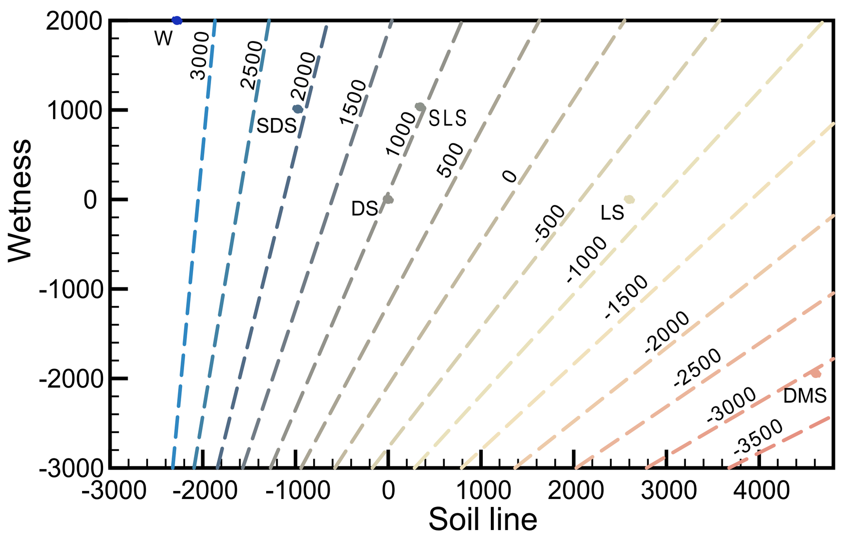
Mapping Water Bodies and Wetlands from Multi-Spectral Optical Satellite Images

Thomas Gumbricht, Karttur AB, Sweden

Abstract. The favored source for mapping surface wetness and water bodies from satellite sensors is microwave data. Optical satellite data has a higher spatial resolution compared to microwave data, and a variety of Normalized Difference indexes combining Short-Wave Infra-Red (SWIR) and visible (VIS) wavelengths have been suggested for mapping water bodies and wetlands. Optical satellite images, however present several obstacles for retrieval of surface wetness, including; minimal surface penetration, cloud and cloud shadow contamination, atmospheric attenuation at different wave-lengths, and the vegetation influence on the signal.
To overcome some of the limitations in using optical images for mapping surface wetness, I developed the Transformed Wetness Index (TWI). TWI makes use of all available spectral bands transforming the reflectance data to fixed biophysical vectors using a unitary (orthogonal) matrix, optimized for separating wet and dry areas. The biophysical vectors representing the soil line and water are then combined in a non-linear normalized difference index, while the biophysical vectors representing photosynthetic and non-photosynthetic biomass are both omitted. The derived index is translated to actual surface wetness using a linear-power equation. TWI was designed to capture the full range of surface water content, from desert dry to deep open water. For non-inundated soils, TWI soil moisture estimates derived from Moderate-resolution imaging spectroradiometer (MODIS) data has a globally estimated Random Mean Square Error (RMSE) of approximately 14.0 %, and a bias of 2.5 % which reduces to an RMSE of 11.6 % (bias: -0.4 %) when compared to only non-forested in situ data.

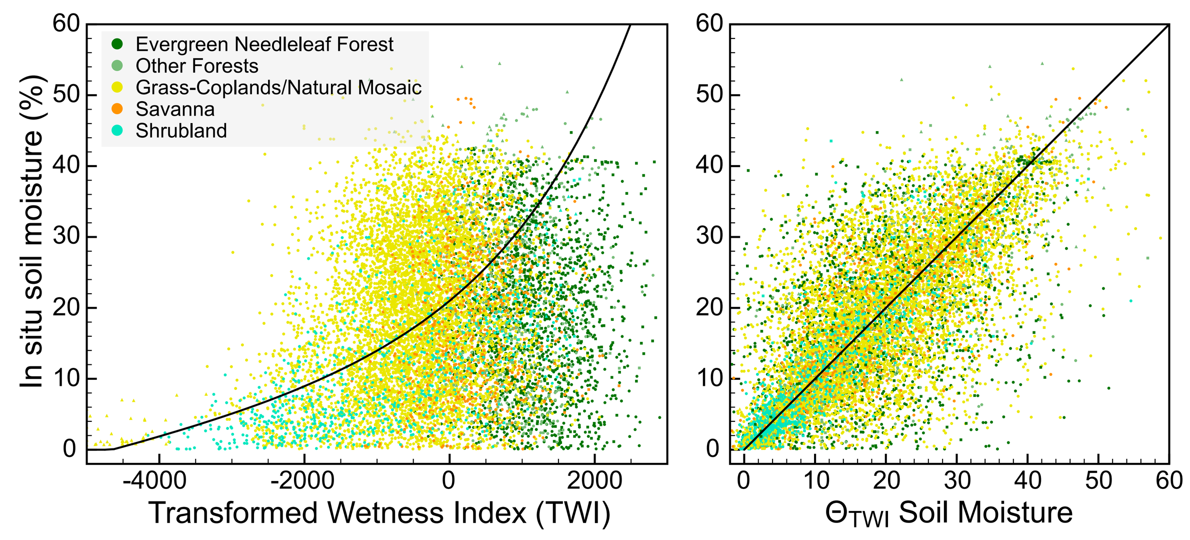
Methods. At its core TWI is a normalized difference (ND) index, but rather than using original satellite image bands as inputs the ND algorithm in TWI uses data obtained after a linear transformation of the image bands. The transformation is achieved by a fixed orthogonal matrix optimized to separate wet and dry pixels.
The first transformation component aligns from dark soil reflectance to light soil reflectance. The second and third components represent photosynthetic and non-photosynthetic vegetation, while the fourth represent open water. The TWI ND algorithm is defined by a reference line of iso-wetness and applied using a trigonometric, scale preserving, rotation combined with a re-scaling factor and a calibration factor allowing for non-linear reflectance mixing between soil and water (Fig. 1). TWI is transformed to actual soil moisture by a linear-power equation (Fig. 2). For the statistical evaluation of the performance the TWI data was locally assimilated to the mean and variance of 745 in situ stations for the calendar year 2011 (Fig. 2, right panel).

Figure 1



Iso-lines of surface wetness as estimated from the Transformed Wetness Index (TWI). The annotated dots represent the theoretical values for; DS: dark soil, LS: light soil, W: water, SDS: saturated dark soil, SLS: saturated light soil, and DMS: dry medium soil.

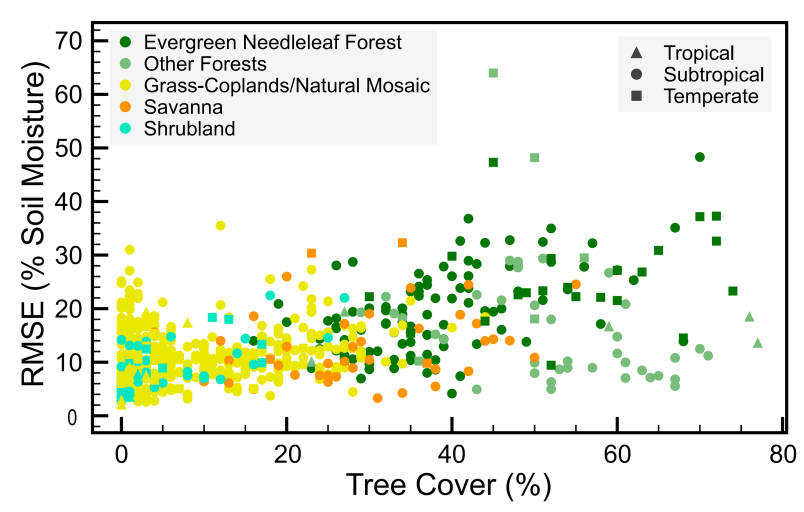
Figure 2



Scatterplots of TWI versus in situ observed soil moisture. The left panel shows the original MODIS TWI values and in situ measured soil moisture. The black line shows the adopted model for converting MODIS TWI to soil moisture (\%). The right panel shows MODIS TWI converted to soil moisture as indicated in the left panel, and then assimilated to fit the local statistical moments of the measured soil moisture of each in situ station. The color codes reveal the dominating land cover (from MODIS product MCD12Q1) of each sample site.

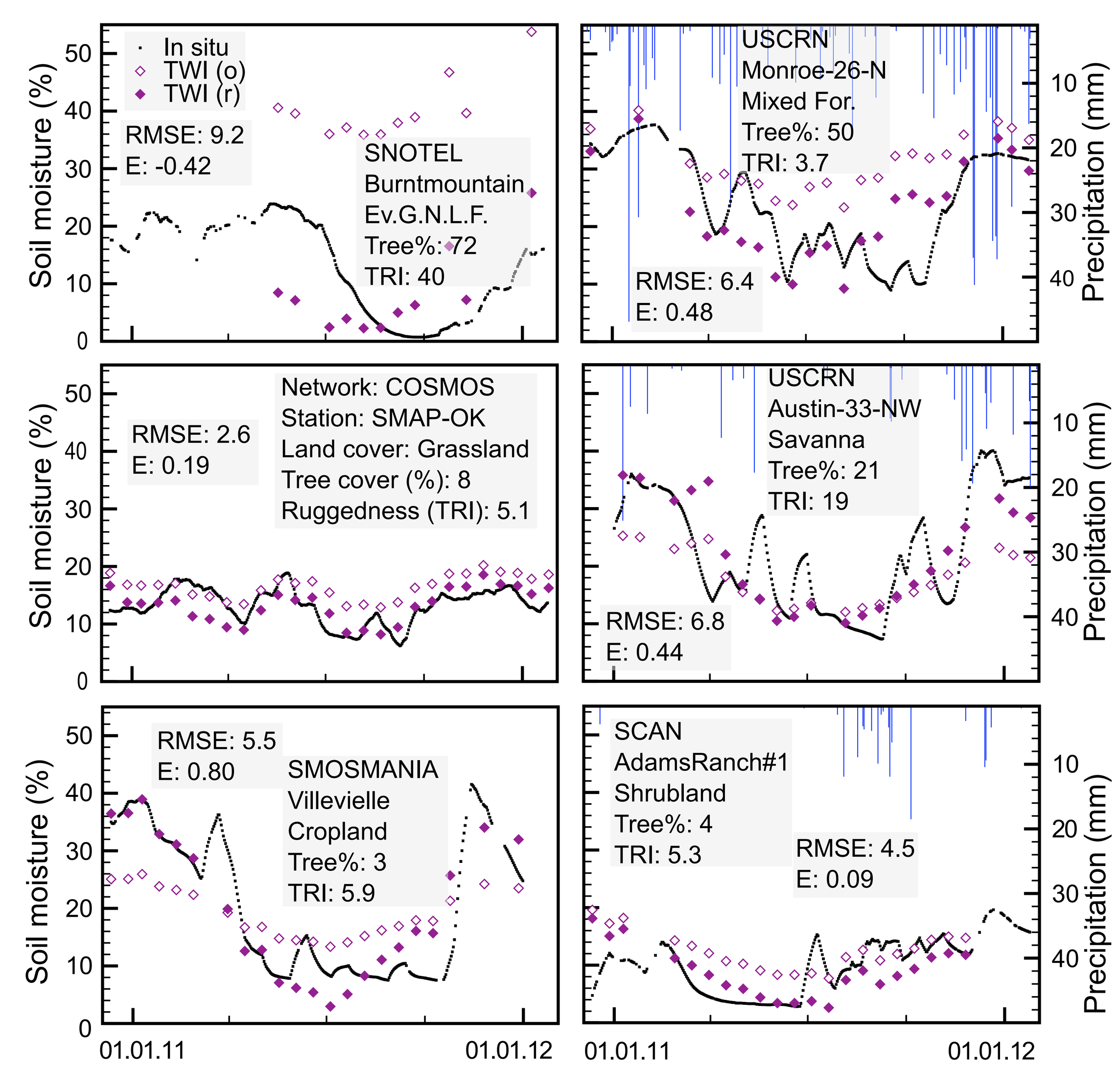
Results. Using an annual time series of MODIS images, the global soil moisture conditions for 2011 could be estimated at a scale of 500 m (Fig. 5) and a global RMSE of 14.0 % compared to 745 ground observation sites (11.6 % when compared to non forested in situ sites). The RMSE is reduced to 8.5 % (8.0 % for non forests) when assimilating the mean and variance of TWI estimated soil moisture to fit the statistical moments to the in situ data. The formulation of the MODIS TWI model in this study was optimized for tropical conditions. The results show that TWI also performs better for the tropical region (assimilated RMSE equal to 6.3 %). MODIS TWI also performs better compared to cosmic-ray probes (assimilated RMSE equal to 5.3 %), with a foot print equalling the spatial resolution of MODIS data (cf. Fig. 4). MODIS TWI over-estimates soil moisture in dense forests (Figs. 3 to 5) and for regions dominated by dark minerals.

Figure 3



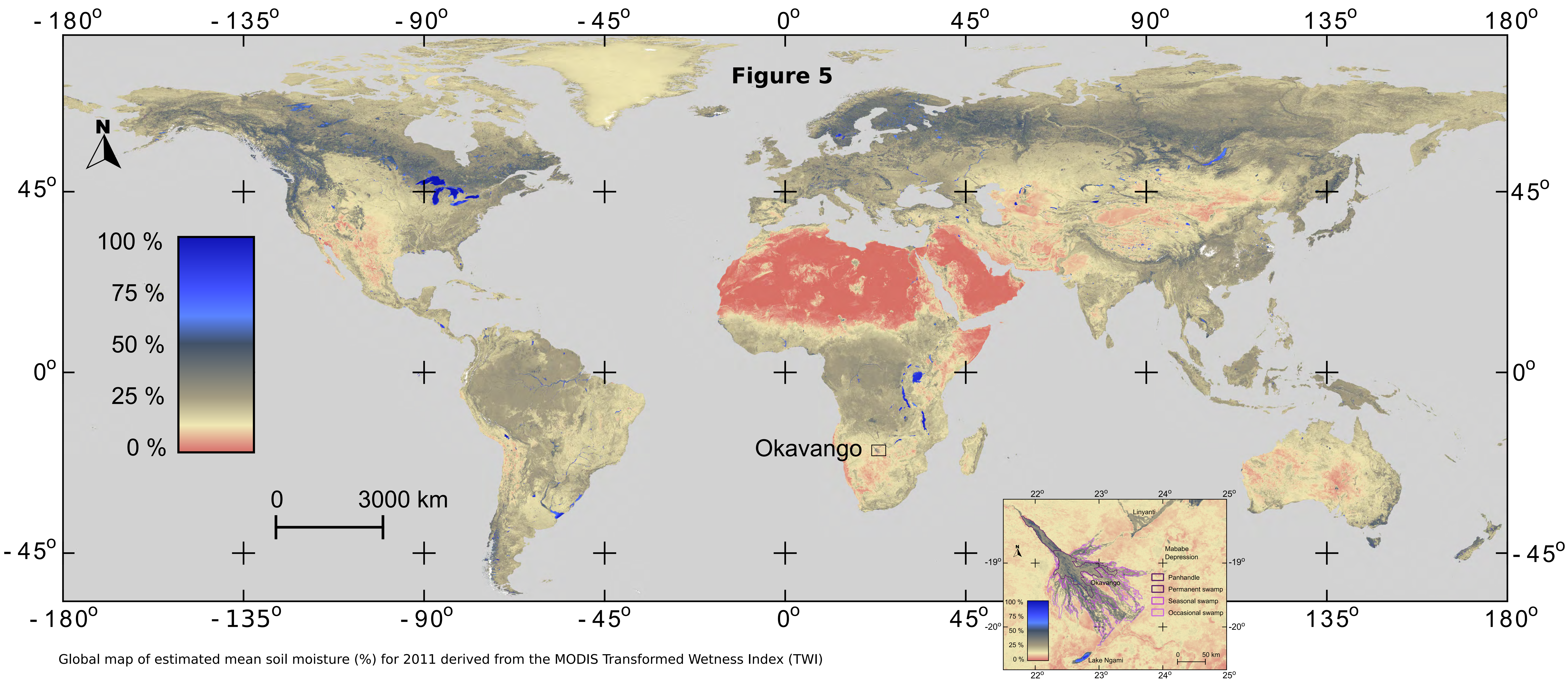
Scatterplots of the MODIS TWI per station fit compared to in situ data. Color codes indicate the dominating land cover (from MODIS product MCD12Q1) of each sample site, and symbol form represent the latitudinal region.

Figure 4



Comparison of soil moisture observations from in situ station data and soil moisture estimated by the MODIS TWI. Each panel shows both the global MODIS TWI model (o) and the locally rescaled model (r), with the statistical fit shown for the latter. Legend codes in the two upper left panels (Ev.G.N.L.F. = evergreen needleleaf forest).

Figure 5



Global map of estimated mean soil moisture (%) for 2011 derived from the MODIS Transformed Wetness Index (TWI)

Acknowledgments. The satellite image data and the landcover data are available a LP DAAC. The in situ soil moisture data are available at the International Soil Moisture Network (ISMN) hosted by Vienna University of Technology. All ISMN datasets with data records for 2011 were used in this study.
This work was supported by USAID (Grant No. EEM-G-00-04-00010-00) as part of the CGIAR research programme on Forests, Trees and Agroforestry.