ON THE POTENTIAL OF ACTIVE AND PASSIVE MICROWAVE REMOTE SENSING FOR TRACKING SEASONAL DYNAMICS OF EVAPOTRANSPIRATION

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ABSTRACT

Tracking seasonal dynamics of evapotranspiration (ET) across global biomes and along seasonal time periods using remote sensing is vital for monitoring ecosystem health and indicating early signals of drought. In this study, we assess the potential of adding weather and illumination-independent signals from active and passive microwave remote sensing (SAR backscatter & vegetation optical depth, VOD) to the established set of ET products, like from optical/thermal remote sensing (MODIS, SEVIRI) and reanalysis (ERA-5 land, GLDAS) data.

Our study covers a four-year period (2017-2020), including dry (2018 & 2019) and wet (2017) years. The study was conducted over eight ICOS sites across Europe. These sites are predominantly forested with a low biomass dynamic over the observation period.

We find that the ET products from in situ Eddy Covariance (EC), MODIS, and GLDAS deviate relatively minor along the seasons (< 1 [mm/day]), but differ between years. Here, the years (2017-2020) indicate a slightly different ET rate between in situ measurements (EC) and derived products (MODIS & GLDAS), which is currently being investigated. The microwave-based indicators (backscatter & VOD) are proxies by their nature and serve as first-order indicators of relative dynamics allowing the identification of seasonal patterns of ET as well as their spatio-temporal anomalies along both dry and wet years.

***Index Terms*—** microwave, SAR, radiometry, evapotranspiration, seasonal dynamics.

1. INTRODUCTION

Land-atmosphere dynamics are of crucial importance in understanding exchanges of matter and energy in the water and carbon cycles [1]. Hence, their uptake, consumption, and release should be monitored for a holistic ecosystem survey. Evapotranspiration (ET) is one of the essential variables to inform about these dynamics [2]. Tracking ET in time and space, meaning at seasonal to multi-year scales and for wide areas, calls for a satellite remote sensing approach [3]. In this study, we are tracking ET not only with classical techniques from optical/thermal sensing, but also open a discussion, if new observation domains, like active and passive microwave remote sensing, are able to provide additional insights. We also include ET estimates from several Earth system modeling approaches (partly including data assimilation) and in situ eddy covariance (EC) measurements for comparison and validation purposes.

2. DATASETS

In the case of optical/thermal remote sensing, we use the ET products from NASA's MODIS sensor on Terra [4], from ESA's SEVIRI sensor on Meteosat (MSG) [5] as well as from NASA's ECOSTRESS sensor on the International Space Station (ISS; [6]). For microwave remote sensing, we apply the backscatter product of ESA's Copernicus Sentinel-1 C-band SAR [7] sensor and the vegetation optical depth (VOD) product of NASA's SMAP L-band [8] and JAXA's AMSR2 X-/C-band radiometer sensors [9]. In the case of Earth system modeling, we include the ET products of NASA's Global Land Data Assimilation System (GLDAS) [10], of Global Land Evaporation Amsterdam Model (GLEAM v3) [11] and of European Centre for Medium-Range Weather Forecasts (ECMWF) European ReAnalysis (ERA5) land [12]. The spatial domain for comparison is 3 km x 3 km and products are re-gridded accordingly depending on product specifications.

Our research study comprises the period from 2017 until 2020 (4 years) including dry (2018 & 2019) and wet (2017) years. The study covers eight ICOS sites [13] in Europe from France, Switzerland, Belgium, Germany, the Czech Republic, and Finland. These sites are predominantly forested (evergreen needle-leaf, deciduous broad-leaf and mixed forests) with a low biomass dynamic over the observation period. In addition, a grassland and an agricultural site are included as a control group with high biomass dynamics over time.

3. METHODS

We test temporal dynamics, their absolute trends, and relative anomalies over time, for tracking dry and wet periods in Europe across the four consecutive years and all individual sites. We evaluate the match between the remote sensing estimates, the modeling outputs and the in situ EC measurements. In this contribution, we particularly focus on the potential of active and passive microwave observations (e.g., backscatter) and products (e.g., VOD) to track ET.

Microwaves are sensitive to the structure, biomass, and moisture of vegetation canopies. Therefore, a monitoring setup with grown-up forests is chosen here to keep woody biomass dynamics and structure influences low and to follow the water dynamics in the canopy over time. We hypothesize that they might correlate at seasonal scales with ET dynamics. How far this correlation holds and under which conditions is the main pillar of our current and future research efforts. Such conditions include medium parameters (e.g., climate, biomes, and species) and system parameters (e.g., frequency, incidence angle, and polarization).

4. RESULTS AND DISCUSSION

Figure 1 presents an exemplary comparison of the seasonal dynamics of the different ET products and in situ EC measurements with the Sentinel-1 (C-band, VH-polarized) backscatter and the AMSR2 (C-band) VOD product. The comparison is shown from January 2017 to December 2020 over the Wuestebach study site (Western Germany; 50.50ºN, 6.33ºE) of the Forschungszentrum Jülich. This site is characterized by a homogenous and mature evergreen needle-leaf forest. Therefore, no significant structural and biomass changes are expected over time. The concurrency of all curves in terms of summer maxima and winter minima encourages the closer investigation of all signals for tracking seasonal ET dynamics.

The ET products from in situ EC, MODIS, and GLDAS serve as direct measures of this land-to-atmosphere flux in millimeters per day. Their deviation along the season is relatively small (< 1 [mm/day]), but differs between years. Here, the years (2018-2020) indicate a slightly different ET rate between in situ measurements (EC) and derived products (MODIS & GLDAS), which is currently being investigated. First indications point toward the spatial scale mismatch between EC tower measurement and the footprint (single resolution cell) of the remote sensing or model domains.

The microwave-based indicators (backscatter & VOD) are proxies by their nature and serve as first-order indicators of relative dynamics, as found in [14]. The focus of this work is the assessment of whether they could allow identifying seasonal patterns of ET as well as their spatio-temporal anomalies along differing dry and wet years. We investigate this potential for all eight individual study sites and across four years by intercomparing the microwave indicators with the concert of evapotranspiration products and measurements as well as with all available auxiliaries (e.g., precipitation, LAI, air temperature).

Figure 2 presents a comparison over the Wuestebach study site in Western Germany and all years (2017-2020) showing correlation (scatterplots) of specialized ET products from remote sensing (MODIS, SEVIRI), from reanalysis data (ERA5-land) and Sentinel-1 backscatter (VH, VV) and VOD (AMSR2) compared with in situ ET data from the EC tower. Colors in Fig. 2 indicate coverage by leaves using the MODIS LAI product. It is obvious that there is a significant drop in correlation moving from specialized products to proxies from microwave observations, but the latter are level-1 observations (backscatter) and level-2 derivates (VOD). At the conference, we will provide an outlook on further developments and potentials to track ET in terms of active and passive microwave sensing in the light of upcoming satellite missions of NASA (e.g., NISAR) and ESA (e.g., CIMR, LSTM & Rose-L) [15-17].

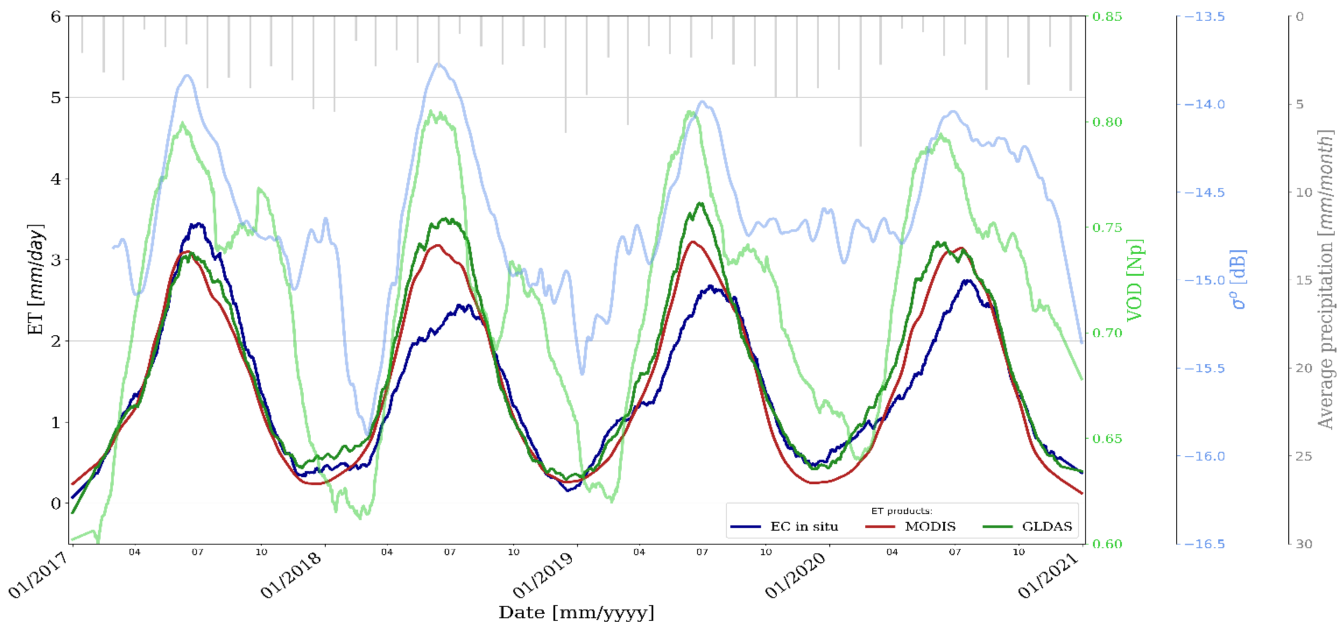

Figure 1: Seasonal dynamics of evapotranspiration [mm/day] from in situ measurements (ICOS Eddy Covariance tower), optical remote sensing (MODIS), and Earth system modeling, including data assimilation (GLDAS) are compared to VH-polarized C-band (5.4 GHz) SAR backscatter (Sentinel-1) [dB] and C-band (7.3 GHz) AMSR2-derived vegetation optical depth (VOD) [Np]. The study is conducted for the period 2017-2020 for an evergreen needle-leaf forest in Wuestebach, Western Germany (6.33ºE, 50.50ºN). All curves are cleaned for daily to weekly dynamics using a 61-day Savitzky-Golay filter. Gray bars from the top indicate the average monthly rainfall [mm/month] from in situ sensors.

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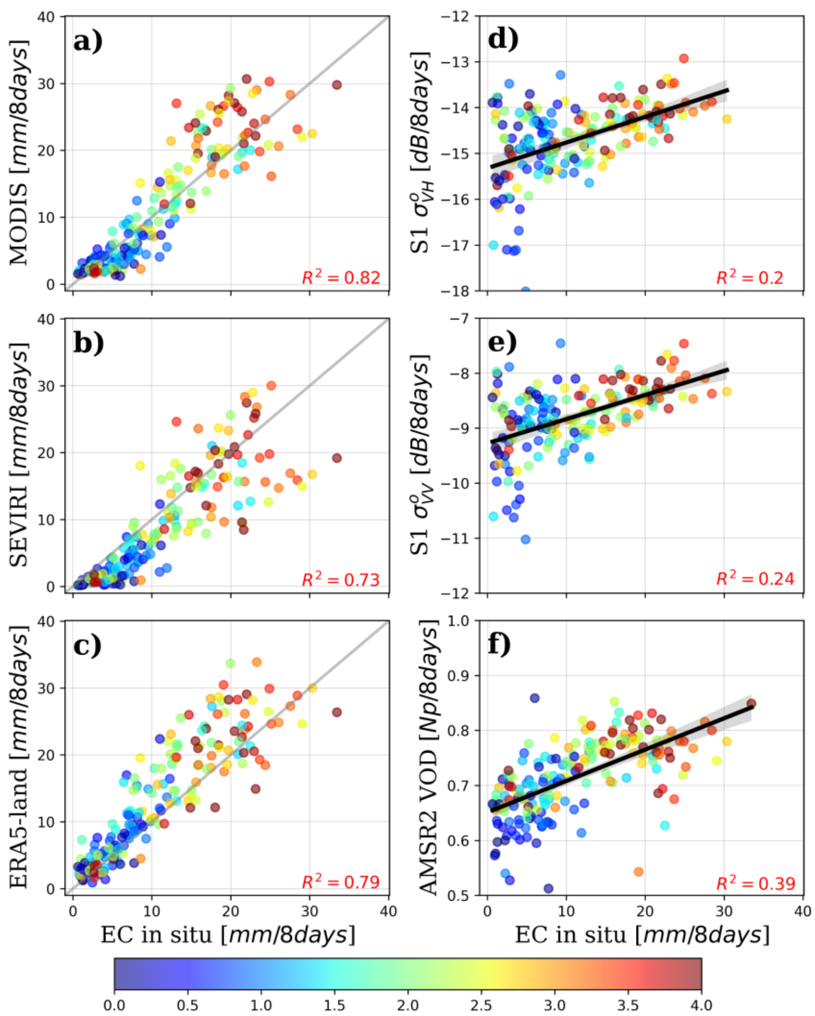

Figure 2: Comparison of specialized evapotranspiration products (left column) from remote sensing (at Wuestebach site from 2017-2020): (a) MODIS & (b) SEVIRI, from reanalysis data (c) ERA5-land and from (right column) (d) VH-backscatter (Sentinel-1), (e) VV-backscatter (Sentinel-1) and (f) VOD (AMSR2) compared with in situ evapotranspiration data from the Eddy Covariance technique. All units in [mm/8days]. Colors indicate coverage by leaves using the MODIS LAI [m²/m²] product.