Use of a soil moisture network in the Czech Republic

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Abstract. Since 2000, the network of stations that make up the Czech Hydrometeorological Institute (CHMI) has measured the soil moisture content at the 0- to 0.9-m layer using sensors placed within the natural soil profile under closely cropped grass cover. In 2012, it was operating in 45 stations with soil moisture measurements. The original measurements using VIRRib sensors have been gradually replaced by measurements taken using more accurate TRIFO3G sensors. In situ measurements of soil moisture are invaluable for calibrating and validating land surface models and satellite-based soil moisture estimates. The routine measurement of soil moisture will alert agricultural producers to newly developing flash drought conditions and indicate the effectiveness of recent rainfall events. Conversely, increases in soil moisture can warn of possible flooding because such increases create the preconditions for floods.

Key words
Soil moisture measurements, network, validation and calibration models, drought, Czech Republic.

Introduction

Soil water content is influenced by weather conditions, particularly precipitation and evaporation. The rate effect depends on soil type, topography, and vegetation (Kutílek et al. 2004). A detailed analysis of drought requires one to monitor the water content of the soil profile in daily steps. Continuous soil water observation makes it possible to determine whether a recent rainfall event effectively recharged a particular soil profile. Determining the effectiveness of rainfall events is especially critical following prolonged dry spells (Hunt et al. 2009a). Continuous daily observations of soil moisture are rare in recent literature (Seneviratne et al. 2010). With the development of automated measurement, several ground-based monitoring networks began for soil moisture (Illston et al. 2008; Zamora et al. 2009; Scott 2009; Hunt et al. 2009b). These include the Oklahoma Mesonet network (Basara and Crawford 2000), the REMEDHUS network (Martinez-Fernandez and Cebullos 2003), the AMMA project (Redelsperger et al. 2006), the SMOSREX ground measurement experiment (De Rosnay et al. 2006), the HyMex project (http://www.hydex.org), and the new TERENO (http://www.tereno.net) and SwissSMEX (http://www.ias.ethz.ch/ur/ research/SwissSMEX) networks. These networks can be used to verify satellite observations (e.g., Seneviratne et al. 2004; Reichle et al. 2004; Hirschi et al. 2006; Guo et al. 2007; Rüdiger et al. 2009; Seneviratne et al. 2010; Mozný et al. 2011).

Material and methods

The network of automatic weather stations is managed by the Czech Hydrometeorological Institute (CHMI). The stations continuously measure basic meteorological elements and report measurements to the center every 10 min. The selected network of stations usually measures the soil moisture content at the 0- to 0.1-m, 0.1- to 0.5-m, and 0.5- to 0.9-m layers using sensors placed within the natural soil profile under closely cropped grass cover (Mozny 2006). The stations use three sensors, one horizontal and two vertical. A detailed pedological survey was carried out for all of the layers that determined the wilting point and the field capacity (Miller et al. 1990), among other things. Sensors were first installed at the Doksany station in 1991 (Mozny 2006). Since 1998, the measurement system has also been introduced at other stations. In 2012, it was operating in 45 stations. The original measurements using VIRRib sensors (www.amet.cz) have been gradually replaced by measurements taken using more accurate TRIFO3G sensors (www.asconsult.cz). The preliminary results have shown that the TRIFO3G sensors do not exhibit the noise problems associated with the VIRRib sensors. Both sensors use the dielectric method to measure soil moisture (Topp et al. 1980). The measured soil moisture is calculated using the following equation:

\[ F_{aw} = (\theta - \theta_{WP}) / (\theta_{FC} - \theta_{WP}) \]

\[ SMC = 100 \times F_{aw} \]

\[ SMI = -5 + 10 \times F_{aw} \]

where \( F_{aw} \) is the fraction of available water, \( \theta \) is the actual volumetric soil water content, \( \theta_{WP} \) is the volumetric soil water content at the wilting point, \( \theta_{FC} \) is the volumetric soil water content at field capacity, SMC is the fraction of available water in per cent, and SMI is the the Soil Moisture Index. The SMI assumes values in the range of ±5, with negative values indicating periods of water deficit. A continuous period with negative SMI values is called a drought episode. The daily SMI is calculated as the average value for the 0-0.5-m-layer soil profile.

The CHMI uses a simplified six categories of soil moisture: 1 - very high (SMC>90 %), 2 - high (70 %< SMC< 90 %), 3 - good (50 %< SMC< 70 %), 4 - weak (30 %< SMC< 50 %), 5 - lower (10 %< SMC< 30 %), and 6 – very lower (SMC< 10 %).
Results and Discussion

To examine the relationships between reference evapotranspiration, precipitation, and soil water, the coefficient of determination ($R^2$) for total precipitation subtracted by total reference evapotranspiration (TP–TRET) over 10-day periods and daily SMI values were calculated for all growing seasons at the Doksany station (50°27′31″ N, 14°10′14″ E, 158 m asl.). The reference values for evapotranspiration are comparable to the values for open water evaporation. We found a statistically significant correlation ($R^2=0.43$, $P<0.01$) between TP–TRET during the 10-day periods examined and daily values for SMI from April to September from 2001 to 2012. The coefficient of determination for each year varied considerably. The $R^2$ of TP–TRET versus SMI fluctuated between 0.35 (2004) and 0.61 (2005). The SMI typically decreases when there is less precipitation than evapotranspiration.

From 2001 to 2012, negative average daily SMI values were prevalent from April through September. Positive average daily SMI values occurred only in short intervals, usually at the beginning of April, which is rich in rainfall. The relatively small territory of the Czech Republic is characterized by rather large diverse SMI values from April through September. On average, the highest SMI values were recorded for April and the lowest for August and September.

Based on our experience, the soil moisture network is not difficult to use. All daily measurements of soil moisture are freely available on the CHMI Doksany web site (www.obsdoksany.cz/smi.html) and on the CHMI web site (www.chmi.cz). The measurements are classified according to soil layer and are expressed as the categories of soil moisture (Fig.1), or the expressed as the SMI index (Fig. 2).

The use of advanced soil moisture sensors allows precise estimates of the beginning and end of particular drought periods. Visual images of soil moisture conditions at several soil depth levels provide a valuable verification tool that is independent of other drought variables. When automatic stations do not measure soil moisture, the resultant missing data can be simulated using an appropriate model. The relationship between the modeled and the measured soil moisture values is not constant over time and varies from year to year. The reason for this variation is that all models rely on the balance between precipitation and evapotranspiration. In comparing the measured and the modeled soil moisture values (model BASET) at the 0- to 0.2-m layer at 31 stations from 2003 to 2006, researchers found that the coefficient of determination ($R^2$) for CHMI varied from 0.05 to 0.93, with an average value of 0.66 (Kott and Valter 2008). Fluctuations in $R^2$ values supported the results regarding the comparative measurements from the Doksany station (Mozny and Bares 2006), which were used to test the AMBAV (Löpmeier 1994) and BASET models. Eleven years of continuous measurement of soil moisture content allowed us to explore the use of SMI to monitor drought conditions in the Czech Republic. The use of TRIFO3G sensors may be appropriate for use in further expanding the network of stations monitoring soil moisture. When one is installing the sensor, the field capacity and wilting point should be determined for the soil layer. One significant benefit of SMI use is that it is possible to calculate how often measurements are available and to verify the accuracy of satellite observations.

Conclusions

CHMI network soil moisture measurements are reported every 10 min. Soil moisture measurements are necessary to determine effective rainfall levels, which in turn help predict the end of the dry period. The disadvantage of using the SMI is that the calculations are performed for the 0- to 0.5-m soil layer. Especially during the spring, in light, sandy soils, the upper layer of soil may dry up and impede the emergence of agricultural crops. Therefore, it is helpful to include SMI values for multiple soil layers.

An SMI of 0 indicates no drought, but could be heading toward drought or recovered from drought. Sridhar et al. (2008) categorized the SMI index into five classes (less intense, moderate, high intense, severe, extreme) to...
quantitatively assess drought in both space and time. SMI below −3 indicates a transition to a severe and extreme drought. The classes are chosen in a similar fashion to that of the US Drought Monitor to maintain the consistency for us to compare the severity of drought. Our results demonstrate the suitability of using these classes for the quantification of drought in the Czech Republic. The increasing incidence of droughts and projected climate changes indicates the benefits of developing a more widespread network of soil moisture measurement in the Czech Republic. The routine calculation of SMI values will alert agricultural producers to newly developing flash drought conditions and indicate the effectiveness of recent rainfall events. Conversely, increases in soil moisture can warn of possible flooding because such increases create the preconditions for floods.

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References


