High resolution soil moisture from radar instruments: Study area of northeast Austria and southeast Czech Republic

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Abstract Soil moisture is an important parameter for hydrological modeling and crop yield prediction. The ability of radar sensors to monitor SM has been demonstrated in numerous studies. Yet, only coarse resolution (>25km) SM products are available over the European continent. In this work, the soil moisture product derived from the ERS scatterometer data at 50 km spatial resolution is presented and a downscaling technique is evaluated that provides SM at 1 km scale. The presented downscaling technique stands upon the concept of temporal stability of SM. Despite the high heterogeneity of the study area, additional SM information to that demonstrated by the ERS data could be retrieved from the downscaled product at 1 km spatial resolution. The SM patterns of the downscaled product correlated to the 1 km SM data from the ENVISAT Advanced Synthetic Aperture Radar (ASAR) Global Mode (GM). While these findings are preliminary, they provide promising results for the hydrological and meteorological community operating at spatial scales of 5 km and higher.

Keywords soil moisture; scatterometer; downscaling; ERS; ScanSAR

INTRODUCTION AND BACKGROUND

Soil moisture plays a key role in the Earth energy, water, and carbon cycle (Wagner *et al.* 2007). It can be measured as in-situ point measurements, with use of thermal remote sensing, or with use of active or passive microwave remote sensing instruments. While the in-situ measurements represent conditions at a single point location and their acquisitions are cost and labour intensive, microwave soil moisture products represent values at the regional scale (pixel dimension) and are freely available from a variety of satellites (i.e. ERS, METOP, AMSR-E). A single footprint, however, represents an area of 25 * 25 km or larger. Thus, the finer scale hydrological processes may be entirely omitted with use of coarse resolution microwave products.

In order to fulfill the needs of the hydrological community for finer resolution data development of a high resolution satellite soil moisture product is necessary. A soil moisture product with a 1 km spatial resolution was developed from the ENVISAT Advanced Synthetic Aperture Radar (ASAR) Global Mode (GM) data (Pathe *et al.*, 2008 and Bartsch *et al.*, 2006). Regrettably, the limited ENVISAT ASAR GM coverage does not y*et al*low for data processing over the entire European continent (Pathe *et al.*, 2008).

Recently, a downscaling technique using ASAR Wide Swath (WS) data with 150 m resolution was introduced by Wagner *et al.* (2008). Wagner presents scaling parameters derived from the ENVISAT ASAR WS backscatter as a tool for downscaling of the coarser resolution data (i.e. ERS, METOP, AMSR-E). The study rests upon the concept introduced by Vachaud (Vachaud *et al.,* 1985) that presents spatial patterns of soil moisture as temporally stable. Similarly, the soil moisture at individual locations follows to some extent the mean regional soil moisture value (Pathe *et al.*, 2008).

Considering soil moisture as a critical factor affecting the temporal dynamics of the radar backscatter, also the radar backscatter has a temporally stable component (Wagner *et al.*, 2008). Similarly, for the soil moisture fields (Vischel *et al.,* 2008), a time-invariant linear relationship is found well suited for relating local scale (pixel) and regional scale (50 km) backscatter and soil moisture.

In this paper the downscaling technique introduced by Wagner was applied on 50 km ERS soil moisture data and the downscaled soil moisture product was studied over northeastern Austria and southeastern Czech Republic. The downscaled product was compared to the 1 km ASAR soil moisture product from 13^{th} of March, 2006. Both ERS and ASAR soil moisture products were derived using the change detection approach initially introduced for the ERS scatterometer (Wagner *et al.*, 2003).

The downscaled soil moisture product is of high importance for the selected study area where the complex landscapes cannot be sufficiently described by products with spatial resolution of 25 km or coarser.

METHODS

Northeastern Austria and southeastern Czech Republic (CR) were selected as a study area in order to investigate the performance of the downscaling model in heterogeneous landscape.

83 ASAR GM scenes were preprocessed to a common database. The steps included georeferencing, resampling, incidence angle normalization, generating of scaling information, and finally computing soil moisture (Figs 1c and 1f). The scaling information consists of the coefficient of determination between the soil moisture value at a single pixel (local scale) and soil moisture value averaged over area of 25 * 25 km (regional scale). At areas where high R^2 was achieved, the regional soil moisture estimates from coarse resolution microwave satellites can be used directly at 1 km scale.

Further, the radar backscatter downscaling coefficients and the soil moisture downscaling parameters were computed (Wagner *et al.*, 2008). The downscaling backscatter coefficients are linear parameters representing the relation between the local and the regional backscatter time series and form the base for computation of the downscaling parameters of soil moisture. The final downscaled product is retrieved according to

$$\theta_{dis}(x,y,t) = c(x,y) + d(x,y) * \theta_{ERS}(x,y,t)$$

where θ_{dis} represents the final downscaled soil moisture at time t, θ_{ERS} stands for the coarse resolution ERS data and c and d are the downscaling soil moisture parameters. The soil moisture downscaling parameters c and d govern how much wetter or dryer is a single pixel in comparison to its regional average. Finally, the ERS, the ERS downscaled and the ASAR GM 1km soil moisture products were spatially compared. One date was selected (13^{th} of March, 2006) from the limited available common dates of the ERS and ASAR GM acquisitions.

RESULTS AND DISCUSSION

Soil moisture at 50km (ERS), 1km (ENVISAT ASAR GM) and the 1 km downscaled product covering the study area at 1 km resolution on March 13th, 2006 are demonstrated in Figs 1a-c. The distribution of the very dry areas (0 – 25%), namely Burgenland (Austria) and the north-western part of the Jihomoravsky district (CR) in the ERS data corresponded to the distribution of dry areas (13 – 50%) according to the ASAR GM data. Similarly, the medium wet areas (37 – 63 %) in the west and the southwest of Lower Austria (Niederösterreich) in the ERS data corresponded to medium wet areas in the ASAR GM (approx. 37 – 87 %). In general, while the relative spatial patterns of the ERS and ASAR GM soil moisture data correlated, the soil moisture levels differed.

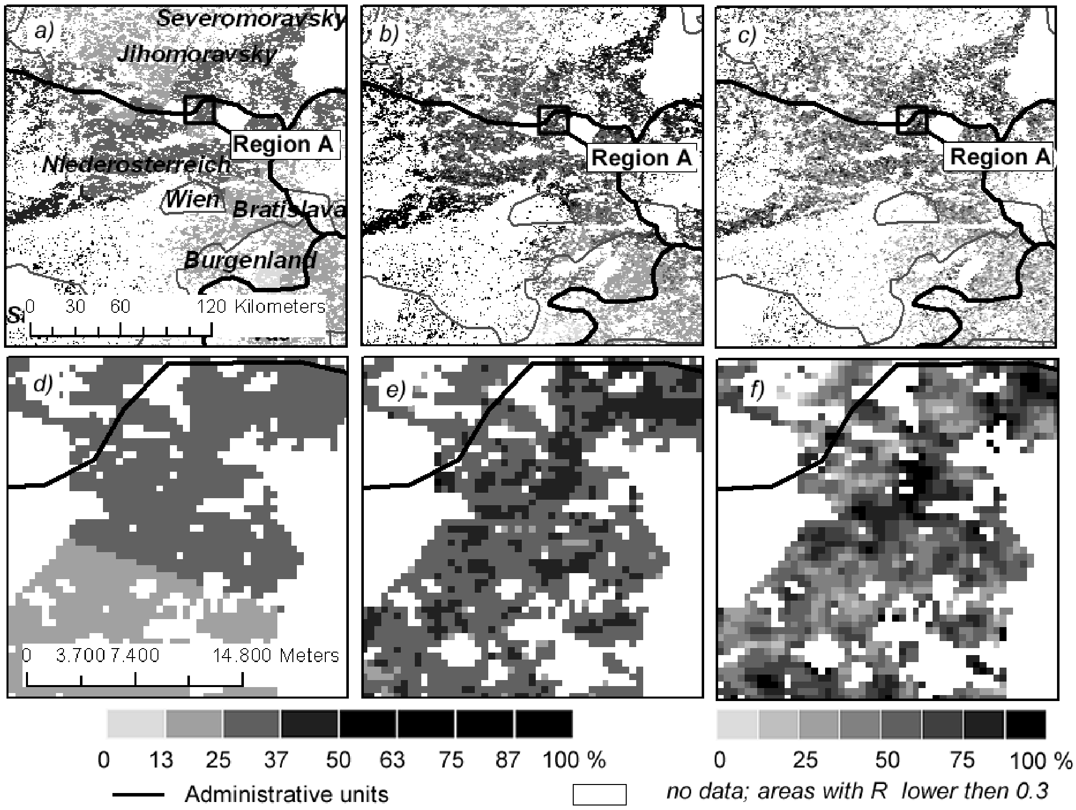

Fig. 1 Soil moisture products over the study area (upper part) and zoomed into the Region A (lower part). Soil moisture products were retrieved from the ERS data (a, d), the ASAR GM data (c, f) and by applying the downscaling techniques on the ERS data (b, e). Data from the downscaling product were masked for areas with R^2 lower than 0.3.

In order to study the additional information gained by the downscaling techniques the soil moisture products were investigated at the scale of single ERS pixels. Two ERS pixels from March 13th, 2006 are displayed in Fig. 1d-f. Agricultural areas dominate the selected area but several forest patches are evident in the east and the southeast (Fig. 2). While narrow range (13 – 37 %) soil moisture values were measured with the ERS data, highly heterogeneous soil moisture patterns were evident in the ASAR GM (13 – 87%). Clearly, large amount of information can not be detected by the ERS coarse measurements.

If a large scale atmospherical forcing dominates over a local forcing (soil type, terrain or land cover), the spatial ASAR GM soil moisture patterns are expected to stay homogenous. Thus, we assumed that the local forcing dominated over the area on 13^{th} of March and gave rise to the fine scale patterns in Fig. 1f. Considering that the fine scale patterns did not correspond to the land cover classes (Figs 1f and 2), we further assumed that the soil types and local terrain conditions functioned as the main local forcings. It's, however, important to mention that the high noise level presented in the ASAR GM product could have increased the uncertainty of these fine scale patterns.

The downscaling linear coefficients *c* and *d* were retrieved by the statistical analyses of the radar backscatter time series at the 1 km scale and are therefore representative of the forcings governing the soil moisture at that scale. Fig. 1 demonstrates the coarse resolution ERS soil moisture (Fig. 1d) and the added spatial information at the 1 km scale via the downscaling coefficients *c* and *d* (Fig. 1e). The patterns in the downscaled product corresponded to the ASAR GM soil moisture patterns (Fig. 1f). While the downscaled product identifies portions of the ERS pixel that are drier or wetter and thus add new information at the 1 km scale, the uncertainties of the downscaled soil moisture levels are still large.

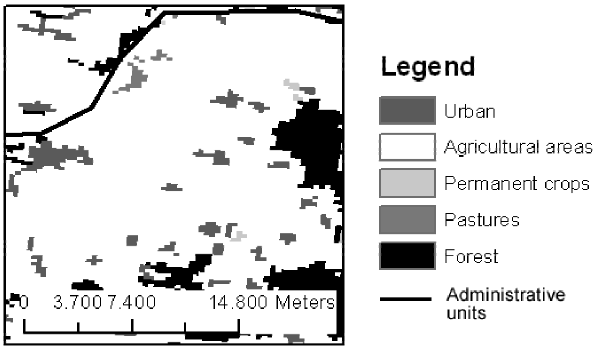

Fig. 2. Land cover classification over the Region A (Fig. 1) from the Corine Land Cover 2000. Classes were simplified.

CONCLUSIONS

The downscaling techniques introduced by Wagner *et al.* (2008) were investigated over northeastern Austria and southeastern Czech Republic.

Despite the high heterogeneity of the landscape, fine resolution spatial patterns were retrieved via the downscaled product. Spatial patterns corresponded well to the ASAR GM 1 km data.

Although these results are preliminary, they present an innovative approach of retrieving 1 km soil moisture information from the coarse resolution products. The downscaling techniques are of high importance for the satellite missions of the coarse resolution microwave sensors (ERS, METOP, AMSR-E).

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