A study on soil moisture monitoring by using airborne SAR images

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Abstract In this paper, a study on soil moisture monitoring by using airborne X-band Synthetic Aperture Radar (SAR) image data for HH polarization has been done with the help of soil moisture and soil backscatter coefficient measured synchronously. The results showed that the image grey value of the SAR image has a good relationship with the surface soil moisture (soil depth 0–10 cm). The soil backscatter coefficient for HH polarization at 35° pitch has good relationship not only with the SAR image data but also with surface soil moisture. Analysis results indicated that radar imaging has great potential for monitoring soil moisture. Because the penetrative depth of the radar image is less than 10 cm, the possibility for investigating section soil moisture from surface soil moisture is discussed in the paper.

Un estudio del monitoreo de la humedad del suelo utilizando datos de imágines aéreas SAR

Resumen Este trabajo presenta un estudio del monitoreo de la humedad del suelo utilizando datos de imágines aéreas SAR de banda-X para ploarización de HH, con la ayuda de coeficientes de humedad y de retención del suelo medidos en forma sincronizada. Los resultados mostraron que el valor gris de la imagen SAR guarda buena relación con la humedad de la superficie del suelo (profundidad de 0–10 cm). El coeficiente de retención del suelo para polarización de HH en un campo de 35° guarda buena relación no solamente con los datos de imágines SAR sino también con la humedad de la superficie del suelo. Los resultados de los análisis indican que la imagen de radar posee gran potencial para el monitoreo de la humedad del suelo. Debido a que la profundidad de penetración de la imagen de radar es menor a 10 cm, el trabajo examina la posibilidad de investigar la humedad del suelo por secciones a partir de la humedad de la superficie del suelo.

INTRODUCTION

Soil moisture is an important factor in regional water balance calculations. It is also an important limit in drought relief and flood forecasting. In recent years, there has been much research using multispectral remote sensing data to monitor soil moisture (Price, 1985; Brest *et al.*, 1987). Because of cloud cover, it is not easy to obtain good remote sensing data. Through experimental research, it was found that the change of soil dielectric permittivity depended on the change of soil moisture. It should be an effective way to monitor soil moisture by using microwave remote sensing. Therefore there has been great interest in using microwave remote sensing to monitor soil moisture (Zotova & Geller, 1986). Considering the previous research (Schmugge *et al.*, 1985; Chanzy, 1993), this paper introduces the method of using Synthetic Aperture Radar (SAR) image data to monitor soil moisture through three synchronous measurements.

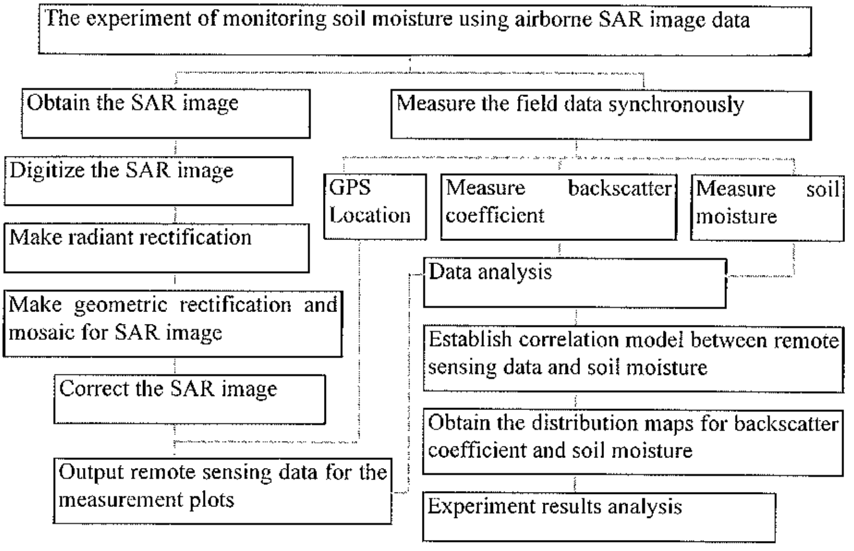

Fig. 1 The technological flow diagram of this experiment.

DATA ACQUISITION

The GPS location, soil moisture and soil backscatter coefficient were measured synchronously when the airborne SAR image data were obtained in Hebei Province in North China.

We used the gravimetric method to measure soil moisture. The depth of soil measurement was 0–10 cm, 10–20 cm and 20–30 cm. To measure the soil backscatter coefficients, we used the scatter meter in the X-band for HH and VV polarization. The angle of pitch was from 5° to 65°. The airborne radar was in the X-band for HH polarization whose resolution was 3 m × 3 m, and the surveying width was 18.5 km, obtained on 22 October 1994. The technological flow diagram of this experiment is shown in Fig. 1.

DATA ANALYSIS

Soil moisture

From the distribution curves (Fig. 2) for the image grey value and the soil moisture in three different soil depths, we know that the tendency of the curves for soil moisture is almost the same. This means that if the soil moisture in the surface is high, that of the other depths is also high. Through correlation analysis, we know that the soil moisture between adjacent soil depths has good relationship. For example, the correlation coefficients are 0.7455 and 0.8087 between 0–10 cm and 10–20 cm, and between 10–20 cm and 20–30 cm, respectively. But the correlation coefficient is very small

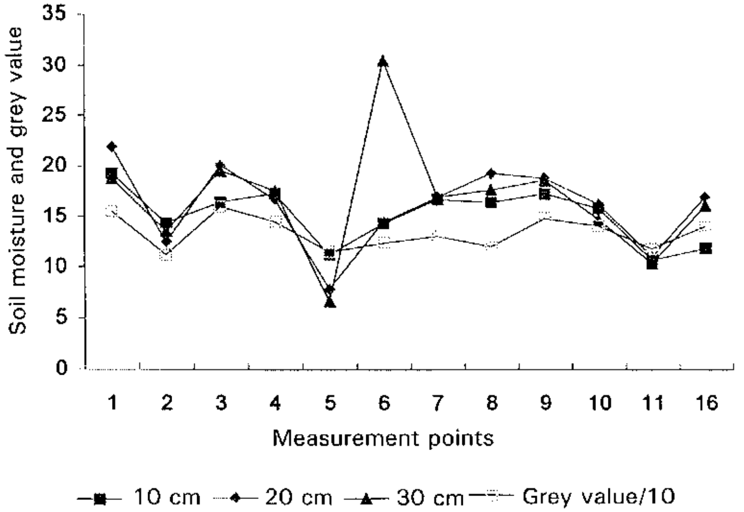

Fig. 2 The distribution curve for image grey value and soil moisture at three different soil depths (10, 20 and 30 cm) (Grey value/10: image grey value divided by 10).

between the interval soil depths. To demonstrate this, we measured soil moisture at three soil depths from nearly 150 measurement plots in Shandong Province from March to September (day 6 of each month) between 1991 and 1992. The results show that almost all the correlation coefficients between soil moisture for adjacent soil depths, especially between 0–10 cm and 10–20 cm, are greater than 0.85. Therefore we can obtain the section soil moisture from the surface soil moisture using the correlation relationship.

Backscatter coefficient

The distribution curves for backscatter coefficient at the angle of pitch from 5 to 65° for HH and VV polarization show that the larger the angle, the smaller the backscatter coefficient in a certain plot. But there is no good relation between them. Different angles have different capacity to reflect the soil moisture.

The relationship among three kinds of data

Backscatter coefficient and image grey value The relationship curves for backscatter coefficient (B) and image grey value (G) in each measurement plot show that these two kinds of data have the same tendency at 35° for HH polarization (Fig. 3). Here we can use only the data for HH polarization because of the radar image. The correlation analysis shows this:

$$B = 0.2723G - 82.0908R = 0.8058 \quad N = 12 \tag{1}$$

where R is the correlation coefficient and N is the number of regression samples.

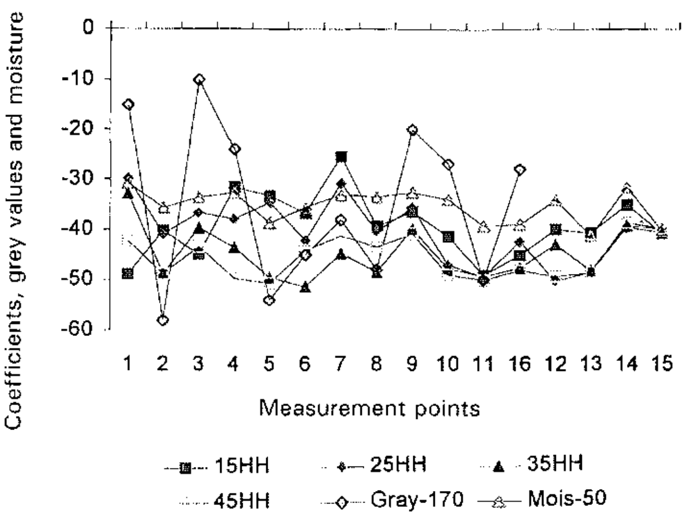

Fig. 3 The distribution curve for soil backscatter coefficient (HH polarization at different pitch angles), image grey value (using image grey value minus 170) and surface soil moisture (using soil moisture value minus 50).

Soil moisture and backscatter coefficient Through comparison of surface (soil depth 0–10 cm) soil moisture (*M*) and backscatter coefficient (*B*) for HH polarization, we know that the backscatter coefficient at 35° has almost the same tendency with the soil moisture. From correlation analysis, we obtain the follow regression equation:

$$M = 0.3388B + 29.930R = 0.5354 \quad N = 16 \tag{2}$$

From equations (1) and (2), we obtain the equation to reflect the relationship between soil moisture and image grey value shown as follows:

$$M = 0.0923G + 2.1176 \tag{3}$$

In addition, the surface soil moisture has good relationship with the backscatter coefficient at 65° for VV polarization. Because the SAR image obtained in this experiment was only for HH polarization, we cannot use the SAR image for further verification. The correlation model is shown below:

$$M = 0.3621B + 31.896R = 0.618 \quad N = 16 \tag{4}$$

Soil moisture and image grey value Figure 2 shows that the tendency for soil moisture and image grey value in each plot is almost the same. The shapes of the soil moisture curves for different soil depth and grey values are not the same. Because of the penetrative depth, correlation calculations were made only with surface soil moisture and image grey values. The regression equation is:

$$M = 0.103G + 1.3272R = 0.6235 \quad N = 12 \tag{5}$$

The above regression equations all pass the correlation test when the confidence degree is 0.05.

OBTAINING THE DISTRIBUTION MAPS FOR SOIL MOISTURE

From equations (1), (2) and (5), we can obtain the distribution map for backscatter coefficient and two distribution maps for soil moisture. One is obtained from SAR image data directly. Another is obtained with the help of backscatter coefficient. They are processed and density sliced as classes. The image grey levels at different classes have different shapes of data points.

The above mentioned distribution maps showed that even the villages, roads and dams had some kind of grey level, but they only represented backscatter coefficient instead of the content of soil moisture. We could distinguish them from their particular forms and constructions: most villages are in the form of rectangles, circles or regular forms; roads are in the form of lines.

The distribution maps showed that most soil backscatter coefficient is in the range of –55 to –31. The corresponding soil moisture ranges from 11 to 20%. This means the surface soil moisture is higher. This is due to the irrigation for sowing winter wheat. Therefore, the radar image reflects the actual situation.

According to above methods, the relative errors for evaluating backscatter coefficient and soil moisture were obtained as follows:

$G \rightarrow B$	$B \rightarrow M$	$G \rightarrow B \rightarrow M$	$G \rightarrow M$
5.6%	17.48%	11.56%	12%

This shows that the precision for evaluating soil moisture is almost the same from the two above methods. So we can use airborne images to monitor soil moisture directly.

CONCLUDING REMARKS

- The above experiment analysis shows that it is practical to monitor soil moisture by using the airborne SAR image for HH polarization directly.
- The soil backscatter coefficient for HH polarization at 35° has good relationship with radar image and soil moisture. The correlation coefficients are 0.8058 and 0.5354 for radar image and soil moisture, respectively. The soil backscatter coefficient for VV polarization at 65° also has good a relationship with soil moisture, with a correlation coefficient of 0.6138.
- The penetrative depth of the radar image is less than 10 cm. From the above analysis the soil moisture between adjacent soil depths has good relationship. Thus, we can first obtain the surface soil moisture from the radar image, and then inquire into the section soil moisture from the correlation relationship between the adjacent soil depth.
- Because in this experiment we used only airborne radar data in the X-band for HH polarization, another band should be used to do further research. In particular, further research should be done using satellite digital synchronous SAR image data for different polarization. We believe that it will be an effective approach to monitoring the change of soil moisture by using SAR image data.

REFERENCES

Brest, C. L. (1987) Deriving surface albedo measurement from narrow band satellite data. *Int. J. Remote Sens.* **8**, 351–367.

Chanzy, A. (1993) Basic soil surface characteristics derived from active microwave remote sensing. *Remote Sens. Reviews* **7**, 303–319.

Price, J. C. (1985) On the analysis of thermal infrared imagery: the limited utility of apparent thermal inertia. *Remote Sens. Environ.* **18**, 59–73.

Schmugge, T. J., O'Neill, P. E. & Wang, J. R. (1986) Passive microwave soil moisture research. *IEEE Trans. Geosci. Remote Sens.* **Ge-24**(1), 12–22.

Zotova, E. & Geller (1985) A soil moisture content estimation by radar survey data during the sowing campaign. *Int. J. Remote Sens.* **6**(2), 353–364.