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 across global biomes and along the time periods of dry and wet seasons 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 evapotranspiration products, like from optical/thermal remote sensing (MODIS, SEVIRI) and reanalysis (ERA-5 land, GLDAS) data.

Our research study covers a four-year period (2017-2020), including dry (even drought - 2018 & 2019) and wet (2017) years. The study was conducted over eleven ICOS sites 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.

We find that the evapotranspiration 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 evapotranspiration rate between in situ measurements (EC) and derived products (MODIS & GLDAS) which is currently being investigated and first indications point towards the spatial scale gap between EC tower measurement and the spatial footprint (single resolution cell) of the remote sensing products or model domains. The microwave-based indicators (backscatter & VOD) are proxies by their nature and serve as first-order indicators of relative dynamics. This may be still of very valuable interest to identify seasonal patterns of evapotranspiration 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 need to be monitored for a holistic survey. Evapotranspiration is one of the essential variables to inform about these ecosystem dynamics [2]. Tracking evapotranspiration 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 evapotranspiration not only with classical techniques from optical/thermal sensing but also open a discussion if a new observation domain of active and passive microwave remote sensing is able to provide additional insights. We also include evapotranspiration estimates from several Earth system modeling approaches (partly including data assimilation) and in situ eddy covariance (EC) measurements for comparison and validation purposes.

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2. DATASETS

In the case of optical/thermal remote sensing, we use the evapotranspiration 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 C-/X-band radiometer sensors [9]. In the case of Earth system modeling, we include the evapotranspiration 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 (even drought – 2018 and 2019) and wet (2017) years. The study includes eleven 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 evapotranspiration. 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. They might correlate at seasonal scales with evapotranspiration 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 evapotranspiration 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) of the Forschungszentrum Jülich. This site is characterized by a homogenous and mature evergreen needleleaf 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 evapotranspiration dynamics.

The evapotranspiration 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 evapotranspiration rate between in situ measurements (EC) and derived products (MODIS & GLDAS), which is currently being investigated, and first indications point toward the spatial scale gap between EC tower measurement and the spatial 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]. This may still be of very valuable interest to identify seasonal patterns of evapotranspiration as well as their spatio-temporal anomalies along differing dry and wet years. We are currently investigating this potential for all eleven individual study sites and all four years and intercompare with the concert of evapotranspiration products and measurements as well as all available auxiliaries (e.g., precipitation, LAI, air temperature).

Figure 2 presents a comparison over all eleven sites and all dates (2017-2020) showing correlation (scatterplots) of specialized evapotranspiration products from remote sensing (MODIS, SEVIRI), from reanalysis data (ERA5-land) and Sentinel-1 backscatter (VH, VV) and VOD (AMSR2) compared with in situ evapotranspiration data from EC towers. 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 is level-1 observations (backscatter) and level-2 derivates (VOD). At the conference, we will provide an outlook about further developments and potentials to track evapotranspiration 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].

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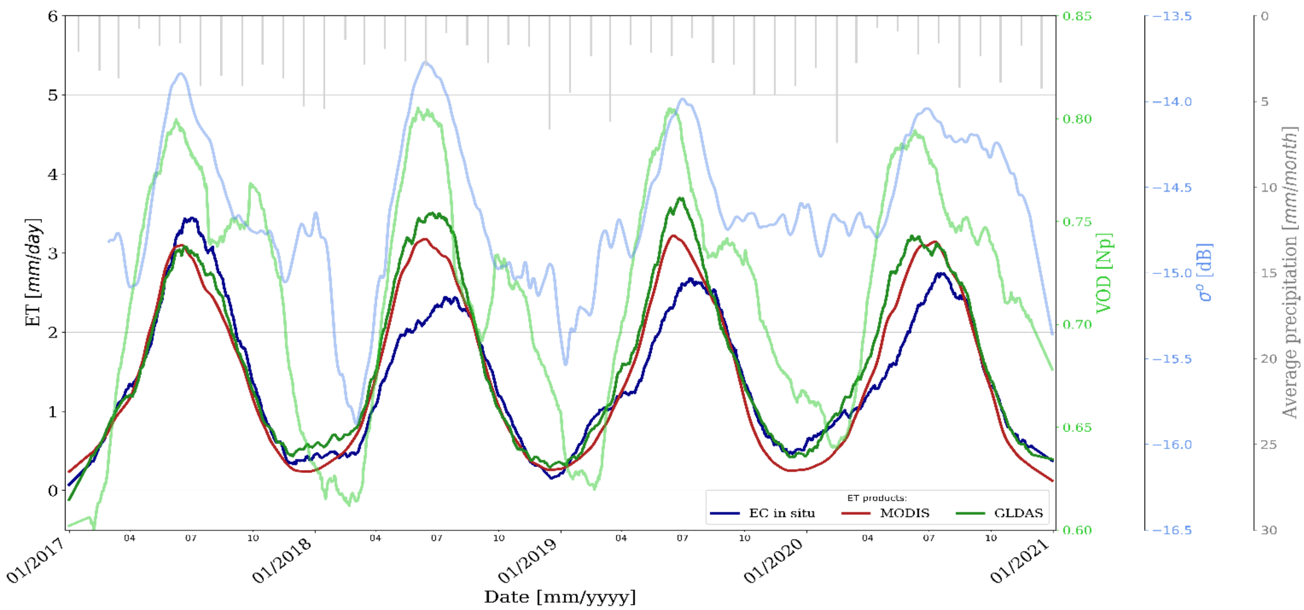

Figure 1: Seasonal dynamics of evapotranspiration [mm/day] from in situ measurements (ICOS EC towers), optical remote sensing (MODIS), and Earth system modeling, including data assimilation (GLDAS) are compared to VH-polarized C-band (5.4 GHz) SAR backscatter (Sentinel-1) [dB] and C-band (7.3 GHz) AMSR2-derived 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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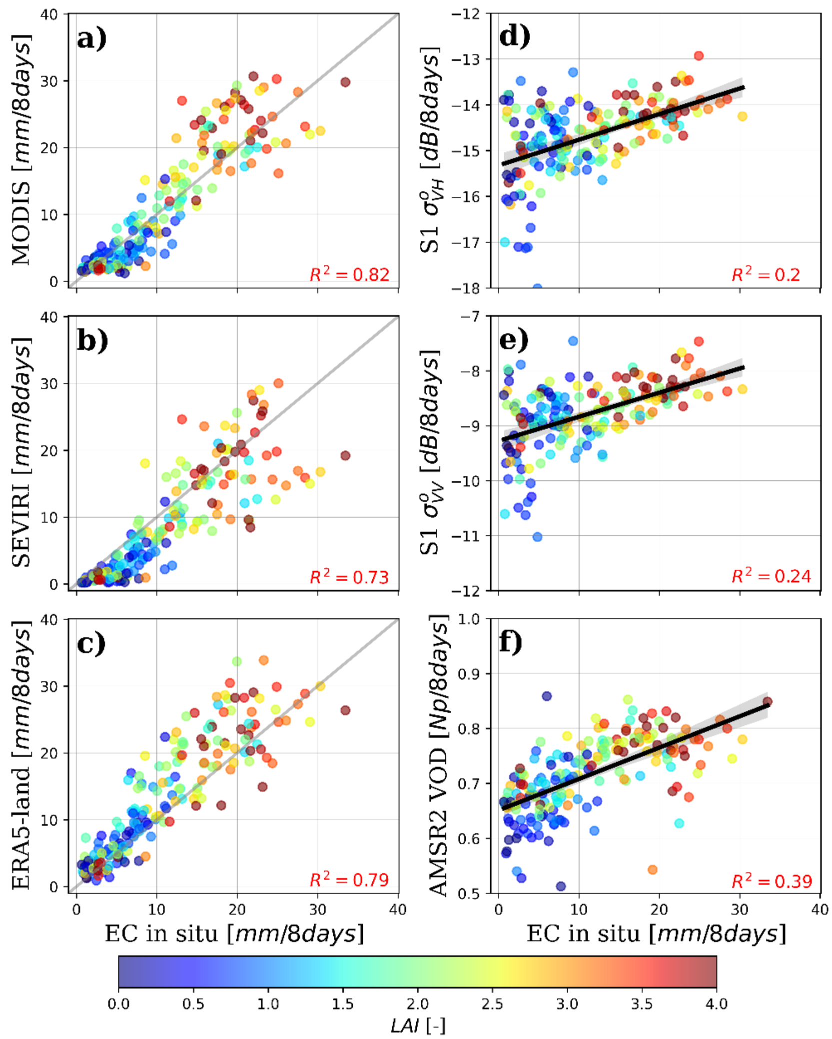

Figure 2: Comparison of specialized evapotranspiration products (left column) from remote sensing (here Wüstebach site from 2017-2020): (a) MODIS & (b) SEVIRI, from reanalysis data (c) ERA5-land and from (right column) (d) VH-backscatter (Sentinel-1), (e) VV-backscatter (Sentinel-1) and (f) VOD (AMSR2)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

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