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Remote Sensing and Synchronous Land Surface Measurements of Soil Moisture and Soil Temperature in the Field

N.V. KOLEV, K.P. PENEV, Y.M. KIRKOVA, B.S. KRUSTANOV
N. Poushkarov Institute of Soil Science and Agroecology,
7, Shosse Bankya 1080 Sofia - BULGARIA
T.G. NAZARSKY, G.K. DIMITROV, C.P. LEVCHEV,
H.I. PRODANOV, L.H. KRALEVA
Space Research Institute,
Bulgarian Academy of Sciences
6, Moskovska Str. 1000 Sofia-BULGARIA

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Abstract

The paper presents the results of remote sensing and synchronous land surface measurements for estimation of soil (surface and profile) water content and soil temperature for different soil types in Bulgaria. The relationship between radiometric temperature and soil surface water content is shown.

The research is illustrated by some results from aircraft and land surface measurements carried out over three test areas near Pleven, Sofia and Plovdiv, respectively, during the period 1988-1990.

1. Introduction

The application of remote sensing methods and technical devices for the measurement of soil moisture and soil temperature has recently become of interest in agricultural practice in Bulgaria.

A number of authors [1-3] describe the estimation of soil properties and crop status using remote sensing and ground-based measurements in the agricultural areas of England, France and Denmark.

Variations of radiometric surface temperature over bare soils tend to be strongly correlated with the variations of soil surface water content [4] manifested in the top 1-2 cm soil layer [5]. During periods of vegetation this relationship is more complex due to the structure of the canopy. The large variety of soil types, crops and size of agricultural fields hampers the direct application of remote sensing without additional ground surface measurements. For this reason, correlation between radiometric surface temperature and soil water content should first be specified either for bare soil or for soil plants at an early stage of growth (LAI = 0.2 - 0.3) [6-9].

This paper presents a method for using remote sensing measurements to estimate soil moisture and soil temperature for soils and agricultural regions that are typical for Bulgaria.

2. Measurements

The measurements were performed aboard an L410 aircraft, synchronously with additional ground surface measurements over several test areas of approximately 2.5 by 2.5 kilometres each. The test areas are representative of the chosen regions. Ground-based agrophysical measurements were carried out along the flight tracks of the aircraft.

The first territory is in North Bulgaria, near Pleven town, with a test area near Totleben village. This place is typical for a relatively large agroecological region of the country, with wheat, maize and sugar beet.

The next chosen territory lies to the south of Pernik town, near Izvor village in the Struma river valley. It is representative of the Sofia agricultural region.

The last test territory pertains to the large agroecological region of the Upper-Thracian Lowland where agricultural fields lying eastward of Plovdiv city were chosen with a test area near Bolyarino village.

The measurements of radiometric temperature were carried out by the RM-1C airborne radiometric system, working in the 4-cm waveband, and constructed in the Space Research Institute of the Bulgarian Academy of Sciences for the Remote Air and Space Soil and Plant Resources Research Project.

Synchronously with these measurements, ground-based measurements of soil moisture and temperature were conducted using a soil moisture and temperature meter with gypsum blocks, designed in the Department of Agrophysics of the Nikola Poushkarov Institute of Soil Science and Agroecology, Sofia [10], and gravimetric sampling for 1-4 cm soil layer was made. The relative humidity, air temperature and soil temperature were measured by a Squirrel meter made by "Grant" (England).

Flights and ground surface measurements were usually carried out between 11 a.m. and 1 p.m. during 25 March - 1 May and 10-30 October when soil is either crop-free or the Leaf Area Index (LAI) is less than 0.2.

Radiometric temperature measurements were performed in the track-aligned scanning mode in the form of continuous paper recordings. The calibration accuracy of the RM-1C radiometer was about 3K. Pixel size for 150m flying height was 50 m in diameter at nadir, and no correction for the viewing angle, water vapour and carbon dioxide attenuation was made. The distance between the flight tracks over the test areas of the agricultural fields was 300 m.

Taking into account the flight tracks and pixel size, representative locations along the tracks were chosen where measurements of soil moisture and temperature were to be conducted. To ensure that sample data provided a representative statement of spatial population, sample size was chosen carefully [1]. Therefore, soil scientists made preliminary detailed observations of the basic soil properties of the test areas.

Following [1], the frequency distribution of the sampled data for a given pixel was determined in advance. The required sample size is given by the equation:

$$n = \left(\frac{\sigma_{qs} \cdot t}{e} \right)^2, \tag{1}$$

where σ_{ws} is the standard deviation of the measured soil moisture values,

t is the value of the Student criterion for 95 % confirence level, and

e is the acceptable error in the same units as standard deviation.

Equation (1) was used to determine sample size, assuming normal frequency distribution of the soil moisture and soil temperature data set.

For example, if the soil moisture data set has normal frequency distribution, σ_{ws} was found to be 0.64 units (dry mass water percentage), $t = 2.2$, and an error of 0.4 units was adopted.

The substitution yields:

$$n = \left(\frac{0.64 \cdot 2.2}{0.4} \right)^2 \approx 12. \tag{2}$$

So a minimum of 12 sample holes per test location were made for soil moisture estimation.

An overall picture of soil moisture and soil temperature in the crop root zone was obtained using the data set from the radiometric measurements and that of the ground-based measurements carried out both for surface and soil (down to 70 cm) profile.

The samples for surface soil moisture were taken manually from the 0-4 cm layer along the flight tracks of 100-150 m each.

For estimation of the soil profile water content, at every representative location of the areas near the villages of Totleben, Izvor and Bolyarino, 24 gypsum blocks were installed at depth of approximately 10, 20, 40 and 70 cm. The standard deviation of dry mass water percentage was about 1.0 %, this variation, though not insignificant, being similar to the values obtained by [1] in field conditions.

The temperature in the soil profile was measured by semiconductor sensors embedded in gypsum blocks installed at depth of approximately 10 and 20 cm and by special thermosensors from the Squirrel meter, with accuracy 0.2°C.

3. Results and Discussion

The test area near Totleben is occupied by typical, moderately leached chernozem soils with about 2.5 % humus content. Near Izvor, the soil's humus content is about 2.0 % while Bolyariano's test area consists mainly of leached chernozem soils with 2.5 - 2.7 % humus content.

The investigation indicates that the uniformity of surface soil moisture distribution greatly depends on the variety of soil type in the test area. Water evaporation is far easier from a soil surface layer with less clay content.

The variation of soil moisture, W, from field capacity to wilting point corresponds, respectively, to the variations of relative humidity from 15 to 2.5 % and radiometric temperature, T_r, from 0 to 50K.

The relationship between surface soil moisture W(%) and radiometric temperature $T_r(K)$ is:

$$W(\%) = a - b.T_r(K), \tag{3}$$

where a and b are coefficients depending on soil type.

Remote and ground-based simultaneous measurements of soil moisture and soil temperature were carried out over the test areas from 1988 to 1990. The data set shown in the Table includes parameters measured in the three test areas during an expedition in the fall of 1989. Days were warm and sunny and the sky was clear.

The schedule included a series of flights of the aircraft over the regions between 11 a.m. and 3 p.m.

The measurements of surface soil moisture were made taking gravimetric samples along the flight track.

On Fig. 1, the measurements in soil profile by gypsum blocks are shown. Despite the considerable scatter, it is clear that the lower layers are relatively more moist. The warm days in South Bulgaria caused intensive evaporation and, for that reason, the surface soil moisture in the Bolyarino test area near Plovdiv is low. The differences between the different areas can be attributed to the different soil types.

In Figs. 2a, 2b, and 2c, the data for radiometric temperature $T_r(K)$, measured by the RM-1C radiometer, as well as those for surface soil moisture W(%), measured by the gravimetric method during the track-aligned flight, are shown.

The appreciable variation in surface soil moisture is due to the great variety of soil types within the test areas. For example, the investigations carried out in the Bolyarino test area revealed an alteration of chernozem and alluvial meadow soils along the flight track.

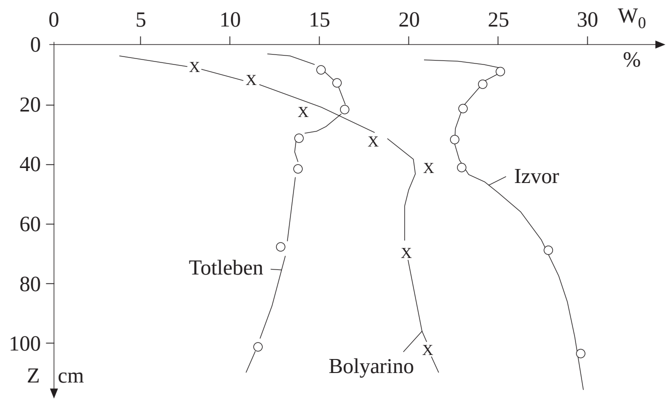
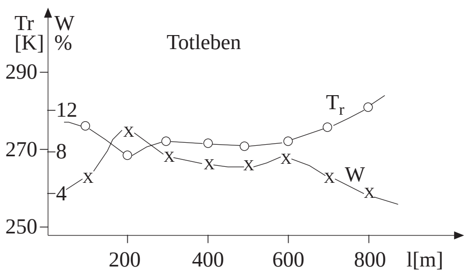
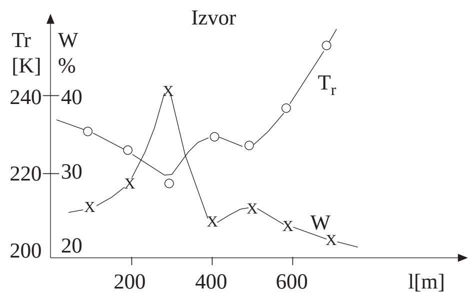


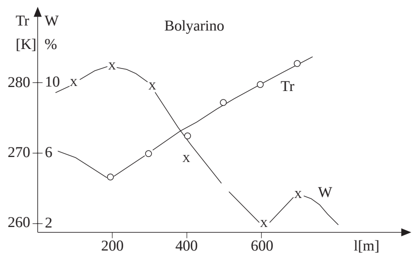
Figure 1.



(a)



(b)



(c)

Figure 2.

The remote sensing measurement of surface soil moisture is less sensitive in comparison with the ground-based synchronous measurements. Since surface soil moisture usually differs from moisture in soil profile, obviously, it is rather difficult to perform irrigation control of a given agricultural field on the grounds of surface soil moisture data only, without proper interpretation.

In Bulgaria, the remote sensing of surface soil moisture can be used for estimation of soil moisture availability over big agricultural territories, thus assisting the process of decision-taking as to sowing and other agricultural activities.

4. Conclusion

The results from remote and synchronous ground surface measurements of soil moisture and soil temperature are presented. They will contribute to the development of the application aspects of remote sensing in agriculture, based on aircraft microwave radiometry.

The relationship between radiometric temperature and surface soil moisture does not display adequate sensitivity, especially in the case of negligible moisture content.

The obtained results point out to the need of many more future experiments over the general soil types in Bulgaria in order to derive a precise coefficient ratio for the relationship between radiometric temperature and surface soil moisture.

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CONTENTS