Supplement of Hydrol. Earth Syst. Sci., 26, 3337–3357, 2022
https://doi.org/10.5194/hess-26-3337-2022-supplement

Hydrology and Earth System Sciences
Open Access
EGU

Supplement of

Exploring the combined use of SMAP and Sentinel-1 data for downscaling soil moisture beyond the 1 km scale

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Supplemantary Material

Table S1: Available satellite data sets and reduction due to temperature and synchronization effects. The temporal interval of synchronized data is three days of consecutive data followed by three days without data.

Days	SMAP	Sentinel-1
original	881	428
Without data	24➔857	
Low T	77➔780	
Lost during synchronization	403➔377	51➔377
Final data set	377	377

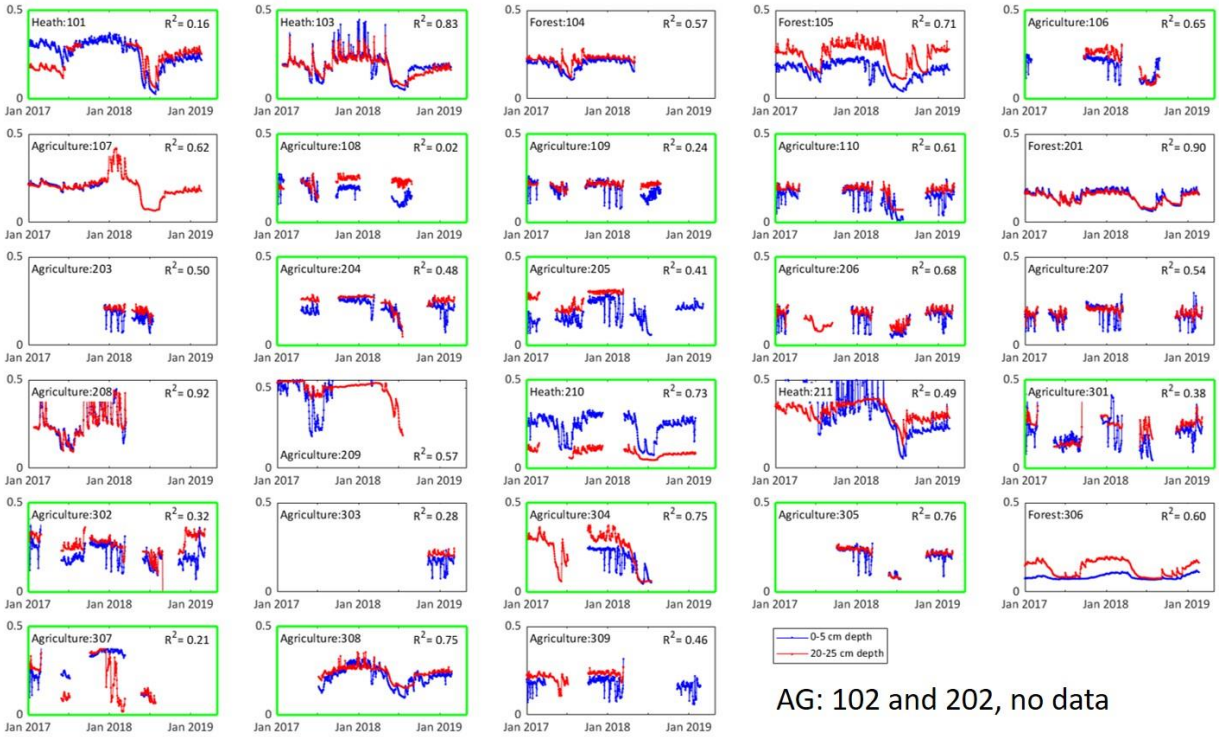

Figure S1: Time series of soil moisture measured by capacitance probes at a depth of 0-5 cm (blue) and at a depth of 20-25 cm (red). R^2 is the coefficient of determination based on the linear regression between the soil moisture measured at the two different depth. Those sensors used for the analysis are highlighted in green.

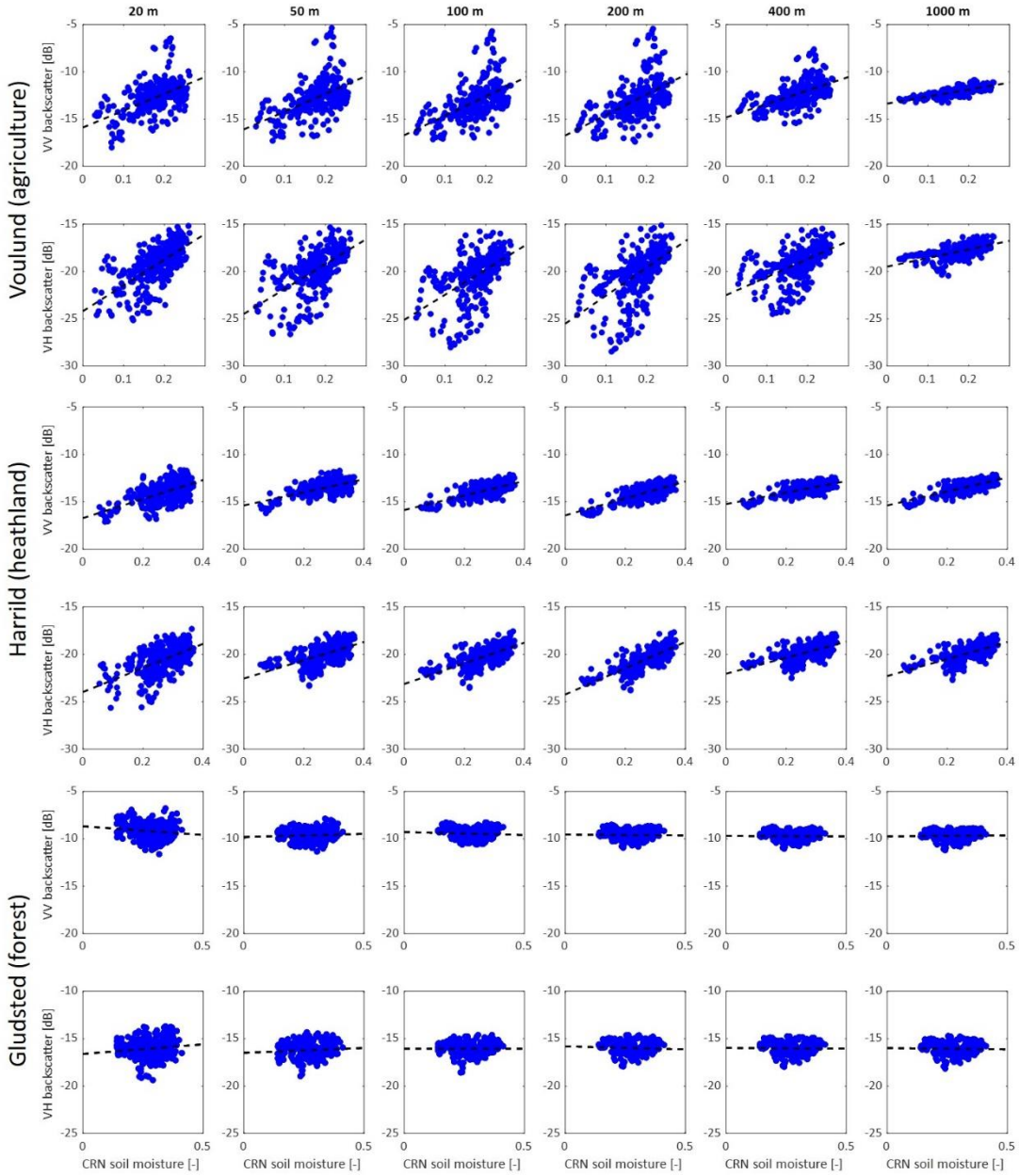

Figure S2: Scatterplot of VV and VH backscatter vs. CRN soil moisture at the three CRN station sites and six different resolutions (20 m - 1000 m). Black dotted line indicates the linear regression line.

Table S2: Statistics of θ (SMAP) versus VH at spatial resolutions of 20 m, 100 m and 1000 m, shown invariant in space (entire area) or variant in space according to the three clusters.

θ vs VH	20 m		100 m		1000 m	
	slope	R^2	slope	R^2	slope	R^2
Entire area	0.036	0.293	0.037	0.293	0.037	0.293
Agriculture	0.018	0.239	0.020	0.249	0.028	0.296
Heathland	0.048	0.378	0.047	0.374	0.042	0.314
Forest	0.082	0.253	0.074	0.226	0.054	0.175

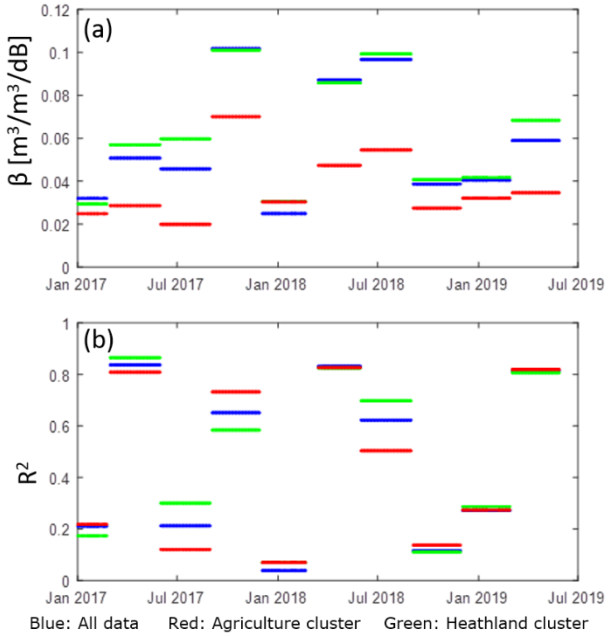

Figure S3: (a) β estimated over an interval of 3 month* (Dec-Feb, Mar-May, Jun-Aug, Sep-Nov, representing the seasons in Denmark) and (b) the respective R.² * except for the first interval, starting with January (2 month interval).

Figure S3 shows the seasonally varying β estimates and the corresponding R^2. It can be concluded that there is a slight seasonality in β with lower values in winter and higher values in summer (Fig S3 a). However, when considering only β-values with an acceptable R^2 of 0.5. (Fig S3 b), this trend might not be as significant. To estimate a robust time variant β, a dynamic in the range throughout the year would be needed, but β maintains a relatively constant value, except during the summer. Hence, it is rather difficult to achieve a good estimation of correlation when there is only little variation in the data (during the rest of the year). On the other hand, it can be observed that particularly the β estimates for the agriculture cluster (Fig. S3 red) deviate significantly from the other data (Fig. S3 all=blue and heathland=green). This supports the approach in estimating spatial varying (land cover dependent) but time invariant β.

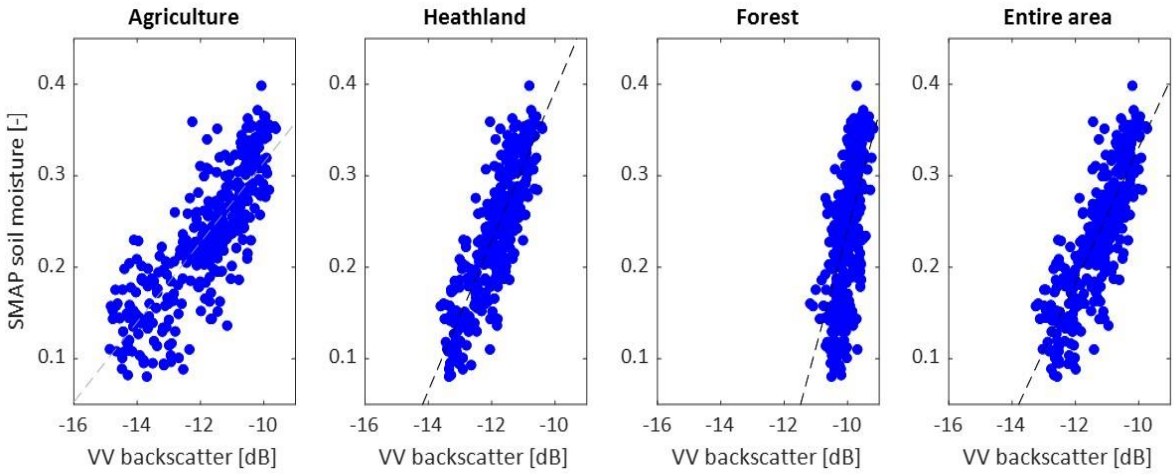

Figure S4: β estimation (θSMAP vs. VV) for the three individual clusters and the entire area.

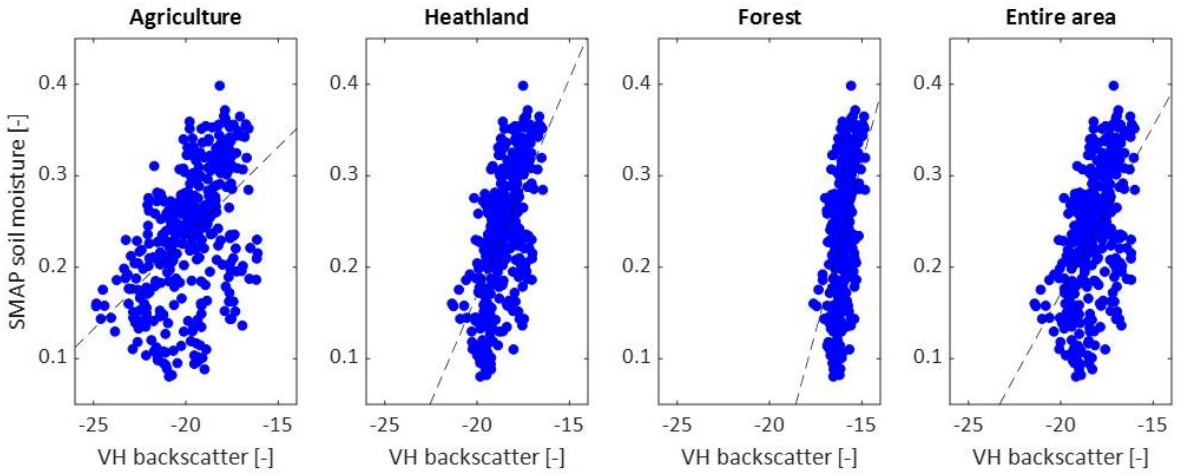

Figure S5: Scatter plots of SMAP estimated soil moisture vs. Sentinel-1 VH backscatter for the different clusters and the entire area.

Table S4: Example of Γ (δ(VV/VH)) estimation results for time-constant and space-independent (entire area) and space-dependent (based on the mean of Clusters) Γ.

Γ estimation	**20 m**		**100 m**		**1000 m**	
	Γ	R^2	Γ	R^2	Γ	R^2
Entire area	0.622	0.719	0.623	0.718	0.625	0.718
Agriculture	0.610	0.660	0.622	0.662	0.628	0.681
Heathland	0.635	0.719	0.634	0.724	0.6230	0.729
Forest	0.630	0.784	0.627	0.776	0.629	0.799

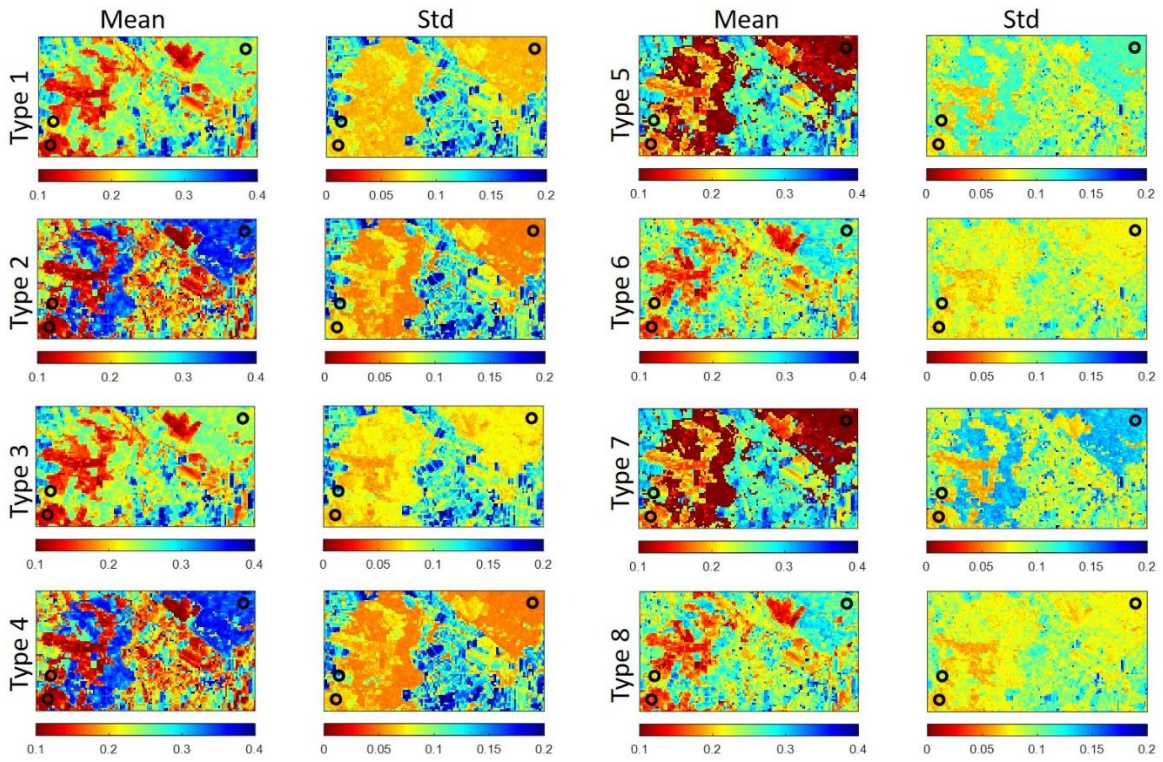

Figure S6: Downscaled soil moisture (mean and std) at a spatial resolution of 100 m shown for all 8 types.

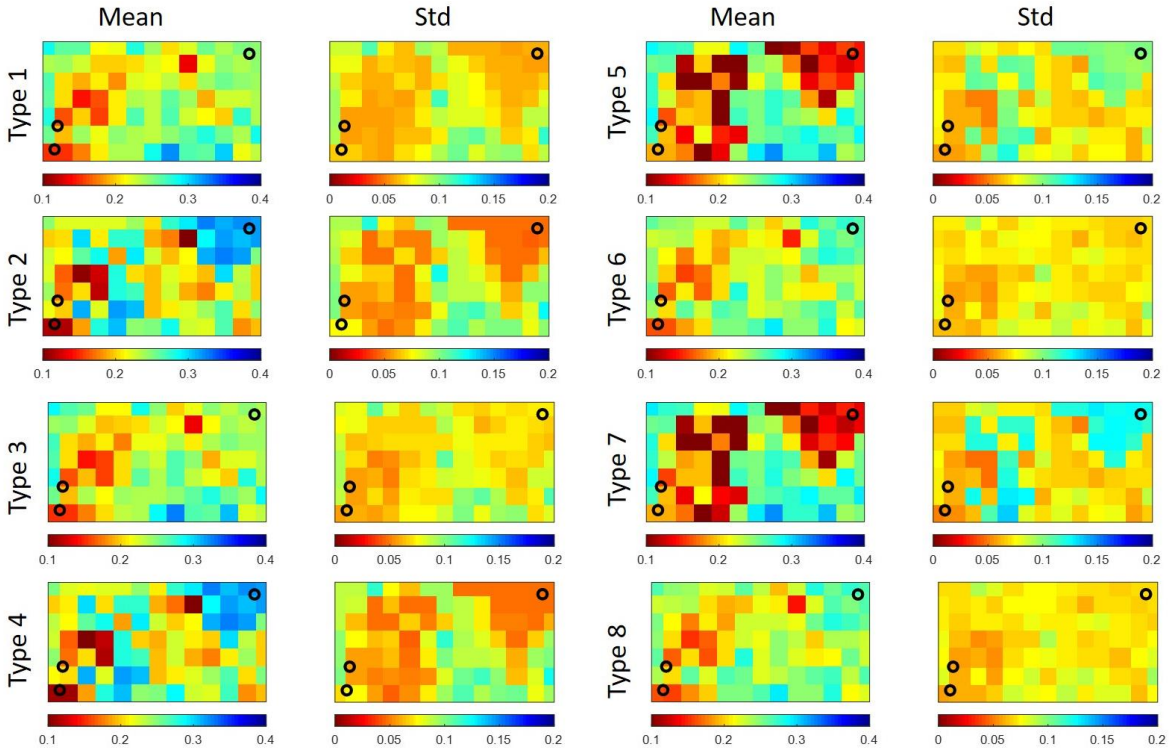

Figure S7: Downscaled soil moisture (mean and std) at a spatial resolution of 1000 m shown for all 8 types.

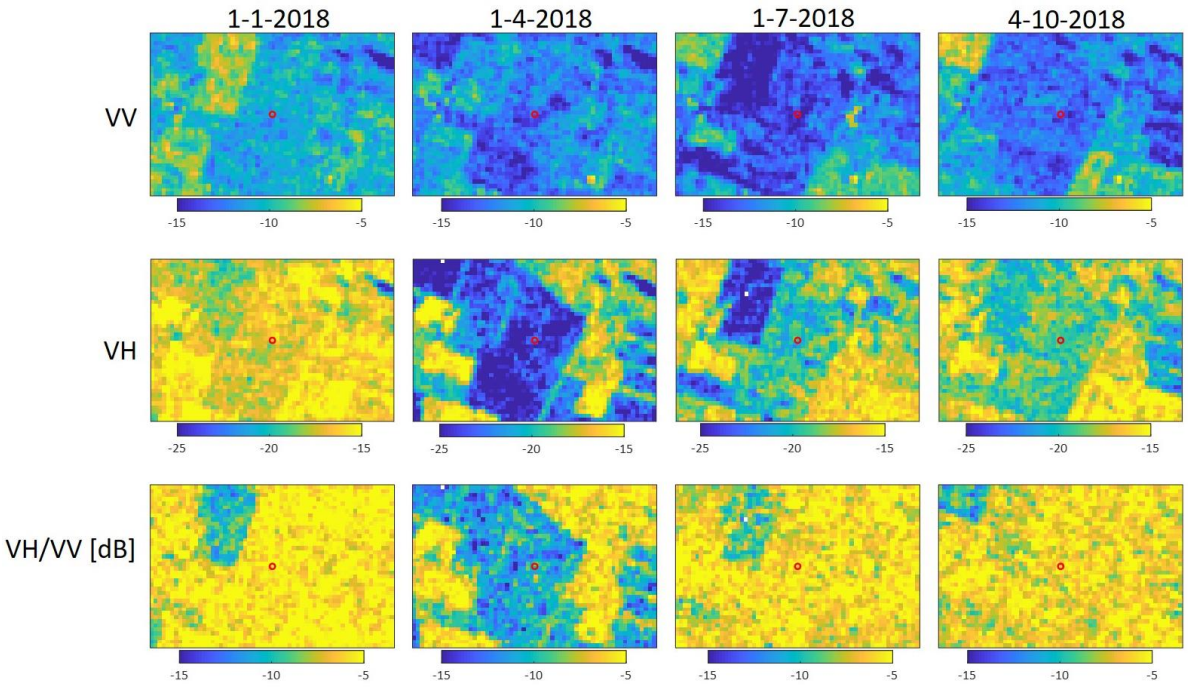

Figure S8: Sentinel-1 backscatter in VV and VH polarization and their cross-ratio at a spatial resolution of 20 m at a zoom into the agricultural field at Voulund for four single dates representing different seasons.