WORKING TOWARDS A GLOBAL-SCALE VEGETATION WATER PRODUCT FROM PASSIVE MICROWAVE OPTICAL DEPTH

Jennifer Grant¹, Marko Scholze¹, Mathew Williams², Jean-Pierre Wigneron³, Yann Kerr⁴

¹Lund University, Sweden; ²University of Edinburgh, Scotland; ³INRA, France; ⁴CESBIO, France
VEGWAC project

- Global-scale dynamic monitoring of VEGetation WAter status for improving Carbon flux estimates

- European Space Agency (ESA) STSE Changing Earth Science Network project, started Feb. 2013

- Objectives:
  - Derive temporally dynamic, global-scale maps of vegetation water from SMOS observations (L4 product)
  - Use this as input in terrestrial ecosystem model + carbon assimilation scheme (BETHY-CCDAS) to improve CO₂ estimates
Vegetation optical depth ($\tau$)

- This study: SMOS satellite, L-band ($\lambda = 21$ cm), 40 km resolution

- Passive microwave land products derived from $T_B$:
  - Soil moisture
  - Vegetation optical depth

- Passive microwave vegetation optical depth ("$\tau$" or "VOD")
  - Measure of vegetation canopy transmissivity
  - Related to vegetation density, structure, water content / dielectric properties
Vegetation monitoring; microwaves vs. optical

- Vegetation information at microwave frequencies different from, but complementary to, that at optical wavelengths

![MODIS EVI - July 2010](image1)
![MODIS EVI - December 2010](image2)

![Vegetation Optical Depth - July 2010](image3)
![Vegetation Optical Depth - December 2010](image4)
Vegetation Water Status (VWS)

- One of the main controls on photosynthesis & transpiration, i.e. is link between global carbon & water cycles

- Currently:
  - global-scale quantitative dynamic information on VWS does not exist
  - vegetation water reservoir is not well accounted for in terrestrial ecosystem models
Vegetation water product

- Gravimetric vegetation water content $M_g$ [kg/kg]
  - Biomass independent, whereas VWC [kg/m$^2$] is not
    (e.g. NH summer: VWC ↑, $M_g$ ↓)
  - Measure of VWS

- Potential applications:
  - Water stress/drought monitoring
  - Agriculture
  - Landscape ecology
  - Terrestrial biosphere modelling
  - Climate studies
  - etc...
Basic methodology

• Effective medium approach (Wegmüller, 1994):

\[
\tau = A_p \cdot \frac{B}{\rho_{veg}} \cdot k_0 \cdot \varepsilon''_{veg} \cdot \frac{1}{\cos(\theta)}
\]

\(\tau = \) optical depth, \(A_p = \) veg. geometry, \(B = \) biomass, \(\rho_{veg} = \) veg. density, \(k_0 = \) wave number, \(\varepsilon''_{veg} = \) (imag.) veg. dielectric constant, \(\theta = \) incidence angle

• Vegetation dielectric constant (Ulaby & El-Rayes, 1987):

\[
\varepsilon''_{veg} = f(T, S, f, \rho, M_g)
\]

\(T = \) temperature, \(S = \) salinity, \(f = \) frequency, \(\rho = \) veg. bulk density, \(M_g = \) gravimetric vegetation water content [kg/kg]
Methods/materials (global-scale)

\[
\tau = A_p \cdot \frac{B}{\rho_{veg}} \cdot k_0 \cdot \varepsilon''_{veg} \cdot \frac{1}{\cos(\theta)}
\]

- \(\tau\) = from SMOS L3 data (25 km global grid)
- \(A_p\) = fitting parameter (0.7 or calibrated per site)
- \(B/\rho_{veg}\) = approximated by MODIS EVI
- \(k_0\) = calculated for 1.4 GHz
- \(\varepsilon''_{veg}\) = calculated according to Ulaby & El-Rayes -> Gives \(M_g\)
- \(T_{veg}\) = approximated by ECMWF \(T_{skin}\) (in SMOS data)
- \(1/\cos(\theta)\) = n.a. for SMOS (\(\theta = 0\))
Average Vegetation Water Content [kg/kg] - February 2010
Preliminary results (global)

+ Values/patterns in southern US/Mexico, Andes and Australia as expected
X Patterns in S-Africa
? July values too low in midwestern US/Canada? (cornbelt -> irrigated?)

-> Needs calibration/validation - per vegetation type!
Cal/val strategy

- $M_g$ not routinely measured in situ (destructive, no timeseries);

**Q: How to validate global maps of $M_g$?**

**A:** Use proxy variable which is also indicator of VWS: Leaf Water Potential (LWP)

- Model LWP with Soil-Plant-Atmosphere (SPA) model (Williams et al., 1996)
- Use 11 FLUXNET sites, each covering different global (UMD) vegetation class
- Use $A_p$ as fitting parameter; calibrate per vegetation class
- 2010-2011 = calibration, 2012-2013 = validation
Methods/materials (site)

Best-fit criteria:

- Positive (linear) correlation
- Highest $R^2$
- $M_g$ in range [0-1]
- $M_g$ values comparable to lit.
- Temporal patterns as expected

\[
\tau = A_p \cdot \frac{B}{\rho_{veg}} \cdot k_0 \cdot \varepsilon''_{veg} \cdot \frac{1}{\cos(\theta)}
\]
Results: Mead

- UMD veg. type: crops
- Location: Nebraska, USA
- SPA validation with (hourly) Fluxnet data:
  - $R^2$ GPP = 0.57
  - $R^2$ LE = 0.73
- Best fit $A_p = 0.3$

(In situ data: AmeriFlux/Andrew Suyker)
Results: Metolius Intermediate Pine

- UMD veg. type: evergreen needleleaf
- Location: Oregon, USA
- SPA validation with (hourly) Fluxnet data:
  - $R^2$ GPP = 0.83
  - $R^2$ LE = 0.66
- Best fit $A_p = 1.2$

(In situ data: AmeriFlux/Beverly Law)
Discussion

• Preliminary results reasonable
  • global maps: within correct $M_g$ value range, spatio-temporal patterns +/-
  • site-scale results: reflect general temporal dynamics of LWP (proxy, different spatial resolution)

• Improvement expected through better data filtering (geophysical & technical factors), adding more years & sites

• Main issue: validation of $M_g$! (TRY?)
Summary & outlook

• VW maps = novel RS-based vegetation product; provides complementary info to commonly-used optical vegetation indices (e.g. LAI, NDVI, etc.)

• Simple but physically-based method, can be used at global scale and at site scale

• Range of potential applications

• Relevant for (potential) future EO land missions Sentinel-2, BIOMASS and FLEX (ESA), and SMAP (NASA)

• Future: long-term, multi-sensor timeseries (e.g. with AMSR-E etc.) -> longer term climate studies
THANK YOU!

-> questions?
-> comments/suggestions welcome!

jennifer.grant@nateko.lu.se