# NDVI and EVI Estimation of Root Zone Soil Moisture in East Texas

Mark T. Schnur
Graduate Student
Department of Earth and Environmental Science
University of Texas at San Antonio

Abstract
The soil surface layer is a critical boundary between land and atmosphere, and soil moisture is a critical condition affecting interaction of land surface and atmosphere. The root zone can be defined as the top 100 cm of the soil layer. Remotely sensed data can indirectly measure soil moisture, but the signal only penetrates the top few centimeters, so soil moisture at deeper layers must be estimated. Remotely sensed vegetation indices (VI) are a valid method to estimate soil moisture at deeper layers. The objective of this study is to determine the potential of Terra-MODIS derived NDVI and EVI to estimate root zone soil moisture at one site in east Texas, representing a humid climate condition.

The relationship between NDVI and EVI, NDVI and root zone soil moisture, and EVI and root zone soil moisture was investigated for a 30 day time period in a humid climate in East Texas. Soil Climate Analysis Network soil moisture and Terra-MODIS daily surface reflectance data were used in this study. Several problems with the surface reflectance data required data adjustment using linear regression. Pearson product-moment correlation was used to estimate the strength of the relationships with same-day VIs and soil moisture, and with one- and two-day VI time lags. NDVI was not correlated with same-day soil moisture at any depth, but was correlated with soil moisture with a one-day time lag. EVI was correlated with same-day soil moisture at 10 and 20cm depths, and at 50cm with a one- or two-day time lag.

The results of this study indicate that EVI may be a better predictor of soil moisture than NDVI in humid climates, and that NDVI and EVI must be derived using established algorithms in order to be useful in predicting root zone soil moisture. A long-term study using quality controlled MODIS products is warranted.

Mark T. Schnur

EES5083: Remote Sensing Image Processing and Analysis, UTSA

# NDVI and EVI Estimation of Root Zone Soil Moisture in East Texas

## Introduction

The soil surface layer is a critical boundary between land and atmosphere, and soil moisture is a critical condition affecting interaction of land surface and atmosphere. The root zone can be defined as the top 100 cm of the soil layer. Remotely sensed data can indirectly measure soil moisture, but the signal only penetrates the top few centimeters, and soil moisture at deeper layers must be estimated. One method to estimate soil moisture at deeper layers is through vegetation indices. Wang et al (2007) investigated the potential of the Normalized Difference Vegetation Index derived from optical remote sensing measurements to estimate root zone soil moisture using an 8-day average of NDVI and soil moisture, and found that remotely sensed vegetation indices could be used to estimate root zone soil moisture. Wang also found a consistent and significant correlation (0.46–0.55) between deseasonalized NDVI and root-zone soil moisture at the three sites in his study. BEN-ZE'EV et al. (2006) found an NDVI-EVI correlation ($R^2$) of 0.86 in the absence of smoke in a desert environment. Deng et al. (2007) found a correlation ($R$) of 0.81 in a subtropic evergreen forest. EVI is nearly always lower than NDVI to provide sensitivity throughout the range (TBRS 2008).

Whereas the NDVI is chlorophyll sensitive, the EVI is more responsive to canopy structural variations, including leaf area index (LAI), canopy type, plant physiognomy, and canopy architecture. The two VIs complement each other in global vegetation studies and improve upon the detection of vegetation changes and extraction of canopy biophysical parameters (Huete et al. 1994). EVI is considered a modified NDVI with improved sensitivity to high biomass regions and improved vegetation monitoring capability through a de-coupling of the canopy background signal and a reduction in atmospheric influences (Matsushita et al. 2007), and is more sensitive in the near-IR range (Gao et al. 2003). Comparing the two indices at the humid Texas site will provide a baseline for further investigations that extend the study to more sites representing a wider variety of climate conditions. Wang et al. (2007) found the strongest correlation between NDVI and root zone soil moisture at the Texas site between May and October. June is the growing season, thus a strong correlation between the VIs and root zone soil moisture is expected, consistent with Wang's findings. The study site is in a humid grassland, thus we expect soil moisture to vary the most at depths between 10 cm and 50 cm, consistent with the grassland root zone.

This investigation will highlight differences between the vegetation indices, and will investigate the feasibility of using the Enhanced Vegetation Index to estimate root zone soil moisture, using techniques described by Wang. The objective of this study is to compare the relationship between NDVI and EVI, NDVI and root zone soil moisture, and EVI and root zone soil moisture at one site in Texas, representing a humid climate condition. This study will also enable this investigator to gain experience in batch processing MODIS data and performing correlation analysis between MODIS data and soil moisture data.

## Study Area

The sites Wang et al. (2007) studied are within two climate regions, humid Texas coast and semi-arid New Mexico and Arizona: Adams Ranch (grass, New Mexico), Prairie View (grass, Texas) and Walnut Gulch (shrub, Arizona). The three sites are naturally and intensively vegetated land with almost flat topography and single type of vegetation and soil. Thus, the point and area sampling difference between ground measurements and satellite sensor is minimized. This study will consider the Prarie View, Texas site (Figure 1). MODIS data from February 2000 through April 2004 were used for the previous study. This study will compare NDVI and EVI to soil moisture for June 2006 using a daily average of vegetation indices and soil moisture. Precipitation was also compared to soil moisture. The Texas site at 30° 5’41.00”N, 98° 58’ 18.00” W is humid grassland with an average pH of 6.0 and is moderately well drained.

## Data and Methods

Neutron probe measurements of volumetric soil water content (referred to as soil moisture hereafter) were measured hourly at the soil climate analysis network (SCAN) sites (ftp://ftp.wccr.nrcs.usda.gov/data/scan/, and is reported as a percentage). Soil moisture was measured at five depths of 5 cm, 10 cm, 20 cm, 50 cm, and 100 cm. Daily soil moisture is the average of hourly soil moisture. Sampling method, uncertainties and variability associated with SCAN data are documented at the National Soil Survey Center (1995). Precipitation data for the study site was also considered in this investigation.

The daily root zone soil moisture data for June 2006 was imported into SPSS and observed for missing data and outliers. The data was scanned for outliers using Grubb’s test, which is the absolute value of the Z-score (Keating 2008). One data value was identified as an outlier, but was less than three standard deviations from the mean and occurred during a period of heavy rainfall. This data value was not deleted or replaced. Daily averages were computed. SPSS and Microsoft Excel were used for statistical analysis. Wang et al. (2007) found a 10–15 day time lag for NDVI to respond to soil moisture from later May to early June, 2001, for the Prarie View site. A time lag was considered for analysis, but with daily data for 30 days, a long time lag would not be practical.

Wang et al. (2007) used an atmospherically corrected surface reflectance two-band product, MOD09Q1. This product is a level 3, 8-day composite Vegetation Indices (VI). Gao et al. (2003) discussed comparison and validation of MODIS vegetation indices and found that the MODIS 16-day composited products performed well with the single-day nadir-view MODIS data, despite some off-nadir view angles and uncertainties with the cloud mask algorithm. The quality assurance (QA)-based constrained view angle–maximum value composite (CV-MVC) algorithm successfully filtered out much of the cloud and aerosol contaminated observations and helped to minimize view angle-related problems. The MODerate-resolution Imaging Spectroradiometer (MODIS) Surface Reflectance product (MOD09GA) provides an estimate of the surface spectral reflectance as it would be measured at ground level in the absence of atmospheric scattering or absorption. Data are corrected for atmospheric gases and aerosols. This study uses the MODIS product MOD09GA which provides Bands 1 through 7 at 500-meter resolution in a daily gridded level-2G product in the Sinusoidal projection. The data was ordered from the EOS data center and resampled using the MODIS Reprojection Tool (MRT) to WGS-84 datum and UTM Zone 13N projection. For this study, a Windows batch file and individual parameter files for each surface reflectance data file were created using the MODIS Import Tool (GIS Lab 2008). The parameter files were revised to output to UTM projection. The batch file, when executed, started the MRT resample program to reproject all the files in one directory, using the individual parameter files. The MRT output data files were saved as Tagged Image Format (TIF) files, with one file per band, and IDL code was created and used to calculate reflectance by multiplying the values by $10^{-4}$. The data files were stacked into one file per day. Band math was used to derive NDVI and EVI using equations 1 and 2. ENVI was used to extract the NDVI and EVI values at the study site for each day. The values for each day were saved in an Excel file corresponding to the soil moisture and precipitation data. This labor intensive process was automated as much as possible given the tools and knowledge available in order to save processing time.

NDVI was derived from the data using equation 1.

$$\text{NDVI} = \frac{\rho NIR - \rho \operatorname{Re} d}{\rho NIR + \rho \operatorname{Re} d} \qquad \text{Equation 1. NDVI}$$

EVI was derived from the MODIS reflectance product using Equation 2 as proposed by Huete et al 1994.

The enhanced vegetation index (EVI) is an 'optimized' index designed to enhance the vegetation signal with improved sensitivity in high biomass regions and improved vegetation monitoring through a de-coupling of the canopy background signal and a reduction in atmosphere influences. The equation takes the form,

$$EVI = G\frac{\rho NIR - \rho \operatorname{Re} d}{\rho NIR + C_1 \rho \operatorname{Re} d - C_2 \rho Blue + L} \qquad \text{Equation 2. EVI}$$

where $\rho$ are atmospherically-corrected or partially atmosphere corrected (Rayleigh and ozone absorption) surface reflectances, L is the canopy background adjustment that addresses non-linear, differential NIR and red radiant transfer through a canopy, and C1 , C2 are the coefficients of the aerosol resistance term, which uses the blue band to correct for aerosol influences in the red band. The coefficients adopted in the MODIS-EVI algorithm are; L=1, $C_1 = 6$, $C_2 = 7.5$, and G (gain factor) = 2.5.

The soil moisture, NDVI, and EVI data was tested for outliers using Grubb's test (Keating 2008). Values that were outside three standard deviations from the mean and values considered highly unlikely or impossible were replaced after joinpoint analysis using linear regression.

Pearson correlation analysis between soil moisture and precipitation, NDVI and EVI, and NDVI and soil moisture and EVI and soil moisture was performed. NDVI and EVI were compared and the difference between the two vegetation indices was analyzed. NDVI and EVI time series transformations with one- and two-day lag times were also considered.

## Results

Soil Moisture, precipitation, NDVI, and EVI values are shown in Table 1. Precipitation during the month of June 2006 totaled 80.2 mm. Most of the precipitation occurred over a 9-day period, with 8.4 mm falling on 13 June and 70.1 mm falling between 15 June and 22 June. 54.6 mm fell on 15-16 June. Daily soil moisture means for June 2006 were calculated by depth and are displayed in Figure 2. The soil moisture values for 5 cm, 10 cm, and 20 cm appear highly correlated with each other, consistent with Wang's time-series results for the same site. Table 2 presents correlation coefficients between precipitation and soil moisture at each depth, in real time and with one- and two-day time lag. Precipitation and 5 cm, 10 cm, and 20 cm soil moisture appear highly correlated. The soil moisture at 5cm correlation coefficient is .386 ($p < .05$), and the 10 cm soil moisture correlation coefficient is .359 ($p = .052$). The 20 cm soil moisture was not correlated with precipitation using same-day or time lags. Adding a one-day and two-day time lag results in a negative correlation at 50 cm ($p < .05$). Correlations for all time-series at other depths were not significant.

The NDVI and EVI values for 26 June 2006 (Julian day 207) were -1.00 and 15.07, respectively. These values were -3.57 and 5.28 standard deviations from the mean. Examination of the EVI image for that day shows a relatively large area of noise (Figure 3) in the image that appears to be a cloud with diagonal striping. The MODIS MOD09GA product includes a QA band with 16-bit quality data about each pixel. The value for the study site for 26 June is 1073742723. The first two digits, 10, indicate that a corrected product was not produced due to cloud effects in all bands (USGS, 2008).

There was a diagonal stripe in the image on days 203-204, and the NDVI and EVI values were each zero for those days. This was classified as missing data. With the exception of day 207, the NDVI and EVI Z scores for these days are less than three standard deviations from the mean.

The raw NDVI and EVI data was problematic, with values declining to near zero, above 1.0, zero values, and on 26 June NDVI was below -1.0 while EVI was 15.07. The zero values on 22-23 June and the 26 June values are due to noise in the image. The other suspect values are highly unlikely or impossible, and may be due to noise.

The NDVI and EVI on 2-4 June declined to near zero then rose to 0.53, after about 1mm of precipitation on 1 June. Wang et al. (2007) found NDVI to average 0.45 to 0.80 in June, and a seasonal average of ~0.65 during June 2000-2004, therefore the wide range of NDVI in this study is highly unlikely. The values were adjusted using linear regression to fit the values between 1 and 5 June. NDVI values on 6 June and 29 June were above 1.0, and EVI values were within the defined range but increased without a reasonable explanation. The NDVI range by definition is -1.0 to 1.0, therefore the values on these dates are impossible. The values were adjusted using linear regression to fit the values on 5 and 7 June and 28 and 30 June, respectively. There was a diagonal stripe in the image on 22-23 June, and the NDVI and EVI values were zero. The values were adjusted using linear regression to fit the values between 21 and 24 June. The impossible NDVI and EVI values on 26 June due to noise were accompanied by a sharp decrease in values on 25 and 27 June, and the values for the three-day period were adjusted using linear regression to fit the values between 24 and 28 June.

The values returned from the study area are hereafter referred to as raw data. The raw NDVI-EVI Pearson correlation was -0.61 ($p = .01$). Adjusting the NDVI and EVI values to zero for day 207 increased the correlation to 0.92 ($p = .01$), close to correlations reported by BEN-ZE'EV et al. (2006) and Deng et al. (2007). Using a three-day moving average for NDVI and EVI during days 184-185, 187, 203-204, 206-208, and day 210, the correlation was -0.72 ($p = .01$).

Joinpoint analysis was used to determine the appropriate method to replace the missing or erroneous values. The overall approach selected was to omit the missing or erroneous cases and use linear regression to fit a model (Keating, 2008). This changed the NDVI-EVI correlation to 0.31 ($p = 0.1$).

NDVI-soil moisture and EVI-soil moisture correlation was calculated using raw data, after replacing the day 207 values with zero (NDVI-0, EVI-0), and after replacing all suspect values using the least squares regression method (adjusted). The moving average for NDVI and EVI on the days considered highly unlikely or impossible was not considered due to a negative correlation. Results are shown in Table 3. The only positive, significant ($p < .05$) correlations were the adjusted EVI at 10 cm and 20 cm depths.

The NDVI and EVI adjusted values were transformed using a time series function with a one- and two-day lag time and correlations with soil moisture values were calculated (Table 4). With a one-day lag, NDVI and 5 cm soil moisture and EVI and 50 cm soil moisture were positively correlated ($p < .05$). With a two-day lag, EVI and 50 cm soil moisture were positively correlated ($p < .05$).

A chart of adjusted NDVI and EVI and soil moisture is shown in Figure 4. A precipitation event occurred on 13 June and NDVI and EVI appear to react on 14 June. Several days of precipitation occurred starting 15 June, with two heavier days on 17 and 18 June. NDVI and EVI increased following these events.

## Discussion

Same-day soil moisture and precipitation values were positively correlated at the 5cm depth (*r* = .386, *p* = .035) and at the 10 cm depth (*r* = .359, *p* = .052), indicating that the precipitation reached the 10 cm depth the same day it fell. The 20cm and 100cm soil moisture values were not correlated (*r* =.051, *r* =.021), probably because the precipitation did not reach those depths the same day. The 50 cm same day soil moisture was negatively correlated (*r* =-.365, *p* =.048) suggesting that other factors were influencing soil moisture at that depth. *VIs not measuring SMV?*

Figure 2 shows the 20 cm and 50 cm soil moisture values reacting to the large precipitation event with a one-day time lag, however a one- and two-day time lag of soil moisture values did not produce significant correlations at those depths, or at the 5 cm depth. The 50 cm time lag soil moisture values were negatively correlated using same-day values and with one- and two-day time lags. *why??*
The 100 cm time lag soil moisture values were not correlated.

These results suggest that daily soil moisture values may not be good indicators of precipitation during the growing season, possibly due to rapid uptake by growing vegetation at shallow depths, and/or precipitation not reaching deeper depths.

The negative correlation of the raw NDVI and EVI was largely due to the noise on 26 June causing the 15.07 EVI value. Changing the NDVI and EVI values to zero on 26 June increased the correlation to 0.92 (*p* = .01), consistent with BEN-ZE'EV (2006) and Deng’s (2007) findings. However, the other suspect values did not support using this data without further adjustment, and the linear regression adjusted values were chosen for further analysis. The correlation using adjusted NDVI and EVI values was 0.31 (*p* = 0.1), well under 0.86 reported by BEN-ZE'EV et al. (2006) and 0.81 reported by Deng et al. (2007), but still positive and significant. The lower correlation is likely due to the NDVI and EVI raw data problems.

NDVI was not significantly correlated with soil moisture at any depth with same-day soil moisture values. NDVI was correlated with soil moisture with a one-day time lag (*r* = .369, *p* = .049, Figure 5).

EVI was significantly correlated with 10 and 20 cm same-day soil moisture (*r* =.428, *p* =.018; *r* =.378, *p* =.039, respectively, Figure 6), and negatively correlated with 50 cm soil moisture (*r* = -.389, *p* =.034). EVI with a one- or two-day time lag was correlated with 50 cm soil moisture (*r* = .448, *p* = .015 with one-day time lag, *r* = .457, *p* = .014 with two-day time lag, Figure 7). EVI appears to better predict soil moisture over short time frames as precipitation flows down into soil depths. Wang et al. (2007) found the highest correlation with a 10-15 day NDVI to soil moisture time lag in late May to early June using the 8-day MODIS composite product. A 10-15 day time lag is not practical with a 30-day dataset, however this does confirm that a time lag needs to be considered in a longer term study. Wang found that raw data, i.e. not deseasonalized, underestimated the correlation coefficient, so the correlation values in this study may be higher using deseasonalized data

## Conclusions

Overall, NDVI was not correlated with same-day soil moisture at any depth, but was correlated with soil moisture with a one-day time lag. EVI was correlated with same-day soil moisture at 10 cm and 20 cm depths, and at 50 cm with a one- or two-day time lag. EVI is more sensitive to high biomass regions, and these results appear to confirm that EVI may be a better indicator of soil moisture in the humid Prarie View climate than NDVI. However, the limited time span of this study warrants a long term study comparing NDVI and EVI in a humid climate to confirm these results.

This study used a daily MODIS surface reflectance product processed to level 2G, corrected for the effects of atmospheric gases, aerosols, and thin cirrus clouds. MODIS composite Vegetation Indices use an algorithm to retain only the higher quality, cloud-free, filtered data for compositing into 8-day and 16-day products. Huete (2002a) explains the VI algorithm is explained in detail. The MODIS gridded vegetation indices include quality assurance (QA) flags with statistical data that indicate the quality of the VI product and input data. The MOD13A1 VI product is a Level 3 16-day composite of Vegetation Indices at 500 meter resolution that would be a better choice for a long term study of NDVI, EVI, and soil moisture.

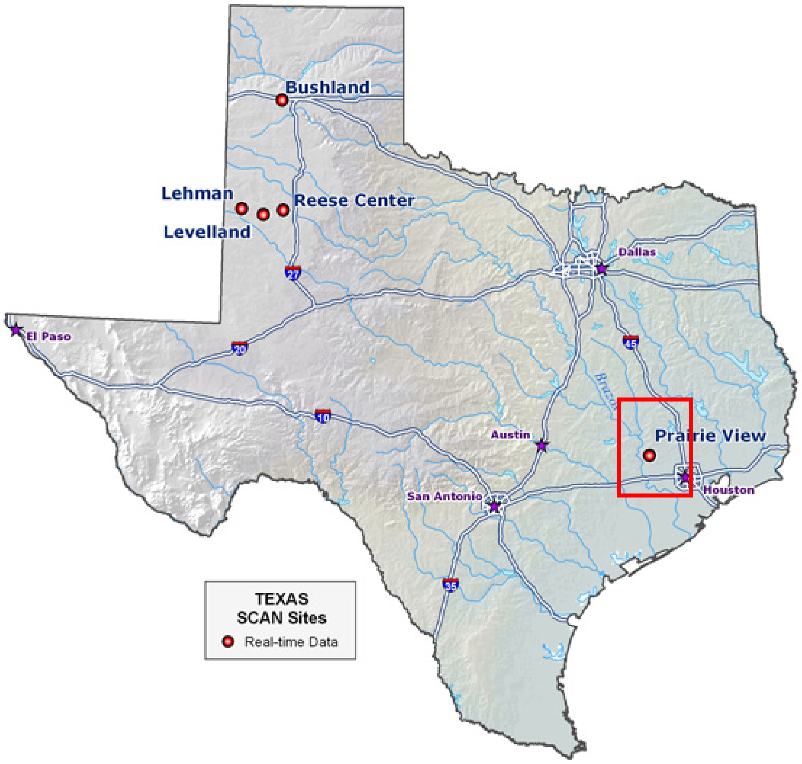

Figure 1. SCAN sites in Texas. The Prarie View site is outlined in red (SCAN Site 2016).

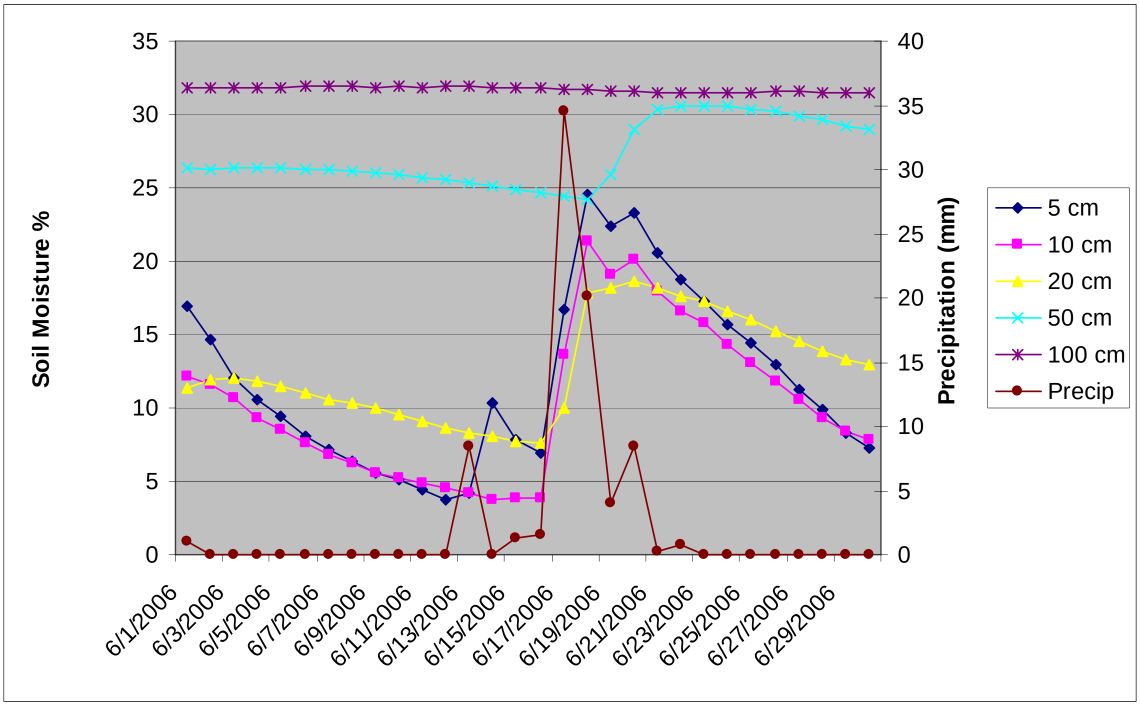

Figure 2. Soil moisture means by depth and precipitation means for June 2006 at the Prarie View SCAN site.

Table 1. Soil Moisture, precipitation, NDVI, and EVI for Prarie View, Texas SCAN site, June 2006. Values in bold were adjusted using linear regression.

| Date | Day | 5 cm | 10 cm | 20 cm | 50 cm | 100 cm | Precip (mm) | NDVI | EVI | NDVI adj | EVI adj |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 01-Jun-2006 | 182 | 16.9604 | 12.2075 | 11.3467 | 26.3258 | 31.8333 | 1.016 | 0.588665 | 0.351278 | 0.588665 | 0.351278 |
| 02-Jun-2006 | 183 | 14.7113 | 11.6146 | 11.9058 | 26.2917 | 31.8088 | 0 | 0.242028 | 0.327876 | **0.574219** | **0.3847567** |
| 03-Jun-2006 | 184 | 12.0050 | 10.6746 | 12.0375 | 26.3663 | 31.7950 | 0 | 0.041520 | 0.169846 | **0.559773** | **0.4416375** |
| 04-Jun-2006 | 185 | 10.5821 | 9.3667 | 11.7958 | 26.3908 | 31.7925 | 0 | 0.004968 | 0.023672 | **0.545327** | **0.4985183** |
| 05-Jun-2006 | 186 | 9.4579 | 8.5096 | 11.4892 | 26.3621 | 31.8329 | 0 | 0.530881 | 0.555399 | 0.530881 | 0.555399 |
| 06-Jun-2006 | 187 | 8.1208 | 7.6192 | 11.0650 | 26.3004 | 31.9025 | 0 | 1.052397 | 0.713905 | **0.490698** | **0.504791** |
| 07-Jun-2006 | 188 | 7.1621 | 6.8350 | 10.6033 | 26.1971 | 31.8929 | 0 | 0.450515 | 0.454183 | 0.450515 | 0.454183 |
| 08-Jun-2006 | 189 | 6.3217 | 6.2767 | 10.3208 | 26.0854 | 31.8754 | 0 | 0.288118 | 0.350540 | 0.288118 | 0.350540 |
| 09-Jun-2006 | 190 | 5.5788 | 5.6204 | 10.0079 | 25.9738 | 31.8658 | 0 | 0.585629 | 0.619435 | 0.585629 | 0.619435 |
| 10-Jun-2006 | 191 | 5.1100 | 5.2071 | 9.5388 | 25.8650 | 31.9092 | 0 | 0.549495 | 0.507916 | 0.549495 | 0.507916 |
| 11-Jun-2006 | 192 | 4.4725 | 4.8808 | 9.0763 | 25.7125 | 31.8729 | 0 | 0.692821 | 0.600830 | 0.692821 | 0.600830 |
| 12-Jun-2006 | 193 | 3.8000 | 4.5804 | 8.5892 | 25.5229 | 31.9158 | 0 | 0.658149 | 0.442580 | 0.658149 | 0.442580 |
| 13-Jun-2006 | 194 | 4.2129 | 4.1625 | 8.2679 | 25.3554 | 31.8988 | 8.382 | 0.822961 | 0.540693 | 0.822961 | 0.540693 |
| 14-Jun-2006 | 195 | 10.3183 | 3.7525 | 8.0300 | 25.1583 | 31.8513 | 0 | 0.444809 | 0.406883 | 0.444809 | 0.406883 |
| 15-Jun-2006 | 196 | 7.8113 | 3.8933 | 7.7721 | 24.9371 | 31.8067 | 1.27 | 0.533176 | 0.473761 | 0.533176 | 0.473761 |
| 16-Jun-2006 | 197 | 6.9221 | 3.8208 | 7.5600 | 24.7108 | 31.8004 | 1.524 | 0.401097 | 0.403231 | 0.401097 | 0.403231 |
| 17-Jun-2006 | 198 | 16.6754 | 13.6854 | 10.0154 | 24.4588 | 31.7413 | 34.544 | 0.662916 | 0.428349 | 0.662916 | 0.428349 |
| 18-Jun-2006 | 199 | 24.5746 | 21.3858 | 17.8550 | 24.2450 | 31.6717 | 20.066 | 0.643720 | 0.549277 | 0.643720 | 0.549277 |
| 19-Jun-2006 | 200 | 22.3429 | 19.0883 | 18.1263 | 25.9104 | 31.6225 | 4.064 | 0.783952 | 0.554182 | 0.783952 | 0.554182 |
| 20-Jun-2006 | 201 | 23.3292 | 20.1013 | 18.6654 | 28.9233 | 31.5688 | 8.382 | 0.580474 | 0.564051 | 0.580474 | 0.564051 |
| 21-Jun-2006 | 202 | 20.5917 | 17.9513 | 18.1950 | 30.3263 | 31.5163 | 0.254 | 0.655685 | 0.486056 | 0.655685 | 0.486056 |
| 22-Jun-2006 | 203 | 18.7567 | 16.5496 | 17.6488 | 30.5554 | 31.4738 | 0.762 | 0.000000 | 0.000000 | **0.602529** | **0.513513** |
| 23-Jun-2006 | 204 | 17.3208 | 15.7904 | 17.2771 | 30.5708 | 31.4425 | 0 | 0.000000 | 0.000000 | **0.549373** | **0.540970** |
| 24-Jun-2006 | 205 | 15.7192 | 14.3471 | 16.6354 | 30.5333 | 31.4713 | 0 | 0.496217 | 0.568427 | 0.496217 | 0.568427 |
| 25-Jun-2006 | 206 | 14.4783 | 13.0938 | 15.9671 | 30.3971 | 31.4946 | 0 | -0.009089 | -0.044435 | **0.491735** | **0.559202** |
| 26-Jun-2006 | 207 | 12.9779 | 11.8667 | 15.2721 | 30.2104 | 31.5417 | 0 | -1.001544 | 15.069652 | **0.487253** | **0.549977** |
| 27-Jun-2006 | 208 | 11.2142 | 10.5754 | 14.5625 | 29.9113 | 31.5550 | 0 | 0.029323 | 0.124596 | **0.482771** | **0.540751** |
| 28-Jun-2006 | 209 | 9.9088 | 9.3146 | 13.8783 | 29.6033 | 31.5225 | 0 | 0.478289 | 0.531526 | 0.478289 | 0.531526 |
| 29-Jun-2006 | 210 | 8.3254 | 8.4267 | 13.2796 | 29.2238 | 31.4900 | 0 | 1.042431 | 0.797060 | **0.420665** | **0.519473** |
| 30-Jun-2006 | 211 | 7.2250 | 7.8875 | 12.9100 | 29.0325 | 31.4350 | 0 | 0.363041 | 0.507419 | 0.363041 | 0.507419 |

**Table 2. Precipitation and soil moisture value correlation, with zero, one, and two-day time lags.**

|  | Depth | 5 cm | 10 cm | 20 cm | 50 cm | 100 cm |
|---|---|---|---|---|---|---|
| Precipitation | Pearson Correlation | .386(*) | .359 | .051 | -.365(*) | .021 |
|  | Sig. (2-tailed) | .035 | .052 | .788 | .048 | .911 |
|  | Depth-Time Lag | 5cm-1 day | 10 cm-1 day | 20 cm-1 day | 50 cm-1 day | 100 cm-1 day |
| Precipitation | Pearson Correlation | -.013 | -.092 | -.269 | -.395(*) | .122 |
|  | Sig. (2-tailed) | .947 | .633 | .158 | .034 | .529 |
|  | Depth-Time Lag | 5cm-2 days | 10 cm-2 days | 20 cm-2 days | 50 cm-2 days | 100 cm-2 days |
| Precipitation | Pearson Correlation | -.162 | -.284 | -.362 | -.389(*) | .164 |
|  | Sig. (2-tailed) | .412 | .143 | .058 | .041 | .403 |

* Correlation is significant at the 0.05 level (2-tailed).

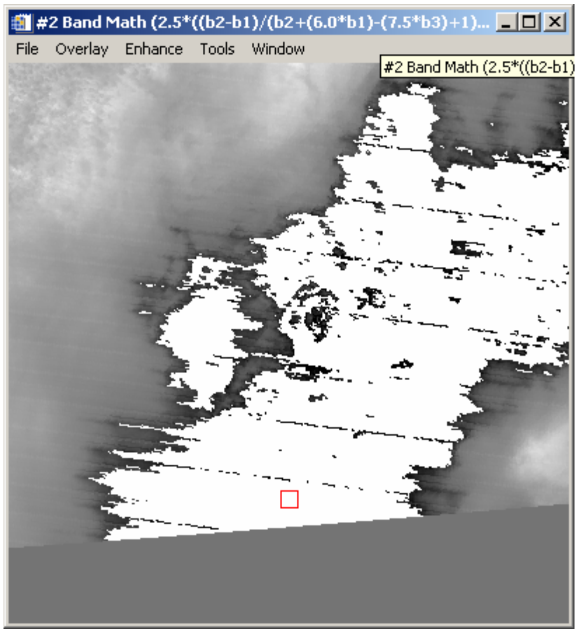

Figure 3. The study area on 26 June. The NDVI and EVI values are -1.01 and 15.07, which are impossible values. The QC data indicates a cloud in the study area.

Table 3. NDVI and EVI correlations with same day soil moisture values for raw data, zero value on day 207 (NDVI-0, EVI-0), and adjusted using linear regression for highly unlikely or impossible raw values.

| | | 5 cm | 10 cm | 20 cm | 50 cm | 100 cm |
|---|---|---|---|---|---|---|
| NDVI raw | Pearson Correlation | -.118 | -.133 | -.240 | -.430(*) | .322 |
| | Sig. (2-tailed) | .534 | .483 | .201 | .018 | .083 |
| EVI raw | Pearson Correlation | .041 | .121 | .231 | -.161 | 1 |
| | Sig. (2-tailed) | .831 | .523 | .219 | .395 | |
| NDVI-0 | Pearson Correlation | -.134 | -.139 | -.230 | -.407(*) | .311 |
| | Sig. (2-tailed) | .482 | .463 | .221 | .026 | .094 |
| EVI-0 | Pearson Correlation | -.212 | -.205 | -.242 | -.374(*) | .277 |
| | Sig. (2-tailed) | .260 | .278 | .198 | .042 | .138 |
| NDVI adjusted | Pearson Correlation | .301 | .309 | .128 | -.240 | .149 |
| | Sig. (2-tailed) | .106 | .097 | .502 | .202 | .431 |
| EVI adjusted | Pearson Correlation | .242 | .428(*) | .378(*) | -.389(*) | 1 |
| | Sig. (2-tailed) | .198 | .018 | .039 | .034 | |

* Correlation is significant at the 0.05 level (2-tailed).

Table 4. NDVI and EVI adjusted values with one and two-day time lags correlated with soil moisture.

| | | 5 cm | 10 cm | 20 cm | 50 cm | 100 cm |
|---|---|---|---|---|---|---|
| NDVI-1 day | Pearson Correlation | .369(*) | .275 | .213 | -.058 | .034 |
| | Sig. (2-tailed) | .049 | .149 | .268 | .766 | .859 |
| EVI-1 day | Pearson Correlation | .015 | .074 | .277 | .448(*) | -.305 |
| | Sig. (2-tailed) | .937 | .701 | .145 | .015 | .108 |
| NDVI-2 days | Pearson Correlation | .255 | .155 | .122 | .105 | -.103 |
| | Sig. (2-tailed) | .190 | .432 | .538 | .595 | .602 |
| EVI-2days | Pearson Correlation | -.080 | -.015 | .133 | .457(*) | -.312 |
| | Sig. (2-tailed) | .687 | .941 | .499 | .014 | .107 |

* Correlation is significant at the 0.05 level (2-tailed).

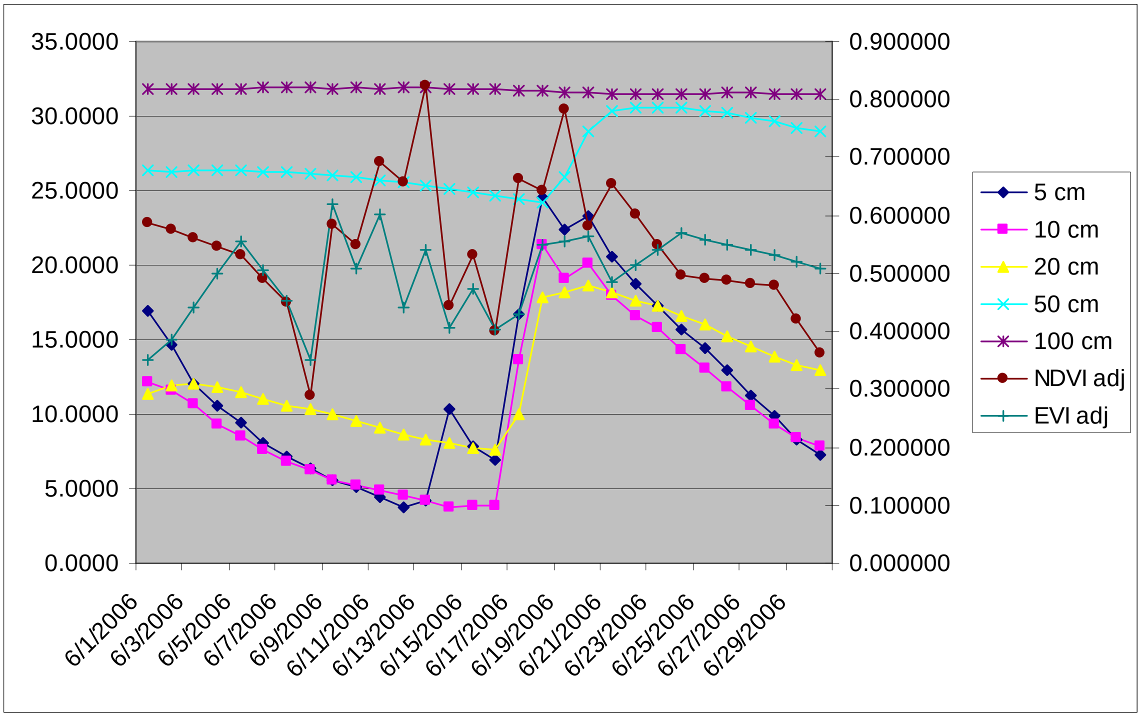

Figure 4. Soil moisture and adjusted NDVI and EVI values for the Prarie View, Texas SCAN site for June 2006.

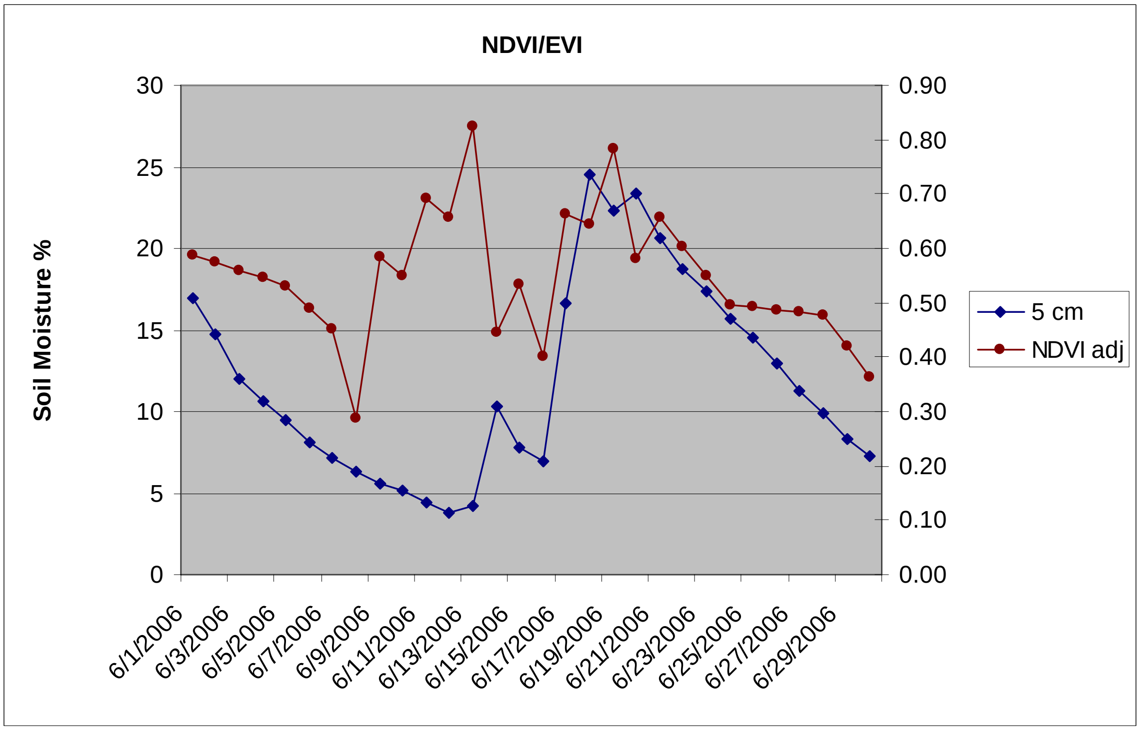

Figure 5. NDVI was correlated with soil moisture with a one-day time lag (*r* = .369, *p* = .049).

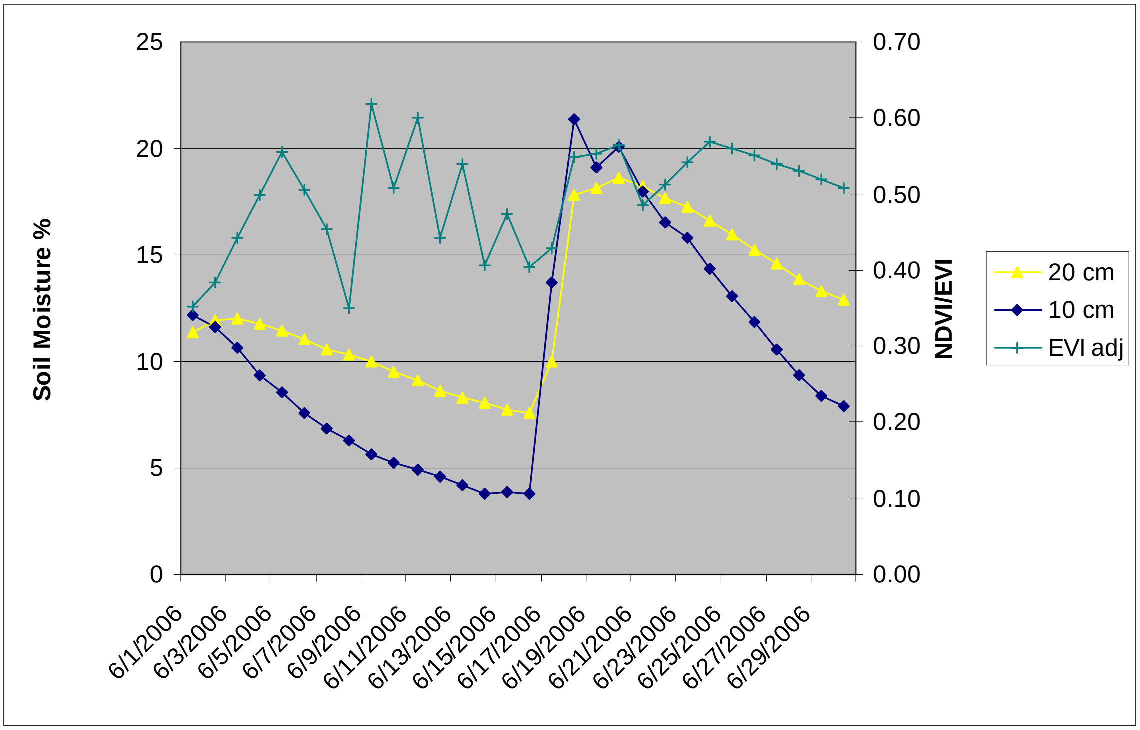

Figure 6. EVI was correlated with 10 cm and 20 cm same-day soil moisture (*r* =.428, *p*=.018; *r* =.378, *p* =.039, respectively).

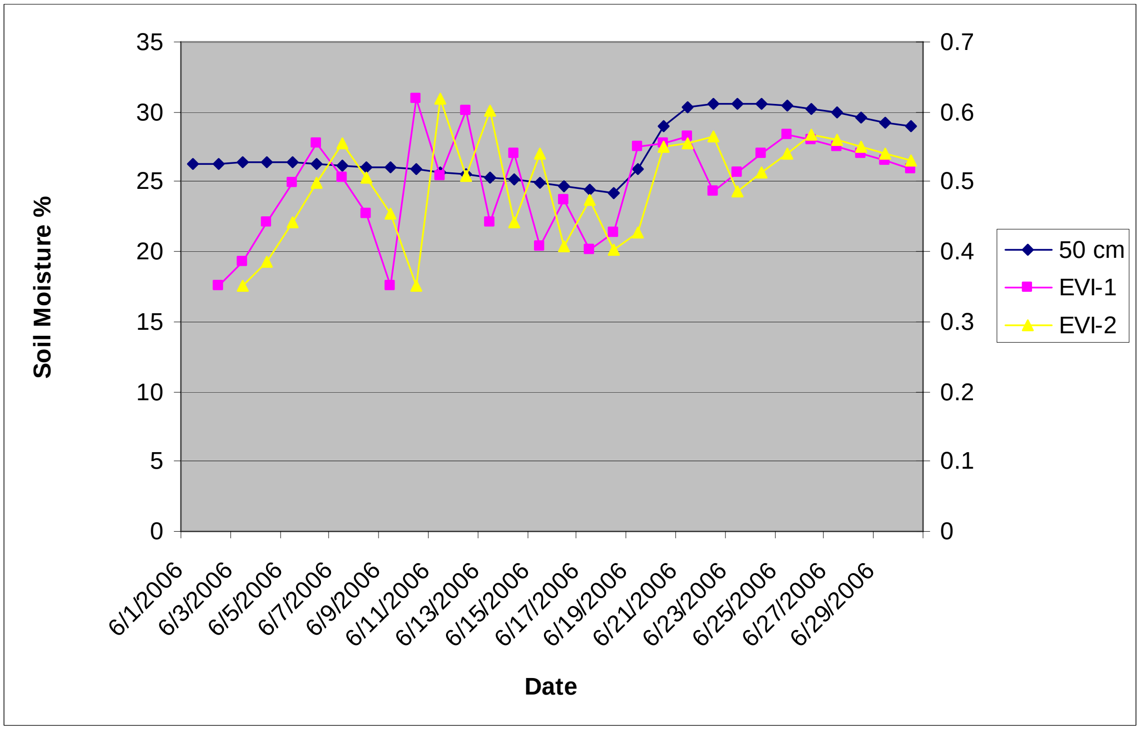

Figure 7. EVI with a one- or two-day time lag was correlated with 50 cm soil moisture (*r* = .448, *p* = .015 with one-day time lag, *r* = .457, *p* = .014 with two-day time lag).

# References

Ben-Ze'ev, E., Karnieli, A., Agam, N., Kaufman, Y., Holben, B., Assessing Vegetation Condition In The Presence Of Biomass Burning Smoke By Applying The Aerosol-Free Vegetation Index (AFRI) On MODIS Images, International journal of remote sensing, (2006), 27, 3203-3221

Deng, FP, Su, GL, Liu, C, Seasonal Variation Of MODIS Vegetation Indexes And Their Statistical Relationship With Climate Over The Subtropic Evergreen Forest In Zhejiang, China, IEEE GEOSCIENCE AND REMOTE SENSING LETTERS, (2007), 4, 236-240

EOS Data Center, http://killians.gsfc.nasa.gov/~imswww/pub/imswelcome/, accessed February 2008

Gao, X., Huete, A., Didan, K., Multisensor Comparisons and Validation of MODIS Vegetation Indices at the Semiarid Jornada Experimental Range, IEEE Transactions on Geoscience and Remote Sensing, (2003), 41, 2368-2381

GIS Lab, http://gis-lab.info/qa/modisimport-tool-eng.html, accessed March 2008

Huete, A., Didan, K., Miura, T., Rodriguez, E.P., Gao, X., Ferreira, L.G., Overview of the radiometric and biophysical performance of the MODIS vegetation indices, Remote Sensing of Environment (2002) 83, 195-213

Huete, A., Didan, K., Yuan, Y., MODIS Vegetation Index CD-ROM, TBRS team, The University of Arizona, (2002), http://tbrs.arizona.edu/cdrom/Index.html, accessed March 2008

Huete, A., Justice, C. and Liu, H., Development of vegetation and soil indices for MODIS EOS, Remote Sensing of Environment (1994) 49, 224–234

Keating, J., University of Texas at San Antonio, personal conversation, 25 March 2008

Matsushita. B., Yang, W., Chen J., Onda, Y and Qiu G, Sensitivity of the Enhanced Vegetation Index (EVI) and Normalized Difference Vegetation Index (NDVI) to Topographic Effects: A Case Study in High-Density Cypress Forest, Sensors (2007), 7, 2636-2651

Terrestrial Biophysics and Remote Sensing Lab (TBRS), Theoretical Basis for the the Enhanced Vegetation Index, http://tbrs.arizona.edu/cdrom/Index.html, accessed March 2008

USGS Land Processes Distributed Active Archive Center, http://edcdaac.usgs.gov/modis/qa/mod09ga_qa_v5.asp, accessed April 2008

Wang, X., Xie, H., Guan, H., and Xiaobing, Z, Different responses of MODIS-derived NDVI to root-zone soil moisture in semi-arid and humid regions, Journal of Hydrology (2007) 340, 12– 24