ACCOUNTING FOR STATIC AND DYNAMIC OPEN WATER IN THE MODELING OF SMAP BRIGHTNESS TEMPERATURES OVER PEATLANDS

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ABSTRACT

Hydrological change in peatlands due to anthropogenic disturbance and global warming can release enormous amounts of greenhouse gas emissions. Passive microwave satellite observations are an opportunity to globally monitor these changes. Abundant static and dynamic open water surfaces in peatlands strongly affect observed brightness temperatures (Tb). Here, we account for these contributions in radiative transfer modeling using NASA's Goddard Earth Observing System Model version 5 (GEOS-5) static open water mask and, for the dynamic open water fraction, the simulated inundated area using a version of the GEOS-5 Catchment land surface model that has been modified for peatland areas (PEAT-CLSM). Modeled Tb is compared against two years of SMAP L-band Tb. Preliminary results indicate: (i) a bias reduction when including the static open water fraction in a simple RTM mixing model, and ii) significantly improved correlation between modeled and observed Tb when using land surface output from PEAT-CLSM instead of the operational CLSM.

Index Terms— passive microwave, L-band, radiative transfer model, organic soil, soil moisture

1. INTRODUCTION

Peatlands represent a globally important carbon pool. About 500 Gt C is stored in peatlands of the Northern Hemisphere [1]. This enormous carbon pool is currently at risk. There are high peat carbon losses in regions of direct anthropogenic influence due to drainage for land use and forestry, and peat extraction for horticulture and energy use. More subtle disturbances of peatlands, but over much larger areas, occur by indirect anthropogenic influence, e.g. regional water level draw down due to groundwater extraction or global warming and changing precipitation dynamics [2].

Microwave remote sensing of soil moisture bears a high potential to provide valuable large-scale insights where and how the hydrological dynamics of peatlands is in transition

due to changing boundary conditions [3, 4]. Being comparatively less affected by vegetation and more sensitive to moisture at greater soil depth (appr. 0-5 cm), the passive microwave missions SMOS and SMAP operating at L-band (1.4 GHz) represent currently the most important technologies for large-scale observations of soil moisture. However, the differences between mineral and organic land surfaces have only been recently addressed in the scope of L-band radiometry, focusing on the specific dielectric properties of organic soils [5] and peatland vegetation [6], and on open water contributions to observed brightness temperatures [7].

Open water fractions within the footprint of L-band passive microwave observations have a strong impact on brightness temperature (Tb) observations. Temporal changes in the extent of smaller water bodies as small as a few percent of the sensor footprint size are known to cause significant and dynamic biases [8]. Dynamical open water is difficult to model, and in case of peatlands, current model structures of global land surface models are not able to reproduce typical hydrological dynamics in peatlands well.

Here, we use output from the GEOS-5 Catchment Land Surface Model (CLSM) [9] in radiative transfer modeling (RTM) to simulate L-band Tb over peatlands with various amounts of static and dynamic open water fractions. We use SMAP Tb observations to evaluate the simulated Tb using two different CLSM versions and various configurations of mixing land and open water contributions.

2. DATA

Our study area is a set of 1500 EASEv2 36 km grid cells over Siberia and Canada (Hudson Bay area) for which peat is the dominant soil type. Selected grid cells are south of the permafrost belt and have a relatively low tree cover of <50%. Over the selected peatlands, the static open water fraction ranges from 0 to about 50%.

The EASEv2 36 km SMAP Level 1C L-band Tb data (source: nsidc.org) were extracted from April 2015 to April 2017. Preliminary results of this abstract did only consider data in H polarization.

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Land surface state variables are simulated at the same EA-SEv2 36 km resolution using (i) the operational CLSM of the SMAP Level 4 Soil Moisture product that takes advantage of a recently revised soil information including a peat class [10], and (ii) a new version of CLSM, hereafter called PEAT-CLSM, that uses a modified model structure over peat dominated grid cells. Major characteristics of peatland hydrology have been implemented as new modules into PEAT-CLSM:

- Surface Water Storage: water can pond in microrelief. Water table dependent total specific yield calculated as average of soil and open water specific yields [11]
- Single runoff function replacing original baseflow and overland flow functions [12, 13]
- Evapotranspiration: water stress linked to water table depth

3. METHODS

Tb is estimated using different versions of RTM mixing models. The individual components are:

Tb_{land} : For non-inundated land, the L-band tau-omega RTM is used to estimate 36 km L-band Tb from 36 km CLSM simulated soil moisture and temperature. Calibrated RTM parameters from [14] were used. 36 km grid cells with open water fractions $>5\%$ were masked in [14] and filled with globally averaged parameters for the same dominant vegetation class. Tb_{land} is simulated using either the operational CLSM or the modified PEAT-CLSM:

$$Tb_{LA1} = Tb_{land,CLSM} \quad (1)$$

$$Tb_{LA2} = Tb_{land,PEAT-CLSM} \quad (2)$$

Tb_{stat} : Static open water surfaces are assumed to be vegetation-free. Assuming that the temperature of the water surface equals the CLSM simulated temperature of the topsoil, the dielectric permittivity of water and subsequently Tb_{stat} is calculated assuming a smooth water surface [15].

Tb_{dyn} : Regarding the dynamical fraction of the open water, we calculate two different Tb that we apply to different mixing model variants. Besides $Tb_{dyn,noveg}$ which equals Tb_{stat} , we also model $Tb_{dyn,veg}$ using the tau-omega RTM assuming a smooth surface but using the same vegetation parameters.

These Tb contributions over static and dynamic open water are mixed with the Tb contribution over land in 3 distinct ways: :

$$Tb_{OW1} = \{(1 - f_{OW,stat}) \times Tb_{LA2} + (f_{OW,stat}) \times Tb_{stat}\} \quad (3)$$

$$Tb_{OW2} = \{(1 - f_{OW,stat+dyn}) \times Tb_{LA2} + (f_{OW,stat+dyn}) \times Tb_{stat}\} \quad (4)$$

$$Tb_{OW3} = \{(1 - f_{OW,stat+dyn}) \times Tb_{LA2} + (f_{OW,stat}) \times Tb_{stat} + (f_{OW,dyn}) \times Tb_{dyn,veg}\} \quad (5)$$

Because PEAT-CLSM has not been calibrated, we assume that the absolute level of the water table depth, and consequently the fraction of dynamical inundation, can be strongly biased locally, overestimating or underestimating the open water fraction. Therefore, additionally Tb_{OW3}^* was estimated using a pixel-specific factor to scale $f_{OW,dyn}$ so that the correlation coefficient between Tb_{OW3}^* and Tb_{obs} is maximal.

4. PRELIMINARY RESULTS AND DISCUSSION

Fig. 1. Pearson correlation coefficient between SMAP Tb and modeled Tb for different scenarios. Mean and the 95% confidence intervals are obtained for a period of 2 years and after averaging across 1500 pixels with dominant peat soils.

Figure 1 shows the temporal correlation coefficients of the different Tb simulations. The currently operational CLSM does not simulate a dynamical open water fraction Tb_{LA1} . Tb_{LA2} based on PEAT-CLSM is the equivalent land-alone estimate to Tb_{LA1} , i.e. without accounting for open water, even if it is simulated. Tb_{LA2} performs significantly better than Tb_{LA1} probably due to the more realistic representation of peatland hydrology in PEAT-CLSM. Including the static open water fraction (Tb_{OW1}) does not further improve the correlation coefficient, but reduces bias related to lack of open water in Tb_{LA2} , as illustrated in Figure 2. The two estimates Tb_{OW2} and Tb_{OW3} include the modeled dynamical open water fraction in a mixing model approach, either without or with vegetation. The correlations does not improve, which may be due to RTM parameters which may partly compensate for open water. . However, it can be noted that Tb_{OW3} results in a much higher R than Tb_{OW2} . It seems thus more appropriate to assume a rather incomplete inundation for the

Fig. 2. Bias (model - observation) as a function of static open water fraction for the temporally averaged modeled brightness temperatures Tb_{LA2} (neglecting open water) and Tb_{OW1} (accounting for static open water.)

dynamical open water fraction in peatlands, i.e. significantly amount of the vegetation mass is still above the water surface. Finally, the first attempt of spatially fine-tuning PEAT-CLSM, by "post-scaling" the modeled dynamical fraction to obtain Tb_{OW3}^* , resulted tentatively, yet insignificant, into the highest R. The preliminary results from the mixing model Tb estimates indicate the strong impact of including dynamical open water surfaces into Tb modeling. Biased modeled results for the open water fraction can have a strong negative effect on the estimated Tb. This is in particularly the case when assuming that the dynamically inundated land is open water that is totally free of vegetation, which results in much lower brightness temperatures than open water surfaces with vegetation.

5. OUTLOOK

The current RTM parameters are probably suboptimal over peatlands, and a recalibration that already includes, at least, the static open water component in the forward modeling, should remove the bias with static open water fraction and lead to more consistent RTM parameters. We will conduct a recalibration for both CLSM and PEAT-CLSM output.

The applied scaling of the dynamically inundated area used for Tb_{OW3}^* produces inconsistent hydrological variables, because the dynamics of the modeled soil moisture must change accordingly. We therefore run PEAT-CLSM for different absolute moisture levels, i.e. more specifically for a set of vertically-shifted runoff functions. This will yield a consistent set of soil moisture and partial inundation time series that can be applied to the set of RTM mixing models.

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