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Online soil moisture retrieval and sharing using geospatial web-enabled BDS-R service

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ABSTRACT

Global navigation satellite system-reflectometry (GNSS-R) signals have recently being used in the monitoring of soil moisture (SM) due to their high availability and widespread existence. GNSS-R signal-based online SM retrieval and real-time product sharing has advantages over other methods because it features the instant and automatic retrieval of SM, and low-latency SM product publishing and sharing, enabling a notable decrease in human and material resource consumption and a timely SM product delivery; however, prior to this manuscript, there has not been a study describing how to do it. This paper uses one type of GNSS-R signals, the Beidou navigation satellite system-reflectometry (BDS-R) signal, as the data source and proposes a geospatial web-enabled BDS-R (GWEB) service. This method tackles the problems of SM retrieval and sharing by implementing the original BDS-R signal publishing, the online SM retrieval, and the SM product sharing. In the GWEB service, a web processing service is adopted to encapsulate the SM retrieval algorithm, and a sensor observation service is applied to publish the original BDS-R observations and the SM products. Signals of the Baoxie BDS-R SM monitoring station in Wuhan, China for the period of November 17, 2014 to November 24, 2014 are used as input in the validation experiment, and the SM products are demonstrated in the sharing platform. Meanwhile, the BDS-R derived SM products are compared with the corresponding SM values measured by ground soil hygrometers, indicating the feasibility of the service for online SM retrieval and sharing.

1. Introduction

Soil moisture (SM) is a critical factor in various environmental studies, and is also a key variable in many applications, such as the estimation of drought severity and duration, irrigation scheduling, the study of soil erosion and evapotranspiration, the control of forest fire hazards, and forest management (Rahimzadeh-Bajgiran et al., 2013). The global navigation satellite system reflectometry (GNSS-R), including reflectometry of the global positioning system (GPS) in the United States, the GLONASS of Russia, the Galileo of Europe, and the COMPASS (Beidou) of China, has some advantages compared with other remote sensing data sources (i.e. data from satellite radiometers or scatterometers) for SM retrieval, including: (1) signals lie in the most sensitive frequency band for SM microwave remote sensing (Schmugge and Jackson, 1993; Shutko, 1982; Ulaby, 1974); (2) signals are continuous, have global coverage, and can be obtained in all weather conditions (Jin and Komjathy, 2010); (3) signal acquisition is inexpensive and is readily available in real time; (4) reflected signals are not dramatically contaminated by thermal background variations in comparison to microwave radiometry signals; and (5) scatterometry from space has the potential for better spatial resolution than microwave radiometry.

With the five characteristics mentioned above, GNSS-R signals begin to be used as a new data source for SM monitoring (Jin and Komjathy, 2010; Rodriguez-Alvarez et al., 2011a; Jin et al., 2011). From 2002 to 2005, the National Aeronautics and Space Administration and Colorado University (both in the USA) conducted a series of experiments on GNSS-R measurement of SM (Masters et al., 2004). Larson et al. (2010) applied the GPS signal-to-noise ratio (SNR) data to invert the near surface SM. Saleh et al. (2009) used a two-step inversion approach to retrieve SM from the L-band data. Rodriguez-Alvarez et al. (2011b) performed SM and vegetation height retrievals by applying the Interference Pattern Technique (IPT). Egido et al. (2012, 2014) studied the effects of different land bio-geophysical parameters on GNSS scattered signals and used experiments to assess the sensitivity of the parameters. Arroyo et al. (2014) reformulated the IPT equations for the dual polarization case and extended its use. Camps et al. (2014)

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proposed a method to optimize the configuration of a generic interferometric GNSS-R altimeter and evaluated its performance.

The aforementioned studies have mainly focused on the development of different inversion algorithms and instrument designs to estimate SM content. None of these studies addressed online SM retrieval or the real-time sharing of SM data retrieved from GNSS-R. Without online retrieval and data sharing, on one hand, the time delay problem between signal acquisition and SM product availability is difficult to solve, affecting the efficiency of SM related decision-making, and on the other hand, repeated but incomplete measurements can be caused, resulting in imbalanced availability of SM measurements and huge wastes of manpower and resources. Therefore, it is imperative to propose an online SM retrieval and real-time data sharing service to resolve these problems.

The sensor web enabling sensor and observation sharing (Nittel, 2009; Bröring et al., 2011) and the web processing service (WPS) capable of algorithm encapsulation and online processing (Schut and Whiteside, 2007) of the open geospatial consortium (OGC) can be used in SM retrieval and real-time data sharing. Sensor web has been used alone or combined with WPS or other web services in wildfire hot pixel determination (Chen et al., 2010a), multiple feature classification and extraction (Chen et al., 2010b), flood detection (Auynirundronkool et al., 2012), integrated sensing of SM (Phillips et al., 2014), and information infrastructure construction for precision agriculture (Chen et al., 2015). This paper adopts the Beidou navigation satellite system reflectometry (BDS-R) signals as the data source, proposes a geospatial web-enabled BDS-R (GWEB) service, and combines sensor model language (SensorML) (Botts and Robin, 2007), observations and measurements (O&M) (Cox, 2007a; Cox, 2007b), and sensor observation service (SOS) (Na and Priest, 2007) of the sensor web with WPS to achieve instant SM retrieval and sharing.

In the forthcoming sections, we illustrate the GWEB service and validate its feasibility for online estimation of SM and SM product publishing. The development of the GWEB method is presented in Section 2. The overall architecture is described in Section 2.1, the BDS-R sensor registration and observation insertion service is presented in Section 2.2, the online SM retrieval service is described in Section 2.3, and the real-time SM product publishing service is presented in Section 2.4. The experiment to instantiate the GWEB service is stated in Section 3. The discussion about the GWEB method for online SM estimation and sharing is provided in Section 4. Finally, Section 5 summarizes this work and describes future directions for this research.

2. GWEB service

2.1. Architecture and components

The GWEB service is composed of a three-tier architecture, including the BDS-R sensor layer, the geospatial web service layer, and the application layer. The BDS-R sensor layer is responsible for data acquisition from the BDS-R equipment, and provides data support for the geospatial web service layer. The geospatial web service layer is the core of the entire architecture and consists of three sub-services: the sensor registration and observation insertion (SROI) service, the online SM retrieval (OSMR) service, and the SM product publishing (SMPP) service. This layer acts as the middleware between the BDS-R sensor layer and the application layer. It first receives observations from the lower BDS-R sensor layer, then completes the process of SM retrieving and product publishing, and finally transmits the SM results to the upper application layer for distribution and sharing. The application layer mainly refers to the clients for SM product sharing. These clients allow users to query and obtain the corresponding SM products conveniently and effectively. The schematic of the entire GWEB service architecture is illustrated in Fig. 1.

The geospatial web service layer is the focus of this work, and the three subservices in it perform different functions: (1) the SROI service registers the GNSS-R sensors and inserts the sensor-associated observations; (2) the OSMR service receives the observations from the SROI service, calculates the SM results according to a specific retrieval algorithm, and transfers the SM products to the upper SMPP service; and (3) the SMPP service associates the SM products to their GNSS-R sensors, and completes SM products publishing. The three sub-services share a common backend database, and all the operations of the sub-services will be eventually turned into the operations on the database to take effect. By integrating the three sub-services together, the online SM retrieval and product sharing can be achieved.

The GWEB service can be used by either BDS-R original observation providers or SM product users. BDS-R observation providers can first register the sensor and insert the observations through the SROI service, then perform online retrieval via the OSMR service, and finally publish their SM products using the SMPP service. The SM product customers can directly obtain the SM products, or they can obtain the original BDS-R observations and calculate the SM results on their own. The interactions of providers, users and the three sub-services are demonstrated in Fig. 2. The following sections will explain the three sub-services in detail.

2.2. SROI service

As shown in Fig. 2, the SROI service allows the provider to register their BDS-R sensors and to insert the sensor-associated observations. Both the sensor registry and the observation insertion conform to the SOS interface specification of the OGC. A producer can publish observations to an SOS only on condition that the SOS already knows about the sensor that generated the observations. Thus, in the SROI service, sensor registration is the premise of observation insertion. The sensor registration could be completed via RegisterSensor, an operation that allows the client to register a new sensor or sensor system with the SOS.

A RegisterSensor request includes a sensor description, such as a SensorML document, and an O&M observation instance which can be used as a template for the sensor's observations to be published through the InsertObservaton operation. Each SROI service has a fixed sensor description and observation instance format. The sensor description template adopted in this work is the eight-tuple sensor metadata description structure (Chen and Hu, 2012), which conforms to the OGC SensorML schema and refines the OGC SensorML template. The observation template used here is the O&M 1.0 standard with five mandatory elements: samplingTime, procedure (the sensor generating the observation), observedProperty, featureOfInterest (mainly refers to the spatial range or location), and result. The SensorML template together with the O&M observation template can be pre-defined within the SROI service, so that clients can easily build a RegisterSensor request by filling in the template. After the request document is built, clients can register their sensors into the SROI service by performing the RegisterSensor operation. The assigned sensor id, usually in alignment with the identification provided in the sensor description document, will be returned as the indicator of successful registration.

After a sensor is registered in the SROI service, observations associated with the sensor can be inserted. Observation insertion can be achieved by using the InsertObservation operation, which is defined in the OGC SOS for allowing clients to insert observations for registered sensors or sensor systems. An InsertObservation request is composed of the assignedSensorId and an O&M