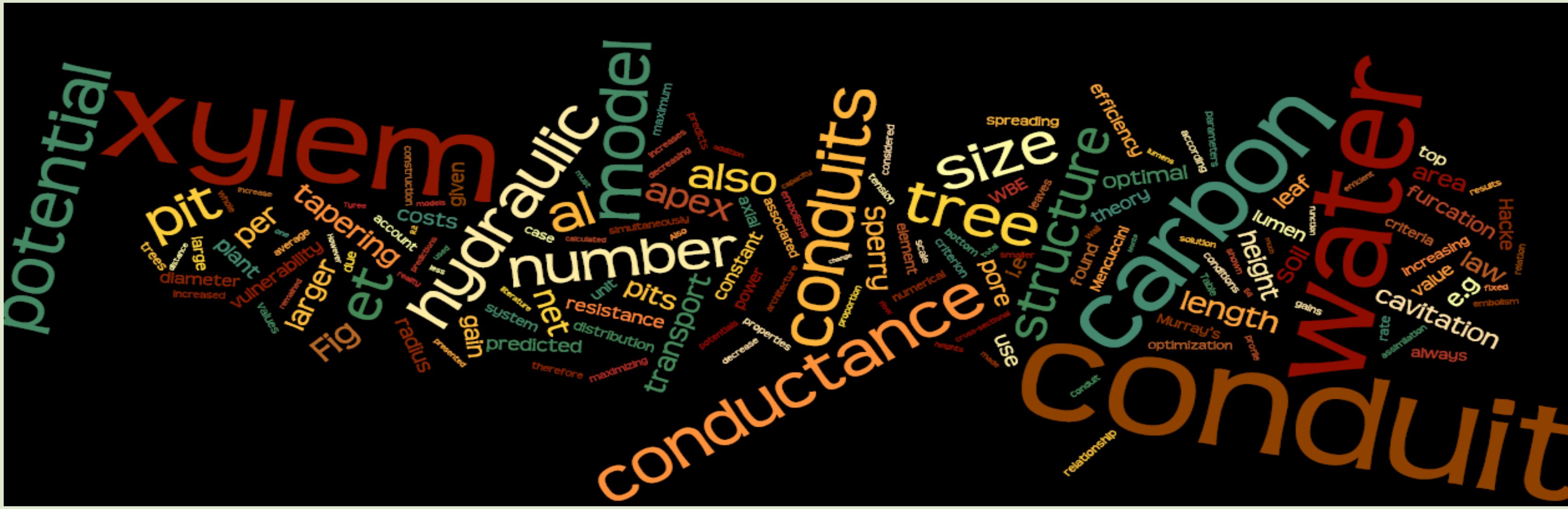
Forest responses to drought: from tissues to biosphere

Maurizio Mencuccini

*iCrea
INSTITUCIÓ CATALANA DE RECERCA I ESTUDIS AVANÇATS

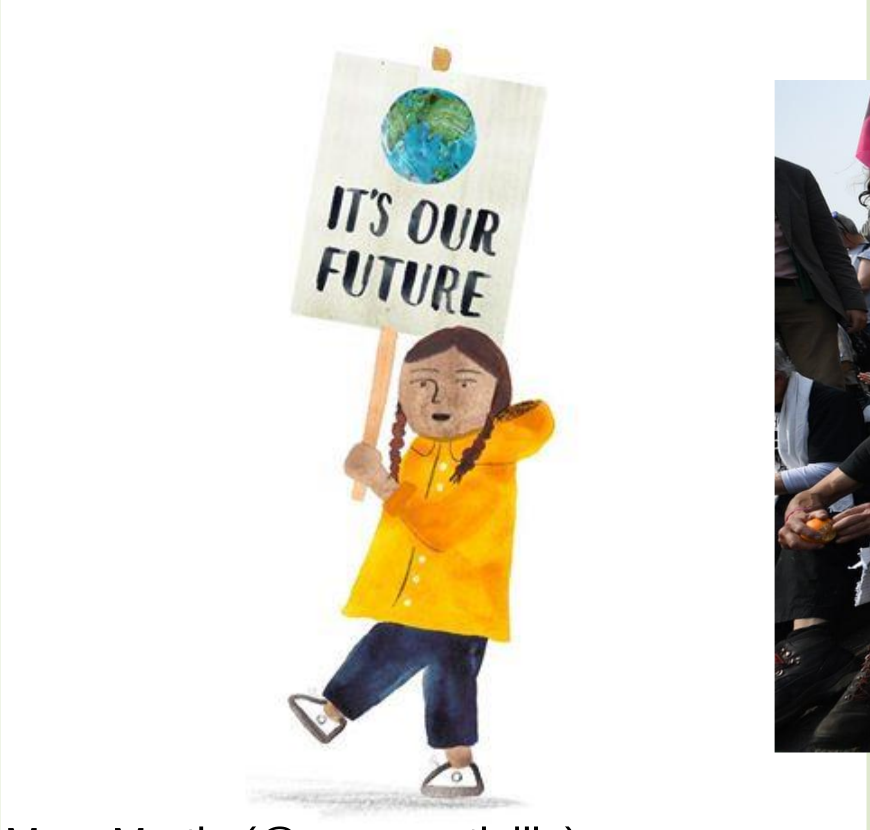
THE UNIVERSITY OF EDINBURGH

CREAF


conduit
water
carbon
conductance
xylem
potential
conduits
hydraulic
model
number
size
tree
structure
pit
et
al
also
apex
length
height
cavitation
law
furcation
area
leaf
lumen
soil
tapering
vulnerability
larger
per
plant
diameter
pits
resistance
predicted
net
gain
radius
Fig
transport
constant
pore
use
sperry
optimal
theory
efficiency
spreading
costs
account
given
distribution
system
unit
found
Mencuccini
optimization
Murray's
criteria
increasing
value
e.g
top
Hacke
always
i.e
WBE
element
numerical
criterion
power
associated
axial
maximum
simultaneously
maximizing
therefore
relationship
rate
embolism


TRANSFER
PHLOEM
SOIL
ET
AL
EFFLUX
TIME
MODEL
PLANT
SISO
DIFFUSION
RESPIRATION
STUDIES
NEW
PHYTOLOGIST
GYMNOSPERM
PROPAGATION
SOLUTION
PHOTOSYNTHESIS
HEIGHT
TIME
TIMES
REGRESSION
ACTIVITY
CONCENTRATION
LENGTH
D13C
13C
14C
SFLUX
PRESSURE
PATH
PULSE
KS
MAXIMUM
TRANSPORT
FIG
VPD
EQN
DP
DICOT
CO2
LABEL
CANOPY
STORAGE
ALSO
TWO
I.E
CONDUCTIVITY
WWW.NEWPHYTOLOGIST.ORG
ESTIMATED
STUDY
XYLEM
TALL
ECOSYSTEM
RESPECTIVELY
CIRCLES
GAS
ROOT
ROOTS
CONSTANT
FUNCTION
AUTHORS
VARIABLES
PROPERTIES
DETERMINED
WAVE
USING
LOADING
DYNAMIC
COMPILATION
SENSITIVITY
HO
OBTAINED
SPECIFIC
LAG
ESTIMATE
LTTA
SPEED
WATER
PHLOEM
TREES
ESTIMATES
SIGNIFICANT
THOMPSON
PICEA
LINK
JOURNAL
MEAN
REGRESSION
FLUX
WHETHER
OSMOTIC
FLOW
APPROACHES
MIXED
ANALYSIS
FLUXES
PINUS
GASEOUS
2A
BASED
FERRIER
ONE
CHANGES
SS
S1
CASE
ISOTOPIC
METHOD
DEPENDENCY
TABLE
RESEARCH
PLANTS
EITHER
TURGOR
WAVES
COEFFICIENTS
MONOCOT
FLUX-BASED
USED
BULK
PARAMETERS
DEPTH
SCALING
HOLBROOK
RATE
CENTRAL
DIFFERENCE
MOLECULES
SUGARS
GBERG
EMPLOYED
POWER
R2
SUGAR
VALUES
SMALL
ISOTOPE
SPECIES
PATHWAY
GROUPS
LINE
EQNS
FIRST
GIVEN
SEE

Extreme events
Tipping points
Cascading feedbacks →
mega-catastrophes



Marc Martin (@marcmartinillo)

Extinction Rebellion movement

Top list you do not want to be on

USA TODAY

2017's three monster hurricanes — Harvey, Irma and Maria — among five costliest ever

Doyle Rice | USA TODAY
Published 11:17 AM EST Feb 1, 2018

- Harvey - $100 billion
- Maria - $90 billion Irma - $50 billion

- Golden medal (Katrina, 160 billion)

Insurance industry

MarketWatch | Latest | Watchlist | Markets | Investing | Barron's | Economy | Personal Finance | Retireme

Home > Industries > Insurance > The Tell

GET EMAIL ALERTS

Here's why Warren Buffett says Berkshire could handle $400 billion 'mega-catastrophe'

Published: Feb 24, 2018 3:01 p.m. ET

Annual probability of 'mega-cat' seen at around 2%

- Berkshire's pre-tax underwriting loss at $3.2 billion
- Forestry industry

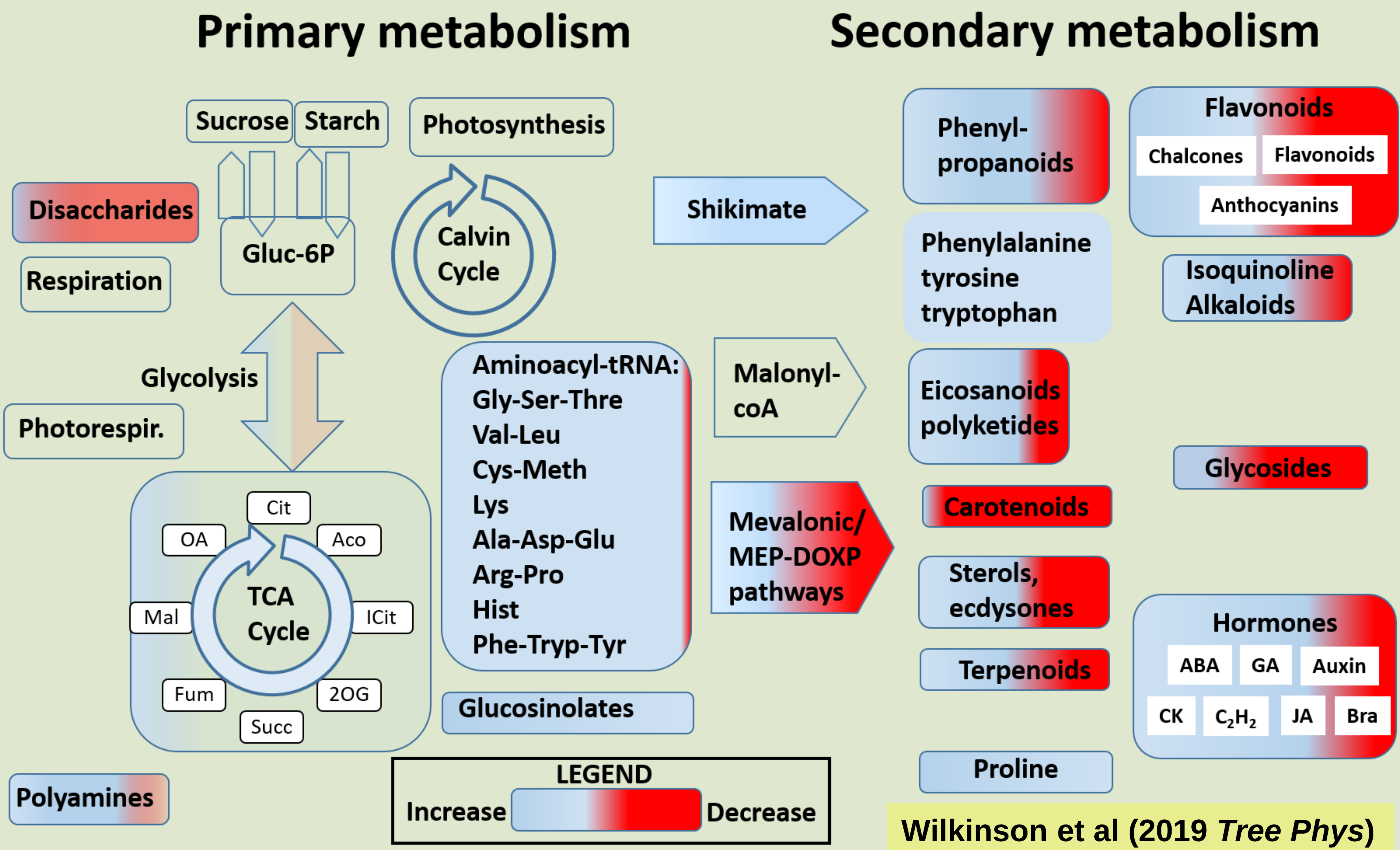
Intro

- Significance of trait-based ecology (terrestrial water fluxes)

- Which traits describe plant water use and response to drought (i.e., understanding)

- Can they help us to infer large-scale processes (climate change, anthropic disturbances, etc.) (i.e., predictions)

Toolbox:-omic worlds



Wilkinson et al (2019 *Tree Phys*)

Toolbox: databases

TRY Plant Trait Database

Quantifying and scaling global plant trait diversity

TRY is a network of vegetation scientists headed by DIVERSITAS, IGBP, the Max Planck Institute for Biogeochemistry and an international Advisory Board.

Main objectives

•Provide a global archive of plant traits

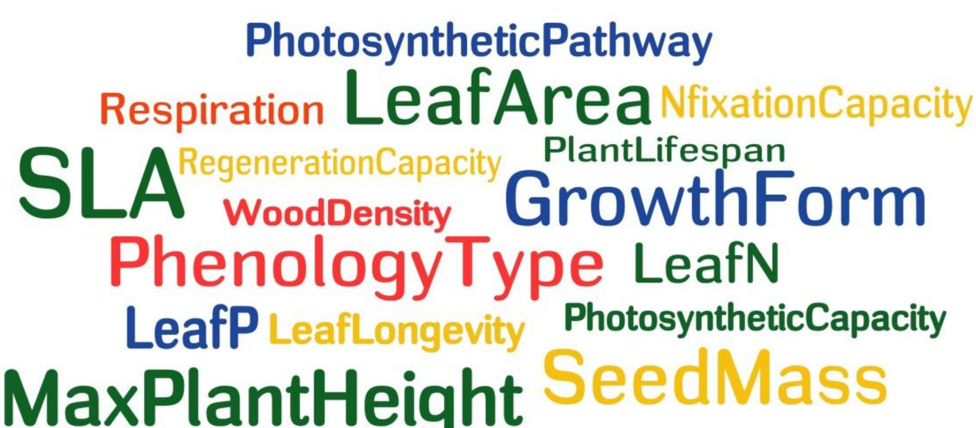
•Promote trait-based approaches in ecology and biodiversity science

•Support the design of a new generation of global vegetation models

Current state (04/19)

• 11.8 million trait records for ~ 300,000 plant species

• >6,000 requests of data



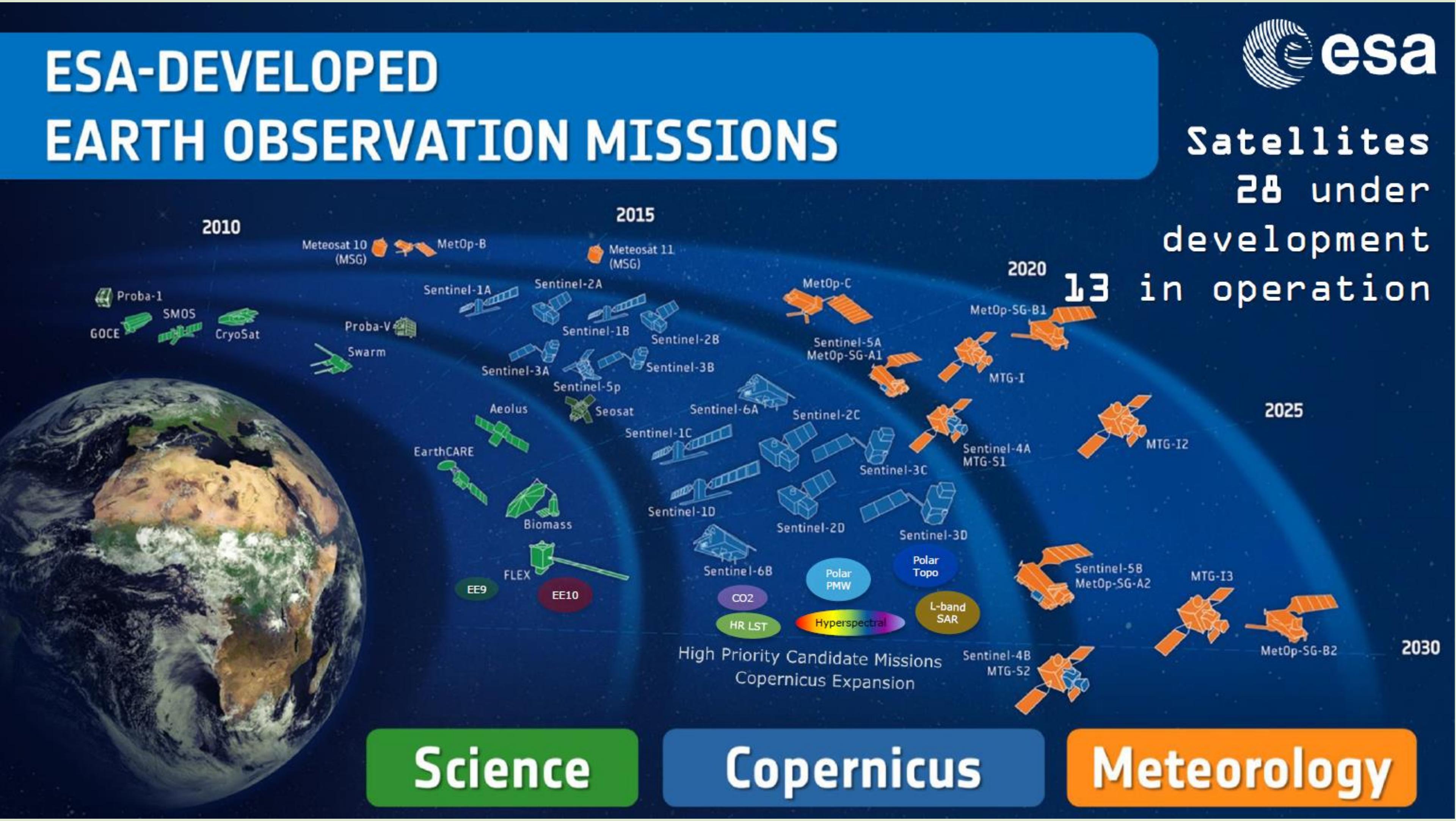
Toolbox: regional/global networks

1. European Gene Conservation Units

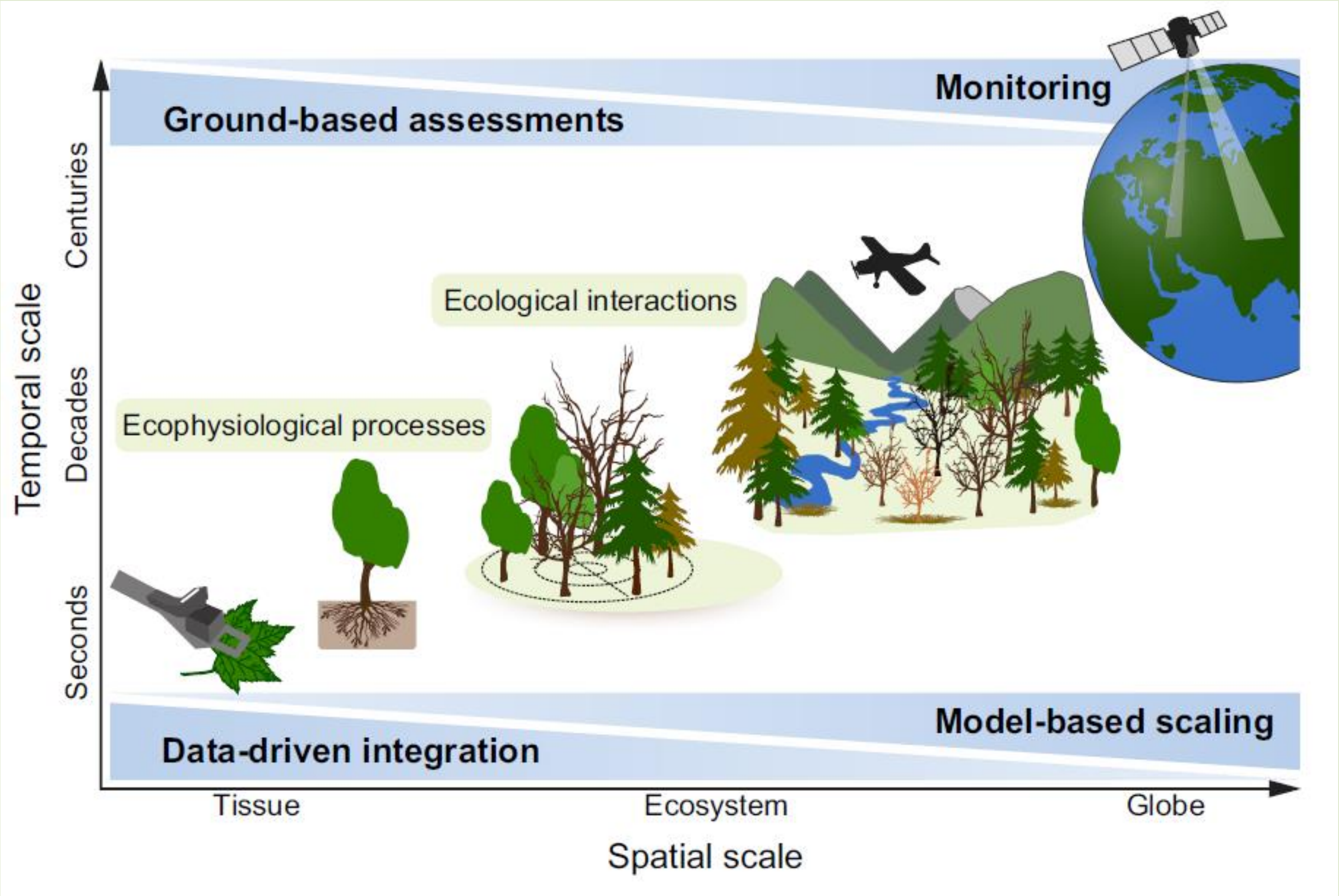
2. Remote sensing coverage for all sites

3. Genome and phenotyping studies on tens of species, 100s sites/spp

Toolbox: Remote sensing

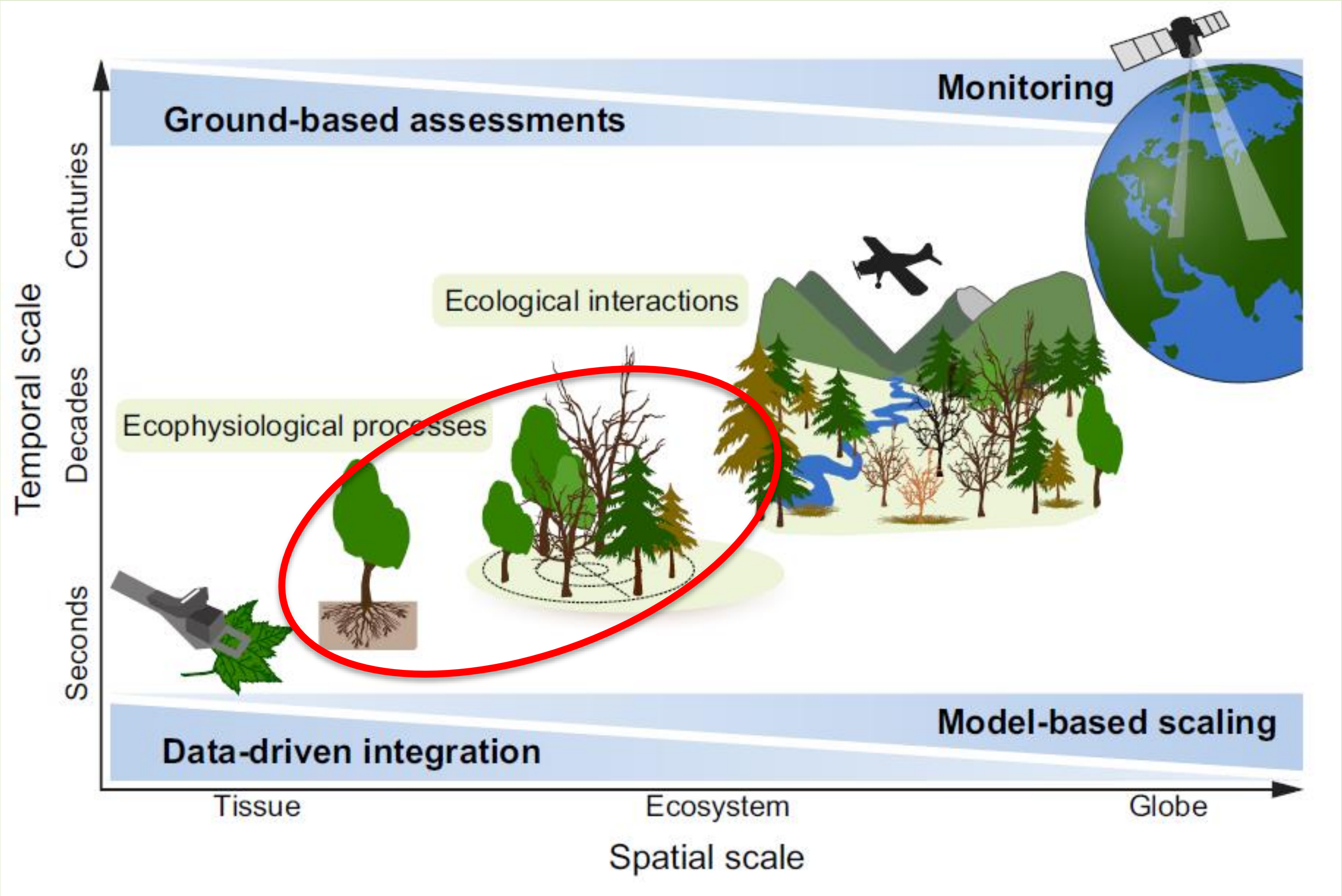


Toolbox: modelling of climate-vegetation feedbacks



Hartmann et al (2018 *New Phy*)

Toolbox: modelling of climate-vegetation feedbacks



Hartmann et al (2018 *New Phy*)

Large uncertainty from land surface modelling

Evaluation of the terrestrial carbon cycle, future plant geography and climate-carbon cycle feedbacks using five Dynamic Global Vegetation Models (DGVMs)

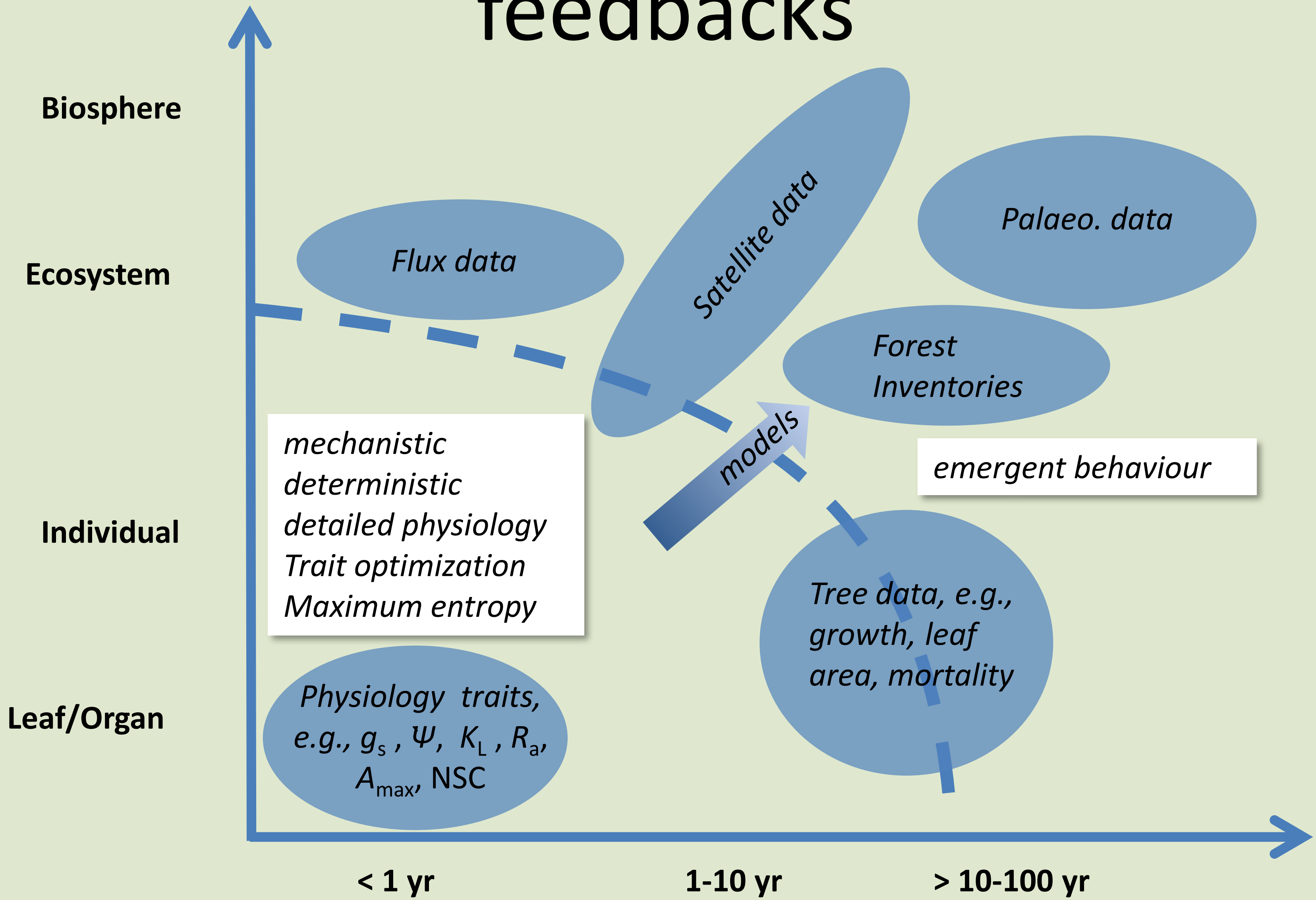
S. SITCH*, C. HUNTINGFORD†, N. GEDNEY*, P. E. LEVY‡, M. LOMAS§, S. L. PIAO¶, R. BETTS‖, P. CIAIS¶, P. COX**, P. FRIEDLINGSTEIN¶, C. D. JONES‖, I. C. PRENTICE†† and F. I. WOODWARD§

**Met Office Hadley Centre, JCHMR, Maclean Building, Wallingford OX10 8BB, UK, †Centre for Ecology and Hydrology Wallingford, Maclean Building, Wallingford OX10 8BB, UK, ‡Centre for Ecology and Hydrology Bush Estate, Penicuik, Midlothian EH26 0QB, UK, §Department of Animal & Plant Sciences, University of Sheffield, Sheffield S10 2TN, UK, ¶IPSL/LSCE, Unite mixte 1572 CEA-CNRS, CE-Saclay, Bat 701, 91191 Gif sur Yvette, France, ‖Met Office Hadley Centre, Fitzroy Road, Exeter EX1 3PB, UK, **School of Engineering, Computer Science and Mathematics, University of Exeter, Exeter ES4 4QF, UK, ††QUEST, Department of Earth Sciences, University of Bristol, Wills Memorial Building, Queens Road, Bristol BS8 1RJ, UK*

Abstract

This study tests the ability of five Dynamic Global Vegetation Models (DGVMs), forced with observed climatology and atmospheric CO_2, to model the contemporary global carbon cycle. The DGVMs are also coupled to a fast 'climate analogue model', based on the Hadley Centre General Circulation Model (GCM), and run into the future for four Special Report Emission Scenarios (SRES): A1FI, A2, B1, B2. Results show that all DGVMs are consistent with the contemporary global land carbon budget. Under the more extreme projections of future environmental change, the responses of the DGVMs diverge markedly. In particular, large uncertainties are associated with the response of tropical vegetation to drought and boreal ecosystems to elevated temperatures and changing soil moisture status. The DGVMs show more divergence in their response to

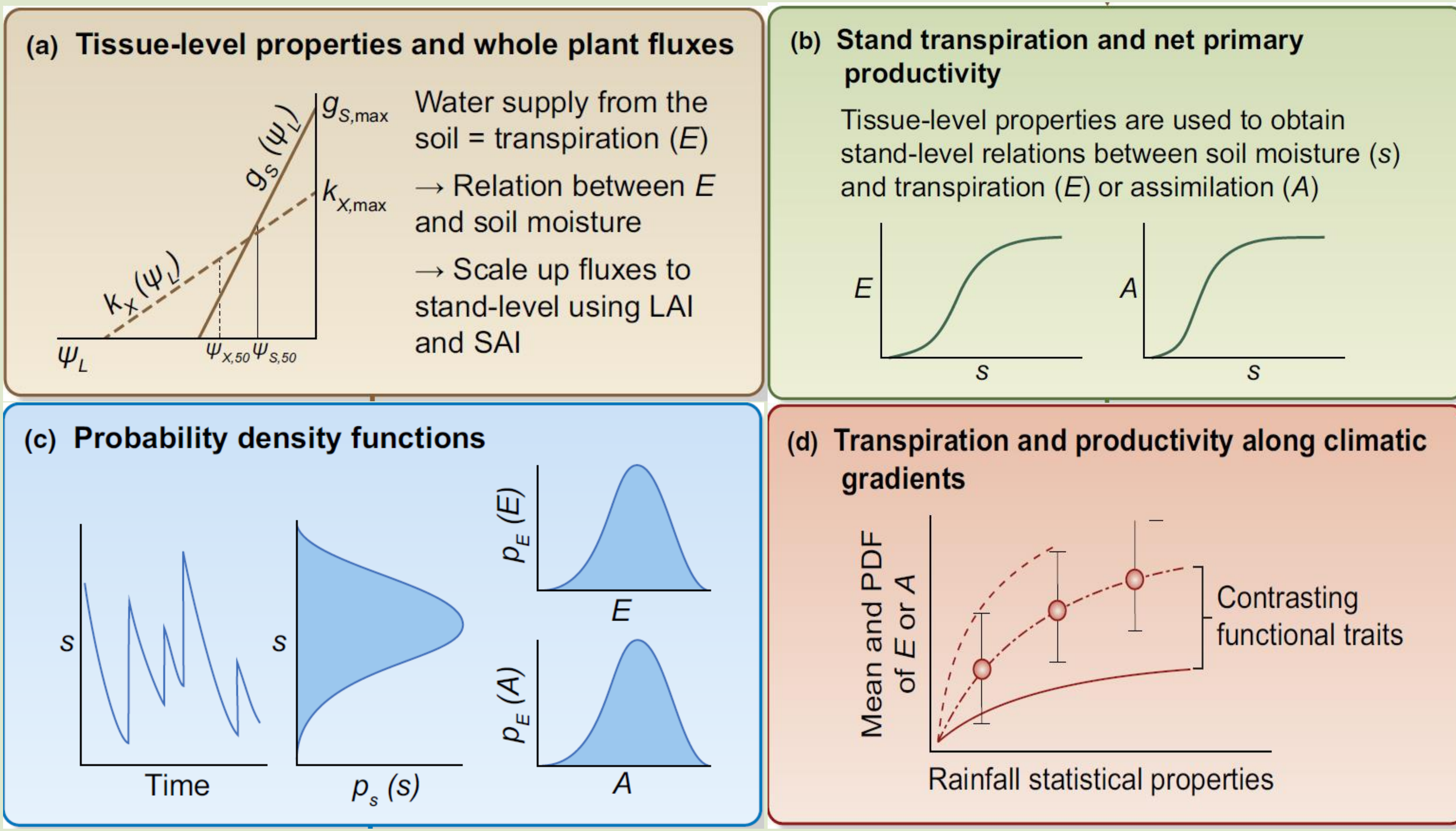
Predictions of climate-vegetation feedbacks



Meir et al.(2015 *New Phy*)

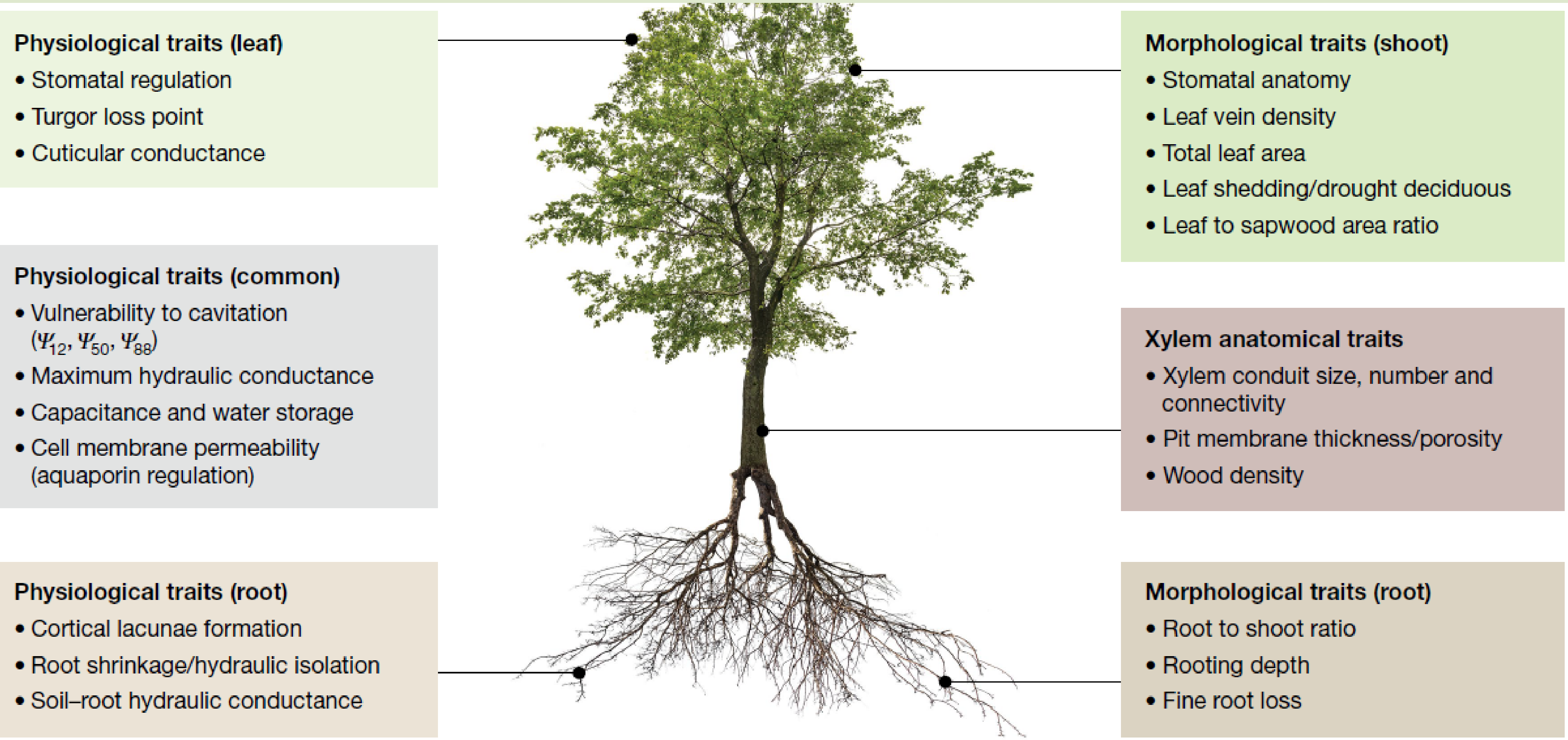
How does a trait-based model work

trait = any morphological, physiological, phenological feature that impacts fitness



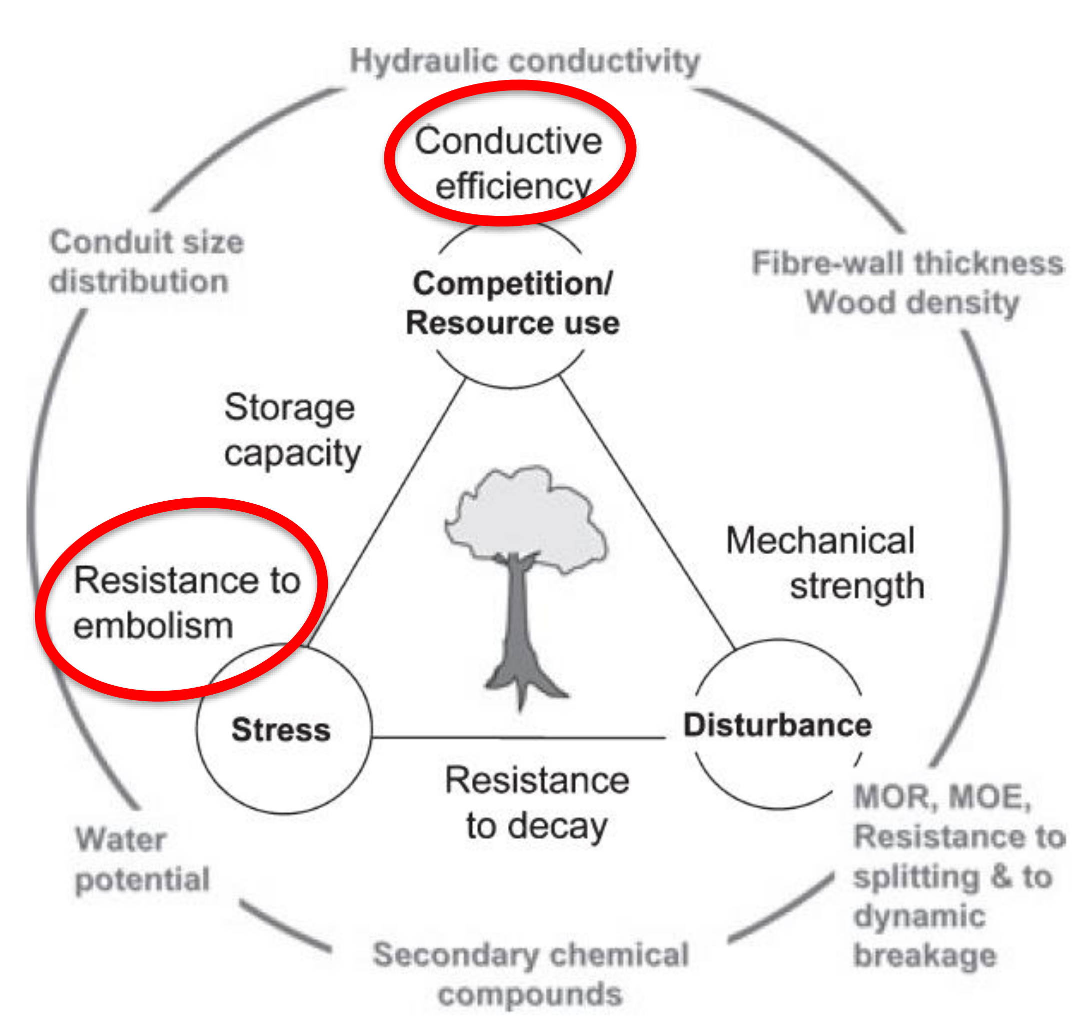
Mencuccini et al (2019 *New Phy*)

If the problem is drought, which ones are THE traits?

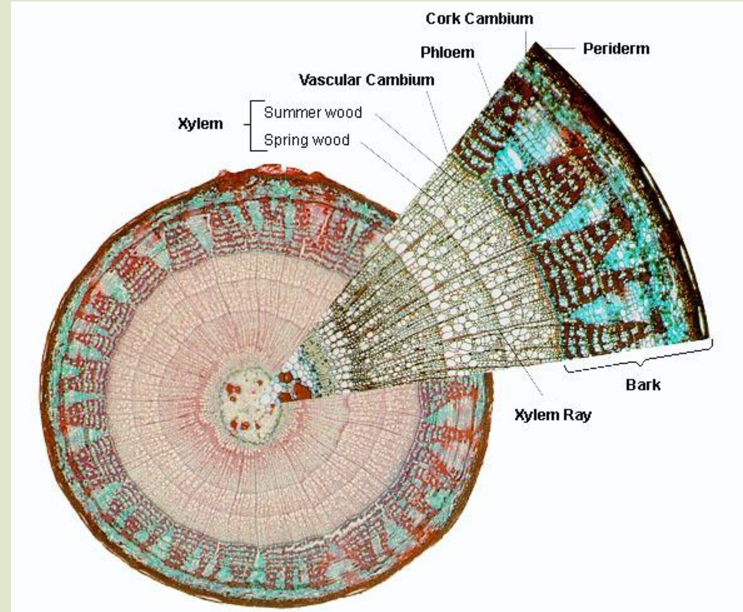


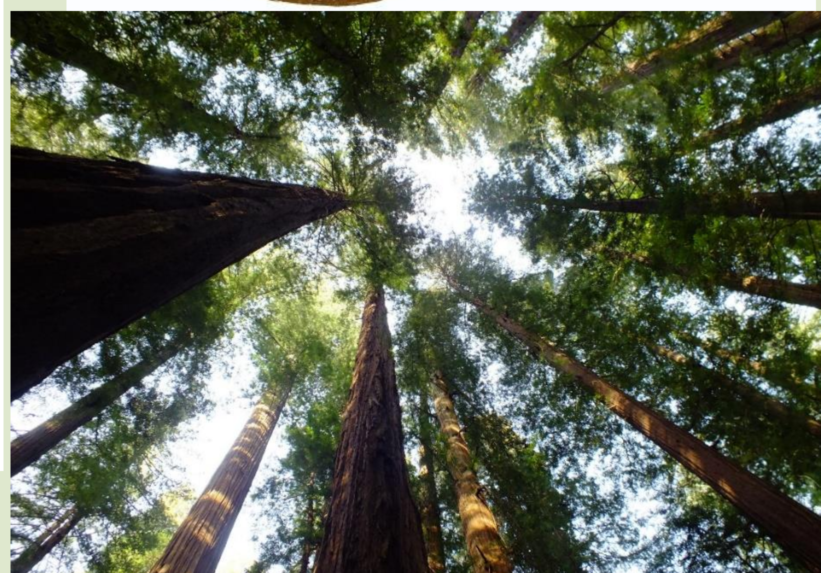
Choat et al. (2018 *Nature*)

Wood economics

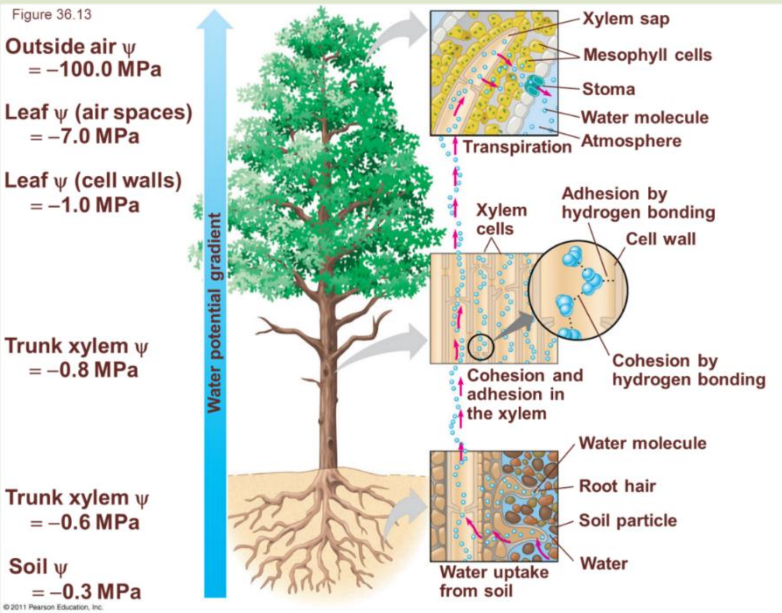


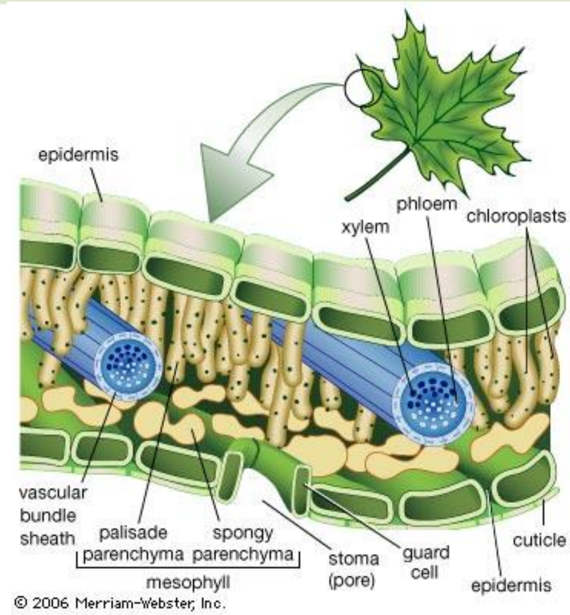
Chave et al. (2009 *Ecol Lett*)

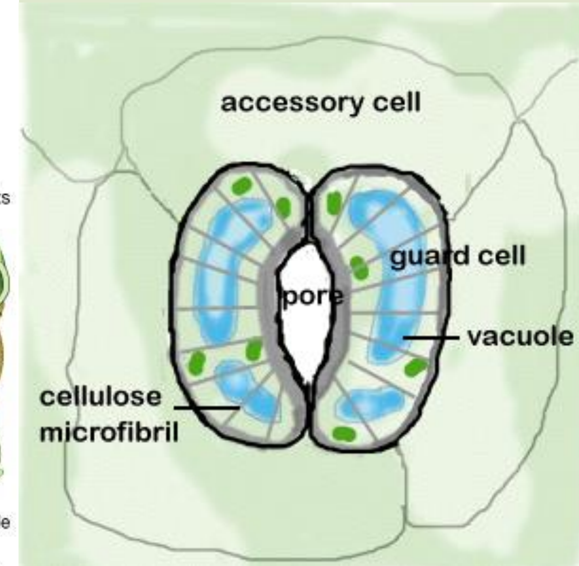




Leaf gas exchange







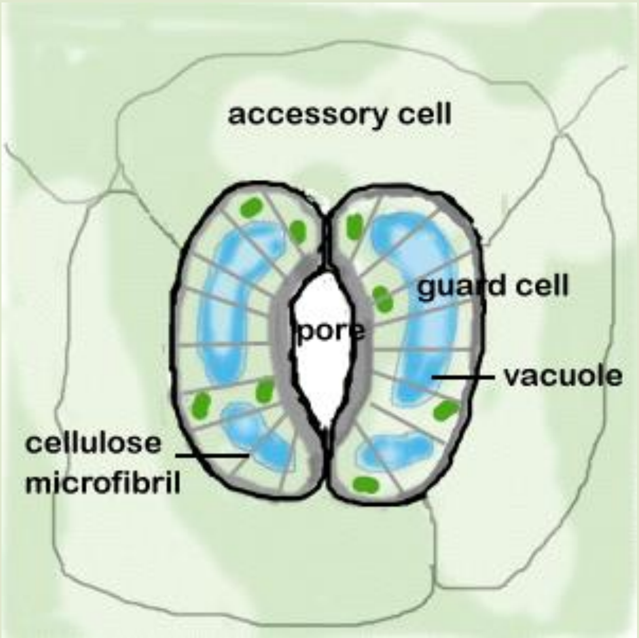
- Leaf stomata
- Inescapable trade-off between CO_2 uptake and water loss

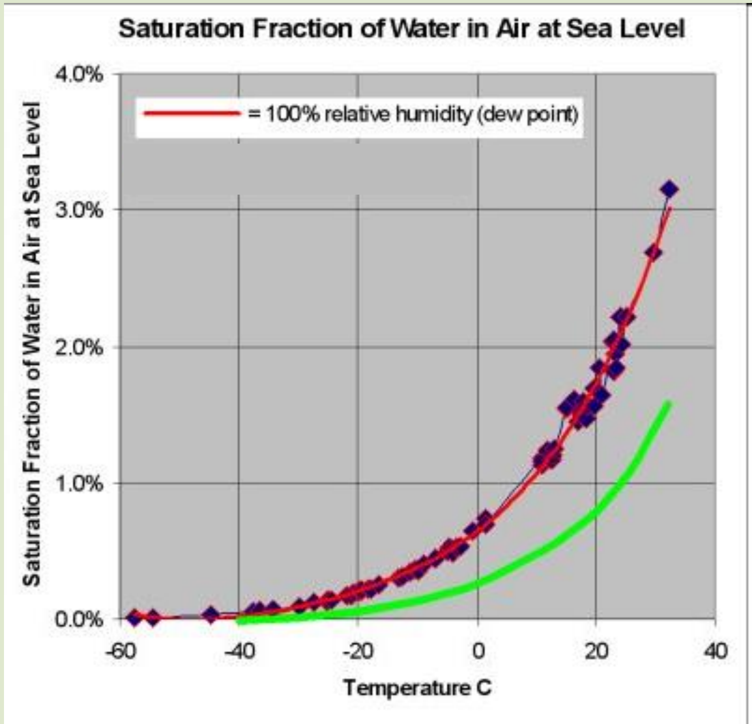
- Predict stomatal behaviour based on this trade-off (Sperry et al (2017 *PCE*)

What is atmospheric moisture demand

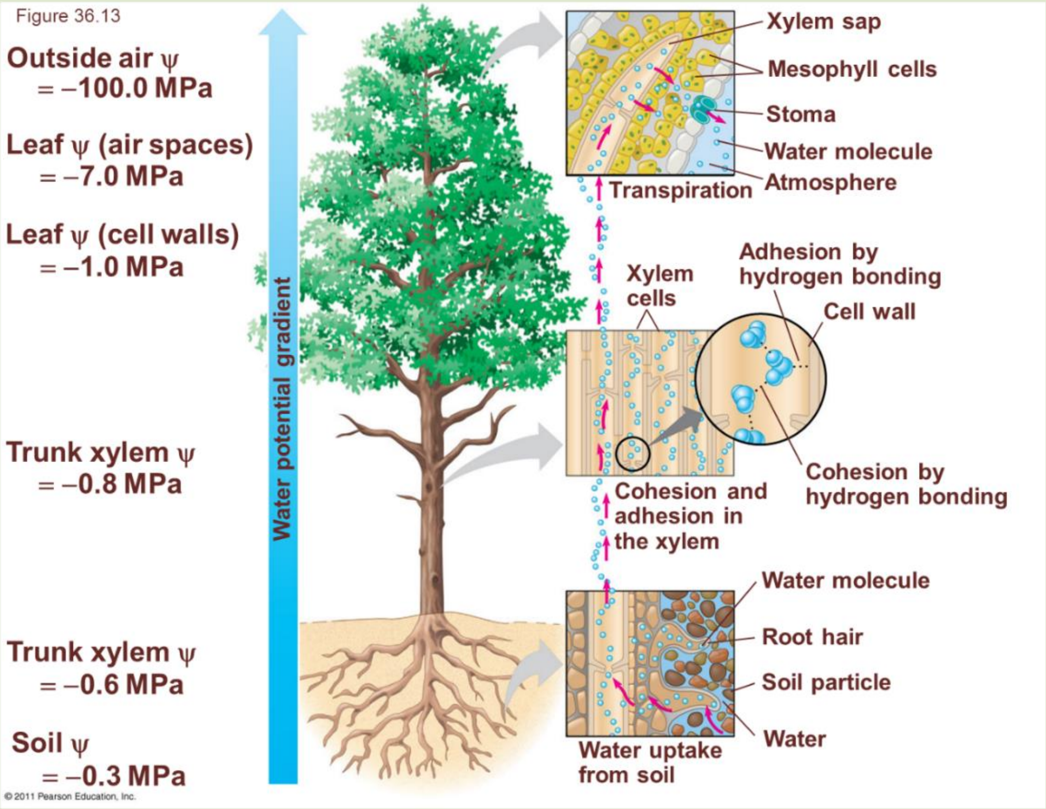
Paradox of warming:

- More vapour in atmosphere (RH ~ constant)
- Deficit in vapour pressure (VPD) increases with T
- But plants perceive less water in atmosphere (in relative terms) $\rightarrow$ ATMOSPHERIC DROUGHT
- Increased plant water loss





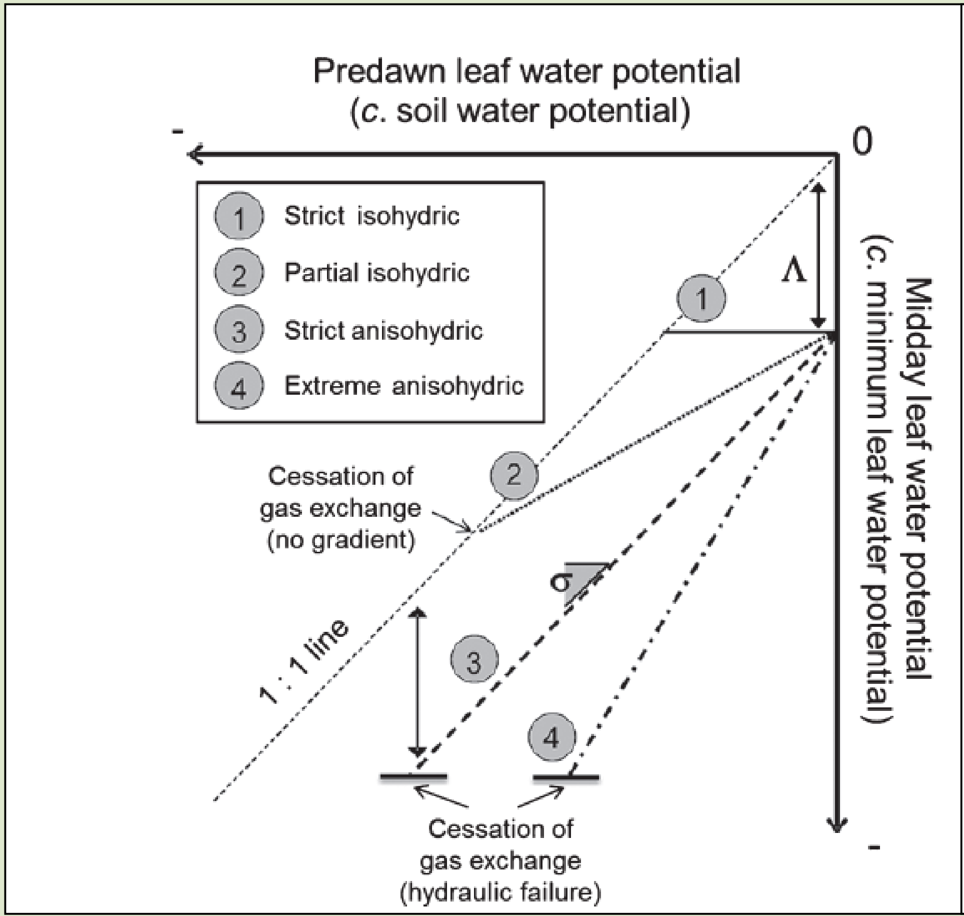
Key hydraulic traits and significance

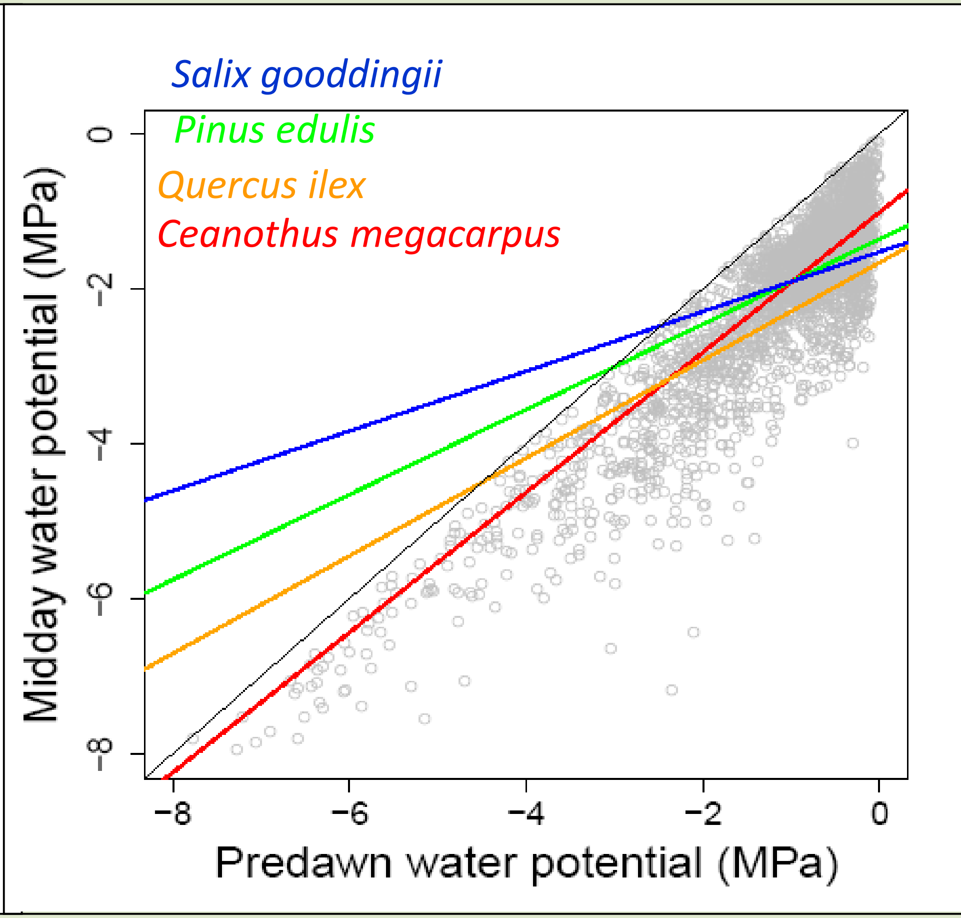


1. Water status: water potential / content
2. Water transport: efficiency
3. Water transport: safety from embolism
4. Allocation ratio: Huber Value (1/leaf-sapwood area ratio)

1) Plant water status

water potential / content



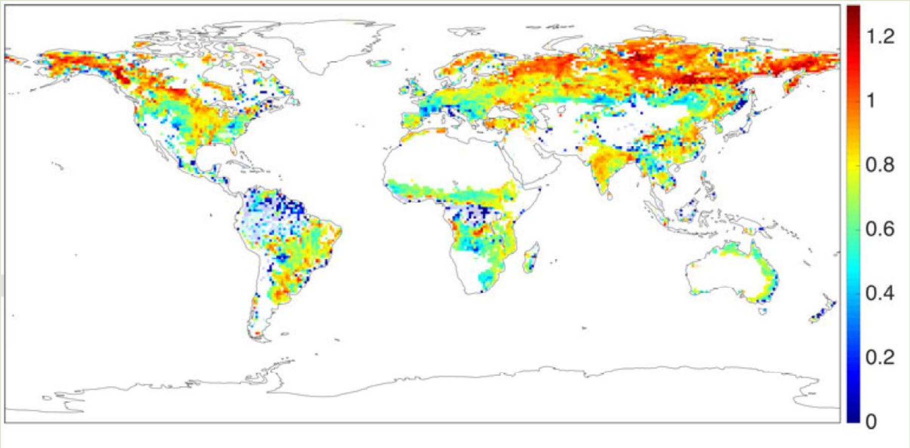


About 100 spp.

Martinez-Vilalta et al. (2015 *New Phy*)

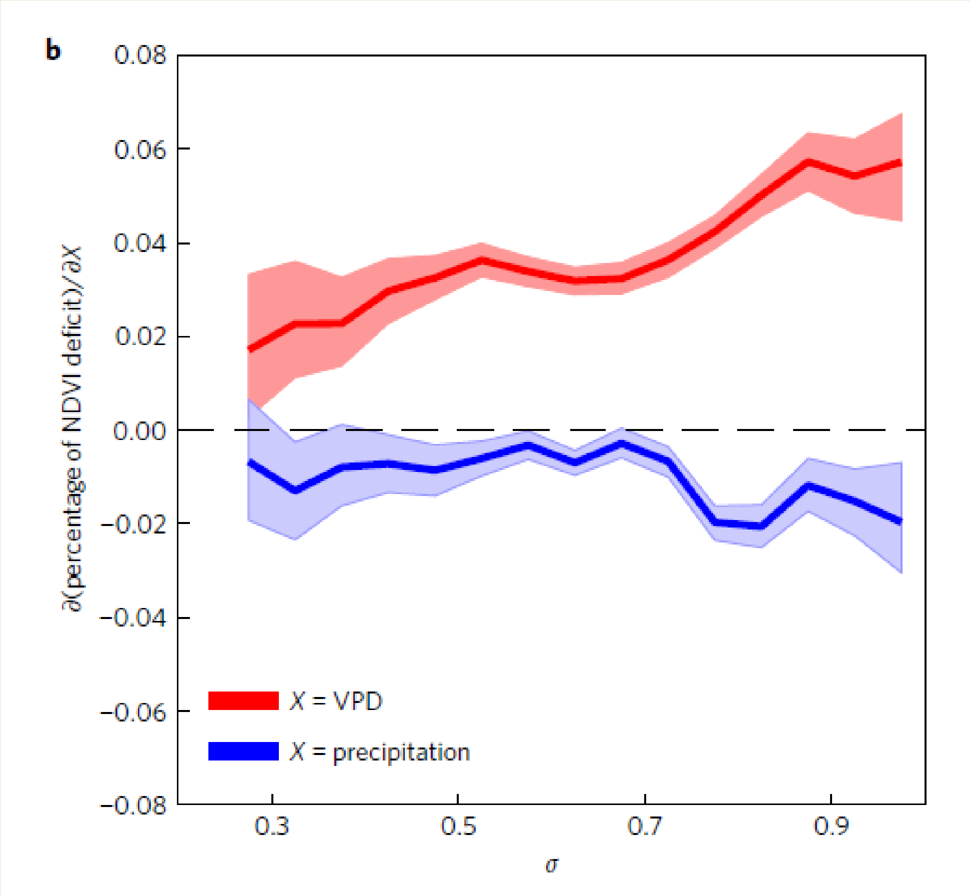
1) Plant water status

(Vegetation optical depth VOD)



Diurnal variations in X-band of passive microwave measurements (Adv. Microw. Scann. Rad.–E or -2)

$$VOD \propto RWC_{veg}$$

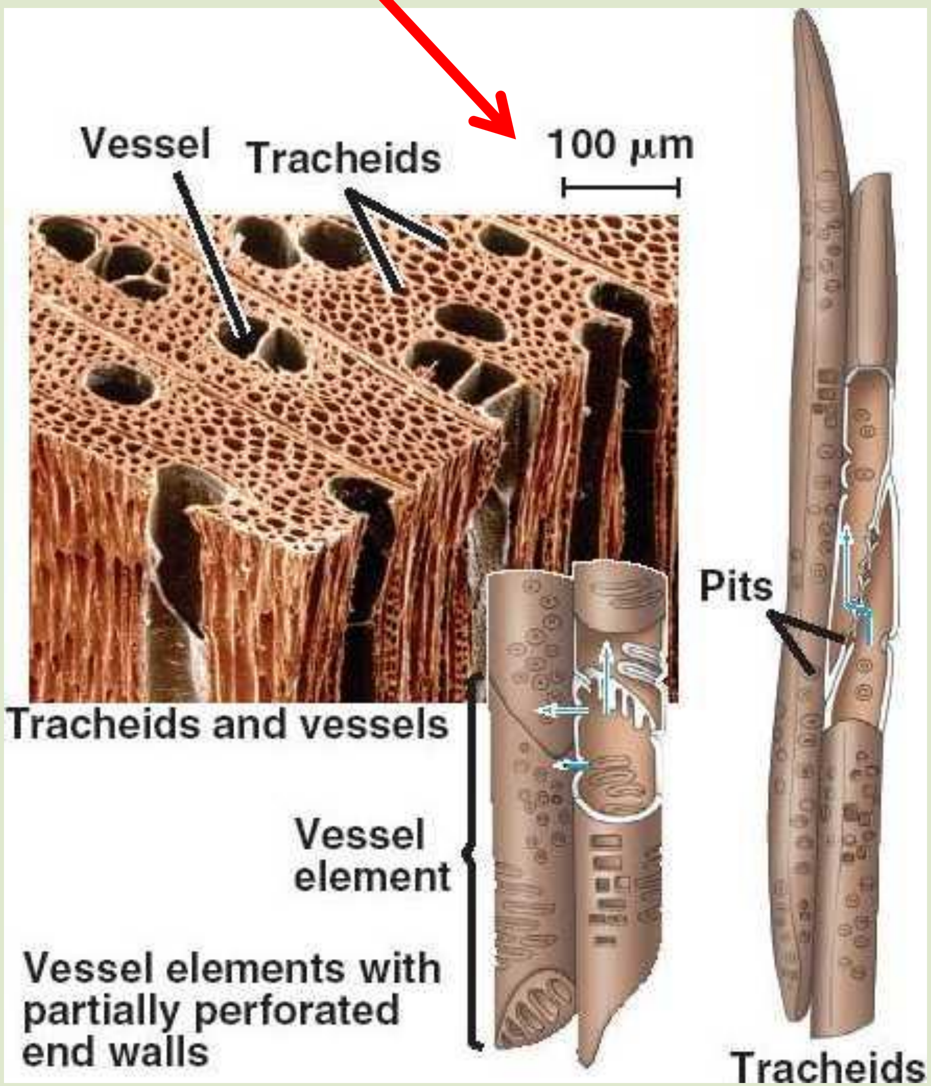


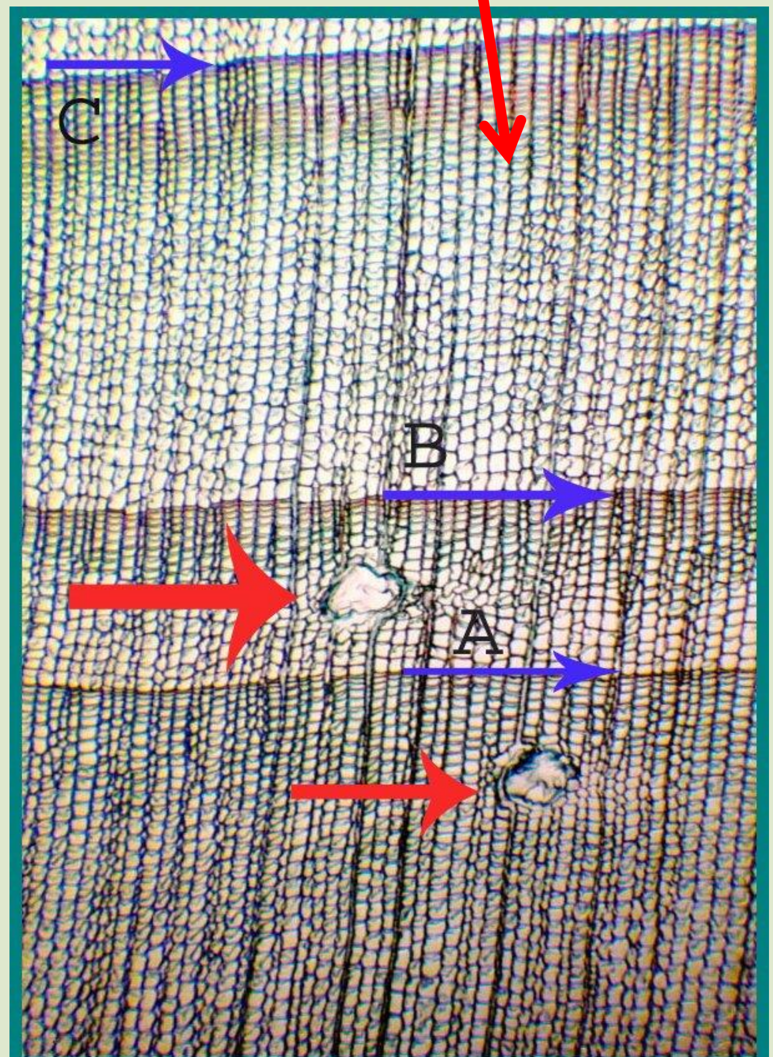
Konings & Gentine (2016 *GCB*); Konings et al. (2017 *Nat GeoSc*)

2) Efficient water transport

Angiosperms

Gymnosperms



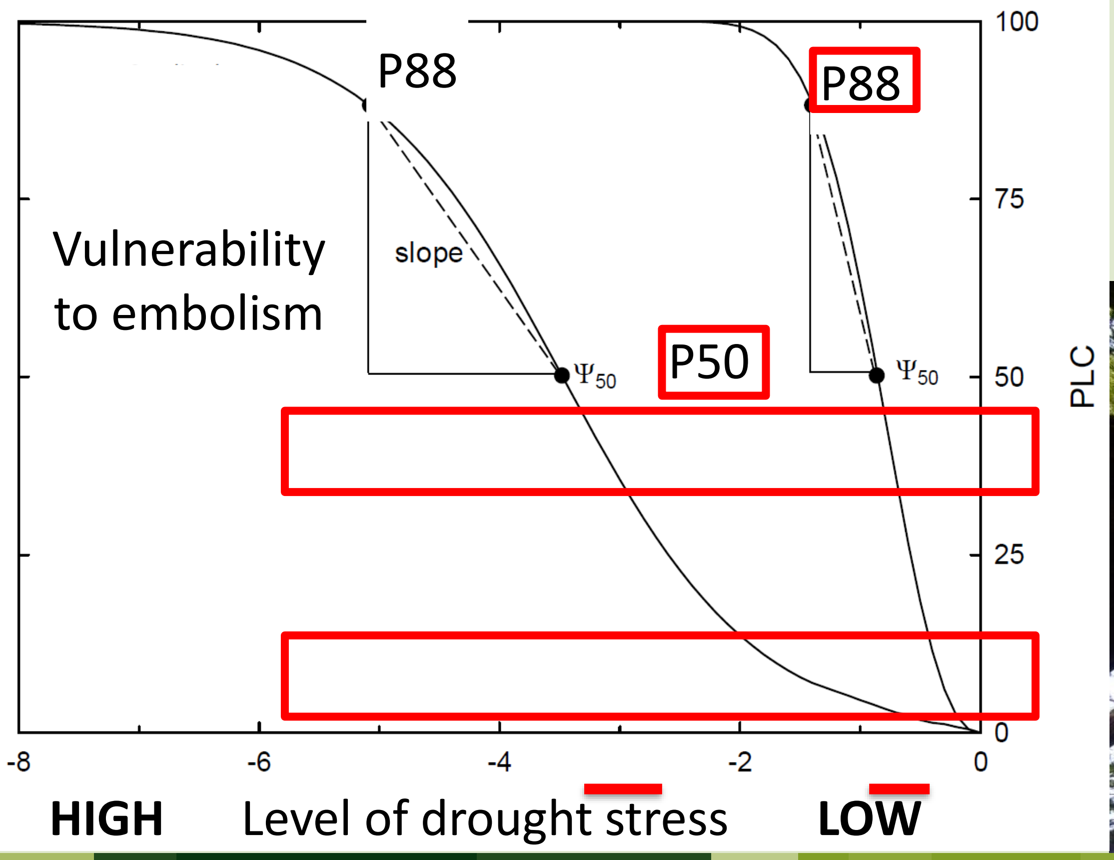


3) Safety from embolism

Vulnerability, exposure, risk

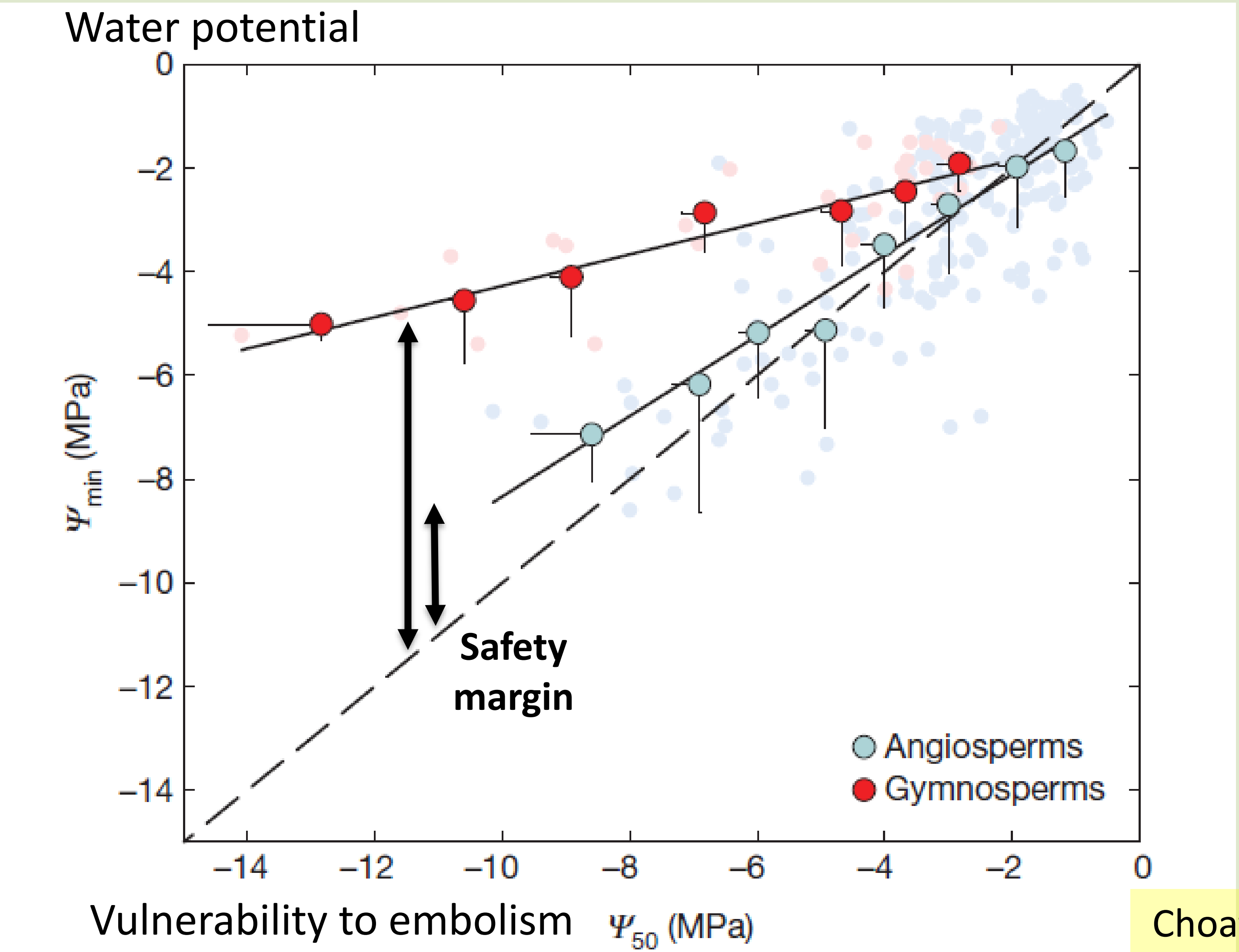
P50/88: Water potential @ 50% PLC

PLC = Percent loss conductivity



3) Safety from embolism

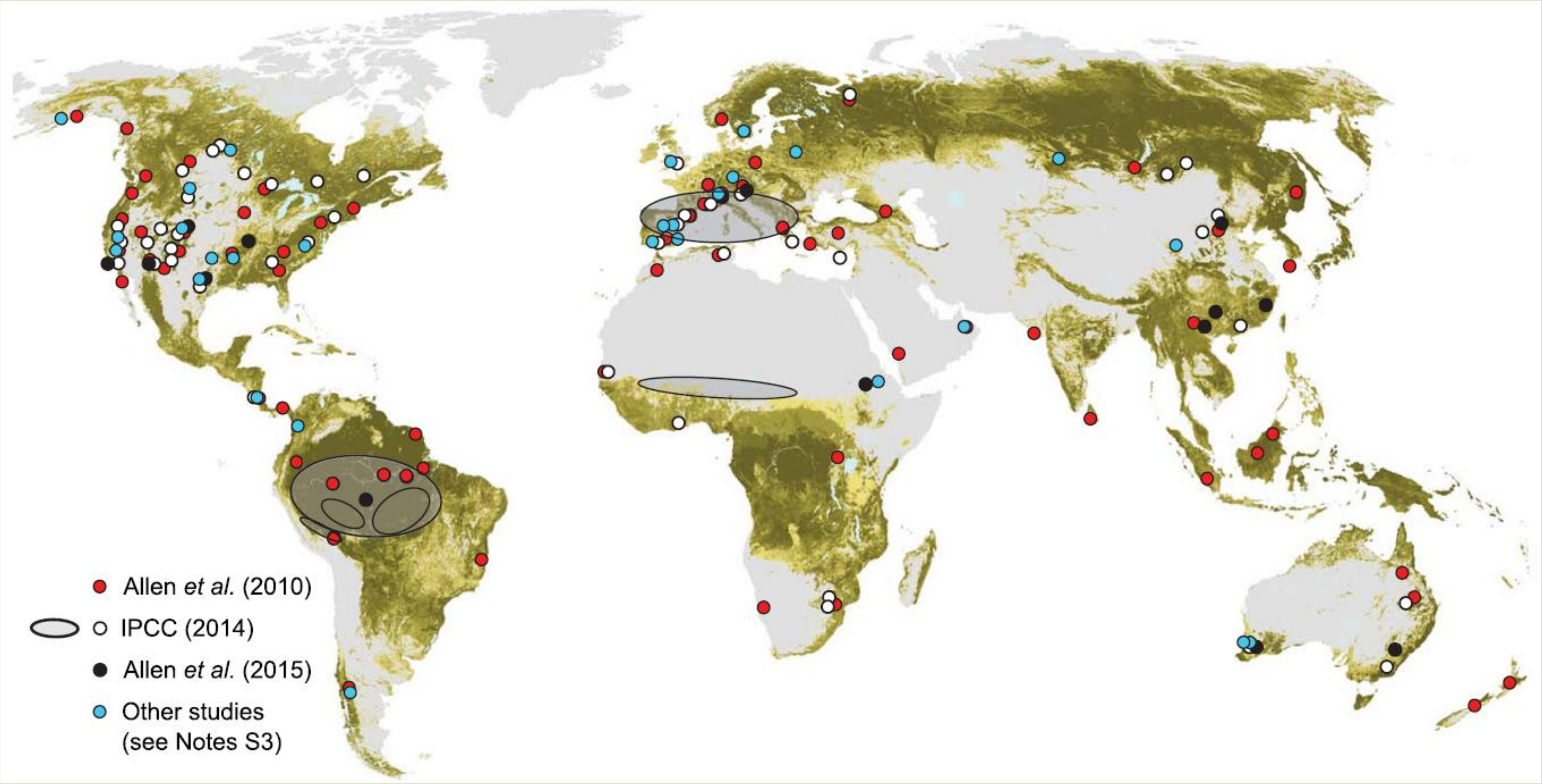
Vulnerability, exposure, risk



Choat et al (2012 *Nature*)

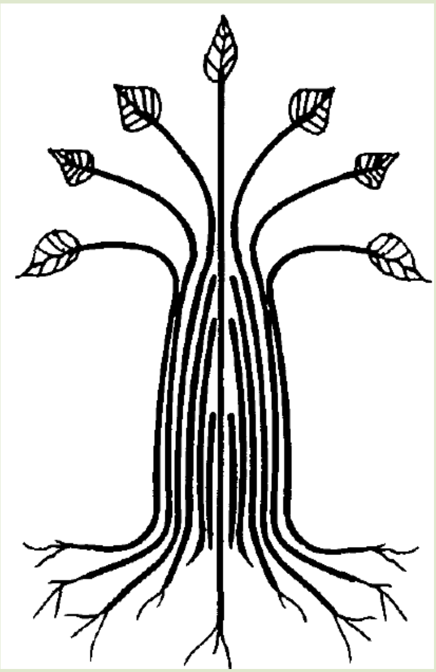
3) Safety under drought

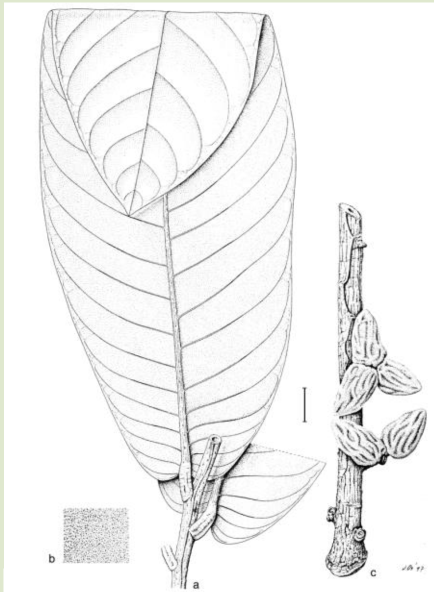
Vulnerability, exposure, risk

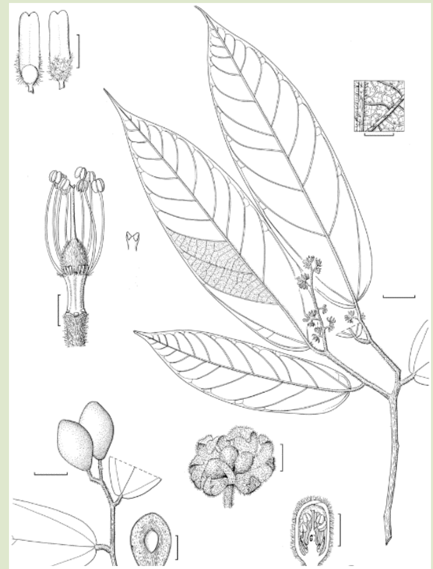


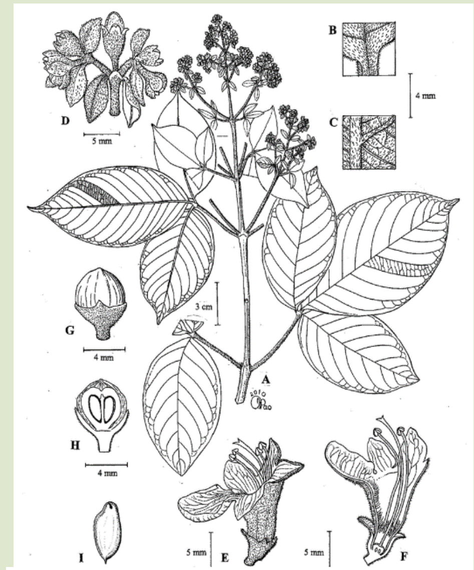
Hartmann et al (2018 *New Phy*)

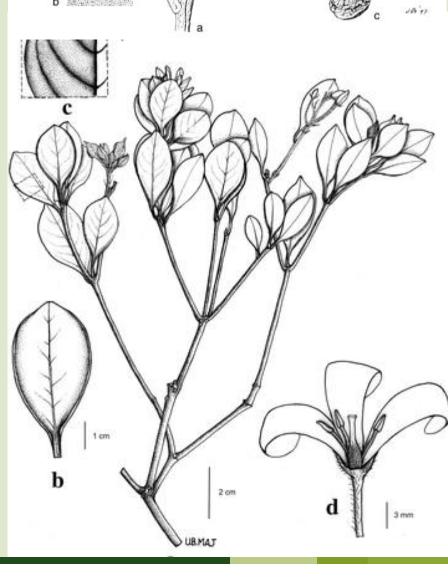
4) Partitioning (Huber value)

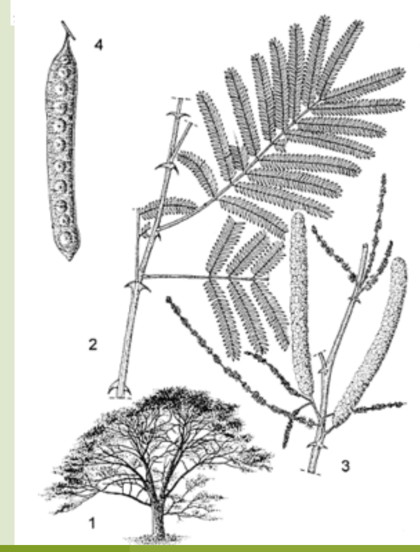


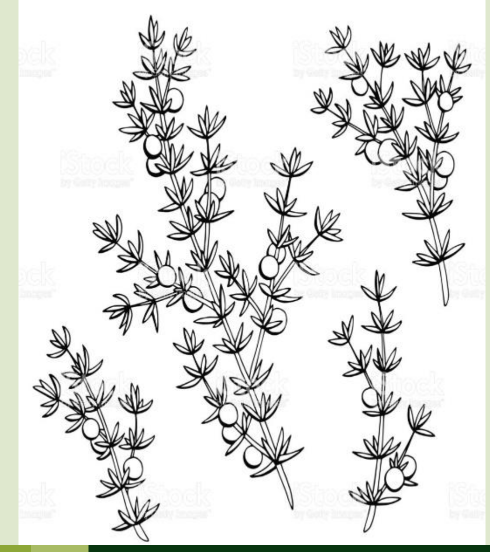






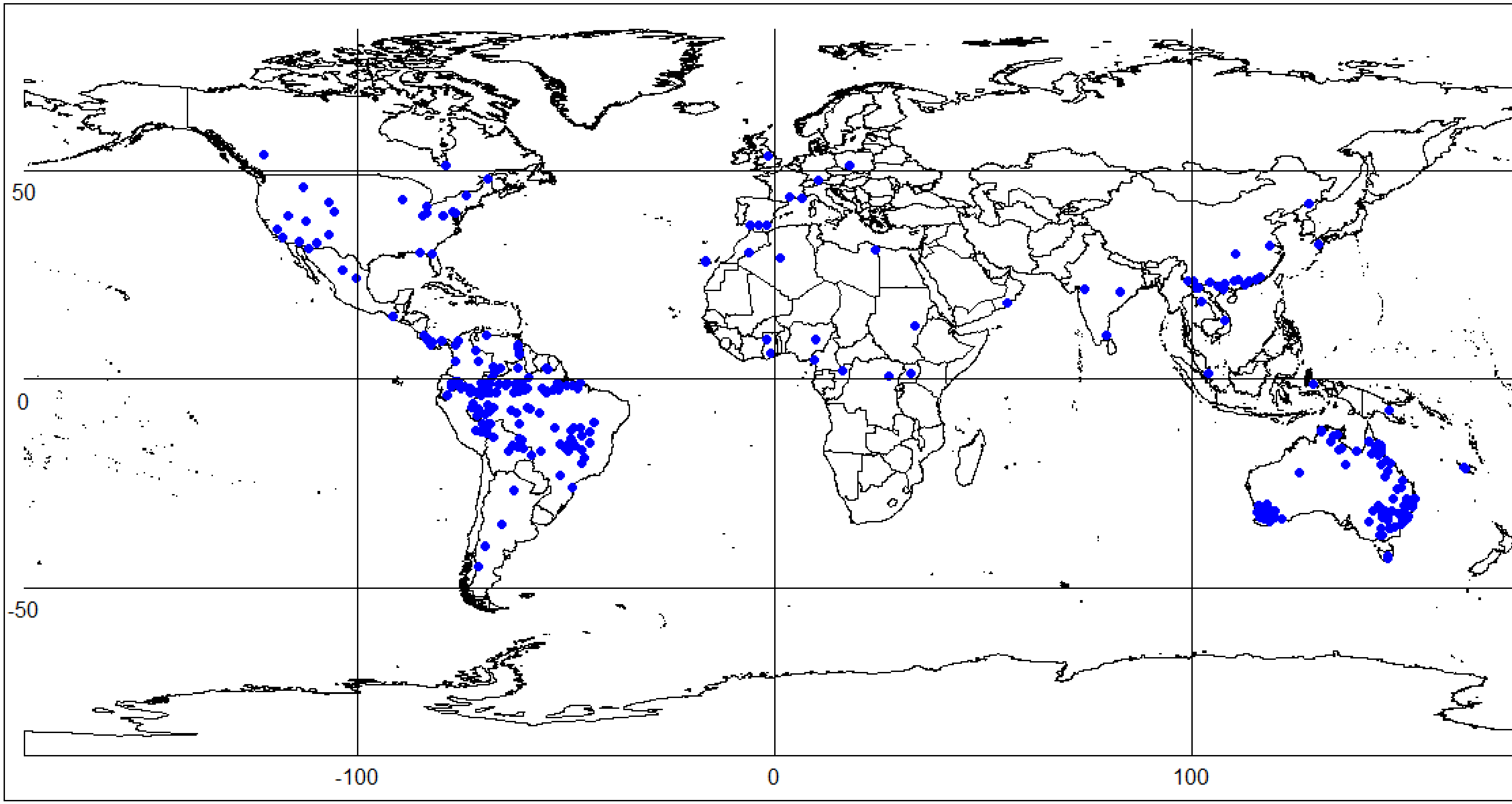






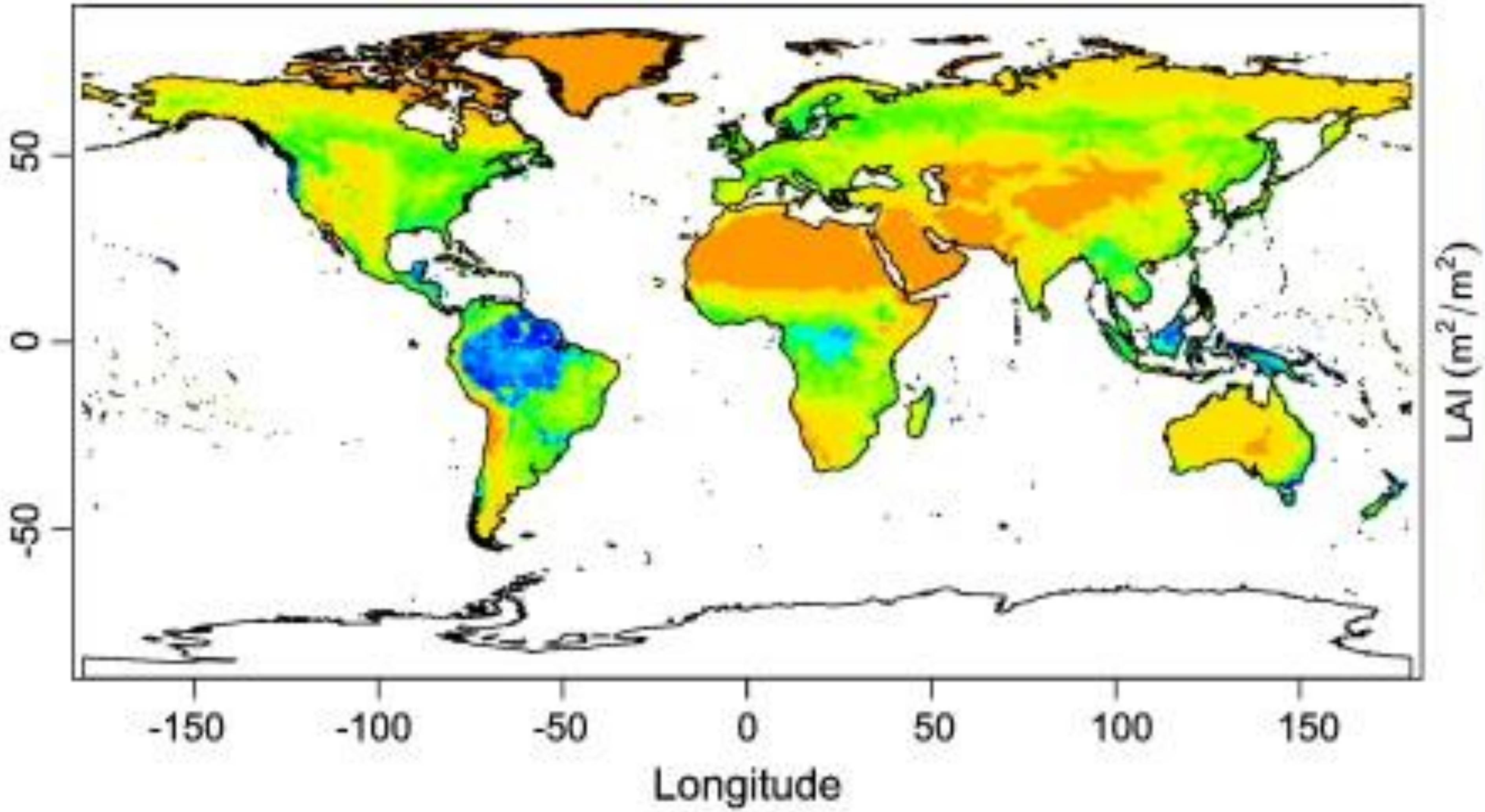
Collating empirical evidence

N = 1,500 points



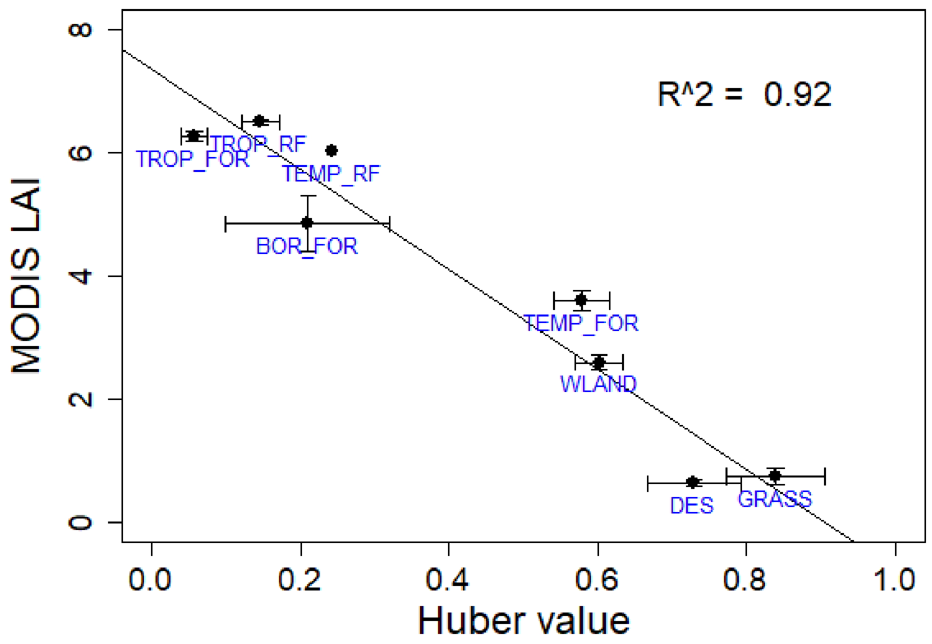
Mencuccini et al (in review *New Phy*)

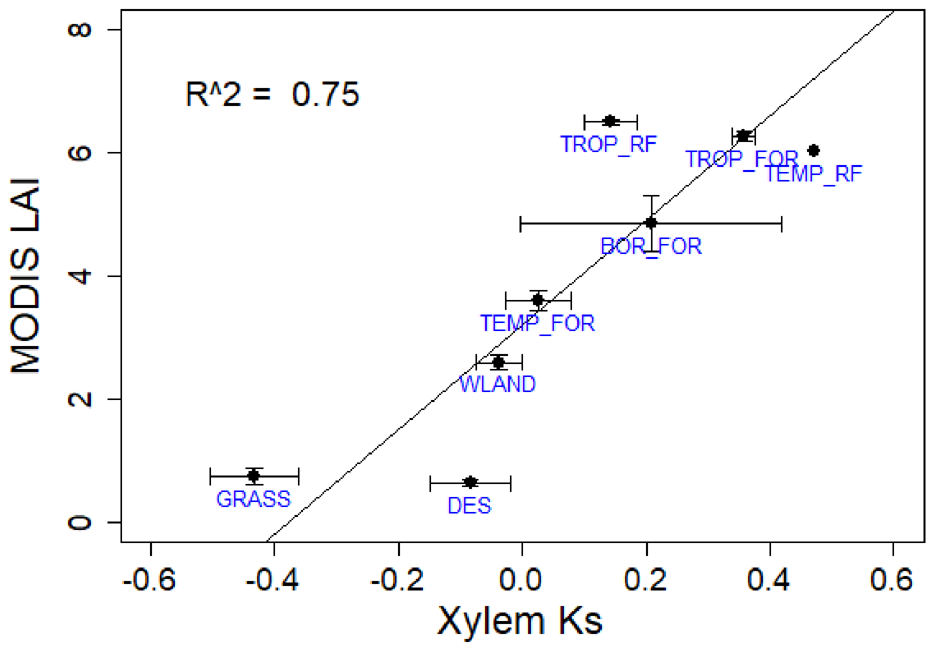
How to upscale these traits



Scaling to biome LAI

N = 1,500 points

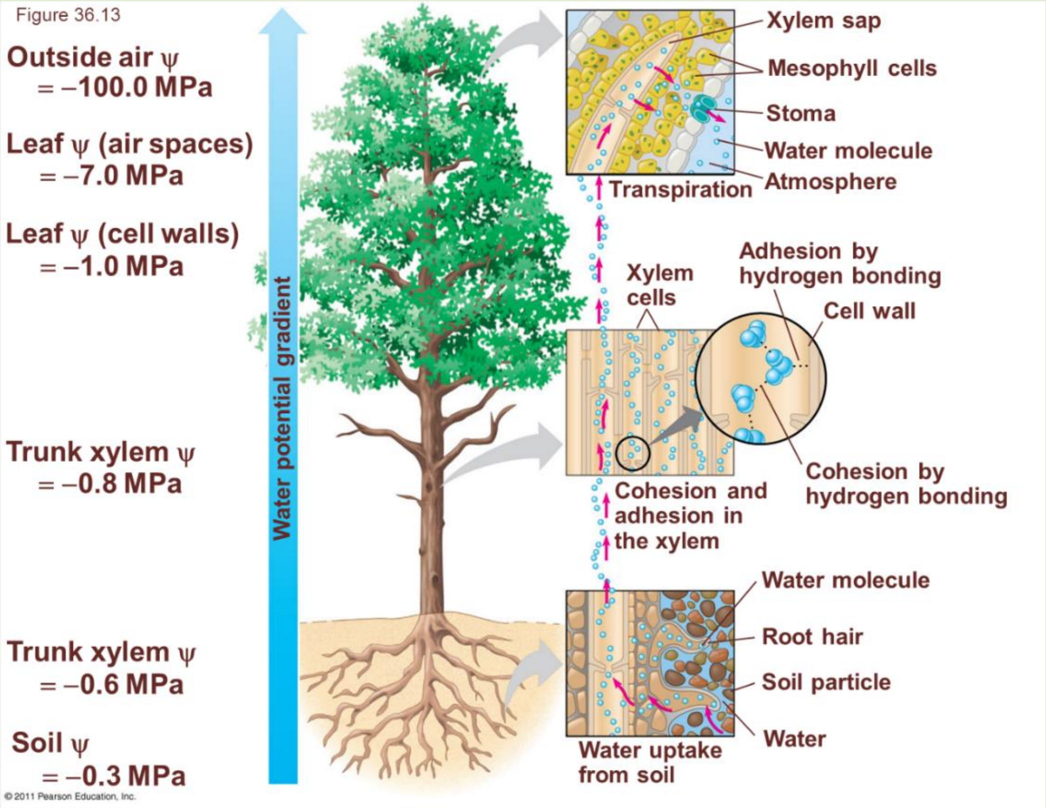




Mencuccini et al (in review *New Phy*)

Mencuccini et al in prep.

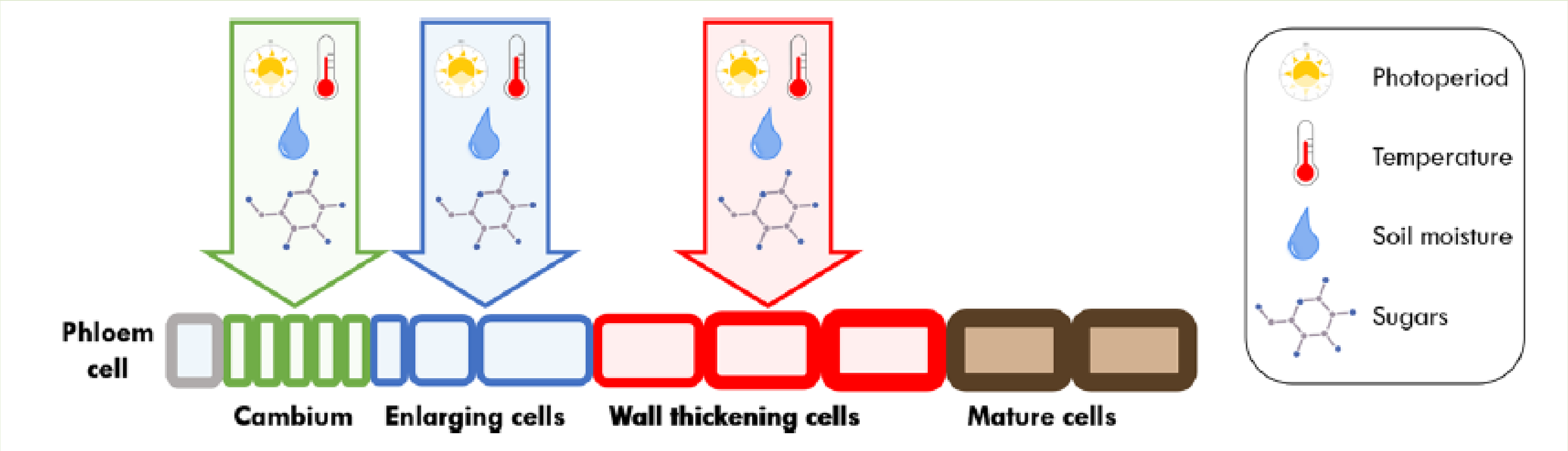
Key hydraulic traits and significance



1. Water status: water potential / content
2. Water transport: efficiency
3. Water transport: safety from embolism
4. Allocation ratio: Huber Value (1/leaf-sapwood area ratio)

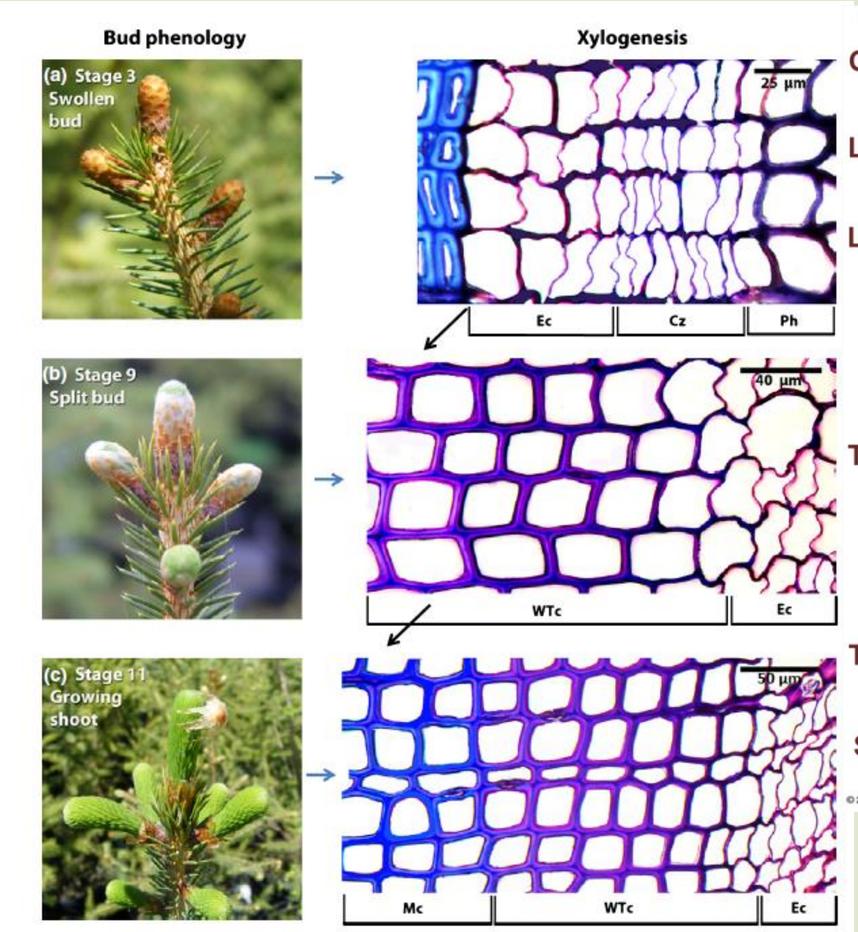
1. Prediction of woody growth
2. Prediction of drought-induced mortality
3. Prediction of water fluxes

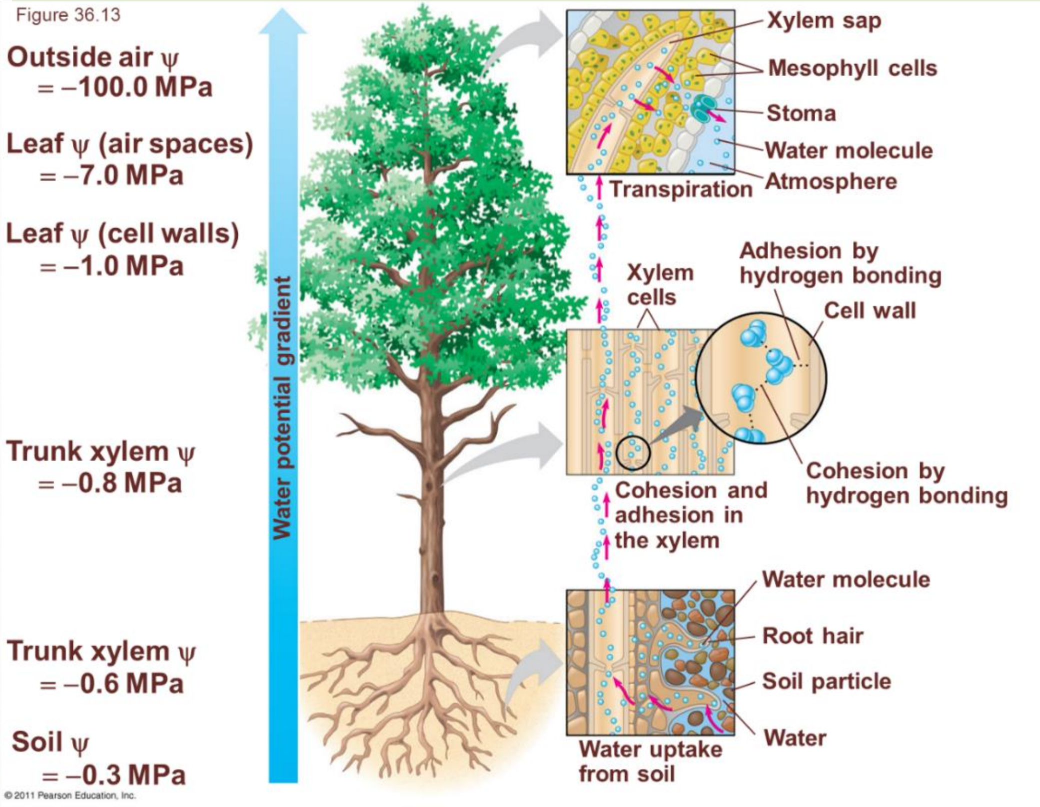
1) Factors controlling tree radial growth



Friend et al (2019 *Ann For Res*)

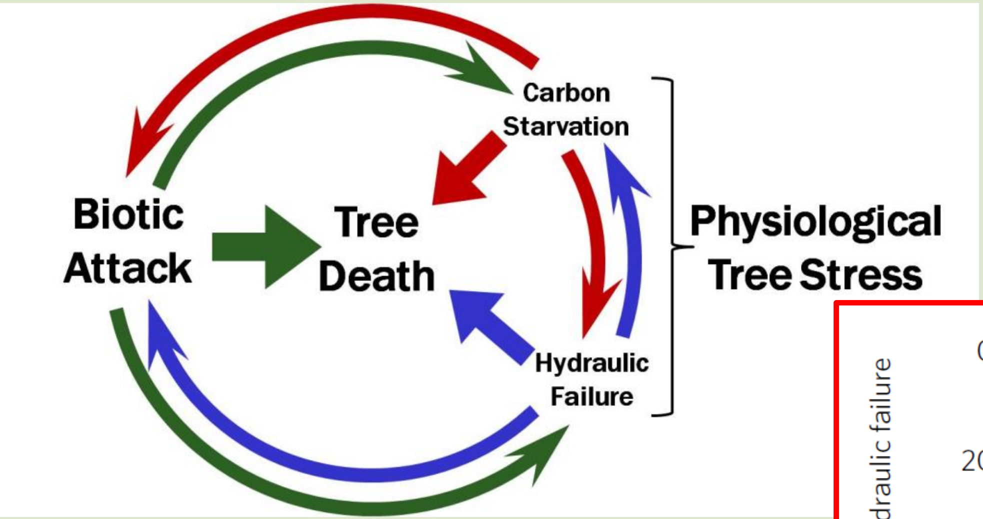
1) Factors controlling growth

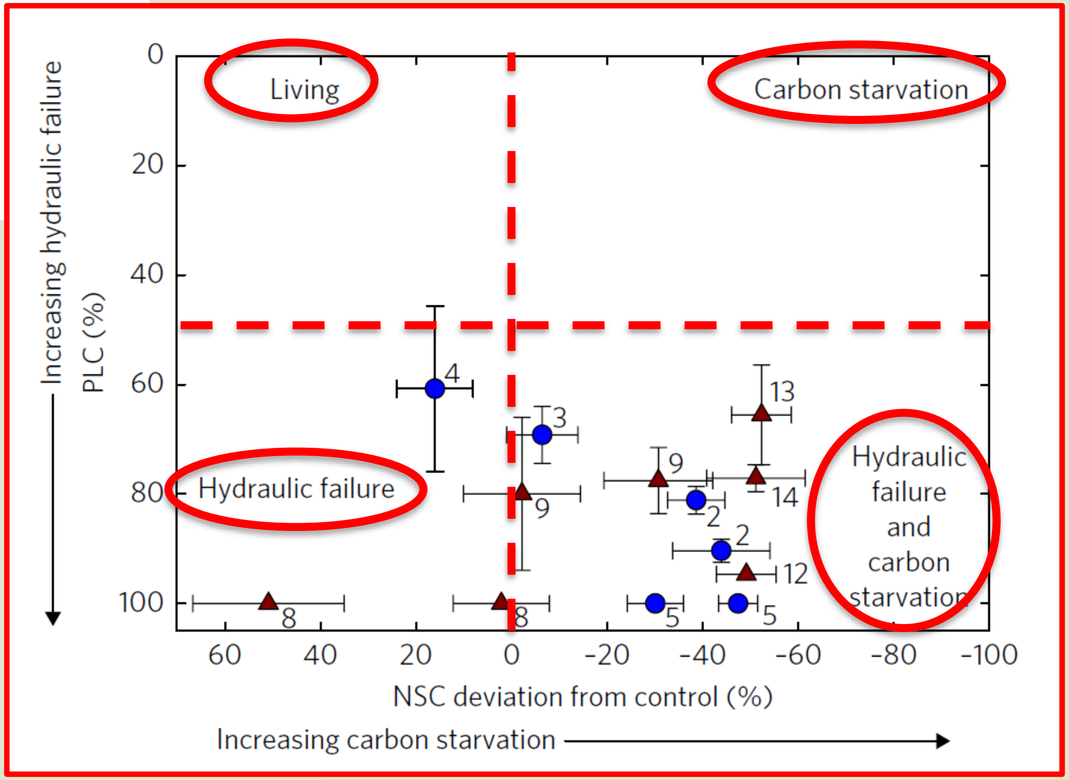




Huang et al (2014 *New Phy*)

2) Prediction of drought-induced tree mortality



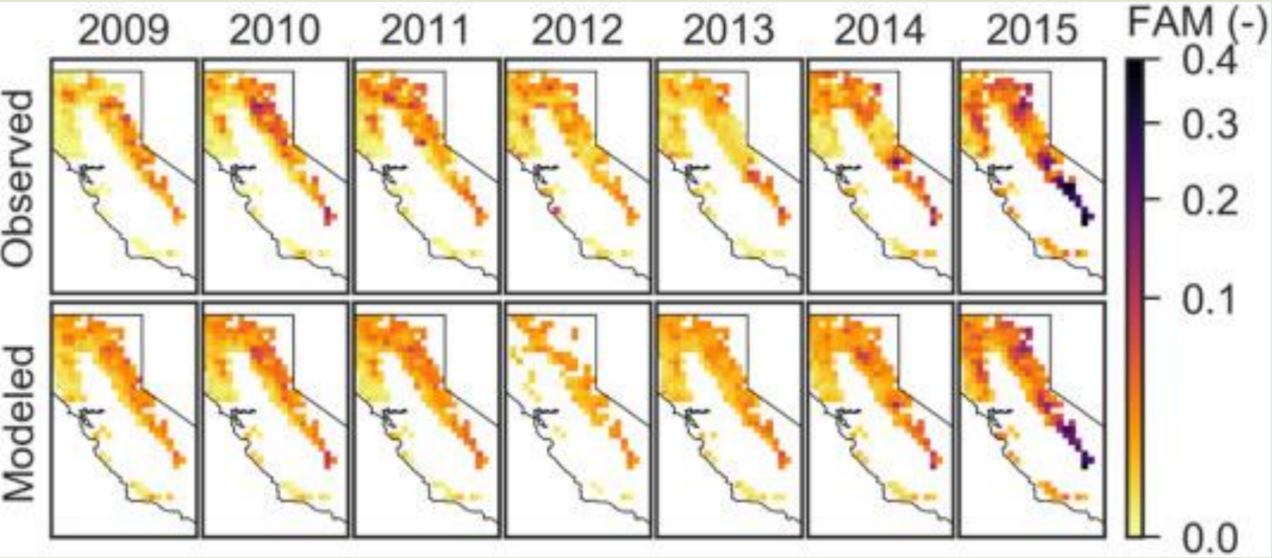


Adams et al (2017 *Nature Ecol Evol*)

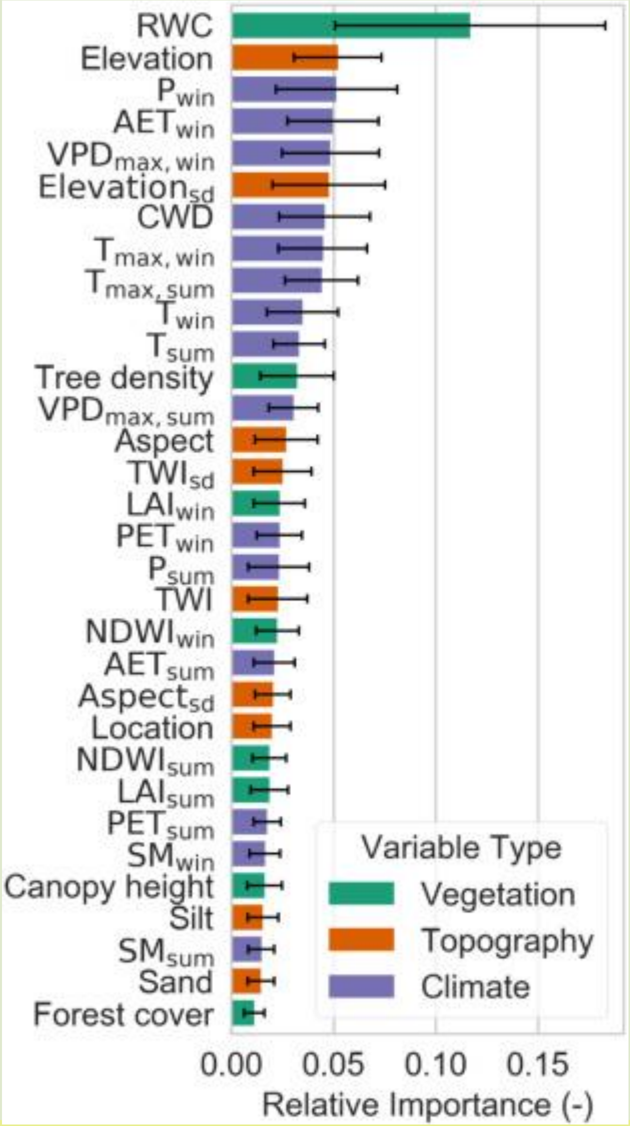
2) Prediction of tree mortality

$$VOD \propto RWC_{veg}$$

Diurnal variations in X-band of passive microwave measurements (Adv. Microw. Scann. Rad.–E or -2)

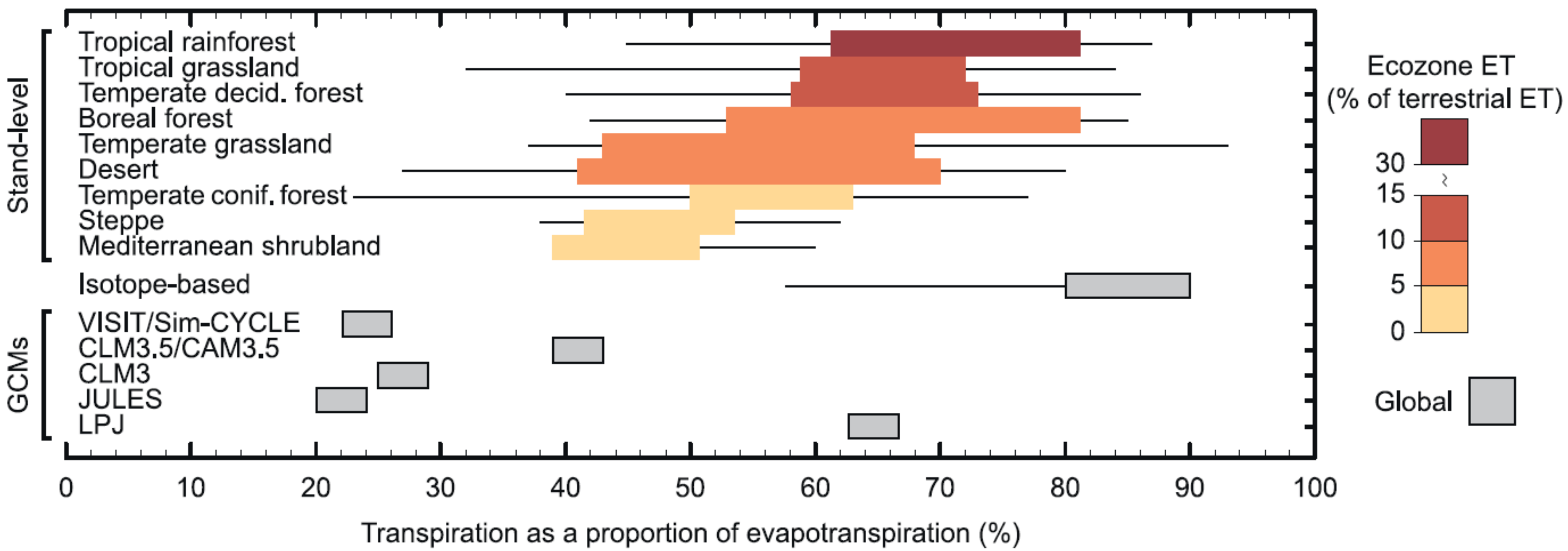


Fractional Area Mortality FAM in California



Rao et al. (2019 *Rem Sens Env*)

3) Predictions of carbon and water fluxes



Jasecko et al (2013 *Nature)*

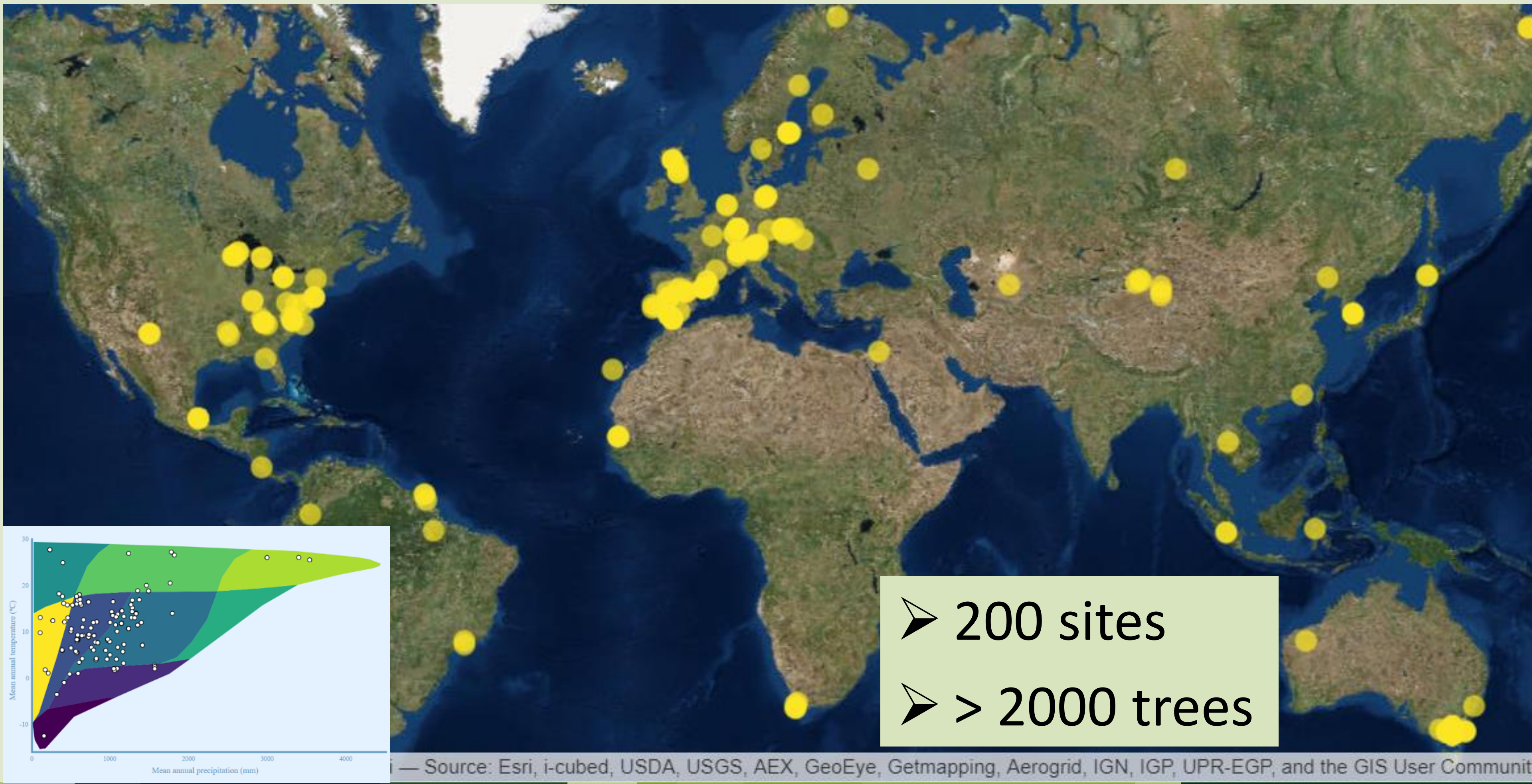
Schlesinger & Jasecko (2014 *AgForMet)*

Editorial

Tree Physiology 36, 1449–1455
doi:10.1093/treephys/tpw110

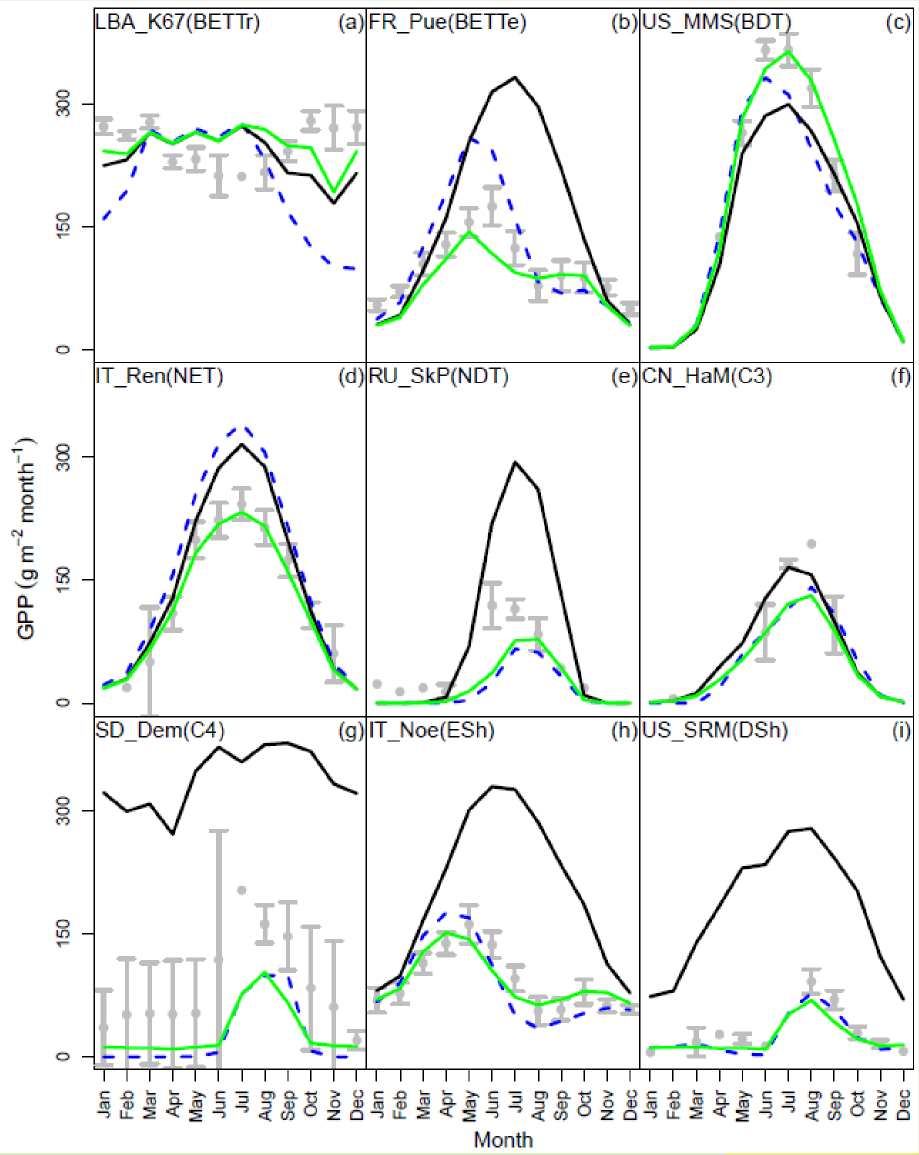
SAPFLUXNET: towards a global database of sap flow measurements

Rafael Poyatos[1,2,6], Víctor Granda[1], Roberto Molowny-Horas[1], Maurizio Mencuccini[3,4], Kathy Steppe[2] and Jordi Martínez-Vilalta[1,5]



- 200 sites
- > 2000 trees

3) DVGM Prediction of water fluxes



- Global Dynamic Vegetation Models
- UK JULES
- Using global hydraulics database
- Ecosystem-scale GPP (Gross Prim. Product.)
- Fewer parameters, better predictions relative to earlier JULES

Eller et al (2018 *ProcRoySoc B*); Eller et al (2019 in review)

Summary

- Overview of current available toolbox (emphasis on trait-based modelling)

- With a focus on drought responses, overview of most important tissue-level traits

- Three examples for prediction of processes from plant to global scales

Concluding themes

- how lucky are you, young biologists?

- Do we want to improve our <u>understanding</u> of the bio-physical world? Or do we want to make <u>predictions</u>?

-Do trait-based approaches fully explain drought responses?

- how do we think of processes across scales?