A path forward to improve the representation of fine roots in terrestrial biosphere models

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13 August 2014

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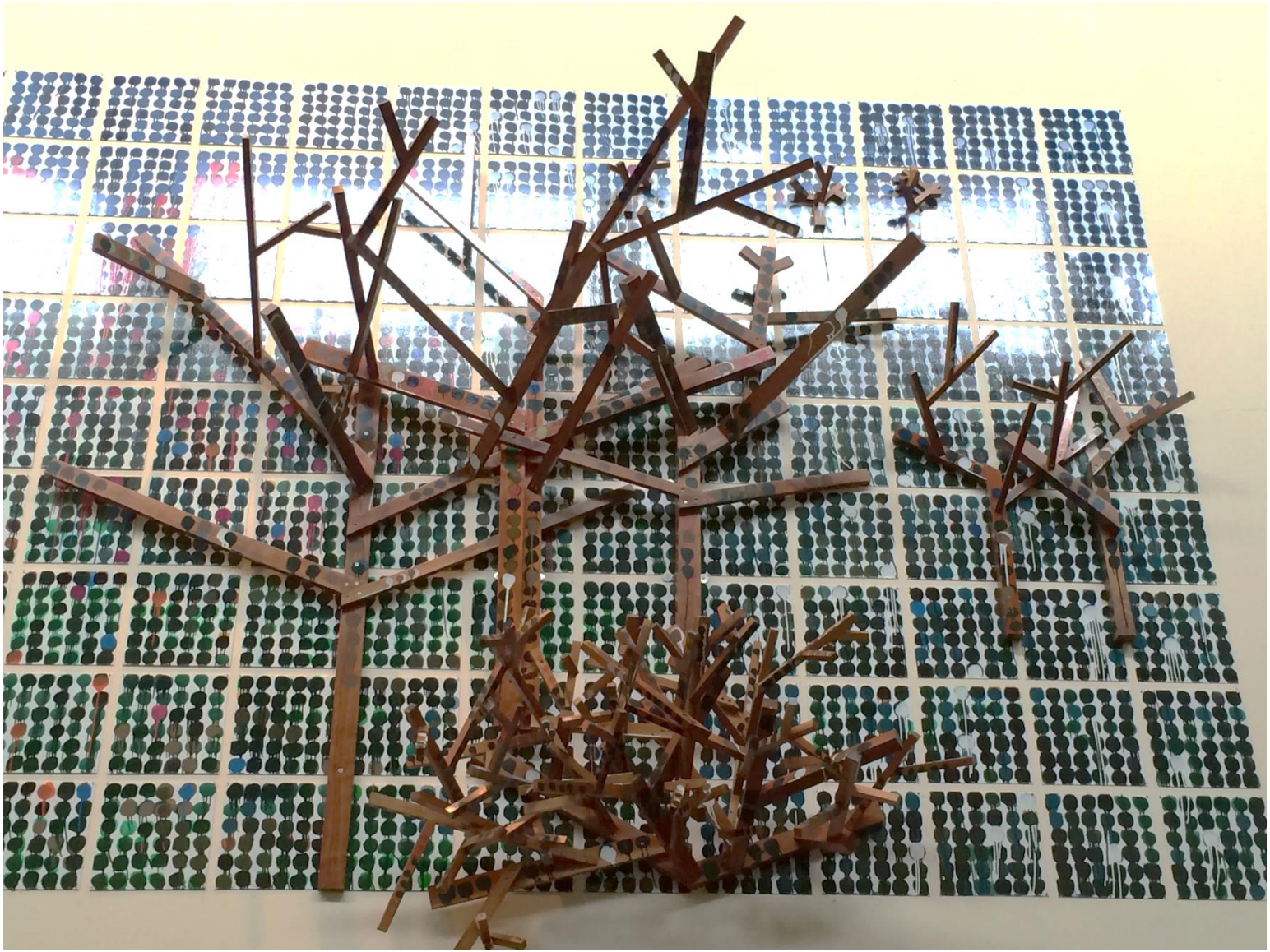
Anthony Walker (ORNL)
Xiaojuan Yang (ORNL)
Dali Wang (ORNL)

Climate Change Science Institute

OAK RIDGE NATIONAL LABORATORY
MANAGED BY UT-BATTELLE FOR THE DEPARTMENT OF ENERGY

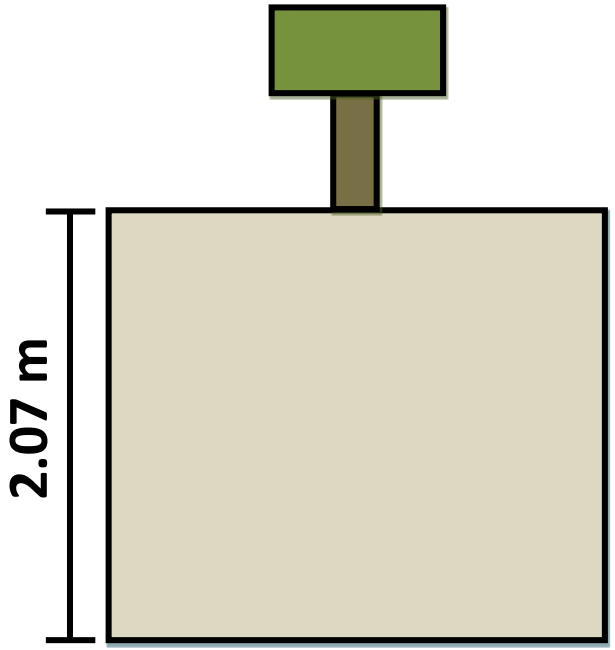


A continuing goal is to **LINK** empirical data with model structure and process.

Models may help pinpoint mechanisms and explain dynamic responses

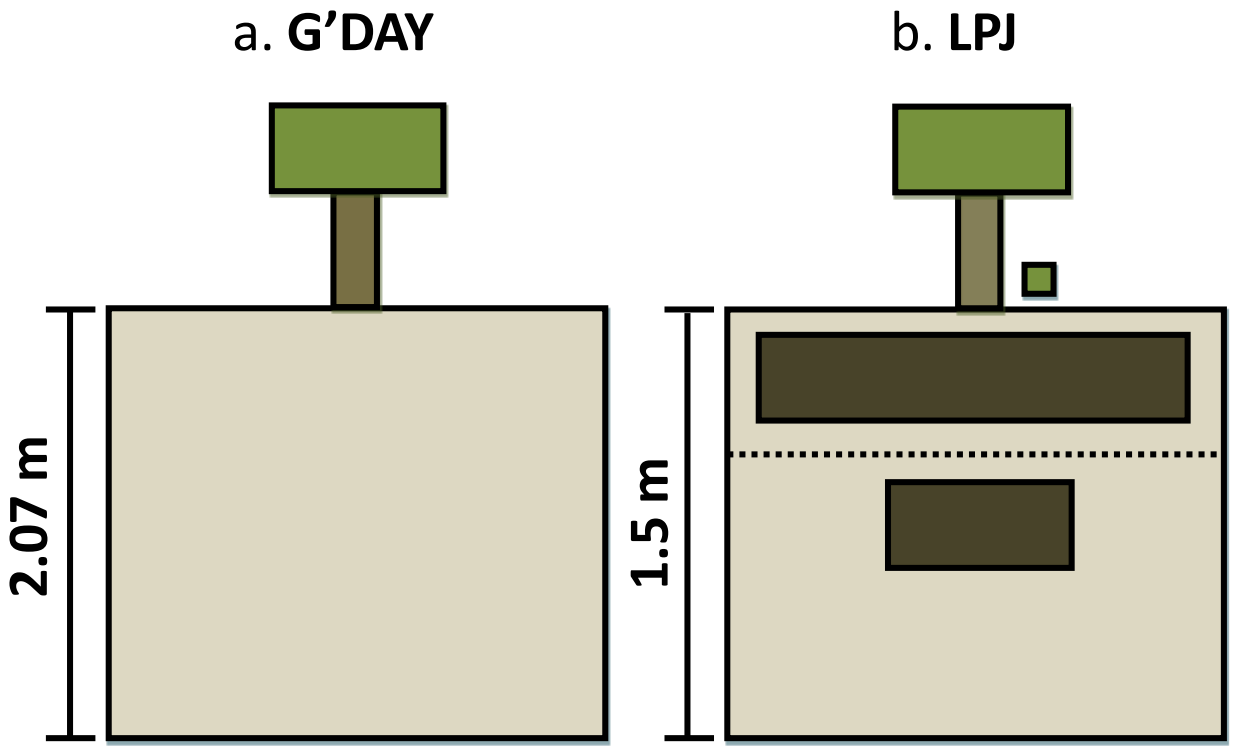
Models may help pinpoint mechanisms and explain dynamic responses

a. **G'DAY**



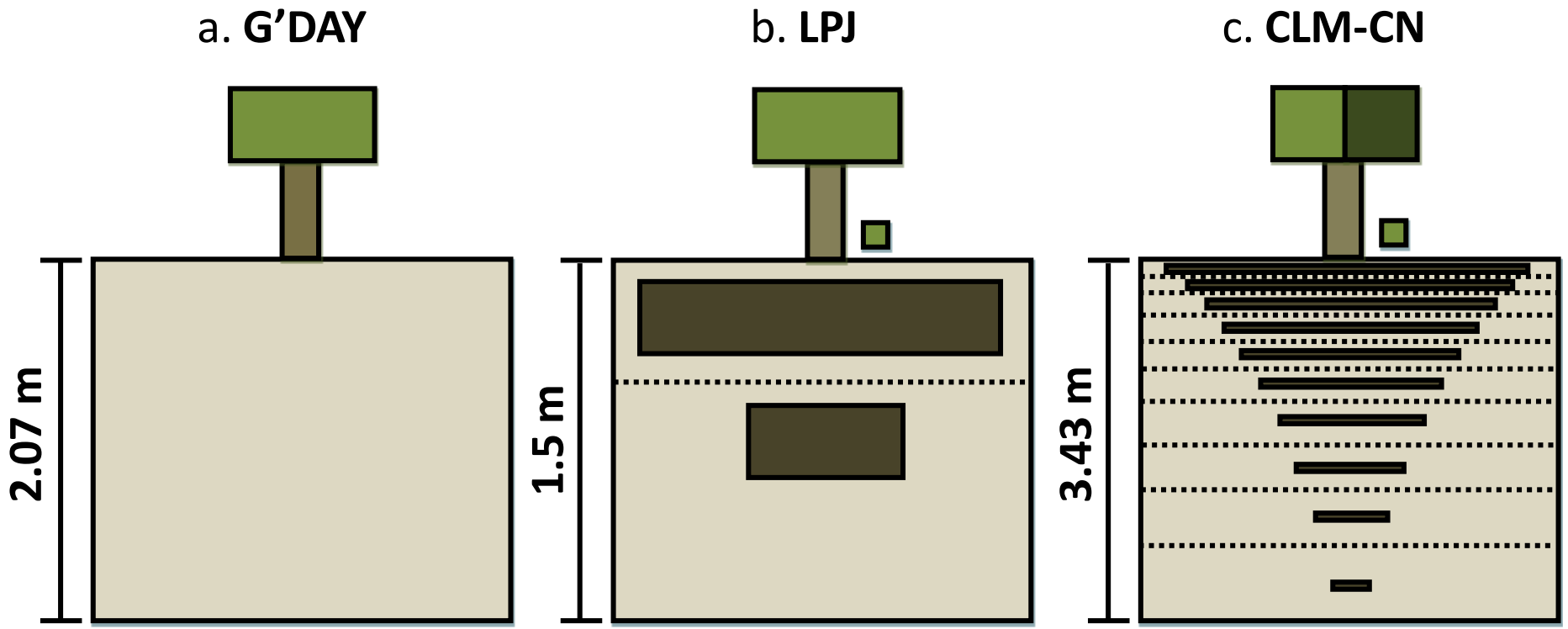
Iversen, 2010 (*New Phytologist*)

Models may help pinpoint mechanisms and explain dynamic responses



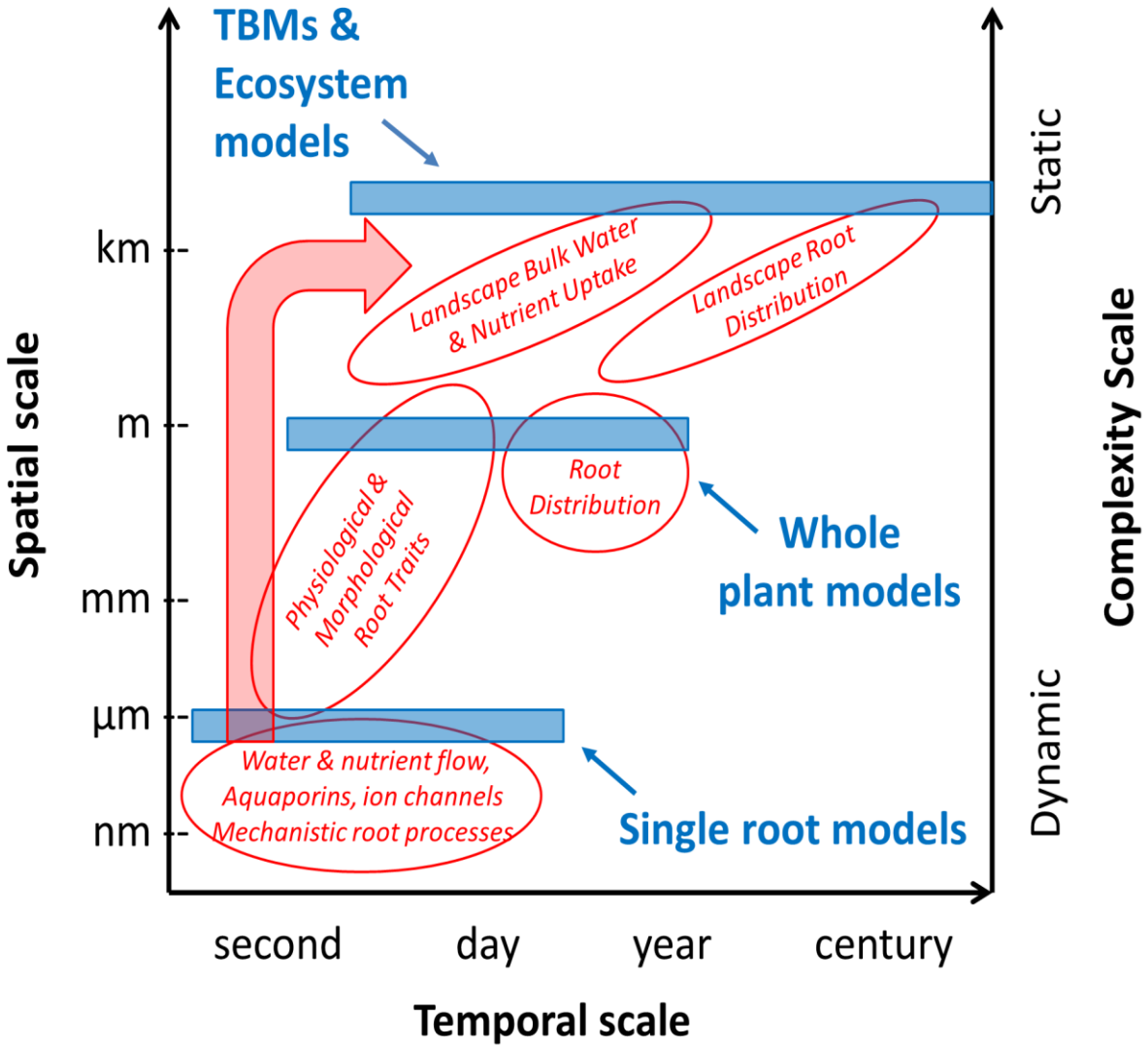
Iversen, 2010 (*New Phytologist*)

Models may help pinpoint mechanisms and explain dynamic responses



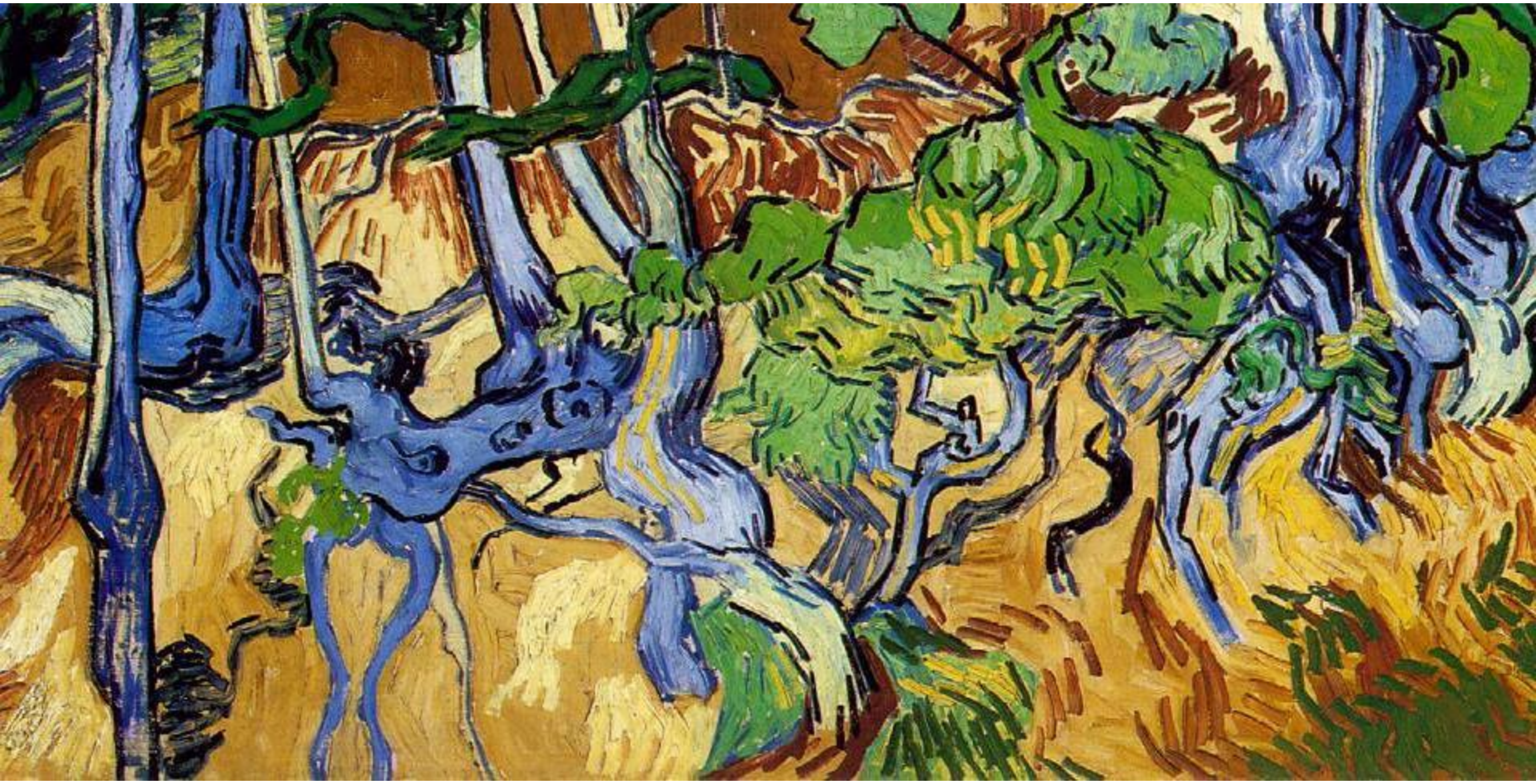
Iversen, 2010 (*New Phytologist*)

Continuing issue is appropriate representation of root form & function at multiple scales



Warren *et al*., 2014 (*New Phytologist*)

At the global scale, plant functional types (PFTs) are groups of traits that represent, or relate to, **PLANT FUNCTION** in large-scale models.



‘Tree Roots’, Vincent van Gogh, 1890

Most plants are grouped into PFTs according to **ABOVEGROUND** traits.

How can we inform the representation of **BELOWGROUND PROCESSES** in large-scale models through PFTs?

We (empirical scientists) need to **PROACTIVELY** provide the information needed for model parameters and processes.

WORKSHOP GOAL:

Improve the representation of roots in the next-generation **TERRESTRIAL BIOSPHERE MODELS**.

*Workshop support from Office of Biological and Environmental Sciences in the Department of Energy's Office of Science

Terrestrial Ecosystem SCIENCE

It was important to bring together an interdisciplinary team of **ROOT AND RHIZOSPHERE ECOLOGISTS**, **MODELERS**, and **DATABASE MANAGERS**.

Workshop continued a historical focus on fine roots and their representation in models

Plant and Soil **165:** 1–6, 1994.
© 1994 *Kluwer Academic Publishers.*

Belowground responses to rising atmospheric CO_2: Implications for plants, soil biota and ecosystem processes

Executive summary

Peter S. Curtis[1], Elizabeth G. O'Neill[2], James A. Teeri[3], Donald R. Zak[4] and Kurt S. Pregitzer[5]

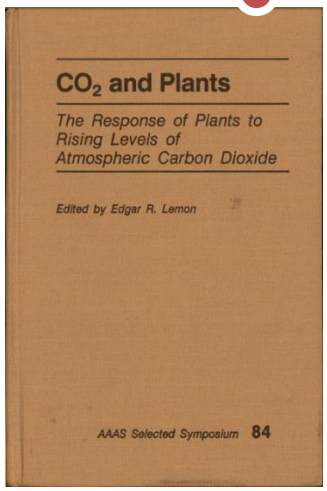
REVIEW *New Phytol.* (2000), **147**, 3–12

Research review

Root dynamics and global change: seeking an ecosystem perspective

RICHARD J. NORBY[1]* AND ROBERT B. JACKSON[2]

1980 1985 1990 1995 2000 2005 2010 2015



Commentary

Introduction to a *Virtual Special Issue*: modeling the hidden half – the root of our problem

Roser Matamala[1]* and Daniel B. Stover[2]

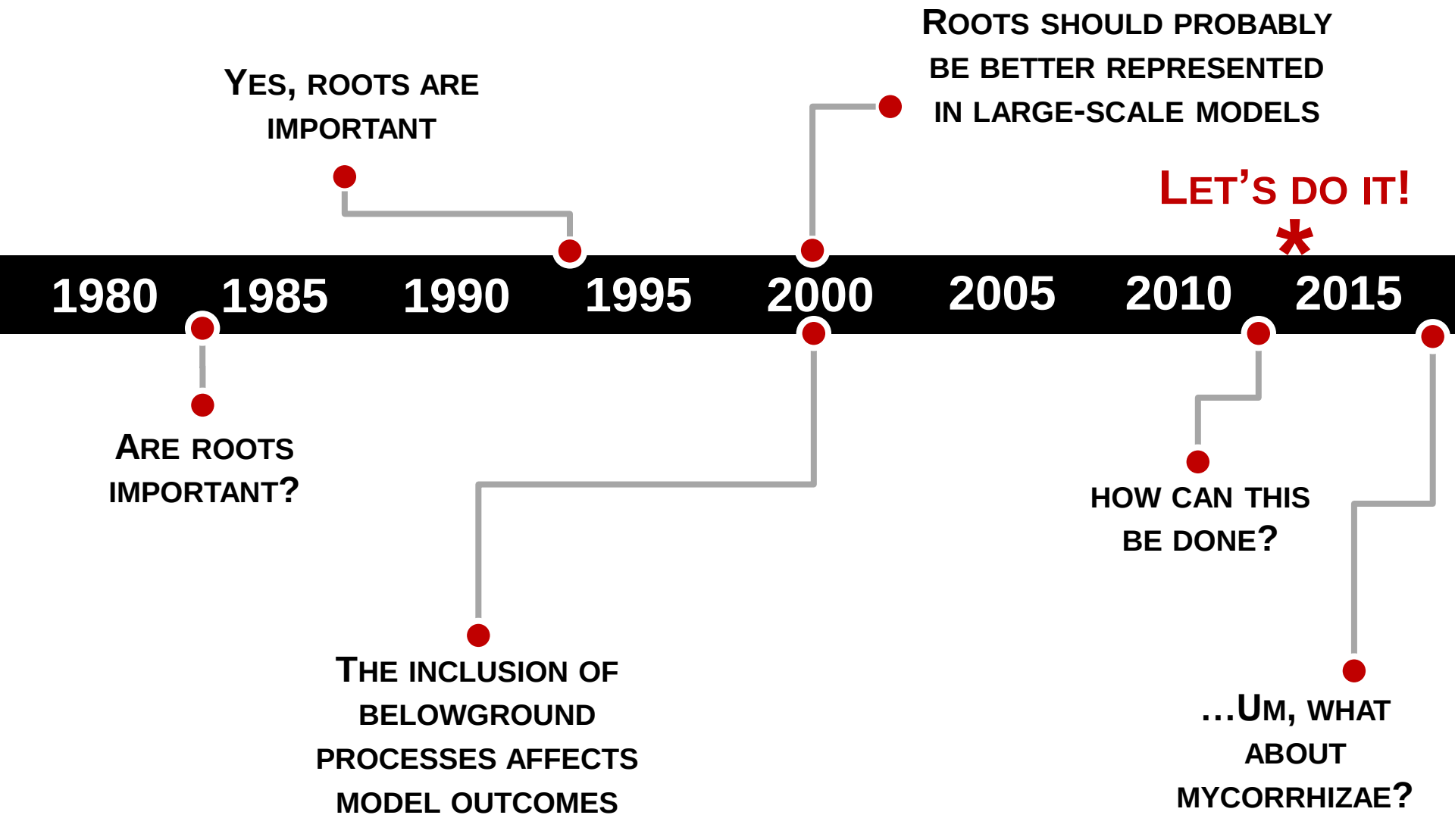
New Phytologist (2013) 200: 939–942
www.newphytologist.com

Ecological Applications, 10(2), 2000, pp -483
© 2000 by the Ecological Society of Ar

BELOWGROUND CONSEQUENCES OF VEGETATION CHANGE AND THEIR TREATMENT IN MODELS

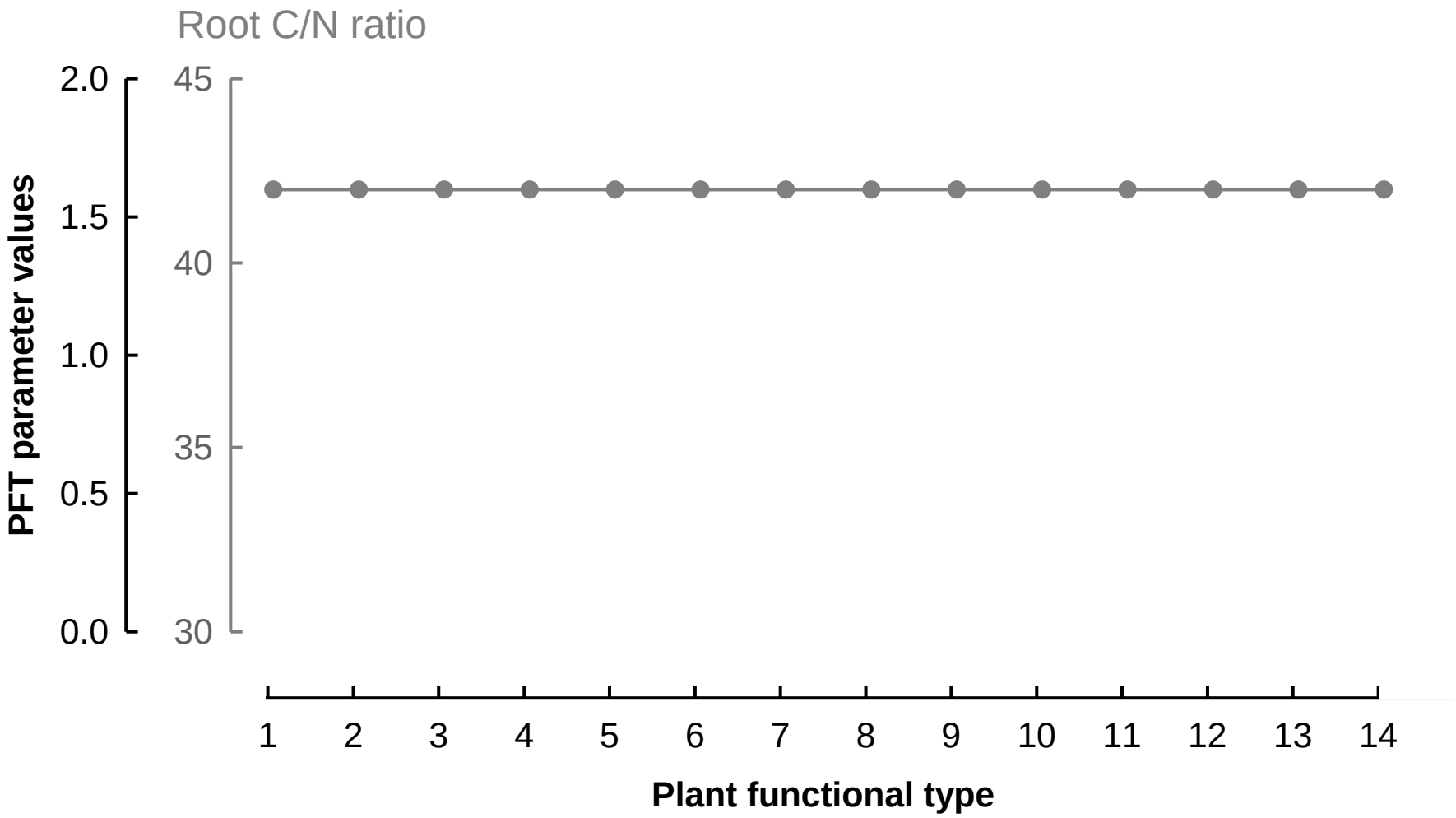
R. B. JACKSON,[1] H. J. SCHENK,[1,2] E. G. JOBBÁGY,[1] J. CANADELL,[3] G. D. COLELLO,[4] R. E. DICKINSON,[5] C. B. FIELD,[4] P. FRIEDLINGSTEIN,[6] M. HEIMANN,[7] K. HIBBARD,[8] D. W. KICKLIGHTER,[9] A. KLEIDON,[7] R. P. NEILSON,[10] W. J. PARTON,[11] O. E. SALA,[12] AND M. T. SYKES[13]

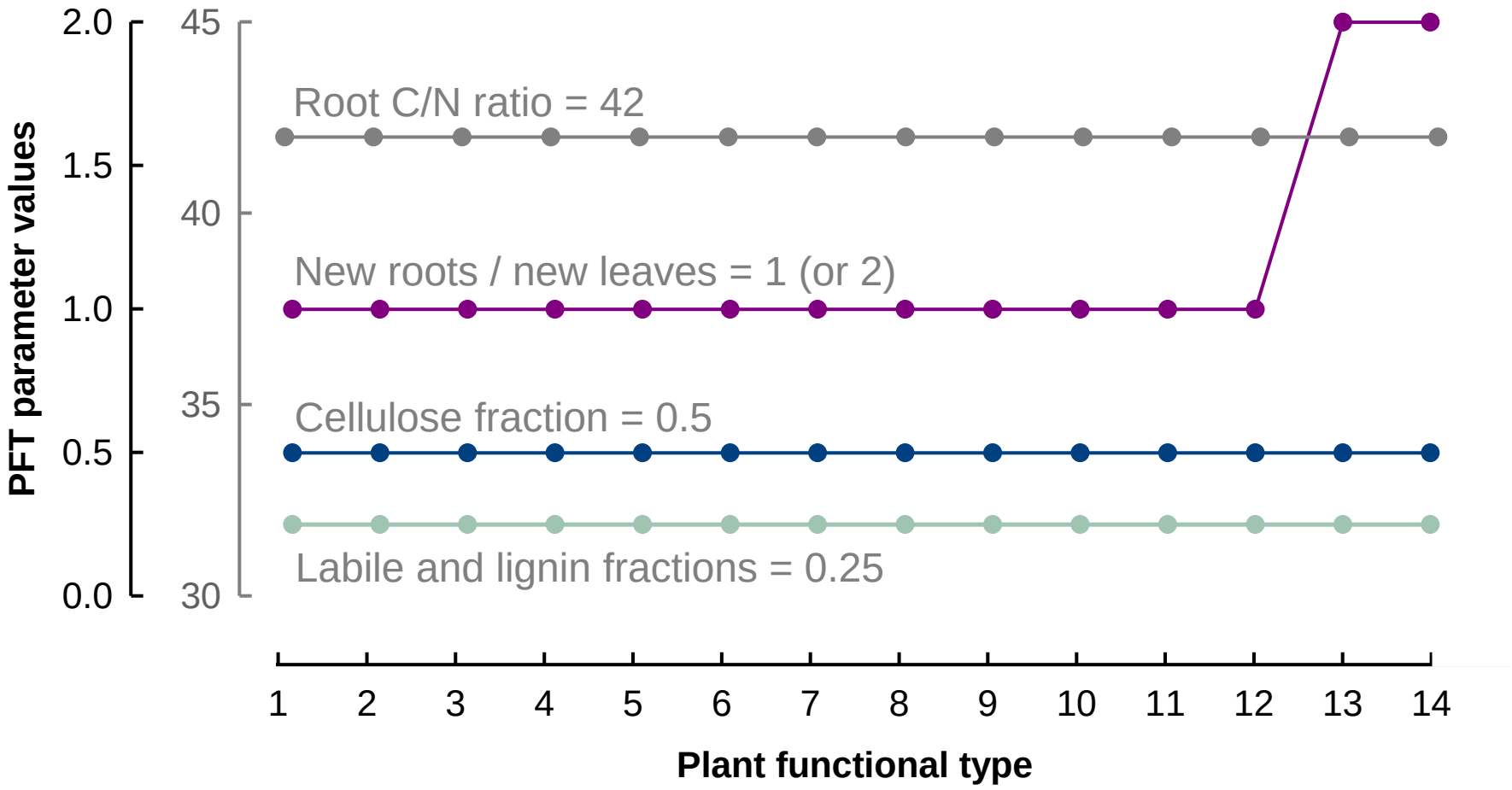
Workshop continued a historical focus on fine roots and their representation in models



WORKSHOP DISCUSSION:

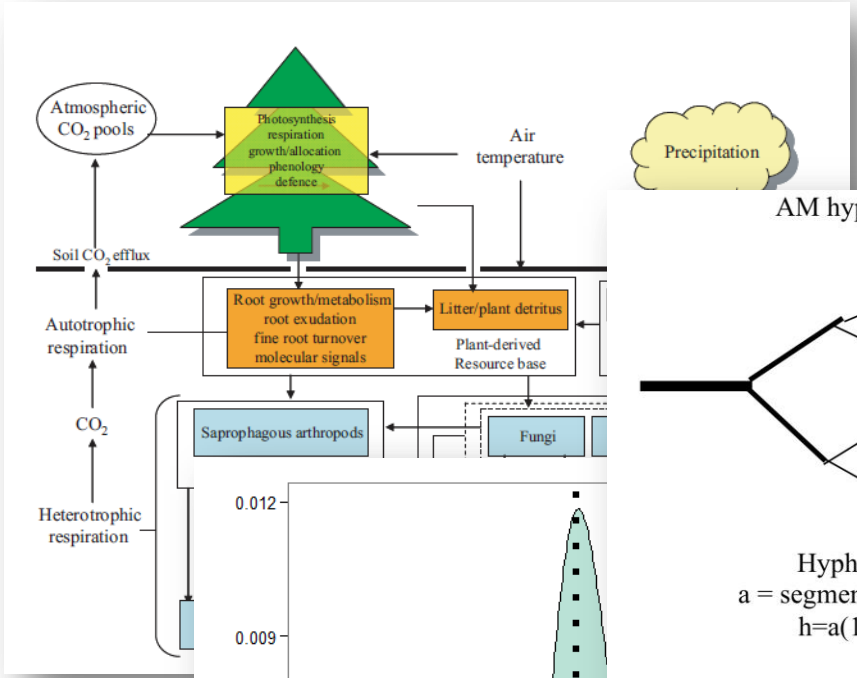
What are the gaps between current **MODEL REPRESENTATION** of roots and **EMPIRICAL UNDERSTANDING** of roots based on current measurements?

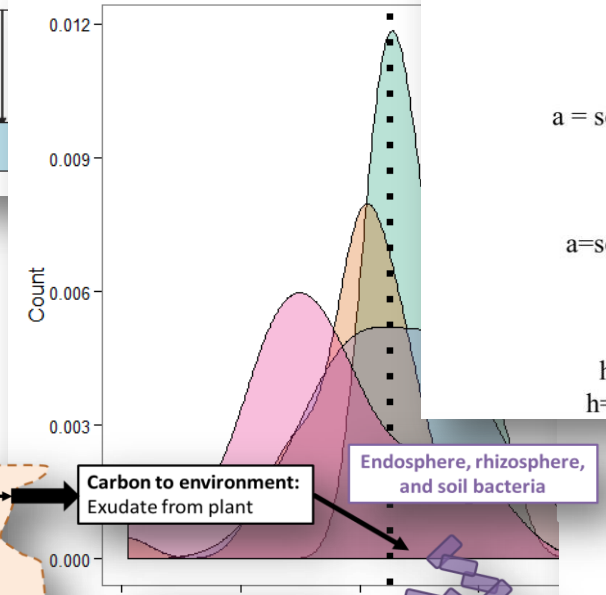

Root C/N ratio
PFT parameter values
2.0
1.5
1.0
0.5
0.0
45
40
35
30
1
2
3
4
5
6
7
8
9
10
11
12
13
14
Plant functional type

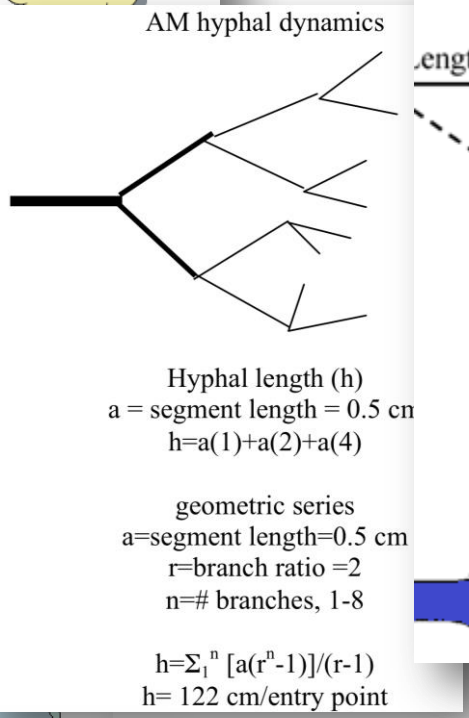

2.0
1.5
1.0
0.5
0.0
PFT parameter values
45
40
35
30
Root C/N ratio = 42
New roots / new leaves = 1 (or 2)
Cellulose fraction = 0.5
Labile and lignin fractions = 0.25
1
2
3
4
5
6
7
8
9
10
11
12
13
14
Plant functional type

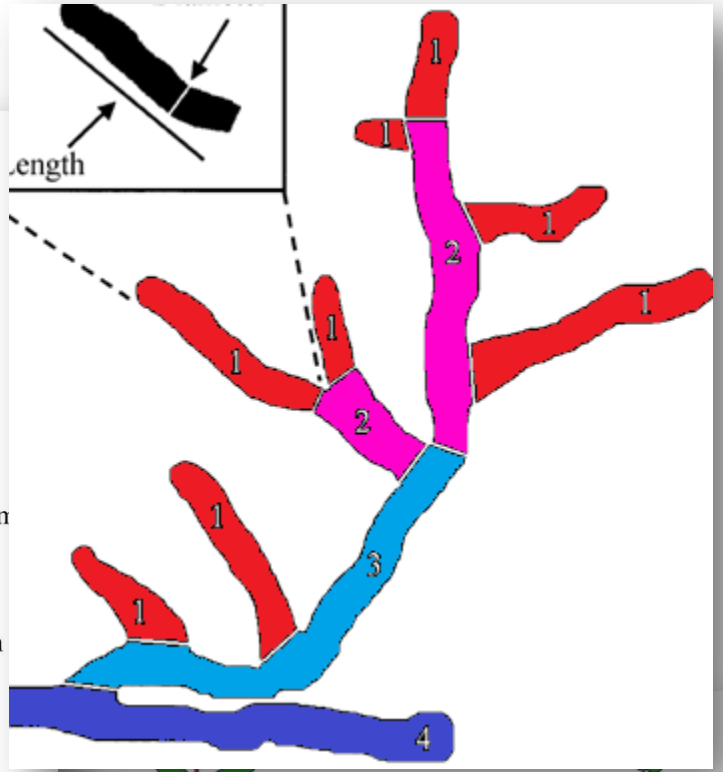
WORKSHOP DISCUSSION:

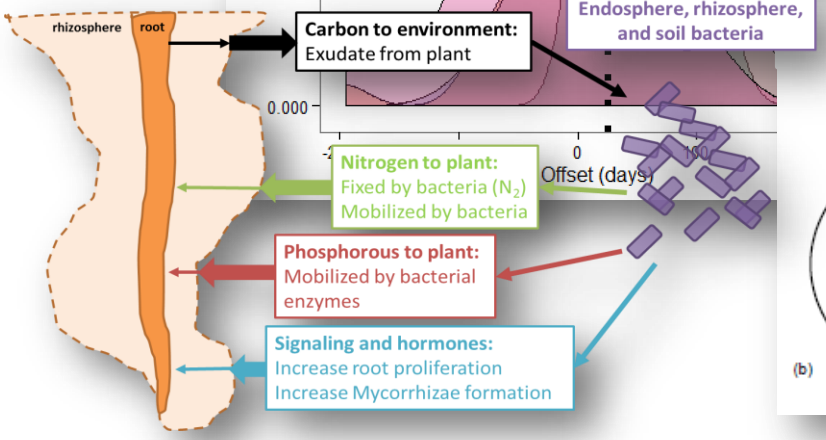
Do we agree on an **IDEAL CONCEPTUAL REPRESENTATION** of root processes that could be made numerical in a model? What are the **PRIORITIES** for the next steps in the evolution of model representation?

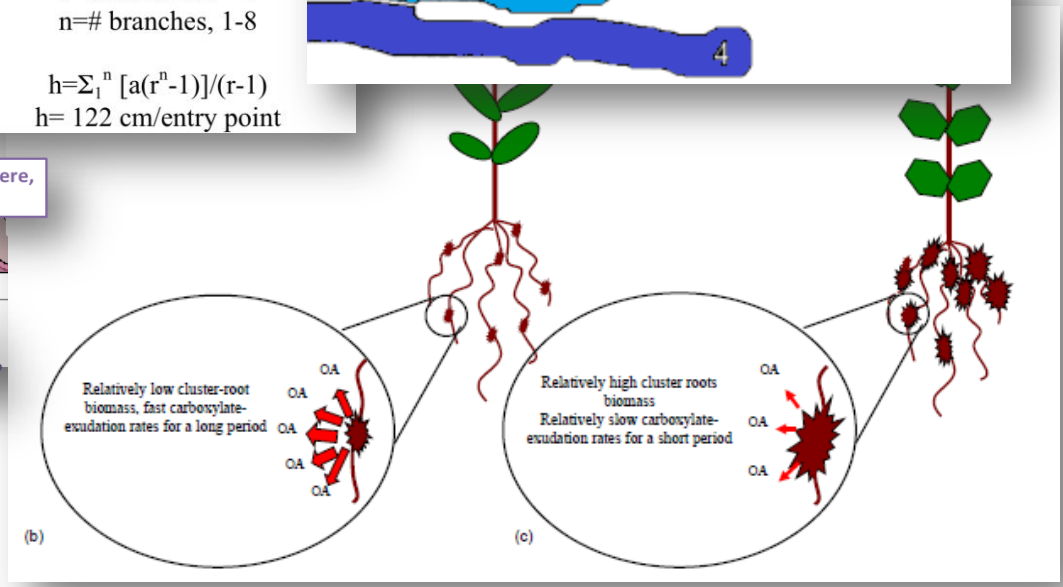

Atmospheric CO_2 pools
Photosynthesis
respiration
growth/allocation
phenology
defence
Air temperature
Precipitation
Soil CO_2 efflux
Autotrophic respiration
Root growth/metabolism
root exudation
fine root turnover
molecular signals
Litter/plant detritus
Plant-derived Resource base
CO_2
Saprophagous arthropods
Fungi
Heterotrophic respiration


0.012
0.009
0.006
0.003
0.000
Count
Offset (days)


AM hyphal dynamics
Hyphal length (h)
a = segment length = 0.5 cn
h=a(1)+a(2)+a(4)
geometric series
a=segment length=0.5 cm
r=branch ratio =2
n=# branches, 1-8
$h=\Sigma_1^n [a(r^n-1)]/(r-1)$
h= 122 cm/entry point


ength
1
2
3
4

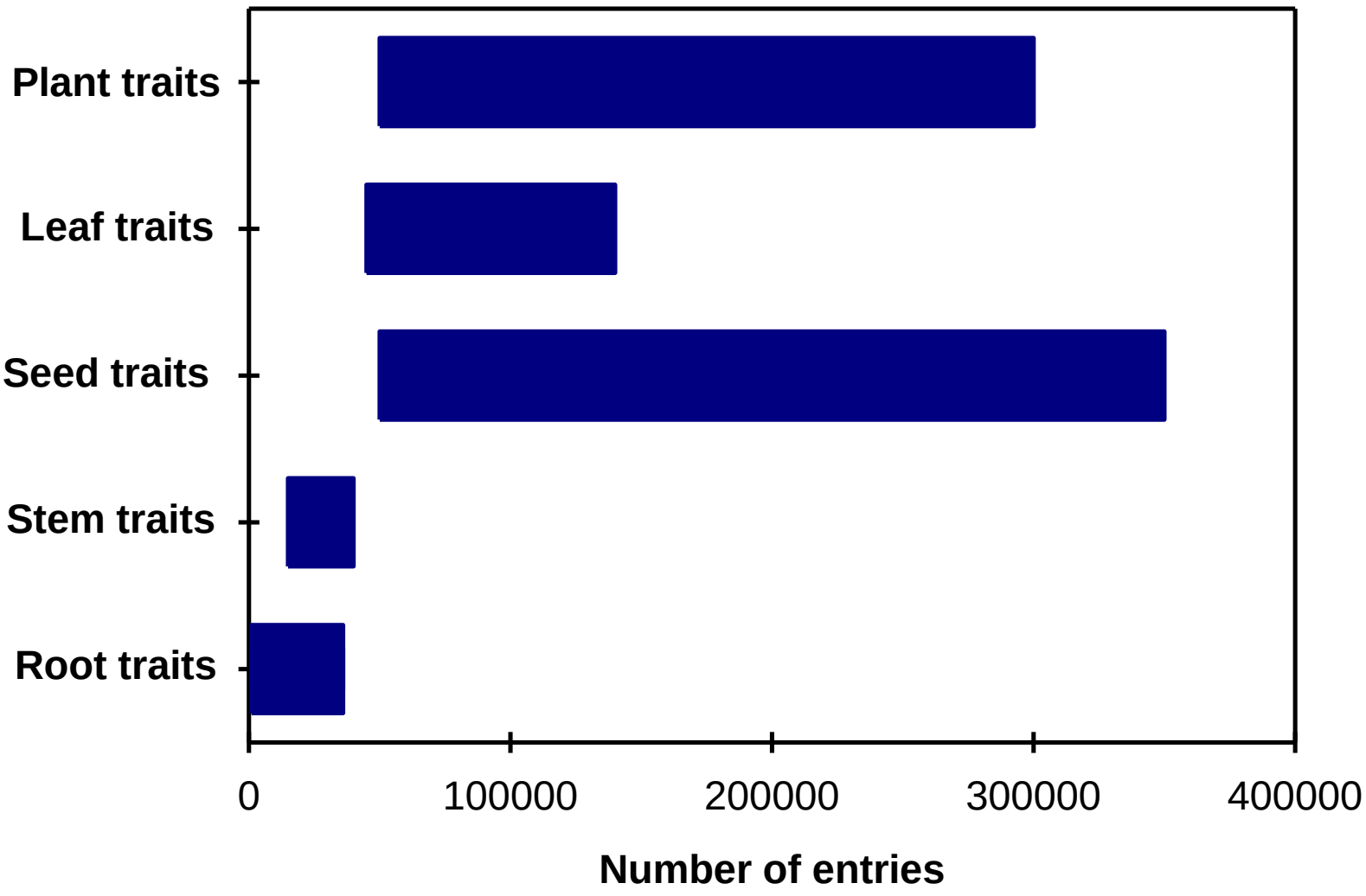

rhizosphere
root
Carbon to environment:
Exudate from plant
Endosphere, rhizosphere, and soil bacteria
Nitrogen to plant:
Fixed by bacteria (N_2)
Mobilized by bacteria
Phosphorous to plant:
Mobilized by bacterial enzymes
Signaling and hormones:
Increase root proliferation
Increase Mycorrhizae formation


Relatively low cluster-root biomass, fast carboxylate-exudation rates for a long period
OA
(b)
Relatively high cluster roots biomass
Relatively slow carboxylate-exudation rates for a short period
OA
(c)

WORKSHOP DISCUSSION:

What are the **BEST ROOT DATA AVAILABLE** across the globe for model use?

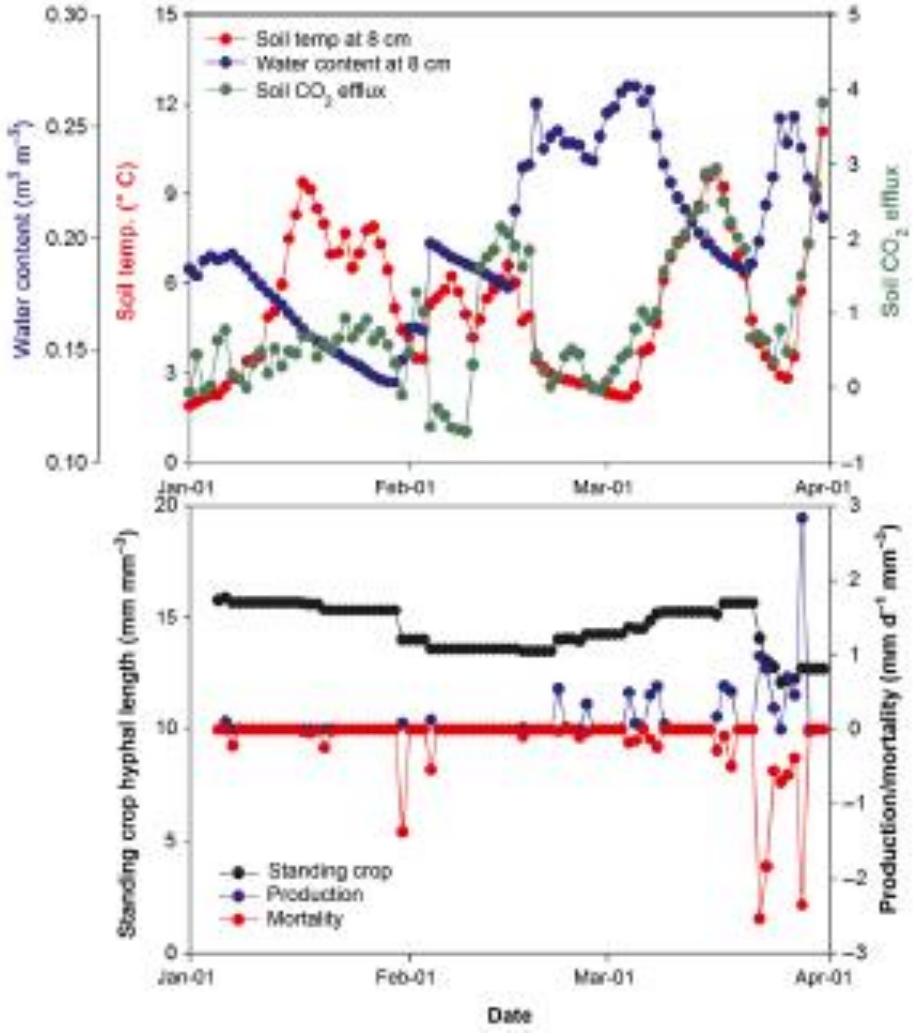
Root traits underrepresented in TRY



J. Kattge, MPI

Do we have continuous measurements of the relationships between **ROOT PROCESSES AND ENVIRONMENTAL CONDITIONS** for representation in models?

Continuous sensor and observation systems are needed



Allen & Kitajima, 2013 (*New Phytologist*)

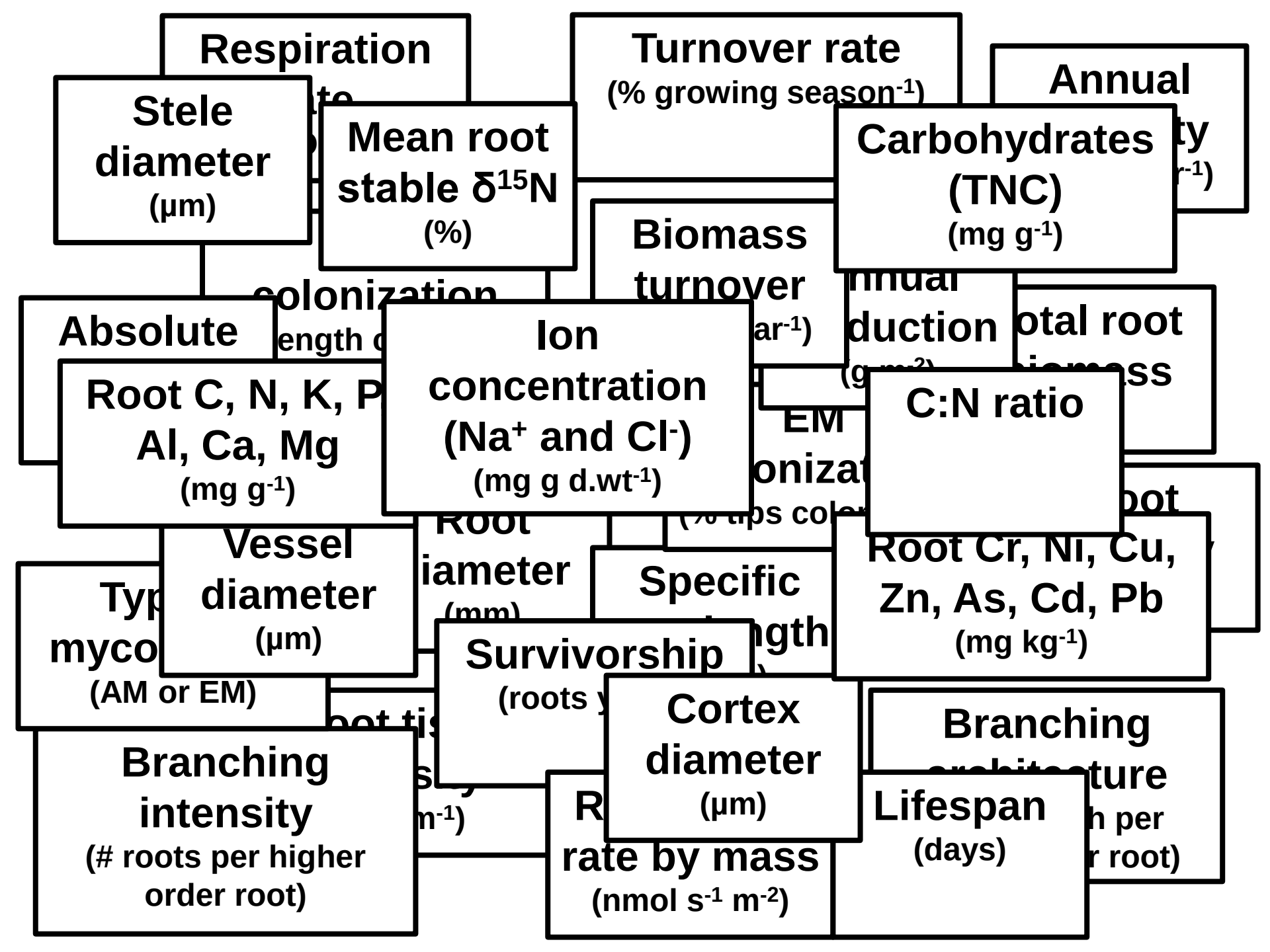
We developed a **PATH FORWARD** to improve the representation of fine roots in terrestrial biosphere models.

1. A ROOT TRAIT DATABASE:

Develop a **ROOT TRAIT DATABASE**, and let it guide our priorities for future data collection.

PLEASE SEND US DATA!
(IVERSENCM@ORNL.GOV)

http://www.try-db.org/TryWeb/Home.php


Respiration
Turnover rate
(% growing season^{-1})
Annual
Stele diameter
(μm)
Mean root stable $\delta^{15}N$
(%)
Carbohydrates (TNC)
(mg g^{-1})
Biomass turnover
Absolute
Ion concentration (Na^+ and Cl^-)
(mg g d.wt^{-1})
C:N ratio
Root C, N, K, P, Al, Ca, Mg
(mg g^{-1})
Vessel diameter
(μm)
Root Cr, Ni, Cu, Zn, As, Cd, Pb
(mg kg^{-1})
Specific
Survivorship
Cortex diameter
(μm)
Branching intensity
(# roots per higher order root)
Lifespan
(days)
rate by mass
(nmol s^{-1} m^{-2})

2. Improved model interface:

Develop a **modularized version of the Community Land Model** to test effects of environmental drivers on root and rhizosphere dynamics, and effects of changing model parameters on ecosystem processes.

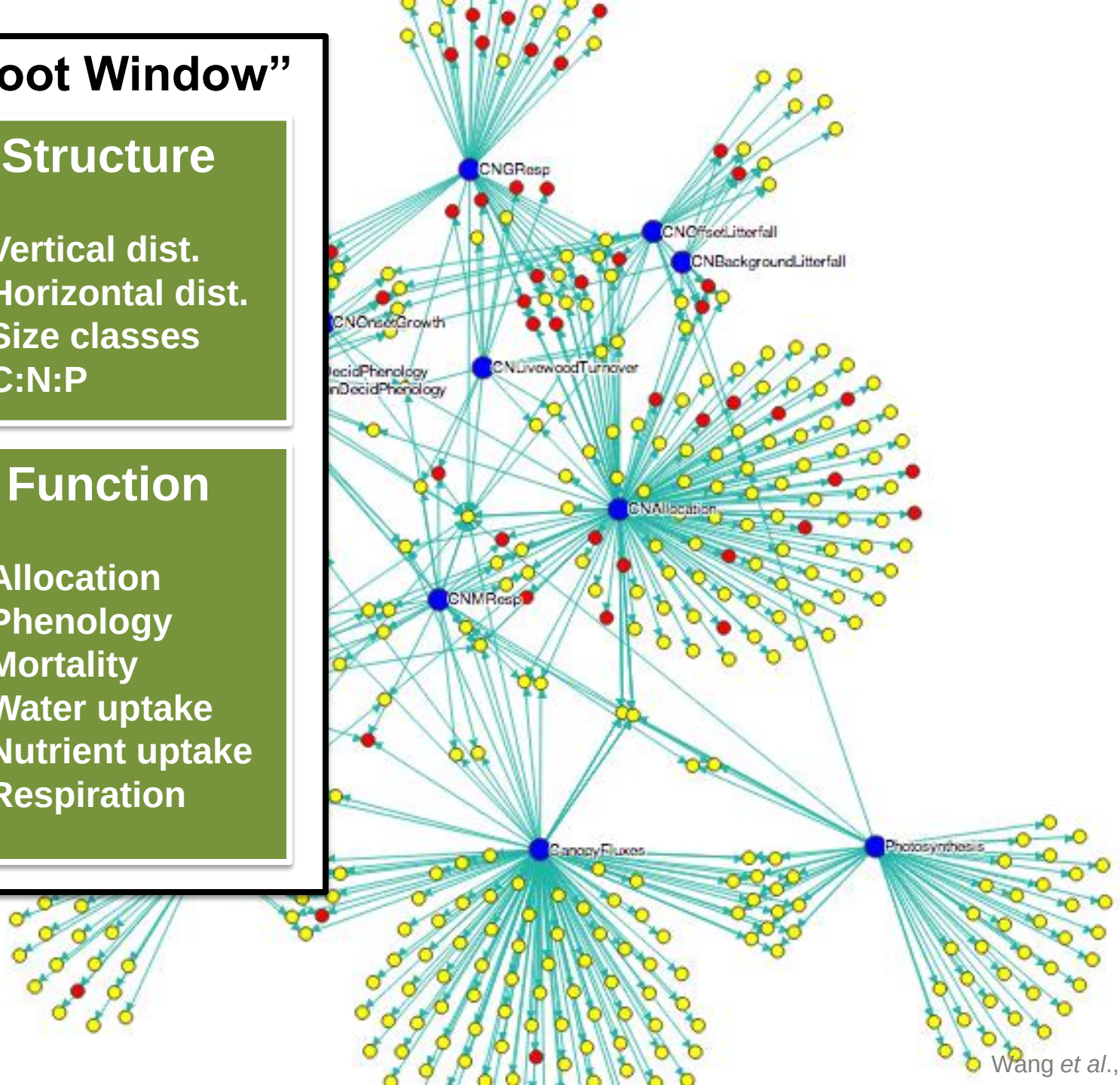
“Root Window”

Structure

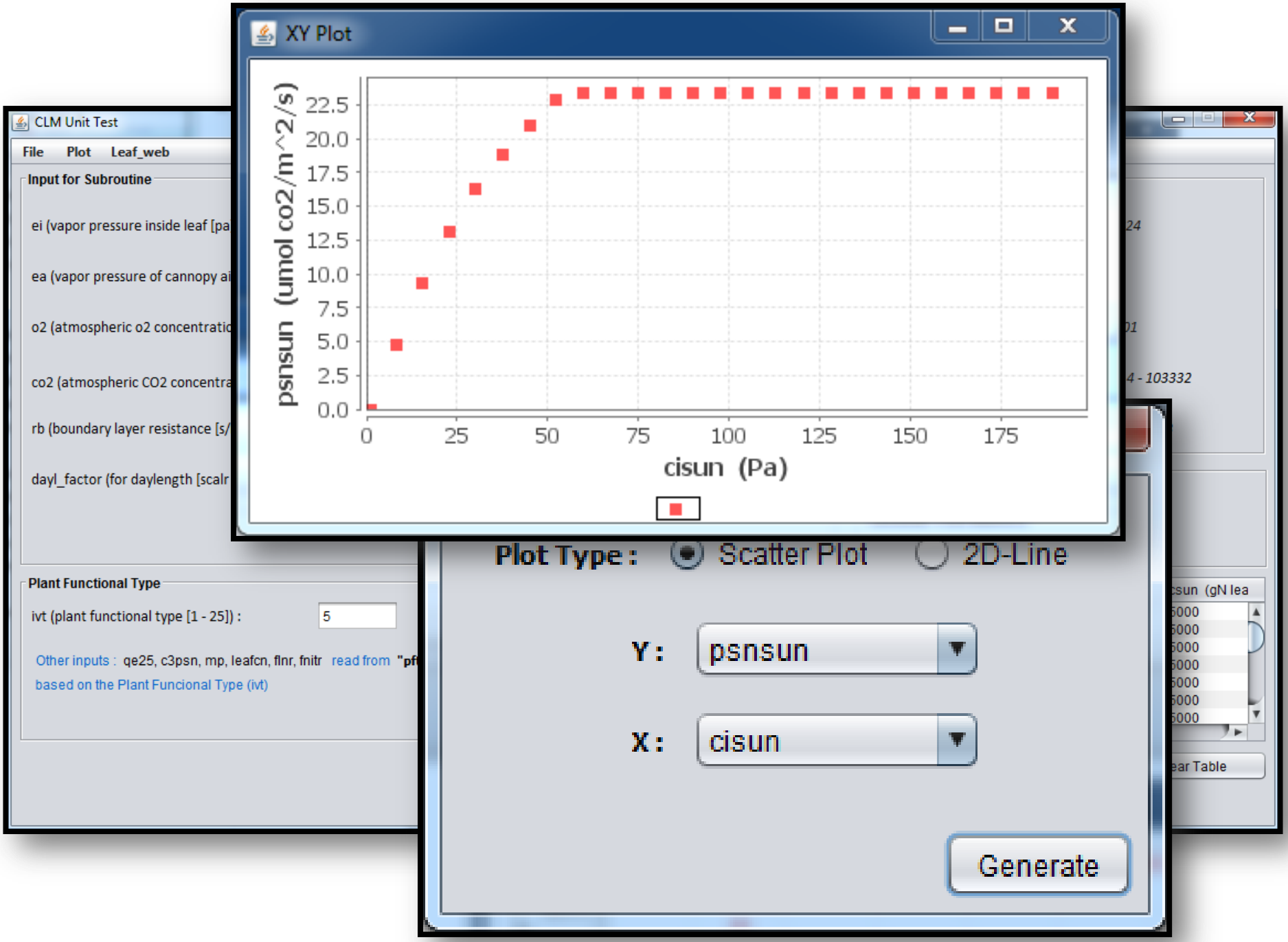
- Vertical dist.
- Horizontal dist.
- Size classes
- C:N:P

Function

- Allocation
- Phenology
- Mortality
- Water uptake
- Nutrient uptake
- Respiration



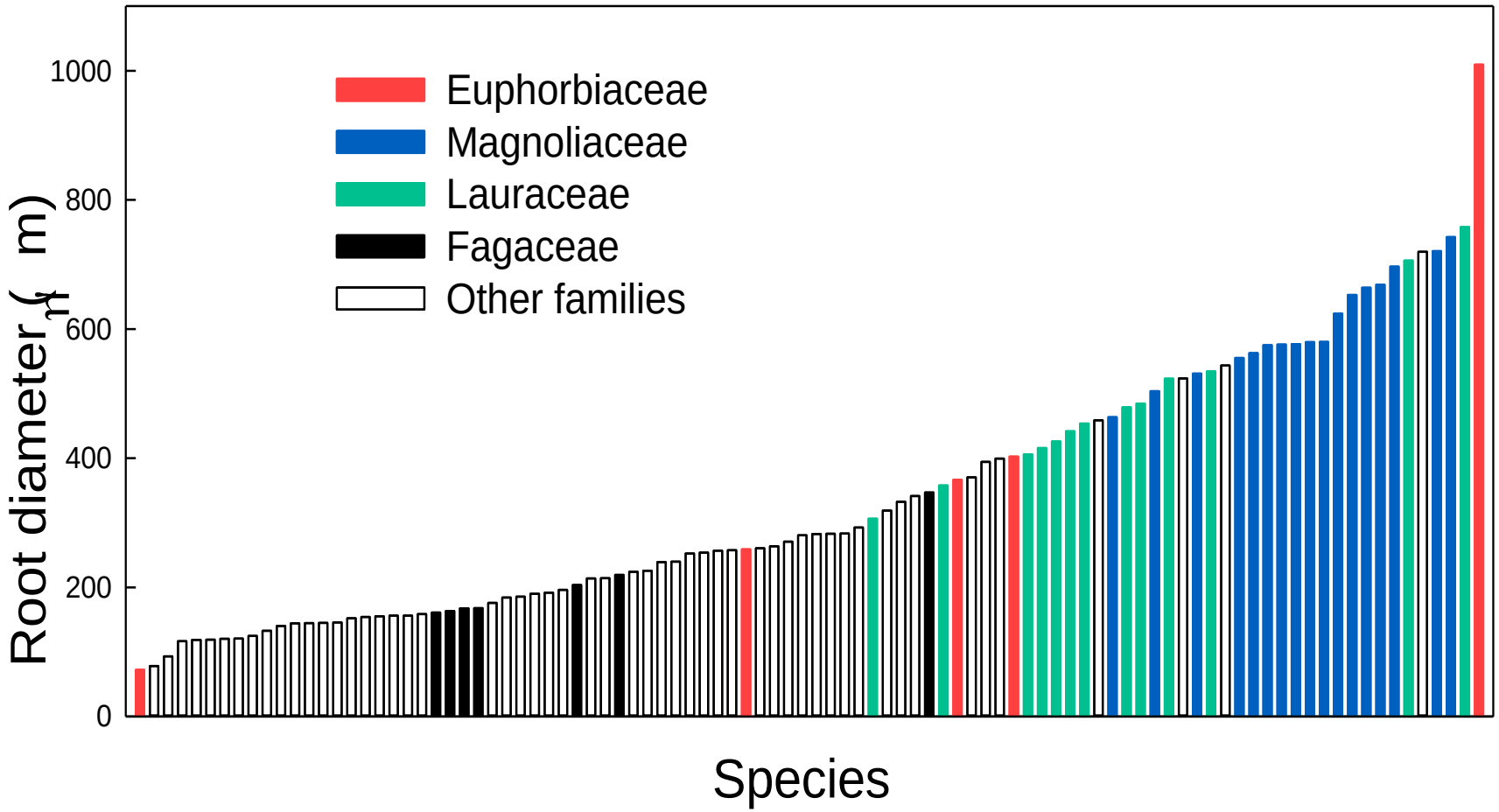
Wang *et al*., 2014 (*EMS*)


XY Plot
psnsun (umol co2/m^2/s)
22.5
20.0
17.5
15.0
12.5
10.0
7.5
5.0
2.5
0.0
0
25
50
75
100
125
150
175
cisun (Pa)
CLM Unit Test
File
Plot
Leaf_web
Input for Subroutine
ei (vapor pressure inside leaf [pa
ea (vapor pressure of cannopy ai
o2 (atmospheric o2 concentratic
co2 (atmospheric CO2 concentra
rb (boundary layer resistance [s/
dayl_factor (for daylength [scalr
Plant Functional Type
ivt (plant functional type [1 - 25]) :
5
Other inputs : qe25, c3psn, mp, leafcn, flnr, fnitr read from "pf
based on the Plant Funcional Type (ivt)
Plot Type :
Scatter Plot
2D-Line
Y :
psnsun
X :
cisun
Generate

3. Modified model structure:

Add an **ADDITIONAL FINE-ROOT POOL** to the Community Land Model representing ephemeral, **ABSORPTIVE ROOTS**, and parameterize PFTs with data compiled in the root trait database.

Where global data are unavailable, begin with phylogeny



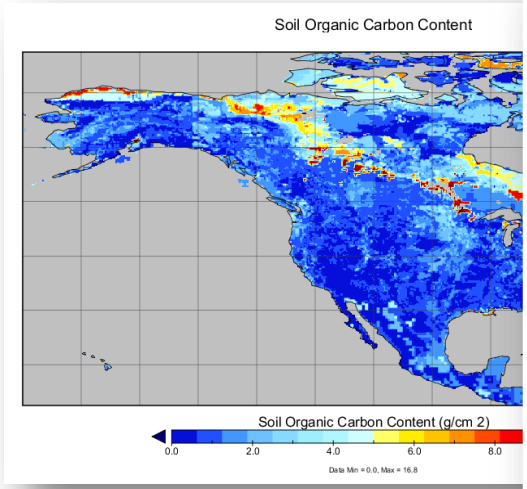
Kong *et al*. 2014. (*New Phytologist*)

4. Continue to solicit community input:

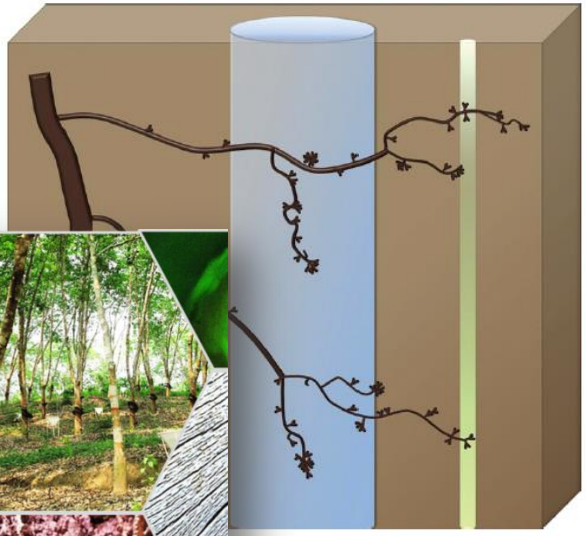
Gain a **CONSENSUS FROM THE BROADER COMMUNITY** on the relative importance of different root traits.

There are some things that **WE DON'T UNDERSTAND** well enough to represent in terrestrial biosphere models.

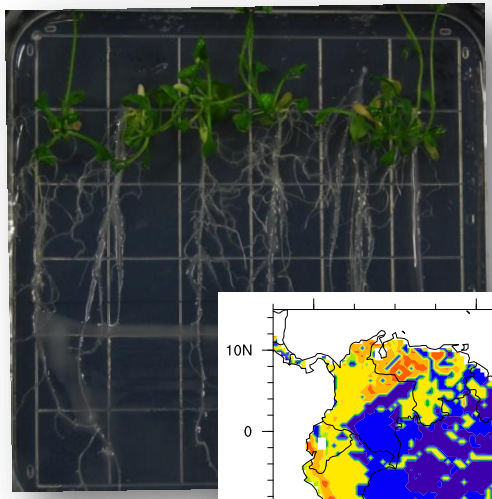
The **NEXT STEPS** in our understanding of roots and their role in the ecosystem involve **NEW QUESTIONS**, **NEW METHODS**, **NEW TECHNOLOGY**, and **IMPROVED REPRESENTATION** of root processes in models of all scales.



Wei *et al*.,

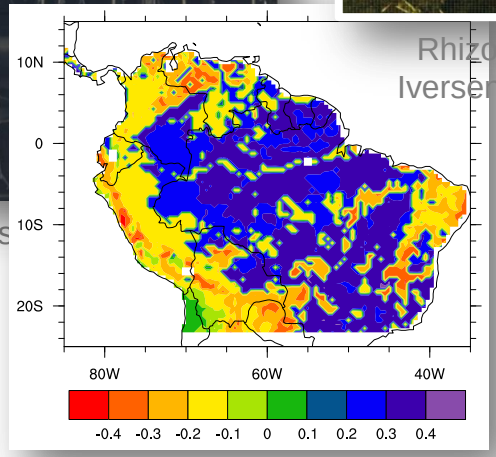


. 2013 (*Ecology Letters*)



Henning, Wes

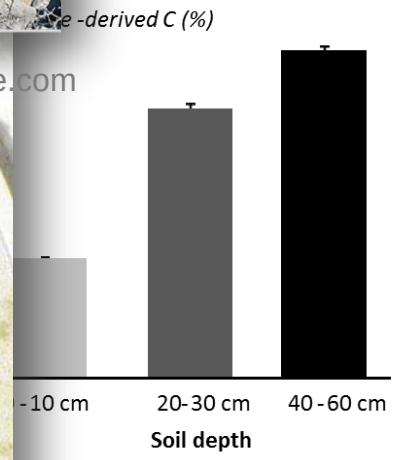
Rhizo Systems, LLC
Iversen, Childs, 2014



Yang *et al*., 2014 (*Biogeosciences*)

www.rhizonetscience.com

Warren *et al*., 2013 (*Plant and Soil*)



e Graaff *et al*., 2014 (*SBB*)

What if my research isn't on fine roots?

Fine roots are where I **START** thinking about ecosystem processes, but not where I stop, and models need the bigger picture too.

Whole-plant C allocation · Soil nutrient availability · Soil C storage

To track our progress, and **LEND YOUR VOICE** (and your data) to the effort, following us at:

http://web.ornl.gov/~ciz/Roots_in_Models.html

Acknowledgements

http://web.ornl.gov/~ciz/Roots_in_Models.html
iversencm@ornl.gov

Funding:

Office of Biological and Environmental Research in the DOE Office of Science supported the Roots in Models Workshop and continuing work.

Workshop attendees:

Mike Allen, Allison Boyer, Eddie Brzostek, Joanne Childs, Bob Cook, Marie-Anne De Graaff, Dave Eissenstat, Adrien Finzi, Josh Fisher, Lianhong Gu, Paul Hanson, Colleen Iversen, Andy Jones, Shujiang Kang, Jens Kattge, Tong King, Jitu Kumar, Hans Lambers, Roser Matamala, Melanie Mayes, Rich Norby, Rich Phillips, Shafer Powell, Seth Pritchard, Dan Ricciuto, H. Jochen Schenk, Ingrid Slette, Jens-Arne Subke, Peter Thornton, Collin Timm, Anthony Walker, Gangsheng Wang, Jeff Warren, Dave Weston, Stan Wullschleger, Xiaojuan Yang