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GNSS-R of soil moisture content in Khuzestan for optimal crop distribution

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Abstract

A new technology based on the reflection of Global Navigation Satellite Systems (GNSS) signals, namely GNSS-Reflectometry (GNSS-R), can monitor soil moisture content (SMC) and provide very valuable data for agriculture and hydrology at a regional and larger scales. In this paper, GNSS-R SMC estimates in the Khuzestan Province of Iran are estimated from the NASA's Cyclone GNSS (GYGNSS) data through the bistatic radar equation and the Fresnel coefficients. We identify a set of optimal areas for agriculture with CYGNSS SMC estimates (SMC>0.1) during the dry season of 2021. We compare the results with the actual distribution of wheat, and provide some suggestions and recommendations for future works on using GNSS-R SMC in agriculture. We provide the first insights of the possible benefits that GNSS-R SMC can deliver to farmers and national government.

1. Introduction

Monitoring and predicting soil moisture content (SMC) is very important for social economy and human activity, while it plays a crucial role in the characterization of the Earth's climate and its hydrological cycle. SMC is a key parameter for planning irrigation strategies, while it simultaneously regulates energy and water exchange between the land and the atmosphere, and other hydrological and climate processes.

Disasters on agriculture and food security need to be mitigated using models that can predict the state of the land held; different crops require different conditions for growing optimally. Some crops need dry climates to mature for harvest. These mainly include crops from the grass family, which are staple food source. For example, the agriculture in Iran uses the climate as an advantage, to grow and harvest crops depending on available soil moisture along the seasons. That being said, all crops require water at the sowing or planting, and become well established. In addition, Iran also may grow crops that require more moisture that that is available for the characteristics of the area, such as rice or sunflowerseed crops, but it is difficult to identify the optimal locations for crops that require more water.

At a local scale, farmers have a large wealth of knowledge of growing crops in in their own country. However, at a regional and larger scales, it is difficult to characterize the land held in terms of SMC. Fortunately, with the recent satellite technology developments with Earth's observation through remote sensing from space, more insights on soil and climate conditions at regional and larger scales allow farmers and national governments to further benefit from agricultural strategies.

In this paper, we estimate SMC using a new technology based on the reflection of Global Navigation Satellite Systems (GNSS) Reflectometry, namely GNSS-R [Carreño-Luengo et al. 2018; Privette et al. 2011, Clarizia et al. 2019; Calabia et al. 2020]. This is a new remote sensing method that is accurate and much cheaper than traditional satellite microwave instruments, such as NASA's SMAP (Soil Moisture Active Passive), or other terrestrial data collection methods marketed to farmers. This technology uses an L frequency band that is suitable for assessing the SMC in the first 10 cm of the soil surface. In this work, we study the region of Khuzestan in Iran during the driest period of 2021, so that it is possible to

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characterize the optimal location of crops depending on their SMC requirements. In the next section, we introduce the study area with it details on climate and crop calendar. Then in section 3, we describe the methods and data used to obtain the results, which are presented in section 4. Final discussion and conclusions are given in the last sections.

2. Study Area

The Khuzestan Province is located in the southwest of the Iran, bordering Iraq and the Persian Gulf. Figure 1 shows the climograph of Khuzestan, where the mean temperature in summer routinely approaches to 38°C, and in the winter drops down to 12°C. In general, the climate of Khuzestan in Summer is hot and dry, with almost no precipitation from June to September.

In Iran, wheat, rice, and barley are the country's major crops. Figure 2 shows the crop calendar of Iran, where rice and Sunflowerseed are planted up to June, Sorghum, soybean, corn, and cotton are mid-season growing crops, and wheat, rapeseed, and barley are harvested in August.

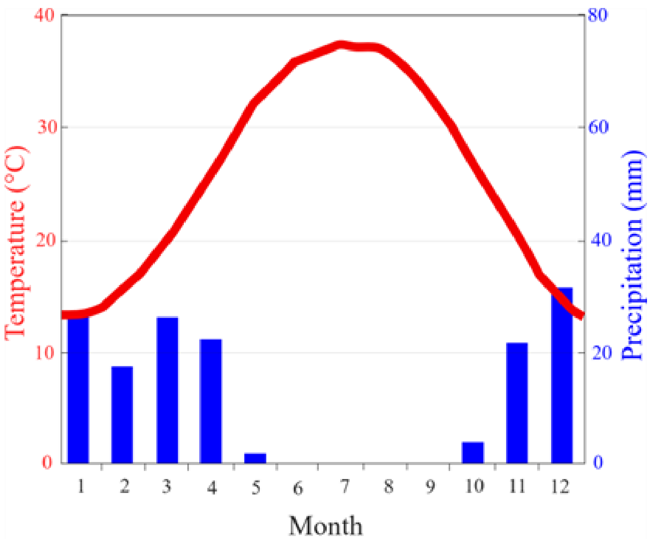

Figure 1. Climograph of Khuzestan (Iran). Data from climatecharts.net

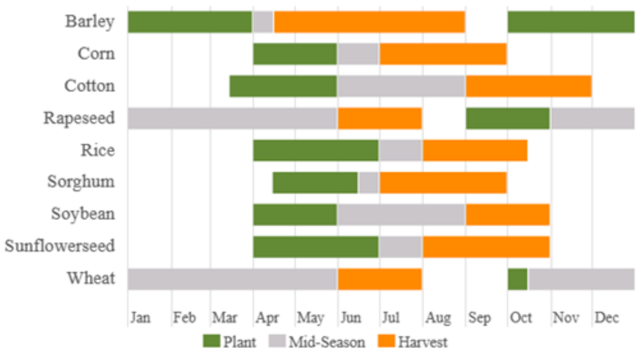

Figure 2. The crop calendar of Iran. From: ipad.fas.usda.gov.

3. Data and Methods

In this study, we employ the NASA's Cyclone GNSS (GYGNSS) data during the month of August 2021. The GNSS-R SMC retrieval approach of Calabia et al. [2020] employs a modification of the bistatic radar model [Masters et al., 2004] for the coherent component of smooth surfaces [Clarizzia et al., 2019]:

$$\Gamma_{lr}(\theta)=\frac{(4\pi)^2(P_{DDM}-N)(R_t+R_t)^2}{\lambda^2 G_t G_r P_t} \tag{1}$$

where P_{DDM} is the peak value from the analog scattered power. The subscript *rl* stands for a scattering mechanism when the incident right hand circularly polarized (RHCP) signal is scattered by the surface and inverts the polarization to left hand circularly polarized (LHCP) at the receiver position. Γ_{lr} is the surface reflectivity for the received *lr* polarization from which the SMC can be estimated.

Land surfaces' reflectivity is affected by its corresponding bare soil roughness (BSR) and vegetation optical depth (VOD) parameters, and their implementation in Equation 1 is as follows:

$$\Gamma_{lr} = \left|R_{lr}(\theta_i)\right|^2 e^{(-2k\sigma\cos\theta_i)^2} e^{-2\tau/(\cos\theta_i)^2} \tag{2}$$

where $R_{lr}(\theta)$ is the Fresnel reflection coefficient for the given polarization, τ stands for the VOD and $h=4k^2\sigma^2$, with $k=2\pi/\lambda$, where λ is the wavelength of the system, and σ is the standard deviation of the surface roughness. Here, NASA's SMAP VOD and BSR ancillary data are used to correct for their corresponding attenuation effects.
The soil permittivity (ε_r) is estimated by means of the Fresnel reflection coefficients, that are related to the reflectivity linear polarization modes [Jia and Pei, 2018]:

$$R_{lr} = R_{rl} = \frac{1}{2}(R_{vv} - R_{hh}) \tag{3a}$$

$$R_{rr} = R_{ll} = \frac{1}{2}(R_{vv} + R_{hh}) \tag{3b}$$

where R_{vv}, and R_{hh} are the Fresnel coefficients for vertical and horizontal co-polarization, respectively. The subscripts, *lr* and *rl* hold for circular cross-polarized reflections, while *rr* and *ll* for co-polarized reflections. For soil surfaces, the Fresnel reflectivity (R_{vv} and R_{hh}) is function of soil permittivity or dielectric constant ε_r and the incidence angle (θ), from which SMC is retrieved. The conversion from the Fresnel reflectivities to the real part of permittivity (ε_r) is based on the model of Jackson et al. [2004]. Once the dielectric constant is retrieved, the volumetric SMC can be derived from the Topp model [Topp et al., 1980]. These models are suitable for low incidence or high elevation angles, which is the case of satellite viewing properties and, particularly, for observations of GYGNSS.

4. Results

The SMC estimates at the specular points of the CYGNSS data for the period of August 2021 are shown in

Figure 3. In this figure, the false color image of land surface heights is shown in the background. Note that data points with heights above 700 m are not suitable for GNSS-R SMC retrieval. Note the geometric distribution of the observed points follows a quasi-random spatiotemporal distribution, due to the changing geometry of GNSS and CYGNSS satellites. Each point in this figure shows the corresponding SMC estimated at each location. We can observe a large number of values below 0.2, while values above 0.2 are more infrequent, forming clear areas of agricultural interest. In Figure 4, these areas have been grouped and segmented for a better identification of the optimal locations with elevated SMC. In this figure, we also include the areas of most frequent crop used in this area, i.e. the wheat pattern shows the areas with the actual production of wheat. We can clearly observe some similarities between the wheat production and the areas with SMC>0.1. However, in several locations, we can observe for a possible optimization by relocating the crops into areas with higher SMC.

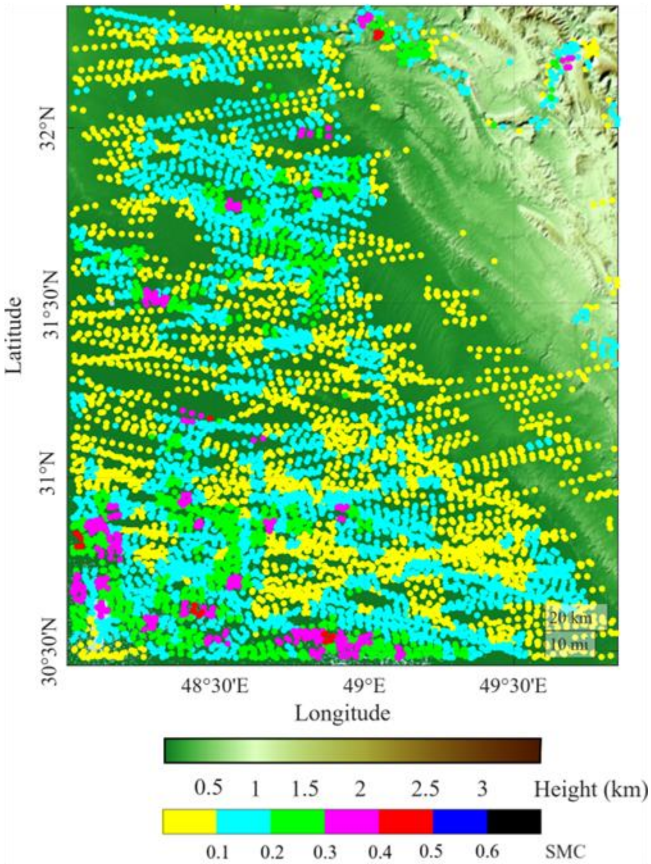

Figure 3. The GYGNSS SMC data during August 2021. The false color image of land surface heights is shown in the background. Note: height data from Beauducel [2022].

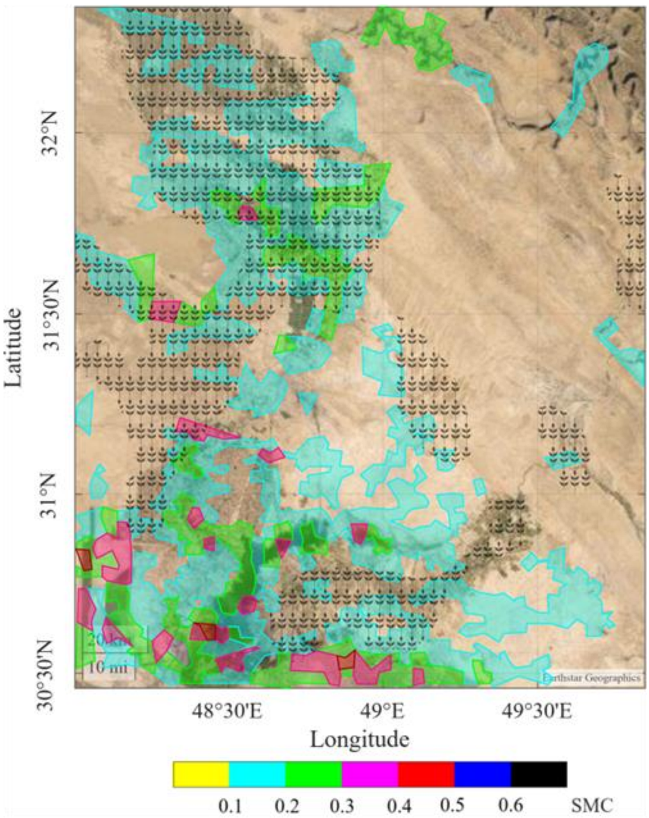

Figure 4. Optimal areas (SMC>0.1) for agriculture classified in terms of SMC levels during August 2021. The true color image is in the background, and the wheat pattern shows the areas with the actual production of wheat. Table 1 shows the optimal crops for each range. Note: wheat data from ipad.fas.usda.go.

Table 1. Usual crops seen in Khuzestan categorized depending on SMC requirements.

Range	Crop Types	Comments
0.4 - 0.5	Rice, Sunflowerseed	Planted up to June
0.3 - 0.4	Sorghum, soybean	Mid-season growing
0.2 - 0.3	Corn, cotton	Mid-season growing
0.1 - 0.2	Wheat, rapeseed, barley	Harvest in August

Table 1 shows the main crops in Iran classified in terms of the available SMC during August. This classification is based on the crop calendar in Figure 2. According to this table, wheat, rapeseed and barley requires lower amount of SMC than the other crops. In this table, the comments show the stage of growth during the period investigated in this study. This table along with the map in Figure 4 is an example of crop optimization which could be applied in future strategies.

5. Discussion

Ground sensors only provide discrete SMC measurements for one point, and the real irrigation needs of other areas are unknown. Compared with the traditional monostatic remote sensing, a GNSS-R platform just need to carry a delay/Doppler receiver (low cost, low mass, and low power consumption). The installation of a GNSS-R receiver can be done in any kind of platform (drones, airplanes, satellites, etc.). In this way, GNSS-R has a wider and flexible coverage, ranging from middle scales to larger scales.

However, in order to provide a suitable SMC product that is beneficial and useful for society, several factors need to be addressed. For example, an interesting issue is how farmers can access to the data, and which scale is the most appropriate for the final products. We want assist both local farmers and national governments with this new data, but also it should be suitable for researchers and climate change decision makers. Note also the governmental issues with existing economic support and regulations to farmers. There may be no grants or support to adopt the crop to new strategies. Another factor for agriculture and food supply is that additional ancillary data such as topography, soil chemistry and composition, are required for accurate studies. Finally, long-term temporal series of GNSS-R data from space can help to climate-change and hydrological-cycle studies at a regional and global scales.

6. Conclusion

In this paper, we have estimated GYGNSS SMC in the region of Khuzestan (Iran) during the dry season of 2021. We have identified a set of optimal areas for different crops and compared the results with the actual distribution of wheat. These results prove that SMC from GNSS-R can be used to help farmers and national governments to take decisions at a regional and larger scales. This promising technique is also very useful for hydrological-cycle and climate-change studies, in which desertification trends and fertilization strategies must be taken into account.

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