GEOPHYSICAL RESEARCH LETTERS, VOL. 34, L14401, doi:10.1029/2007GL030098, 2007

L-band microwave observations over land surface using a two-dimensional synthetic aperture radiometer

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Received 23 March 2007; revised 18 May 2007; accepted 29 May 2007; published 17 July 2007.

[1] Antenna size is a major factor that has limited realization of the potential capabilities of L-band (1.4 GHz) microwave radiometry to estimate surface soil moisture from space. However, emerging interferometric technology, called aperture synthesis, has been developed to address this limitation. The Soil Moisture and Ocean Salinity (SMOS) mission will apply the technique to monitor these parameters at a global-scale in the near future. The first airborne experiment using an aircraft prototype called the Two-Dimensional Synthetic Aperture Radiometer (2D-STAR) was performed during Soil Moisture Experiment in 2003 (SMEX03). To gain insight, the L-band brightness temperature data acquired by 2D-STAR in Alabama was compared with C-band data collected simultaneously by another aircraft instrument called the Polarimetric Scanning Radiometer (PSR), and also compared with surface soil moisture measurements from in-situ observations sites. Results show that there was fairly good radiometric sensitivity of the synthetic aperture radiometer to the soil moisture both in pasture and also in forest areas. The overall performance of the L-band synthetic aperture radiometer in the presence of vegetation appears to be better than the C-band real aperture radiometer. **Citation:** Ryu, D., T. J. Jackson, R. Bindlish, and D. M. Le Vine (2007), L-band microwave observations over land surface using a two-dimensional synthetic aperture radiometer, *Geophys. Res. Lett.*, *34*, L14401, doi:10.1029/2007GL030098.

1. Introduction

[2] Passive microwave remote sensing of the earth's surface can provide valuable information about the surface conditions in the hydrosphere, biosphere, and cryosphere. This includes soil moisture, ocean salinity, vegetation water content, and snow water equivalent [*Kelly et al.*, 2003; *Kerr et al.*, 2001; *Njoku et al.*, 2003]. Among these surface conditions, remotely sensed surface soil moisture plays an important role in understanding and modeling the exchanges of water and energy between land and atmosphere. Currently, the Advance Microwave Scanning Radiometer (AMSR-E) utilizes primarily X-band data in order to provide global coverage of surface soil moisture. However, it has been widely accepted that L-band (~1.4 GHz) is the optimal choice for remote-sensing of soil moisture, because the microwave signal from the surface is less attenuated by vegetation at lower frequencies [*Jackson et al.*, 1999; *Schmugge*, 1998]. In addition, the L-band signal is sensitive to the moisture content in a thicker layer of the soil column [*Njoku and Li*, 1999]. These capabilities of L-band radiometry have motivated the Soil Moisture and Ocean Salinity (SMOS) mission by the European Space Agency (ESA) [*Kerr et al.*, 2001].

[3] However, because of the long wavelength (21 cm at 1.413 GHz), antenna size is a major factor limiting passive remote sensing from space at L-band. The radiometer on SMOS will employ the new interferometric technology, aperture synthesis, designed to help overcome this limitation. In aperture synthesis, an array of small antennas is used to achieve the spatial resolution of a large antenna [*Skou and Le Vine*, 2006]. SMOS will be the first spaceborne radiometer deploying this technology to monitor the surface of the Earth.

[4] The technology has been demonstrated in experiments with airborne instruments. One of the first instruments to employ aperture synthesis in two dimensions is the 2D-STAR [*Le Vine et al.*, 2007]. 2D-STAR operates at L-band and shares many common features with SMOS (see Table 1). The first field experiment using the 2D-STAR was performed as part of the Soil Moisture Experiment in 2003 (SMEX03). During SMEX03, 2D-STAR was flown onboard the NASA P3B aircraft over four regional-scale sites (approximately 50 km $\times$ 100 km) located in Alabama, Georgia, and Oklahoma during periods of June and July, 2003. The Polarimetric Scanning Radiometer (PSR) was mounted on the same aircraft adjacent to the 2D-STAR and collected C- and X-band data simultaneously with the 2D-STAR over the same regions. The main objective of the PSR in SMEX03 was to simulate and validate C- and X-band brightness temperature from AMSR-E [*Jackson et al.*, 2005]. The concurrent operation of the 2D-STAR and PSR provided a unique opportunity to compare the performance of the L-band synthetic aperture radiometer with a C-/X-band real aperture radiometer. In this paper, the brightness temperatures from 2D-STAR and PSR will be compared with in-situ soil moisture data collected from a pasture and a forest site in order to examine their sensitivities to the surface wetness under light and dense vegetation conditions. The brightness temperature is the conventional product from radiometers, and as a first approximation it is inversely proportional to soil moisture. The implications of the comparison for the future SMOS mission and the potential benefit of L-band data from SMOS over currently operating spaceborne C-/X-band instruments will be discussed.

2. Data and Methods

2.1. Two-Dimensional Synthetic Aperture Radiometer (2D-STAR)

[5] The 2D-STAR was developed under NASA's Instrument Incubator Program to demonstrate the potential of

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0094-8276/07/2007GL030098$05.00

Table 1. Instrument Facts of 2D-STAR and SMOS

Contents	2D-STAR	SMOS
Frequency	1.413 GHz	1.413 GHz
Polarization	H and V	H and V
Bandwidth	20 MHz	19 MHz
Integration time	0.2 seconds	1.2 seconds
Number of receivers	21	69
Receiver spacing	10.6 cm (0.5λ)	18.87 cm (0.89λ)
Tilt angle	∼0°	∼32.5°
View angle range	0°–40°	0°–50°
Array type	+	Y
Platform	Aircraft	Satellite
Altitude	7.7 km	763 km
Footprint resolution	∼800 m	∼50 km

two-dimensional aperture synthesis for observing surface variables such as soil moisture [*Le Vine et al.*, 2007]. Aperture synthesis is a relatively new technique that has been explored as a solution to the limitations on antenna size for low-frequency radiometry from space [*Ruf et al.*, 1988]. Synthetic aperture radiometers utilize an array of small antennas and signal processing to achieve the high spatial resolution of a single large antenna. Due to the large field of view of the small antennas, mechanical scanning of the antenna array is not required. An one-dimensional L-band interferometric radiometer, the Electronically Scanned Thinned Array Radiometer (ESTAR), was successfully demonstrated for mapping surface soil moisture at regional scales [*Jackson et al.*, 1999; *Le Vine et al.*, 2001]. Flexibility in the antenna-array configuration is limited in the 1-D array. More flexibility, including more highly thinned arrays, is possible with synthesis in two dimensions which makes it more desirable for remote sensing from space [*Skou and Le Vine*, 2006].

[6] The 2D-STAR instrument is composed of a fully populated 11 × 11 array of small square antennas, each of which is 6.86 × 6.86 cm^2. Each antenna is dual polarized and separated by 0.5 wavelength (∼10.6 cm at L-band) from adjacent antennas. Of the possible 11 × 11 elements, 21 antennas along the principle axes, which is a "+" shape configuration, were activated for data collection during SMEX03. Complex correlations of the signals, calculated from all the possible pairs of the 21 antennas, are transformed to form an image with a circular footprint on the surface. The radius of the circle is limited to points within a cone angle of about 40 degrees from nadir to avoid distortion at larger angles. An image is produced every 0.2 seconds during the experiment. At the nominal flight altitude of 7.7 km utilized in SMEX03, the image processing results in a 10 km swath and a resolution of approximately 800 m. Other features of the instrument are summarized in Table 1. The instrument is described in more detail by *Le Vine et al.* [2007].

[7] Each circular footprint of 2D-STAR is composed of numerous pixels of the brightness temperature value. The view-angle of the pixels increases from 0° to 40° from the center. For this study, we used data with view-angles ranging from 30° to 40° in order to reduce the effect of variable view-angles and to facilitate the comparisons to the PSR. The selected data was mapped on 800-m-scale grids where the value of each grid was calculated by averaging all the pixels included in the grid.

2.2. Soil Moisture Experiment in 2003 (SMEX03)

[8] SMEX03 was conducted over four regional-scale sites (∼50 km × 100 km) in Oklahoma (2 sites), Alabama (1 site), and Georgia (1 site) during periods of June and July, 2003. A main objective of SMEX03 was validating AMSR-E brightness temperatures and soil moisture products using airborne and ground-based observations collected over a wide range of land surface conditions. Among the four sites, surface wetness conditions exhibited the largest range in Alabama during the experiment period as the result of two intermediate-to-heavy rainfall events. In addition, the Alabama site has a variety of land-cover types and topographic conditions, ranging from flat pastures to hilly forests. In this paper, airborne and in-situ data collected in Alabama during SMEX03 will be analyzed.

[9] Figure 1b is a Landsat Thematic Mapper false-color image (blue, band 2; green, band 3; red, band 4) of the Alabama site. The image is a composite of two images obtained on April 19 and May 14, 2000. Vegetated areas are colored red in this image. The Alabama study area includes agricultural (40%) and forested lands. Forested land is located mostly in the eastern half and northwestern corner of the study area, and the agricultural land spans from the southwestern to the northeastern portions of the region. The large feature in blue on the southeastern corner is the Tennessee River. The eastern part of the area is covered by dark-reddish brown silt loam with moderate infiltration rates. The topsoil of the western part is primarily fine sandy loam.

4. Discussion

[17] In this study, brightness temperature images from the first airborne experiment utilizing a two-dimensional synthetic aperture radiometer were presented and compared with surface soil moisture data from an in-situ observation network. The results confirm that the radiometric signal received by an L-band synthetic aperture radiometer is more sensitive to soil moisture than a C-band real aperture radiometer and that this advantage in sensitivity becomes more pronounced as vegetation canopy increases. The observed sensitivities of the 2D-STAR provide encouraging support for the future SMOS mission because: (1) it demonstrates that radiometric sensitivity of the reconstructed images are sufficient to monitor realistic changes in soil moisture [*Skou and Le Vine*, 2006]; and (2) it also demonstrated the potential for mapping soil moisture under dense vegetation (i.e., vegetation water content >5 kg/m^2) which has been a concern for the SMOS mission [*Kerr et al.*, 2001]. Moreover, considering the instrumental similarities of AMSR-E and PSR, and SMOS and 2D-STAR, we can expect improved sensing performance in soil moisture retrieval over a wide range of vegetation conditions from SMOS mission as compared to the currently operating spaceborne radiometers.

[18] In addition to the benefits in terms of antenna deployment mentioned in the introduction, the synthetic aperture radiometer can obtain TB over a range of view angles as a snapshot. The multi-angular brightness temperature data can be used to reduce the number of parameters in soil moisture retrieval algorithms [*Wigneron et al.*, 2000]. 2D-STAR did produce TB with view angles varying from 0° to 40°. More in-depth studies about the relationship between the view angle and TB-H/-V are planned.