Microhabitats thermiques

Climat

Peuplement

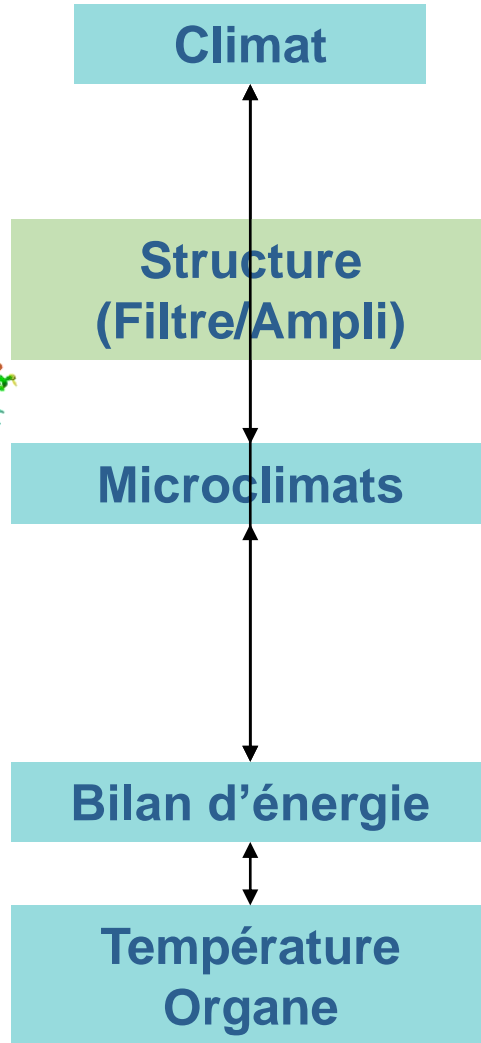
Individus

Organe

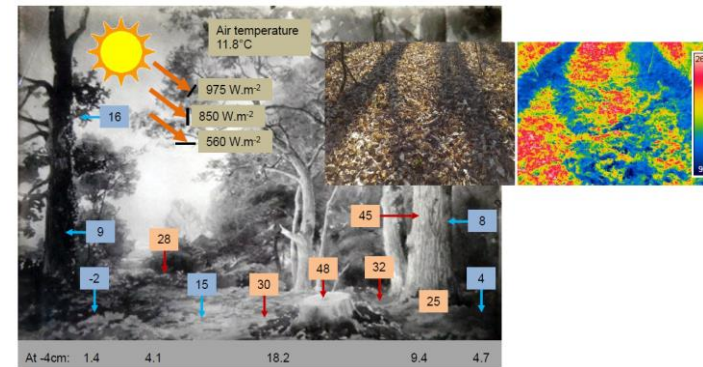
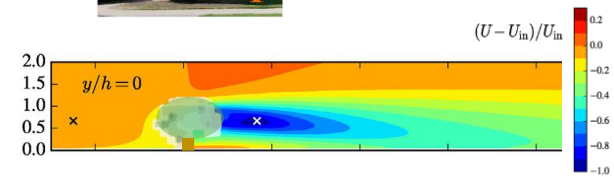
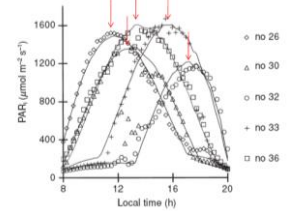
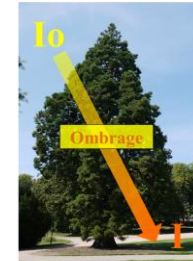


INRAE

Séminaire TEMPO
 4 Octobre 2023 / Saudreau

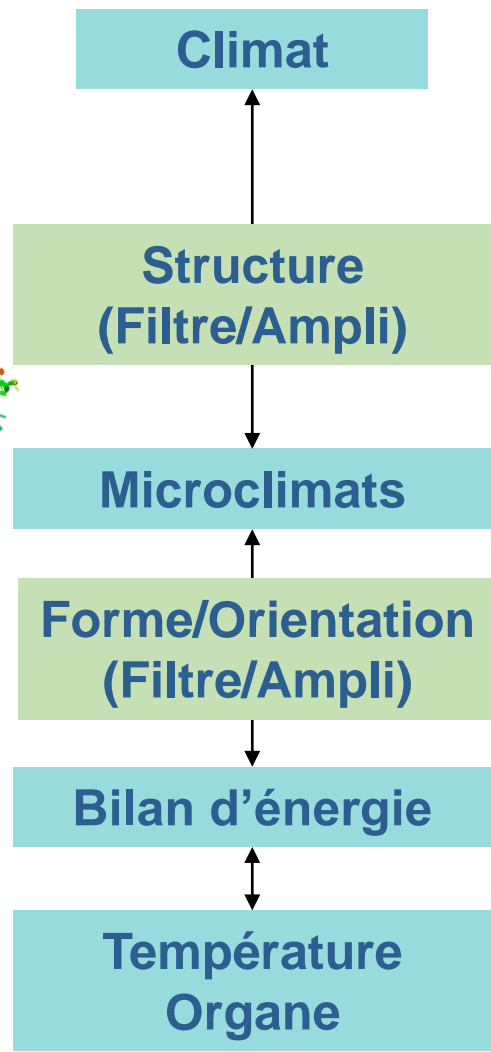
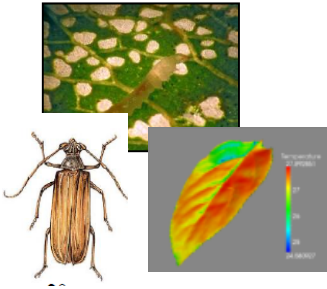
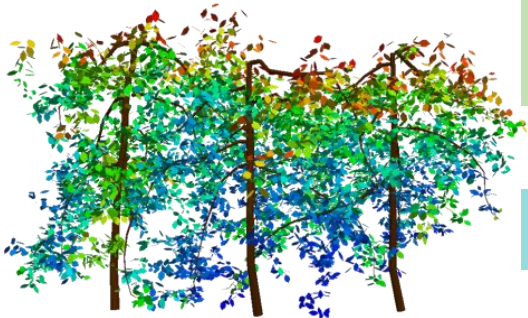
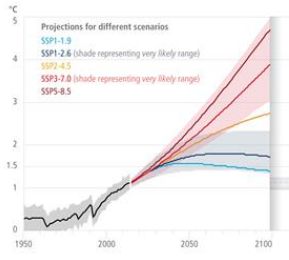
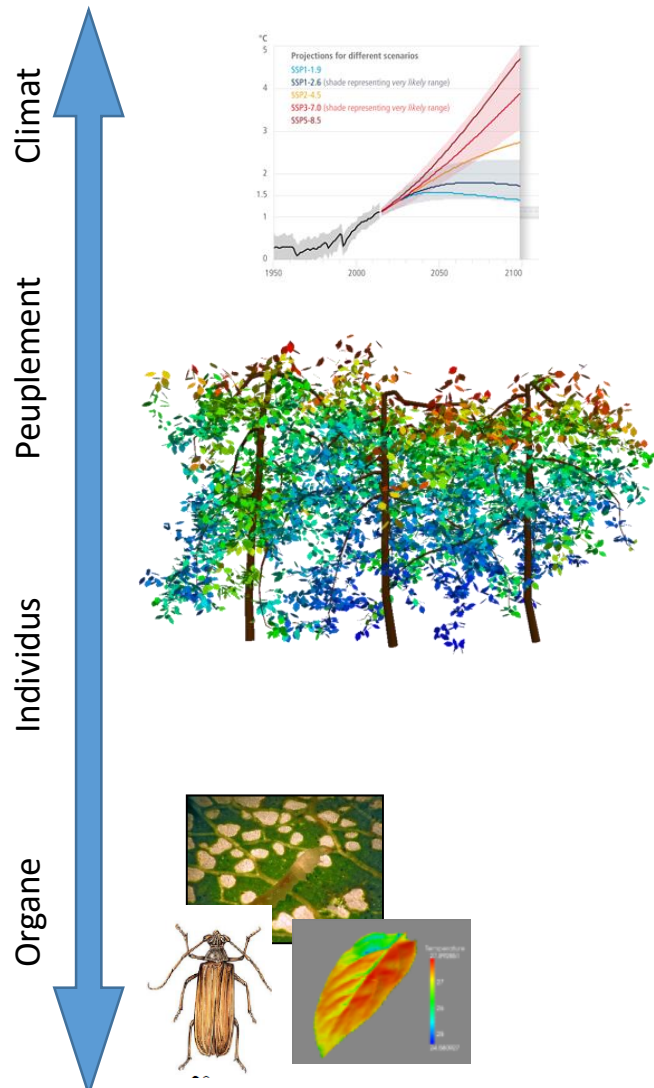


Variabilités spatiale et temporelle
 Composantes du microclimat

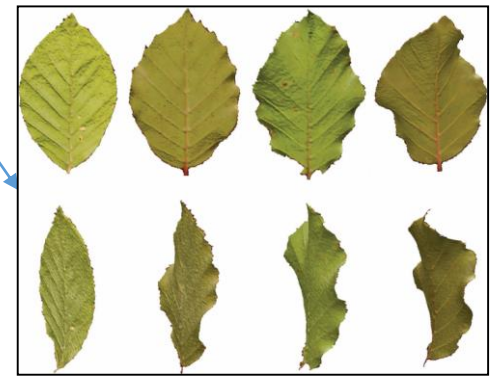
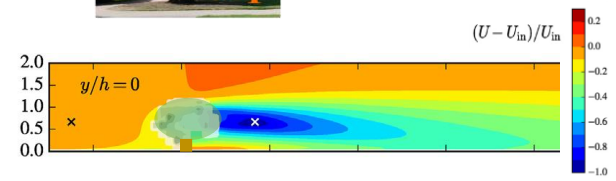
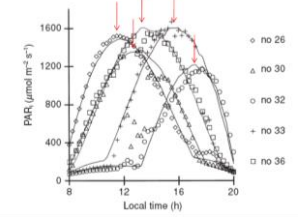
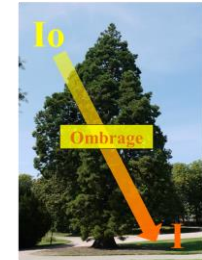


Pincebourde & Woods (2020) *Current Opinion Insect Science*

Contexte – Microhabitats thermiques



Variabilités spatiale et temporelle
Composantes du microclimat



Contexte – Microhabitats thermiques

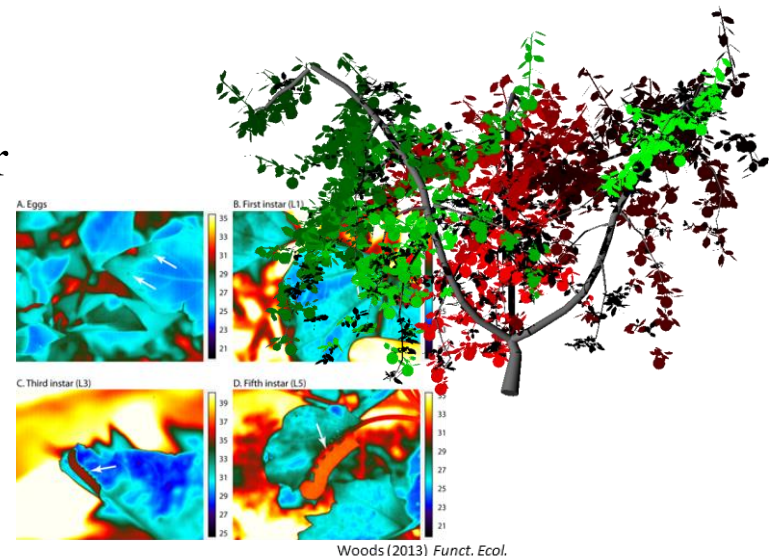
Quelles conséquences sur les températures ressenties ?

1. Quelle est la variabilité spatiale aux échelles des organes et des houppier ?
Température est-elle différente de celle de l'air ?
2. Quels sont les facteurs qui sont responsables cette variabilité ?
3. Est-on capable de prédire la T° locale d'une plante (feuille, fruit, partie ligneuse) ? Conséquences sur les organismes ?

Exemples et ordres de grandeur



Mesures
et
Modélisation



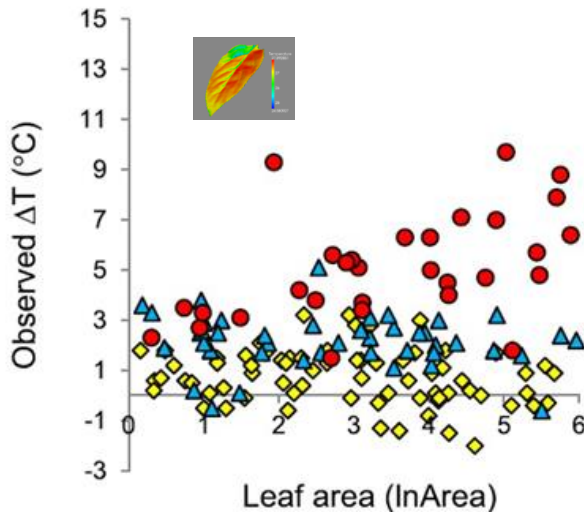
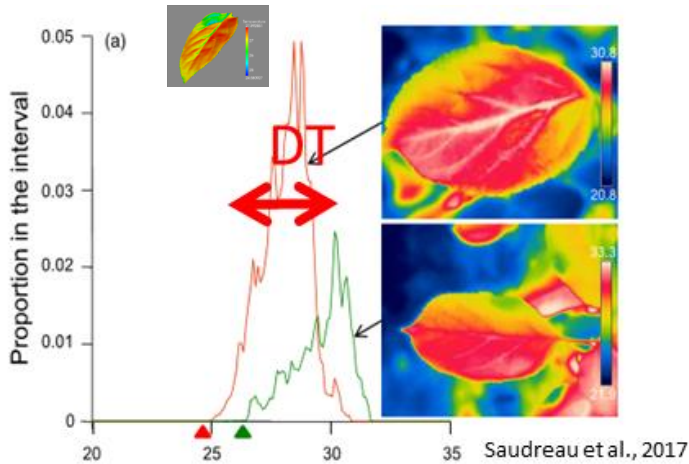
Déterminisme températures foliaires - Climat Vs Structure Vs Physiologie ?

$T_{\text{moyenne feuille}} \sim T_{\text{air}} + [-2, 10] \text{ } ^\circ\text{C}$

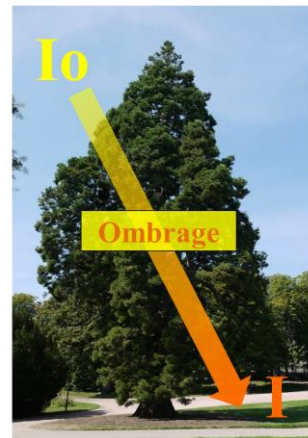
Gradient - $DT \sim 10^\circ\text{C}$



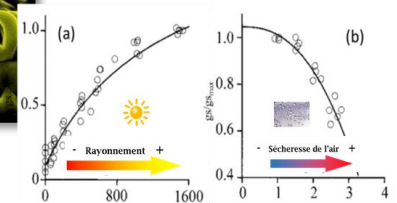
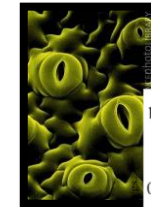
Bilan d'énergie



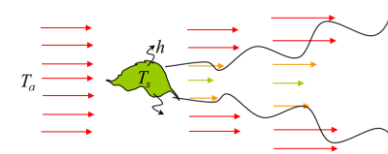
Lumière



Transpiration



Vent



Déterminisme températures foliaires - Climat Vs Structure Vs Physiologie ?

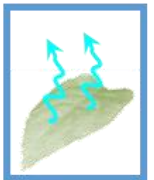
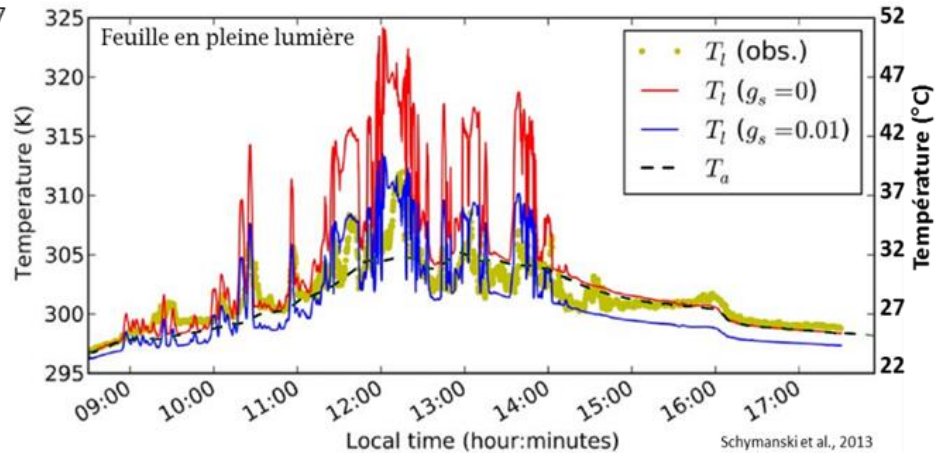
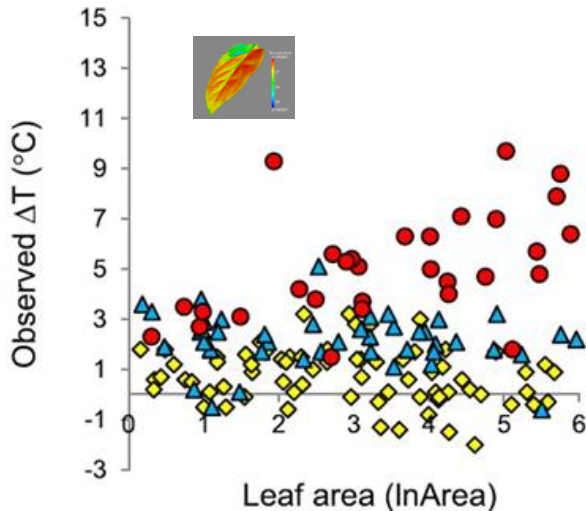
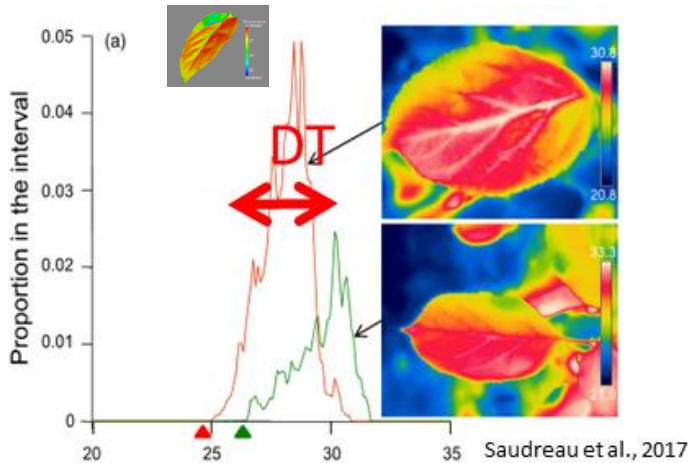
$$T_{\text{moyenne feuille}} \sim T_{\text{air}} + [-2, 10] \text{ } ^\circ\text{C}$$

$$\text{Gradient} - \Delta T \sim 10 \text{ } ^\circ\text{C}$$



Bilan d'énergie

T moyenne feuille

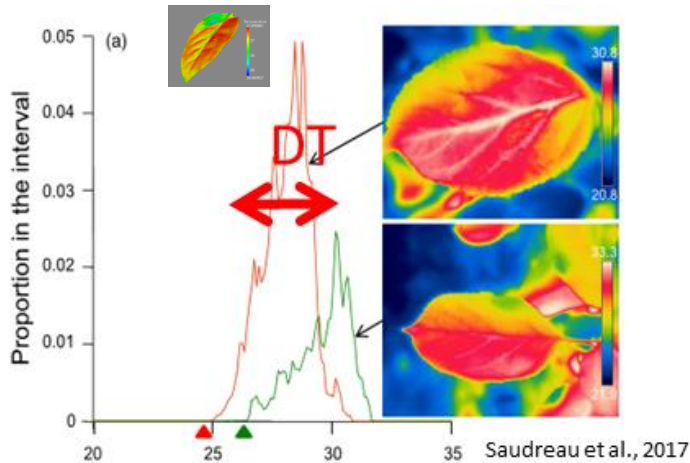


$$\underline{T_{\text{feuille}} (g_s=0)} - \underline{T_{\text{feuille}} (g_s)} \sim 10 \text{ } ^\circ\text{C}$$

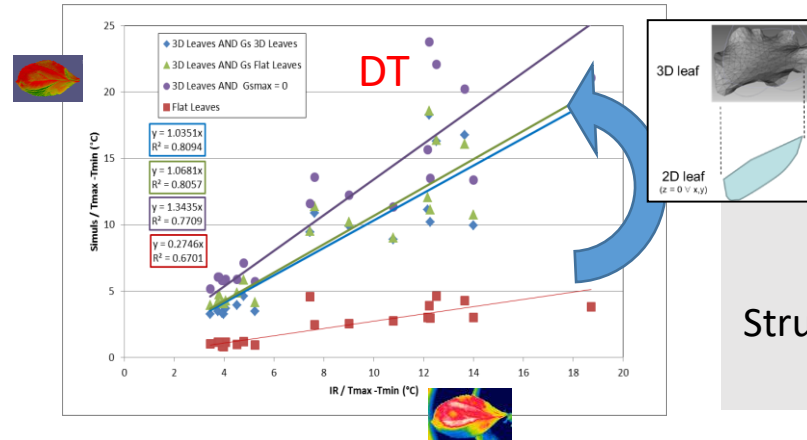
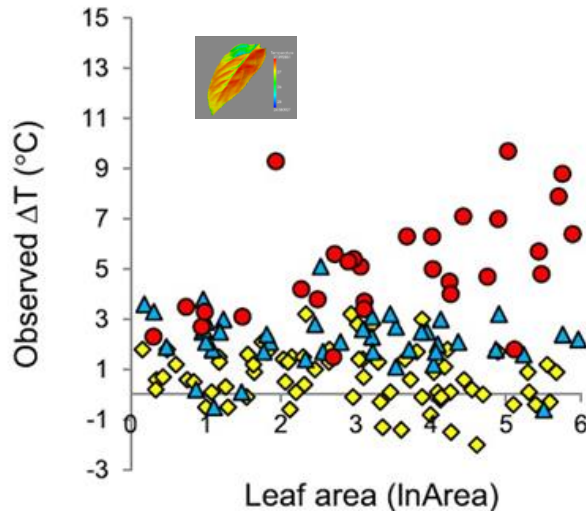
Déterminisme températures foliaires - Climat Vs Structure Vs Physiologie ?

T moyenne feuille \sim T air + [-2, 10] °C

Gradient - DT \sim 10 °C

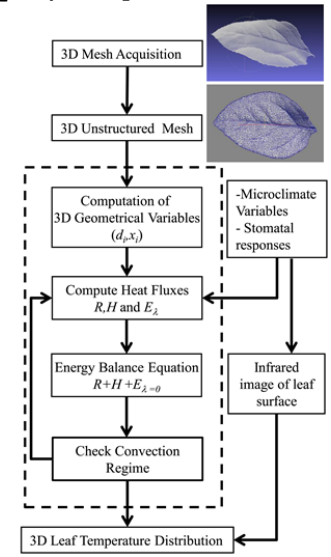
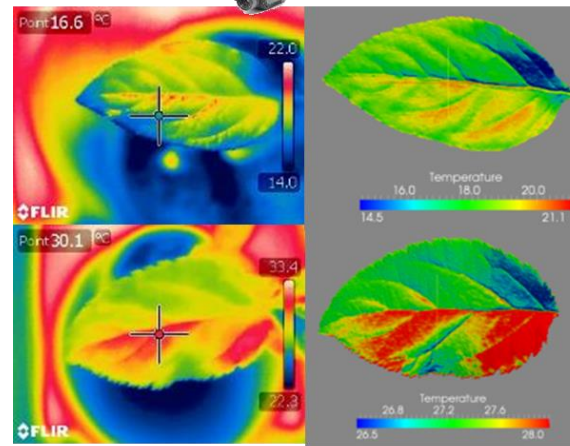


Saudreau et al., 2017



Saudreau et al., 2017

Mesure IRT Modélisation



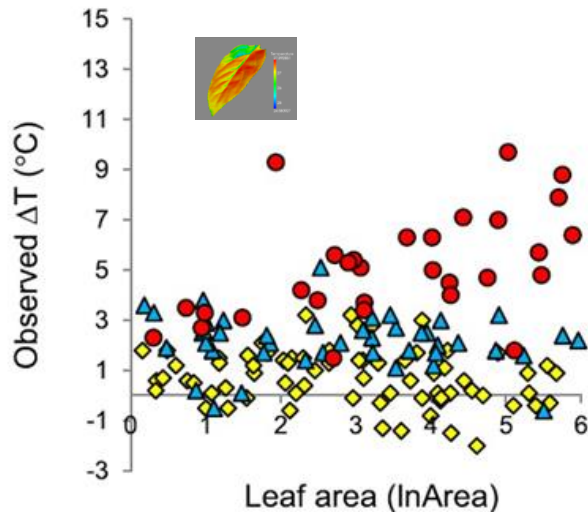
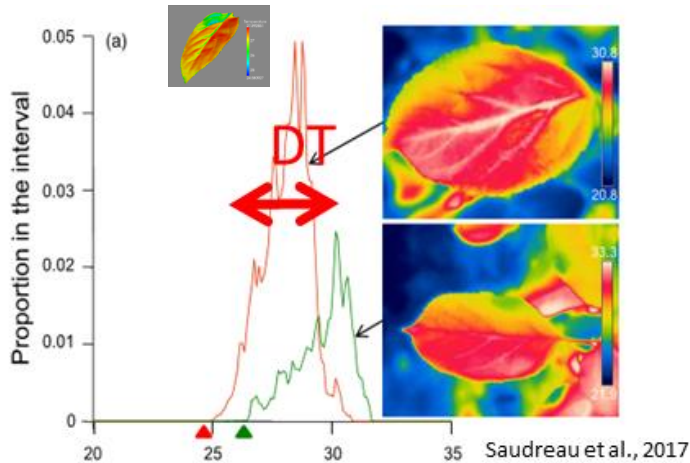
Gradient = Structure 3D de la feuille (rayonnement)

Déterminisme températures foliaires - Climat Vs Structure Vs Physiologie ?

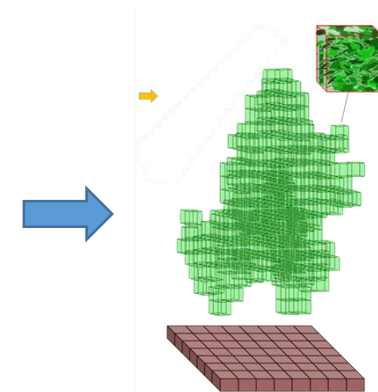
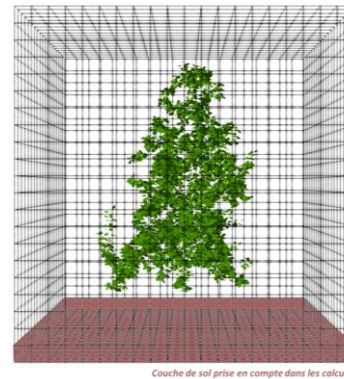
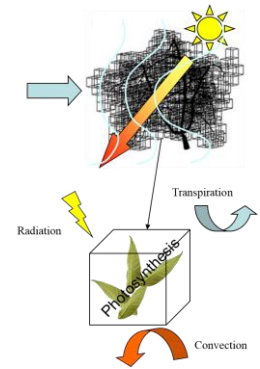
$T_{\text{moyenne feuille}} \sim T_{\text{air}} + [-2, 10] \text{ } ^\circ\text{C}$

Gradient - $\Delta T \sim 10 \text{ } ^\circ\text{C}$

Résolution du **bilan d'énergie** échelle foliaire distribué au sein houppier



- For each cell:
 - Structure:
 - n components
 - LAD, inclinations
 - Radiation budget:
 - Leaf irradiance
 - Leaf nitrogen content*
 - Energy budget:
 - Wind speed
 - Stomatal conductance
 - Transpiration
 - Leaf temperature
 - Photosynthesis:
 - CO2 net assimilation

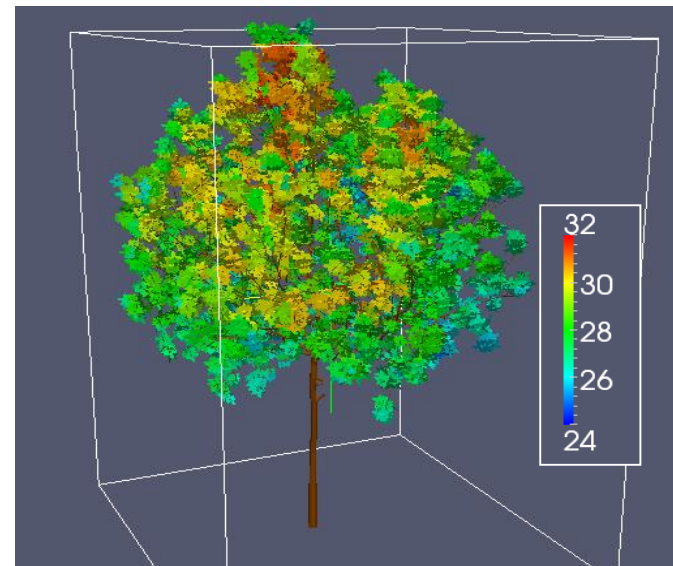
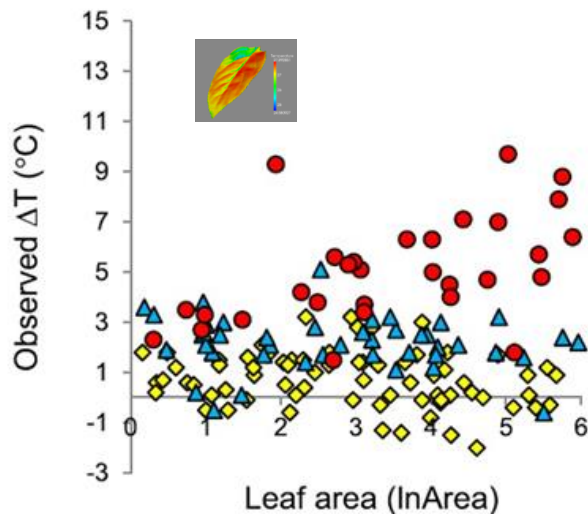
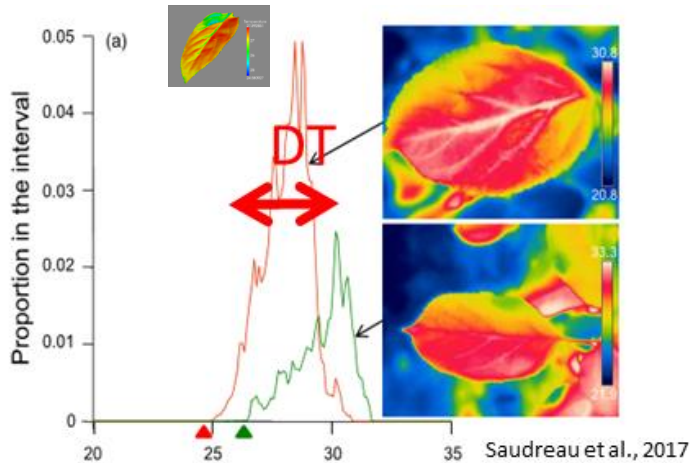


Sinoquet, H., X. Le Roux, et al. (2001). "RATP: a model for simulating the spatial distribution of radiation absorption, transpiration and photosynthesis within canopies: application to an isolated tree crown." *Plant Cell and Environment* 24(4): 395-406.

Déterminisme températures foliaires - Climat Vs Structure Vs Physiologie ?

$T_{\text{moyenne feuille}} \sim T_{\text{air}} + [-2, 10] \text{ } ^\circ\text{C}$

Gradient - $\Delta T \sim 10 \text{ } ^\circ\text{C}$



Saudreau, pers. comm.

Variabilité

=

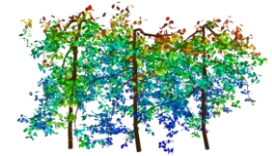
Feuilles ombre Vs Feuille soleil

Orientation feuilles

Effet du vent

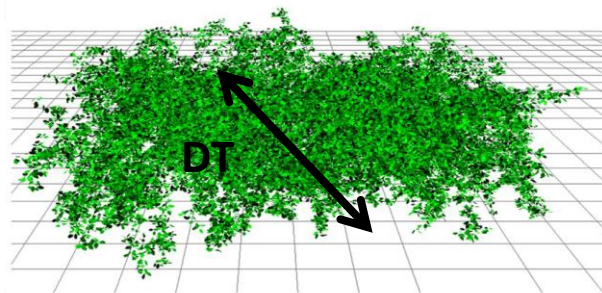
Transpiration (conductance stomatique)

Déterminisme températures foliaires - Climat Vs Structure Vs Physiologie ?



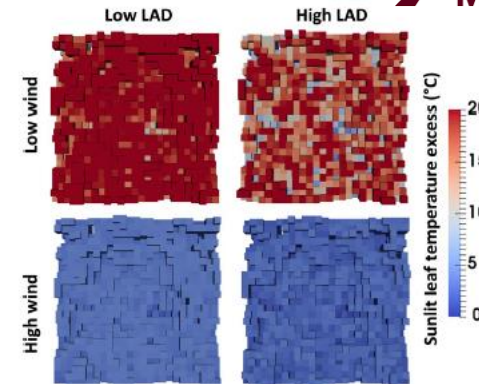
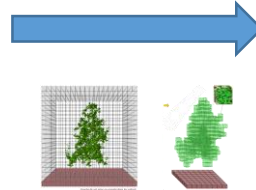
Analyse de sensibilité

Méthode de Morris – Modèle RATP



Couvert continu 202 m² (100 000 feuilles)

Voxelisation

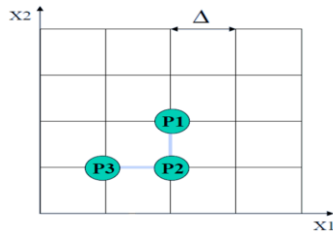


Woods et al., 2018

Vent et Densité foliaire

Méthode de Morris

méthode qualitative de « criblage »



Espace des paramètres

Param	mu.star	sigma
Wind	2.813	4.864
Kt	1.813	3.521
Totallrrad	1.565	3.031
Tair	1.219	2.172
aLAD	1.189	2.451
aLIAD	0.371	0.831
bTemp	0.272	1.081
cTemp	0.109	0.545
GsMAX	0.108	0.376

Variabilité spatiale (DT)

=

Conditions météo

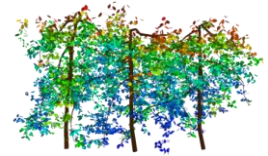
>

Densité foliaire (Structure)

>

Réponse fonctionnelle

Au sein d'un houppier

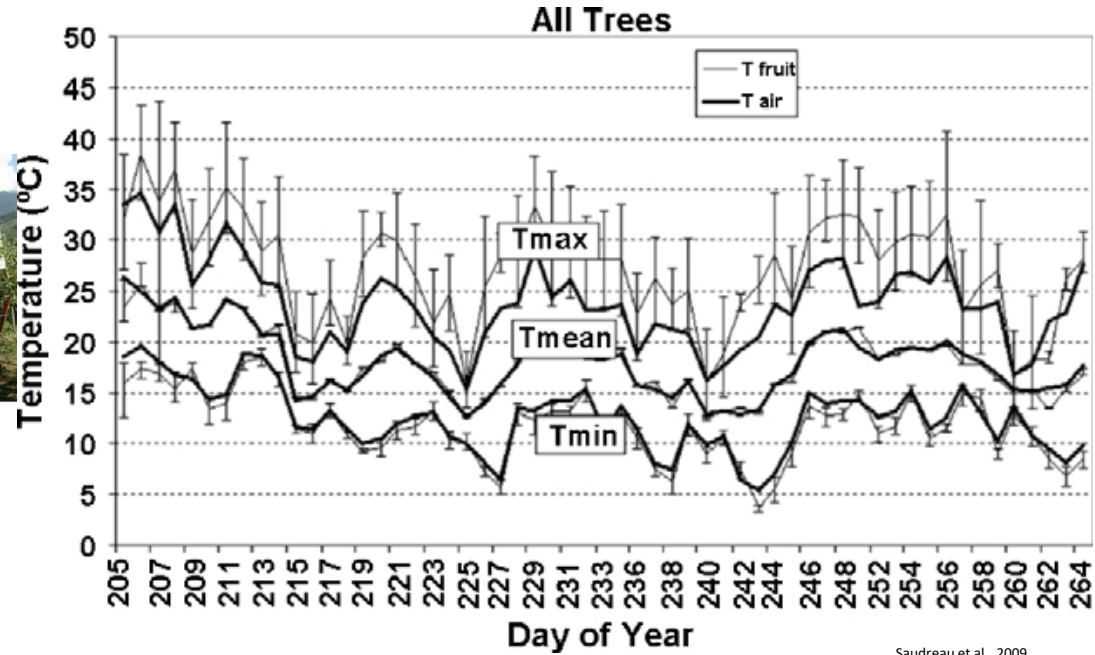
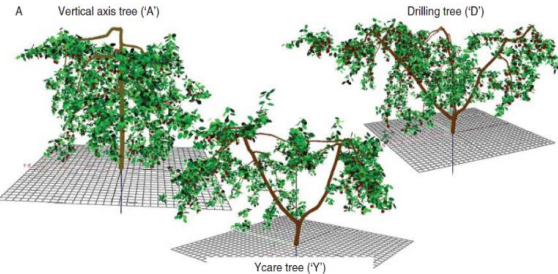


Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

Agroscope



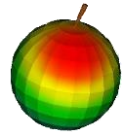
Dynamique des gradients
Température fruit \neq Température air
Importance échelle observation



Saudreau et al., 2009

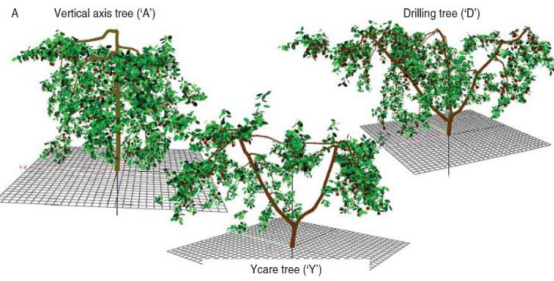
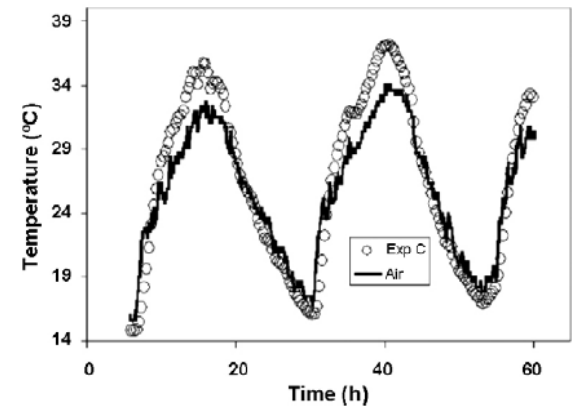
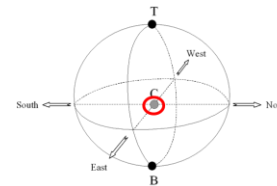
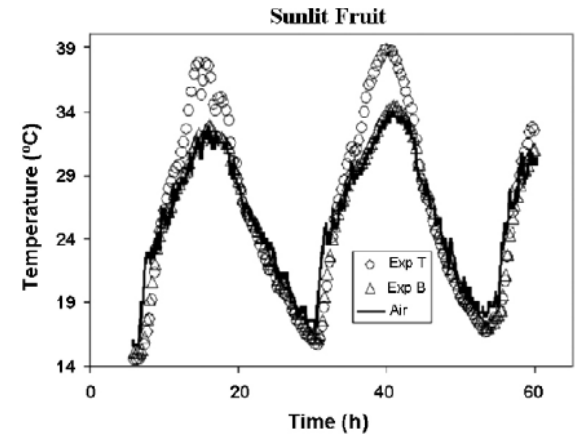
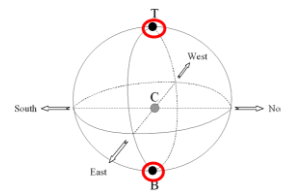


Au sein d'un fruit



Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

Agroscope



Gradients thermiques (~1°C/cm)
Température fruit ≠ Tair

Saudreau et al., 2009



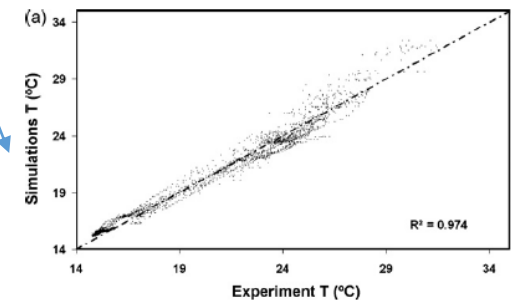
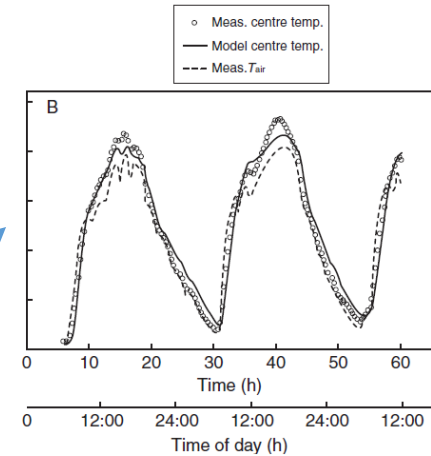
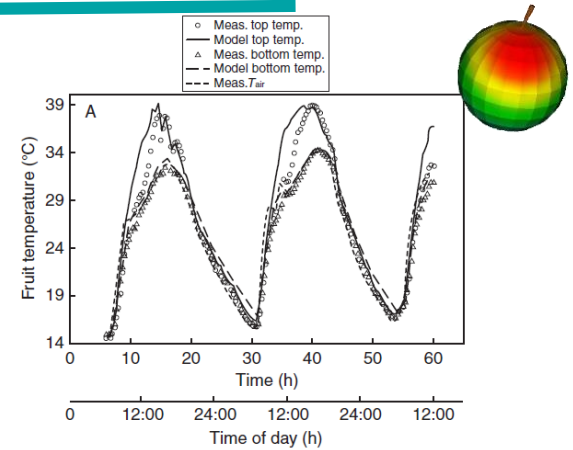
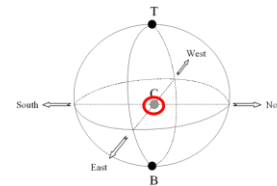
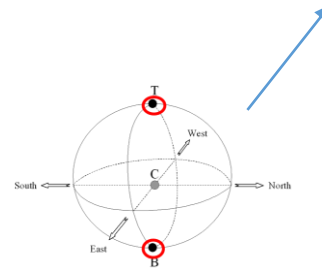
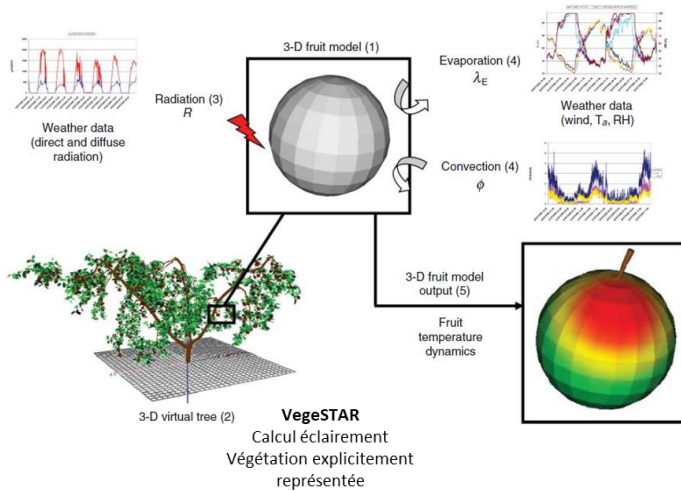
INRAE

Séminaire TEMPO

4 Octobre 2023 / Saudreau

Au sein d'un fruit

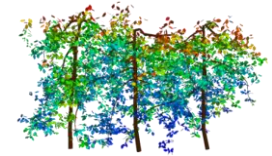
Modélisation



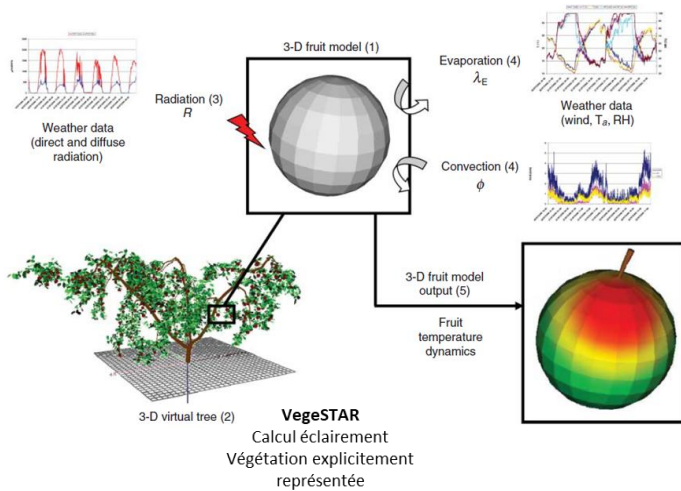
Modèle validé et fonctionnel
Lien avec le levier architectural via
le microclimat



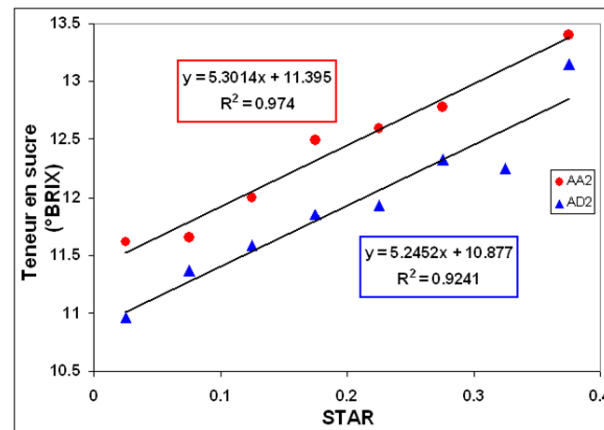
Variabilité spatiale température au sein d'un houppier



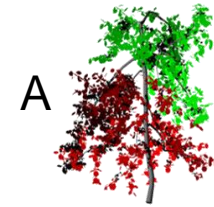
Modélisation



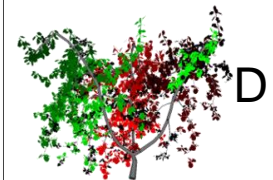
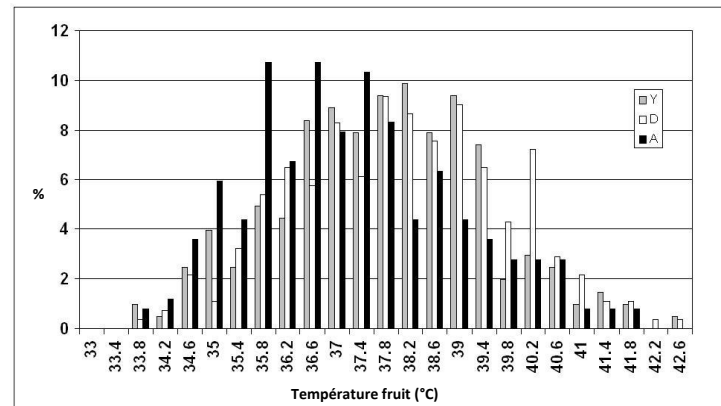
Liens entre **microclimat lumineux, structure** et **qualité** des fruits
 Liens entre **structure** et **dynamique température** des fruits



Coll. Agroscope-Suisse



Modèle validé et fonctionnel
 Lien avec le levier architectural via
 le microclimat



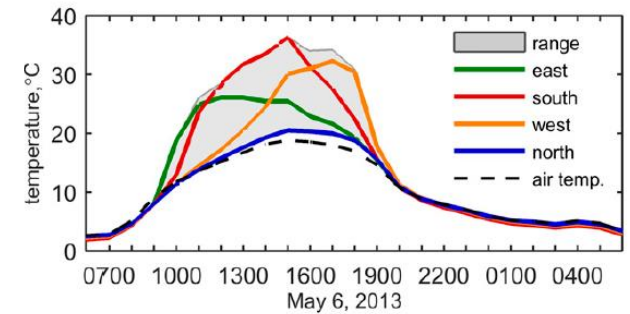
Gradients forts liés aux aspects volumiques

Hiver 2012/2013
Conifère Alberta (Ca) - 40 cm Ø

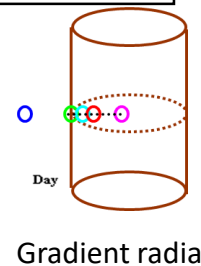
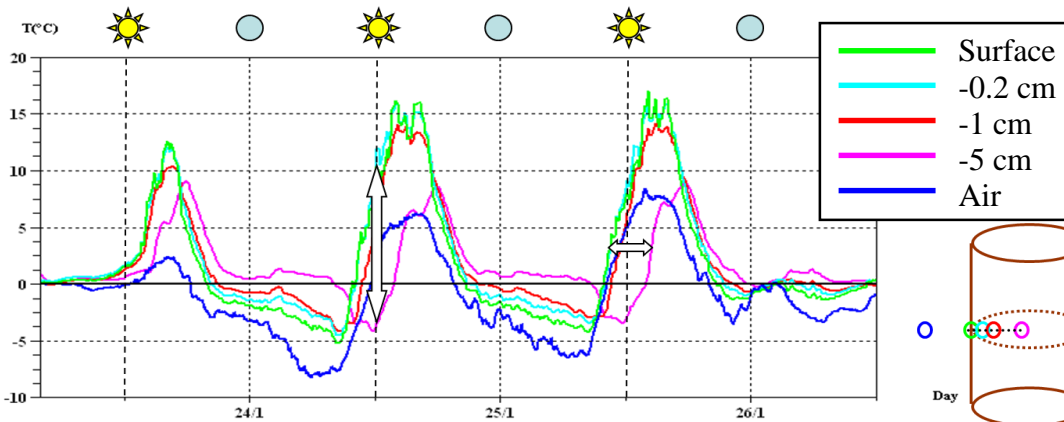
Rayonnement différencié
-
Dissymétrie entre les faces - Gradient thermique $\sim 15^{\circ}\text{C}$



Gradient surface



Musselman et al., 2017

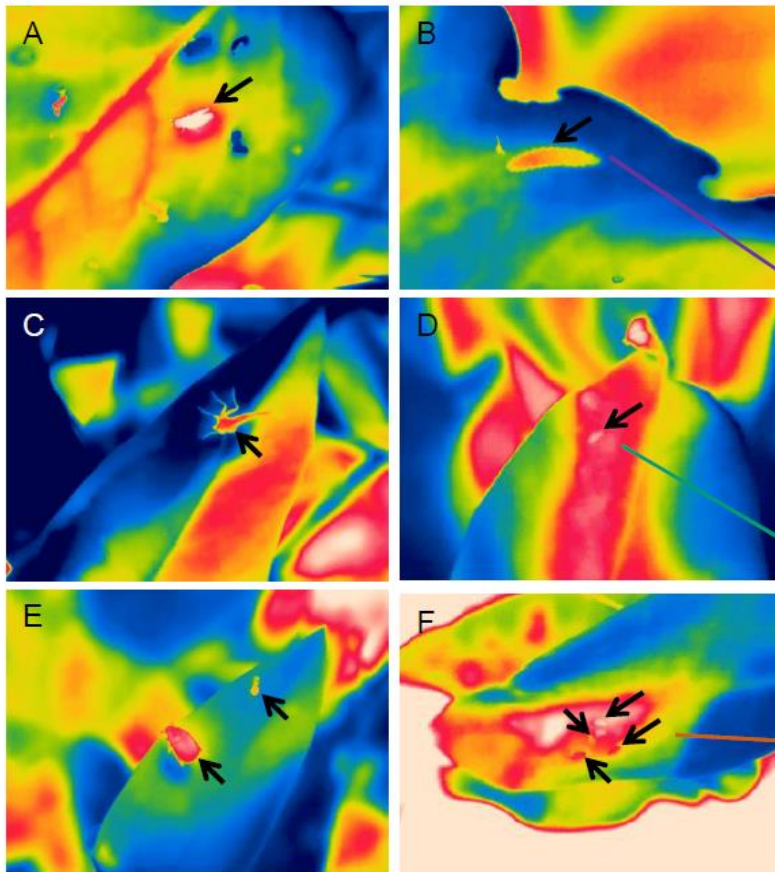
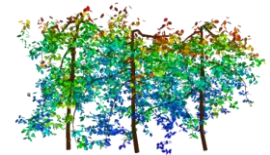


Hiver 2005/2006
Noyer Clermont-Fd - 12 cm Ø

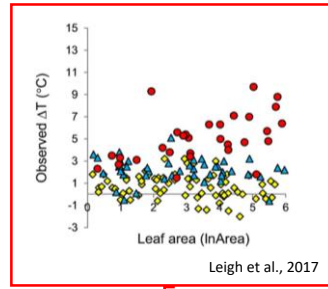
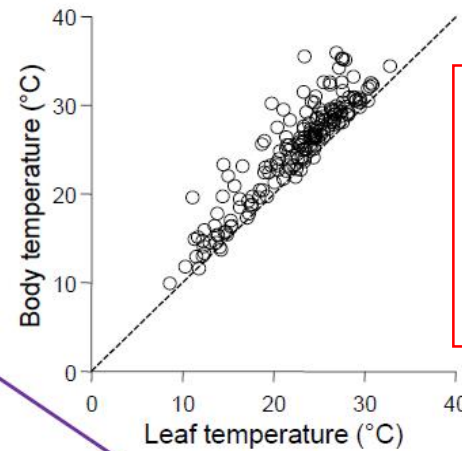
Diffusion thermique
-
Gradient radial ($\sim 3^{\circ}\text{C}/\text{cm}$)
Décalage temporel ($\sim 3\text{h}30\text{mn}$)



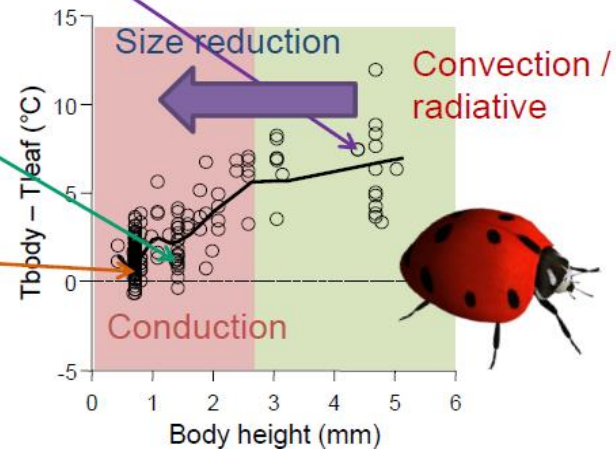
Conditions locales variables -> Quid des ravageurs ?
 Maladies -> température des organes infectés
 Insectes c'est plus compliqué ...



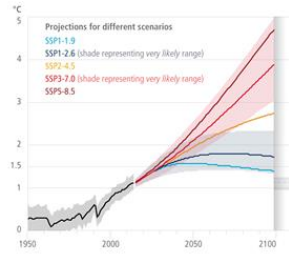
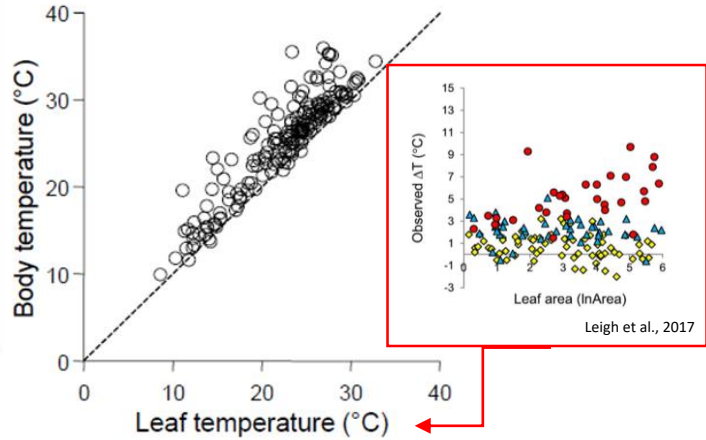
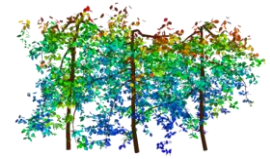
Pincebourde, Dillon & Woods (2021) *Functional Ecology*



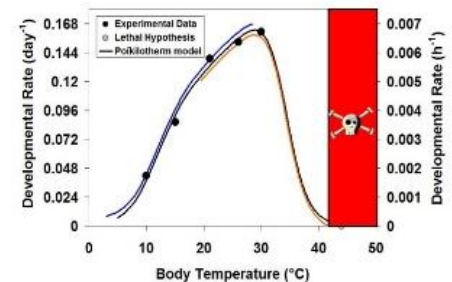
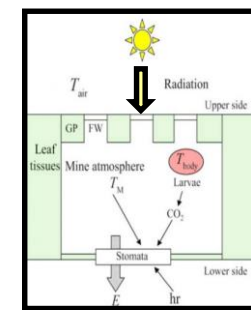
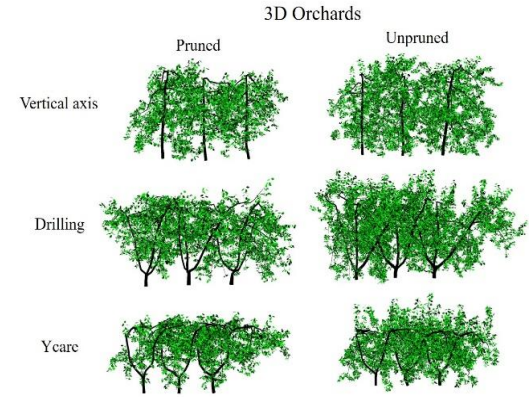
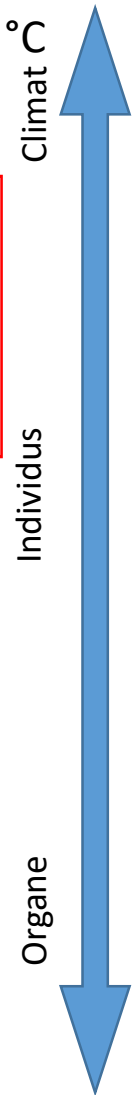
Leigh et al., 2017



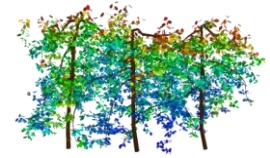
Température ravageur = $T_{organe} + [0, 10] \text{ } ^\circ\text{C}$



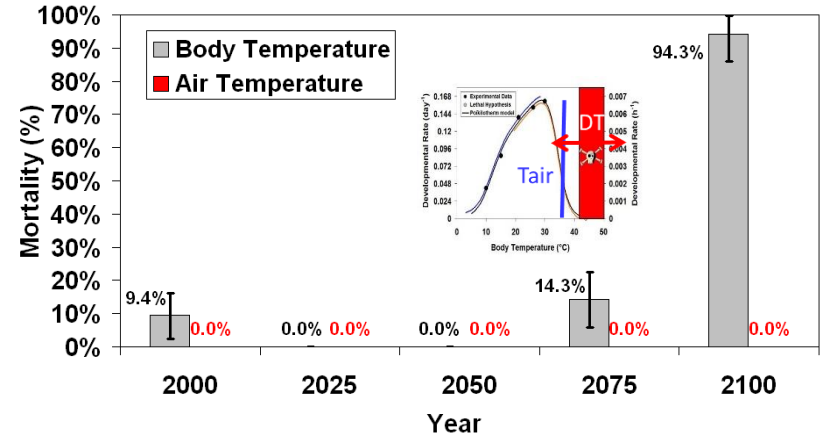
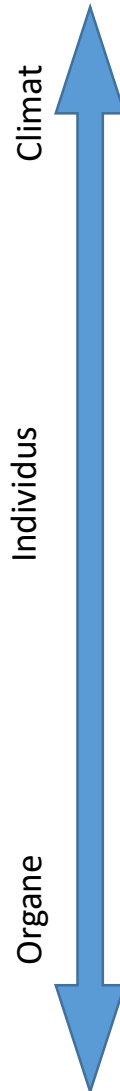
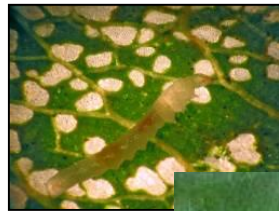
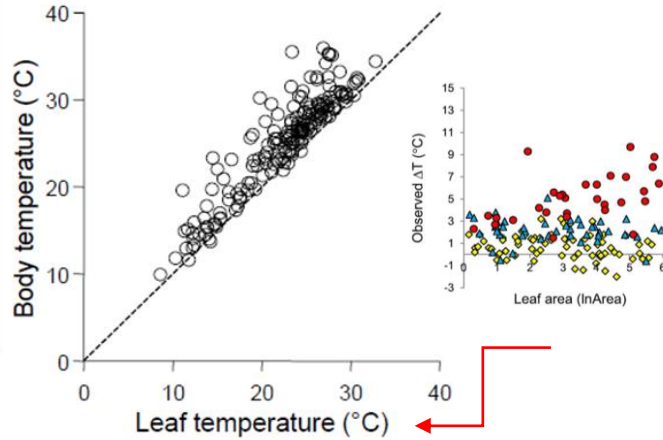
Quelles conséquences sur leurs développements ?



Température ravageur = $T_{air} + [1, 10] \text{ } ^\circ\text{C}$



Quelles conséquences sur leurs développements ?



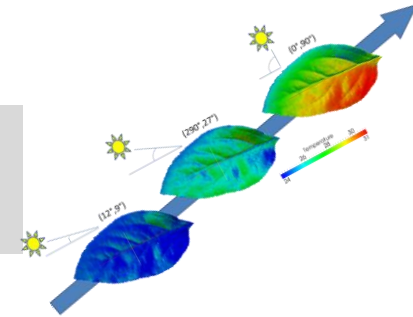
Levier architectural faible vis-à-vis du CC

Importance de la prise en compte de la température réelles Vs T air

Conclusions ...

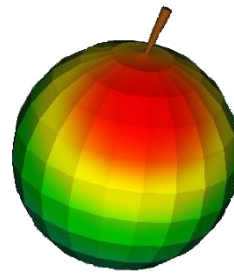
- Quelle est la variabilité spatiale aux échelles des organes et des houppier ?
Température organe est-elle différente de celle de l'air ?

En général température surface = $T_{air} + [-2, 10] \text{ } ^\circ\text{C}$
2D vs 3D effet important \Rightarrow gradient $> 15^\circ\text{C}$



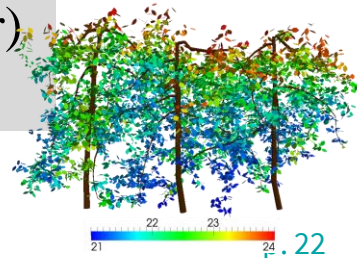
- Quels sont les facteurs qui sont responsables cette variabilité ?

Structure (Microclimat local) $>$ Réponse fonctionnelle



- Est-on capable de prédire la T° locale d'une plante (feuille, fruit, partie ligneuse) ? Conséquences sur les organismes ?

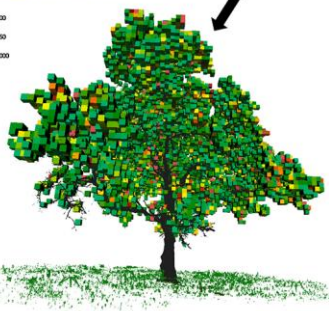
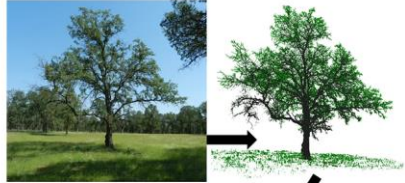
Principes physiques assez simples - Approches mécanistes possibles
Difficulté = Appréhender la variabilité spatiale (forme houppier)
et temporelle (fluctuations) - Paramétrage



Perspectives ...

➤ Phénotypage - Caractérisation de la variabilité spatiale : structure et température

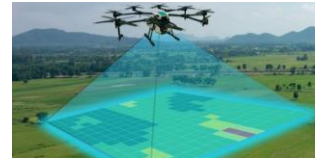
Structure - Lidar terrestre



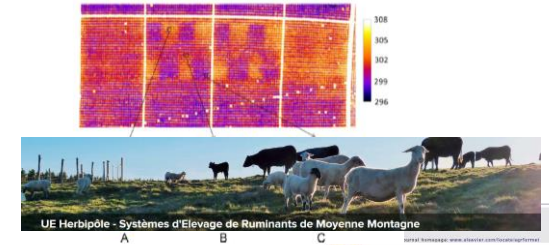
Densité
Foliaire

Béland et al., 2014

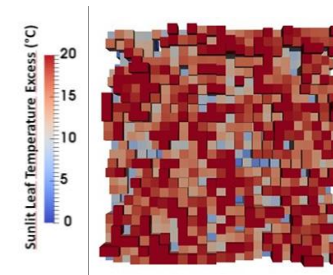
Température – Télédétection Infra-rouge thermique...



<https://www.inrae.fr/actualites/dossier-teledections>



... et modélisation
lien avec stress
(CWSI et autres)



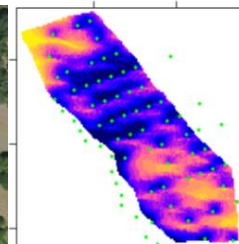
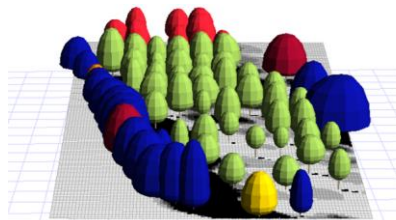
Almost tree canopy temperature reveals intra-crown variability that is water stress-dependent
V. Gonzalez-Dugo¹*, P. Zarco-Tejada¹, J.A. Benn¹, L. Salmer¹, D. Göttschman¹, E. Herrera¹
¹ Instituto de Investigación en Recursos Cinegéticos, IREC (CSIC-UCM-JCCM), Avda. de España s/n, 13005 Ciudad Real, Spain
*Corresponding author: vgonzalez@irec.uclm.es

➤ Parcelle au paysage - Variabilité spatio-temporelle plus grande échelle

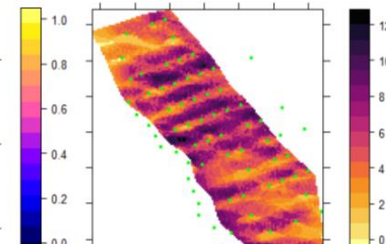


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Transmis au sol



Cumul heures à l'ombre



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