Remote Sensing of Soil Moisture

Lecture 20

Nov. 7, 2005

What is soil moisture?

- Is defined as the ratio of liquid water content to the soil in percentage of volume or weight, is an inheritage and memory of previous precipitations.
  - Water content on mass (weight) basis: ratio of the mass of liquid phase to solid soil mass
  - Volumetric water content on volume basis: ratio of the liquid phase in soil to total volume of the soil.

- Commonly this is used as a measure of the amount of water in the vadose zone (above the water table).

- Soil moisture is a key variable used to describe water and energy exchanges at the land surface/atmosphere interface

How to get soil moisture (in situ)

- Directly in the laboratory, it is measured gravimetrically; by weighing the moist volume of soil, drying it, and then weighing it again.
- Indirectly: Time Domain Reflectometry (TDR), neutron probe, capacitance probe, etc. these methods must be calibrated against gravimetric measurements.
- Global soil moisture data bank
  - http://climate.envsci.rutgers.edu/soil_moisture/
- USA SCAN
  - **http://www.wcc.nrcs.usda.gov/scan/**

How to get soil moisture (Remote sensing)

- Microwave
  - SAR
  - Passive

Top 2-5 cm, less than 10 cm

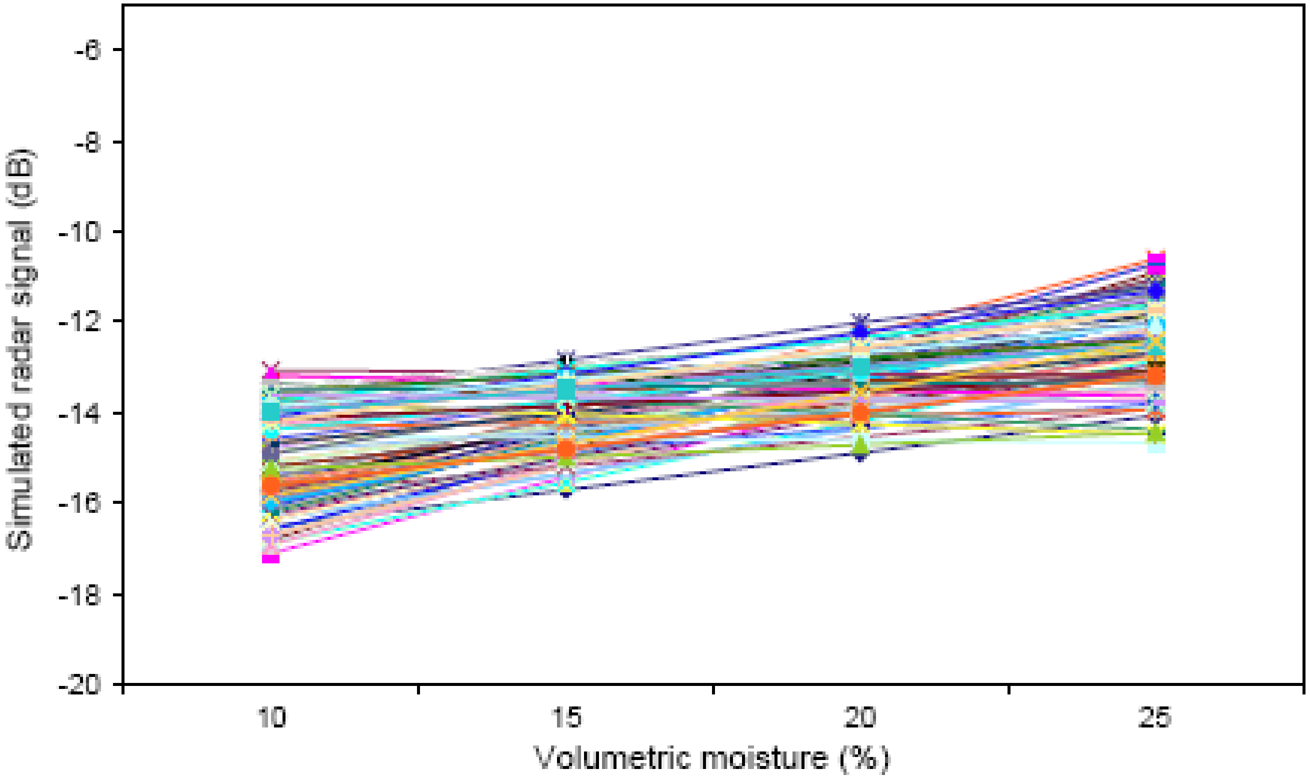
- Optical
  - using solar radiation as a direct energy source, is a passive remote sensing covering visible and near infrared

Possible for root-zone

SAR for surface soil moisture

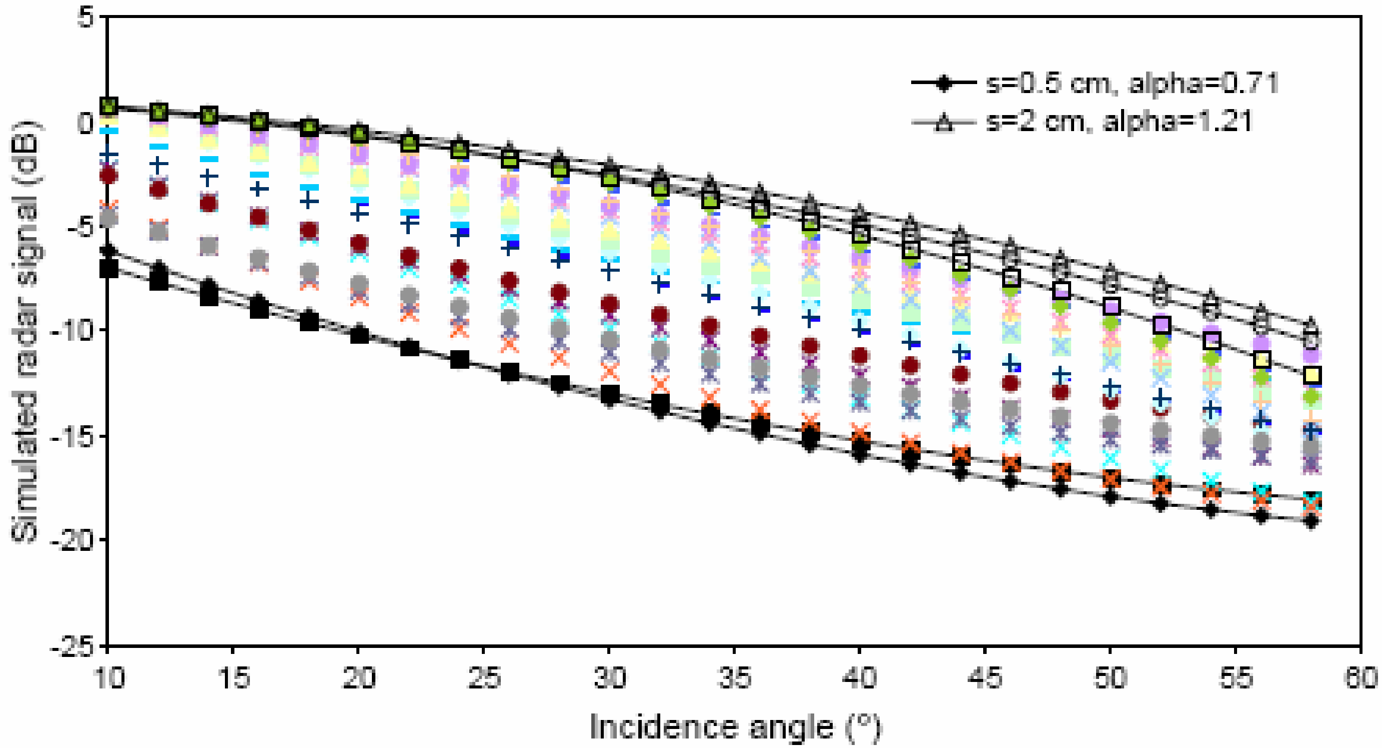
- Can map soil moisture at high resolution over large areas
- Affected by surface roughness, vegetation cover, and incidence angle

Linear relation between soil moisture and radar signal (backscatter)



$$\sigma_0(\mathrm{dB}) = a \cdot W_s(\%) + b$$

Zribi et al. 2005



Radar signal has an inverse relation with incidence angle, so soil moisture has a relation between both radar signal and incidence angle.

Zribi et al. 2005

Passive microwave remote sensing for surface soil moisture

- Passive microwave remotely sensed data providing estimates of soil moisture with good temporal resolution on a daily basis and on a regional scale (~10 km)
- Statistical approaches
- Forward model inversion
- Neural networks
- Data assimilation

Statistical Approaches

These results were used to develop a simple model to derive soil wetness index API from both SMMR (Tb_H) and AVHRR observations (NDVI). The general form of the model developed in CG88 is given by:

$$\mathrm{API_E} = \frac{a + b\mathrm{NDVI} - Tb_H(6.6\ \mathrm{GHz})}{c + d\mathrm{NDVI}} \quad (14)$$

where $\mathrm{API_E}$ is the estimated API index; and a, b, c, and d are parameters obtained from a regression analysis. This

$$\mathrm{API_E} = \frac{a + b\mathrm{PD}(37\ \mathrm{GHz}) - Tb_H(19.3\ \mathrm{GHz})}{c + d\mathrm{PD}(37\ \mathrm{GHz})} \quad (15)$$

PD: polarization difference

$$\mathrm{API_E} = a - b(Tb_V(6.6\ \mathrm{GHz}) + Tb_H(6.6\ \mathrm{GHz})) - c(Tb_V(6.6\ \mathrm{GHz}) - Tb_H(6.6\ \mathrm{GHz}))^d \quad (16)$$

Wigneron et al. 2005

Optical remote sensing for root-zone soil moisture

- A research result from PhD student Xianwei Wang

Introduction

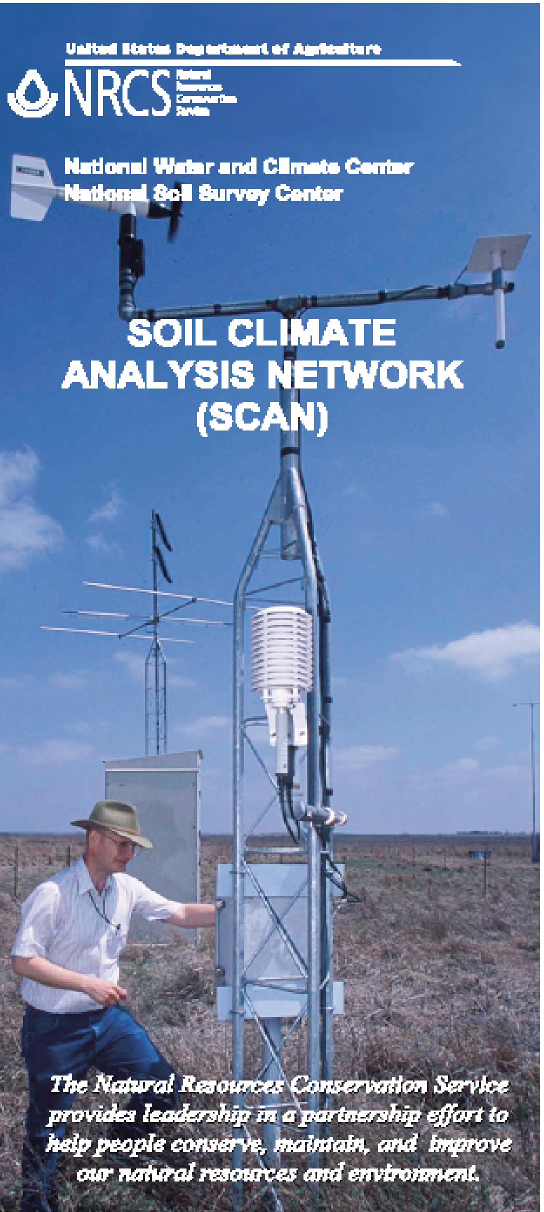
- Soil moisture is very important variable for agricultural, ecological, climatic, and hydrological studies.

- Spatial and temporal soil moisture is very expensive and difficult to obtain.

- Current microwave RS method can only obtain the top (<10 cm-depth) soil moisture.

- How can we get the root-zone soil moisture?

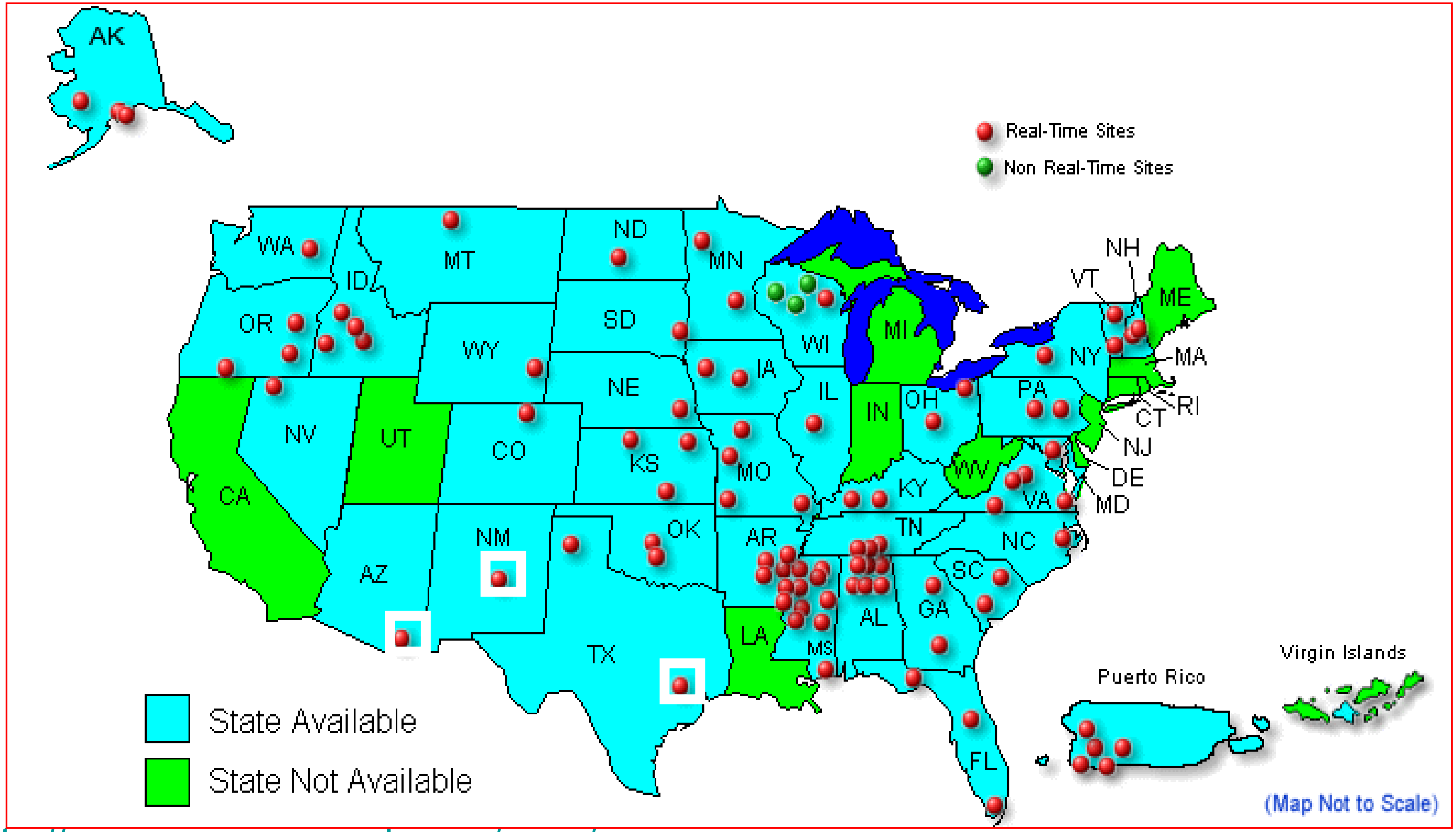
Objective



- To develop an efficient method to estimate the root-zone soil moisture using optical RS.

  - Response of MODIS-derived NDVI to soil water content at various depths.

Soil Climate Analysis Network (SCAN) Sites



http://www.wcc.nrcs.usda.gov/scan/

SCAN Site Information

Walnut Gulch: 2026
Cochise County, in AZ
Latitude: 31° 44' N
Longitude: 110° 03' W
Elevation: 4500 feet
Period of Record: 3/19/1999 to Present

Adams Ranch: 2015
Lincoln County in NM
Latitude: 34° 15' N
Longitude: 105° 25' W
Elevation: 6175 feet
Period of Record: 10/1/1994 to Present

Prairie View: 2016
Waller County in TX
Latitude: 30° 05' N
Longitude: 95° 59' W
Elevation: 270 feet
Period of Record: 10/1/1994 to Present

Data Sources

- **Soil moisture**

  Soil Moisture data was downloaded from three SCAN Sites. (ftp://ftp.wcc.nrcs.usda.gov/data/scan/).

  - Measured with neutron probe;
  - Include 5cm, 10cm, 20cm, 50cm, and 100cm depths.
  - Frequency: hourly
  - Study period is from Jan, 2000 through Apr, 2004

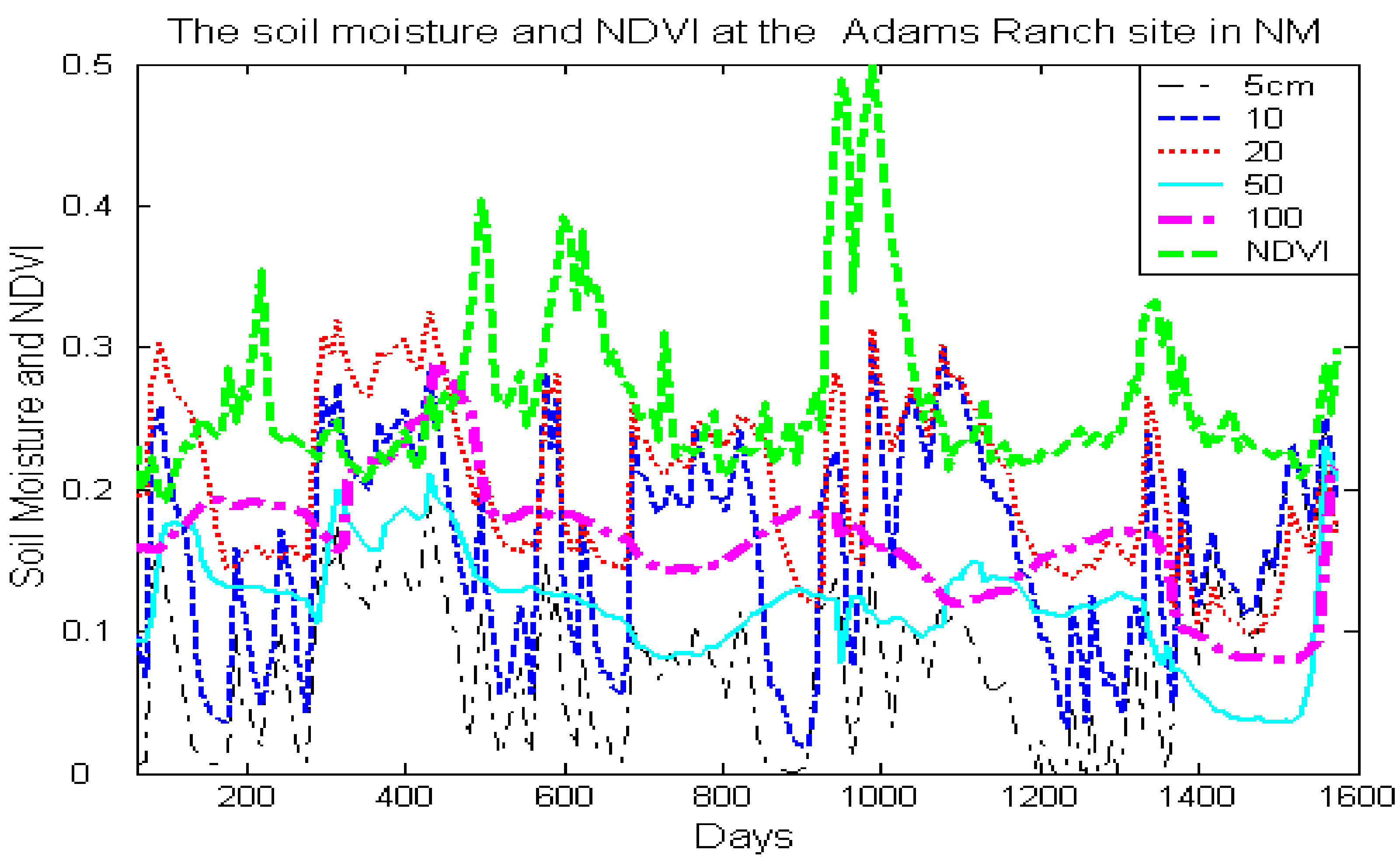
- **NDVI--MODIS Reflectivity**
  - NDVI was calculated using band1 and band2's reflectivity of **MODIS** images ordered free from EOS data gateway.

$$NDVI = (R2-R1) / (R2+R1) \qquad (1)$$

R1, R2: Reflectance of band1, 2.

- 250 by 250 meter spatial resolution
- Using 8-day average

Example of time series



Methods

Seasonality and Differencing Series.

- **Time series average of five-year data**

$$AverM(i) = \frac{\sum_{k=1}^{n} M(i,k)}{n}$$

- **Moving Average**

$$SeasM(i) = \frac{\sum_{j=i-p}^{i+p} Weig(j) * AverM(j)}{\sum_{j=i-p}^{i+p} Weig(j)}$$

- **Deseasonalization**

$$DesM(i,k) = M(i,k) - SeasM(i)$$

Cross Correlation analysis

$$r = \frac{C(i,j)}{SQRT(C(i,i)) * SQRT(C(j,j))}$$

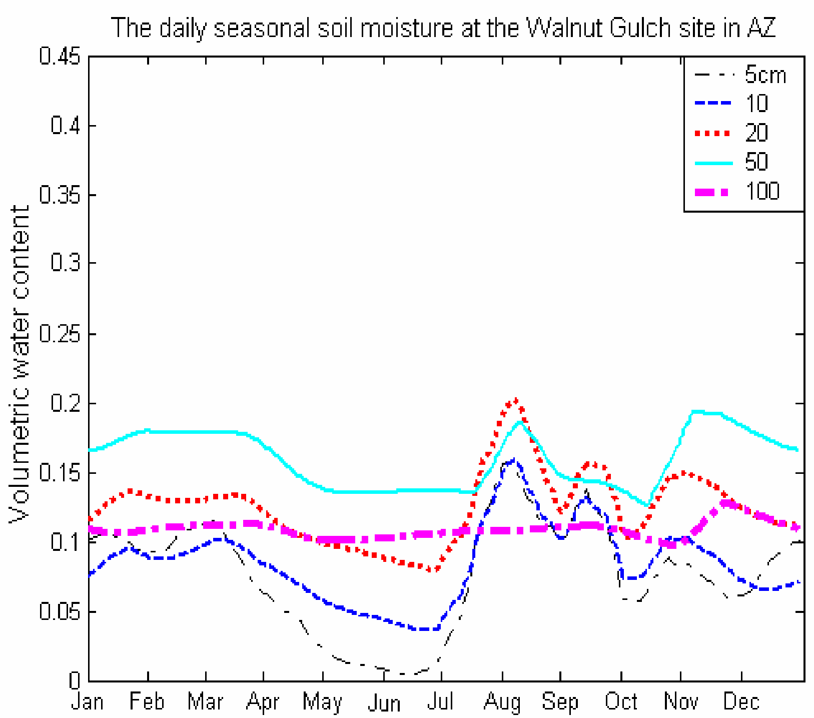
- r is a matrix of **correlation coefficients (CC)** from matrix X.
- C is the covariance matrix of Matrix X.
- X is a matrix composed of time series of deseasonalized soil moisture and NDVI

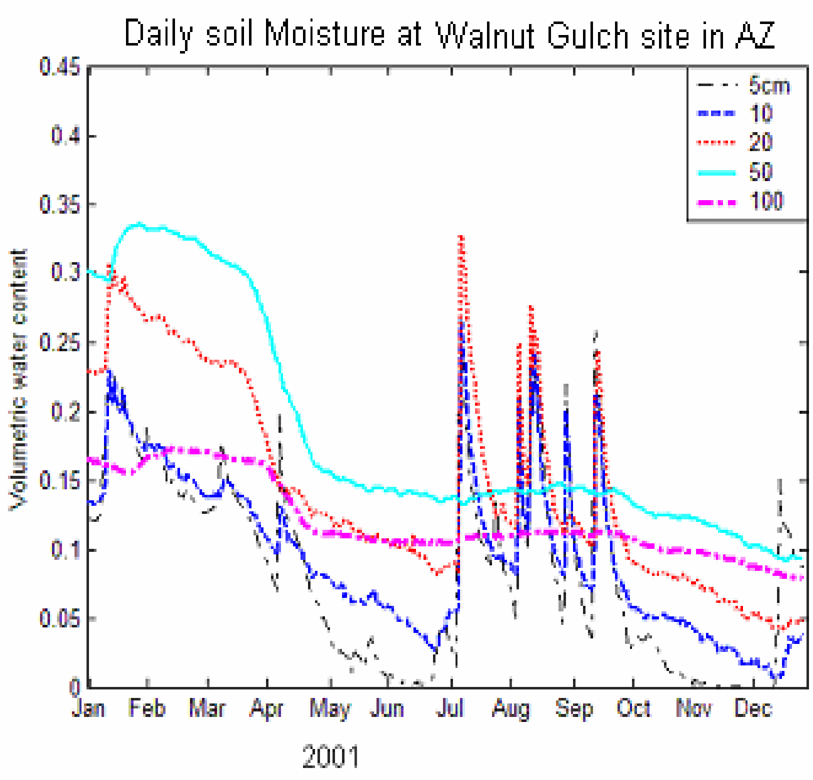
Regression analysis

- $Y = X\beta + \varepsilon$
- $\beta = (X`X)^{-1} X`Y$
- $\hat{Y} = X\beta$

where Y is an n×1 vector of observed soil moisture, X is an n×2 matrix composed of 1 and NDVI, β is a p×1 regression function vector calculated from X and Y, ε is the random error component, $\hat{Y}$ is an estimated n×1 vector

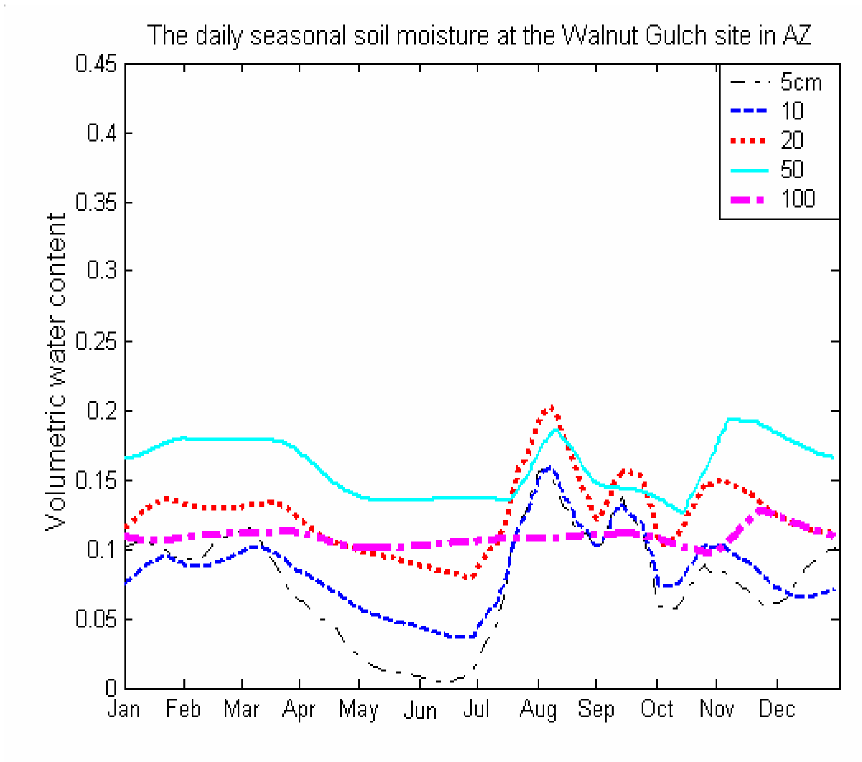
An example

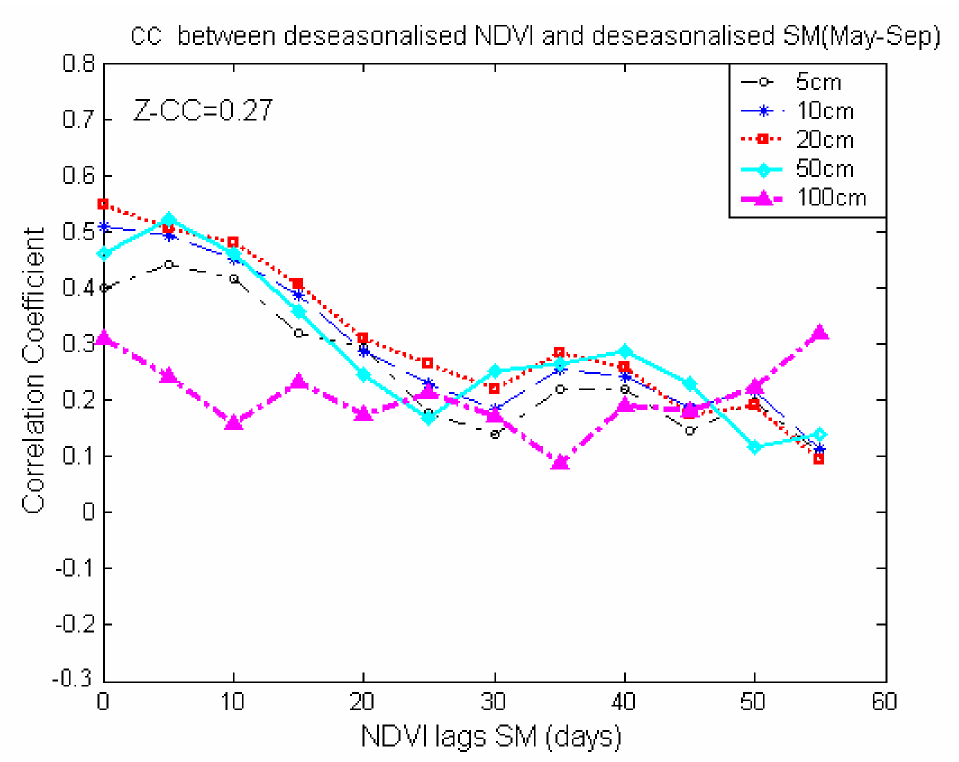




Seasonal soil moisture ⟵ **Daily Soil Moisture**

AZ site

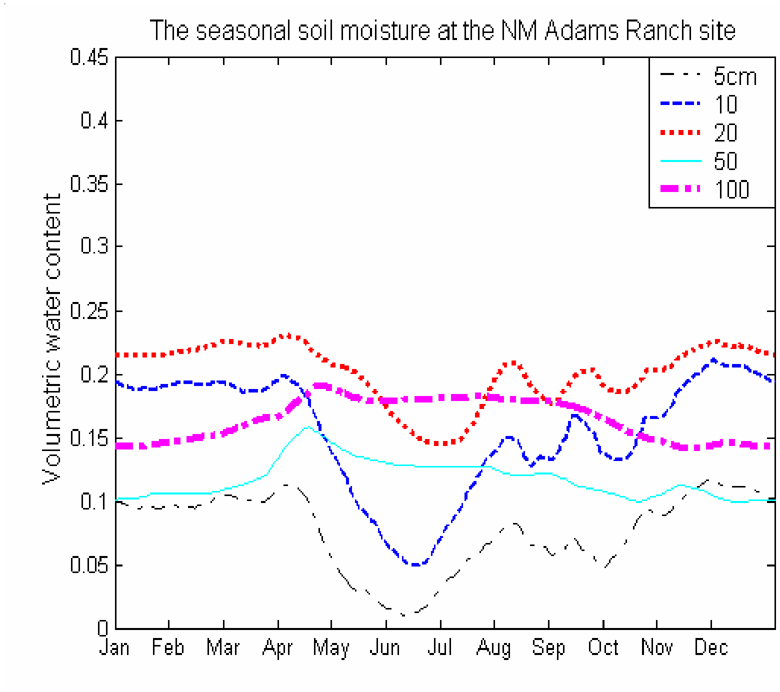


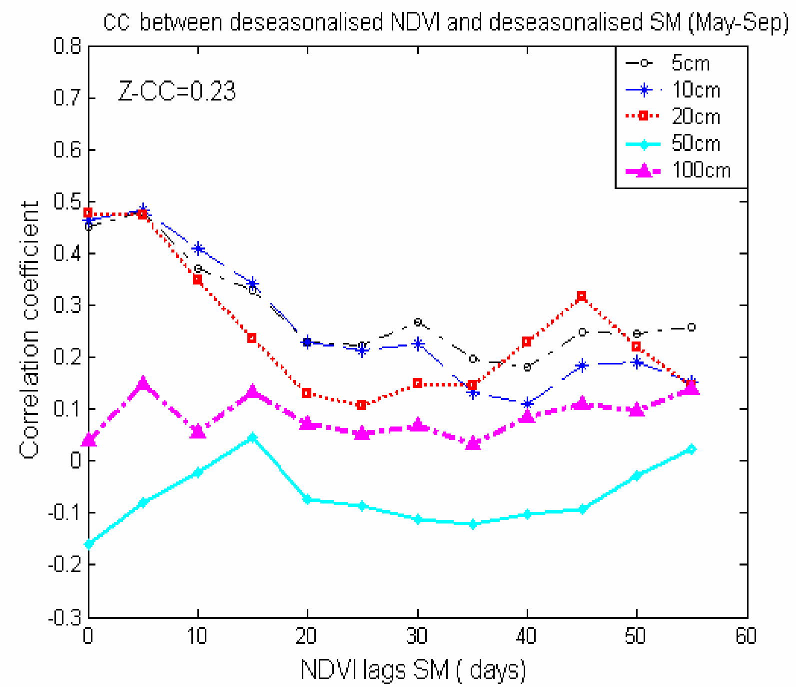


Seasonal soil moisture

Correlation coefficient (CC) vs time lag of NDVI

NM site

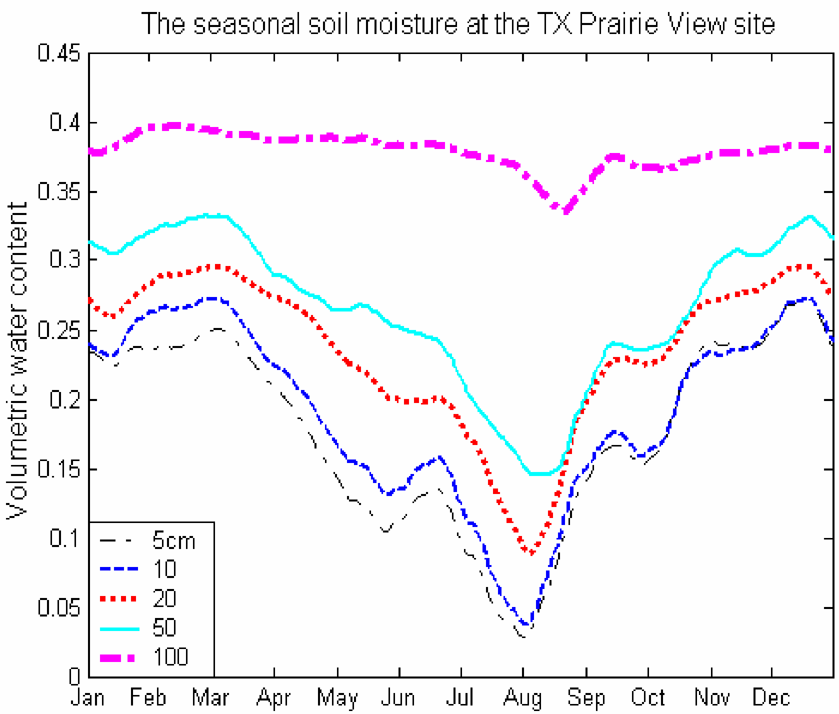




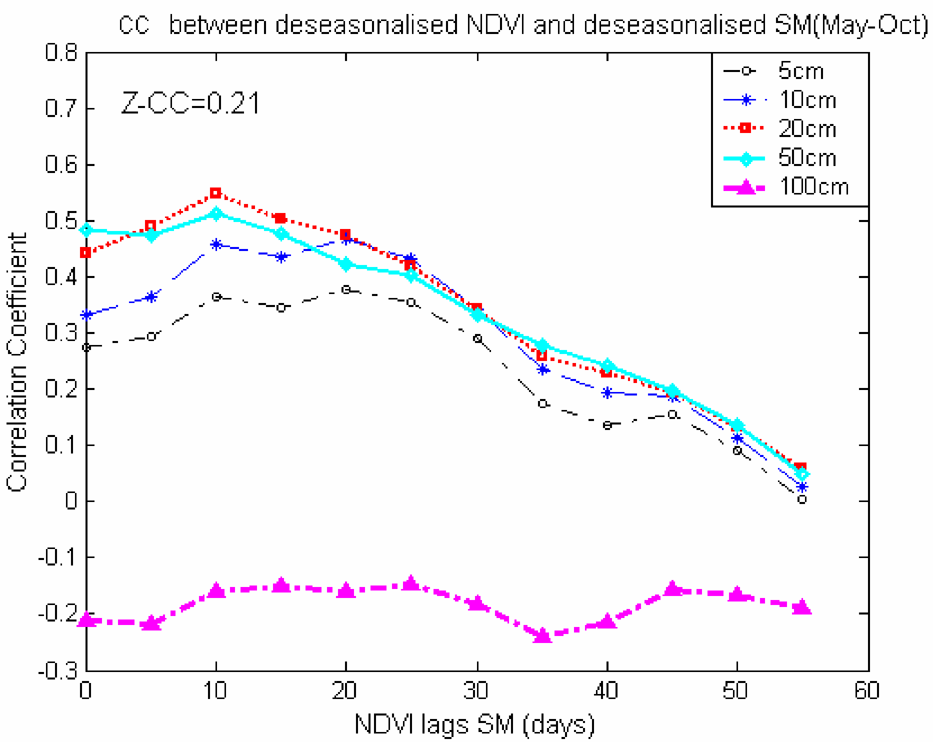
Seasonal soil moisture

Correlation coefficient (CC) vs time lag of NDVI

TX site



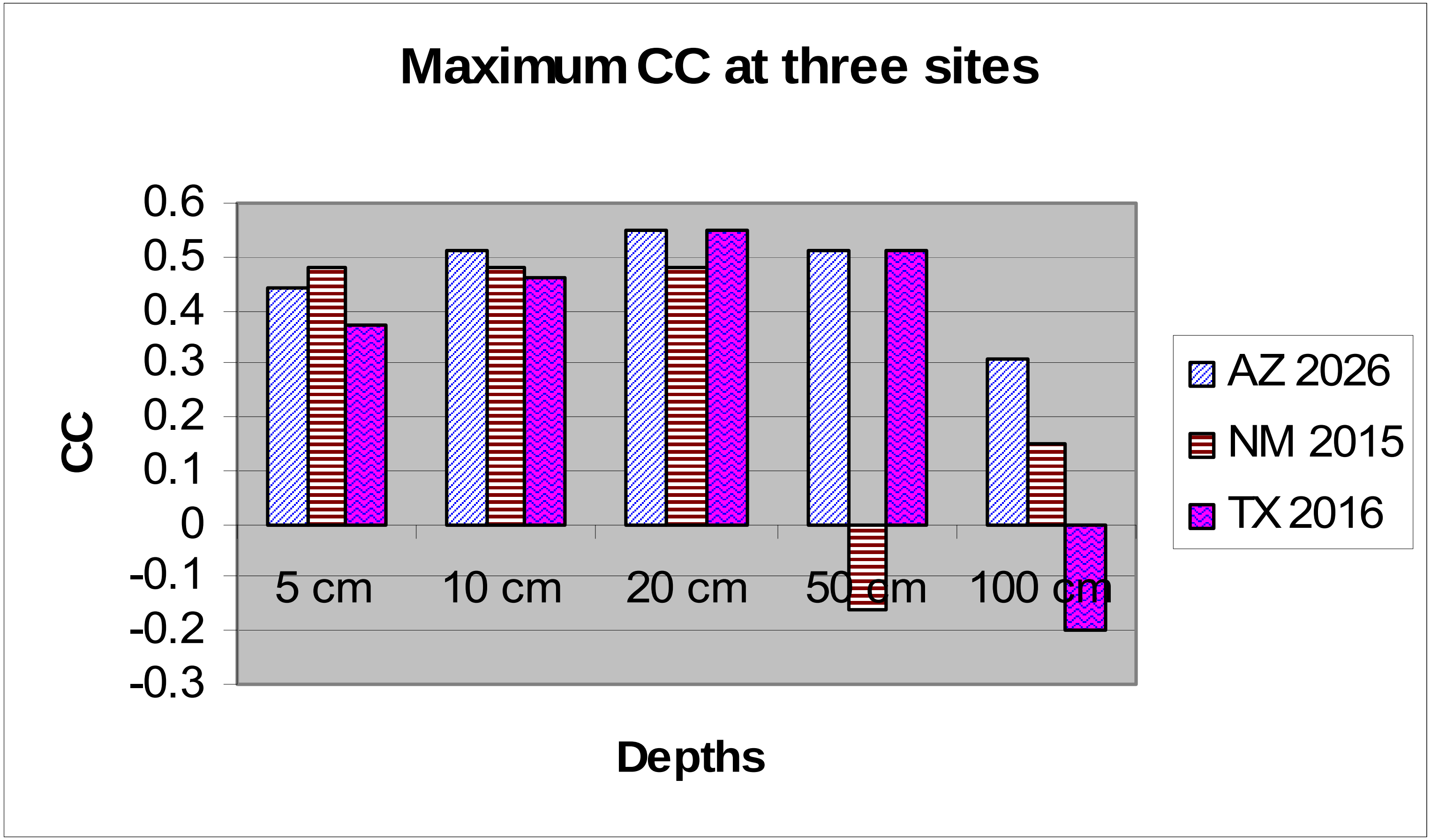
Seasonal soil moisture



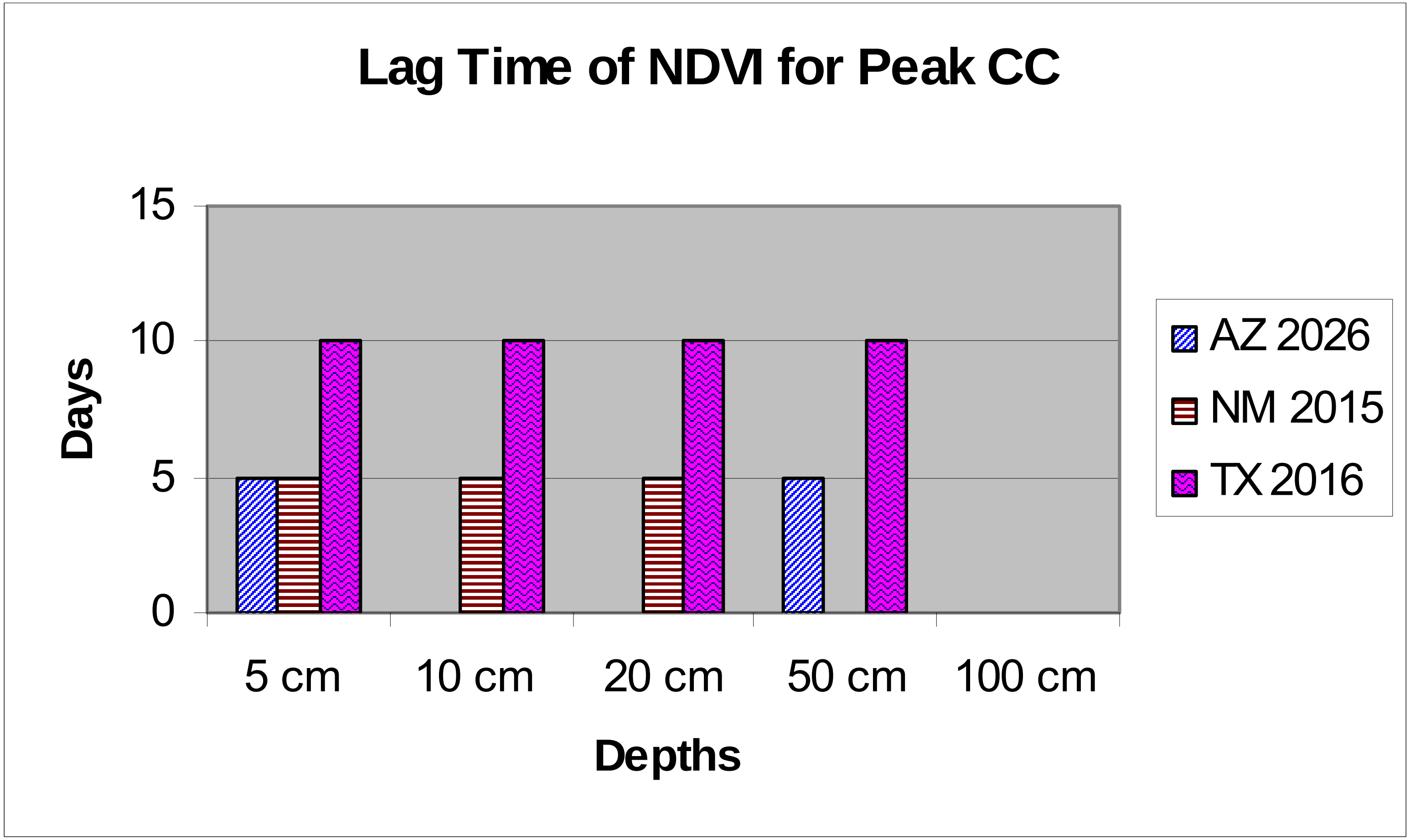
Correlation coefficient (CC) vs time lag of NDVI

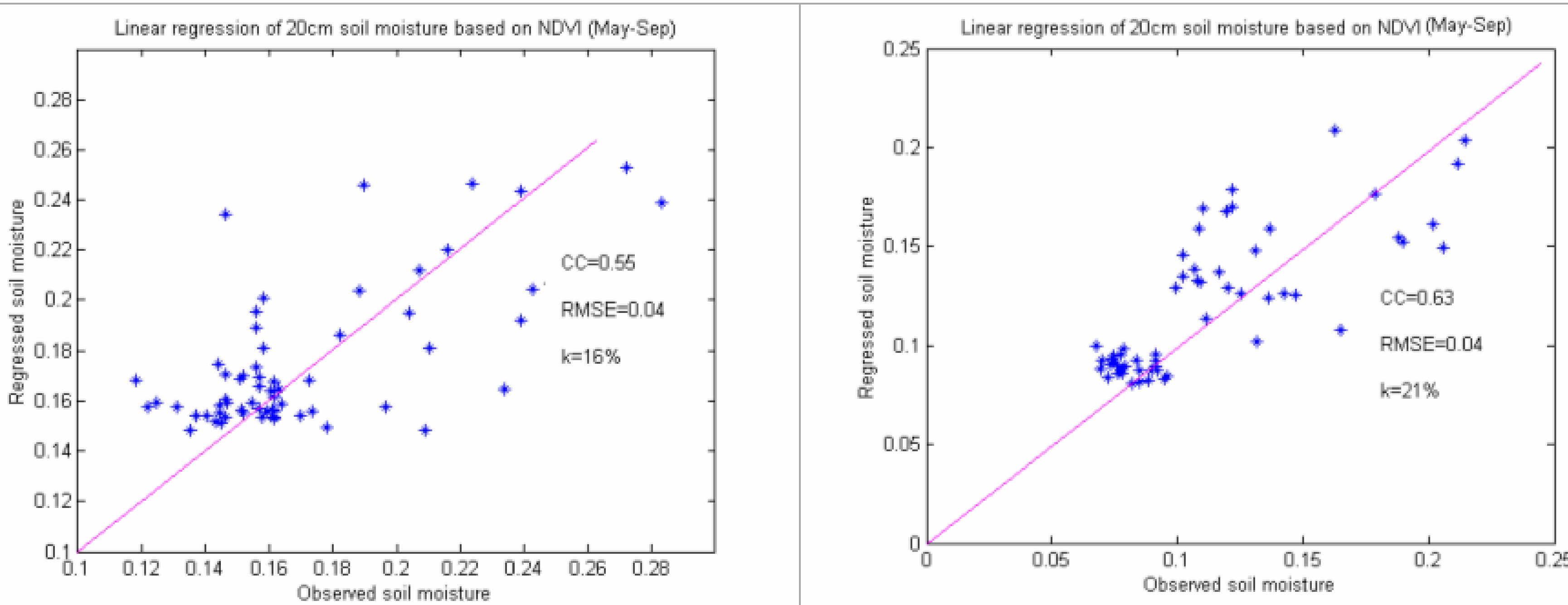
Summary of the CC

Maximum CC during the growing season at 95% CL.



- Lag time of NDVI for peak CC





a. NM

b. AZ

Figure 4. Estimated soil moisture at the 20 cm depth using raw NDVI versus the observed soil moisture at the same depth during May to Sep at the Adams Ranch site in NM and Walnut Gulch site in AZ at 95% CL (P = 0.05). This is only a sample among many results.

Conclusion

- During growing season, deseasonalized NDVI shows a statistically significant correlation (CC: 0.46~0.55) with deseasonalized root-zone soil moisture at all three sites.
- NDVI responds to the change of soil moisture at different root-zone depths at different climate and vegetation conditions. **This infers that root-zone soil moisture can be estimated using NDVI**.
- NDVI shows longer time lag in the humid TX site than in the semi-arid NM and AZ sites.