TreeNet 10-year anniversary conference,
Session 3 Linking Sites - Near real-time biological signals

Potential and challenges of sap flow monitoring

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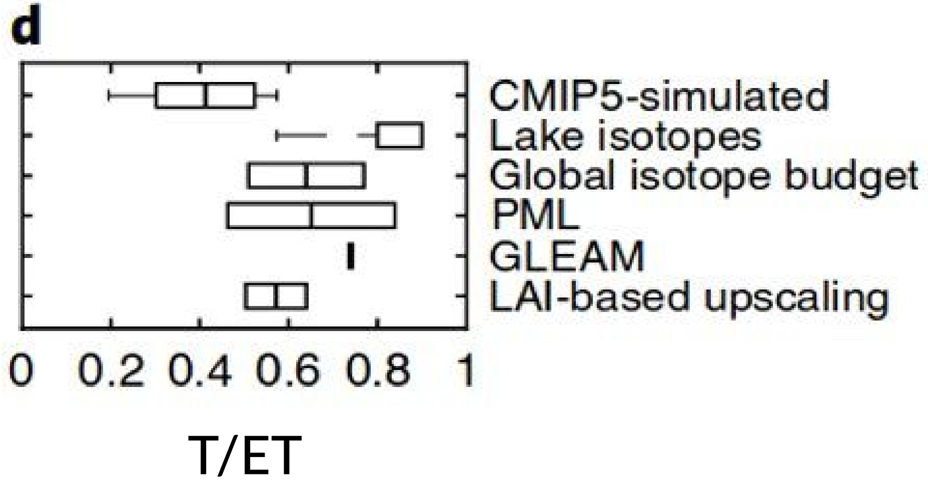
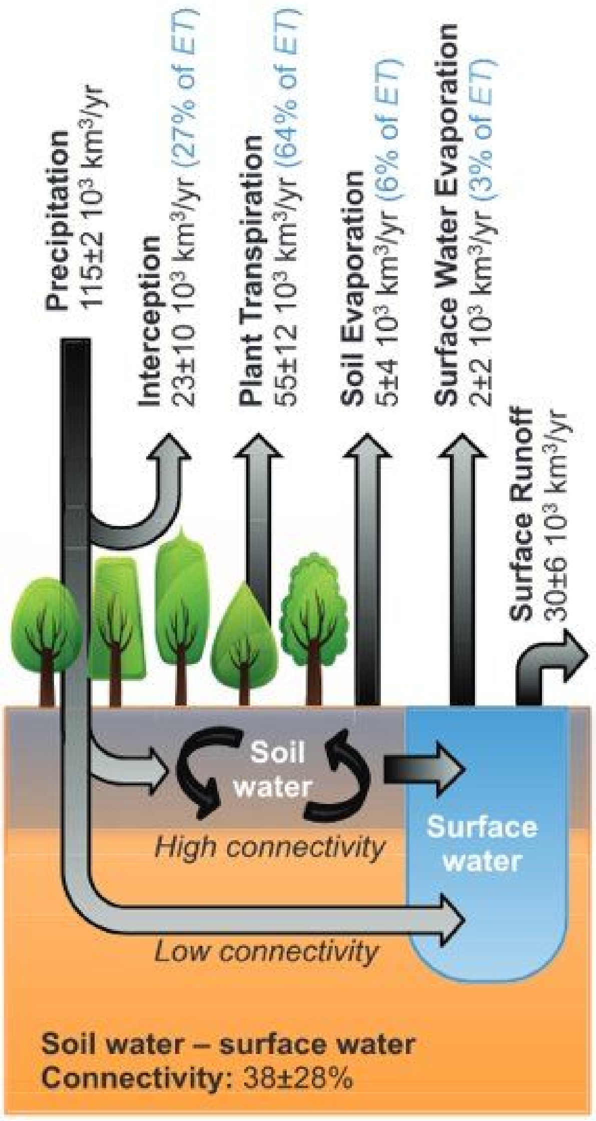
Why monitor tree-level water use?

Vegetation controls biosphere-atmosphere water fluxes.

The partition of plant vs soil contributions to ET is essential to understand and model hydrological changes at local to global scales.



Lian et al. 2019, Nature Climate Change

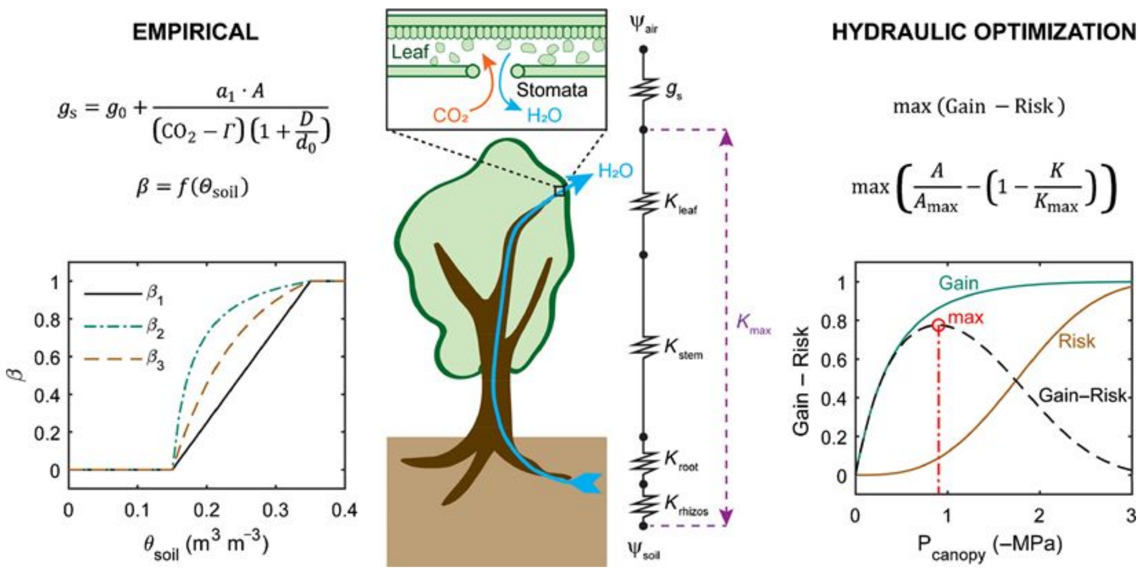


Good et al. 2015, Science

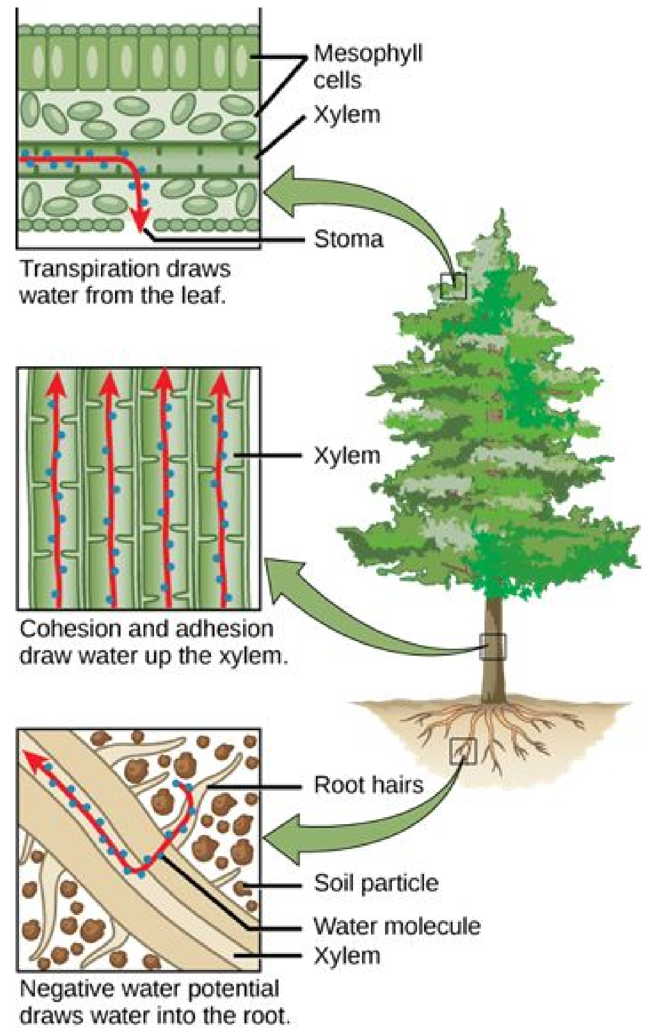
Why monitor tree-level water use?

Increased understanding of whole-tree hydraulics and drought responses (hydraulic optimization, mortality estimation)

-> Importance for land surface models and remote sensing products (parameterisation, calibration, validation).



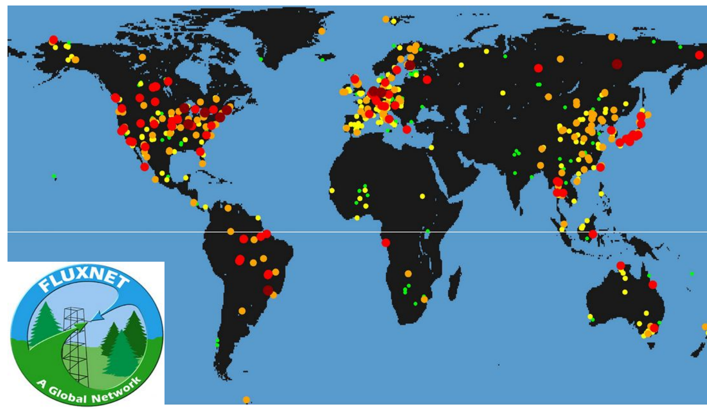
Anderegg & Venturas 2020, New Phyt



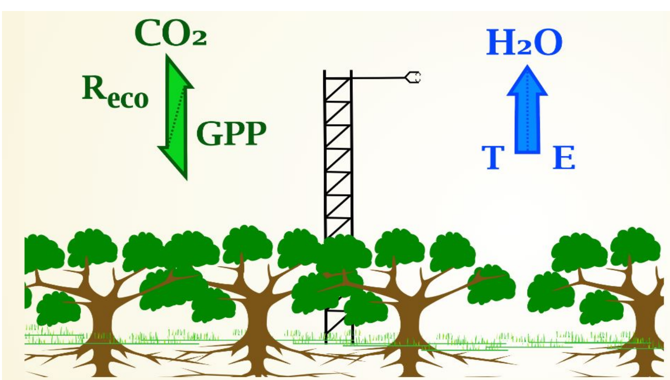
Lack of global networks monitoring tree water use

Compared to the growing success of global ecosystem-level flux networks (FLUXNET) built from regional networks (Ameriflux, ICOS Europe)

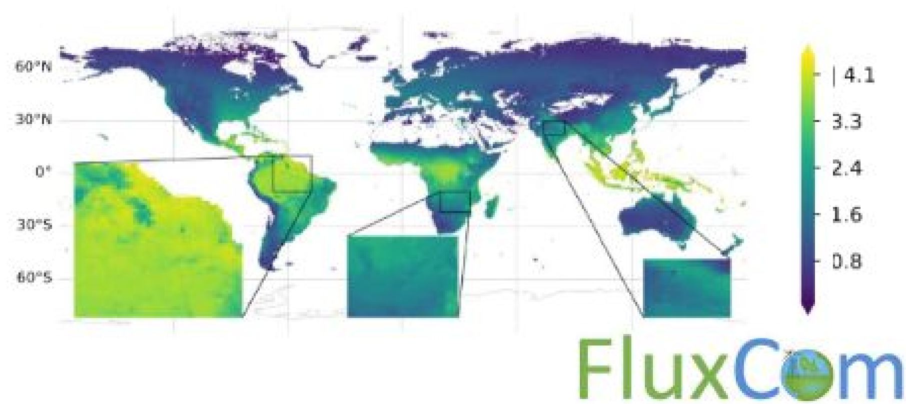
Downscaling



Upscaling



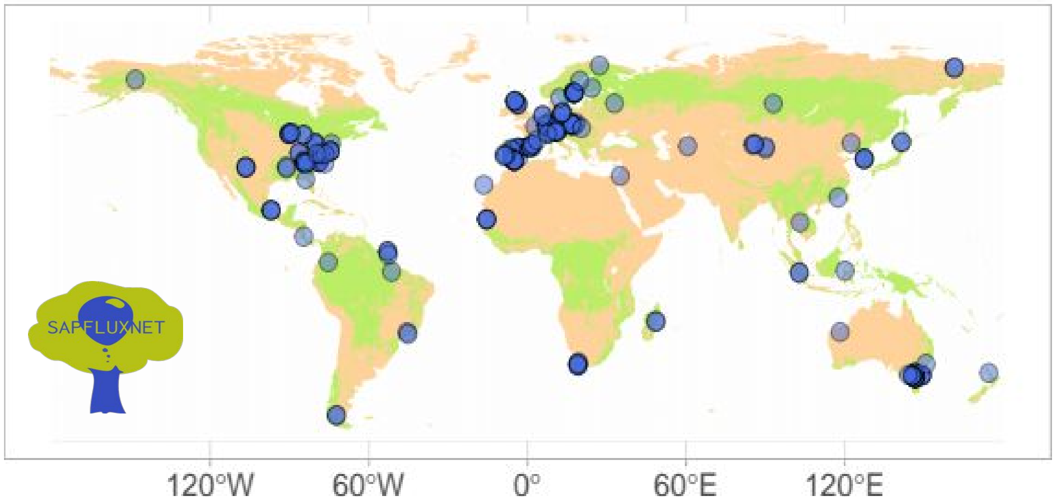
Nelson et al. 2020 GCB

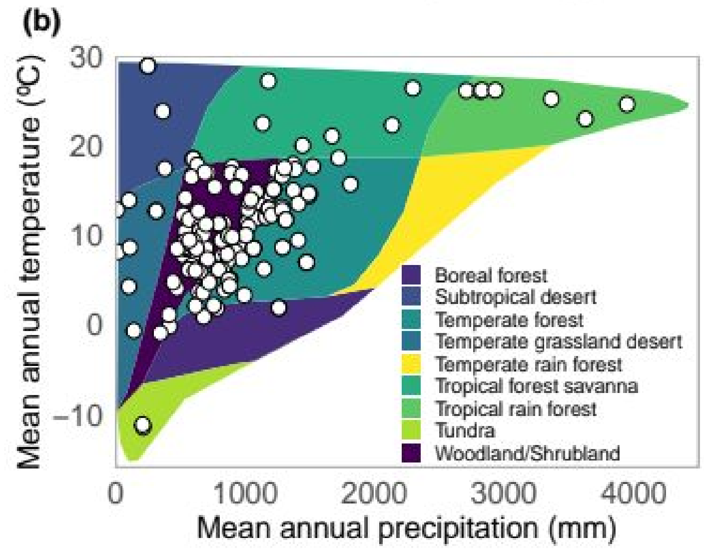


Jung et al 2019, Scientific Data

Global sap flow data now available in SAPFLUXNET

Poyatos et al. 2021. *Earth System Science Data*





> 10^8 subdaily sap flow data

202 datasets

> 2700 trees

174 species

> 165 participants worldwide

> 2300 downloads

SAPFLUXNET is a great start but…

- Opportunistic scheme (compiles the data that is available).
- Lack of strategic design and standardized protocols.
- Processed sap flow data, not raw records: uncertainties derived from different data processing methods.
- Sap flow data at the individual level (not at the sensor level).
- Continuous updates are possible but not implemented.
- Metadata available at different levels (site, stand, species, plant, environmental) but static and incomplete (e.g., plot-level inventories and plot size unavailable).

Towards a site-level sap flow monitoring network

Some aspects to consider:

- Experimental design
- Choice of sap flow method(s)
- Sensor calibration and installation
- Accounting for within-tree variability
- Data processing
- Ancillary data
- Data and metadata format
- Considerations on costs and energy requirements

Experimental design

- **Site selection:** critical to guarantee representativeness at large (ideally global) scales. Best strategy involves linking with already existing networks (e.g., FLUXNET, TreeNET, ...) plus additional sites focused on sap flow measurements.
- **Plot characteristics:** should be representative at the landscape scale and have a minimum size (e.g. >0.1 ha) to allow more robust upscaling and link with ecosystem-level measurements. Plot replication desirable but not required.
- **Tree selection:** minimum of ~10 measured trees, proportional to the species and size-class abundance in the plot, to allow upscaling.
- **Temporal coverage:** commitment for multi-year, continuous monitoring is desirable.

Sap flow method(s) and installation

TD and CHP are the most popular methods, but no method is perfect. Prescribing a specific method is unrealistic and perhaps undesirable.

Method	*Potential source of measure error*									*Adequate for measuring...*				
	Wounding	*Radial velocity profile*	*Wood properties*	*Natural thermal gradients*	*Sensor installation*	*Sensor design*	*Baselining*	*Power input*	*Pulse length*	*Reverse flows*	*Low flows**	*High flows**	*Absolute flows*	*Relative flows*
CHP	x	x	x	x	x				x					
T-max	x	x	x		x		x							
HR	x	x	x		x									
HFD	x	x		x	x	x	x	x						
SHB				x			x	x						
TD	x	x	x	x		x	x	x						
TTD	x	x	x	x		x	x	x						

*(Low/High: SFD methods: <5 / >80 $cm^3\ cm^{-2}\ h^{-1}$; SF methods: <260 / >3900 $cm^3\ h^{-1}$)

Flo et al. 2019, Agr Forest Meteo

Sensor calibration and installation

- **Calibration required for absolute flux determination, especially for heat dissipation methods.**
- However, **calibration is tricky**:
  - differences in sensor construction
  - are calibrations for stem segments valid for large trees?
  - to what extent are calibrations stable in time?
  - use of positive pressure vs potometric approaches?

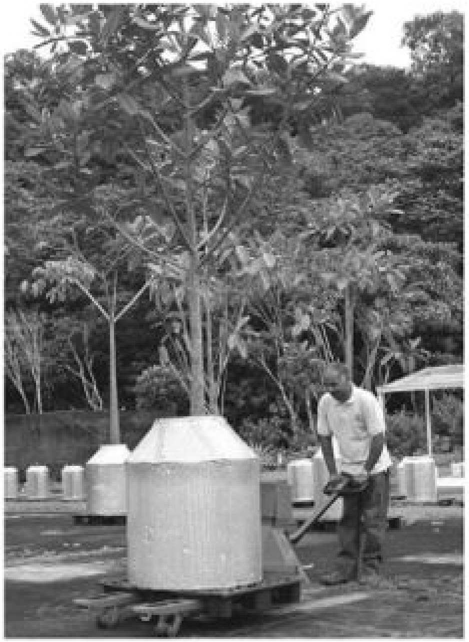


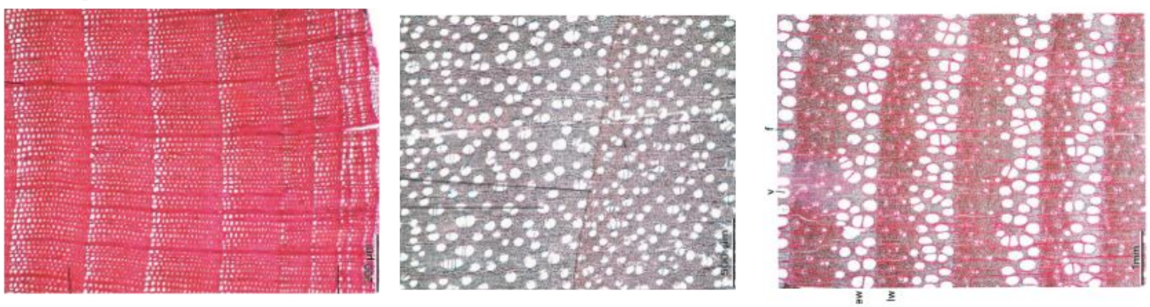
Figure 1. Weighing one of the *Calophyllum longifolium* saplings with the pallet truck scale.

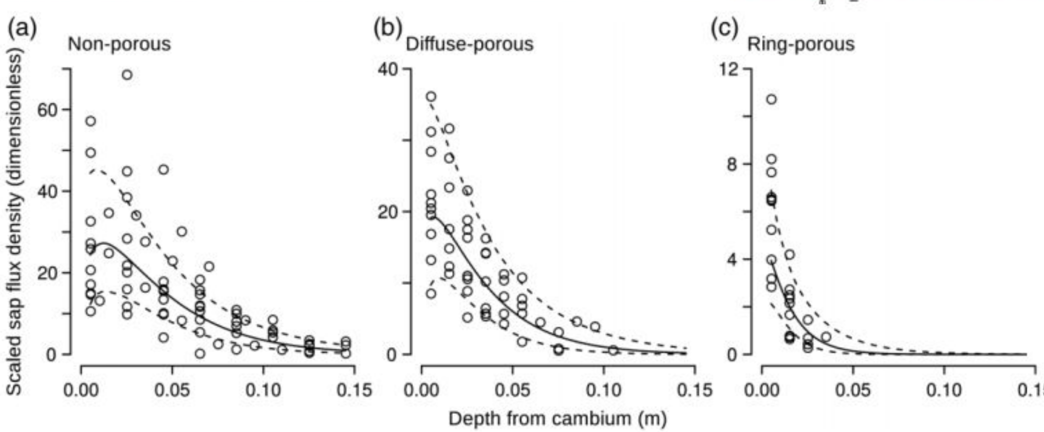
- Consider the possibility of **centralising calibrations,** at least for most popular methods.
- Establishing direct **collaborations with sensor manufacturers** also an option.
- Define the operational lifespan of different sensor types and set **reinstallation** recommendations accordingly.

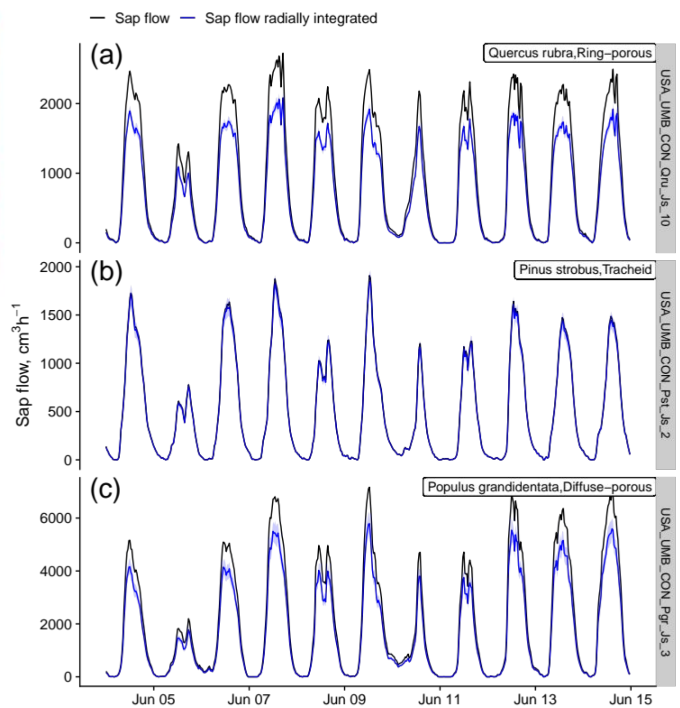
Accounting for within-tree variability

- Network designed at the **sensor level** to account for radial and azimuthal variability.
- **Radial variability** needs to be assessed (multi-depth measurements for a subsample of trees), but link to wood anatomy facilitates upscaling.
- **Azimuthal variability** not well understood yet: require >1 sensor for larger trees.

Schweingruber et al 2008. Atlas of Woody Plant Stems



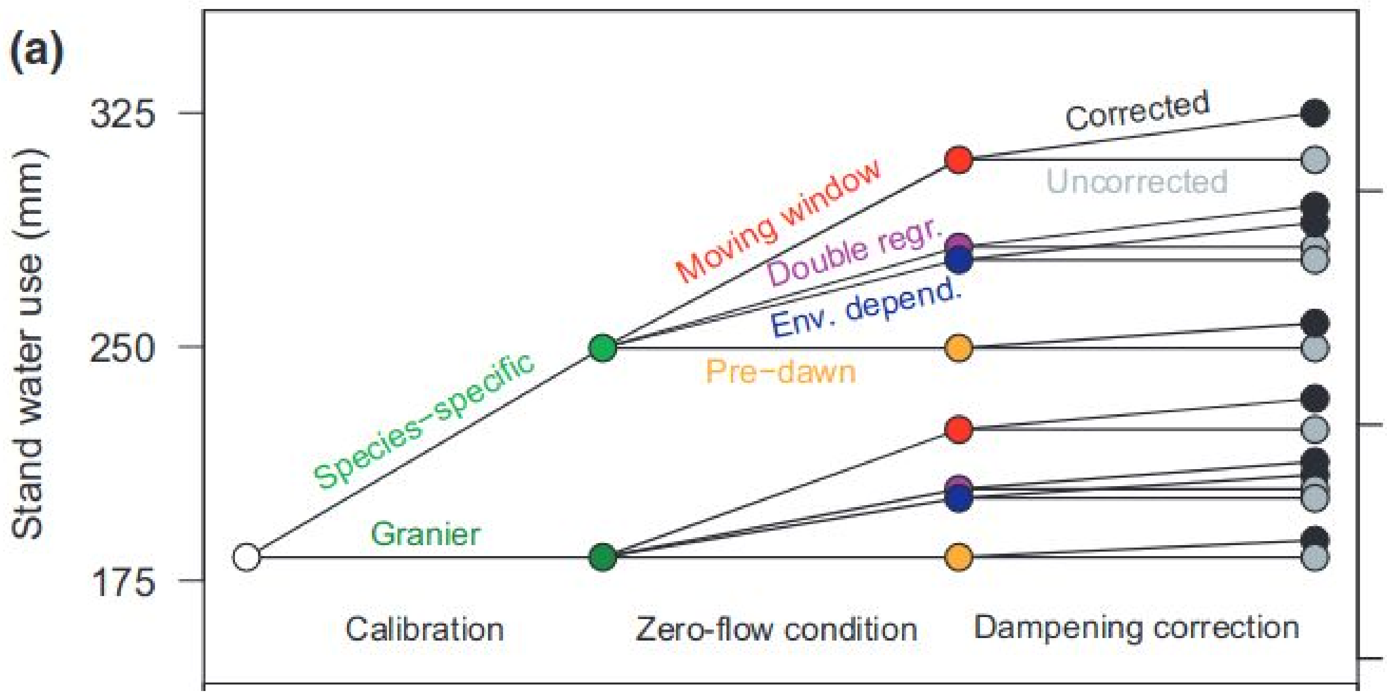




Berdanier et al. 2016. https://doi.org/10.1093/treephys/tpw027

Data processing

- Data processing practices impact sap flow estimation for TD -> **Common protocols** for calibration, zero-flow determination, accounting for signal dampening, etc. need to be established.
- Need to account for the effect of wood moisture content on wood properties (thermal diffusivity) for heat pulse-based methods.
- Wounding effects usually addressed only by heat pulse methods.



Peters et al. 2018, New Phyt

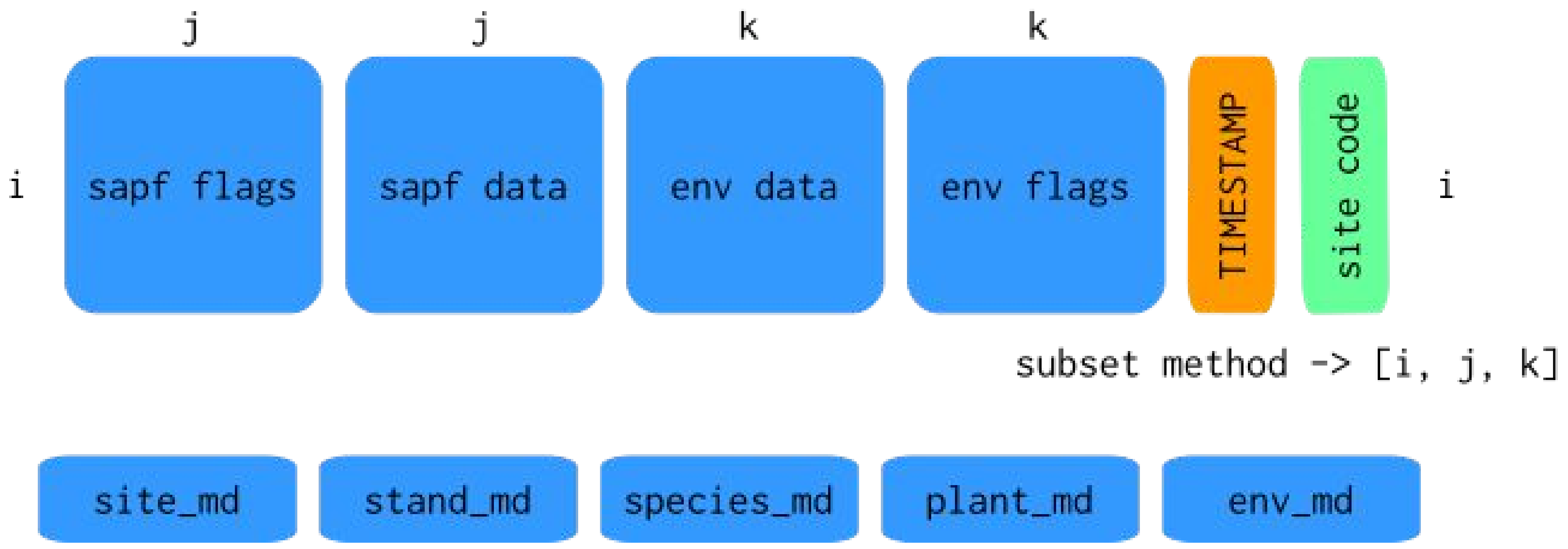
Ancillary data

The list of important variables includes (* denotes essential information for upscaling and analysis):

a. sapwood area of measured trees*
b. leaf area of measured trees
c. height of measured trees
d. stand basal area by species*
e. LAI (by species)
f. stand height (by species)
g. time series of soil water content to a standard depth (e.g., 30 cm?)*
h. time series of air temperature and RH, to calculate VPD*
i. time series of solar radiation (photosynthetic photon flux density)

Data and metadata format

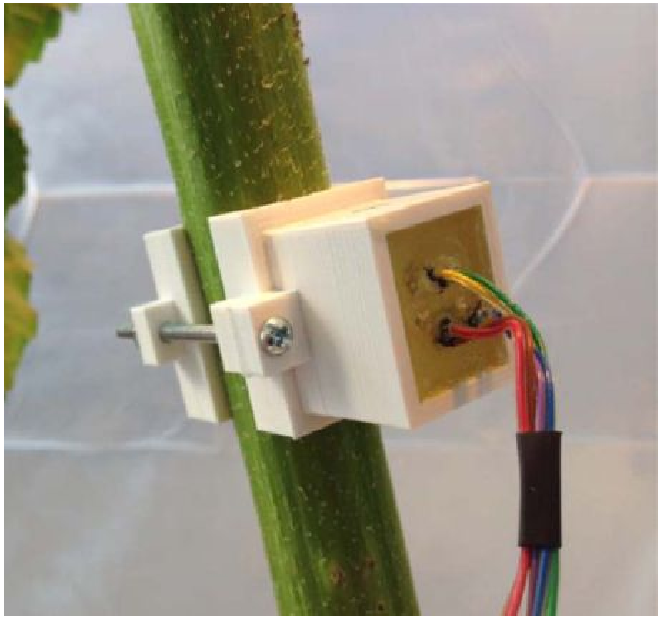
Dataset structure may follow the 'sapfluxnetr' R package format, and take advantage of the functions to summarize, aggregate and plot data in this package (https://cran.r-project.org/web/packages/sapfluxnetr/index.html)



Considerations on costs and energy requirements

- **Costs for commercial TD probes** may be 10-20 times higher than for lab-made sensors (~20 € per probe, including materials and training). Same goes for TD constant current heating boxes.
- Continuous TD systems are also **power demanding** (0.4 W per sensor).
- Heat pulse methods demand much less power and may be more promising for production of low cost sensors (3D printing).
- Recent developments in microcontrollers (Arduino, Raspberry Pi) reduce the cost of data acquisition and energy demands by more than an order of magnitude.

Miner et al. 2017, Agr For Meteorol



Conclusions

- **Monitoring tree-level water use** is essential to understand and model the changes in vegetation water (and carbon) fluxes, as well as drought responses and mortality at local to global scales (link with land surface models and remote sensing communities).
- The time is ripe for a **global network monitoring tree water use** that goes beyond current 'static' datasets (i.e., SAPFLUXNET).
- This network should be **connected to current networks** monitoring tree growth and ecosystem-level fluxes.
- Developing such a network requires **common** protocols and agreed best practices in terms of **experimental design**, choice of sap flow method, sensor calibration, methods to account for within-tree variability, data processing, ancillary data, and data and metadata format.

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