Spaceborne Observations of Water in Tress

Alexandra Konings
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(and many other contributors)

Outline

- Remote sensing benefits and possibilities
- Why microwave remote sensing?
- Microwave sensitivity to water content
- Evidence for microwave sensitivity to plant hydraulics
- What is the role of biomass?

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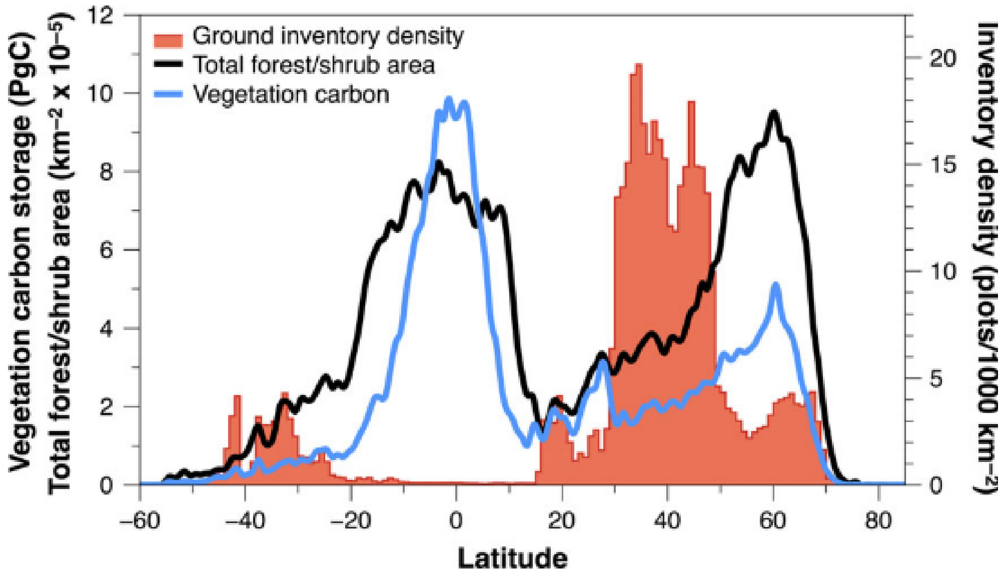
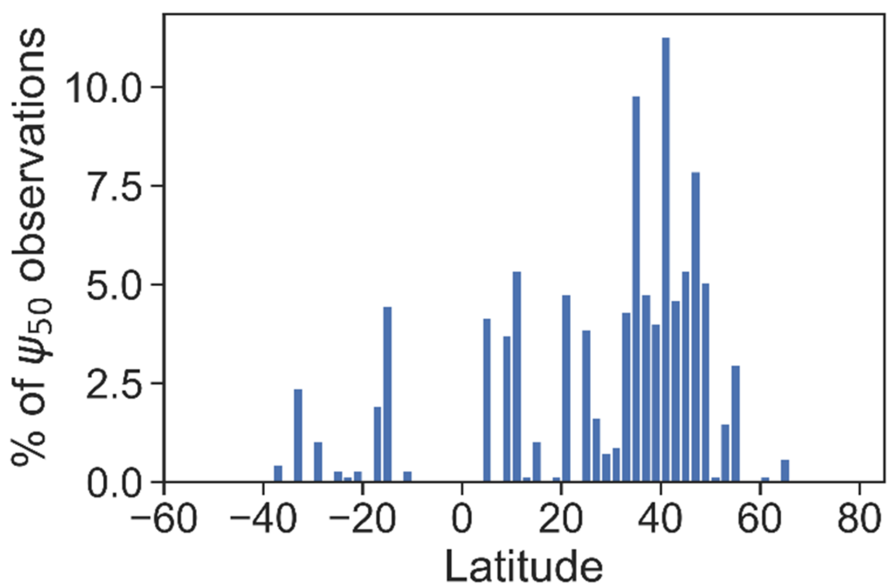
Why remote sensing? Biases in in situ meas

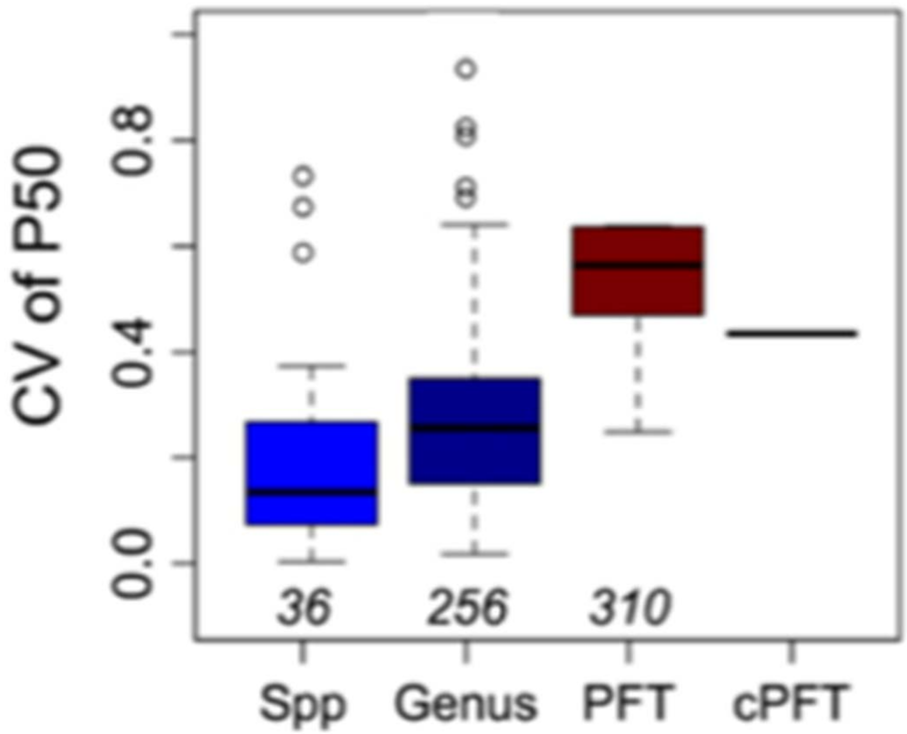


Schimel et al, GCB 2015



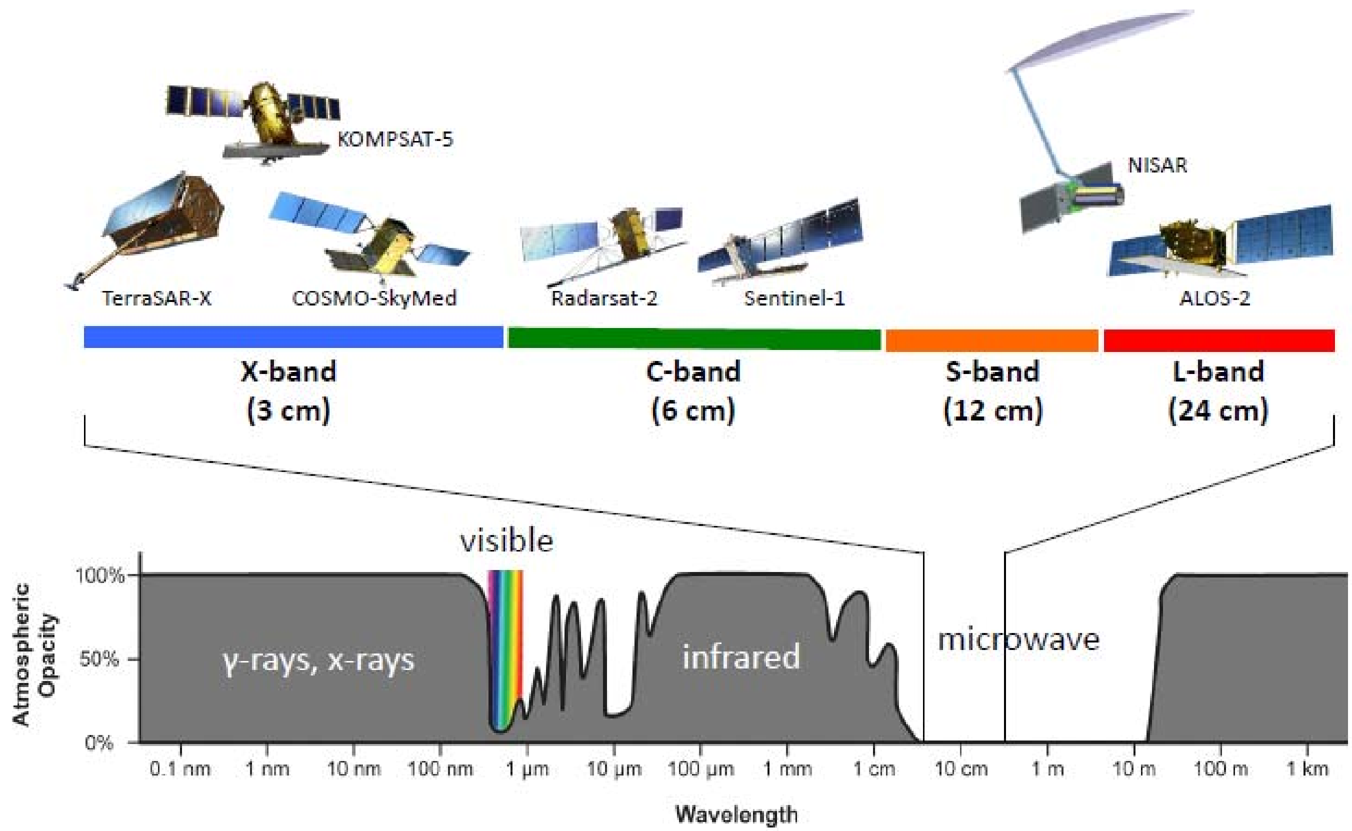
(Figure by Yanlan Liu)

Why remote sensing? Plant water response varies *a lot*



Anderegg, New Phyto 2015

Microwave frequencies particularly useful

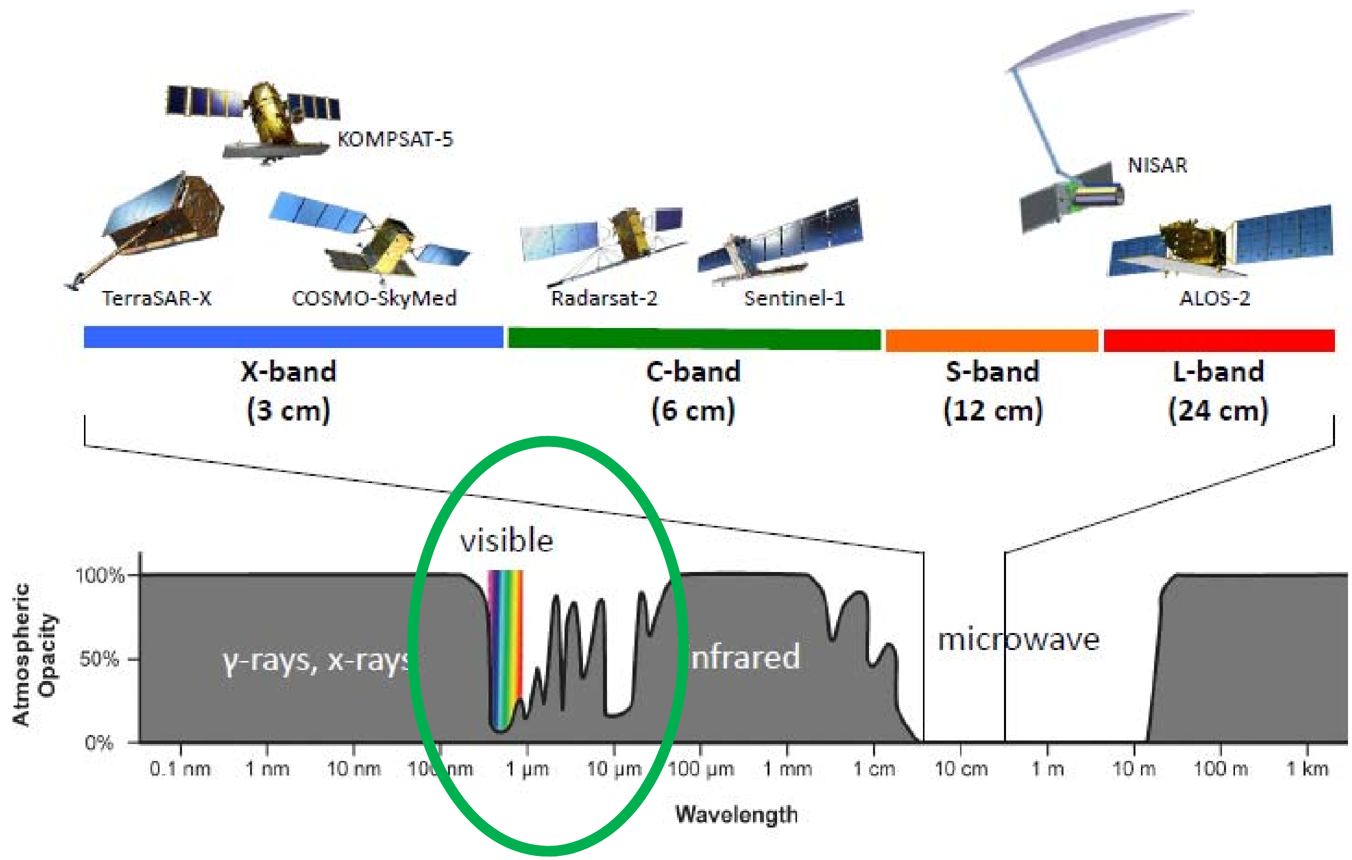


Two advantages:

1) Directly sensitive to water content

2) Ability to penetrate clouds

VIS/IR measurements also have opportunities



Advantages to VIS/IR

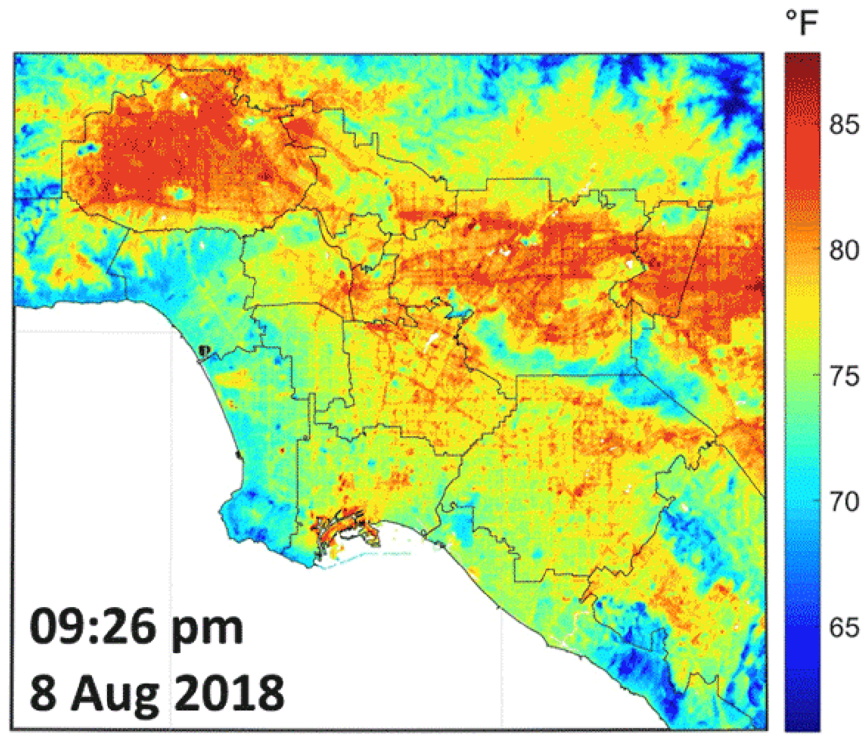
1) Greater resolution

2) Several measurement types

RS1: ET estimated from LST (VIS/IR)

ECOSTRESS

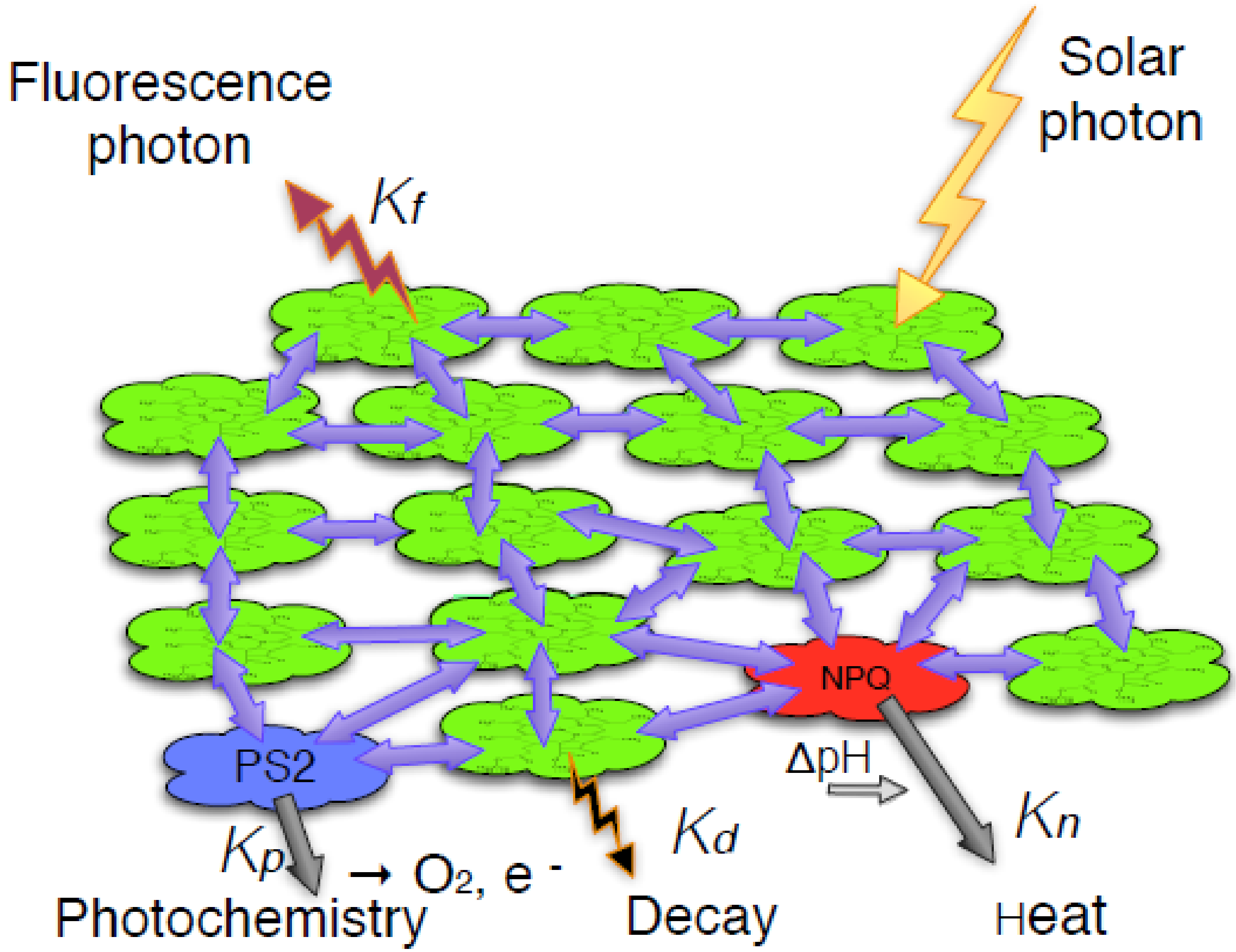
30 m resolution



Indirect, semi-empirical estimate based on temperature & others

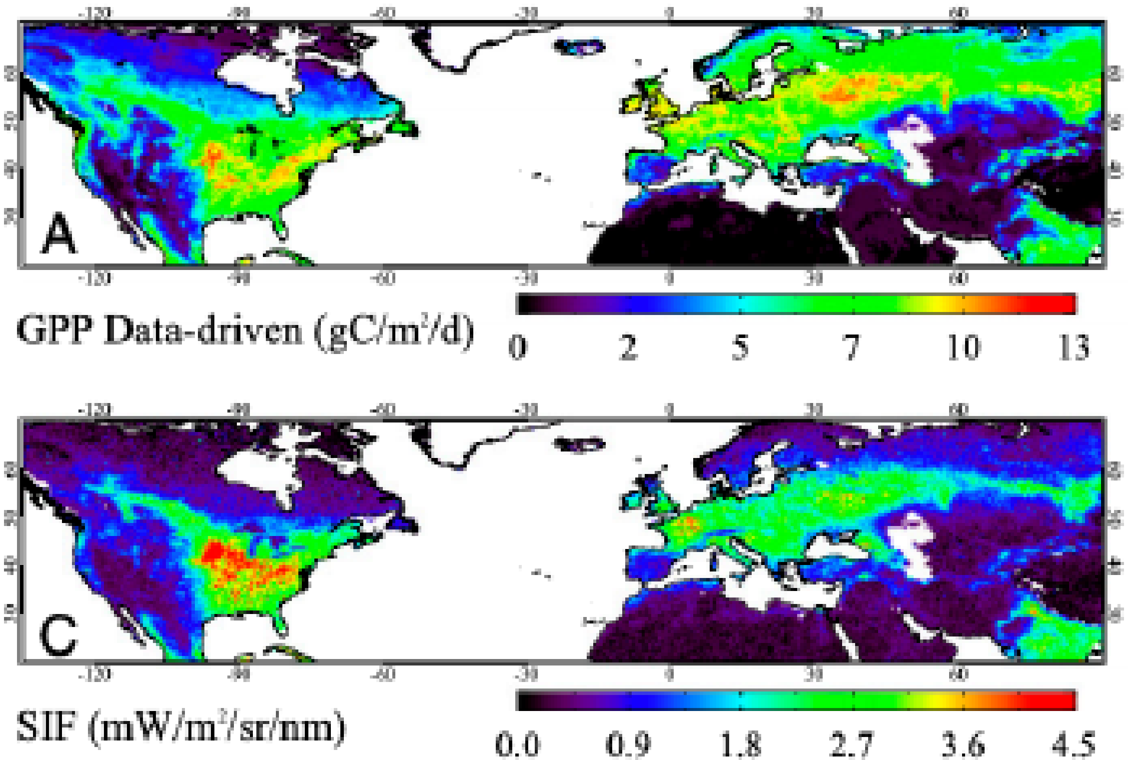
Many approaches:
Penman-Monteith, Priestley-Taylor, surface energy balance, …

RS2: Solar-induced fluorescence



RS2: Solar-induced fluorescnece

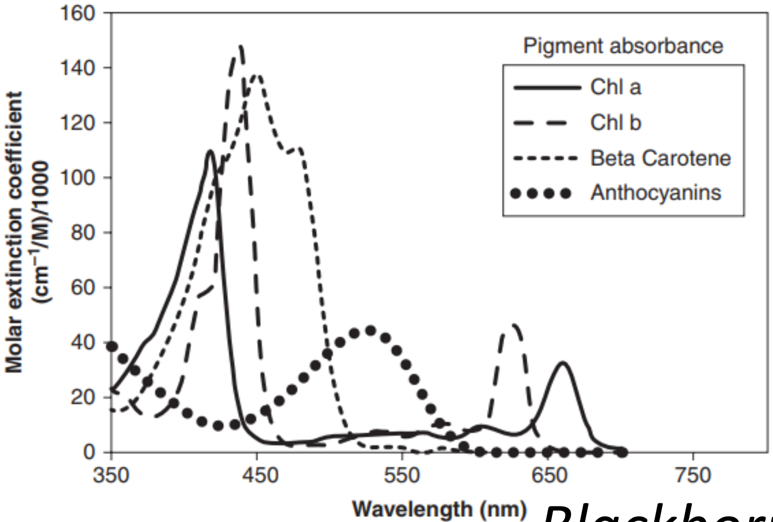
Remote sensing products compare well against flux towers, alternative GPP estimates



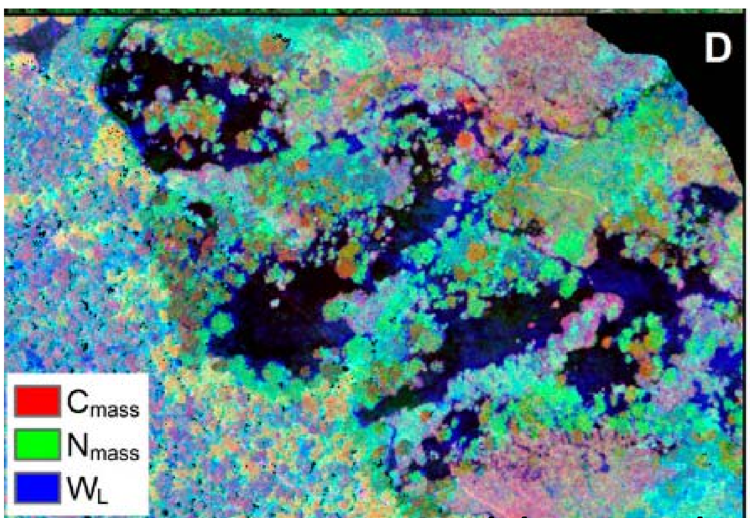
GOME-2
2009-present
0.5° resolution

TROPOMI
2017-present
0.05° resolution

RS3: Hyperspectral observations of plant traits



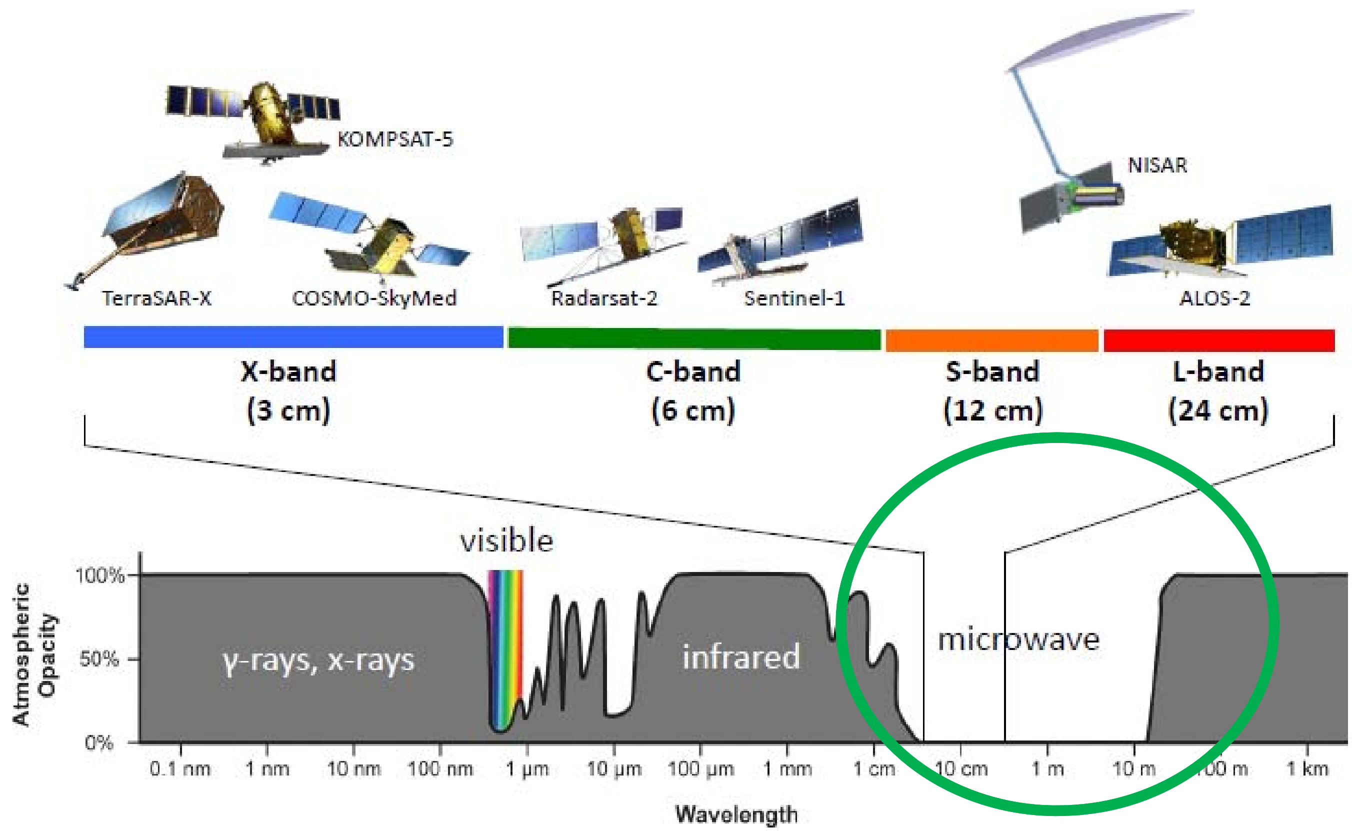
Blackborn 2007



Dahlin et al 2017

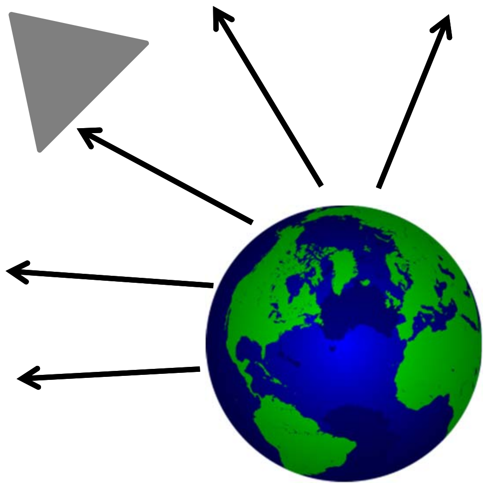
Leaf figure Phil Townsend

Microwave frequencies particularly useful



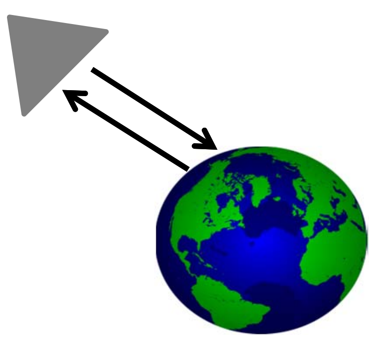
Microwave sensors: radars and radiometers

RADIOMETER (passive)



- Measure graybody emission
- Low resolution – O (10-100 km)

RADAR (active)



- Send wave, measure backscatter σ
- Low resolution scatterometers
- High resolution SAR – O (100 m)

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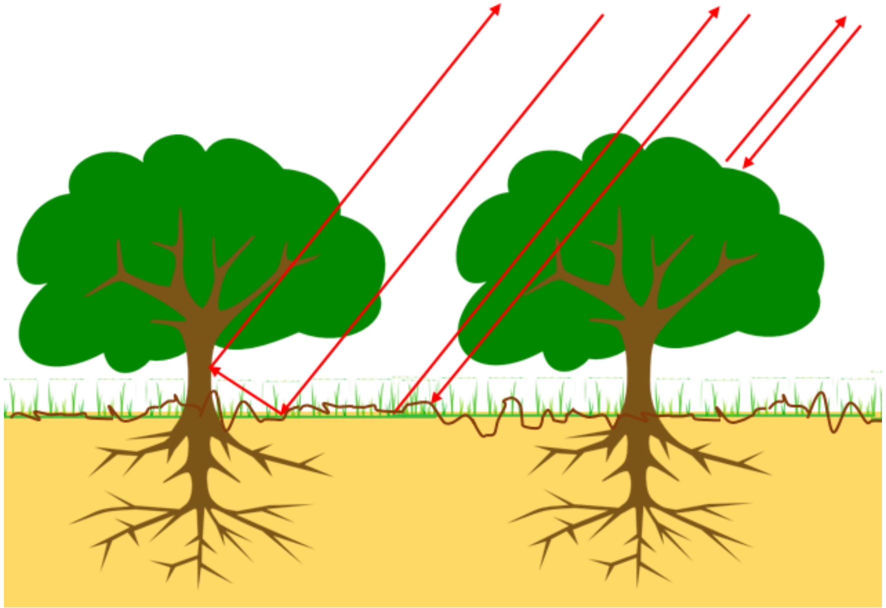
What influences signal?

Three main components to obs:

1) Scattering from vegetation
2) Direct scattering from soil (depends on moisture & others)
3) Interactions between soil and vegetation

→ all 3 are attenuated by water in vegetation!



What influences signal? (radiometry)

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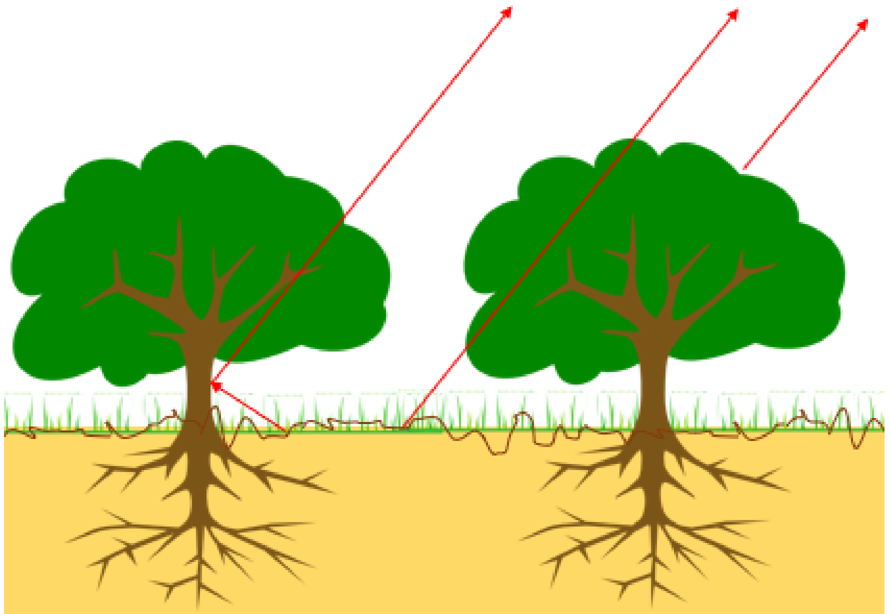
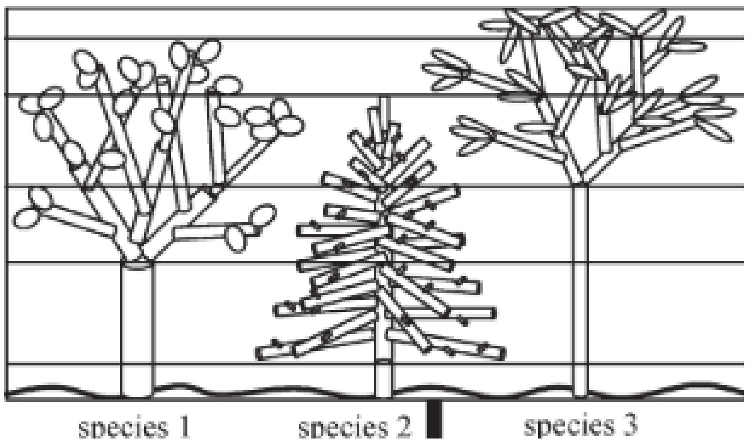


What influences vegetation attenuation?



Burgin et al, TGARS, 2011

The relevant parameters of the aspen canopy used in the model calculations are

canopy density: 0·11 trees m^{-2}	trunk height: 8 m
crown thickness: 2 m	trunk diameter: 24 cm
leaf density: 830 m^{-3}	trunk moisture: 0·5 (gravimetric)
leaf moisture: 0·8 (gravimetric)	branch density: 4·1 m^{-3}
LAI (single-sided): 5	branch length: 0·75 m
leaf diameter: 6·18 cm	branch diameter: 0·7 cm
leaf thickness: 0·03 cm	branch moisture: 0·4 (gravimetric)
soil r.m.s. height: 0·45 cm	soil volumetric moisture: 0·15
soil correlation length: 18·75 cm	soil type: silty clay

The leaves are considered to be randomly oriented, and the branches have an orientation uniform in ϕ_c and a PDF $p(\theta_c)$ in θ_c given by

$$p(\theta_c) = \begin{cases} \dfrac{\sin^4 2\theta_c}{\int_0^{\pi/2} \sin^4 2\theta'_c \, d\theta'_c} & \text{for} \quad 0 \leqslant \theta_c \leqslant \frac{1}{2}\pi \\ 0 & \text{otherwise} \end{cases} \qquad (7)$$

Ulaby et al, IJRS, 1990

Effect per element -> geometry, dielectric constant ε

ε = f(water content)

Vegetation attenuation depends on mass of H_20

Radio Science, Volume 13, Number 2, pages 357–364, March–April 1978

Vegetation modeled as a water cloud

E. P. W. Attema[1]

Radiometer

$$\gamma = \exp\left(\frac{-VOD}{\cos\theta}\right) = \exp\left(\frac{-b \times VWC}{\cos\theta}\right)$$

Radar

$$\gamma = \exp\left(\frac{-B_{pq} \times VWC^{\beta_{pq}}}{\cos\theta}\right)$$

A brief note on retrievals

More vegetation parameters in radar than in radiometric

→ VOD datasets are relatively more established

Radiometer

$$T_{B,p} = T_s \gamma (1 - r_p) + T_c (1 - \omega)(1 - \gamma)(1 + r_p \gamma)$$

Radar

$$\sigma_{pq} = A_{pq} (VWC^{\alpha_{pq}}) \cos\theta (1 - \gamma) + C_{pq} r_{pq} (VWC^{\delta_{pq}}) \sin\theta \gamma + \sigma_{pq} \gamma$$

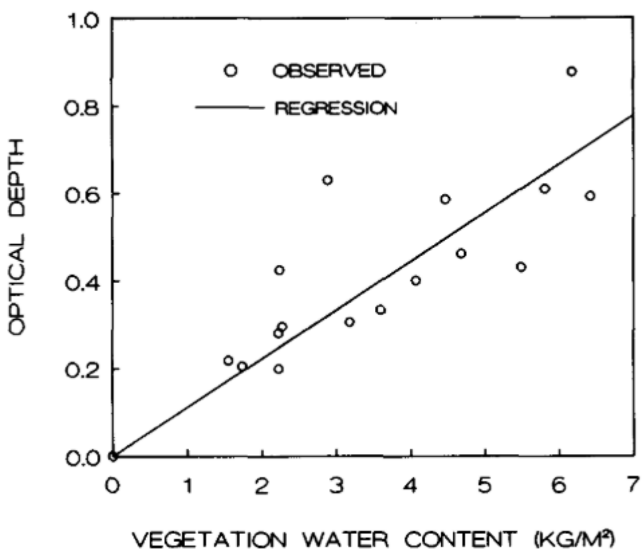
However, VOD retrieval also sensitive to other assumptions.

Not necessarily more reliable

Retrievals compare well w/ gravimetric field meas

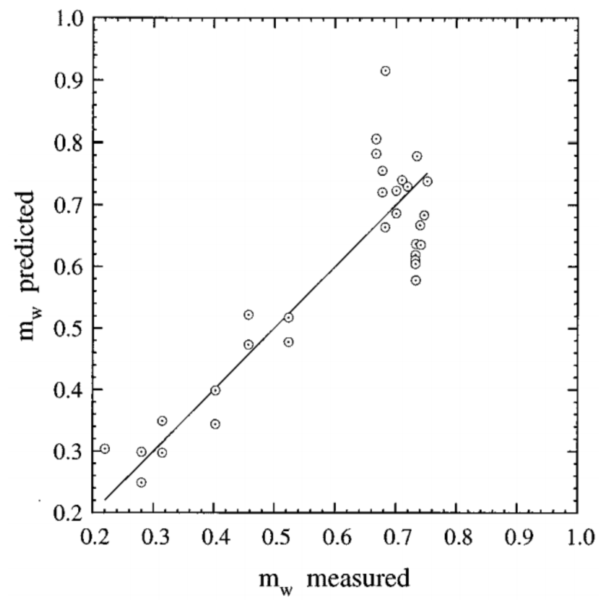
Ex for soybeans:

Radiometry



Jackson & O'Neill, RSE 1990

Radar



De Roo et al, TGARS 2001

…but confined to a few cover types

Source	*Cover Type*
Shutko (1986)	Broad leaf
Jackson and O'Neill (1990)	Corn
	Soybeans
Kirdiashev et al. (1979)	Winter rye
Ulaby and Wilson (1985)	Wheat
	Soybeans
Pampaloni and Paloscia (1986)	Alfalfa
	Corn
Ulaby et al. (1983)	Corn
Brunfeldt and Ulaby (1984)	Soybeans
Chukhlantsev and Shutko (1988)	Cereals Alfalfa
Jackson et al. (1982)	Corn
	Soybeans
O'Neill et al. (1983) pp	Corn
	Sweet sorghum
Wang et al. (1980, 1982)	Short grass
	Tall grass
Wang et al. (1990)	Tall grass
Matzler (1990)	Oats
Vyas (1990)	Broadleaf

Almost no forest measurements

Jackson & Schmugge, RSE 1991

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Almost no forest measurements

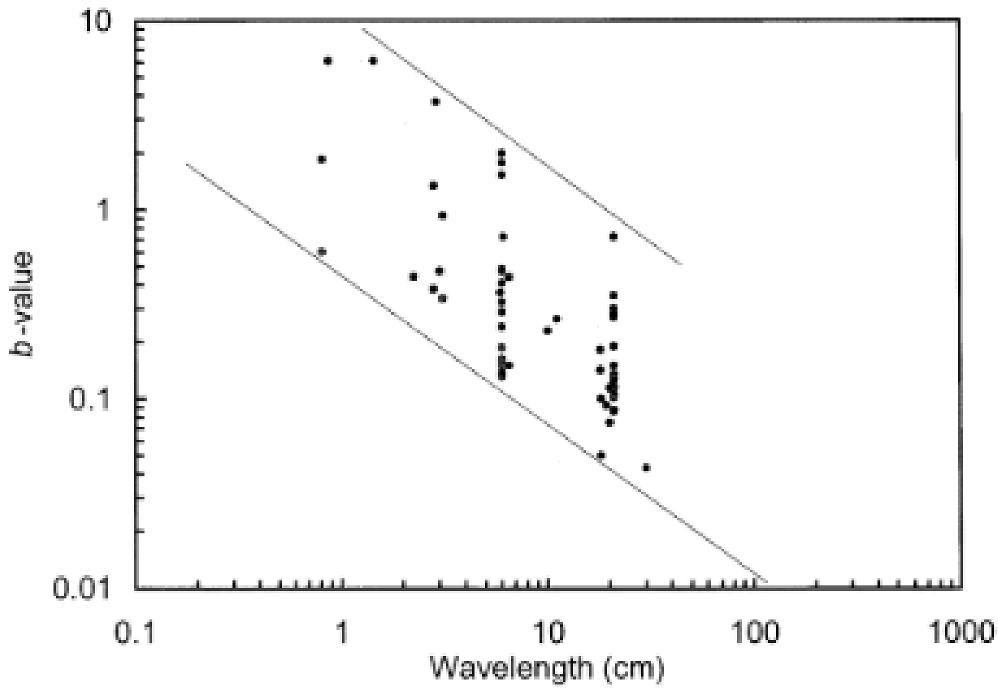
…some exist, but only partial tree meas

Jackson & Schmugge, RSE 1991

Overall relationship

VOD = b VWC

b-factor contains residual structure dependence



λ = 6 cm: b = 0.57 ±0.47

λ = 20 cm: b = 0.20 + 0.12

Van de Griend & Wigneron, TGARS 2001

Further interpretations of VWC

$$
\begin{aligned}
VWC = M_w &= \frac{M_w}{M_{tot}} \times M_{tot} \\
&= RWC \times AGB
\end{aligned}
$$

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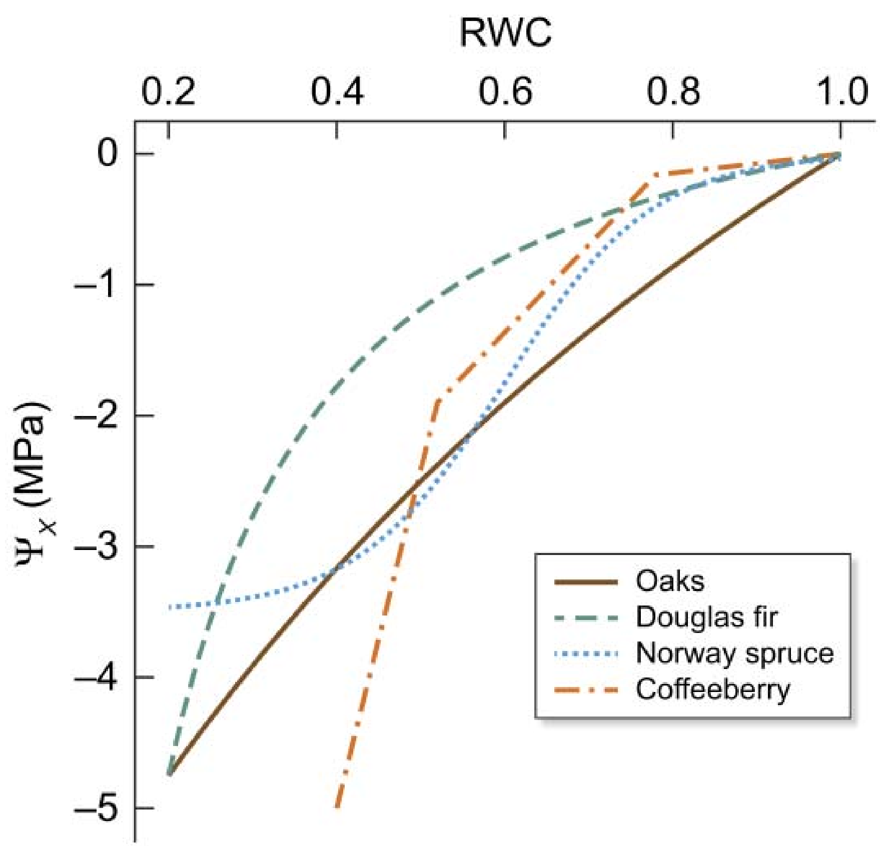
Can we go further towards hydraulics?

Xylem and leaf water potential more physiologically relevant

→ pressure-volume curves suggest the two should be related



Konings et al, New Phyto, 2019

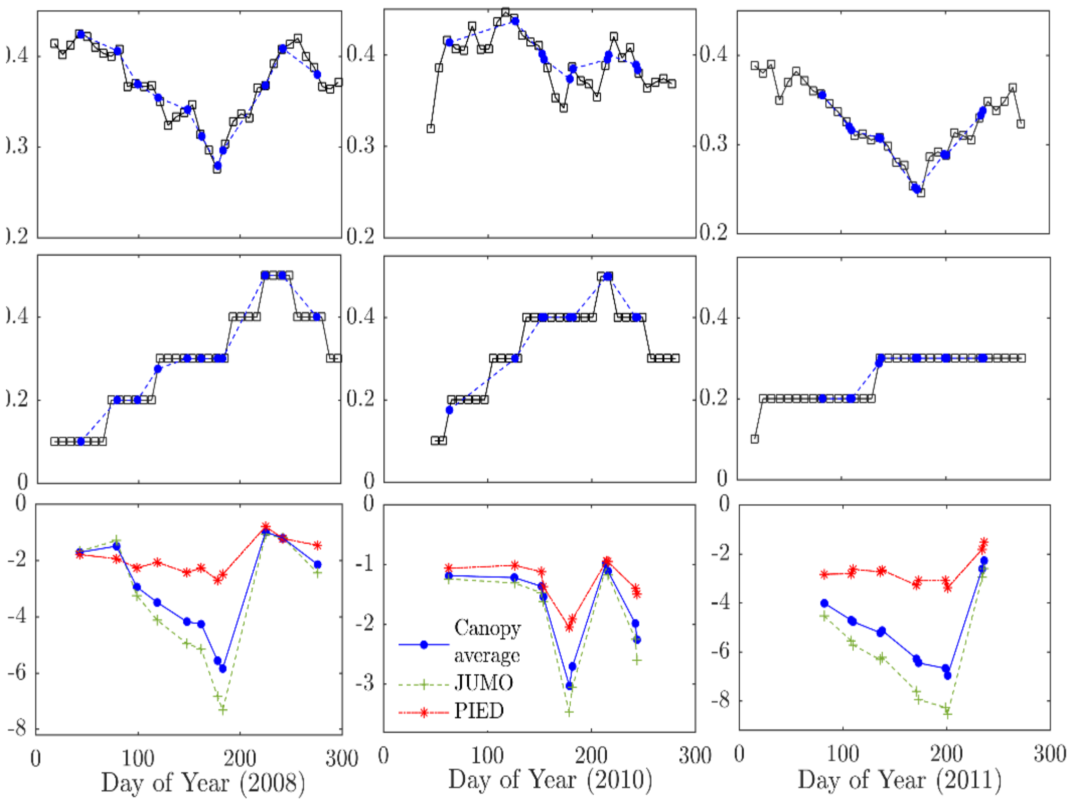
VOD seasonal dynamics co-vary with Ψ_L

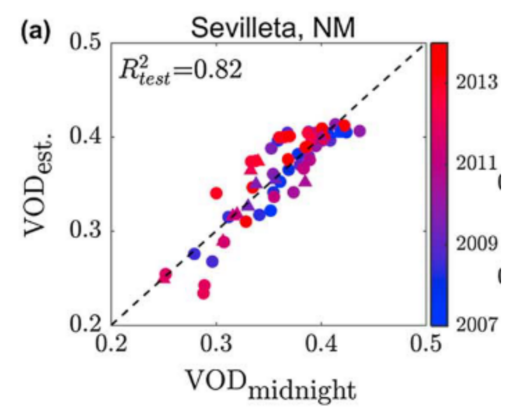
Ex: AMSR-E VOD for Pinion-Juniper woodland at Sevilleta, NM

VOD

LAI

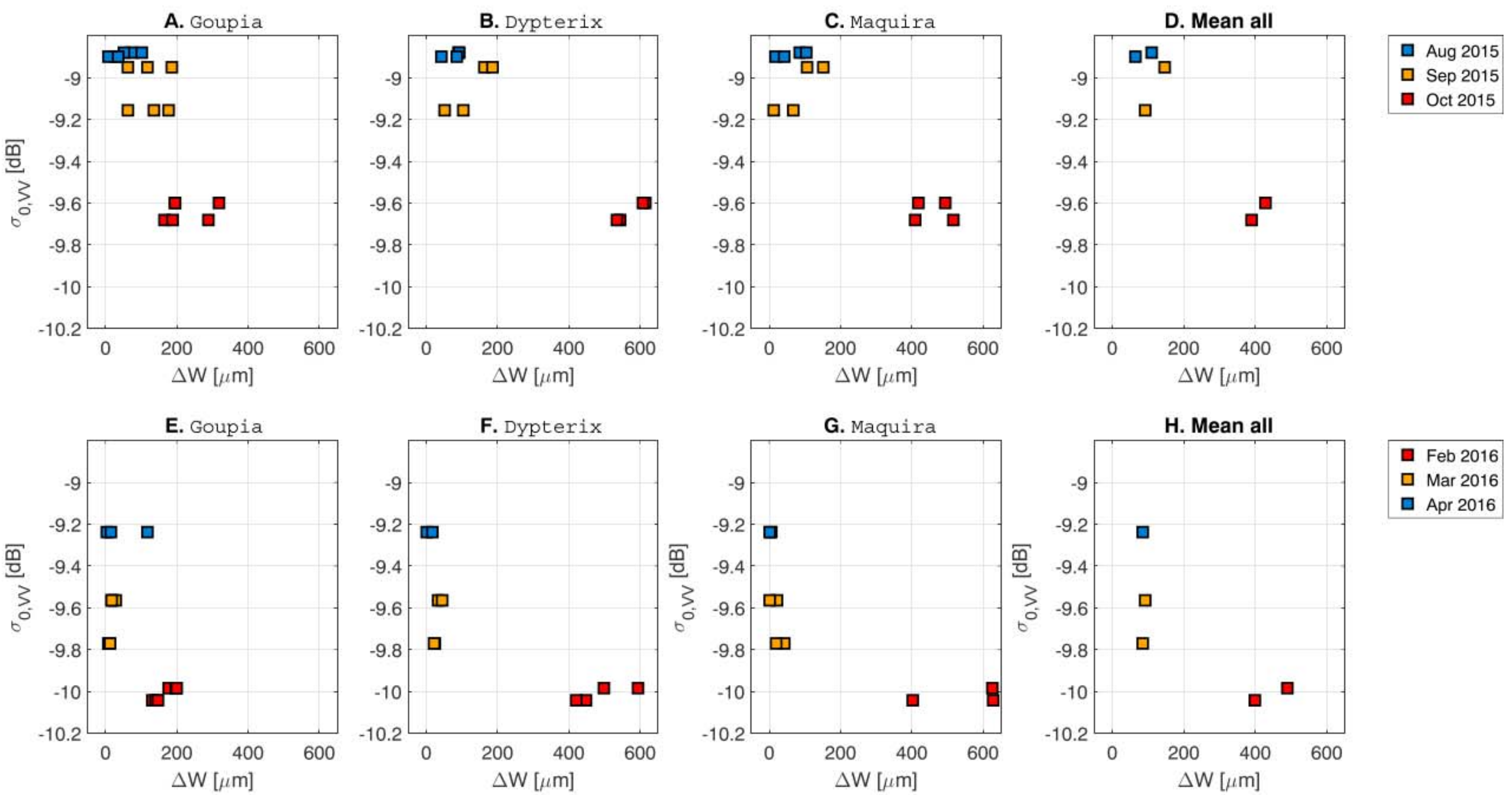
Ψ_L





Momen et al., JGR-B 2017

RapidScat σ and dendrometers at Manaus



Van Emmerik et al., GRL 2017

NB: High-frequency radar over wet tropics

→ assume μwave doesn't penetrate vegetation

→ no soil moisture influence

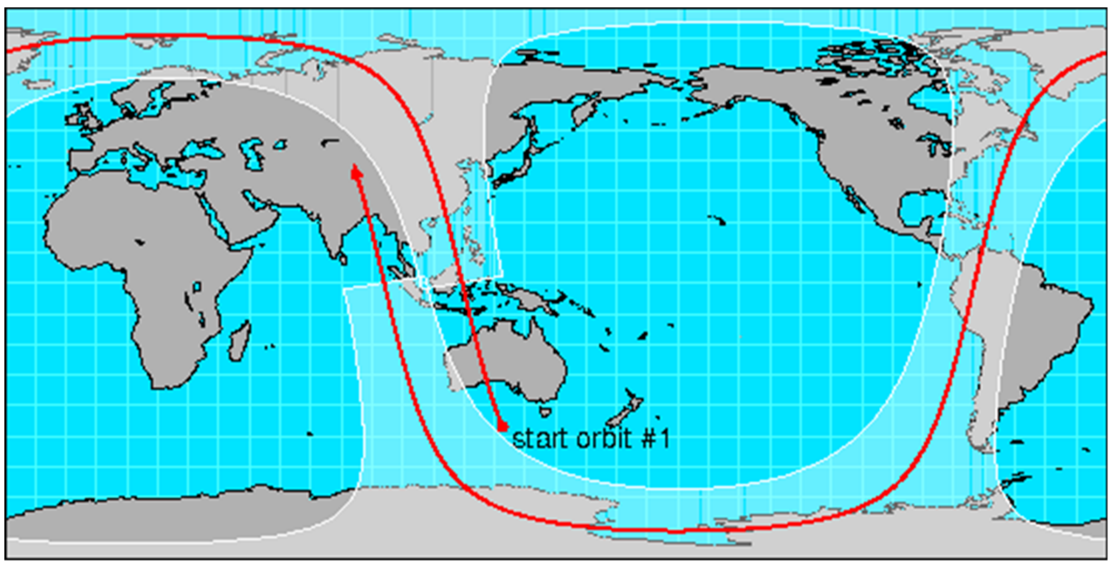
What about diurnal variations?

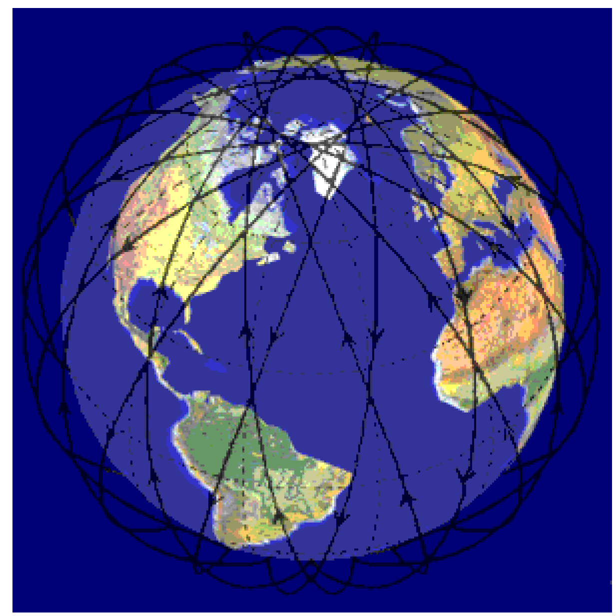
Most μwave satellites have low-earth, sun-synchronous orbit

→ same local time everywhere

→ twice daily measurements, 12 hrs apart

(usually 6:00 AM/PM or 1:30 AM/PM)

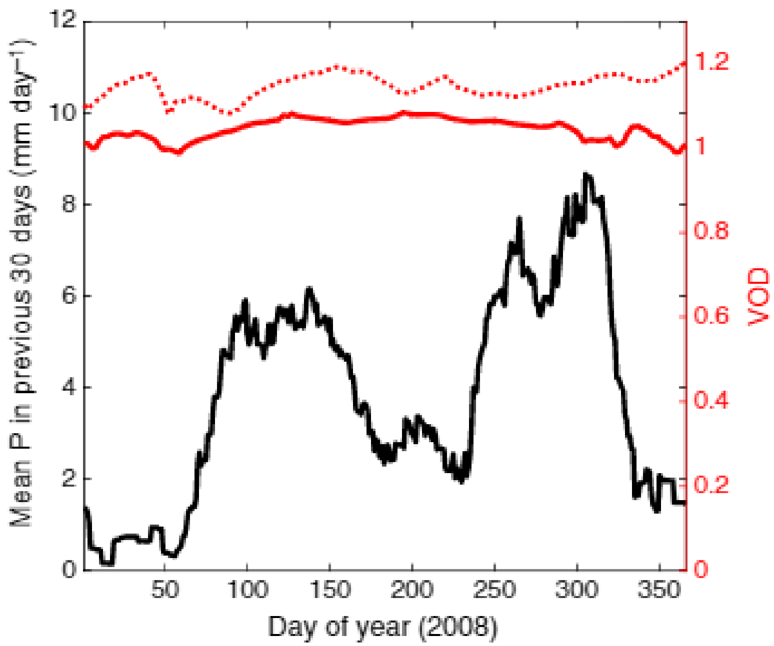




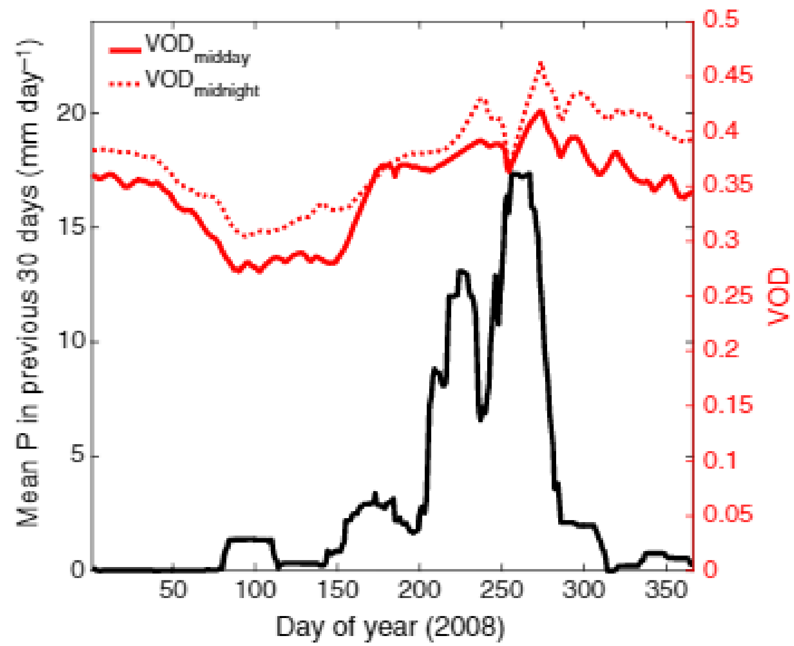
Mid-day VOD ‘drier’ than mid-night VOD

AMSR-E LPRM obs, at 1:30 AM & 1:30 PM

Central Africa



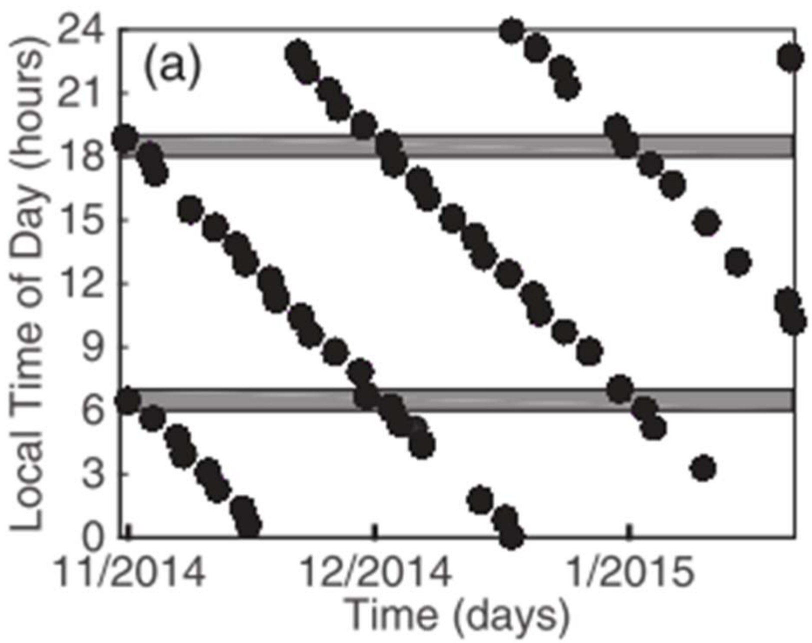
India



Konings and Gentine, GCB 2017

ISS shows further diurnal dynamics

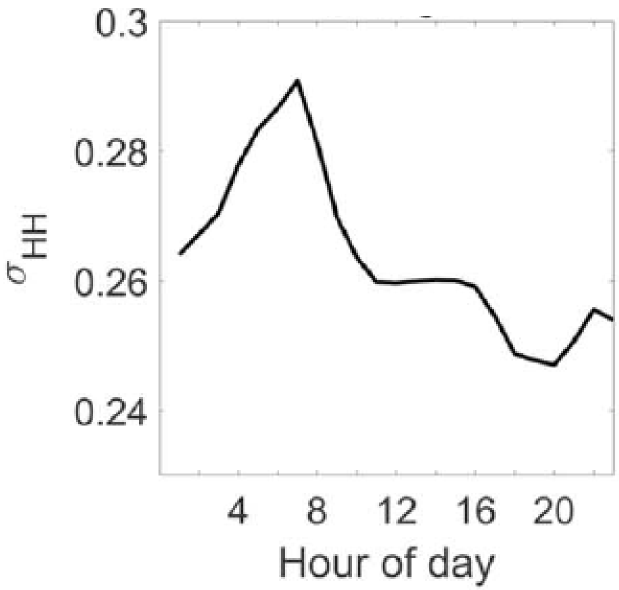
RapidScat orbit allows different local time of day for each observation



Paget et al, TGARS 2016

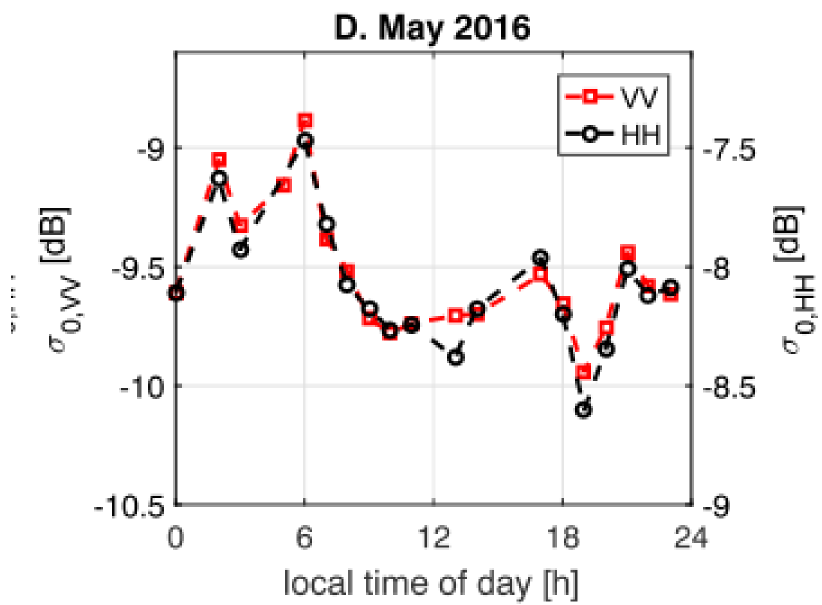
Diurnal cycle 'reasonable'

Average across Central African Rainforests, 10/2014-03/2016



Konings et al, GRL 2017

Single pixel in Manaus

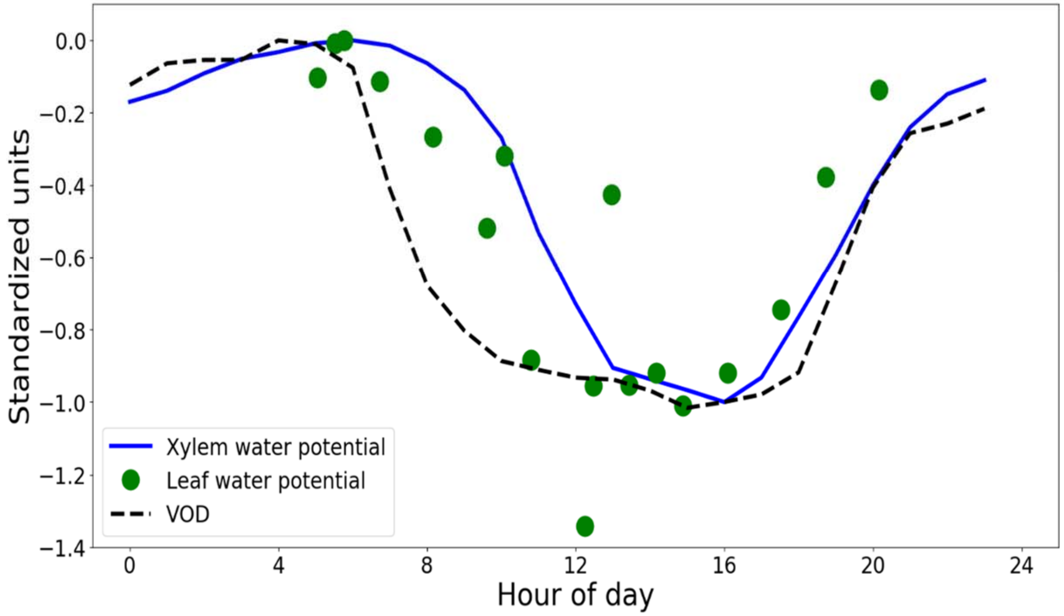


Van Emmerik et al., GRL 2017

Field experiment to reduce scaling error

Harvard Forest experiment summer 2019

Relatively homogeneous red oak canopy



ψ_L meas from 5 trees over 3 days

1 psychrometer

Long-term average diurnal cycle shown

Holtzman et al, in prep

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Why do people use VOD for biomass?

nature ecology & evolution
ARTICLES
PUBLISHED: 6 MARCH 2017 | VOLUME: 1 | ARTICLE NUMBER: 0081

Human population growth offsets climate-driven increase in woody vegetation in sub-Saharan Africa

LETTERS
PUBLISHED ONLINE: 30 MARCH 2015 | DOI: 10.1038/NCLIMATE2581
nature climate change

Recent reversal in loss of global terrestrial biomass

Global Ecology and Biogeography, (Global Ecol. Biogeogr.) (2013) **22**, 692–705
RESEARCH PAPER

Global vegetation biomass change (1988–2008) and attribution to environmental and human drivers

nature ecology & evolution
ARTICLES
https://doi.org/10.1038/s41559-018-0530-6

Satellite passive microwaves reveal recent climate-induced carbon losses in African drylands

etc…

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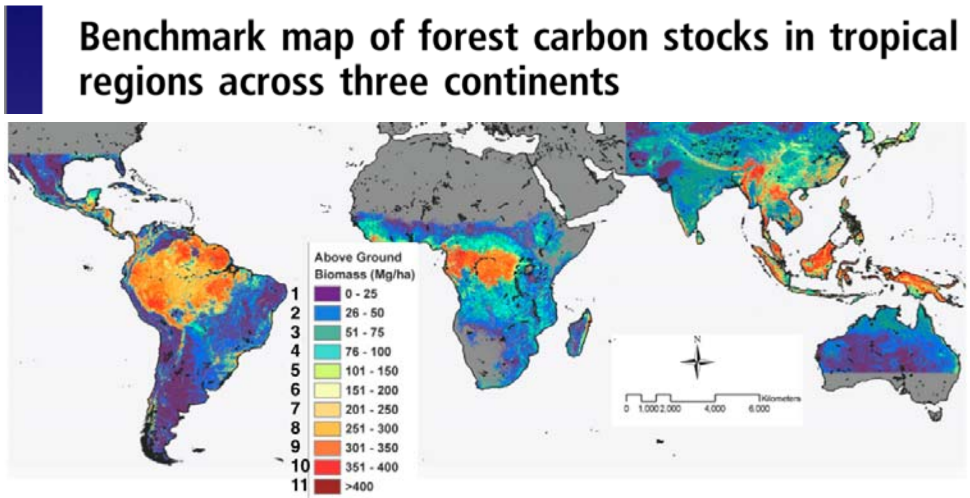
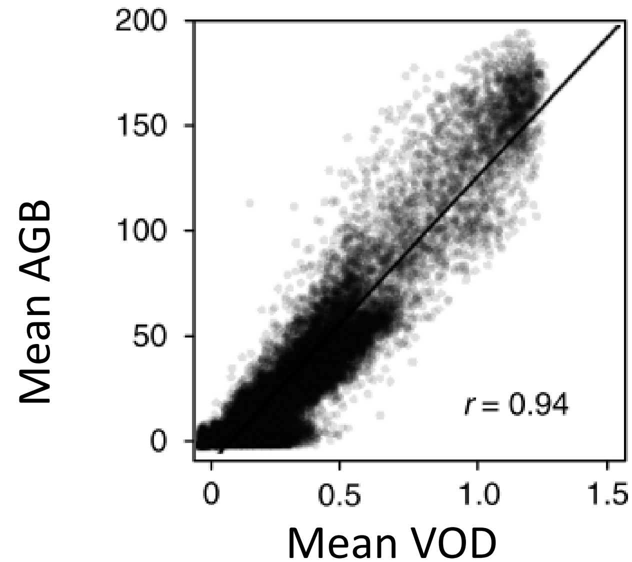




Saatchi et al, PNAS, 2011

Brandt et al, Nat EE, 2018

Recall

$$VOD = RWC \times AGB$$

Conclusions

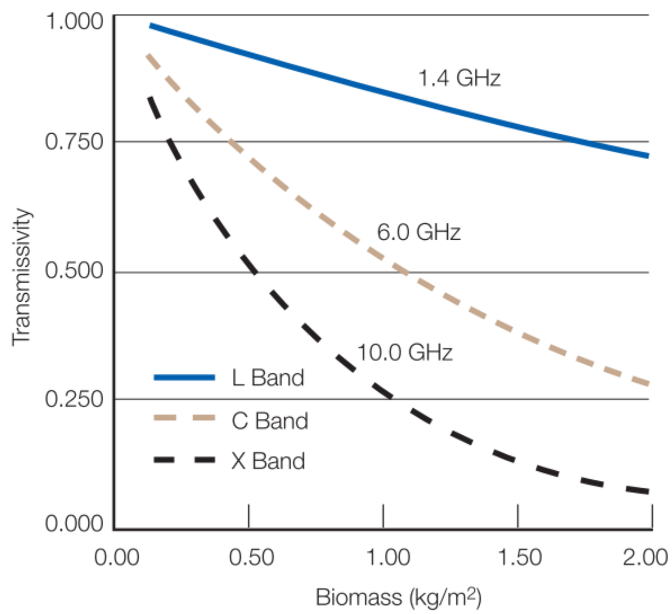
- There is empirical evidence going back decades demonstrating a relationship between microwave obs and vegetation water content … though little in forests
- Lots of indirect evidence is consistent with the idea that can see meaningful signal of plant hydraulics/water stress in microwave data, but no exact relationships
- Biomass is a conflating factor
- How can we validate this at scale?

Outstanding issues not covered

1) Role of dew, interception

2) Do retrieval parameters (e.g. b, radar) vary only spatially or also temporally?

3) Penetration, sensitivity to different tree components



SMAP handbook
Adapted from Ulaby et al 1991