STUDY ON RELATION BETWEEN INSAR COHERENCE AND SOIL MOISTURE

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ABSTRACT:

Coherence is an important parameter to measure InSAR data quality in repeat-pass interferometry and soil moisture change can cause de-correlation. Relation between coherence and soil moisture was examined in this paper by using the ERS-1 interferometry pairs on Cangzhou area for which there are some heavy rain between the acquisition dates of the two images. The soil moisture is obtained based on the distributed hydrological model and the coherence is calculated by reducing the other de-correlation factors as much as possible. Correlation and regression analysis are carried out on the two images. It is found that the relation between the two may satisfy exponential distribution and is different with the area. Different soil types and land use appear different patterns.

1. INTRODUCTION

Interferometrical SAR (InSAR) as a powerful mean for topographical mapping, measurement of subtle earth surface shift, was chosen to monitor the ground surface subsidence in CangZhou, southeast of HeiBei province. However, due to the decorrelation between the interferometric pairs, we couldn't get the accurate subsidence measurement of the study area. This made us quite puzzle. First, the interferometric pairs were acquired on Apr 1995 and May 1995 with about one month interval over CangZhou area; then the perpendicular baseline of these two images was very small, and the precise orbits data were also used to reduce the co-registration errors during InSAR processing. In addition, the ground surface subsidence in Cangzhou area is quite serious. So all these condition should be quite good for Interferometry, but why we got an unqualified result. For further research, we find that during the period, there was a heavy rainfall in the research area, which might cause the soil moisture changed. If this is true, the soil moisture could change the surface scattering rate which will promote temporal de-correlation and cause an adverse effect on interferometric coherence. At present, the specific influence relation is seldom studied at home and abroad, so, we carry out the study on the relation between InSAR coherence and soil moisture.

This paper shows the method of calculating the soil moisture and obtaining the coherence and the comparison and analysis results with the two, and also presents an approach to reduce the effect that soil moisture makes on coherence.

2. STUDY AREAS AND DATA

Cangzhou is situated in the east of North China Plain and is one of the areas which is short of water most seriously around the Bohai area. The climate is usually dry in Cangzhou area, but during our study periods, heavy rain happened for several times. The study area covered by the SAR images is located on the quadrate area with longitude from 116.143°E to 117.474°E and latitude from 37.715°N to 38.831°N.

The data used in the model contain SRTM elevation data provided by NASA, daily meteorological data (rainfall, temperature, wind speed, vapor pressure, radiation of sunshine, etc) from April to middle of June in 1995 provided by Hebei Meteorological Bureau, soil map and land use map. The rainfall data of nine meteorological stations are used and the location of these stations is shown with green dots in figure 4. The rainfall distribution can be seen from figure 1 and the numbers in the legend represents Station Number. Besides, two ESA-1 images with approximate pixel resolution of 5m×15m were acquired on Apr. 6, 1995 and Jun. 15, 1995 over Cangzhou areas to obtain coherence. The perpendicular is 122.53m, which is short and very suitable for interferometry.

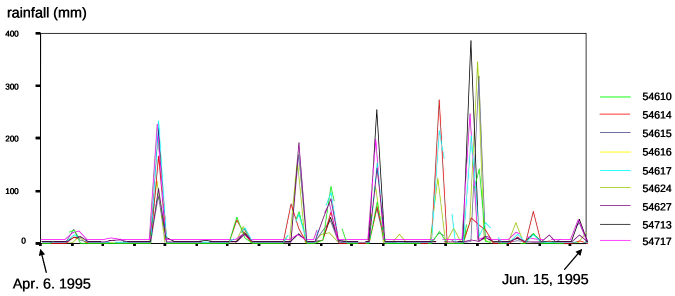

Figure1 The rainfall distribution between Apr. 6, 1995 and Jun. 15, 1995.for different stations.

3. METHODS

For the study on the relation between coherence and soil moisture, we need coherence and soil moisture data. Coherence can be derived in the process of InSAR interferometry from the image pair. Because very precise measurement data of soil moisture can not be acquired directly, we calculate it through meteorological data by building hydrologic model. Our work is based on the raster data model of GIS because the distributed hydrologic model is popular at present and applied widely. The model is built according to water balance principle. All point data, such as rainfall, is interpolated to surface raster maps.

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Then, these obtained maps together with DEM, the land use map and soil type map participate in the model to get a rougher soil moisture distribution map. This map is resampled into the same size as the coherence Thus, a preliminary comparison and analysis between coherence image and soil moisture map can be done. In this section, the detail methods of acquiring soil moisture and InSAR coherence are introduced.

3.1 Soil moisture

The distributed hydrologic model which is based on raster data model in GIS and popular at presrnt is used to build the distributed model of soil moisture. There are four models: soil evapotranspiration model, raster water flow model, rainfall runoff model and soil moisture model. In the model, three main factors that affect soil moisture are considered. That is rainfall, runoff and soil evapotranspiration. The point data on the rainfall provided is interpolated to get rainfall distribution maps of the whole area on which the physical processes of rainfall runoff is simulated. Other meteorological data are processed in the same way of interpolation to calculate daily soil evapotranspiration of the area by the function of raster calculator in ArcGIS according to the evapotranspiration model.

Based on the soil water balance principle, the soil moisture model uses the other three models to get the final soil moisture. When no rainfall happens, soil evapotranspiration model is used. In the area where there is rainfall, raster water flow model and rainfall runoff model are needed.

Actual soil evapotranspiration is calculated according to Penman equation.
Raster water flow model is based on DEM. Compare slope drops between the processing cell with the nearest eight cells. The direction of the line that join the processing cell center with the one which has the largest gradient among the eight is defined as the water flow direction of the processing cell, and the water flow direction of a cell is represented by a number. 1, 2, 4, 8, 16, 32, 64 and 128 correspond to east, southeast, south, southwest, west, northwest, north and northeast respectively. The gradient equation is as follows

$$MD = \frac{Z_k - Z_i}{\sqrt{(X_k - X_i)^2 + (Y_k - Y_i)^2}} \times 100 \qquad (1)$$

Where, MD is the gradient between two cells; (X_k, Y_k) and (X_i, Y_i) represent the coordinates of the calculating cell and the nearest ones respectively; Z_k and Z_i represent their elevation values.

Curve number method created by Soil Conservation Board in United States Department of Agriculture is widely used by all countries so far and is accepted to calculate rainfall runoff on our study.. In this method, daily rainfall data easily acquired is used and runoff of land surface is connected with soil type, land use, management, etc. This method links runoff with daily rainfall directly and the relationship between runoff and rainfall is:

$$\begin{aligned} Q &= \frac{(P-0.2S)^2}{(P+0.8S)} \qquad && P > 0.2S \\ Q &= 0 && P \le 0.2S \end{aligned} \qquad (2)$$

Where, Q is daily runoff (mm); P is daily rainfall (mm); S is retention parameter which is different with area and time and is related with the soil, slope, land use, management and prior soil moisture.

The following equation links S with curve number CN:

$$S = 254(\frac{100}{CN} - 1) \qquad (3)$$

The range of CN is 0～100(does not equal 0). When CN is 100, S is 0 and Q equals P.

3.2 Coherence

The coherence is the key product of SAR interferometric process, which is the magnitude of the complex correlation of both amplitude and phase information from two interferometric signals. It is an important parameter to measure InSAR data quality because the area with high coherence could usually obtain qualified interferometric measurements. The coherence of two co-registered complex SAR images I_1 and I_2 can be defined as:

$$\gamma = \frac{\langle I_1 I_2^* \rangle}{\sqrt{\langle I_1 I_2^* \rangle \langle I_2 I_2^* \rangle}} \qquad (4)$$

Where, γ stands for the coherence. The brackets 〈〉 is the estimated ensemble average and * denotes the complex conjugate. The value of γ is in the range [0.0, 1.0].
The degree of coherence that is estimated from a complex SAR image pair can be considered as the product of different de-correlation factors as long as the sources of decorrelation are statistically independent.

$$\gamma = \gamma_{System\ SNR} \cdot \gamma_{Processor} \cdot \gamma_{Baseline} \cdot \gamma_{Registration} \cdot \gamma_{Temporal} \qquad (5)$$

Where, SNR is the radar system signal-to-noise-ratio. $\gamma_{Processor}$ is de-correlation due to the SAR processor, which is the processing stages from the SAR raw data to the single-look-complex (SLC) SAR image product. Baseline stands for the across-track distance between the two satellite passes, and Registration is referring to the accuracy a SLC SAR image pair can achieve in the coregistration process.

The four first terms on the right-hand side of the equation are factors that one will desire to minimize (i.e., obtain values close to 1.0) so that the estimated coherence in an area is corresponding more or less to the amount of temporal decorrelation from the ground surface. $\gamma_{\text{System SNR}}$ and $\gamma_{\text{Processor}}$ will contribute very little to the overall decorrelation when using ERS SAR data that are processed with the high performance phase preserving SAR processor at FFI. The coregistration of the complex SAR images is done with high accuracy. Baseline decorrelation can be compensated by the model proposed by Zebker, etc[3].

4. DATA PROCESSING

The daily soil moisture distribution maps from Apr 6 to Jun 15 are obtained with the method introduced above and compared with the coherence image derived from the InSAR image pair with EV-INSAR software. The soil moisture difference map between Apr 6 and Jun 15 was resampled to the same size as the coherence image using bilinear sampling. Then, the statistical analysis between the two images is carried out. The whole processing flow is shown in figure 2:

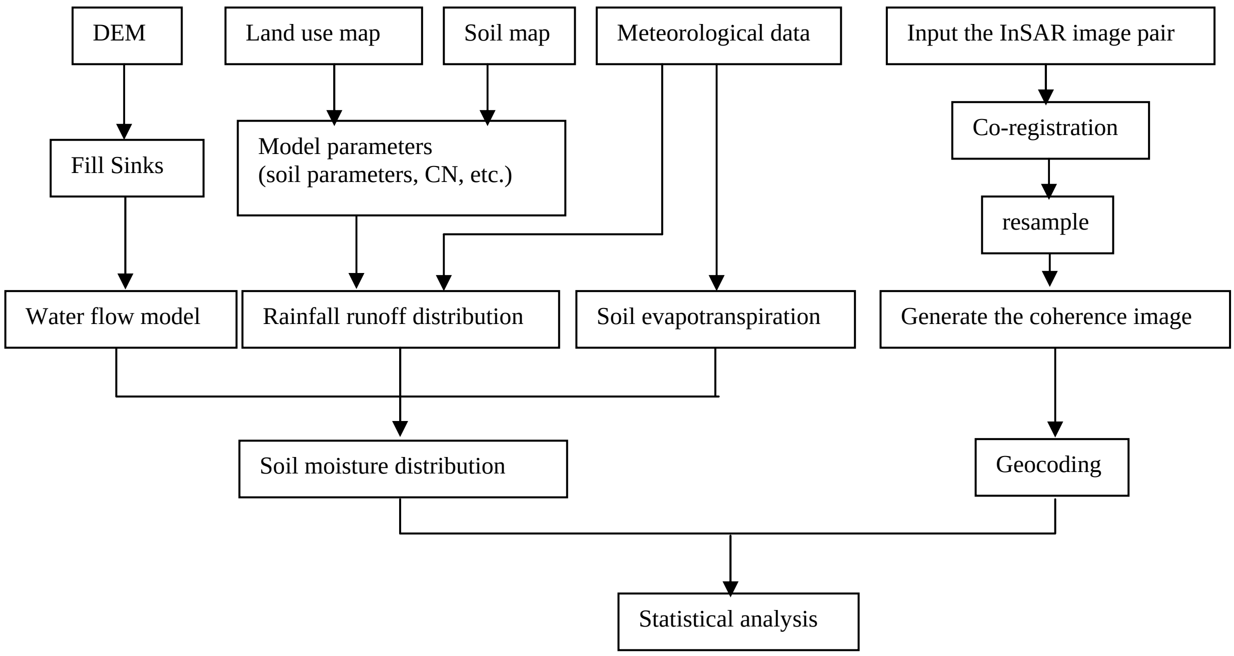

Figure 2. The whole data processing flow

5. RESULTS AND DISCUSSION

The coherence image derived is shown in Figure 3. The moisture difference map between Apr 6 and Jun 15 is shown in Figure4. The area enclosed by the red square frame corresponds to the coherence image in position. It is seen from the two images that, the coherence is low widely and reaches the high value only in the places where the soil moisture hardly change, and there is a certain relation between the two images. The urban area and very few significantly unreasonable points that may be caused by errors and the limitation of the models are removed from the images. The whole correlation coefficient between the soil moisture difference and the coherence reaches to -0.423, which shows that the coherence is reduced due to the increase of the soil moisture, and the more the moisture increases, the more the coherence drops. Then regression analyses between the two for different land use and soil types are carried out and fifty points of each group were arbitrarily selected for this, shown in figure 5 and figure 6. Different classes show different distribution form, but they satisfy exponential or polynomial function. In the polynomial, cubic function is used mostly, and linear and quadratic are also used. For bare soil and grass land in land use, the correlation is higher than the other two types. In soil type, coherence is more sensitive to soil moisture change for seashore saline soil and silt clay.

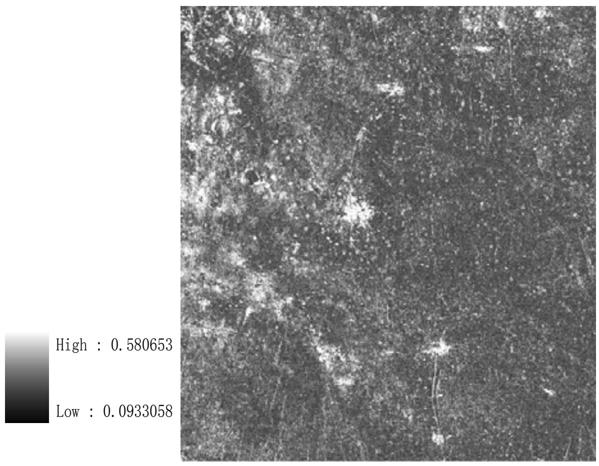

Figure 3. The coherence image derived from the image pair.

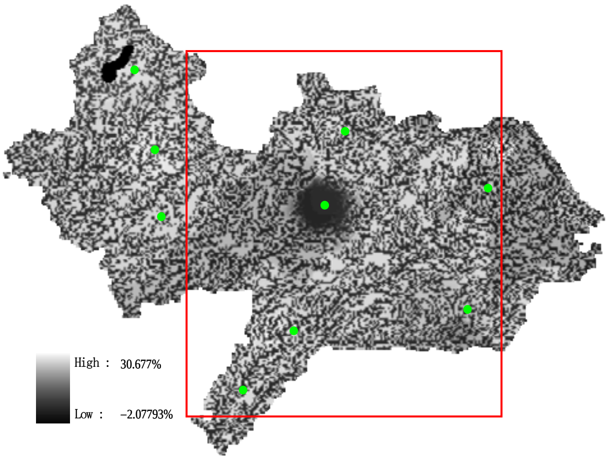

Figure 4. The soil moisture difference map between Apr 6, 1995 and Jun. 15, 1995. The area enclosed by the red square frame is the range of the coherence image.

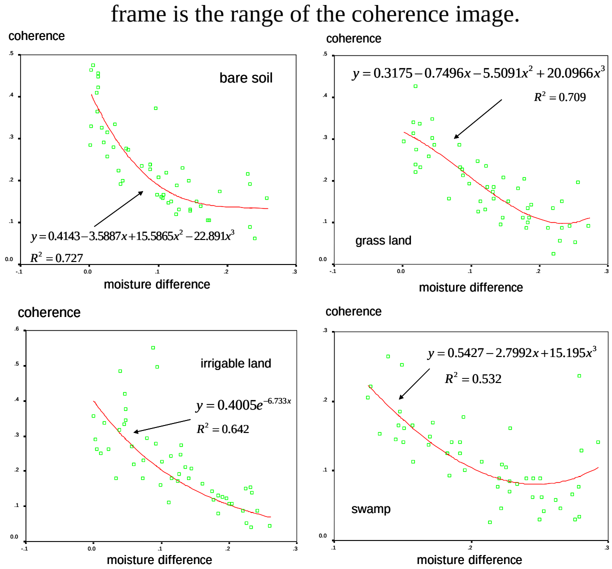

Figure 5. Regression analyses between coherence and moisture difference for bare soil, grass land, irrigable land and swamp.

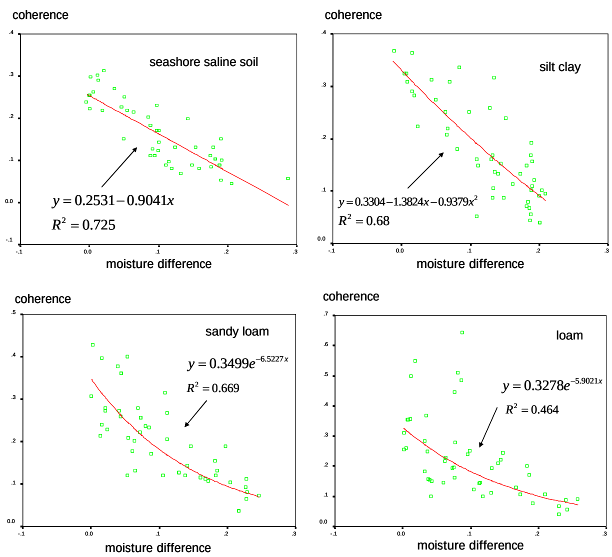

Figure 6. Regression analyses between coherence and moisture difference for seashore saline soil, silt clay, sandy loam and loam

6. CONCLUSION

In this paper, we compare the soil moisture difference map between the two days when the InSAR pairs were obtained with the derived coherence image and analyze the relation for the whole study area, different soil types and land use. Because the polynomial function can be applied for the fitting of any curve, we infer that the relation between the two may satisfy exponential distribution and is different with soil type and land use. We only make the preliminary study, and how to build the common model of the relation between the soil moisture and the coherence for all areas and use it to modify the coherence and phase image is the work we will do next.

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REFERENCES

[1] N.F. Glenn and J.R. Carr, Establishing a relationship between soil moisture and RADARSAT-1 SAR data obtained over the Great Basin, Nevada, USA. Can. J. *Remote Sensing*, Vol. 30, No. 2, pp. 176–181, 2004.

[2] Dan Johan Weydahl. Analysis of ERS Tandem SAR Coherence From Glaciers, Valleys, and Fjord Ice on Svalbard. *IEEE TRANSACTIONS ON GEOSCIENCE AND REMOTE SENSING*, VOL.39, NO.9, SEPTEMBER 2001

[3] H. A. Zebker and J. Villasenor. Decorrelation in interferometric radar echoes. *IEEE Trans. Geosci. Remote Sensing*, vol. 30, pp. 950–959, 1992.

[4] Bruno Aiazzi, Luciano Alparone,etc., Coherence Estimation From Multilook Incoherent SAR Imagery, IEEE TRANSACTIONS ON GEOSCIENCE AND REMOTE SENSING, VOL. 41, NO. 11, NOVEMBER 2003

[5] Moeremans, B. and Dautrebande, S., 2000. Soil moisture evaluation by means of multi-temporal ERS SAR, PRI images and interferometric coherence. *Journal of Hydrology*, Vol. 234, pp. 162–169.

[6] D. Massonnet and K. L. Feigl, “Radar interferometry and its application to changes in the earth’s surface,” *Rev. Geophys.*, vol. 36, pp. 441–500, 1998.