Modeling hydrodynamic stress limitations on transpiration

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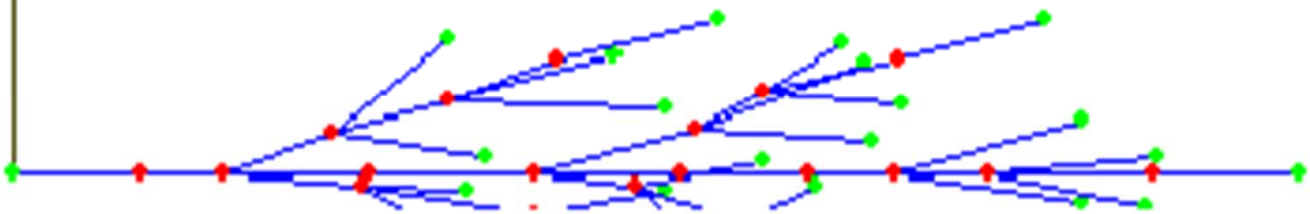
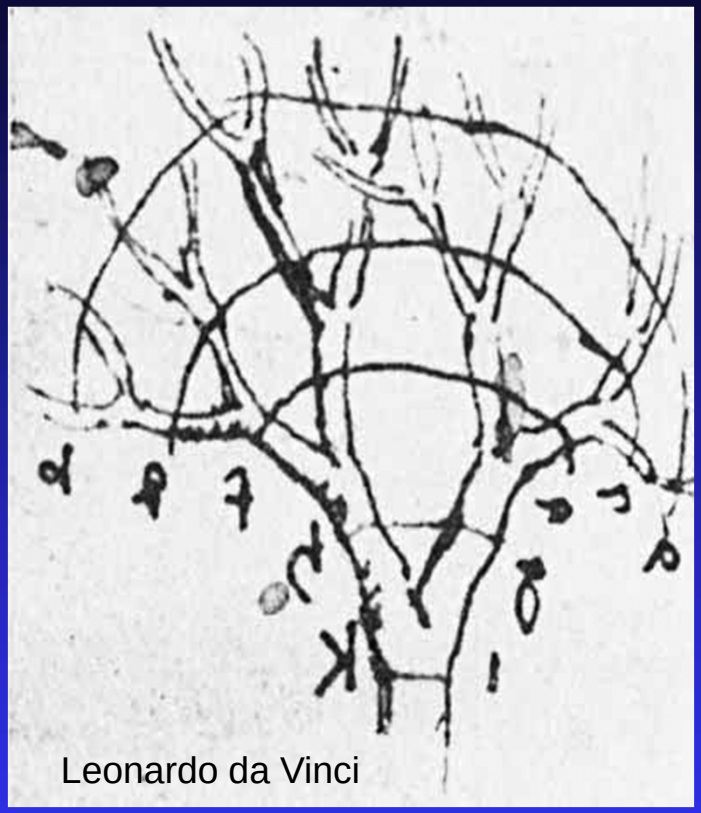


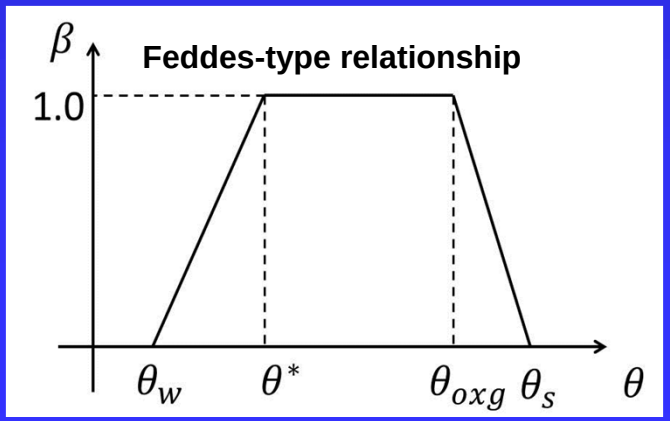
Incorporating the hydraulic structure of trees



Leonardo da Vinci

Plant structure is driven by optimization of its hydrological function

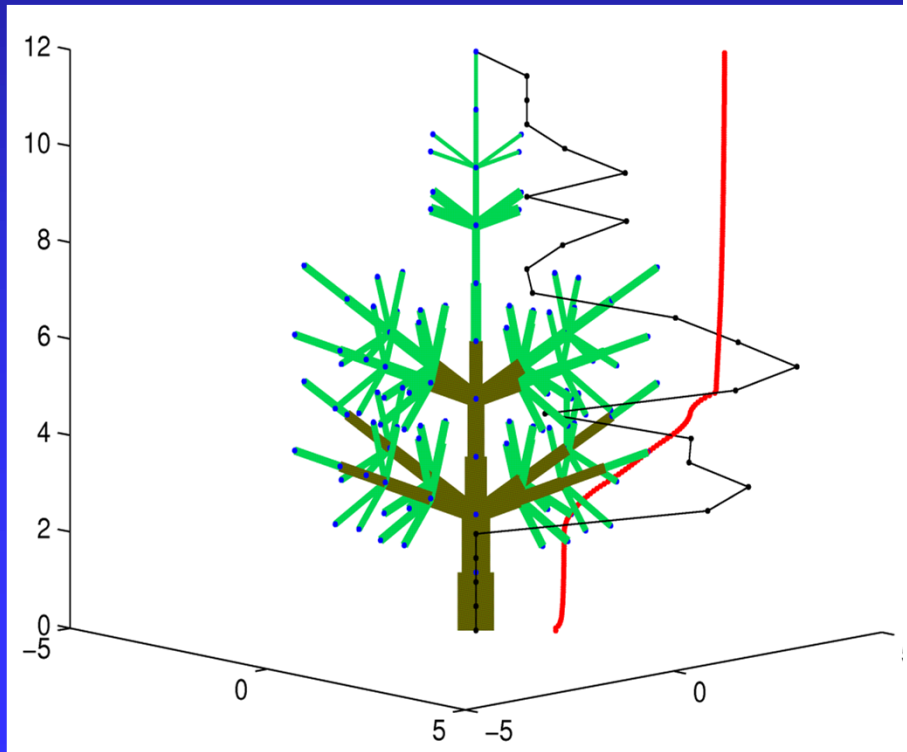
However, current hydrological and land-surface models do not represent structure OR plant hydrology



Finite Elements Tree-Crown Hydrology (FETCH) model

- Advantages:
  - Accounts for trees' structure
  - Physical sense of hydraulics
  - 3-D sub-tree-scale solution of fluxes
  - Improved representation of fast temporal dynamics
  - Ability to forecast the effects of tree growth and structure on transpiration

Bohrer et al. 2005 WRR



1-D Richards equation in Pressure form

$$C(\Phi)\frac{\partial \Phi}{\partial t} = -\frac{\partial(K(\Phi)[\partial\Phi/\partial z + \rho g \cos(\alpha)])}{\partial z} - Ev$$

Capacitance | Conductance | Pressure gradient | Gravitational term | Transpiration

- Mass conservation of water in a porous media
- Describes change of Φ (water pressure) in space and time

New "tricks":

- Maximal potential transpiration restricted by stomatal response to water potential in branches
- 3D→1D coordinate conversion
- C(Φ) derived from empirical cavitation curves θ = f(Φ)
- $E_{V,max}$ based on atmospheric conditions within-above canopy

$$C(\Phi) = \frac{\partial\theta}{\partial\Phi} = p\theta_{sat}\frac{1}{\Phi_0}\left(\frac{\Phi_0 - \Phi}{\Phi_0}\right)^{-(p+1)}$$

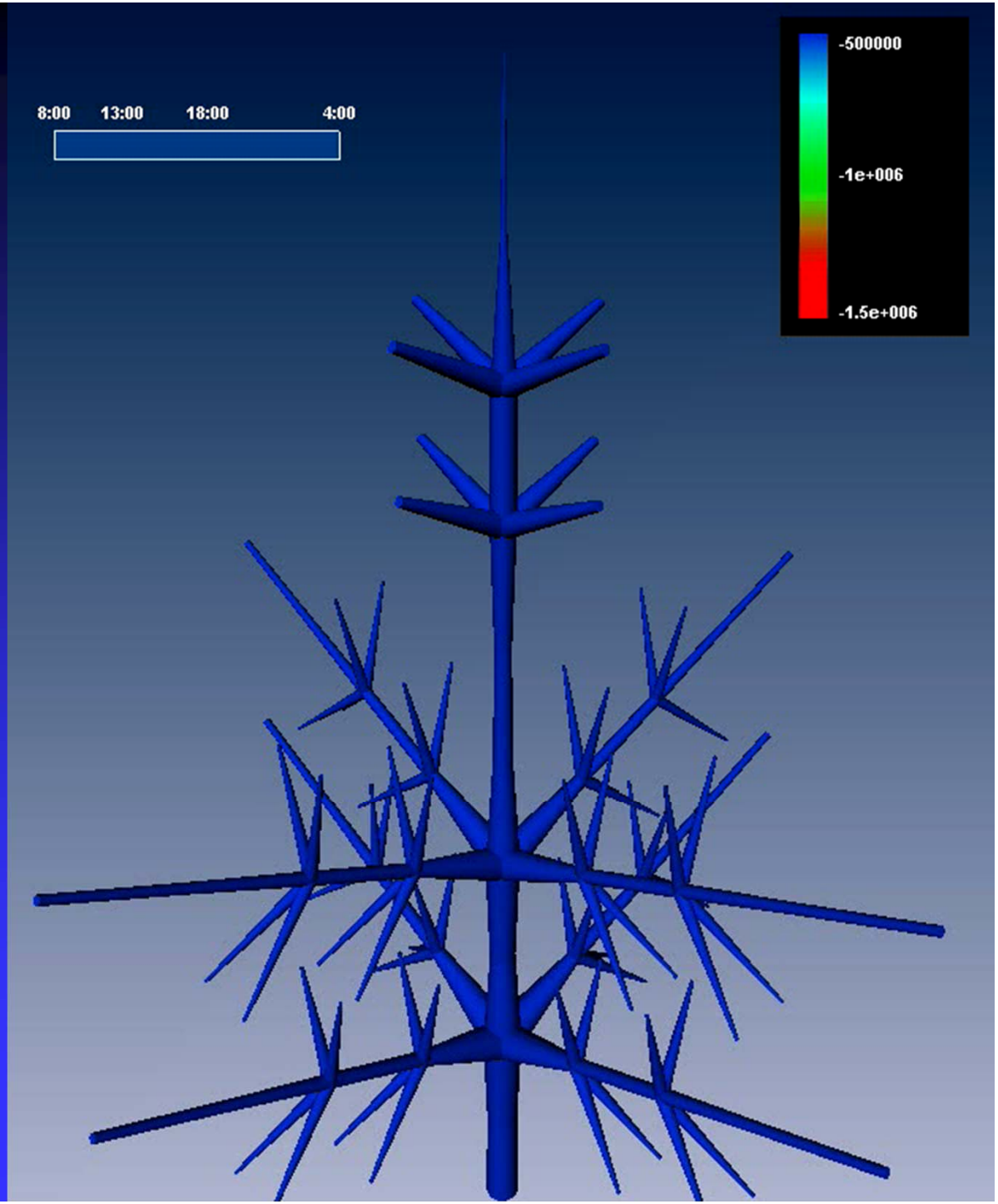
$$K(\Phi) = f(A_z)K_{\max}e^{-(-\Phi/d)^{c1}}$$

$$E_V = E_{V,\max} \times \exp\left[-\left(\frac{-\Phi^{(n-1)}}{\Phi_\sigma}\right)^{c_3}\right]$$

What can FETCH do?

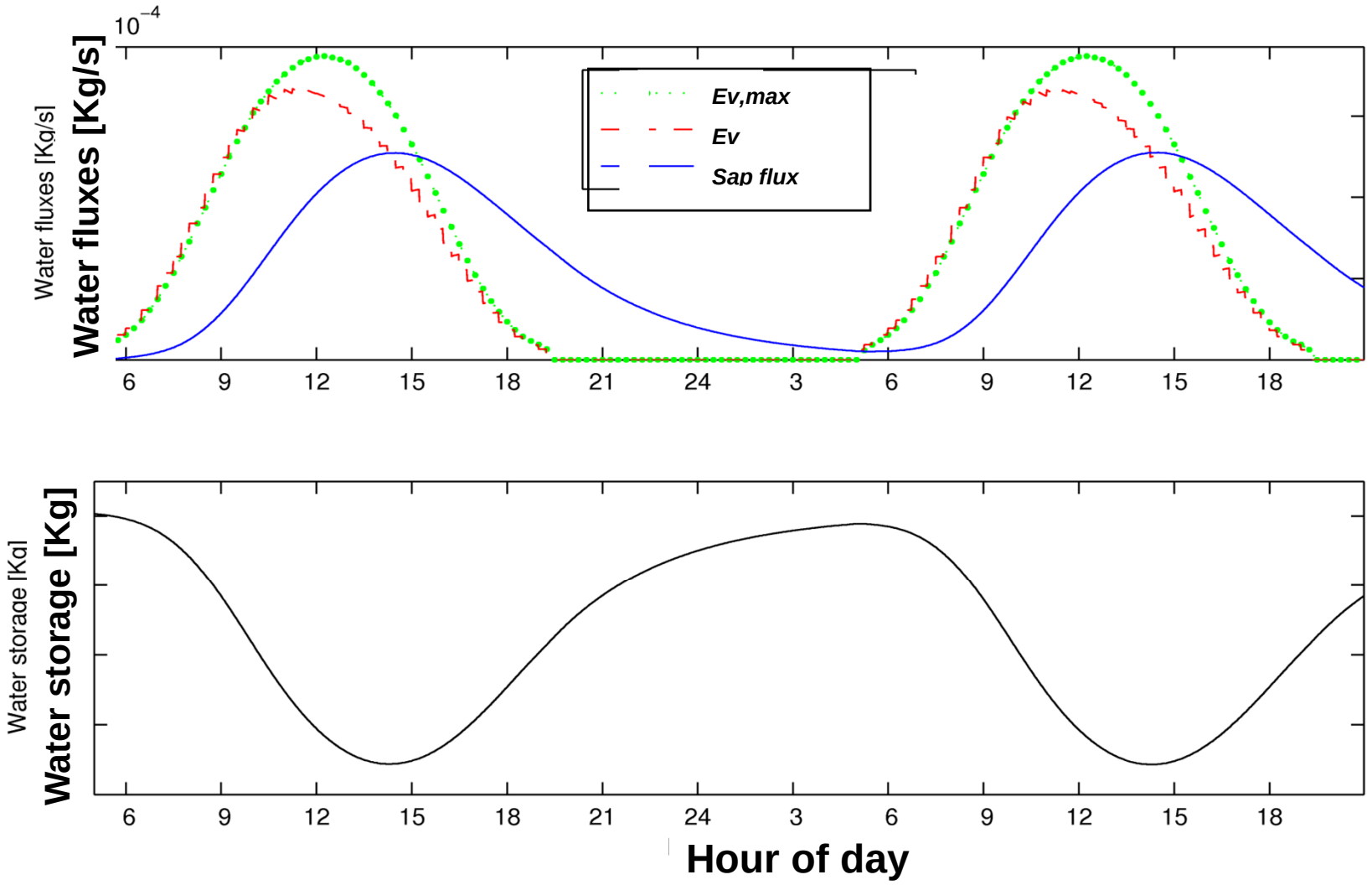
Daily dynamics

Pressure [Pa]
in model tree



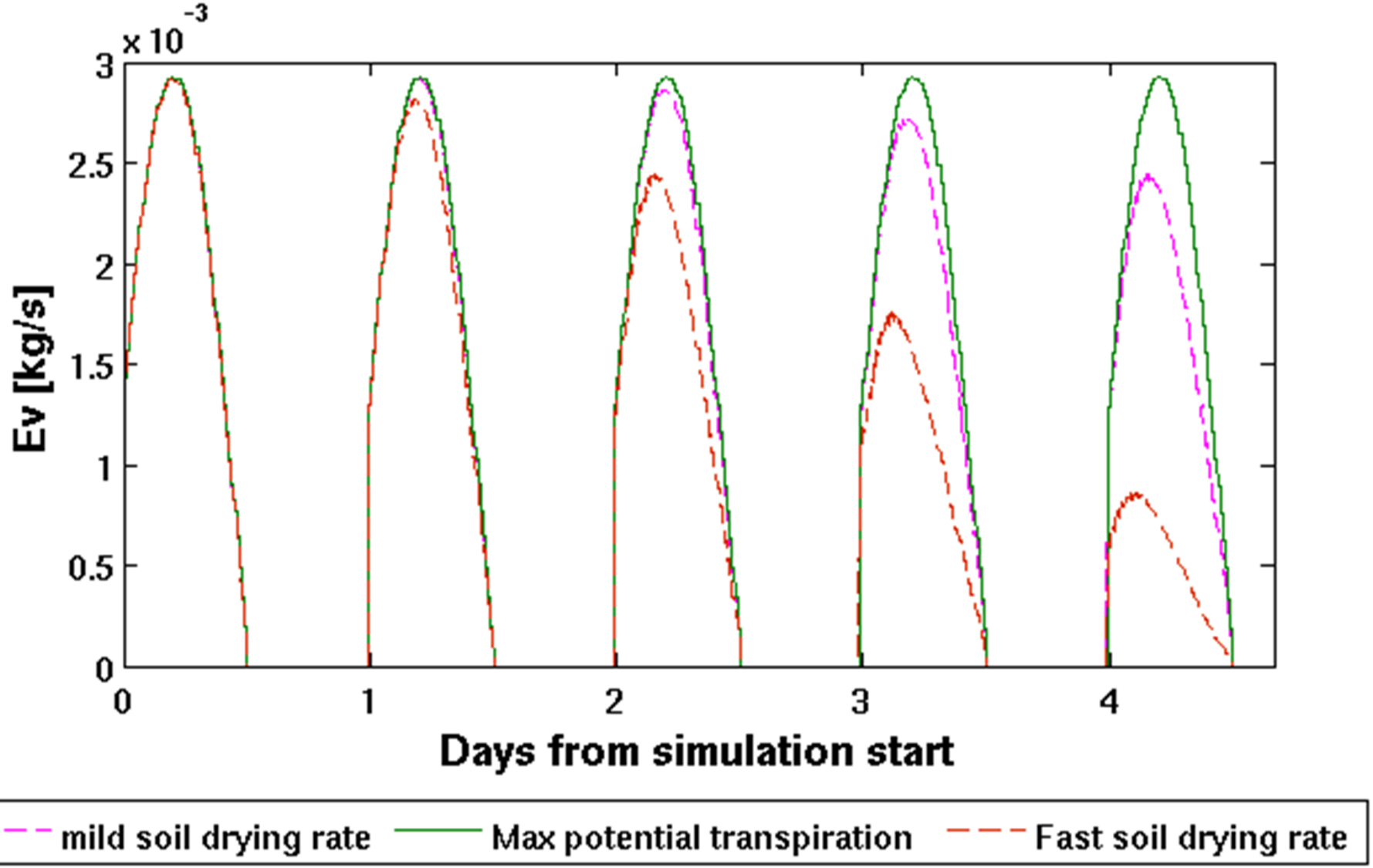
Daily dynamics from FETCH

Branch (leaf) water potential is resolved
sap flow and storage calculated dynamically



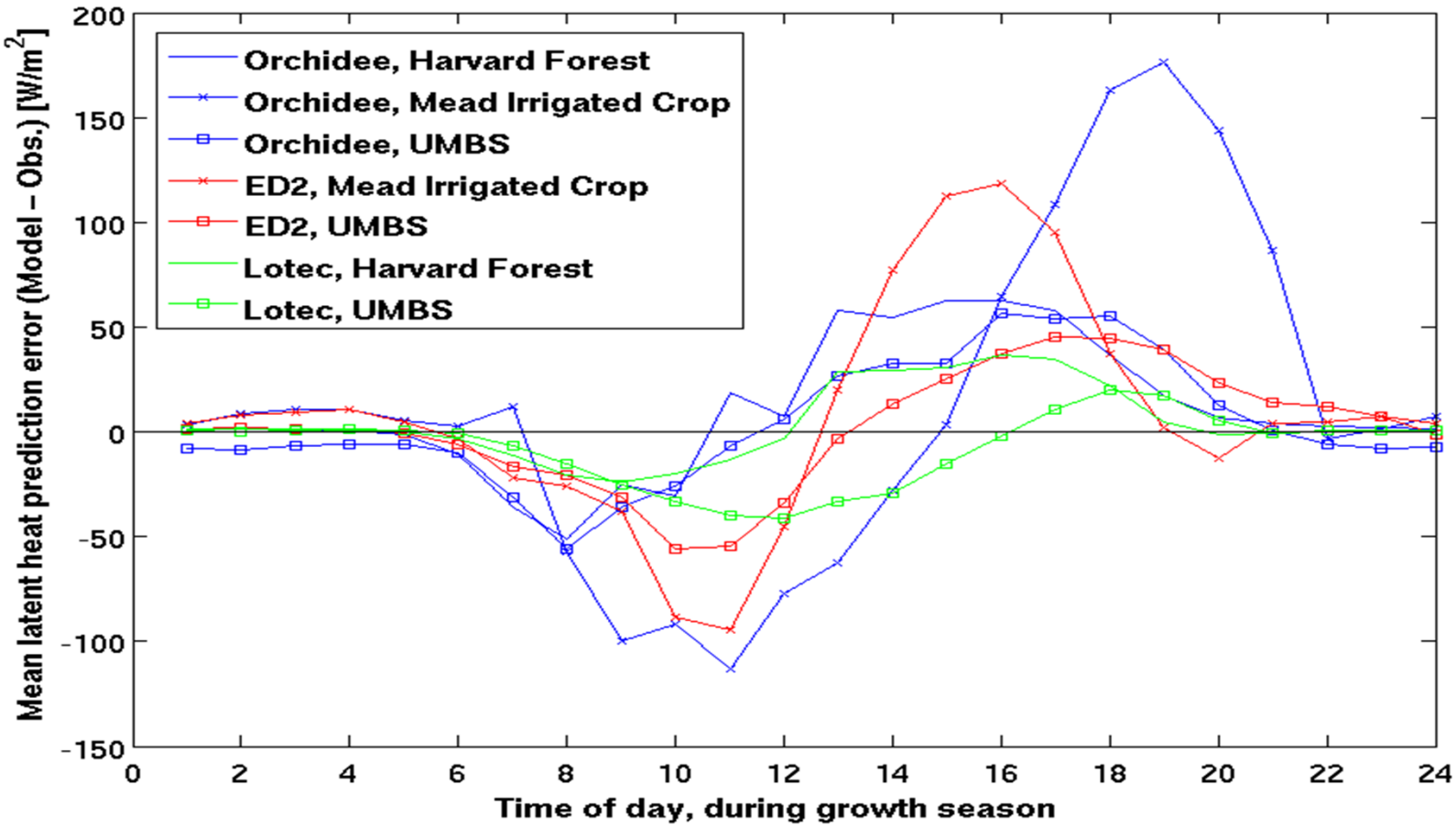
Daily dynamics from FETCH

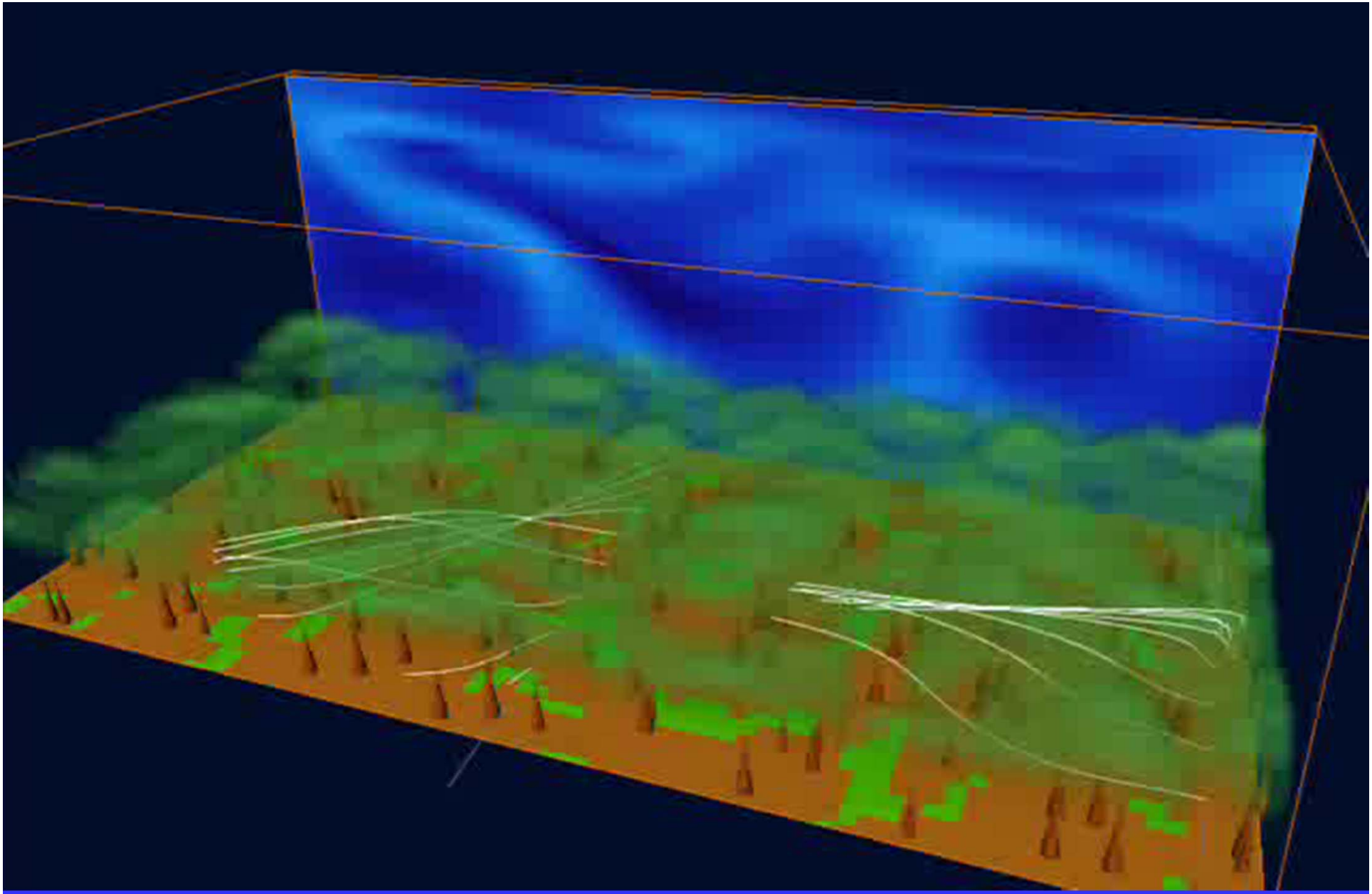
Drought sequence



Hydrodynamic stress is everywhere !

Non-hydrodynamic transpiration models produce typical pattern of error because they do not account for hydrodynamic stress effects in the afternoon

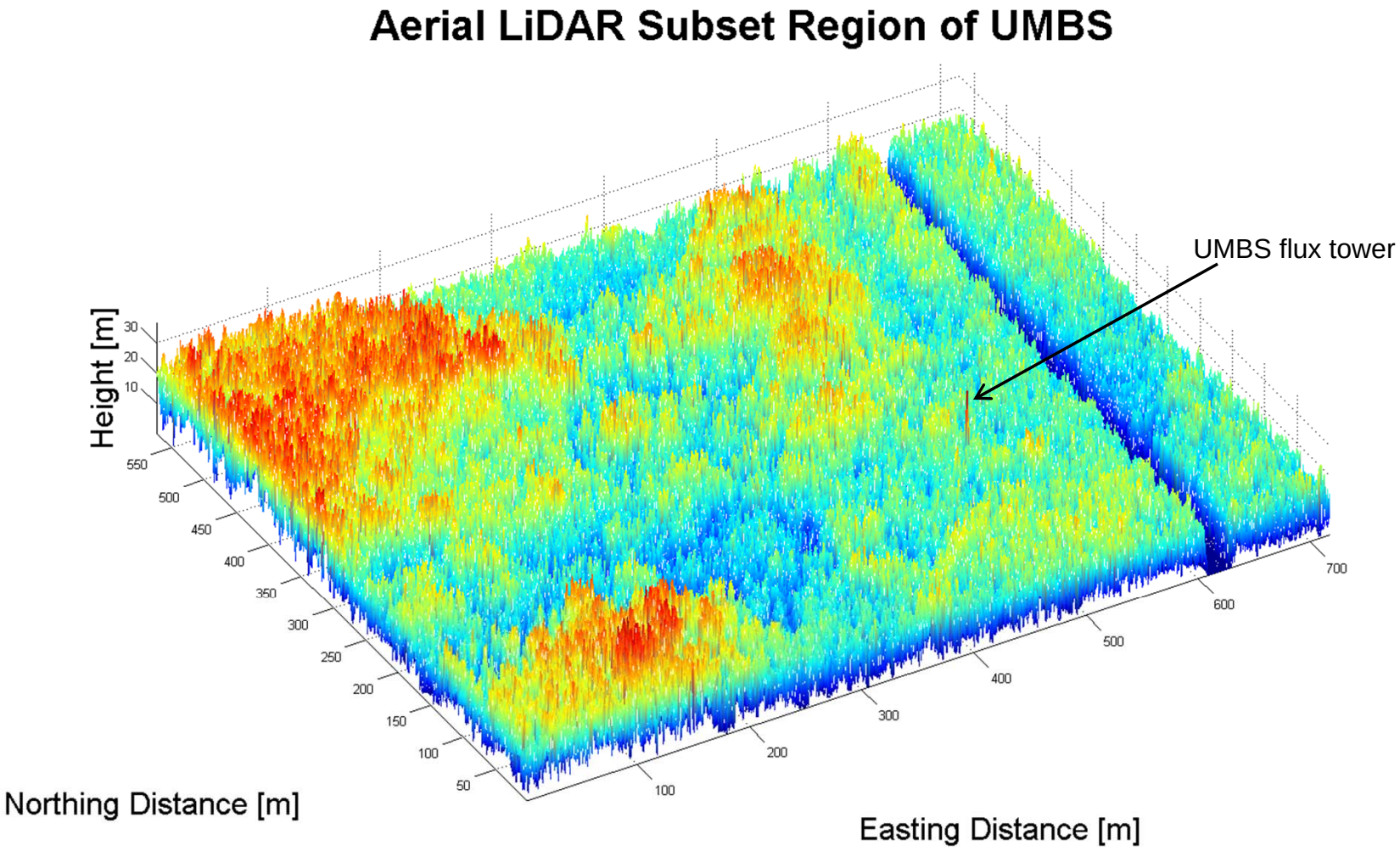




Application for ecological-atmospheric modeling

Accounting for canopy-structure effects on hydrological processes

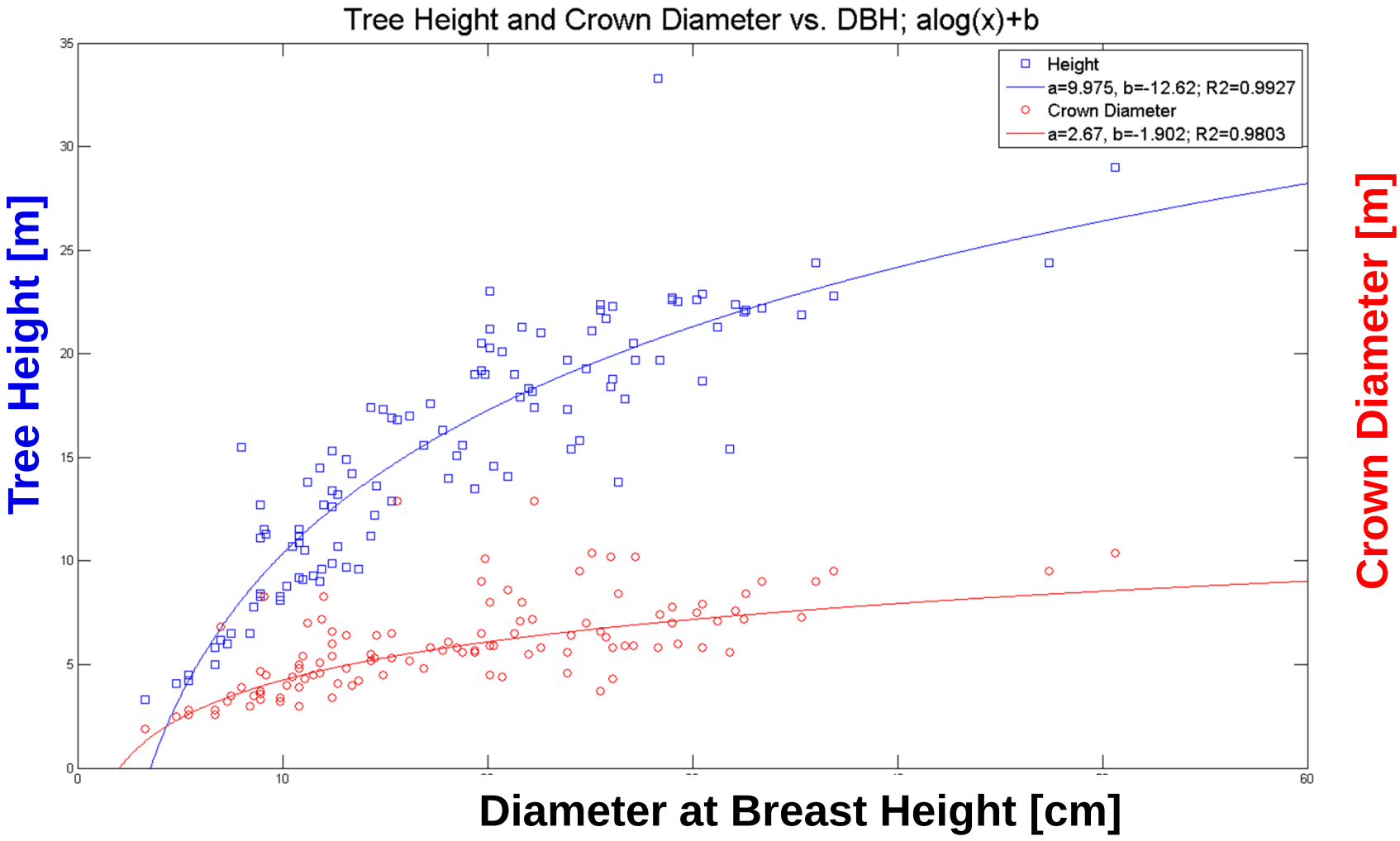
How to get branch-level explicit description of canopy structure?



Airborne LIDAR (example sub-domain, 0.55 x 0.7 km^2)

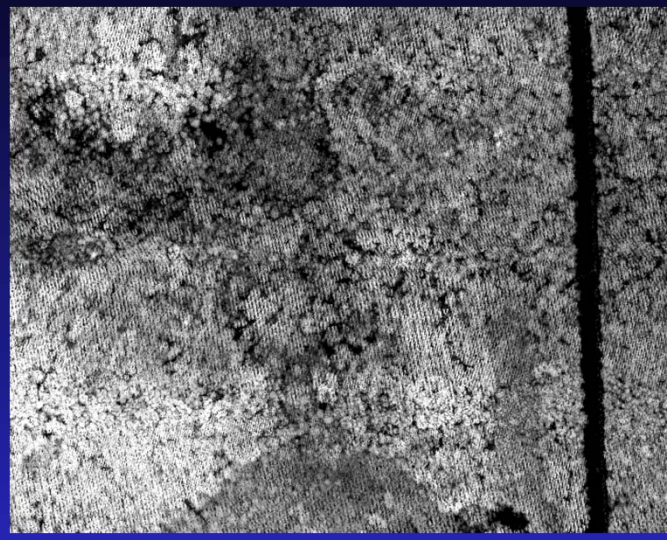
Garrity et al 2012 RSL

Use allometry to translate height-crown size data to DBH



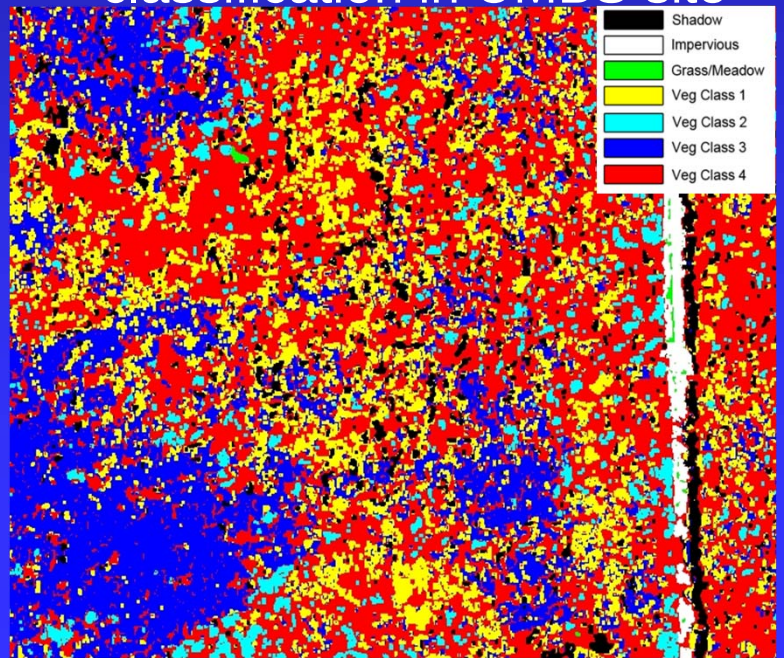
How to get branch-level explicit description of canopy structure?

Airborne hyper-spectral image



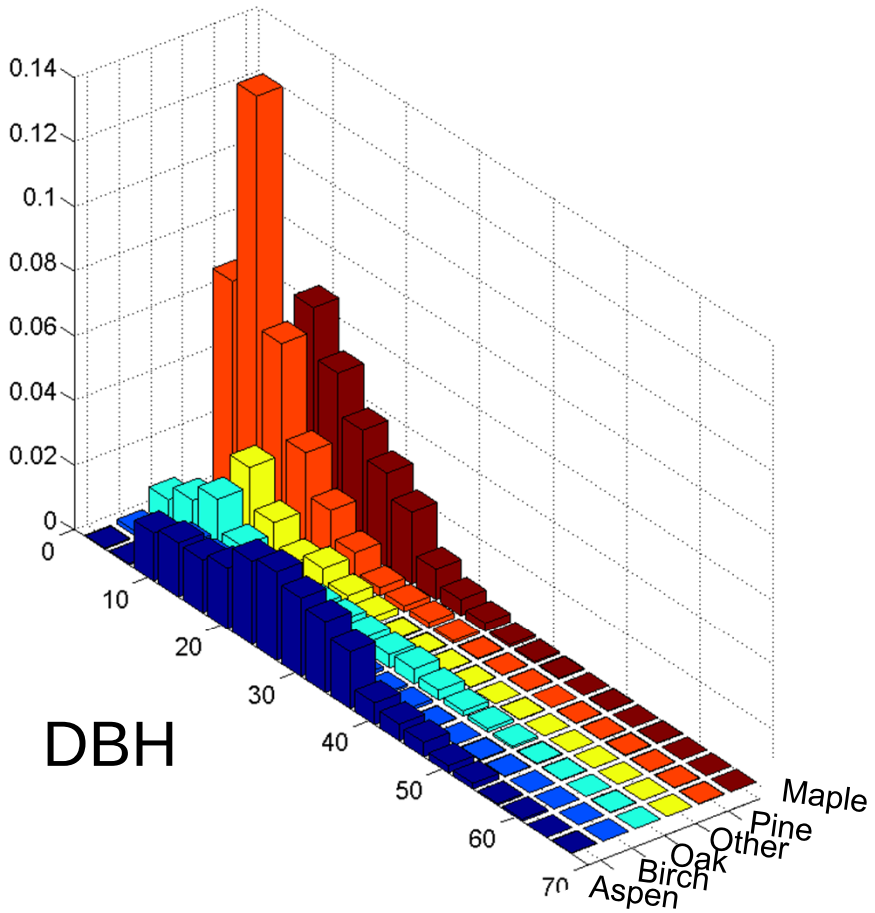
Airborne LIDAR

Combined to tree-type classification in UMBS site

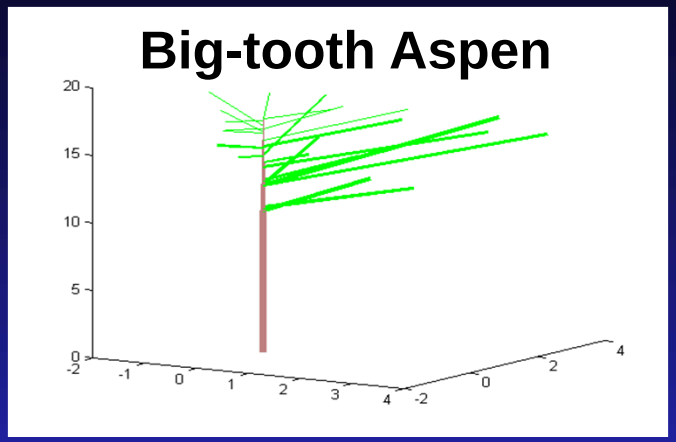


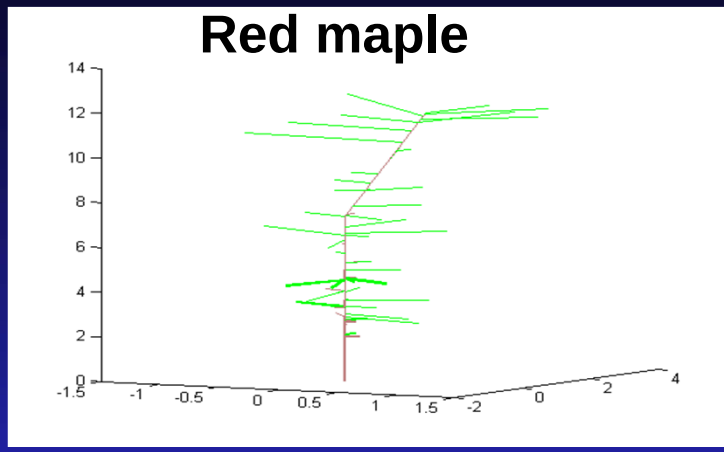
Decompose the forest to representative size/species DBH bins

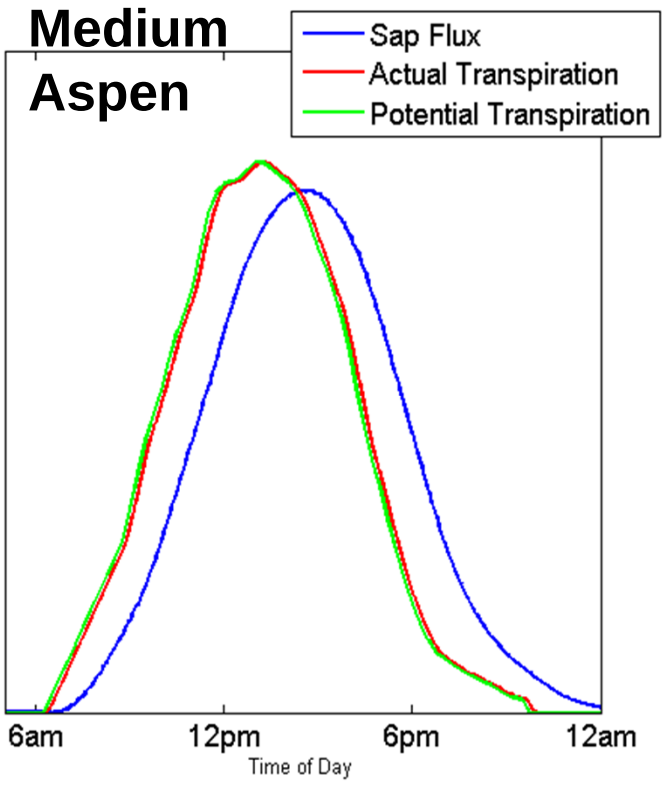
Distribution

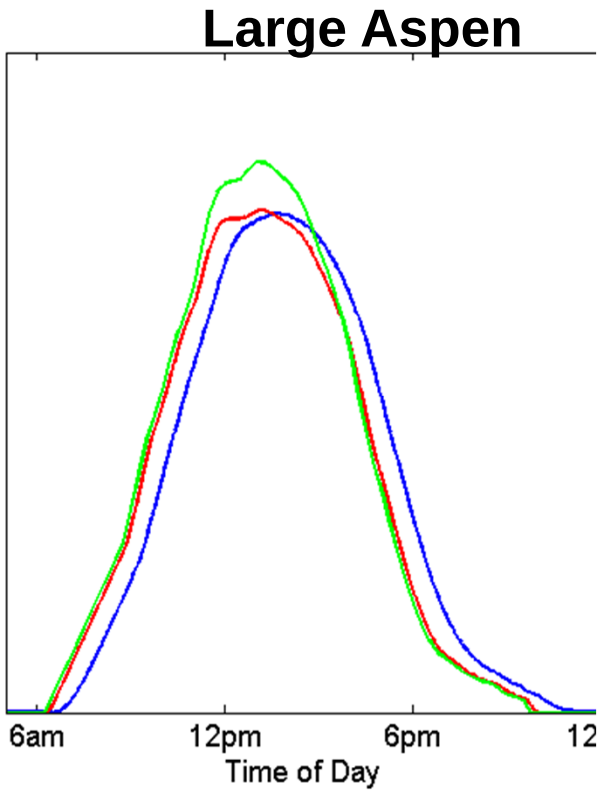


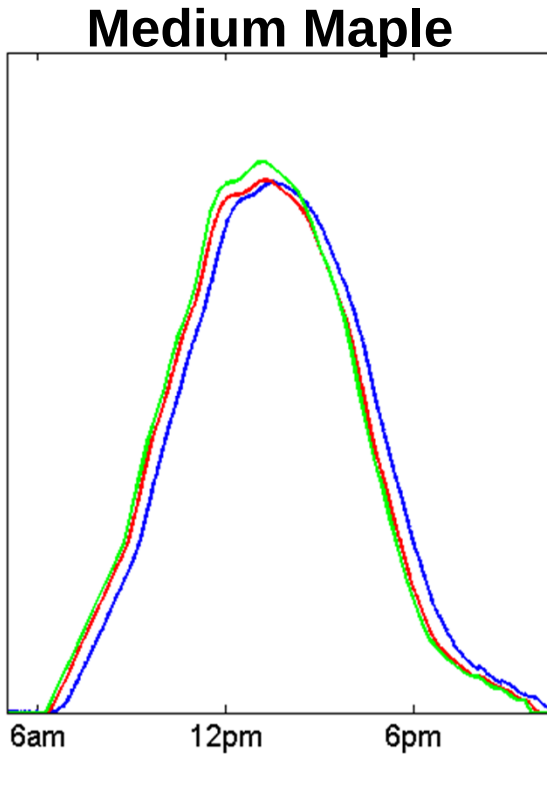
Will changes in structure also affect water demand?



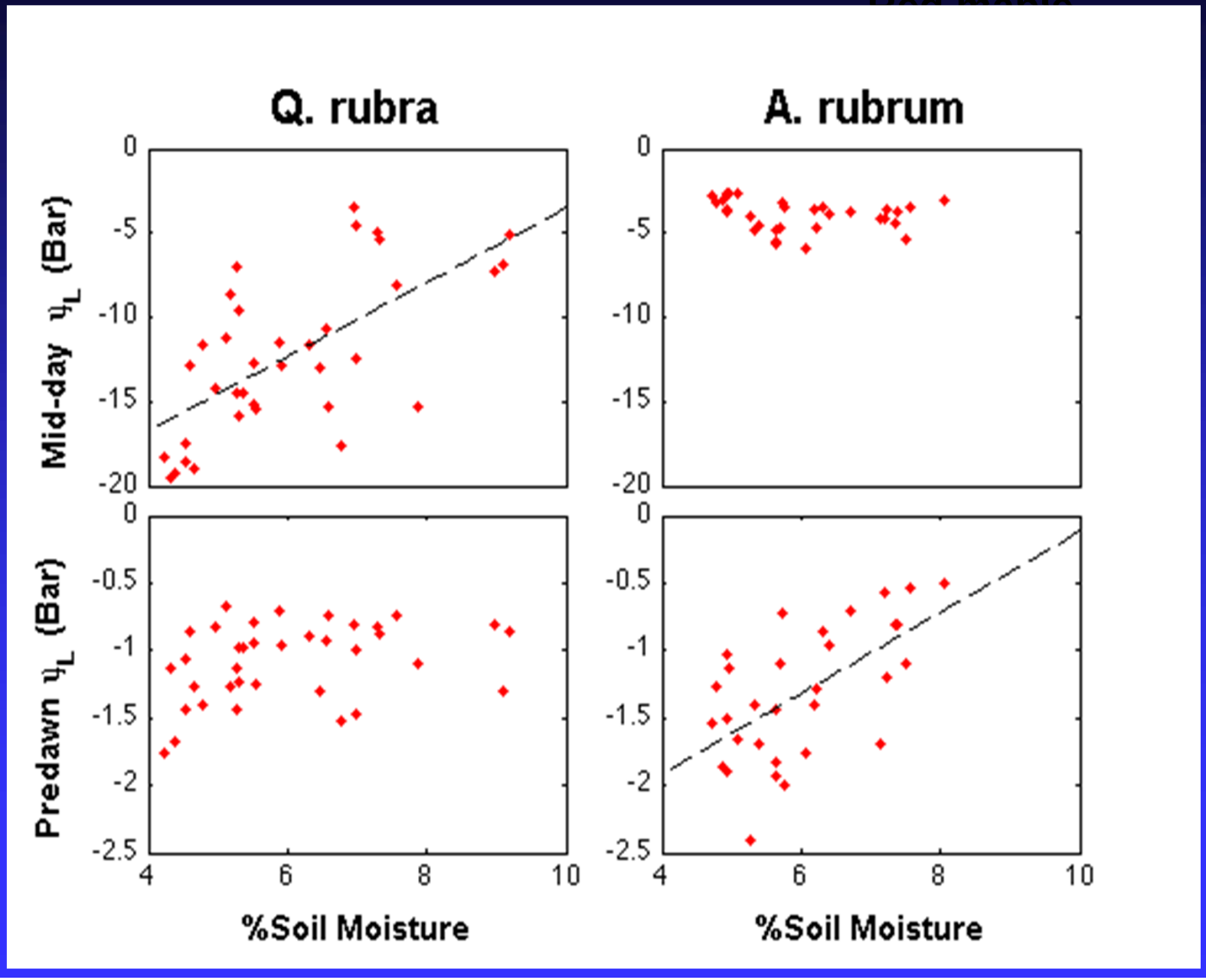








Differences between hydrologic-functional types



Acknowledgements

The FASET team:
Peter Curtis, Brady Hardiman, Chris Vogel, Chris Gough, Luke Nave

The CASSSH team:
Valeriy Ivanov, Lingli He (U of M)

Sap-flux measurements: Karina Schafer (Rutgers U)

Eddy flux processing: Matteo Detto (STRI)

Airborne LIDAR – NCALM (UMBS data)

USDA United States Department of Agriculture National Institute of Food and Agriculture

National Science Foundation WHERE DISCOVERIES BEGIN

BART Biosphere Atmosphere Research and Training

NASA

DOE National Institute for Climatic Change Research

AmeriFlux

Forest Service US Department of Agriculture

Ohio Supercomputer Center Empower. Partner. Lead.