Physics and Chemistry of the Earth 83–84 (2015) 36–56

Contents lists available at ScienceDirect

Physics and Chemistry of the Earth

journal homepage: www.elsevier.com/locate/pce

Surface soil moisture retrievals from remote sensing: Current status, products & future trends

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ARTICLE INFO

Article history:
Received 18 December 2014
Received in revised form 18 February 2015
Accepted 19 February 2015
Available online 14 March 2015

Keywords:
Soil moisture
Remote sensing
Hydrology
Climate change
Water balance
Land surface interactions

ABSTRACT

Advances in Earth Observation (EO) technology, particularly over the last two decades, have shown that soil moisture content (SMC) can be measured to some degree or other by all regions of the electromagnetic spectrum, and a variety of techniques have been proposed to facilitate this purpose.

In this review we provide a synthesis of the efforts made during the last 20 years or so towards the estimation of surface SMC exploiting EO imagery, with a particular emphasis on retrievals from microwave sensors. Rather than replicating previous overview works, we provide a comprehensive and critical exploration of all the major approaches employed for retrieving SMC in a range of different global ecosystems. In this framework, we consider the newest techniques developed within optical and thermal infrared remote sensing, active and passive microwave domains, as well as assimilation or synergistic approaches. Future trends and prospects of EO for the accurate determination of SMC from space are subject to key challenges, some of which are identified and discussed within.

It is evident from this review that there is potential for more accurate estimation of SMC exploiting EO technology, particularly so, by exploring the use of synergistic approaches between a variety of EO instruments. Given the importance of SMC in Earth's land surface interactions and to a large range of applications, one can appreciate that its accurate estimation is critical in addressing key scientific and practical challenges in today's world such as food security, sustainable planning and management of water resources. The launch of new, more sophisticated satellites strengthens the development of innovative research approaches and scientific inventions that will result in a range of pioneering and ground-breaking advancements in the retrievals of soil moisture from space.

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http://dx.doi.org/10.1016/j.pce.2015.02.009

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1. Introduction

The need – especially in the context of global climate change – to develop a holistic understanding of how land surface parameters characterising the planet's energy and water budget has never been more important (WMO, 2002; ESA, 2014). In this context, the important role of soil moisture content (SMC) in various processes and feedback loops of the Earth system cannot be overstated. SMC generally refers to the water contained in the unsaturated soil zone (Seneviratne et al., 2010), expressed usually as either a dimensionless ratio of two masses or two volumes, or given as a ratio of a mass per unit volume (see Fig. 1). These dimensionless ratios can be reported either as decimal fractions or percentages, if multiplied by 100.

Being able to accurately estimate SMC is of great importance (Petropoulos et al., 2013a). Accurate information on SMC is of high relevance to a number of bio-physical processes related to the exchanges of energy and mass between the hydrosphere, atmosphere and biosphere (Zhang et al., 2014a). Soil moisture has long been recognised as a key state variable within the global energy cycle due to its control on the partitioning of available energy at the Earth's surface into latent (LE) and sensible (H) heat exchange (Vereecken et al., 2014). It is also a significant component of the hydrological cycle, governing the partitioning of rainfall into infiltration and runoff, thus affecting stream flow, groundwater recharge and precipitation (Tuttle and Salvucci, 2014). Notably, SMC has a strong influence on hydro-meteorological processes within the atmospheric boundary layer, thus, it has a direct relationship with global climate and weather systems. Evidently, accurately quantifying SMC is of great importance to a wide range of disciplines and practical applications (e.g. see Petropoulos et al., 2013b) which has led to it being recognised as an Essential Climate Variable (ECV) by the Global Climate Observing System (GCOS) (Zhao and Li, 2013; Al-Yaari et al., 2014).

A number of quantitative methods have been utilised to analyse the spatio-temporal dynamics and distribution of soil moisture properties across a broad range of scales (Vereecken et al., 2014). At smaller scales, a number of approaches have been developed to measure SMC directly using ground instrumentation (for a review see Verstraeten et al., 2008; Petropoulos et al., 2013b). Such methods can be broadly grouped into, amongst others, point measurements with electromagnetic soil moisture sensors, hydrogeophysical methods and electrical resistivity tomography (Vereecken et al., 2014). Within these groups, gravimetric sampling and networks of impedance probes based on dielectric methods are generally two of the most reliable methods, able to provide an accuracy level of ~4% v/v in SMC estimation. Use of ground instrumentation has certain advantages, such as instrument portability, easy installation, operation and maintenance, ability to provide direct measurements at different depths, as well as their relative maturity. Although direct or ground-based measurements are the most accurate methods for estimating soil moisture, such techniques are often rather complex, expensive, and labour-intensive, (Rahimzadeh-Bajgiran et al., 2013), where some can also be destructive (e.g. gravimetric sampling) (Zhang et al., 2014b).

Many factors affect the spatial variability of SMC, such as changes in topography, types of soil, vegetation cover, climate, and depth of water table, which predominantly depend on surface heterogeneity and dynamic forces distribution (Fernández-Prieto et al., 2013). Ground-based measurements of SMC are currently limited to discrete measurements at particular locations. Such point-based measurements do not represent the spatial distribution exhibited by highly variable soil moisture (Srivastava et al., 2013a). Extrapolating such point-based measurements to a larger scale is practically expensive, time consuming, and complex, particularly over heterogeneous land surfaces (Byun et al., 2014; de Tomás et al., 2014). Thus, it is understandable that

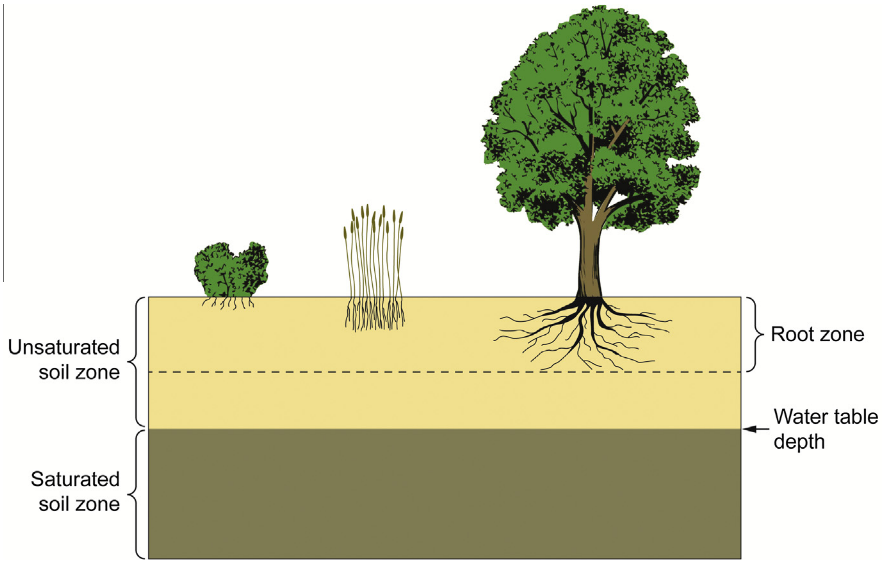

Fig. 1. The saturated and unsaturated soil zones (adapted from Seneviratne et al., 2010).