Working towards a global-scale functional relationship between vegetation optical depth and water content in forest areas

Jennifer Grant, Jean-Pierre Wigneron, Matthias Drusch, K. Bible, Peter D. Blanken, Danilo Dragoni, Thomas E. Kolb, Beverly E. Law, Tilden P. Meyers, Nathalie Novello, et al.

Working towards a global-scale functional relationship between vegetation optical depth and water content in forest areas

Grant, J.P.[1], Wigneron, J.-P.[2], Drusch, M.[1], Bible, K.[3], Blanken, P.D.[4], Dragoni, D.[5], Kolb, T.E.[6], Law, B.E.[7], Meyers, T.P.[8], Novello, N.[2], Kerr, Y.[9]

[1]European Space Agency (ESA-ESTEC), The Netherlands; [2]Institut National de la Recherche Agronomique (INRA-EPHYSE), France; [3]University of Washington, USA; [4]University of Colorado, USA; [5]Indiana University, USA; [6]Northern Arizona University, USA; [7]Oregon State University, USA; [8]National Oceanic and Atmospheric Administration (NOAA/ARL), USA; [9]Centre d'Etudes Spatiales de la Biosphère (CESBIO), France

Background

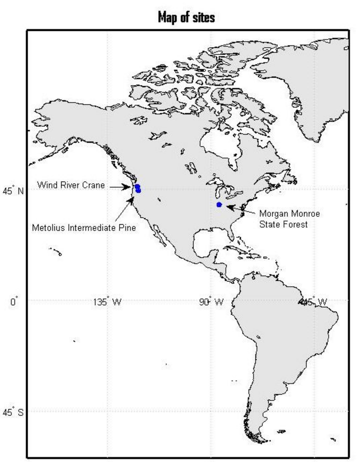
Vegetation optical depth is one of the parameters which can be retrieved from passive microwave observations over land, such as those made by ESA's Soil Moisture and Ocean Salinity (SMOS) mission. The optical depth is known to be related to vegetation biomass/structure and water content and is therefore potentially very interesting for vegetation modelling. This study focuses on the relationship between optical depth and gravimetric vegetation water content (M_g). Seasonal and diurnal variations of M_g are known to be related to plant water potential and ET. Obtaining global-scale information on M_g can therefore contribute to applications in the fields of climate, ecohydrology, and agriculture.

Methods

In this study, vegetation optical depth was retrieved from brightness temperature observations made by ESA's Soil Moisture and Ocean Salinity (SMOS) satellite mission. A number of FLUXNET forest sites in North America were chosen as focus areas (see map) and provided in situ data such as temperature, soil moisture, VPD and precipitation. The nearest most representative SMOS gridcell was selected for analysis. Optical depth was retrieved from L1C brightness temperatures by inversion of a simple radiative transfer model, L-MEB. The relationship between optical depth (τ) and vegetation gravimetric water content (M_g) is given in equation (1):

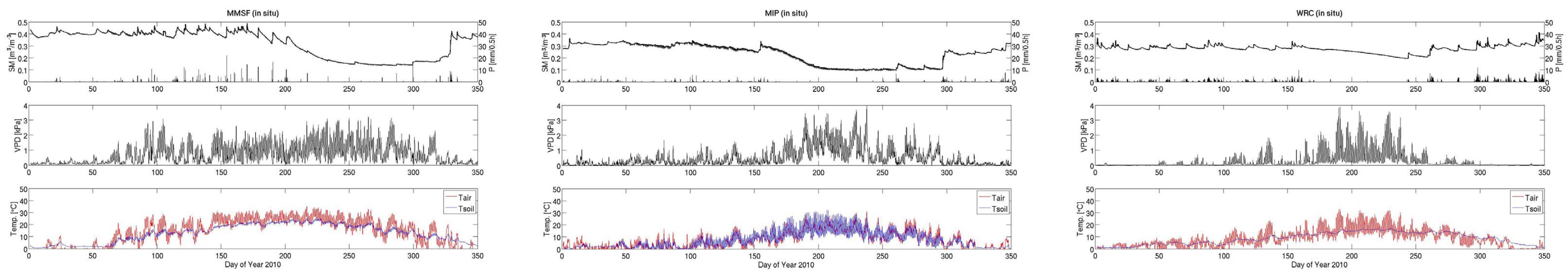
$$\tau = A \cdot \frac{B}{\rho_{veg}} \cdot k_0 \cdot \varepsilon''_{veg} \cdot \frac{1}{\cos 0^{\circ}} \qquad (1)$$

In this equation [Wegmüller *et al.*, 1995], A describes the structure of the vegetation, B is the fresh biomass per area [kg/m^2], ρ_{veg} the vegetation density [kg/m^3], k_0 the wavenumber and ε''_{veg} the vegetation dielectric constant. The latter parameter is a function of temperature, salinity, frequency, vegetation bulk density and gravimetric water content (M_g) expressed as [kg water/kg fresh biomass]. In this study, we used MODIS NDVI (MOD13A1) as a proxy for B/ρ_{veg}, and $A = 0.3$.

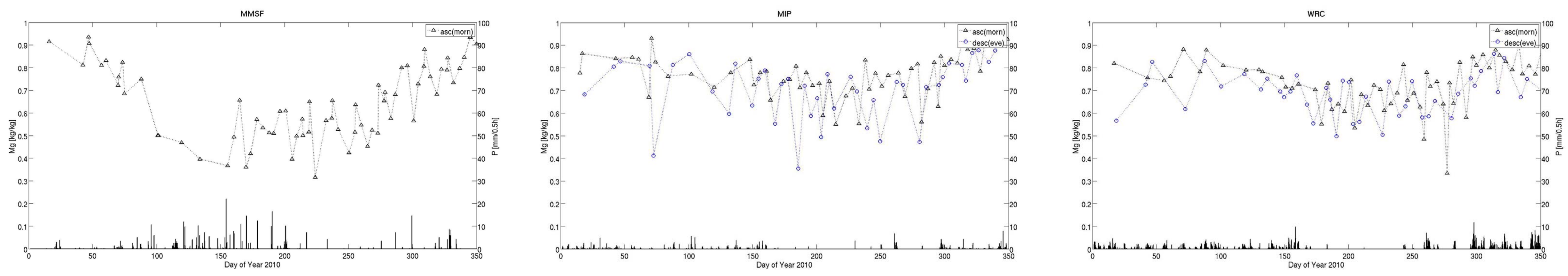


Morgan Monroe State Forest: Broadleaf deciduous	Metolius Intermediate Pine: Pine	Wind River Crane: Fir/hemlock

FLUXNET site values of soil moisture (SM), precipitation (P), vapour pressure deficit (VPD), and air & soil temperatures (Tair & Tsoil), based on in situ measurements



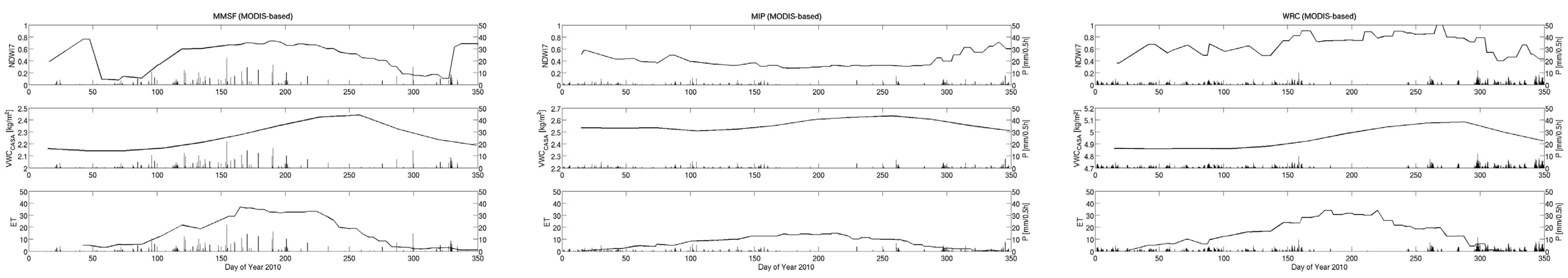
Timeseries (2010) of gravimetric vegetation water content (M_g) obtained from SMOS optical depth with eq. (1). SMOS has ascending (6:00 AM) and descending (6:00 PM) overpasses.



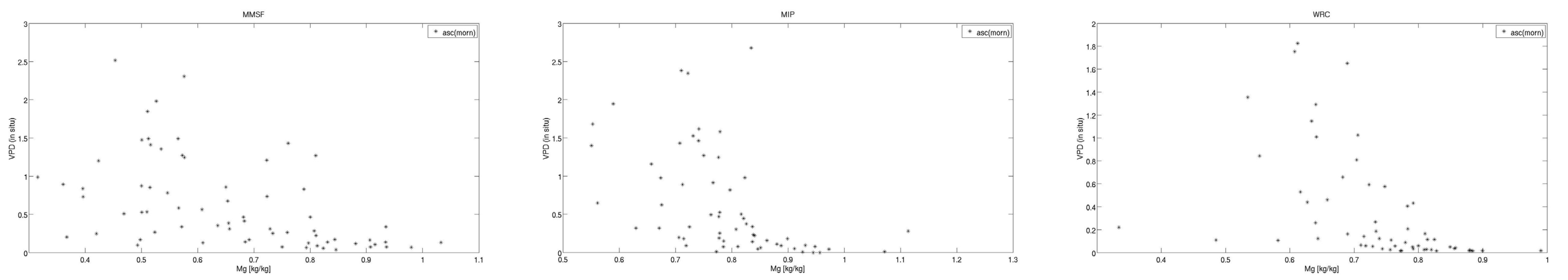
Timeseries (2010) of
- Normalized Difference Water Index

$$NDWI = (\rho_{NIR} - \rho_{SWIR})/(\rho_{NIR} + \rho_{SWIR})$$

using MODIS bands 2 (860 nm) and 7 (2130 nm)
- Vegetation Water Content: calculated with monthly dry biomass from the CASA model and literature values of the annual ratio dry/wet biomass for each vegetation type
- 8-day Evapotranspiration (MOD16A2)



Spearman's rank correlation coefficients for the relationship M_g - VPD:
MMSF: $\rho = -0.59$
MIP: $\rho = -0.66$
WRC: $\rho = -0.75$
(All with $p < 0.005$)



Conclusions

The range of resulting M_g values is in agreement with literature values, which generally range between 0.45-0.85, depending on vegetation type, status and material. However it should be noted that validation of M_g values is still lacking. The morning values of M_g (ascending orbits) found here are not always higher than the evening values. More investigation is needed to determine whether this is due to geophysical effects or to instrumental factors. It seems that there is some correlation of M_g with VPD, and that this is generally higher for the morning observations.

In general, the results indicate that when biomass increases during the summer period, even though the amount of vegetation water per area increases, the gravimetric vegetation water content [kg water/kg fresh weight] decreases. The latter effect is assumed to be a result of higher net radiation and evapotranspiration, and lower soil moisture conditions during summer. Therefore, the timeseries of M_g show opposite seasonal behaviour to those of NDWI or VWC-CASA. M_g derived from the vegetation optical depth can thus give different, and complementary, information to optical-based remote sensing observations of vegetation water status.

Future research

Future plans include extending this study to provide global scale maps of gravimetric vegetation water content (M_g). To this end, M_g values will need to be validated and model parameters (e.g. A and B/ρveg) calibrated per global vegetation type. Also, more investigation into the temporal patterns of M_g is needed.

MODEL WANTED: I am looking for a model which can produce global- or regional-scale values of Mg, or any parameter linked to M_g (e.g. sapflow, VPD, ET, plant water potential, etc.). If you work with, or know of, such a model then please let me know! (jennifer.grant@esa.int)