Bridging the gap between carbon cycle models and remote sensing

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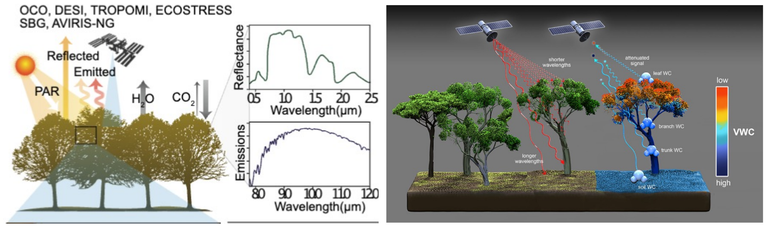
Introduction

To constrain land surface models parameters, or even more importantly, evaluate model structure, a direct link between models and remote sensing is required, literally taking out the middle-man that traditionally links these on an empirical basis [Shiklomanov et al., 2020].

The missing building block is the lack of a direct connection to remote sensing within the model structure itself. The land surface model within the CliMA initiative was built to directly link model prognostic and diagnostic variables with diverse remote sensing observations. This enables us to rigorously test model parameters and structure. This is a critical step towards the robust prediction in the changes of the coupled water and carbon cycles under global warming and CO_2 fertilization. We tackle this scientific challenge through the use of novel remote sensing and modeling approaches as well as field measurements of diurnal changes in plant water status and physiology.



Objectives

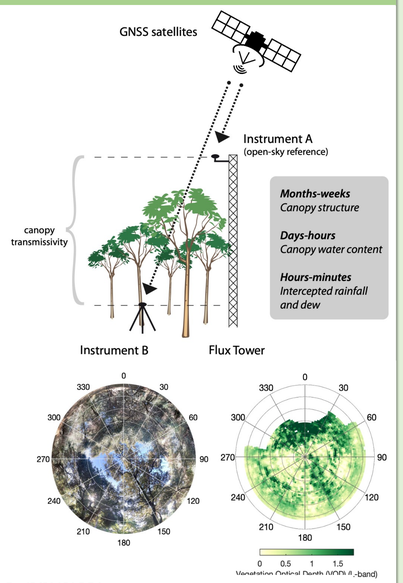
- Mechanistically link land surface model to remote sensed parameters
- Establish a super-site with high-frequency ecosystem flux measurements and novel physiological observations for satellite ground-truthing and model validation
- Establish early warning signs and drought vulnerability estimates for the central US forest.

Continuous canopy water content measurements

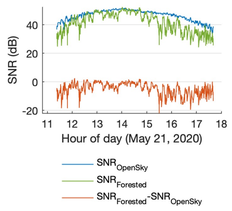
Novelty| We developed a new ground-based system to measure vegetation optical depths (and infer canopy water content) using a dual-antenna GPS system to measure GPS signal attenuation by a canopy.

The system was tested at the Huntington Gardens in Pasadena and has now been employed at the Ozark site in Missouri, building a Water Stress super-site.

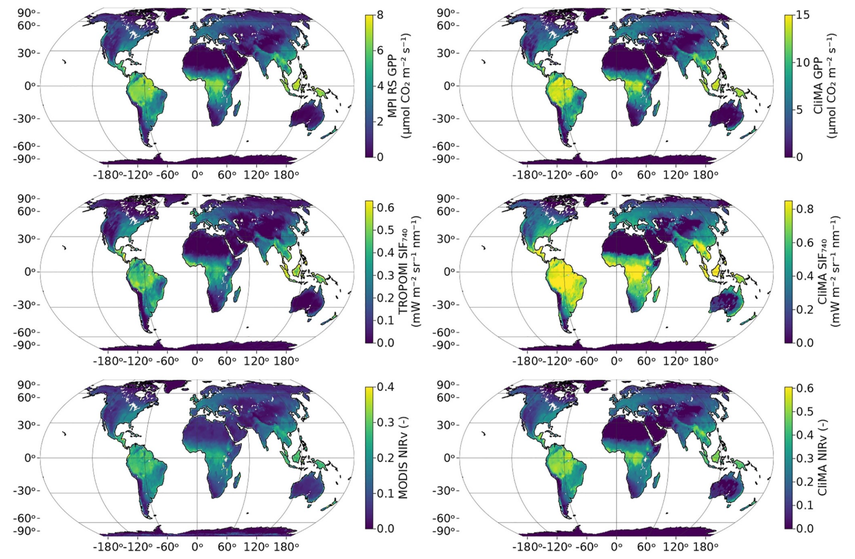
Measurement Principle| Each GPS satellite signal strength is tracked with both the open-sky and within-canopy attenuation. Matching pairs are used to compute optical depth within different viewing directions. Composites of diurnal, seasonal and annual time-scale changes of VOD and CWC can be constructed.



Canopy Water Content retrieval| We use a physical model of the canopy transmissivity to investigate the potential roles of canopy, volumetric density, water content, and temperature on the GNSS-based VOD measurements, assuming a homogeneous layer, with randomly distributed elements .



CliMA Land Surface model – Direct link to RS from space



Novelty| CliMA Land can now model a vertically resolved canopy, photosynthesis, transpiration and plant hydraulics, thus also canopy water content and changes in leaf optical properties. At the same time, a 4-Stream canopy radiation scheme enables direct computation of SIF, and hyperspectral reflectance using the same radiation code that drives APAR per leaf and the energy balance in a vertically resolved canopy.

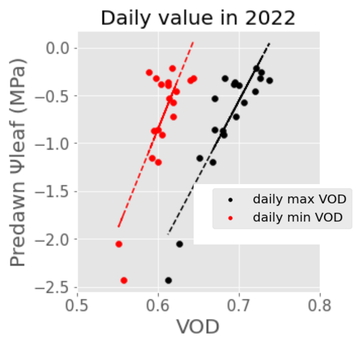
Key References

Humphrey, V. and Frankenberg, C., 2023. Continuous ground monitoring of vegetation optical depth and water content with GPS signals. Biogeosciences, in press

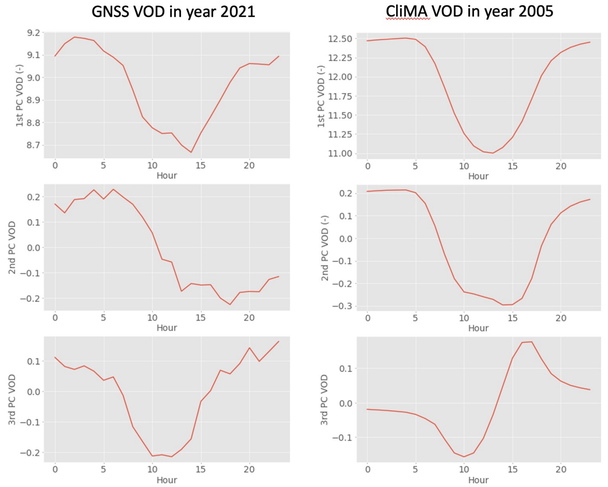
Wang, Y., Braghiere, R.K., Longo, M., Norton, A.J., Köhler, P., Doughty, R., Yin, Y., Bloom, A.A. and Frankenberg, C., 2023. Modeling global vegetation gross primary productivity, transpiration and hyperspectral canopy radiative transfer simultaneously using a next generation land surface model—CliMA Land. Journal of Advances in Modeling Earth Systems, 15(3), p.e2021MS002964.

Holtzman, N., Y. Wang, J.D. Wood, C. Frankenberg, and A.G. Konings. Constraining plant hydraulics with microwave radiometry in a land surface model: Impacts of temporal resolution. Hydrology and Earth System Science, submitted.

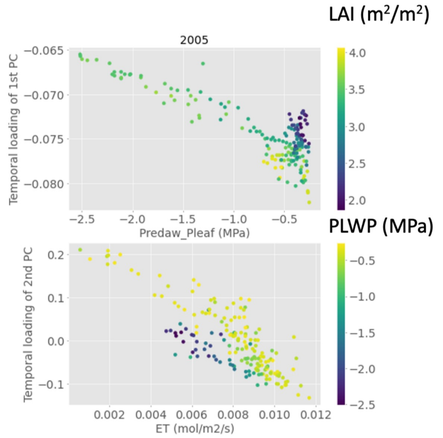
Field Site results from the Ozarks



VOD correlates well with predawn leaf water potential| At the Ozark site, pre-dawn leaf water potential (PLWP) is measured biweekly, presenting a unique opportunity to measure water stress and a proxy for root-zone soil matric potential directly and compare it against canopy VOD. We find a very strong linear correlation between VOD and PLWP at the Ozark site, underlining the promise of VOD to sense water stress through canopy water content measurements



Decomposition of VOD diurnal cycles | We decomposed the diurnal cycles of measured and modeled VOD using Singular Value Decomposition. For the measurements, we find that the first component represent mean VOD changes, the 2nd one a shift to a wetter morning (mostly related to dew) and the 3rd component to a deepening of the diurnal cycle amplitude. The model misses the dew component as it is not modeled, so the 2nd EV shows the deepening.



Power of SVD| Using the model, we confirm that the first EV represents PLWP (modulated by LAI of course) and that the amplitude of the diurnal cycle is tightly correlated with ET, with a send dependence of PLWP as well (as canopy conductance depends on the matric potential. We find the same relationship in our data, showing promise to measure ET and PWLP from a very simple GNSS system in the field continuously.

To summarize| We developed a Land surface model that inherently simulates remote sensing signal within its core radiation scheme. This holds for short-wave reflectance as well as microwave measurements.

In addition, we developed and tested a new continuous measurement system for canopy water content, which is robust and simple to deploy. The diurnal cycle in VOD reveals patterns that are related to dew formation and maximum rates of transpiration. The new model can simulate these processes using plant hydraulics and water storage capacity within canopies. At the Ozark site, we now have a unique set of measurements.

Impact of T| We show that the relationship between CVC and VOD can depend on leaf temperature in the L-band, which can hide reductions in CWC during heat events, which increase leaf T and deplete canopy water (but can stay similar in VOD). These effects will be important to consider