Forest responses to drought: from tissues to biosphere
Maurizio Mencuccini
Extreme events
Tipping points
Cascading feedbacks → mega-catastrophes

Extinction Rebellion movement
Top list you do not want to be on

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

- Harvey - $100 billion
- Maria - $90 billion
- Irma - $50 billion
- Golden medal (Katrina, 160 billion)
Insurance industry

• 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)
**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

http://portal.eufgis.org/maps/

This is our collection

3,132 units for 3,778 tree populations
103 tree species in 34 countries
ESA-DEVELOPED EARTH OBSERVATION MISSIONS

Satellites
28 under development
13 in operation

Science
Copernicus
Meteorology
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

Abstract

This study tests the ability of five Dynamic Global Vegetation Models (DGVMs), forced with observed climatology and atmospheric CO₂, 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

- Biosphere
- Ecosystem
- Individual
- Leaf/Organ

- Flux data
- Satellite data
- Palaeo. data
- Forest Inventories

- Tree data, e.g., growth, leaf area, mortality
- Physiological traits, e.g., $g_s$, $\psi$, $K_L$, $R_a$, $A_{max}$, NSC

- $< 1$ yr
- 1-10 yr
- $> 10$-100 yr

mechanistic
deterministic
detailed physiology
Trait optimization
Maximum entropy

Meir et al. (2015 New Phy)
How does a trait-based model work

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

(a) Tissue-level properties and whole plant fluxes

Water supply from the soil = transpiration (E)

→ Relation between E and soil moisture

→ Scale up fluxes to stand-level using LAI and SAI

(b) Stand transpiration and net primary productivity

Tissue-level properties are used to obtain stand-level relations between soil moisture (s) and transpiration (E) or assimilation (A)

(c) Probability density functions

(d) Transpiration and productivity along climatic gradients

Mean and PDF of E or A

Contrasting functional traits

Rainfall statistical properties

Mencuccini et al (2019 New Phy)
If the problem is drought, which ones are THE traits?

- **Physiological traits (leaf)**
  - Stomatal regulation
  - Turgor loss point
  - Cuticular conductance

- **Physiological traits (common)**
  - Vulnerability to cavitation ($\Psi_{12}$, $\Psi_{50}$, $\Psi_{85}$)
  - Maximum hydraulic conductance
  - Capacitance and water storage
  - Cell membrane permeability (aquaporin regulation)

- **Physiological traits (root)**
  - Cortical lacunae formation
  - Root shrinkage/hydraulic isolation
  - Soil–root hydraulic conductance

- **Morphological traits (shoot)**
  - Stomatal anatomy
  - Leaf vein density
  - Total leaf area
  - Leaf shedding/drought deciduous
  - Leaf to sapwood area ratio

- **Xylem anatomical traits**
  - Xylem conduit size, number and connectivity
  - Pit membrane thickness/porosity
  - Wood density

- **Morphological traits (root)**
  - Root to shoot ratio
  - Rooting depth
  - Fine root loss

**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) → 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)

\[ \text{VOD} \propto \text{RWC}_{\text{veg}} \]


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

Vulnerability to embolism

HIGH Level of drought stress LOW
3) Safety from embolism

Vulnerability, exposure, risk

Water potential

Vulnerability to embolism

$\Psi_{\text{min}}$ (MPa)

Safety margin

$\Psi_{50}$ (MPa)

Angiosperms
Gymnosperms

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
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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

\[ \text{VOD} \propto \text{RWC}_{\text{veg}} \]


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*)
SAPFLUXNET: towards a global database of sap flow measurements

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- 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

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 understanding of the bio-physical world? Or do we want to make predictions?

- Do trait-based approaches fully explain drought responses?

- how do we think of processes across scales?