# Changes in Hydrological Conditions and Surface Fluxes Due to Seasonal Vegetation Greening in the North American Monsoon Region

by

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# ABSTRACT

The North American monsoon (NAM) region in northwestern Mexico is characterized by seasonal precipitation pulses which lead to a major shift in vegetation greening and ecosystem processes. Seasonal greening in the desert region is particularly important due to its impact on land surface conditions and its potential feedback to atmospheric and hydrologic processes. In this thesis, we utilize remotely-sensed and ground-based measurements to infer land surface energy changes that can influence the NAM through a vegetation-rainfall feedback mechanism. Our study is focused over the period 2004-2007 for the Río San Miguel and Río Sonora basins, which contain a regional network of precipitation and soil moisture observations. Results indicate that seasonal changes in vegetation greenness, albedo and land surface temperature are dramatic for all regional ecosystems and are related to interannual differences in hydrologic conditions. Vegetation responses depend strongly on the plant communities in each ecosystem, with the highest greening occurring in the mid elevation Sinaloan thornscrub (or subtropical scrubland). Results from the analysis of remote sensing data indicate that the ground observations at an eddy covariance tower are representative of the land surface dynamics in subtropical scrublands. This large region exhibits a high seasonality in vegetation greenness, albedo and land surface temperature. Spatial and temporal persistence of remotely-sensed Normalized Difference Vegetation Index (NDVI), albedo and land surface temperature (LST) fields were then used to distinguish the arrangement of functional groups with cohesive organization by using cluster analysis and unsupervised classification. We identified six functional groups exhibiting different surface response in albedo, NDVI and LST. Subtropical scrublands exhibited large spatial extents in the region with significant seasonal changes in land surface conditions. The work also indicates that accumulated seasonal precipitation is a strong indicator of biomass production across the regional ecosystems with higher greenness precipitation ratio for the Sinaloan thornscrub. Further, precipitation was found to have higher lagged correlations to the vegetation dynamics, while soil moisture was the primary factor influencing vegetation greening during concurrent periods. Multiyear comparisons across ecosystems indicate that different plant water use strategies may exist in response to interannual hydrologic variations and are strongly controlled by elevation along semiarid mountain fronts. Finally, analysis of land-atmosphere observations prior to and during the NAM from an eddy covariance tower are used to infer the necessary conditions for a vegetation-rainfall feedback mechanism in subtropical scrublands. We find that precipitation during the monsoon onset leads to changes in vegetation that impact land surface states and fluxes in such a way as to promote subsequent convective rainfall. Persistence cloudiness, however, can weaken the feedback mechanism. This land-based inference of the existence of positive vegetation-rainfall feedback should be corroborated with atmospheric measurements and modeling.

Keywords: North American monsoon, semiarid ecosystems, ecohydrology, remote sensing, Sonoran Desert, soil moisture, precipitation, vegetation.

## ACKNOWLEDGMENTS

This thesis is dedicated to my wife Alma and my daughter Ximena.

*Inside us there is something that has no name that something is what we are.*

- *Jose Saramago*

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This dissertation is accepted on behalf of the faculty of the Institute by the following committee:

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Date

# CHAPTER 1

# INTRODUCTION

This section describes the North American Monsoon and its main characteristics. In addition, we briefly discus the relation between vegetation greening, precipitation and soil moisture as well as the remote sensing approach to monitoring vegetation dynamics. This shift in vegetation dynamics lead to large changes in surface conditions (energy balance and depth of boundary layer), which can promote subsequent convective rainfall, hence, a hypothesized positive vegetation-rainfall feedback mechanism.

## 1.1. Overview of North American Monsoon Region

The North American Monsoon (NAM) is an important meteorological phenomenon causing an increment in rainfall in northwestern Mexico and southwestern United States. The core of monsoon precipitation, in the months of July, August and September, is located in the western slope of Sierra Madre Occidental (Gochis et al., 2004). Precipitation in areas peripheral to this core region shows high spatiotemporal variability due to transient features such as the passage of tropical easterly waves (Fuller and Stensrud, 2000). The region is generally semiarid with an annual precipitation regime dominated by warm season convection that strongly interacts with the regional topography. Conditions before monsoon onset are characterized by high temperatures and


**Figure 1.1:** Vegetation greening in the study region during (a) June 30, 2007 and (b) August 12, 2008. Note the mountainous terrain (~820 m) and the Sinaloan thornscrub ecosystem.

minimal rainfall. The monsoon transition is well documented in several articles (Douglas et al., 1993; Higgins et al., 1997; Higgins and Shi, 2000), among others. There is a seasonal surface wind reversal over some areas affected by the North American monsoon, notably the Gulf of California (Badan-Dangon et al. 1991), a reversal that is similar to but a much smaller scale to the Asian Monsoon. Krishnamurti (1971) noted that there were two planetary scale east-west (or monsoonal) circulations, a dominant one associated with Asia and a much weaker one associated with the Mexican plateau in the summer. Histograms of monthly mean rainfall and mean temperature for many of the stations in northwest Mexico are similar to those in southern Asia with most of the annual rainfall taking place during a short period (2-4 months) and with the highest temperature just prior to the onset of rains (Douglas et al. 1993). The geographical extent of the NAM includes the region surrounding the southern part of the Gulf of California, the axis of the Sierra Madre Occidental extending into southeastern Arizona, the Rio Grande Valley in New Mexico and into the high plains of southern Colorado. However, the NAM is most spatially consistent over northwest Mexico with greater variability to the north.

As an ocean–atmosphere-land coupled system, the NAM exhibits apparent dependence on land and ocean surface conditions (Adams and Comrie 1997). For this reason, pre-monsoon land surface and oceanic conditions are promising predictors for NAM precipitation at seasonal lead times, especially where these predictors are temporally persistent. Higgins et al. (1999) examined the relation between anomalous monsoon behavior over Arizona-New Mexico, NW Mexico and SW Mexico, and the El Niño Southern Oscillation (ENSO) signals. They found that wet (dry) conditions in southwest Mexico tend to occur during La Niña (El Niño), which they attribute partly to the impact of local sea surface temperature (SST) on the land sea thermal contrast, hence the strength of the monsoon. They also found a weak association between dry monsoons in NW Mexico and El Niño. Hu and Song (2002) showed that south central Mexico monsoon rainfall is highly affected by interannual variations in SST and the location of the intertropical convergence zone (ITCZ) in the eastern tropical pacific. Cooler (warmer) than normal SST co-existed with the more northern (southern) position of ITCZ and more (less) monsoon rainfall in central-south Mexico.

Matsui et al. (2003) investigated the influence of land-atmosphere interactions on the variability of the NAM by testing a hypothesis regarding the connection between observed land surface variables (April snow water equivalent, surface temperature and precipitation) in the NAM region, including NW Mexico, for the period 1979-2000. Their result showed that there is a weak negative relationship between April snow water equivalent in the Rocky Mountain region and subsequent spring temperatures that persist into June in the NAM region. They concluded that this inverse relationship could not directly influence monsoon rainfall in July and August because it disappears during the monsoon season. These results are similar to those found by Small (2001) who showed an inverse relation between southern Rocky Mountains antecedent season snowpack and monsoon rainfall. Zhu et al. (2007) found that soil moisture anomalies correlate negatively with surface temperature anomalies over most of the U.S. and Mexico, except in the desert regions. The onset of the monsoon is negatively correlated to May surface temperature, suggesting that antecedent land surface conditions may influence the pre-monsoon thermal conditions, which then affects monsoon onset. They also confirmed that the strength of the monsoon is related to pre-monsoon land-sea surface temperature contrast. This statement confirms that late monsoon years are associated with colder land and warmer adjacent ocean than early monsoon years. In addition, a strong positive relation between May surface temperature anomalies and the large-scale mid-tropospheric circulation anomalies was found which suggest that large-scale circulation may play a strong role in modulating the monsoon onset. In fact, the role of the large-scale circulation may well be larger than the apparent land surface feedback effect.

The role of vegetation after precipitation onset and the subsequence changes in land surface processes are poorly understood in the context of the land surface effects on the monsoon. A few studies have started to address the seasonal changes in vegetation greenness, surface fluxes, and soil moisture (Watts et al., 2007; Vivoni et al., 2008b). The

NAM is the main climate phenomenon controlling summer rainfall in northwestern Mexico and the southwestern U.S. (Douglas et al., 1993; Adams and Comrie, 1997; Sheppard et al., 2002) and accounts for ~40 to 70% of the annual precipitation in the region. Understanding vegetation dynamics and its relation to hydrologic conditions during the NAM is important as this period coincides with the plant greening and growing season in the region (Watts et al., 2007). Fig. 1.1 is an example of the vegetation greening observed in the mountainous study area of northwestern Mexico.

The ecohydrology of northwestern Mexico is particularly interesting as the seasonal precipitation pulses from the NAM lead to a major shift in vegetation greening and ecosystem processes. Plant responses during the monsoon include the production of leaf biomass required for photosynthesis, flowering and seed dispersal (e.g., Reynolds et al., 2004; Weiss et al., 2004; Caso et al., 2007). The vegetation transition occurs relatively rapidly and is closely tied to the monsoon onset and its variability.

Few studies exist to understand the relation between climatic variables and vegetation greening in Mexico. Gomez-Mendoza et al. (2008) found that NDVI values for several vegetation types are correlated with the spatial and temporal variability of precipitation in the Mexican state of Oaxaca. Nevertheless, they observed intraannual changes in the response time of vegetation to the onset and distribution of precipitation. Their results suggest that temperate forest may be considered as good indicators of inter-annual climate variability, whereas, tropical dry forest and grasslands are more sensitive to intraannual variability. Precipitation pulses are essential for the regeneration of drylands in northwest Mexico. Caso et al. (2007) found that El Niño events tend to increase rainfall in northwest Mexico, but tend to increase aridity in the southern tropical

Pacific slope. El Niño produced a large increase in winter rainfall above 22 degrees latitude, whereas La Niña conditions tend to produce an increase in summer monsoon type rainfall that predominates in the tropical south. In addition, Salinas-Zavala et al. (2002), found that the negative ENSO phase is associated with drought conditions with delay of 4-6 months related to the start of the event, while the positive phase is related to high NDVI values during the driest season in the region. Summers with high NDVI values are related to an intensification of the summer monsoon, while, in dry summers, the regional atmospheric circulation is characterized by the presence of an enhanced ridge of high pressure aloft over most of Mexico. Mora et al. (1998) found significant non-linear relations between vegetation productivity, precipitation and evapotranspiration in Mexico. Variation of vegetation pattern of productivity and seasonality is explained less at the ecoregion scale relative to the country level, but water balance variables still account for more than 50% of the variation in vegetation.

The climate conditions in Mexico lead to a gradual replacement of the Sonoran Desert by the subtropical thornscrubs and dry forest of Sinaloa (Caso et al, 2007). Farther into the tropics, a long corridor of tropical dry deciduous forest runs along the coast in Jalisco and Chiapas (Martin et al., 1998). The Sonoran Desert receives winter precipitation in its northwestern reaches near the Mojave Desert, but is fed predominantly by summer monsoon rains in its tropical southern boundary with the Sinaloan thornscrubs (Dimmit et al., 2000). Tropical summer-rain drylands in western and southern Mexico are dominated by drought deciduous trees and shrubs, often with succulent stems or fleshy trunks and tropical evolutionary origins (Bullock et al., 1995). Despite its high biodiversity and biomass production, this ecosystem is one of the most threatened vegetation types in Mexico. In Sonora, this biome has been replaced by introduced species as buffel grass as result of land use changes (Arriaga et al., 2004). The three main pathways of vegetation changes associated with land use changes in tropical deciduous forest in Mexico have been documented as: (1) Forest replaced by agriculture in flatlands, (2) pasture established on slopes and (3) wood extraction carried out without slash and burn on hillcrests. If cultivated areas in flatlands and pasture fields on slopes are not continuously maintained by farmers, thorny vegetation can develop within one to 3 years. If left untouched, this secondary vegetation becomes a low forest dominated by thorny species (Burgos and Maass, 2004, Alvarez-Yépiz et al., 2008). Losses in total above ground biomass can account up to 80% as result of slash fires in tropical deciduous forest, where the dramatic loss of biomass may affect future site productivity and the capacity for these sites to function as carbon pools (Kauffman et al., 2003).

While the seasonally dynamics of the subtropical and tropical ecosystems in northwest Mexico has been recognized previously (e.g., Brown, 1994; Salinas-Zavala et al., 2002), the linkage between hydrologic conditions and ecosystem responses has not been quantified primarily due to a lack of observations in the region. Fortunately, the scarcity of field observations has been recently addressed through the North American Monsoon Experiment (NAME) and Soil Moisture Experiment 2004 (SMEX04) (Higgins and Gochis, 2007; Watts et al., 2007; Vivoni et al., 2007, 2008a; Bindlish et al., 2008). As a result, an opportunity exists to quantify vegetation dynamics from remote sensing data and relate these directly to ground-based observations. For example, Vivoni et al. (2008a) analyzed soil moisture for different ecosystems arranged across an elevation gradient through field and remote sensing observations

### 1.2. Remote Sensing and Vegetation Monitoring

Remote sensing from satellite platforms has become an indispensable tool for monitoring the phenological status of vegetation and its potential role in controlling the land surface energy and water balance in terrestrial ecosystems (e.g., Xinmei et al., 1993; Guillevic et al., 2002; Bounoua et al., 2000; Wang et al., 2006; Watts et al., 2007; Méndez-Barroso et al., 2008). The spatiotemporal characteristics of remote sensing data provide an advantage as compared to ground observations by allowing quantification of vegetation phenological changes over large areas and extended periods. For example, the Normalized Difference Vegetation Index (NDVI) is a useful ratio widely used to estimate seasonal changes in plant greenness (Sellers, 1985; Tucker et al., 1985; Goward, 1989; Anyamba and Estman, 1996; Zhang et al., 2003). NDVI is based on the reflectance properties of green vegetation and is determined by the ratio of the amount of absorption by chlorophyll in the red wavelength (600-700 nm) to the reflectance of the near infrared (720-1300 nm) radiation by plant canopies. Through the use of spatiotemporal NDVI fields, the seasonal and interannual changes in vegetation greenness can be analyzed and related to biotic and abiotic factors, including rainfall, fire and land cover disturbances (Zhang et al., 2004; Franklin et al., 2006; Wittenberg et al., 2007).

Currently, one of the most reliable sources of remotely-sensed NDVI data is the MODIS (Moderate Resolution Imaging Spectroradiometer) sensor on board the EOS Terra and Aqua satellites (Huete et al., 1997, 2002). This sensor offers excellent radiometric and geometric properties, as well as improved atmospheric and cloud corrections (see Huete and Liu, 1994 for details). For studies of vegetation phenology, MODIS products can be used to indicate the spatial and temporal variations in: (1) the onset of photosynthesis, (2) the peak photosynthetic activity, and (3) the senescence, mortality or removal of vegetation (e.g., Reed et al., 1994; Zhang et al., 2003).

In recent work, Lizarraga-Celaya et al. (2009) found a gradient in MODIS-based vegetation indices and albedo as a function of latitude in the NAM region. A large inter-seasonal variability can be observed in the tropical deciduous forests (in the southern state of Jalisco and Durango), while there is a small variability in the grasslands located in Arizona. In addition, the authors found different responses in the inter-seasonal albedo at northern latitudes in the NAM region (grasslands and open shrublands) as compared to the southern region. In this thesis, we use MODIS-derived NDVI fields to examine a set of semiarid, mountainous ecosystems in northwestern Mexico, which respond vigorously to summer precipitation during the North American monsoon (Salinas-Zavala et al., 2002; Watts et al., 2007; Vivoni et al., 2007)

### 1.3. Relation between Vegetation Indices, Rainfall and Soil Moisture

Seasonal characteristics of vegetation dynamics, such leaf emergence or senescence, are strongly linked with atmospheric conditions and surface processes such as rainfall, soil moisture and temperature. As a result, the detection of phenological changes in entire ecosystems from remote sensing may allow us to monitor seasonal variability as well as distinguish spatial patterns in hydrologic processes. In prior studies, remote sensing of vegetation has yielded metrics that are useful for monitoring ecosystem changes (e.g., Lloyd et al., 1990; Reed et al., 1994; Zhang et al., 2003). An important contribution has been the time integrated NDVI (iNDVI) over a seasonal period, which is related to the net primary productivity (NPP) in an ecosystem (Reed et al., 1994). iNDVI measures the magnitude of greenness integrated over time and reflects the capacity of an ecosystem to support photosynthesis and produce biomass. The relation between rainfall and iNDVI has been utilized as an indicator of ecosystem productivity. For example, Prasad et al. (2005) and Li et al. (2004) used iNDVI to study the relation between precipitation and vegetation in several ecosystems in India and Senegal, respectively. In both studies, iNDVI showed a strong relationship with rainfall, suggesting this method may be useful for inferring hydrologic controls on vegetation dynamics in other regions.

Relations between vegetation and precipitation have been studied widely in water-limited ecosystems. In previous studies, the maximum photosynthetic activity in the plant growing season has been linked with precipitation in the current and preceding months (Davenport and Nicholson, 1993; Wang et al., 2003; Al-Bakri and Suleiman, 2004; Chamaille-Jammes et al., 2006; Prasad et al., 2007). For water-limited ecosystems, the greenness-precipitation ratio (GPR) has been used to infer the productivity of different plant associations (Davenport and Nicholson, 1993; Prasad et al., 2005). GPR is defined as the net primary productivity per unit of rainfall (Le Houerou, 1984). Although vegetation growth is correlated to rainfall, the incoming precipitation is also modified by the soil water balance, such that soil moisture is a key intermediary between storm pulses and plant available water (Breshears and Barnes, 1999; Loik et al., 2004). For example, Farrar et al. (1994) found that the correlation between NDVI and soil moisture is a concurrent effect, suggesting a direct linkage between vegetation dynamics and soil wetness. In addition, the authors found that the accumulated precipitation over several prior months was related to the vegetation response. Grist et al. (1997) also found discrepancies in NDVI-rainfall relations and attributed these to soil moisture.

### 1.4. Changes in Surface Conditions and Energy Balance at the Surface

It has well known that land surface and atmospheric processes are interrelated (e.g., Pielke et al., 1998). For example, changes in soil moisture alter the surface albedo and the partitioning of turbulent fluxes, with potential effects on convective rainfall (Eltahir, 1998). The explicit link between vegetation changes and their subsequent effects on rainfall have been less explored, though Brunsell (2006) indicates these are more relevant than soil moisture variations. In the NAM region, remote sensing datasets allow for monitoring of land surface conditions that can be useful for inferring changes that may promote (positive feedback) or suppress (negative feedback) subsequent rainfall. Brunsell (2006) found through remotely-sensed LST and NDVI that the NAM region exhibited a positive land surface-precipitation feedback. Nevertheless, the feedback was found through correlations with precipitation that do not necessarily indicate causality.

In this thesis, remotely-sensed and ground-based observations are used to infer the existence of a vegetation-rainfall feedback in the NAM region by tracking the necessary land surface conditions. Identifying a feedback mechanism in this manner involves inspection of three variables from remote sensing: NDVI, LST and albedo. NDVI is related to chlorophyll amount and energy absorption and is indicative of vegetation phenology (Tucker, 1979). LST is indicative of soil moisture availability and evapotranspiration and thus closely linked with vegetation function (Matsui et al., 2003; Brunsell, 2006). Surface albedo is also regulated by soil moisture and vegetation conditions and has important controls on the radiation budget. After the monsoon onset, the seasonal vegetation greening should alter the land surface temperature, albedo and surface turbulent fluxes (e.g., evapotranspiration) and lead to changes in boundary layer conditions that promote more convective rainfall.

The remote sensing and ground-based data are used together in the following manner. With the satellite data, zones (or functional groups) with similar responses in terms of NDVI, albedo and LST are identified, since these are strongly related to the water and energy balances. This permits an assessment of the representativeness of an eddy covariance tower in the region. Remote sensing data are then compared with ground measurements at the tower to ensure consistency. Finally, changes in land surface conditions (e.g., surface fluxes, soil moisture and temperature) are used to infer the existence and sign of the vegetation-rainfall feedback.

### 1.5. Interactions Surface-Atmosphere and Possible Feedback Mechanisms

The total energy in the atmospheric boundary layer can be described by moist static energy (mse), which includes potential energy, sensible heat and latent heat (Eltahir, 1998):

$$mse = gz + C_p T + Lq \qquad , \qquad (1.1)$$

where $g$ is the acceleration of the gravity, $z$ is the elevation, $C_p$ is the specific heat capacity at constant pressure, $T$ is temperature, $L$ is latent heat of vaporization and $q$ is the water mixing ratio. Moist static energy is supplied by the total heat flux from the surface into the atmosphere ($F$). This energy reservoir is depleted by a combination of three main processes: (1) Entrainment at the top of the boundary layer ($EN$), (2) Radiative cooling flux ($R$), and (3) the negative heat fluxes associated with convective downdraft during rainfall events ($C$). If we consider large spatial scales, we can neglect horizontal heat fluxes and only consider vertical heat fluxes from the surface, then the moist energy budget is transformed to:

$$\frac{\partial mse}{\partial t} = F - EN - R - C \quad . \qquad (1.2)$$

The total heat flux from the surface into the atmosphere is the main source of energy into the atmospheric boundary layer. Wet soil conditions should favor a larger magnitude of moist static energy in the atmospheric boundary layer due to a decrease in sensible heat flux and the rate of entrainment. These factors tend to increase the magnitude of moist static energy per unit mass of boundary layer air and reduce the boundary layer depth.

Boundary layer moist static energy plays an important role in the dynamics of local convective storms. At local scales, Williams and Reno (1993) found that wet bulb potential temperature (a measure of boundary layer moist static energy) is correlated with convective available potential energy (CAPE). CAPE is an important variable that describes the atmospheric environment of local convective storms. When CAPE is large, the atmosphere will be more unstable. However, convection also depends on the convective inhibition (CIN) that is the amount of energy needed to elevate an air parcel up to the level of free convection. Large values of CIN imply large resistance to convective development. Therefore, favorable conditions for convection and precipitation are identified by large values of CAPE and small values of CIN. For example, reduced soil moisture in the surface with a drier and warmer boundary layer, reduces the CAPE with a systematic decreases of about 30% throughout the month (Collini et al., 2008).

Eltahir and Pal (1996) studied the relation between surface wet bulb temperature and subsequent rainfall in convective storms using observation in the Amazon. They found that the frequency and the magnitude of localize convective storms increases with surface bulb temperature which confirms that the boundary layer moist static energy plays an important role in the dynamics of the convective storms. Adams et al. (2009) found that the North American monsoon convective regime requires essentially only moisture advection interacting with the strong surface sensible heating over complex topography. Elimination of strong convective inhibition through intense surface sensible heating in the presence of sufficient water vapor leads to the positive CAPE-precipitation relationship on diurnal time scales. In fact, the results from Adam et al. (2009) contradict results from other continental and maritime regions, which show negative correlations.

In general, recycling refers to how much of the evapotranspiration (ET) in an area contributes to the precipitation in the same area. As the area is reduced to a point, the ET contribution tends to zero and all the moisture precipitated is transported in from outside the region. Eltahir and Bras (1996) reviews estimates of precipitation recycling and Eltahir and Bras (1994) estimates that 25- 35% of the rain that falls in the Amazon is contributed by evaporation within the basin. In the Mississippi Basin the recycling estimates range between 10-24%. Dominguez et al. (2008) shows that evapotranspiration is responsible for a positive feedback in the NAM onset. Recycling ratios during the NAM are consistently above 15% and can be as high as 25%. Furthermore, they found that long monsoons present a characteristic double peak in precipitation where intense precipitation during July is followed by a period of dry conditions, and then followed by subsequent peak in late August. The author also established a feedback mechanism for long monsoons where evapotranspiration is originated predominantly in tropical dry forests then transported north and east where it later falls as precipitation.

## 1.6. Objectives and Goals of this Thesis

Among the main objectives in this thesis include:

1. To use of remote sensing to quantify the seasonal and interannual vegetation dynamics in the NAM region and relate these to ground-based measurements of precipitation and soil moisture.
2. To identify possible relations between vegetation indices, precipitation and soil moisture as tool for prediction in the region. In addition, it is important to identify the ecosystems, which are more efficient in producing vegetation biomass with a smaller precipitation amount.
3. To evaluate the temporal and spatial persistence of land surface conditions in order to identify regions that are highly seasonally variable, as well as ecosystems that represent well the spatial mean of the domain.
4. To evaluate the changes in land surface conditions (e.g., surface fluxes, soil moisture and temperature) to infer the existence and sign of the vegetation-rainfall feedback.

Few studies have been conducted in the NAM region to understand the role of vegetation during the monsoon season. This work is important because relatively little knowledge exists on the interaction between the North American monsoon and land features such as vegetation dynamics. In addition, vegetation dynamics have received less attention among the factors that can influence the North American Monsoon.

# CHAPTER 2

# METHODS

In the following, we describe the study region in northwest Mexico, the continuous precipitation and soil moisture observations, and the remotely-sensed datasets processed from the MODIS sensor. We selected a three year period (2004 to 2006, with portions of 2007) to capture vegetation dynamics and change in land surface conditions during three separate monsoon seasons that exhibited different rainfall amounts and coincided with the operation of the regional network. We also describe a set of spatiotemporal analyses used to investigate the relationships between precipitation, soil moisture and vegetation dynamics, as well as, land surface conditions for different ecosystems in the mountainous region.

## 2.1. Study Region and Ecosystem Distributions

Our study region is a large domain that encompasses the Río San Miguel and Río Sonora basins in northwest Mexico in the state of Sonora (Fig. 2.1). The total area for both watersheds is ~15,842 $km^2$ (3798 $km^2$ for the Río San Miguel and 11,684 $km^2$ for the Río Sonora). Our analysis extends beyond the basin boundaries to cover an area of 53,269 $km^2$ including portions of the Río Yaqui and San Pedro River basins. The study region is characterized by complex terrain in the Sierra Madre Occidental with north-south trending mountain ranges. The two major ephemeral rivers are Río San Miguel and Río Sonora, which run from north to south. Basin areas were delineated from a 29-m digital elevation model (DEM) using two stream gauging sites as outlet points (Fig. 2.1).

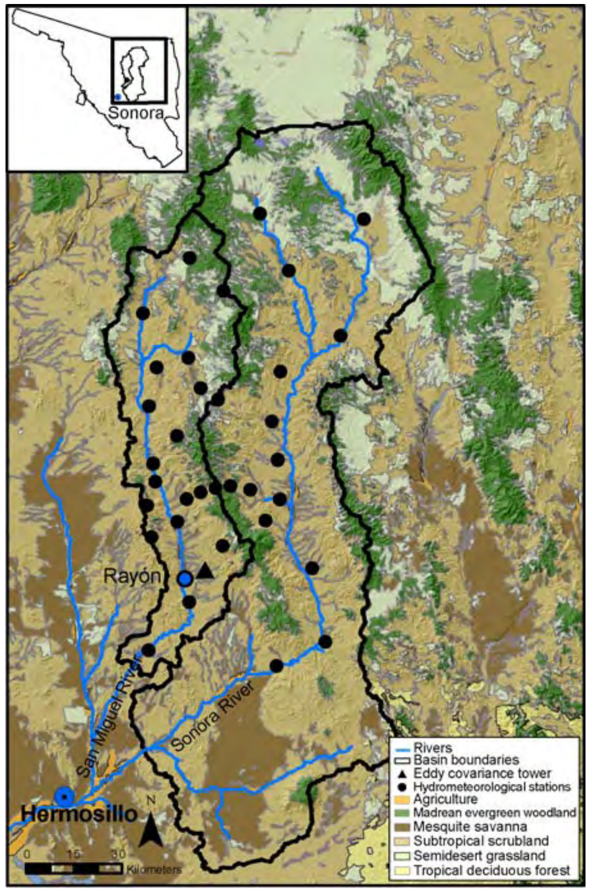


**Figure 2.1:** Location of the Río San Miguel and Río Sonora basins in Sonora, Mexico including hydrologic stations and an eddy covariance tower. Topographic features are shown by means of a hillshaded 29-m Digital Elevation Model. Land cover classes correspond to the National Institute of Statistics, Geography and Informatics of Mexico (INEGI, 2008).

For the Río San Miguel, the outlet is a gauging site managed by the Comisión Nacional del Agua (CNA) known as El Cajón (110.73° W; 29.47° N), while the Río Sonora was delineated with respect to the El Oregano CNA gauge (110.70° W; 29.22° N). Elevation above sea level in the region fluctuates between 130 and 3000 m, with a mean elevation of 983 m and a standard deviation of 391 m. The mean annual precipitation in the region varies approximately from 300 to 500 mm and it is controlled by latitudinal position and elevation (Chen et al., 2002; Gochis et al., 2007). A wide variety of ecosystems are found in the study region due to the strong variations in elevation and climate in short distances (e.g., Brown, 1994; Salinas-Zavala et al., 2002; Coblentz and Riitters, 2004). Ecosystems are arranged along elevation gradients in the following fashion (from low to high elevation): Sonoran desert scrub, Sinaloan thornscrub, Sonoran riparian deciduous woodland, Sonoran savanna grassland, Madrean evergreen woodland and Madrean montane conifer forest.

Brown (1994) presented the following ecosystem descriptions. Vegetation type in Sonora is strongly related to elevation. Lowlands are found in the coastal plains adjacent to the Gulf of California and are characterized by trees less than 3 meters in height and a small number of thorny tropical species (Figure 2.2). Foothills of Sonora are characterized by the location of tropical deciduous forest which contains a high diversity in tropical tree species (30 to 49 species per acre). Usually, tropical forests are followed by oak woodlands. In the region, they are found in two ways: (1) as a narrow band between tropical forest and pine forest (about 1000 m) and a savanna-like woodland that is common in the east slope of the Sierra Madre Occidental. Oak-dominated vegetation also occurs on smaller scales at lower elevations in narrow canyons and altered acid soils. Finally, pine-oak forest is the most extensive vegetation type in the high elevations of the northern Sierra Madre Occidental (about 1300 to 1800 m). At least two dozens of species of oaks and 13 pines are found in the region (Martin et al., 1998). In the following sections, we will describe in more details the characteristics of the principal ecosystems.

### 2.1.1 Sonoran Desert Scrub

The desert region spans from 23º to 35º N and includes two subdivisions: Arizona uplands and Plains of Sonora. The Sonoran Desert differs from other North American deserts due to its trees, large cacti and succulents. Arizona uplands are encountered on slopes, rocky surfaces and sloping plains, with an elevation range of 300 to 1000 m. The Plains of Sonora is characterized by open stands of low branching trees and shrubs, interspaced with short lived herbaceous plants and bare ground, with an increment in tropical species. This subdivision is primarily found in alluvial valleys and hills closer to the coastal plain.

### 2.1.2 Sinaloan Thornscrub

The Sinaloan thornscrub covers southern and southeastern Sonora south of 28° N from sea level to over 900 m. An abundance of shrubbery, short microphyllus trees and subtropical species is observed along with the absence of common Sonoran Desert species. The basic structure and composition is of drought-deciduous, thorny, pinnate-leaved, multi-trunked trees and shrubs, typically found on slopes and alluvial fans.

### 2.1.3 Sonoran Riparian Deciduous Woodland

In this ecosystem, we find associations of tropical and subtropical trees such as willows, cottonwood and mesquite, which are restricted to near stream areas below 1100 m. Mesquite woodlands attain their maximum development on alluvial material on old dissected floodplains. Riparian woodlands along streams are also interspersed with herbaceous and shrub species in understory and intercanopy patches.

### 2.1.4 Sonoran Savanna Grassland

These subtropical grasslands are encountered at elevations between 900 and 1000 m on flat plains and along large river valleys on deep, fine textured soils. This ecosystem is commonly found in central and eastern Sonora. Tree and scrub components vary in composition, with mesquite as the dominant tree and the presence of large cacti.

### 2.1.5 Madrean Evergreen Woodland

This ecosystem is found in the foothills and mountains of the Sierra Madre Occidental. A large variety of oak species are present, including Chihuahuan oak and Mexican blue oak. In northern Sonora, oak woodlands descend to about 1200 to 1350 m in proximity to savanna grasslands, while in central and southern Sonora, this ecosystem occurs as low as 880 to 950 m and borders Sinaloan thornscrub. Some cacti and leaf succulents of the savanna grassland also extend into this ecosystem.

### 2.1.6 Madrean Montane Conifer Forest

These forests are encountered in higher plateaus and mountains of Sonora with an elevation range from 2000 m to 3050 m, but more commonly from 2200-2500 m. The most common tree species include white Mexican pine and Chihuahuan pine. The lower limits of the conifer forest are in contact with Madrean evergreen woodland.

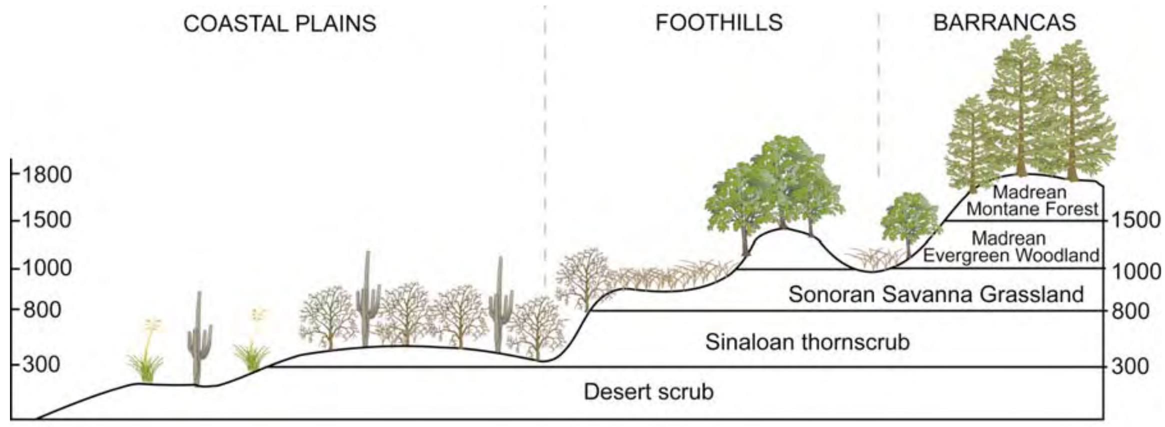


**Figure 2.2:** Regional cross-section with the distribution of the ecosystems. Elevation is expressed as meters above sea level.

### 2.2. Field and Remote Sensing Datasets

Ground-based precipitation and soil moisture observations were obtained from a network of fifteen instrumentation sites installed during 2004 as part of SMEX04 (Vivoni et al., 2007). Fig. 2.1 presents the locations of the continuous stations, with five sites in the Río Sonora and ten sites in the Río San Miguel. Table 2.1 presents the station locations, ecosystem classifications and elevations. Precipitation data (mm/hr) were acquired with a 6-inch funnel tipping bucket rain gauge (Texas Electronics, T525I), while volumetric soil moisture (%, in hourly intervals) was obtained at a 5-cm depth with a 50-MHz soil dielectric sensor (Stevens Water Monitoring, Hydra Probe). The Hydra Probe determines soil moisture by making high frequency measurements of the complex dielectric constant in a 22 $cm^3$ soil sampling volume. We used a factory calibration for sandy soils to transform the dielectric measurement to volumetric soil moisture (%) (Seyfried and Murdock, 2004).

| Station ID | Ecosystem | Easting [m] | Northing [m] | Altitude [m] |
|---|---|---|---|---|
| 130 | Sinaloan thornscrub | 531465 | 3323298 | 720 |
| 131 | Sinaloan thornscrub | 532166 | 3317608 | 719 |
| 132 | Sinaloan thornscrub | 546347 | 3314298 | 900 |
| 133 | Sinaloan thornscrub | 539130 | 3305014 | 638 |
| 134 | Madrean evergreen woodland | 551857 | 3343293 | 1180 |
| 135 | Sonoran riparian deciduous woodland | 546349 | 3346966 | 1040 |
| 136 | Sonoran desert scrub | 532579 | 3353405 | 1079 |
| 137 | Sonoran savanna grassland | 571287 | 3312065 | 660 |
| 138 | Sonoran savanna grassland | 570690 | 3324453 | 726 |
| 139 | Sonoran savanna grassland | 568744 | 3336421 | 760 |
| 140 | Sonoran savanna grassland | 571478 | 3352076 | 1013 |
| 143 | Sonoran riparian deciduous woodland | 542590 | 3356533 | 960 |
| 144 | Sonoran desert scrub | 530134 | 3341169 | 800 |
| 146 | Madrean evergreen woodland | 551091 | 3315638 | 1385 |
| 147 | Sinaloan thornscrub | 544811 | 3290182 | 620 |

**Table 2.1:** Regional hydrometeorological station locations, altitudes and ecosystem classifications. The coordinate system for the locations is UTM 12N, datum WGS84.

Table 2.2 presents the limited amounts of missing data during the study period due to equipment malfunction or data loss related to site inaccessibility during floods. We also use observations from a 9-m eddy covariance tower deployed in a subtropical scrubland near Rayón, Sonora at an elevation of ~630-m (Fig. 2.1). Measurements at the tower include precipitation, net radiation and albedo (CNR-1 net radiometer), sensible and latent heat flux (L17500 hygrometer, CSAT3 sonic anemometer), and soil moisture and soil temperature at 5-cm depth (Stevens Vitel sensor). Data from the 2007 summer season are used as these capture the monsoon transition. Half-hourly measurements were aggregated to the daily scale to facilitate comparisons between pre-monsoon (DOY 151-184) and monsoon (DOY 185-240) periods. More details on the sampling methods can be found in Watts et al. (2007) and Vivoni et al. (2009).

| Station ID | Start Date | End Date | Missing Data in 2004 | Missing Data in 2005 | Missing Data in 2006 |
|---|---|---|---|---|---|
| 130 | 06/14/2004 | 12/31/2006 | 09/12 - 10/16 | – | 07/08 - 08/08 |
| 131 | 06/14/2004 | 12/31/2006 | 09/12 - 10/16 | 07/30 - 08/15<br>12/16 - 12/31 | 01/01 - 01/08<br>03/16 - 03/27 |
| 132 | 06/14/2004 | 12/31/2006 | 09/12 - 10/16 | 03/18 - 03/29<br>07/30 - 08/15<br>12/29 - 12/31 | 01/01 - 01/08<br>03/16 - 03/27<br>07/27 - 09/03 |
| 133 | 06/14/2004 | 12/31/2006 | 09/12 - 10/16 | – | 07/28 - 08/10 |
| 134 | 06/13/2004 | 12/31/2007 | 09/11 - 10/17 | 03/19 - 03/30<br>06/06 - 06/12<br>10/21 - 10/22<br>12/29 - 12/31 | 01/01 - 01/07<br>03/15 - 03/26<br>07/26 - 08/24 |
| 135 | 06/22/2004 | 12/31/2006 | 09/11 - 10/16 | 01/10 - 01/20 | 07/26 - 08/08 |
| 136 | 05/07/2004 | 12/31/2006 | 09/11 - 10/26 | 01/10 - 01/20 | 07/26 - 08/08 |
| 137 | 05/26/2004 | 12/31/2006 | 09/11 - 10/17 | 03/19 - 03/20<br>05/03 - 10/17 | 07/10 - 08/18 |
| 138 | 05/22/2004 | 12/31/2006 | 08/04 - 08/09<br>09/11 - 10/17 | 03/19 - 03/20<br>10/21 - 11/17 | 07/26 - 08/08 |
| 139 | 05/22/2004 | 12/31/2006 | 09/11 - 10/26 | 01/10 - 01/20<br>10/21 - 11/17 | 07/26 - 08/08 |
| 140 | 05/22/2004 | 12/31/2006 | 09/11 - 10/26 | 01/10 - 01/20<br>03/19 - 03/20<br>10/21 - 11/17<br>11/17 - 12/31 | 01/01 - 03/15<br>07/26 - 08/28 |
| 143 | 05/13/2004 | 12/31/2006 | 09/11 - 10/26 | – | 07/26 - 08/08 |
| 144 | 05/22/2004 | 12/31/2006 | 09/12 - 10/16 | – | 07/06 - 08/08 |
| 146 | 05/14/2004 | 12/31/2006 | 09/12 - 09/22 | 07/30 - 08/15<br>12/29 - 12/31 | 01/01 - 01/08<br>03/16 - 03/27<br>07/07 - 09/03<br>10/08 - 10/24 |
| 147 | 07/17/2004 | 12/31/2006 | 07/17- 07/23 | 06/13 - 07/27<br>12/30 - 12/31 | – |

**Table 2.2:** Missing observations periods at regional stations during 2004 to 2006. Note that the lower data gaps in the monsoon season of 2005.

MODIS datasets were acquired from the EOS Data Gateway. For this work, we used sixteen day composites of the 250-m NDVI (MOD13Q1) product from MODIS-Terra. MODIS-Terra overpasses the region around 11:00 A.M. local time (18:00 UTC).

In the other hand, MODIS-Aqua overpasses the same area at 12:00 P.M. local time (19:00 UTC). For each overpass, the NDVI is calculated from reflectance as:

$$NDVI = \frac{\rho_{NIR} - \rho_{red}}{\rho_{NIR} + \rho_{red}} \quad , \qquad (2.1)$$

where $\rho_{NIR}$ and $\rho_{red}$ are the surface bidirectional reflectance factors for MODIS bands 2 (841-876 nm) and 1 (620-670 nm), respectively. The advantage of MODIS vegetation indices is that they rely on the level 2 daily surface reflectance product (MOD09), which it is corrected for external factors such as molecular scattering (Raleigh scattering), ozone absorption and aerosols (Vermote et al., 2002). A more complex effect on the degradation of NDVI is caused by topographic variation, including effects of shadow, adjacent hill illumination, sky occlusion and slope orientation. However, MODIS vegetation indices eliminate or significantly reduce topographic effects by three different approaches: 1) by the band ratio concept of NDVI that reduces many forms of noise (including illumination differences, cloud shadows, atmospheric attenuation and certain topographic variations). Matsushita et al. (2007) found that MODIS NDVI is not affected by topographic variations considering its ratio format, while EVI is very sensitive to topographic conditions because it is not expressed as a function of ratio vegetation index and is using the soil adjustment factor "L". 2) The standardization of sun-surface-sensor geometries with bidirectional reflectance distribution function (BRDF) models. The BRDF is a mathematical description of the optical behavior of a surface with respect to angles of illumination and observation. Description of BDRFs for actual surfaces permits assessment of the degrees to which they approach the ideals of specular (anisotropic reflection) and diffuse (isotropic reflection) surfaces (Campbell, 2007). 3) The moderate spatial resolution of MODIS reduces the effects of topography because within one pixel are of 62,500 m2, a larger samples of slopes and illumination conditions are aggregated (Burgess et al., 1995). The main purpose of compositing over the 16-day periods is to select the best observation, on a per pixel basis, from all the retained data. The MODIS vegetation index compositing algorithm utilizes three main components as shown in figure 2.3: (1) Maximum Value Composite (MVC), (2) Constrained-View angle Maximum Value Composite (CV-MVC) and (3) BRDF-C: Bidirectional reflectance distribution function composite. The technique employed depends on the number and quality of observations. The MVC selects the pixel observation with the highest NDVI to represent the compositing period (Holben, 1986). A disadvantage of the MVC approach is that it selects pixels with NDVI values greater than the nadir value. The CV-MVC and BRDF methods compositing techniques are designed to constrain the angular variations of the MVC selection method. These latter methods compare the two highest NDVI values and select the observation closest to nadir view to represent the composite. This helps to reduce the spatial and temporal discontinuities in the composite. Finally, the BRDF method uses all bidirectional reflectance observations with acceptable quality to interpolate to their nadir-equivalent band reflectance values. With these reflectance values, then NDVI or EVI is calculated. The BRDF model used in MODIS is the Walthall semi-empirical BRDF model.

$$\rho_{\lambda}\left(\theta_{v},\phi_{s},\phi_{v}\right)=a_{v}\theta_{v}^{2}+b_{\lambda}\theta_{v}\cos(\phi_{v}-\phi_{s})+c_{\lambda}\,, \qquad (2.2)$$

where $\rho_{\lambda}$ is the atmospherically corrected reflectance in band $\lambda$, $\theta_v$ is the satellite view zenith angle, $\phi_v$ is the satellite view azimuth angle, $\phi_s$ is the solar azimuth angle, and $c_\lambda$, $b_\lambda$, $c_\lambda$ are model parameters coefficients.

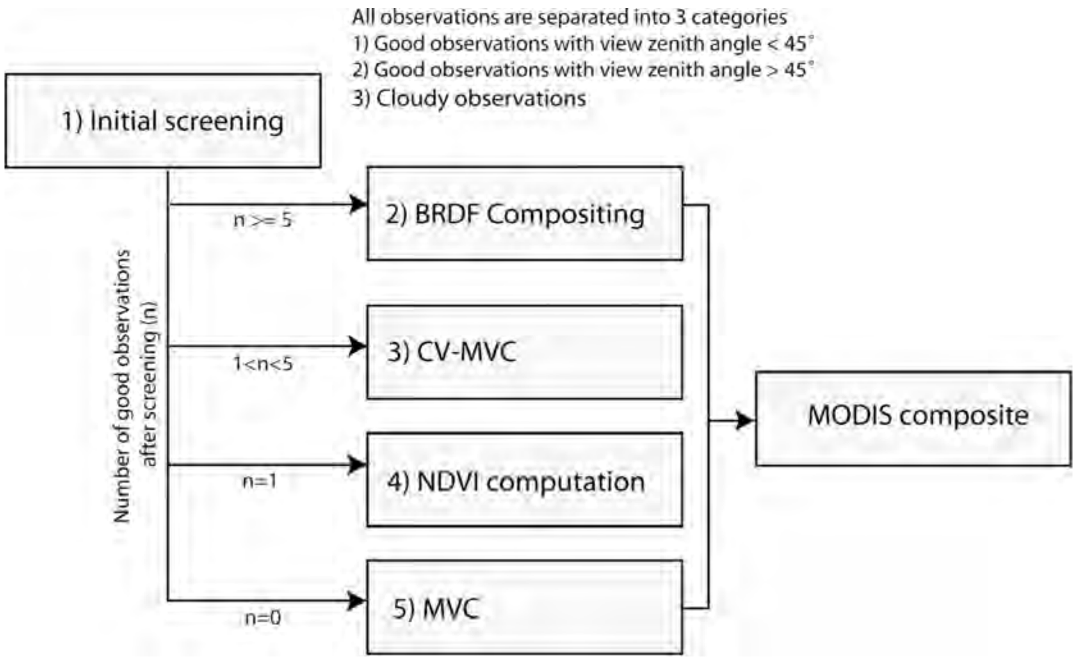


**Figure 2.3:** Diagram of MODIS compositing method. Taken from Huete et al. (2002).

The model is fitted to the observations by a least squares procedure on per-pixel basis to estimate nadir view equivalent reflectances ($c_\lambda$). At least five good quality observations ($\theta_v \leq 45°$) after initial screening process are required for model inversion. (Huete et al., 2002).

MODIS land surface temperature is derived from thermal infrared data using bands 20 (3.660-3.840 μm), 22 (3.929-3.989 μm), 23 (4.020-4.080 μm), 26 (1360-1390 nm), 29 (8.400-8.700 μm), 31 (10.780-11.280 μm), 32 (11.770-12.270 μm) and 33 (13.185-13.485 μm). The LST/Emissivity algorithms use MODIS data as input, including geolocation, radiance, cloud masking, atmospheric temperature, water vapor, snow, and land cover (Wang, 1999). For this study, we used eight-day composites with a spatial resolution of 1 kilometer (MOD11A2) for the same time period as NDVI datasets.

The MODIS Bidirectional Reflectance Distribution Function (BRDF)/Albedo products describe how land surfaces appear under perfect scattering conditions without the influence of view angle. The BRDF/Albedo algorithm relies on multi-date, atmospherically corrected, cloud-cleared data and a semiempirical kernel-driven bidirectional reflectance model to determine a global set of parameters describing the BRDF of the land surface (Schaaf et al., 2002).

For this study, we used a sixteen-day white sky albedo composite, which is defined as albedo in the absence of a direct component when the diffuse component is isotropic, with a spatial resolution of 1 km (MOD43B3). Each of the MODIS images was mosaicked, clipped and reprojected using the HDF-EOS to GIS Format Conversion Tool (HEG tools version 2.8). This tool allows reprojection from the native MODIS Integerized Sinusoidal (ISIN) grid to the Universal Transverse Mercator (UTM) Zone 12N projection used in our analysis. Figure 2.4 shows an example of a MODIS scene that was reprojected using HEG tools. In addition to the reprojection, this tool allows to cut the entire MODIS scene into a smaller domain. This software also allows converting the native MODIS HDF data format (Hierarchical Data Format) into a GEOTIFF image, a format that is widely used in most image processing software.

To minimize the effect of human-impacted regions, we created a mask excluding zones with minimal NDVI changes over time (e.g., mines, urban areas and water bodies), thus focusing our analysis to areas of natural vegetation. All datasets encompass 83 images from January 2004 to June 2007, with a domain size of ~198 by 265 kilometers overlying the study region (Fig. 2.5).

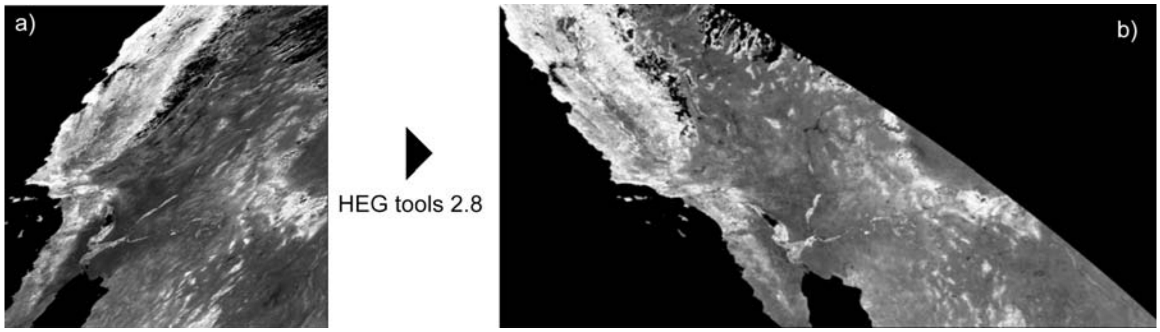


**Figure 2.4:** Reprojection of MODIS image using HEG tools conversion software: (a) Original MODIS sinusoidal projection. (b) UTM projection using WGS-84 datum.

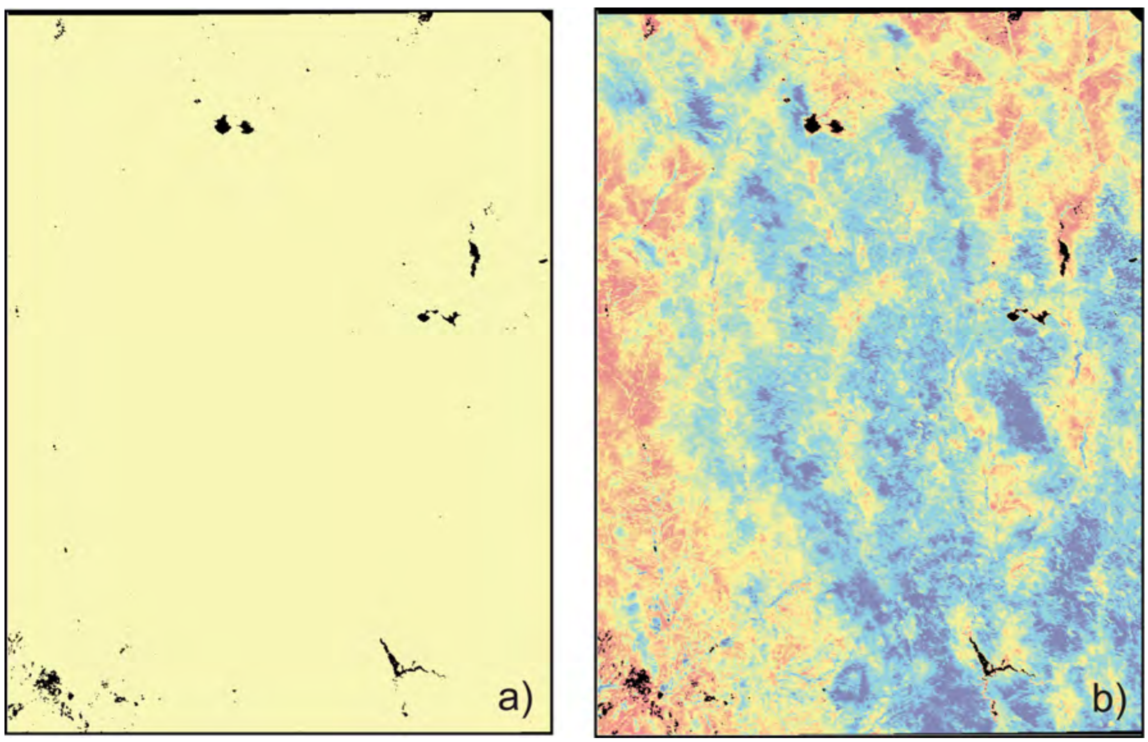


**Figure 2.5:** (a) Masked image excluding water bodies, urban areas and mines. These black-colored regions have NO DATA value. (b) Final product by multiplying the masked image with the clipped and projected EVI or NDVI image.

### 2.3. Metrics of Spatial and Temporal Vegetation Dynamics

In the following, we describe analyses conducted to quantify the seasonal and interannual vegetation dynamics. Remotely-sensed NDVI data were characterized through: (1) analysis of temporal variations at each continuous station; (2) derivation of vegetation metrics; (3) analysis of time stability of the spatiotemporal fields; and (4) identification of elevation controls on the vegetation statistics along two transects.

### 2.3.1 Temporal Variation of Vegetation Metrics

Temporal evolution of vegetation dynamics is important because it is an indicator of climate parameters such as temperature, solar radiation and precipitation. For example, knowing when the vegetation greening begins is an indication of the onset of NAM. Interannual variability of climatic variables can also be identified with long-term observations. In this particularly case, the use of remote sensing techniques allow land surface observations at regional scale at analysis of spatial, temporal and spectral patterns. In addition, these patterns can be measured, described and correlated with other information (like ground information or another source of ancillary data). Therefore, this technique has more advantages than conventional methods like field surveying.

Temporal variations at specific sites were obtained by determining the mean and standard deviation of NDVI for each MODIS composite image from the 3 × 3 pixel (750 x 750 m) domain around a station. The arithmetic mean provides the averaged conditions at a site and accounts for uncertainties in the georeferencing of the station and MODIS image. The standard deviation captures the spatial variability around an instrument site. Figure 2.6 shows how the mean value of 250 m resolution MODIS products was obtained.

Temporal variations of NDVI were then used to estimate a set of vegetation metrics using the methods of Lloyd (1990) and Reed et al. (1994). In order to extract the vegetation metrics, we applied a smoothing method to the raw NDVI time series using a

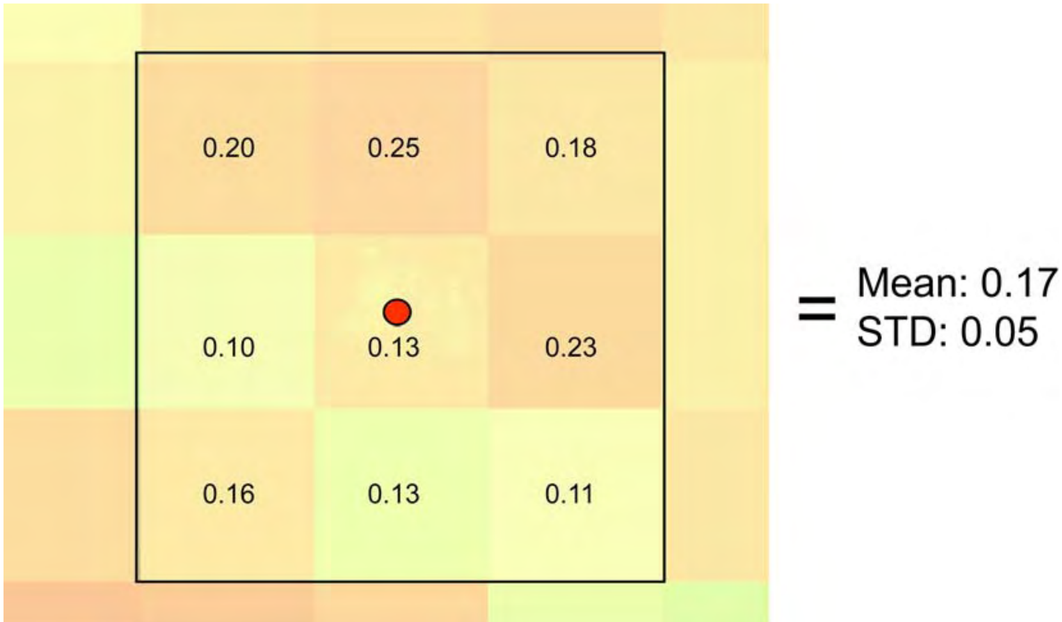


**Figure 2.6:** Extraction of pixel values. The red dot represents the station location and the pixel beneath the location is considered the central pixel. Then for the estimation of the mean value, we took into consideration the eight values around the central pixel.

LOESS regression. The name LOESS is derived from the term "locally weighted scatter plot smooth" because the method uses a locally weighed linear regression to smooth the data. The method is considered local because, like the moving average method, each smoothed value is determined by neighboring data points defined within the span. The process is weighted because a regression weight function is defined for the data points contained within the span. Finally, this smoothing process uses a quadratic polynomial model. (Mathworks, 2004). The main goal of the smoothing process is to reduce the effects of outliers and preserve the essential features of the NDVI variations.

With the smoothed NDVI time series, we generated two different lagged time series which we have applied to different moving averages following Reed et al. (1994): (1) A backward moving average (BMA) was applied to the first lagged time series in reverse chronological order and it was overlapped to the original smoothed NDVI time series; and (2) a forward moving average (FMA) was applied to the second lagged time series in forward direction and overlapped again to the original smoothed NDVI time series. The two lagged time series were subsequently lagged by 3 time periods, each 16 days in length, to detect the crossing properties of the NDVI time series (e.g., timing of vegetation greening and senescence). The intersection between the forward lagged time series curve and the original smoothed NDVI time series curve is considered the point where the photosynthetic activity of vegetation starts. Conversely, the intersection between the backward lagged time series curve and the original smoothed NDVI curve is considered the point where the senescence of vegetation starts.

We tested the sensitivity of the method to different lag lengths to best match the annual NDVI cycle in the study region. Based on the above, we found the beginning of the vegetation greening as the crossing between the smoothed NDVI and the FMA. Similarly, the end of the greening season was found as the crossing between the smoothed series and the BMA. Fig. 2.7a is an example of the original NDVI data, the smoothed series and moving averages. Once the start and end of the greening are found, several vegetation metrics can be estimated (Reed et al., 1994): (1) Duration of Greenness (days), defined as the period between the onset and end of the greenness; (2) Growing season integrated NDVI (iNDVI, dimensionless), measured as the area under the smoothed NDVI series; (3) Seasonal range of NDVI (ΔNDVI, dimensionless) simply determined as the difference between the maximum seasonal ($NDVI_{max}$) and minimum seasonal ($NDVI_{min}$) NDVI values; and the (4) Rate of Greenup and the (5) Rate of Senescence, defined as the change in NDVI per time ($day^{-1}$) for the beginning and end of the greening season, respectively.

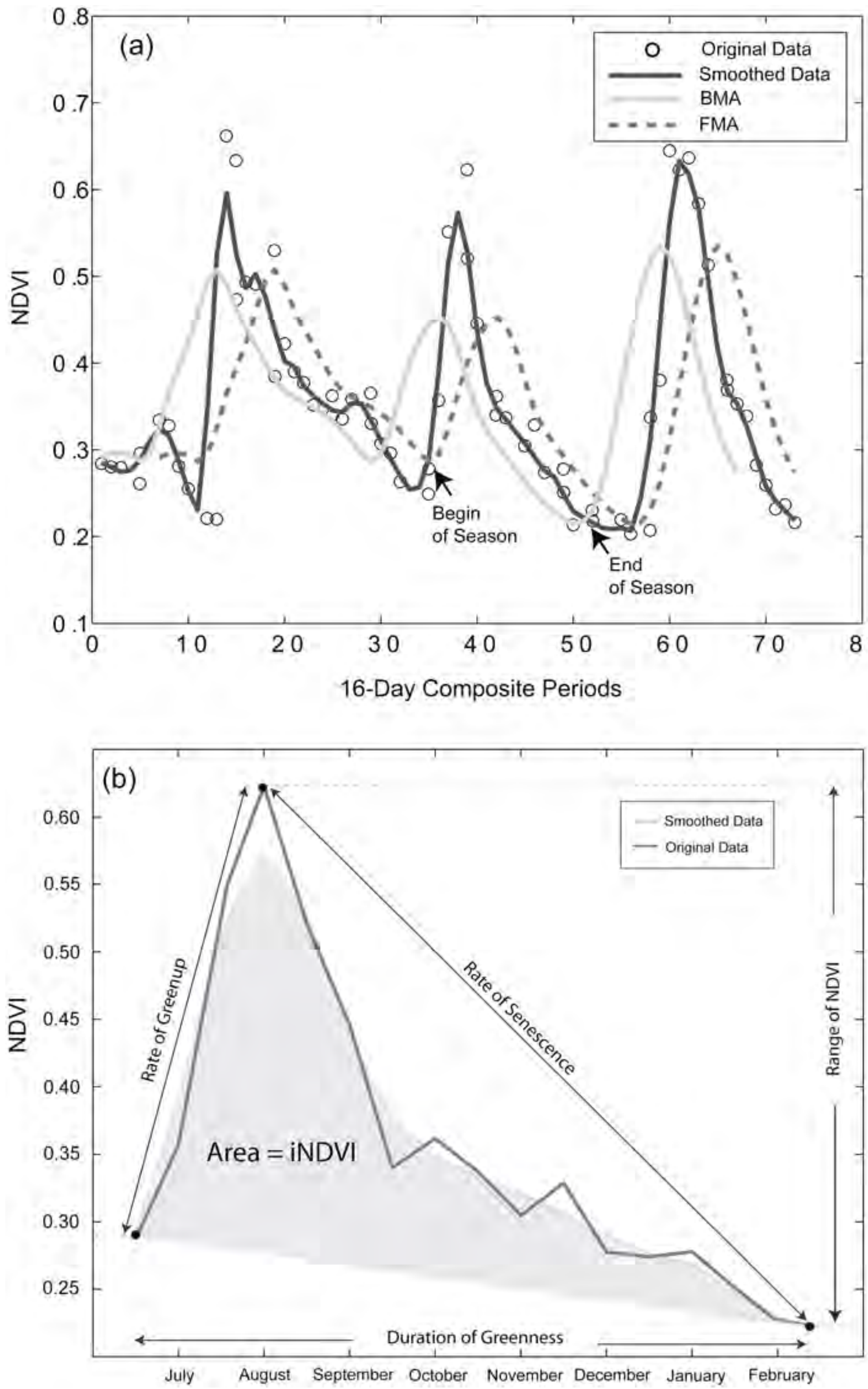


**Figure 2.7:** Determination of vegetation metrics. (a) Identification of the beginning and end of the vegetation greening using the smoothed NDVI series and the backward (BMA) and forward (FMA) moving averages for station 130 (Sinaloan thornscrub). The original NDVI data is represented by the open circles. (b) Example of the vegetation metrics (iNDVI, ΔNDVI, Rate of Greenup, Rate of Senescence and Duration of Greenness) for station 130 during the 2004 season.

One simple way to estimate the Rate of Greenup is to calculate the slope between the point of vegetation green up and the maximum seasonal NDVI ($NDVI_{max}$). In the case of Fig. 2.7b presents an example of the determination of the vegetation metrics for a Sinaloan thornscrub site during the 2004 growing season.

Sensitivity to the selection of the time periods was performed in order to assess the impact on the vegetation metrics. We changed the number of lagged days in the forward moving average (FMA) and the backward moving average (BMA) in order to establish the starting point of photosynthetic activity and the ending point of plant activity (senescence). We compared the results using 2, 3, 4, 5, 6 and 7 lagged time periods and how they affect the calculation of iNDVI or iEVI (the area under the curve). The sensitivity analysis was done for the year 2005 at station 132. Figure 2.8 shows the results for FMA in order to get the beginning of greening season. As observed, the beginning of growing season starts between time period 33 or 34. The difference is not large among the number of lagged periods. Figure 2.9 shows the result for modifying the number of lagged days in the BMA. Vegetation senescence lies between time period 49 and 51, hence difference in ending season point is not large. Table 2.3 shows the comparison among different lagged time periods and their influence in the estimation of iEVI (area under the time series curve of EVI). The iEVI is slightly affected by the change in starting and ending point selection. The largest difference is around 6% in iEVI values with 4 and 5 lagged time periods. Conversely, low difference of 3% occurs between areas values with 2 and 6 lagged time periods.

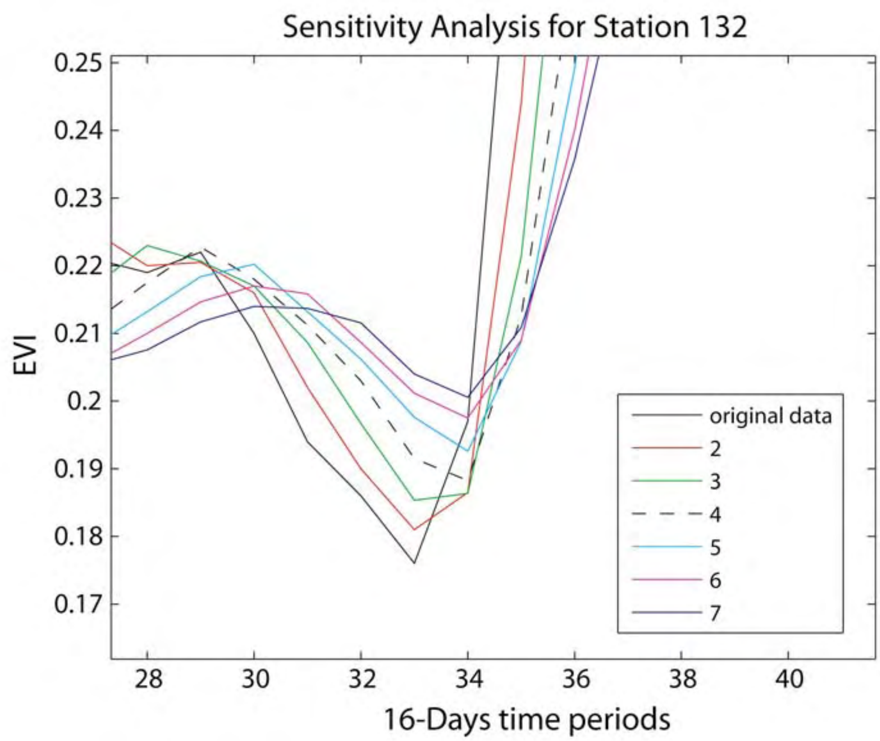


**Figure 2.8:** Sensitivity analysis for Forward Moving Average (FMA).

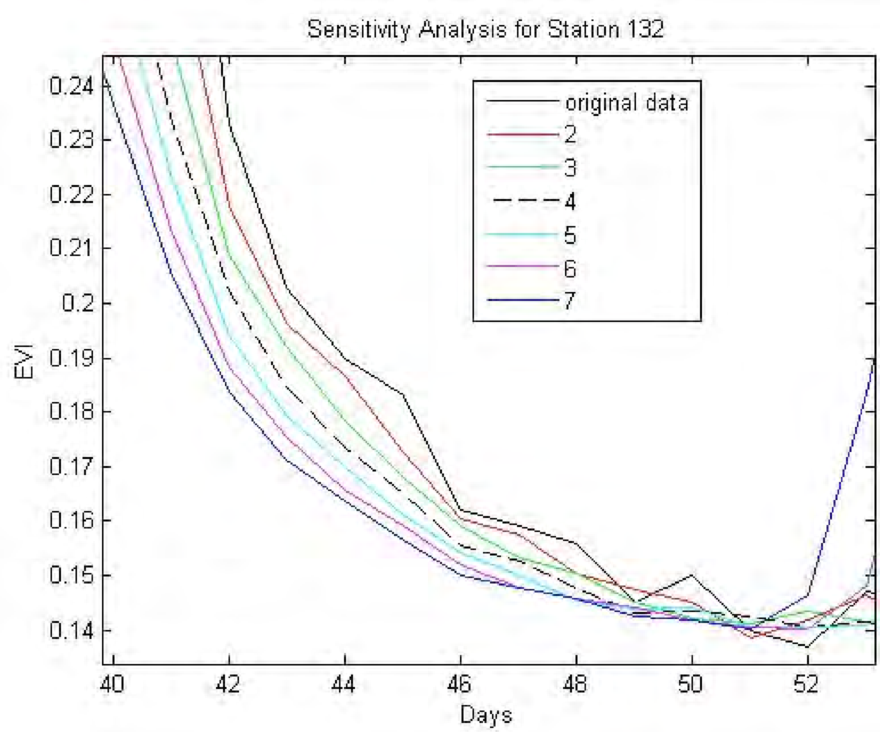


**Figure 2.9:** Sensitivity analysis for Backward Moving Average (BMA).

| Lagged 16-Days time periods | Starting 16-Day Period | Ending 16-Day period | Area |
|---|---|---|---|
| 2 | 33.30 | 48.70 | 4.21 |
| 3 | 33.45 | 49.00 | 4.21 |
| 4 | 33.65 | 50.70 | 4.47 |
| 5 | 33.85 | 50.90 | 4.47 |
| 6 | 34.00 | 50.94 | 4.32 |
| 7 | 34.05 | 50.98 | 4.32 |

**Table 2.3:** Comparison among different lagged time periods and their influence in the estimation of time integrated EVI (iEVI).

### 2.3.2 Spatial and Temporal Analysis: The Time Stability Concept

To analyze the temporal and spatial variability of NDVI, albedo and LST, we applied the concepts of spatial and temporal persistence (e.g., Vachaud et al., 1985; Mohanty and Skaggs, 2001; Grant et al., 2004; Jacobs et al., 2004; Vivoni et al., 2008a). We quantified the spatial and temporal root mean square error (RMSE) of the mean relative difference ($\delta$) for each MODIS pixel during the study period. This analysis is important because it allows us to perform statistics of the spatial and temporal distributions of the land surface processes, as well as, identifying locations with temporal and spatial persistence. Basically, the persistence is captured by the mean relative difference that evaluates the difference between a specific location and the temporal or spatial mean. With the spatial stability, we can estimate locations that capture the basin-average conditions in NDVI, LST and albedo. Conversely, the temporal persistence identifies locations that show high or low seasonality.

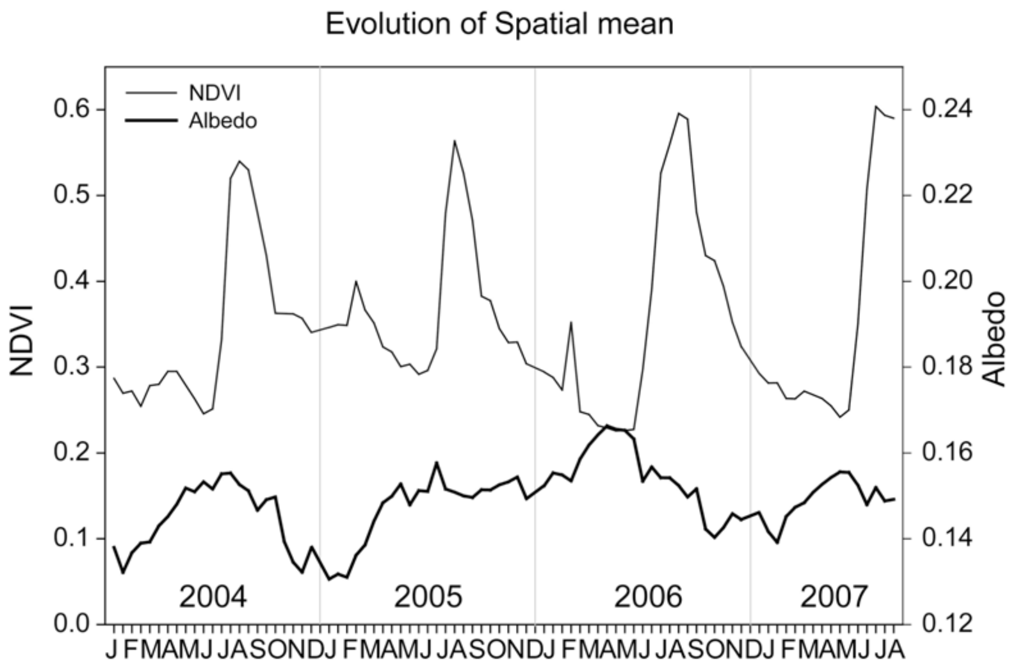


**Figure 2.10:** Temporal evolution of the mean spatial NDVI and surface albedo during the study period. Every point in the plot represents a mean spatial value used to estimate the spatial RMSE of the difference.

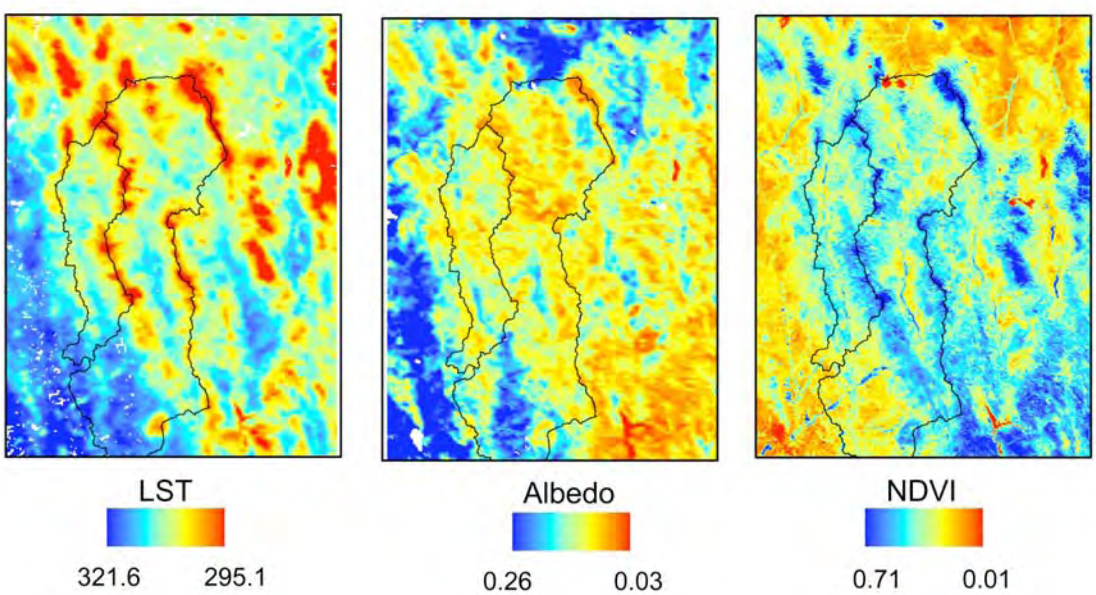


**Figure 2.11:** Temporal mean NDVI, surface albedo and land surface temperature used to estimate the temporal RMSE of the difference. Every images is the result of averaging 83 MODIS composite images.

The main difference between the spatial and temporal RMSE $\delta$ is the mean value used to compute the relative difference. In the case of the spatial RMSE $\delta_s$, we used the spatial mean of each image and calculated the difference between every pixel and the spatial mean. Figure 2.10 shows the mean spatial values for NVDI and albedo used to estimate the spatial RMSE $\delta$. Every point in the plot represents one mean value in the regional domain and was subtracted from all pixels per MODIS scene. Conversely, for the temporal RMSE $\delta_t$, we used the temporal mean for each pixel over all images and then calculated the difference between each pixel and its temporal mean. Figure 2.11 shows the temporal mean for NDVI, LST and albedo used to estimate the temporal RMSE $\delta$ for the study period.

To compute the spatial RMSE $\delta_s$, we first calculated the spatial mean of the parameter of interest in the region for each MODIS composite as:

$$\overline{X}_{sp,t} = \frac{1}{n}\sum_{s=1}^{n} X_{s,t} \quad , \qquad (2.3)$$

where $\overline{X}_{sp,t}$ is the spatial mean for the MODIS parameter (NDVI, albedo or LST) for each date ($t$) over all pixels ($s$) and $n$ is the total number of pixels (i.e., 992,450 pixels, 863 × 1150). Using this method, we obtained 83 spatially-averaged MODIS values. Conversely, the temporal mean of MODIS parameter in each pixel is computed as:

$$\overline{X}_{tm,s} = \frac{1}{N_t}\sum_{t=1}^{N_t} X_{s,t} \quad , \qquad (2.4)$$

where $\overline{X}_{tm,s}$ is the temporal mean of the MODIS parameter and $N_t$ is the total number of processed MODIS images (83 in total). In (2) and (3), $X_{s,t}$ is the MODIS parameter value for pixel ($s$) at time ($t$). The mean relative difference captures the difference between a pixel and the mean (spatial or temporal) for all MODIS parameter images. In the spatial case, the mean relative difference $\overline{\delta_s}$ is computed as:

$$\overline{\delta_s} = \frac{1}{N_t} \sum_{t=1}^{N_t} \frac{X_{s,t} - \overline{X}_{sp,t}}{\overline{X}_{sp,t}}. \qquad (2.5)$$

In addition, the temporal mean relative difference $\overline{\delta_t}$ is computed as:

$$\overline{\delta_t} = \frac{1}{N_t} \sum_{t=1}^{N_t} \frac{X_{s,t} - \overline{X}_{tm,t}}{\overline{X}_{tm,t}}. \qquad (2.6)$$

The variances of the relative difference ( $\sigma(\delta_t)^2$ for temporal and $\sigma(\delta_s)^2$ for spatial cases) are:

$$\sigma(\delta_s)^2 = \frac{1}{N_t - 1} \sum_{t=1}^{N_t} \left( \frac{X_{s,t} - \overline{X}_{sp,t}}{\overline{X}_{sp,t}} - \overline{\delta_s} \right)^2, \quad \text{and} \qquad (2.7)$$

$$\sigma(\delta_t)^2 = \frac{1}{N_t - 1} \sum_{t=1}^{N_t} \left( \frac{X_{s,t} - \overline{X}_{tm,t}}{\overline{X}_{tm,t}} - \overline{\delta_t} \right)^2 . \qquad (2.8)$$

Finally, the root mean square error of the mean relative difference (RMSE $\delta$) is a single metric which captures both the bias and the spread around the bias (Jacobs et al., 2004). It is computed here for the temporal and spatial cases as:

$$RMSE\ \delta_s = \left( \overline{\delta_s}^2 + \sigma(\delta_s)^2 \right)^2, \text{ and} \qquad (2.9)$$

$$RMSE\ \delta_t = \left( \overline{\delta_t}^2 + \sigma(\delta_t)^2 \right)^2 . \qquad (2.10)$$

Low $RMSE\ \delta_s$ sites are stable pixels that closely track the spatially-averaged conditions in the region over time. This metric can identify ecosystems that capture the temporal surface conditions for a region. We would expect ecosystems that dominate the regional greening, such as the Sinaloan thornscrub, would exhibit low $RMSE\ \delta_s$. On the other hand, low $RMSE\,\delta_t$ indicates pixels with values close to the temporal mean at the site. This metric indicates ecosystems that have more limited seasonal changes.

We expect that ecosystems, such as the Madrean evergreen woodland with lower seasonality, would exhibit low $RMSE\,\delta_t$. RMSE $\delta$ values range from 0 to 1, with values near zero having high persistence. Thus, spatial RMSE $\delta$ near zero represents pixels that closely track the spatial mean of the region (and vice-versa). In the case of temporal RMSE $\delta$, values near zero are sites that exhibit low temporal variations (and vice-versa).

### 2.3.3 Elevation control on Vegetation Statistics

Few studies in the region have addressed the potential interactions between the monsoon system and land surface properties as topography. Vivoni et al. (2007) found that topography exerted a strong control on the spatial and temporal variability in soil moisture, with distinct landscape regions experimenting different hydrologic regimes. Gochis et al. (2004) showed important terrain control on the distribution of precipitation using rain gauge observations along topographic transects in the Sierra Madre Occidental. The authors found that at high elevations, summer precipitation was more frequent but with lower intensity, meanwhile, lower elevations showed less frequency but higher intensity. This suggests that topography controls the diurnal cycle of convection. Because NDVI is strongly correlated with precipitation, we can infer surface hydrological conditions by observing the temporal evolution of vegetation indices along a topographic transect.

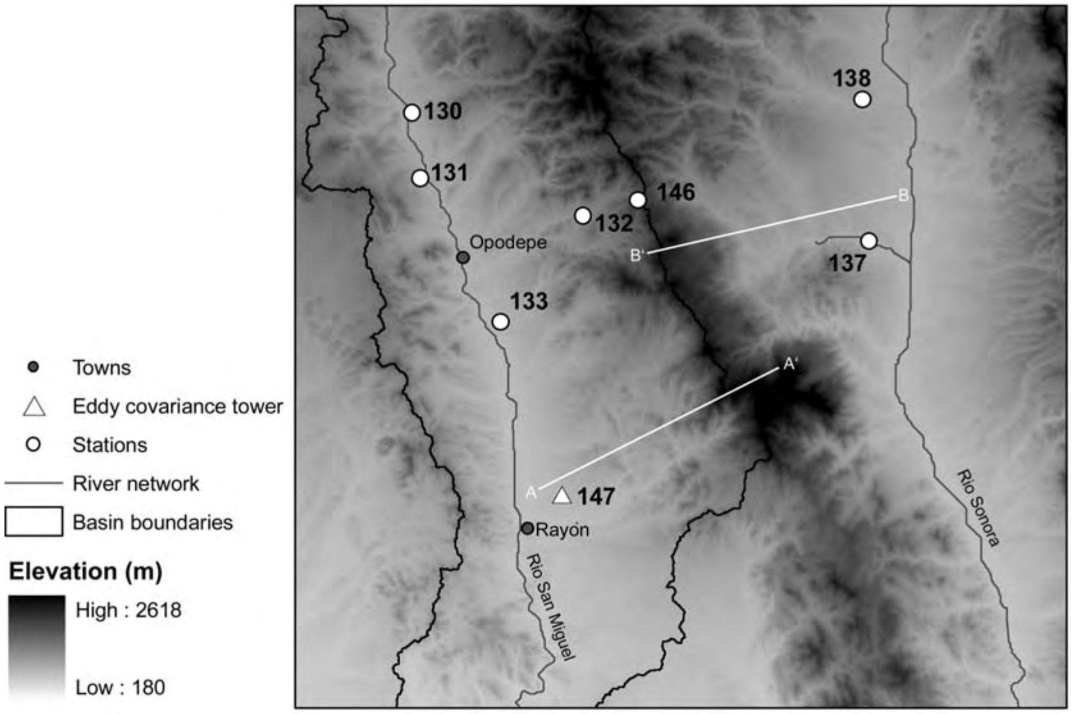


**Figure 2.12:** Location of the two topographic transects for the Rio Sonora and Rio San Miguel Basin.

In order to assess the role of topography and elevation in controlling NDVI, we established two topographic transects along different locations in the Río San Miguel and Río Sonora (Fig. 2.12). Each transect is ~23 km in length, and samples elevations from nearly 600 m to 1600 m. In addition, both transects traverse different ecosystems along the elevation gradient. We expect this analysis reveals that topography affects the variability in albedo, land surface temperature and NDVI. Therefore, changes in these land surface characteristics can lead to distribution of different precipitation regimes and soil moisture persistence in the San Miguel and Sonora river basins.

## 2.4. Relationships between NDVI, Precipitation and Soil Moisture

Several approaches were pursued to explore the relations between NDVI, precipitation and soil moisture. A linear regression between vegetation greening and precipitation was carried out using iNDVI and accumulated seasonal rainfall. Due to sampling gaps, this analysis was focused on the 2005 monsoon. In order to assess the efficiency of the ecosystems to express plant growth and biomass production with precipitation, we used the Greenness-precipitation ratio (GPR), which is analogous to the Rain Use efficiency (RUE). The original RUE equation was proposed by Le Horeau (1994):

$$RUE = \frac{ANPP}{R} , \qquad (2.11)$$

where ANNP is the aboveground net primary productivity and R is the seasonal precipitation. Paruelo et al. (1997) found that ANPP is closely related to time integrated NDVI. This author explored the relationship for the central grassland region in United States and it is expressed as an exponential function:

$$ANPP = 3803 * iNDVI^{1.9028}. \qquad (2.12)$$

The functional relation from Paruelo et al. (1997) suggests that iNDVI is related to rainfall use efficiency. Based on this we developed a relation between GPR and iNDVI from our datasets:

$$GPR = \left[\frac{iNDVI}{R_{season}}\right] \times 100 , \qquad (2.13)$$

where iNDVI is the time integrated NDVI during the growing season and $R_{season}$ is the accumulated rainfall during the growing season. The goal of multiplying the ratio by 100 is to produce GPR values greater than 1 and make them easier to compare.

In addition, we calculated correlation coefficients between NDVI and accumulated rainfall and time-averaged soil moisture in the current and previous months using a combination of different monthly lags for 2005.

### 2.5. Cluster Analysis and Unsupervised Classification

Time stability analysis can be used to identify patterns in land surface conditions and group these into zones with similar behavior. We performed an unsupervised classification using the spatial and temporal RMSE $\delta$ of the three land surface variables (NDVI, albedo, LST) as input fields. Before the unsupervised classification, we performed a cluster analysis, which returns naturally occurring groupings in the data based on multivariate statistics. The cluster analysis results were subsequently used to perform a maximum likelihood classification (MLM) that calculates the probability of the cell belonging to that class given its attribute values (e.g., Campbell, 2007). Through this analysis, we identify classes representing different land surface dynamics. In this case, the classes are grouped by high or low seasonality in NDVI, albedo and LST, as well as, high or low spatial representation of the region. As a result, the classes are distinct functional groups capturing different land surface responses. Functional groups occupying large spatial domains and exhibiting significant seasonal changes in LST, albedo and NDVI are expected to have higher potential contributions to a vegetation-rainfall feedback mechanism. The optimum number of functional groups will be determined based on the highest accuracy obtained by comparing the resulting functional group map with a reference map. In this thesis, we will use a land cover map generated by Yilmaz et al. (2008) of the region as reference image. The classification accuracy will be determined using an error matrix and by comparing around 10,000 randomized points between the new functional group map and the reference image.

# CHAPTER 3

# RESULTS AND DISCUSSION

In the following, we present the set of spatial and temporal analyses used to quantify the vegetation dynamics in the study region and relate these to metrics that quantify the precipitation and soil moisture observations from the regional network. Our focus is primarily on the regional characterization of vegetation dynamics afforded by the remote sensing data, with more detailed study at representative stations of particular ecosystems arranged along topographic transects. In addition, we present the results of the cluster analysis by using RMSE $\delta$ as input in order to demonstrate that the eddy-covariance tower in the region in located in a functional group that closely tracks the regional spatial mean with high seasonality in NDVI, albedo and LST. Finally, we show time series at eddy-covariance tower demonstrating the highly coupled relation between soil moisture conditions, vegetation green up and land surface processes. These changes in surface conditions during monsoon transition show evidence for a potential land surface-atmosphere feedback mechanism that can promote convective rainfall.

## 3.1. Spatial and Temporal Vegetation Dynamics in Regional Ecosystems

Vegetation conditions in the regional ecosystems are assessed to determine the seasonal and interannual variations induced by differing amounts of NAM precipitation and soil moisture. Fig. 3.1 presents the seasonal change in NDVI ($D_{NDVI} = (NDVI_{max} – NDVI_{min})/NDVI_{min}$, expressed as a percentage) for the three monsoons (2004 to 2006).

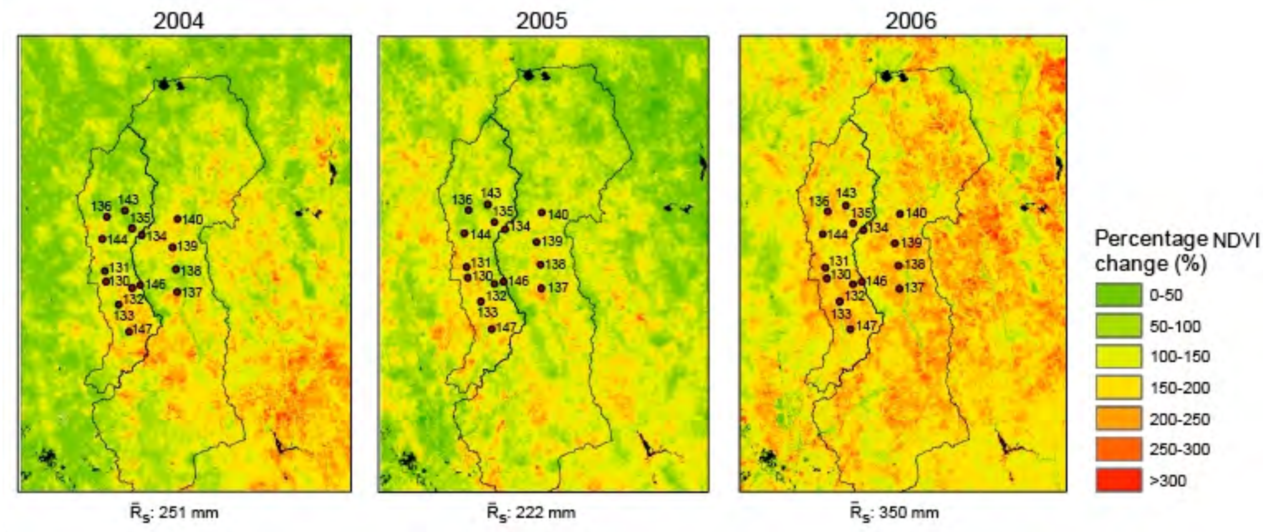


**Figure 3.1:** Comparison of seasonal NDVI change (%). The percentage of NDVI change is calculated using the lowest and highest NDVI for a particular summer season (2004 to 2006). $\overline{R_s}$ is the total summer rainfall (July to September) averaged over all stations.

There is an evident variation in the spatial pattern of $D_{NDVI}$ related to ecosystem distributions, terrain characteristics and rainfall amounts. The spatial distribution of $D_{NDVI}$ and its range varies for each year, following the total rainfall averaged over all regional stations ($\overline{R_s}$) from July to September. In the year 2004 ($\overline{R_s}$ = 251 mm), the largest degree of vegetation greening occurs in the southeastern part of the domain, outside the regional network. Nevertheless, the region between stations 146 and 147 in the Río San Miguel exhibited high greening, in agreement with the elevated soil moisture observed from aircraft-based retrievals (Vivoni et al., 2008a). In contrast, the year 2005 was the driest in the record ($\overline{R_s}$ = 222 mm) and as a result experienced the smallest $D_{NDVI}$, with a range from 50 to 150%. Note, however, that isolated patches experience high degrees of greening, suggesting localized storms during this monsoon. Conversely, the year 2006 exhibited the largest change in NDVI due to the elevated precipitation

($\overline{R_s}$ = 350 mm). The spatial distribution of $D_{NDVI}$ is also more uniform in the region, ranging from 200 to 300%, indicating that the overall ecosystem response was vigorous and spatially extensive. Interestingly, small changes in seasonal NDVI are always observed in forested riparian corridors (Sonoran riparian deciduous woodland) and high altitude mountains (Madrean montane conifer forests) as these remain green throughout the year. Overall, the spatial NDVI fields indicate seasonal and interannual changes linked to rainfall, ecosystem pattern and topography.

Fig. 3.2 presents the temporal variations of NDVI, precipitation and soil moisture over the period January 2004 to June 2007 (at 16-day intervals) at four regional stations: (a) station 146 (Madrean evergreen woodland), (b) station 132 (Sinaloan thornscrub), (c) station 139 (Sonoran savanna grassland), and (d) station 144 (Sonora desert scrub). The four stations were selected to represent different ecosystems as well as the changes in hydrologic conditions along elevation gradients (see Table 2.1 for station descriptions). For each site, hourly precipitation and soil moisture observations were accumulated or averaged, respectively, over the 16-day intervals to match the MODIS compositing period. Remotely-sensed NDVI time series are depicted as the station mean (symbols) and ±1 standard deviation (error bars) over a 3 × 3 window (250-m pixels) around the station. Any data gaps in the ground or remotely-sensed observations resulted in the removal of the composites and are shown as broken lines (see Table 2.2 for data gaps).

The temporal variations in vegetation greenness, as captured by the station NDVI, are dramatic in each ecosystem and closely related to the hydrologic conditions at each site. The Madrean evergreen woodland (Fig. 3.2a) exhibited the highest precipitation of the ecosystems in the region, with an exceptional rainfall in 2006 (up to 300 mm in July).

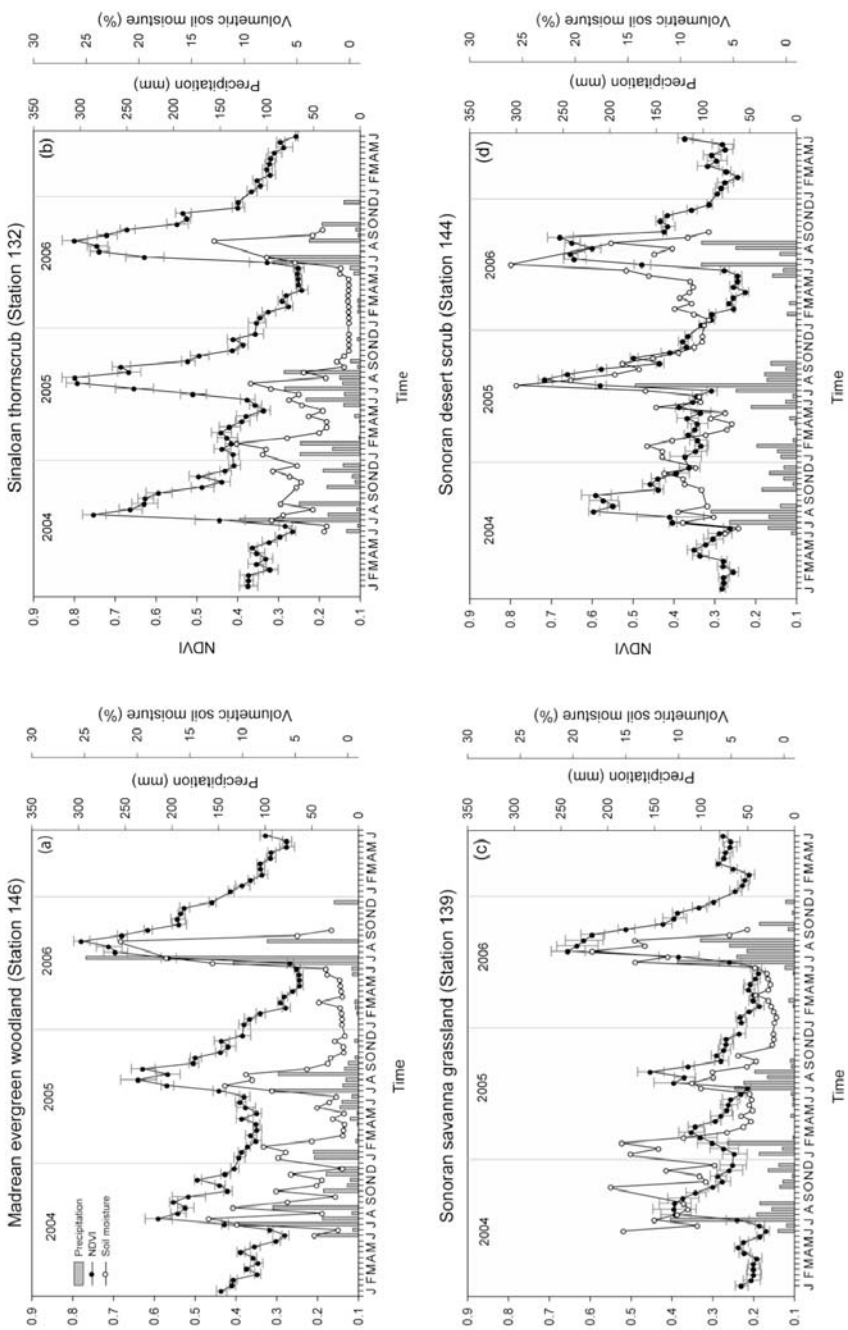


**Figure 3.2:** Temporal variation of NDVI among different regional ecosystems: (a) Madrean evergreen woodland (station 146), (b) Sinaloan thornscrub (station 132), (c) Sonoran savanna grassland (station 139), and (d) Sonoran desert scrub (station 144). NDVI symbols correspond to the average value calculated in the 3 × 3 pixel region around each station for each composite. The vertical bars depict the ±1 standard deviation of the 3 × 3 pixel region. Precipitation (mm) is accumulated during 16-day intervals and shown as gray bars, while the averaged surface volumetric soil moisture (%) during the 16-day periods is shown as open circles.

In response, soil moisture was elevated in the 2006 summer, reaching >20% in the surface soil layer. This plant-available water led to a vigorous summer greening reflected in a peak NDVI of nearly 0.8. Similar summer processes are observed in station 146 for 2004 and 2005, albeit with lower precipitation, soil moisture and peak NDVI. In contrast, the Sinaloan thornscrub (Fig. 3.2b) showed less rainfall than higher sites, but more consistent greening in the different summers. The NDVI range (~0.25 to ~0.8) varied slightly across the different monsoons, suggesting this ecosystem is fairly resilient to hydrologic changes. Sonoran savanna grasslands (Fig. 3.2c) have a more muted vegetation response (smaller NDVI range) as compared to the other ecosystems. Nevertheless, the station NDVI exhibits high temporal variations in response to wet and dry periods, including a spring peak in 2005 after a wet winter. Finally, the Sonoran desert scrub (Fig. 3.2d) also experiences summer greening, with relatively small year-to-year variations in response to variations in rainfall and soil moisture. Interestingly, summer 2005 had more favorable hydrologic conditions than 2006 at this station and thus the highest peak NDVI in the three-year record.

It is important to mention that NDVI values during the dry season never reached values near zero which it is commonly identified as scarce vegetation. We have observed that the dynamic range of vegetation in the region varies between 0.2 and 0.8. However, Huete et al., 2002; found that the dynamic range of MODIS NDVI varies from about 0.05 to nearly 0.9 using as reference different ecosystems in the world. The highest value of NDVI were found in the broadleaf Harvard forest (Massachusetts), while the minimum NDVI value was measured in the hyper-arid sites located in the Atacama and Uyuni deserts (LAI = 0). These latter sites were considered as zero baselines for vegetation indices values. However, it is important to mention that the NDVI values for MODIS NDVI baseline (bare soil) never fell below 0. Furthermore, Huete et al. (2002) compared MODIS NDVI values with NDVI values from AVHRR. He found that MODIS NDVI is signicantly higher than those from AVHRR resulting in greater seasonal dynamic range for all sites he analyzed. Furthermore, Buheaosier et al. (2003) compared MODIS NDVI with other sensors on broad leaf forest. They found that NDVI derived from MODIS is the largest followed by those of ETM (landsat), ASTER and AVHRR (see table 3.1). In addition, MODIS showed the largest minimum, mean and maximum numerical values while ASTER showed the opposite characteristics. The reason why the values of NDVI are higher in MODIS can be caused by the influence of water vapor content in the atmosphere, which strongly affects the reflectance values in the NIR band of other sensors, especially AVHRR; causing NDVI values to decrease. The narrower MODIS-NIR infrared band (see table 3.1) avoids the water absorption regions of the spectrum and it was nearly unaffected by variations in water vapor content in the atmosphere. Furthermore, the higher sensitivity of MODIS-NDVI may also be attributed to increased chlorophyll sensitivity in the MODIS red band (Gitelson & Kauffman, 1998) and the compositing method.

Fig. 3.2 also allows inspection of vegetation response in the three winter seasons, receiving smaller and more variable rainfall amounts (e.g., Sheppard et al., 2002; Nagler et al., 2007). While this is not the primary focus of this study, it is important to highlight these variations. A relatively wet winter in 2005 impacted vegetation dynamics in two ways:

| Sensor | Band Width (μm) | |
|---|---|---|
| | Red | NIR |
| ASTER | 0.63-0.69 | 0.76-0.86 |
| ETM+ | 0.63-0.69 | 0.75-0.90 |
| MODIS | 0.62-0.67 | 0.84-0.88 |
| AVHRR | 0.58-0.68 | 0.72-1.00 |

**Table 3.1:** Comparison of the red and infrared bands for several remote sensing sensors. Taken from Buheaosier et al. (2003).

(1) Maintaining green conditions for a longer period of time, or (2) leading to spring season plant growth. In contrast, a relatively dry winter in 2006 caused a significant decrease in NDVI in spring and early summer for all ecosystems. The linkages between winter and summer precipitation, soil moisture and vegetation greening is of considerable importance and has not been addressed in the region.

### 3.2. Quantifying Ecosystem Dynamics Through Vegetation Metrics

Vegetation metrics can aid in the quantification of ecosystem responses to the precipitation and soil moisture during the North American monsoon. Table 3.2 presents the phenological metrics obtained for each regional station during the monsoon seasons in 2004 to 2006. Overall, the various metrics, in particular the iNDVI and ΔNDVI, confirm that summer 2006 had the most dramatic vegetation greening in most of the regional stations. In contrast, stations during summer 2004 exhibited the shortest Duration of Greenness and Days to $NDVI_{max}$ as well as the smallest iNDVI and ΔNDVI.

| Station ID | Year | iNDVI | $NDVI_{max}$ | $NDVI_{min}$ | $\Delta NDVI$ | Duration of Greenness | Days to $NDVI_{max}$ |
|---|---|---|---|---|---|---|---|
| | | [ ] | [ ] | [ ] | [ ] | [days] | [days] |
| 130 | 2004 | 5.72 | 0.66 | 0.22 | 0.44 | 208 | 32 |
| | 2005 | 5.70 | 0.62 | 0.21 | 0.41 | 256 | 48 |
| | 2006 | 6.36 | 0.64 | 0.21 | 0.43 | 256 | 64 |
| 131 | 2004 | 5.18 | 0.61 | 0.23 | 0.38 | 176 | 32 |
| | 2005 | 6.47 | 0.70 | 0.23 | 0.47 | 272 | 64 |
| | 2006 | 6.27 | 0.68 | 0.22 | 0.46 | 240 | 64 |
| 132 | 2004 | 5.86 | 0.75 | 0.28 | 0.47 | 176 | 32 |
| | 2005 | 8.56 | 0.80 | 0.27 | 0.53 | 288 | 64 |
| | 2006 | 8.68 | 0.80 | 0.25 | 0.55 | 272 | 80 |
| 133 | 2004 | 3.71 | 0.52 | 0.21 | 0.31 | 144 | 32 |
| | 2005 | 6.10 | 0.70 | 0.22 | 0.48 | 272 | 32 |
| | 2006 | 6.74 | 0.62 | 0.20 | 0.42 | 288 | 96 |
| 134 | 2004 | 4.91 | 0.49 | 0.27 | 0.22 | 192 | 64 |
| | 2005 | 6.07 | 0.53 | 0.25 | 0.28 | 272 | 48 |
| | 2006 | 6.18 | 0.58 | 0.24 | 0.34 | 256 | 80 |
| 135 | 2004 | 4.53 | 0.58 | 0.30 | 0.28 | 224 | 32 |
| | 2005 | 6.18 | 0.73 | 0.23 | 0.50 | 240 | 48 |
| | 2006 | 6.46 | 0.71 | 0.23 | 0.48 | 240 | 80 |
| 136 | 2004 | 7.57 | 0.60 | 0.24 | 0.36 | 272 | 64 |
| | 2005 | 7.19 | 0.73 | 0.23 | 0.50 | 304 | 80 |
| | 2006 | 6.53 | 0.71 | 0.21 | 0.50 | 272 | 64 |
| 137 | 2004 | 2.74 | 0.52 | 0.19 | 0.33 | 128 | 48 |
| | 2005 | 4.93 | 0.56 | 0.21 | 0.35 | 256 | 48 |
| | 2006 | 6.10 | 0.63 | 0.19 | 0.44 | 240 | 48 |
| 138 | 2004 | 2.91 | 0.42 | 0.23 | 0.19 | 144 | 32 |
| | 2005 | 4.93 | 0.58 | 0.21 | 0.37 | 240 | 32 |
| | 2006 | 6.21 | 0.67 | 0.19 | 0.48 | 224 | 48 |
| 139 | 2004 | 2.93 | 0.39 | 0.19 | 0.20 | 144 | 48 |
| | 2005 | 4.02 | 0.45 | 0.19 | 0.26 | 224 | 48 |
| | 2006 | 5.91 | 0.65 | 0.19 | 0.46 | 224 | 48 |
| 140 | 2004 | 4.78 | 0.60 | 0.23 | 0.37 | 176 | 32 |
| | 2005 | 5.49 | 0.56 | 0.23 | 0.33 | 256 | 48 |
| | 2006 | 7.08 | 0.69 | 0.21 | 0.48 | 272 | 64 |
| 143 | 2004 | 3.61 | 0.58 | 0.28 | 0.30 | 144 | 32 |
| | 2005 | 5.28 | 0.58 | 0.24 | 0.34 | 224 | 80 |
| | 2006 | 6.31 | 0.69 | 0.20 | 0.49 | 304 | 96 |
| 144 | 2004 | 5.85 | 0.60 | 0.26 | 0.34 | 208 | 48 |
| | 2005 | 6.79 | 0.72 | 0.23 | 0.49 | 256 | 48 |
| | 2006 | 6.87 | 0.68 | 0.24 | 0.44 | 240 | 96 |
| 146 | 2004 | 6.78 | 0.59 | 0.32 | 0.27 | 240 | 32 |
| | 2005 | 7.48 | 0.64 | 0.28 | 0.36 | 272 | 48 |
| | 2006 | 8.69 | 0.78 | 0.36 | 0.42 | 272 | 80 |
| 147 | 2004 | 5.48 | 0.54 | 0.19 | 0.35 | 240 | 32 |
| | 2005 | 6.29 | 0.66 | 0.20 | 0.46 | 336 | 112 |
| | 2006 | 7.02 | 0.66 | 0.19 | 0.47 | 288 | 96 |

**Table 3.2:** Comparison of vegetation metrics for the regional stations during the three monsoons.

The metrics also reveal differences and similarities in vegetation productivity among the regional stations. For example, although stations 130, 131, 132, 133 and 147 are located in the same ecosystem (Sinaloan thornscrub), we can see differences in productivity and the vegetation metrics. Station 132 obtained the highest vegetation metrics among the stations located in Sinaloan thornscrub. This can be attributed to its location in the foothills of Sierra Los Locos (elevation 900 m) and the influence of higher precipitation and soil moisture conditions. The other stations fluctuate in elevation between 620-730 m and have lower precipitation resulting in lower soil moisture. In addition, these stations are located in the floodplain of the Rio San Miguel and have experienced larger modifications in land cover. It is common to observe native vegetation replaced by agriculture, resulting in an important decrease in vegetation metrics.

Another example of differences in the same ecosystem can be seen in stations 134 and 146, both located in Madrean evergreen woodland. Station 134 (elevation 1134 m) showed lower vegetation metrics as compared to station 146 (elevation 1385 m). Differences in vegetation metrics can be attributed to anthropogenic modifications. At station 134, the oak forest stand has been impacted by introduced pasture for cattle. Conversely, station 146 is not very accessible, although livestock activity has been seen near the station. We also expect more rainfall because of the higher elevation.

Finally, riparian zones have been seriously impacted by human activities. While we expect to see high vegetation productivity in these areas, their metrics values are as low as grasslands. Among the factors that can influence the reduction in riparian zones are deforestation, replacement of woodland by pastures, and decreases of water table height impacting riparian vegetation access to groundwater. Long-term observations from remote sensing would be needed to more carefully evaluate land use changes with time and the impact of anthropogenic activities.

As observed in Fig. 3.2, the ecosystem composition at each site has a strong control on the vegetation metrics for the different years. Stations with common plant communities share similar response to summer rainfall. For example, lower productivity stations are all in Sonoran savanna grasslands (stations 137, 138, 139) with low iNDVI, ΔNDVI and Duration of Greenness. Similarities are also observed in vegetation metrics for stations in the Sonoran riparian deciduous woodland (stations 135, 143). For the wet 2006 summer, however, precipitation amount and soil water availability lead to certain degrees of homogenization in the vegetation response across different ecosystems. For instance, Madrean evergreen woodlands (station 146) and Sinaloan thornscrub (station 132) share similar responses to the 2006 NAM precipitation (e.g., iNDVI = 8.69 and 8.68 for 2006, respectively), despite having different plants and ecophysiological processes.

To explore this further, Table 3.3 presents temporal coefficients of variation (CVs) for each vegetation metric computed for the average conditions in each ecosystem across all years. As a result, the CV primarily captures the interannual variations in vegetation metrics in a particular ecosystem. Ecosystems with high CVs imply large interannual changes in the 2004 to 2006 summer monsoons. Note that Sonoran savanna grassland and Sonoran riparian deciduous woodlands exhibit higher CVs for iNDVI, ΔNDVI and Duration of Greenness, indicating strong variations between years. Small CV in iNDVI and high CV in ΔNDVI is observed in the Sonoran desert scrub, suggesting this ecosystem varies primarily in the NDVI range from year-to-year.

| Ecosystem | N | Coefficient of Variation (CV) | | | | | |
|---|---|---|---|---|---|---|---|
| | | iNDVI | $NDVI_{max}$ | $NDVI_{min}$ | ΔNDVI | Duration of Greenness | Days to $NDVI_{max}$ |
| Madrean evergreen woodland | 2 | 0.19 | 0.17 | 0.15 | 0.22 | 0.13 | 0.33 |
| Sinaloan thornscrub | 5 | 0.20 | 0.12 | 0.12 | 0.14 | 0.21 | 0.47 |
| Sonoran savanna grassland | 4 | 0.30 | 0.17 | 0.09 | 0.28 | 0.24 | 0.20 |
| Sonoran desert scrub | 2 | 0.09 | 0.35 | 0.35 | 0.30 | 0.41 | 0.46 |
| Sonoran riparian deciduous forest | 2 | 0.21 | 0.26 | 0.30 | 0.31 | 0.41 | 0.50 |

**Table 3.3:** Coefficient of variation (CV) of vegetation metrics for different ecosystems during the period 2004-2006. CV is calculated as the temporal standard deviation divided by the temporal mean averaged over all stations in each ecosystem (*N* sites in each ecosystem).

The Madrean evergreen woodland and Sinaloan thornscrub have intermediate CVs for the vegetation metrics that appear to offset each other. For example, in the Madrean evergreen woodland, CV in iNDVI is lower than the Sinaloan thornscrub, while CV in ΔNDVI is higher. This suggests that different ecosystems in the region respond in variable ways to interannual hydrologic changes. Evergreen woodlands appear to vary their maximum greening (ΔNDVI) in response to increased rainfall amounts, while deciduous trees and shrubs vary the total productivity (iNDVI) during the growing season. These two plant greenup strategies may explain how these ecosystems exist at different elevation in the region. Finally, the vegetation metric with the highest year-to-year variation is Days to $NDVI_{max}$, indicating that the rate of ecosystem greening is highly influenced by rainfall amounts during the monsoon onset.

### 3.3. Relations Between Vegetation and Hydrologic Indices

To further explore the relation between ecosystem dynamics and the precipitation and soil moisture conditions, we compared iNDVI, the greenness-precipitation ratio (GPR = [iNDVI/$R_s$]*100) and the total precipitation ($R_s$) at each station for the 2005 monsoon (Table 3.4). This particular summer was selected due to its limited amounts of missing data in the regional stations. Fig. 3.3 presents a linear relation between iNDVI and precipitation ($R_s$) at the 12 stations with complete data. The linear regression between iNDVI and $R_s$ results in ($r^2 = 0.64$) with the regression line passing through the origin:

$$\text{iNDVI} = 0.021 R_s. \qquad (3.1)$$

Conversely when the regression line was not forced to pass through the origin, the equation slightly changes in the following way:

$$\text{iNDVI} = 0.025 R_s - 1.036. \qquad (3.2)$$

We noticed that the change in slope is hardly observable, hence; we can use either formulas. However, we consider that is more correct to use equation 3.1 because we expect to see no increment in biomass production (iNDVI) with zero units of rainfall. Furthermore, in the case of equation 3.2, with a seasonal accumulated rainfall of 54.4 mm we have an iNDVI value of zero. We do not have enough information to assume that this value of precipitation is a threshold in vegetation productivity in the region.

Clearly, as rainfall amounts increase across the regional stations, ecosystem productivity during the summer monsoon also increases. While ecophysiological differences are present in the regional ecosystems, seasonal rainfall is good predictor of biomass production. Station 132 (Sinaloan thornscrub) is an outlier in the general trend, exhibiting a higher than expected iNDVI for the given precipitation, possibly due to rainfall underestimation in the MODIS pixel around the site. Results are consistent with studies in other regions where higher iNDVI and biomass production are observed with increasing rainfall (e.g., Li et al., 2004; Prasad et al., 2005). Further testing of the proposed relation during other summers and for a larger number of stations may provide an indication of its robustness.

The GPR is a measure of the efficiency of an ecosystem to convert available water into biomass. As shown in Table 3.4, the range in GPR among the regional stations is from 1.86 (station 144, Sonoran desert scrub) to 2.87 (station 133, Sinaloan thornscrub). The spatial variability in GPR indicates that ecosystems in the southern region of the Río San Miguel were able to more efficiently use precipitation for biomass production. Interestingly, each of these ecosystems corresponds to the Sinaloan thornscrub (stations 130, 131, 132, 133, 147), suggesting that this plant community is well-tuned to utilizing summer rainfall to produce vegetation greening. The response in the Sinaloan thornscrub is consistent with seasonal changes in NDVI for 2005 (Fig. 3.1b) and a high temporal RMSE $\delta_t$ (Fig. 3.6b). Other regional ecosystems, such as Sonoran savanna grassland (stations 137, 138, 139) and Sonoran riparian deciduous woodland (stations 135, 143), show smaller GPR, suggesting lower rainfall use efficiency in grasslands and riparian trees. GPR estimates in the regional ecosystems for different monsoons would indicate if a convergence to common rainfall use efficiency occurs during dry periods, as noted by Huxman et al. (2004). It is important to remark that the efficiency in water use in all ecosystems is accentuated when the vegetation have developed fully foliage. In semiarid ecosystems evapotranspiration is strongly coupled to precipitation and soil moisture (Kurk and Small, 2004). Before the arrival of the NAM, evaporation and transpiration are close to zero, then, during the onset of the monsoon the evapotranspiration process is dominated by evaporation, while the vegetation starts to respond to higher soil moisture soil moisture content.

| Station ID | iNDVI [ ] | Precipitation [mm] | GPR [$cm^{-1}$] |
|---|---|---|---|
| 130 | 5.70 | 251.21 | 2.27 |
| 131 | 6.47 | 300.74 | 2.15 |
| 132 | 8.55 | 300.74 | 2.85 |
| 133 | 6.10 | 212.34 | 2.87 |
| 135 | 6.18 | 322.58 | 1.92 |
| 136 | 7.19 | 335.50 | 2.14 |
| 138 | 4.93 | 245.36 | 2.01 |
| 139 | 4.02 | 200.40 | 2.01 |
| 143 | 5.28 | 262.89 | 2.01 |
| 144 | 6.79 | 364.49 | 1.86 |
| 146 | 8.98 | 432.05 | 2.08 |
| 147 | 6.30 | 284.50 | 2.21 |

**Table 3.4:** Comparison of iNDVI, precipitation (mm) and GPR for the regional stations during 2005. Note that data gaps existed for stations 134 and 140.

Conversely, during the growing season when vegetation biomass is high, evaporation only dominates immediately after a rain event. Transpiration is relatively more important during inter-storm periods since soil rapidly dries, thus increasing resistance to water flux from deeper layers (Whyters, 1999).

For example, transpiration accounts for 40-70% of ET in ecosystems with high response to NAM (Dugas et al., 1996, Kemp et al., 1997) during the growing season. However transpiration is highly variable and depends on plant communities and functional responses. The relationships between vegetation dynamics as quantified by NDVI and the hydrologic conditions in each regional station are explored using lagged Pearson correlation coefficients.

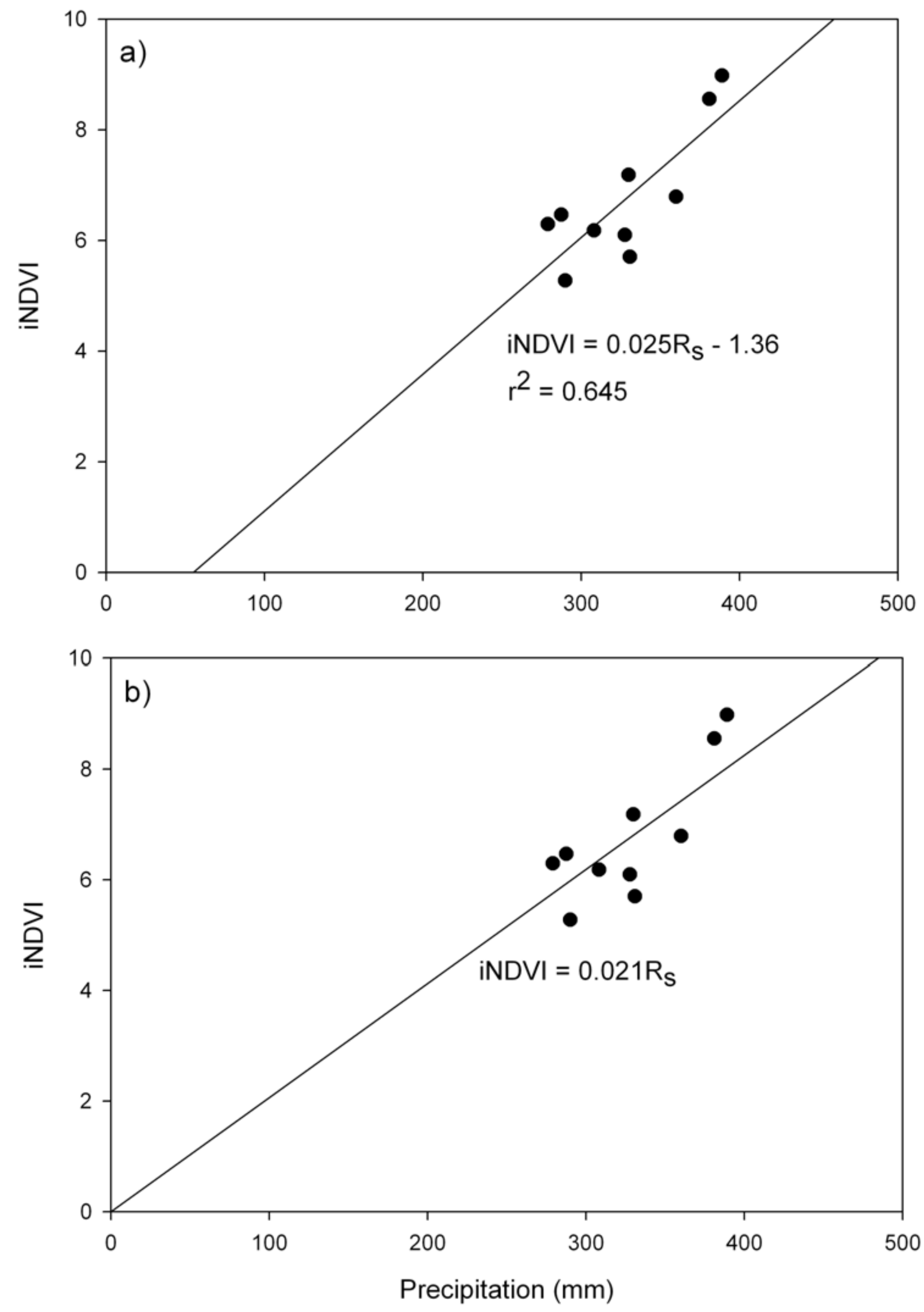


**Figure 3.3:** Relation between the seasonal precipitation accumulation and iNDVI for the monsoon season in 2005 where each point is a station located in a different ecosystem. a) Linear regression without adjustment to the origin. b) Linear regression with adjustment to the origin.

The analysis consists of correlating the monthly-averaged NDVI (consisting of two compositing periods) with the current (lag 0) or preceding (monthly lags from 1 to 3) accumulated precipitation (Table 3.5) or time-averaged surface soil moisture in the top 5 cm (Table 3.6). To obtain significant relations, the correlation coefficients (CCs) are averaged for all months during the 2005 year, selected due to its limited amounts of missing data. For each table, maximum CCs at each regional station are italicized. Table 3.5 reveals that most stations have strong correlations between NDVI and accumulated rainfall in the current plus the two previous months (lag 0+1+2), while none of the stations have high CCs in the current month (lag 0). This suggests that regional ecosystem responses depend on the accumulated seasonal rainfall during the current and previous two months, with limited controls of the current conditions.

| **Station ID** | **NDVI and Precipitation Correlation Coefficients Monthly Lags** | | | | | | |
|---|---|---|---|---|---|---|---|
| | **0** | **1** | **2** | **3** | **0+1** | **1+2** | **0+1+2** |
| 130 | 0.442 | 0.836 | 0.387 | 0.172 | 0.784 | 0.749 | *0.843* |
| 131 | 0.465 | 0.824 | 0.704 | 0.247 | 0.727 | 0.872 | *0.874* |
| 132 | 0.494 | 0.770 | 0.553 | 0.199 | 0.721 | 0.741 | *0.805* |
| 133 | 0.477 | 0.885 | 0.537 | -0.004 | 0.807 | 0.876 | *0.885* |
| 135 | 0.559 | 0.800 | 0.407 | 0.032 | 0.831 | 0.745 | *0.847* |
| 136 | 0.580 | 0.828 | 0.361 | 0.127 | *0.900* | 0.790 | 0.859 |
| 143 | 0.495 | 0.781 | 0.532 | 0.151 | 0.819 | 0.822 | *0.903* |
| 144 | 0.314 | *0.812* | 0.415 | 0.432 | 0.735 | 0.805 | 0.789 |
| 146 | 0.429 | 0.800 | 0.571 | 0.340 | 0.608 | *0.844* | 0.736 |
| 147 | 0.691 | 0.868 | 0.347 | -0.072 | 0.927 | 0.802 | *0.928* |

**Table 3.5:** Linear correlation coefficients between NDVI and accumulated rainfall (mm) at different monthly lags. Precipitation was accumulated at lag 0: rainfall accumulated in the current month, 1: rainfall accumulated one month earlier, 2: two months earlier, 3: three months earlier, 0+1: accumulated rainfall in the current month plus the previous month, 1+2: two previous months, and 0+1+2: current and the two previous months.

Conversely, the correlation coefficients between monthly NDVI and time-averaged soil moisture in Table 3.6 exhibit larger values for the current (lag 0), previous (lag 1) or current and previous (lag 0+1) months. The shorter monthly lags observed for the maximum CCs between NDVI and soil moisture are evidence of a more immediate control of plant available water on vegetation dynamics, as compared to current precipitation. Nevertheless, overall CCs between NDVI and precipitation are higher than those for soil moisture at longer monthly lags across most of the regional stations. Fig. 3.4 summarizes the differences between the precipitation and soil moisture correlations with NDVI for a range of lags arranged from the current month (lag 0) toward longer prior periods (lag 0+1+2). Results are shown as average values (symbols) over all stations and their variability depicted as the ±1 standard deviation (vertical bars). Clearly, the concurrent correlation (lag 0) is higher between soil moisture and NDVI, as compared with the current precipitation amount. For longer lags (e.g., lag 0+1, 0+1+2), however, the accumulated rainfall has a stronger relation with the vegetation dynamics, indicating that the delayed response between NAM rainfall and seasonal greening in the region. It is important to clarify that we used superficial soil moisture (5 cm depth) and one concern is if this depth is representative of the entire root profile. In order to demonstrate if the surface soil moisture is representative of the root soil moisture profile, we performed a correlation matrix for station 147. The dataset includes soil moisture readings at 5, 10 and 15 cm from the period 2004-2006 (not shown here). We found that surface soil moisture is well correlated with deeper soil moisture values (see Figure 3.5).

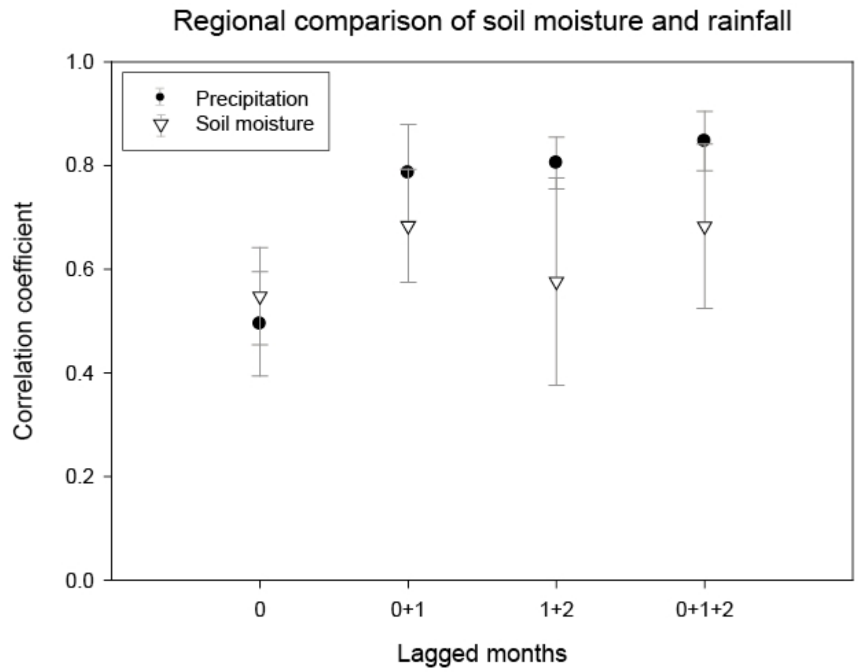


**Figure 3.4:** Linear correlation coefficients (CCs) between monthly NDVI and accumulated precipitation and averaged soil moisture over a range of different monthly lags, arranged from current (lag 0) toward longer prior periods (lag 0+1+2). CCs are shown as averages (symbols) and standard deviations (±1 std as vertical bars) over all stations in 2005.

| Station ID | NDVI and Soil Moisture Correlation Coefficients Monthly Lags | | | | | | |
|---|---|---|---|---|---|---|---|
| | **0** | **1** | **2** | **3** | **0+1** | **1+2** | **0+1+2** |
| 130 | 0.450 | *0.706* | 0.344 | 0.080 | 0.675 | 0.612 | 0.700 |
| 131 | 0.406 | *0.828* | 0.631 | 0.153 | 0.672 | 0.818 | 0.803 |
| 132 | 0.435 | 0.627 | 0.557 | 0.381 | 0.572 | *0.631* | 0.616 |
| 133 | 0.673 | 0.720 | 0.274 | -0.200 | *0.781* | 0.584 | 0.752 |
| 135 | *0.582* | 0.381 | -0.174 | -0.421 | 0.537 | 0.120 | 0.347 |
| 136 | 0.548 | 0.454 | 0.093 | -0.040 | *0.554* | 0.381 | 0.528 |
| 143 | 0.683 | 0.778 | 0.381 | -0.008 | 0.877 | 0.677 | *0.881* |
| 144 | 0.572 | 0.766 | 0.351 | 0.154 | *0.769* | 0.635 | 0.754 |
| 146 | 0.542 | 0.790 | 0.505 | 0.229 | 0.717 | 0.765 | *0.819* |
| 147 | 0.589 | 0.655 | 0.293 | -0.063 | *0.684* | 0.541 | 0.629 |

**Table 3.6:** Linear correlation coefficients between NDVI and averaged surface soil moisture at different monthly lags. Soil moisture was averaged over lag 0: current month, 1: one month earlier, 2: two months earlier, 3: three months earlier, 0+1: current month plus the previous month, 1+2: two previous months, and 0+1+2: current plus the two previous months

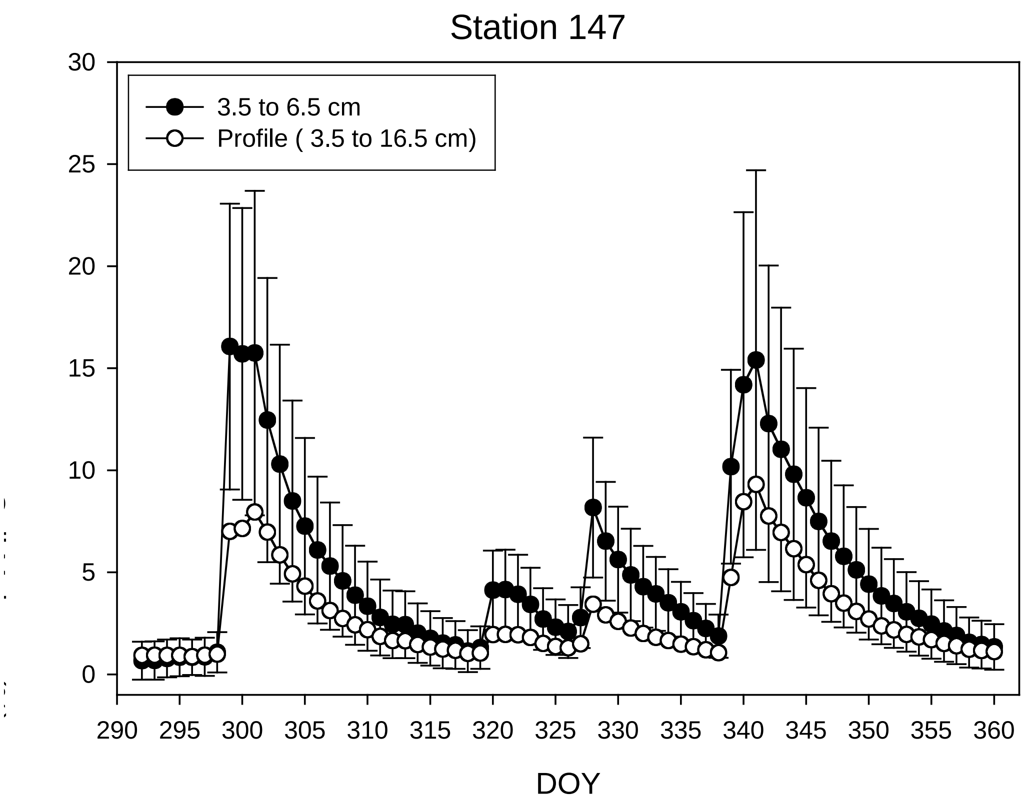


**Figure 3.5:** Comparison between surface soil moisture and root zone profile at station 147 (Rayon tower). Dots represent mean daily values and the bars ±1 standard deviation.

This is in agreement with several authors (Martinez et al, 2008; Mahmood et al, 2007; Calvet et al 1998, Grayson and Western, 1998) who found that surface soil moisture is well correlated with root zone soil moisture (0-30 cm). However, the correlation declines fast at deeper soil layers. Furthermore, according to Hillel (1971), the upper dry surface layer in sandy soils (most of the soils in the region are sandy-loam) forms, during soil drying, a type of barrier that restricts the evaporation of soil water only to this dry surface layer (DSL). Therefore, the soil moisture is well distributed below this DSL. In addition, Barnes and Allison (1983) explained that water moves upward in the liquid phase in the zone below the DSL, hence; water is transported by vapor diffusion in the zone above the DSL.

In addition, we observed that in wet periods the variability in the profile is high and decreases with soil drying. Therefore it is more reliable to compare the surface and root zone soil moisture in dry rather than wet periods. This is in agreement with authors that reported that variability in soil profile increases with increase in soil moisture content (Martinez et al, 2008; Famiglietti et al, 1998; Mohanty et al 2008; De Lannoy et al, 2006). Hence, surface soil moisture is a good predictor of root zone status; however, it is more accurate if we compare both values during drying periods. For the shallow rooted plants in regional ecosystems, the surface moisture determines plant water uptake and evapotranspiration (Casper et al., 2003; Seyfried and Wilcox, 2006; Vivoni et al. 2008).

### 3.4. Spatial and Temporal Stability Analyses of Vegetation Dynamics

#### 3.4.1 Spatial and Temporal Stability of NDVI

The ecosystem response to precipitation and soil moisture conditions, as captured by the NDVI fields, can be discerned through spatial and temporal persistence. Fig. 3.6 presents spatial maps of: (a) the spatial RMSE $\delta_s$, and (b) the temporal RMSE $\delta_t$, calculated using the eighty-three (83) MODIS NDVI images in the domain. Regions with low spatial RMSE $\delta_s$ (Fig. 3.6a, red colors) correspond to zones that closely track the spatially-averaged conditions in the two basins. These areas coincide well with the location of Sinaloan thornscrub and Sonoran desert scrub (Brown, 1994) that exhibit strong seasonal variations in NDVI and occupy large regional extents. Note these areas are located over a range of elevations, but are not observed in the highest peaks or riparian corridors (Vivoni et al., 2007).

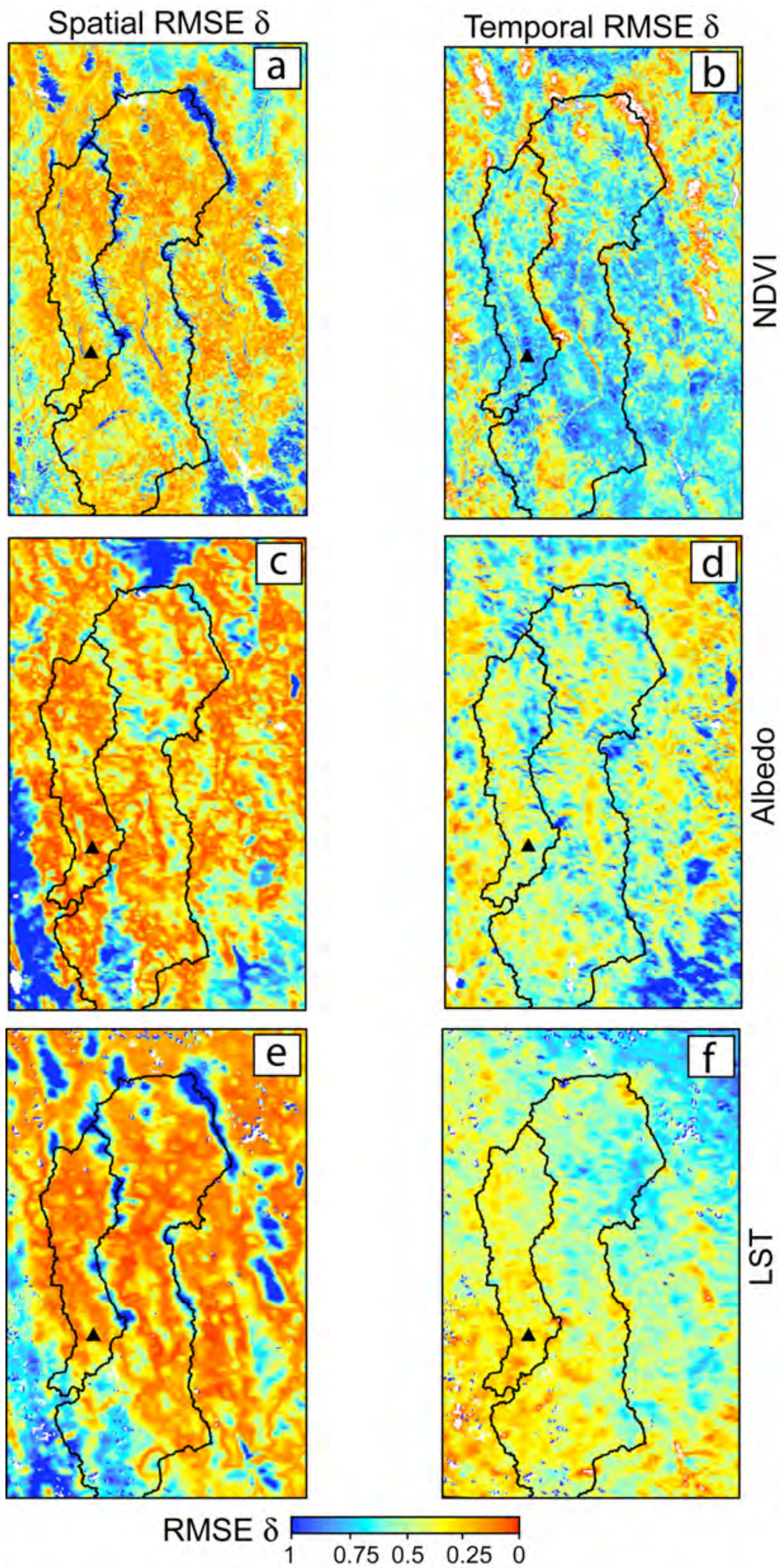


**Figure 3.6:** Spatial distributions of spatial and temporal RMSE $\delta$ for: (a, b) NDVI, (c, d) Albedo and (e, f) LST. Resolution for NDVI is 250-m, while albedo and LST are 1-km.

In these locations, high spatial RMSE $\delta_s$ (Fig. 3.6a, blue colors) indicate zones behaving differently from the spatial mean and correspond to Madrean evergreen woodland and montane conifer forests at high elevations and Sonoran riparian deciduous woodland along the main stems of the Río San Miguel and Río Sonora. Clearly, the distribution of RMSE $\delta_s$ is a useful tool to classify ecosystem patterns, in particular to sharply distinguish between evergreen woodlands at high elevations and deciduous scrublands at mid elevations.

The temporal RMSE $\delta_t$ (Fig. 3.6b) supports the above analysis by distinguishing locations in the domain that closely track the temporal mean in each pixel. Regions with low RMSE $\delta_t$ (blue colors) have relatively smaller changes in time and correspond to Madrean evergreen woodland and montane conifer forests at high elevations and Sonoran riparian deciduous woodlands along rivers. Despite having deciduous trees, the riparian woodlands are able to directly access groundwater and thus remain green during longer periods of time, as compared to ecosystems that rely solely on summer rainfall. Lower temporal persistence is observed for regions with high RMSE $\delta_t$ (red colors) which depict zones with large temporal changes. Clearly, these match the areas with low RMSE $\delta_s$, in particular the Sinaloan thornscrub and Sonoran desert scrub. Interestingly, the temporal RMSE $\delta_t$ is able to more clearly separate the locations of these ecosystems, with Sinaloan thornscrub further south in the domain and replaced by Sonoran desert scrub at similar elevations in the north (Brown, 1994). In conjunction, the spatial and temporal persistence maps reveal ecosystem patterns that are not observed through simpler metrics such as seasonal NDVI changes (Fig. 3.1). Further, this analysis extends applications of RMSE $\delta$ beyond traditional soil moisture studies (e.g., Jacobs et al., 2004; Vivoni et al., 2008a). Recognition of these patterns is important because we can identify zones with dramatic changes in vegetation dynamics that can affect the ecosystem energy balance. As result, we expect to find vegetation-rainfall feedback regions where greater changes in the energy balance are observed, helping to generate more convective rainfall.

### 3.4.2 Spatial and Temporal Stability of Albedo

Fig. 3.6 also presents the RMSE $\delta$ metrics for albedo and LST at a coarser resolution (1-km). Correspondence between the spatial RMSE $\delta$ for albedo and NDVI indicates that albedo changes are primarily due to vegetation greening. Regions with low spatial persistence in albedo include grasslands located in the northern part of the study region and semidesert shrublands found in the coastal plains, which do not track the spatial mean of the region (Fig. 3.6c). In addition, these ecosystems also showed low variability in time (very low seasonality). High elevation sites, as well as some riparian corridors had a moderately spatial representativeness of the region. Conversely, subtropical scrublands represent the spatial mean well and have moderate seasonality linked to their dynamic NDVI changes (Fig. 3.6d). In the other hand, high elevations showed high variability in time. Because albedo is highly affected by soil moisture status and high elevation ecosystems tend to receive more rainfall than the rest of the biomes in the region, therefore we expect more fluctuations in albedo values. Since the temporal RMSE $\delta$ in albedo has a heterogeneous pattern with a low range, this indicates a local control by soil and vegetation conditions on its moderate temporal changes.

### 3.4.3. Spatial and Temporal Stability of Land Surface Temperature

LST exhibits spatial RMSE $\delta$ (Fig. 3.6e) that resembles the NDVI pattern suggesting that surface temperature variations are closely tied to vegetation dynamics. Differences, however, are observed between the temporal RMSE $\delta$ of LST (Fig. 3.6f) and NDVI. A clear gradient in LST RMSE $\delta$ from high to low variability occurs from the northwest to the southwest corners of the region. This can be attributed to larger LST variations in mountain regions, as compared to more consisted high temperatures in desert areas. The differences in surface temperature variability reflects very well the climatic differences along the state of Sonora with the less variability found in the coastal plains (desert scrub, with smaller range of temperature differences during seasons) and higher variability when we approach the mountain ranges to the east (larger range of temperature during seasons). Also, there is a latitudinal effect observed in the variability of land surface temperature. Variability increases from southern to northern latitudes where snow is present and we can find a wider range of temperatures between seasons.

## 3.5. Topographic Control on Vegetation Dynamics

Given the observed effects of topography on spatial and temporal persistence, it is important to understand how ecosystem responses vary along elevation gradients in the study region. Figs. 3.7 and 3.8 present the variation of NDVI, spatial RMSE $\delta_s$ and temporal RMSE $\delta_t$ for two topographic transects depicted in Fig. 2.1 (A–A’ in the Río San Miguel and B–B’ in the Río Sonora). The transects were selected to capture a range of elevations (550 to 1900 m in A–A’, and 680 to 1600 m in B–B’), span several ecosystems and be in proximity to a subset of the regional stations. Note that Figs. 3.7

and 3.8 indicate the topographic variations (solid lines) with distance along the transects, which have a total planform length of ~23 km. In both topographic transects, the temporal mean NDVI (symbols) increases with elevation, while the temporal standard deviation (vertical bars depict ±1 std) typically decreases with altitude. These variations indicate that the mid elevation Sinaloan thornscrub and Sonoran desert scrub are characterized by lower time-averaged greenness, which is more variable in time, as compared to the high elevation Madrean evergreen woodland. Notably, the Río San Miguel transect exhibits higher NDVI (> 0.70) in the mountain peak (up to 1900 m) than the Río Sonora peak (NDVI > 0.55). Interestingly, the relation between NDVI and elevation at lower and mid elevations (e.g., ~600 to 1000 m for Río San Miguel) is linear, with similar rates of increase along the transect. At high elevations, however, a lag is observed in the increase in NDVI as compared to elevation as well as a displacement of the NDVI maximum value away from the peak elevation.

The relation between elevation and ecosystem response is further analyzed using the spatial and temporal persistence in Fig. 3.7b and 3.8b. In both transects, the mid elevation ecosystems exhibit low spatial RMSE $\delta_s$ and high temporal RMSE $\delta_t$, which indicate areas closely tracking the mean conditions in the region. These elevations correspond to Sinaloan thornscrub and Sonoran desert scrub which are highly responsive to NAM precipitation and occupy large regional extents. At high elevations along each transect, the Madrean evergreen woodland has a larger spatial RMSE $\delta_s$ and a smaller temporal RMSE $\delta_t$. This suggests that the evergreen species have time-stable conditions that do not track the spatially-averaged response. In addition, the maximum spatial RMSE $\delta_s$ is displaced slightly from the mountain peak, as observed for the mean NDVI.

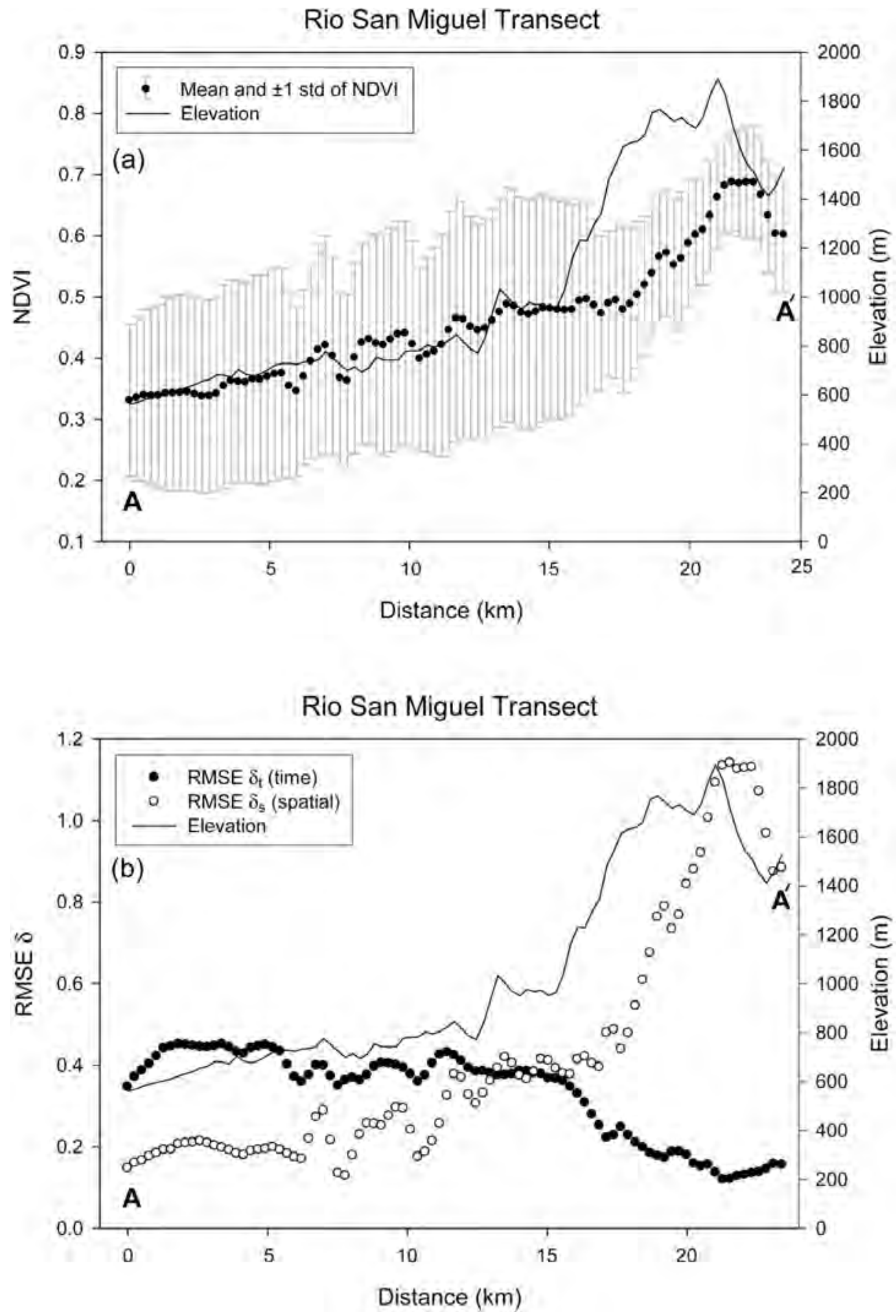


**Figure 3.7:** Topographic control on vegetation metrics in the Río San Miguel transect. (a) Relation between elevation and temporal mean NDVI (closed circles) and the temporal standard deviation (±1 std as vertical bars). (b) Relation between elevation and spatial and temporal RMSE *δ*.

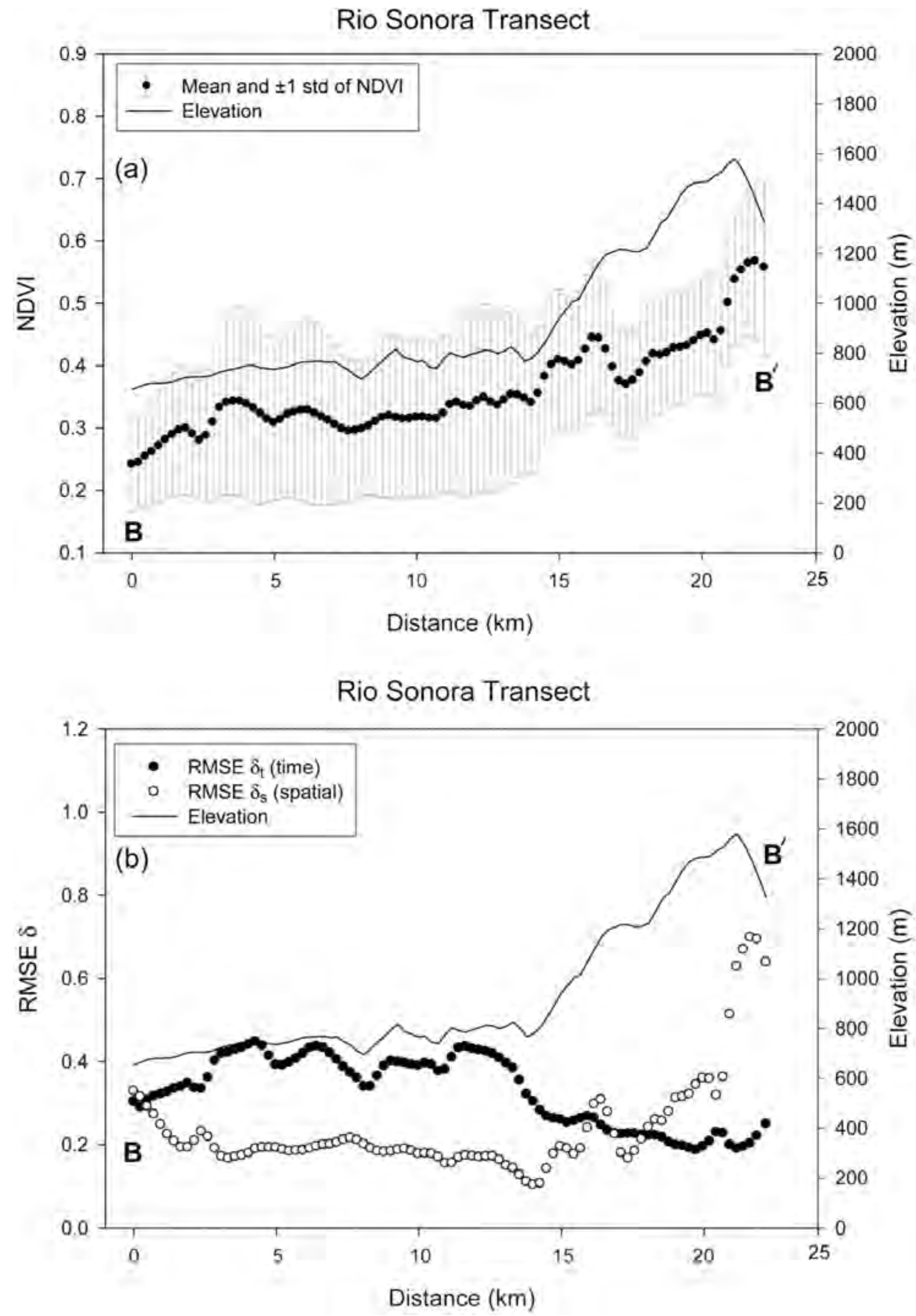


**Figure 3.8:** Topographic control on vegetation metrics in the Río Sonora transect. (a) Relation between elevation and temporal mean NDVI (closed circles) and the temporal standard deviation (±1 std as vertical bars). (b) Relation between elevation and spatial and temporal RMSE $\delta$.

In both transects, a range of elevations (e.g., ~600 to 900 m in the Río San Miguel) simultaneously have small spatial and temporal RMSE $\delta$. We interpret this as an elevation band of significant monsoonal response, which dominates the regional greening, as suggested by Vivoni et al. (2007).

Clearly, spatial and temporal persistence reveal variations in vegetation dynamics along topographic transects and can aid in the interpretation of vegetation-elevation relations in semiarid mountain fronts. Because both transects in San Miguel and Sonora Basins give similar results we will focus only in San Miguel basin transect for the analysis of albedo and land surface temperature. Figure 3.9a shows the topographic controls on mean value of albedo for the San Miguel transect for the period 2004-2007. We can clearly see that albedo is decreasing with increase in elevation along the transect. Conversely, we observe that albedo variability (expressed as error bars with the value of standard deviation) increases as elevation increases. It is important to mention that variability as well as mean albedo showed an inflection point around 1200 m above sea level. As we argue in the previous section, we believe that high elevation leads to more precipitation and, in consequence, higher surface soil moisture as well as vegetation cover. These two conditions highly affects albedo, therefore we expect more variability in albedo in higher elevation ecosystems such as Madrean evergreen forest. Figure 3.9b shows the behavior of the spatial and temporal RMSE $\delta$. Spatial RMSE $\delta$ as well as temporal RMSE $\delta$ increases with elevation. Hence, higher elevation sites moderately represent the regional mean and moderately deviate from the temporal mean of the region, showing slightly higher seasonality than lower elevation ecosystems.

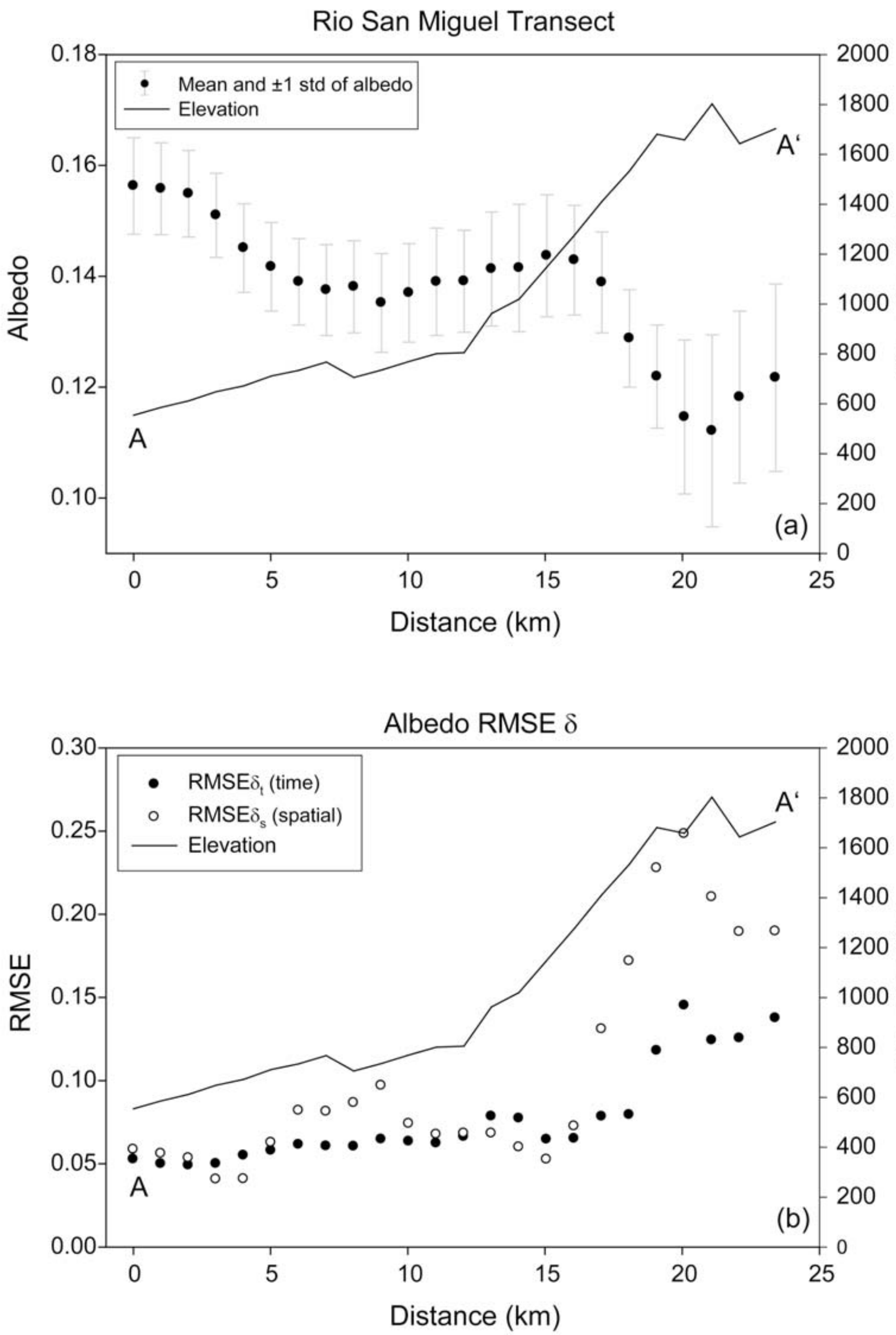


**Figure 3.9:** Topographic control on albedo in the Río San Miguel. (a) Relation between elevation and temporal mean albedo (closed circles) and the temporal standard deviation (±1 std as vertical bars). (b) Relation between elevation and spatial and temporal RMSE $\delta$.

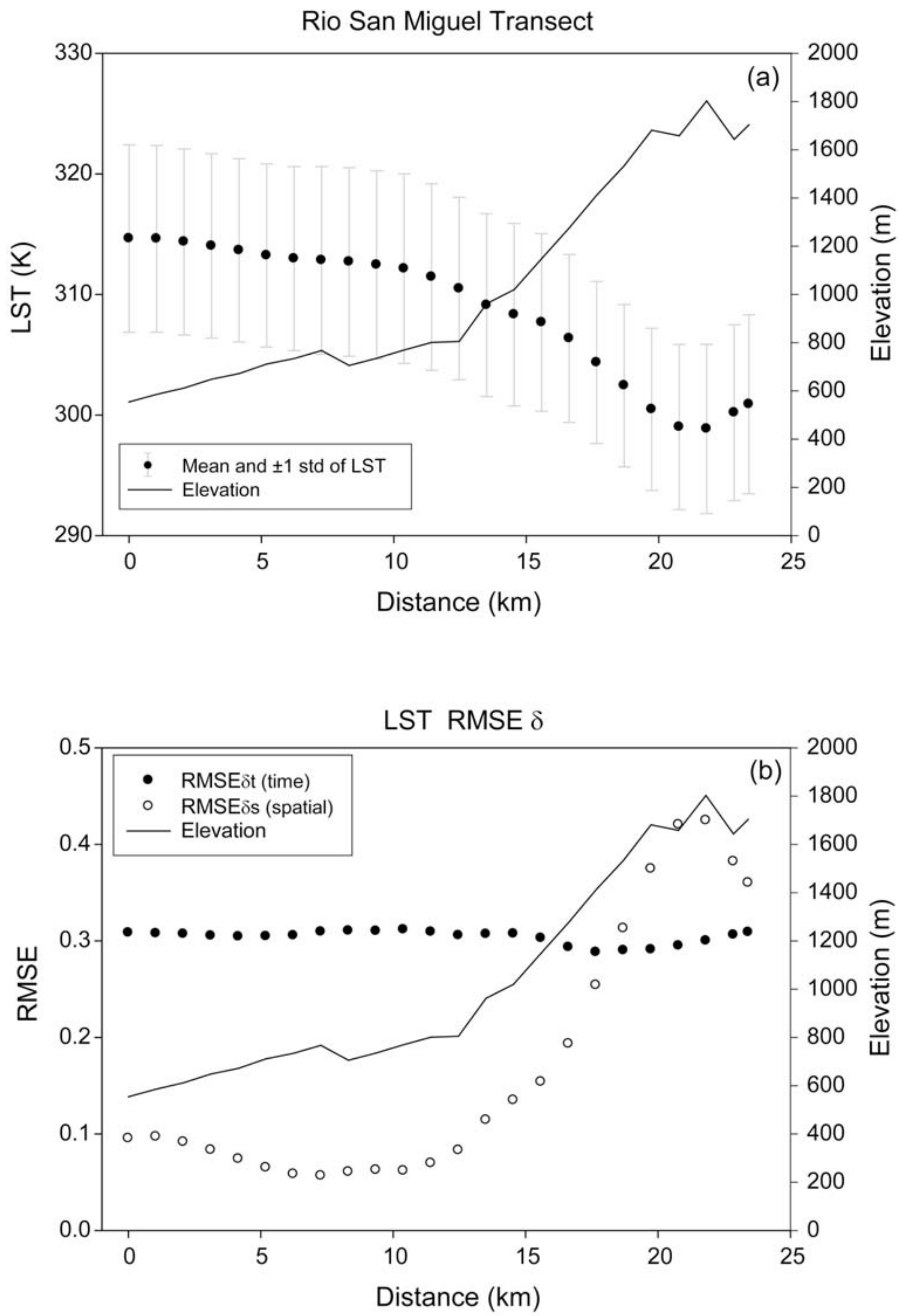


**Figure 3.10:** Topographic control on land surface temperature in the Río San Miguel. (a) Relation between elevation and temporal mean albedo (closed circles) and the temporal standard deviation (±1 std as vertical bars). (b) Relation between elevation and spatial and temporal RMSE $\delta$.

Figure 3.10a shows the topographic control on mean Land Surface Temperature (LST). As we expected, surface temperature decreases with elevation. How ever, there is a slightly decrease in variability for LST with elevation. Again, elevation is playing an important role in the decrease of surface temperature. Higher elevation leads to more precipitation; hence, increasing the soil moisture at the soil surface and plant greening. Water released from the soil and plant leaves (as evaporation and transpiration) produces a cooling effect on the surface and air temperatures. Finally, we observed a slightly decrease in temporal RMSE $\delta$ with elevation (seasonality). At least in this region, temperature does not change as much as shown in Figure 3.6, where larger LST variability is observed in the northern latitudes and in higher elevation in the Sierra Madre Occidental. Figure 3.10b shows the distribution of spatial RMSE $\delta_s$ increases with elevation, suggesting that higher elevation ecosystems did not track the spatial mean of the region, unlike lower elevation ecosystem, such as the Sinaloan thornscrub. We calculated a lapse rate for the San Miguel Basin of 14 °C/km which is more than double of the atmospheric lapse rate (6.5 °C/km). The difference is caused by thermal properties of both materials where soil has higher thermal conductivity than air (2.4 W/mK compared to 0.025 W/mK respectively).

### 3.6. Identifying Land Surface Response Functional Groups

Fig. 3.11 presents the characteristics of six functional groups (FG) derived from the cluster analysis and unsupervised classification of the spatial and temporal persistence of NDVI, albedo and LST. FGs represent zones that have similar land surface responses to precipitation and solar radiation forcing. Their spatial distribution (Fig. 3.11a) corresponds well to the coarse resolution land cover map, in such a way that FGs can be associated with ecosystems. Both maps were compared using an error matrix to evaluate the accuracy of our new functional group map.

We selected the six-Functional Group map among several sets of maps with different number of FG's because this choice showed the highest correlation with the reference land cover map (58.9 % of correctly classified pixels). Table 3.7 shows the result of the error matrix. Table 3.7 presents the total number of MODIS pixels (~1-km$^2$) for each FG. This approach for mapping ecosystems using land surface responses is more suited to distinguishing units arranged along an elevation gradient. For example, the evergreen forests and subtropical scrublands positioned along mountain fronts correspond well to the land cover map. Identifying ecosystems with heterogeneous compositions (i.e., mixtures of grass, shrubs and trees) is more challenging. Figs. 3.11b, d and f present the change in NDVI, albedo and LST during the monsoon transition for each FG. Percent change (%) is calculated as the land surface property during mid-August referenced to the observations in mid-June, averaged over the 2004 to 2006 monsoons. Clearly, the FGs vary in the magnitude and direction of changes occurring during the monsoon transition. All ecosystems experience a net increase in NDVI, with the subtropical scrublands (FG 4 and FG 5) having the largest changes (~150% increase). In contrast, semidesert shrublands (FG 1) have the smallest change in NDVI (~83% increase). Interestingly, the spatial variations in the percent NDVI change is highest for evergreen forests (FG 6) and lowest for the semidesert grasslands (FG 1), indicating different levels of heterogeneity in each ecosystem.

| Class | Semidesert shrubland | Semidesert grassland | Mixed shrubland | Subtropical scrubland (low elevation) | Subtropical scrubland (high elevation) | Madrean evergreen woodland | Totals |
|---|---|---|---|---|---|---|---|
| 1 | 291 | 78 | 35 | 97 | 66 | 309 | 876 |
| 2 | 268 | 510 | 103 | 964 | 21 | 46 | 1912 |
| 3 | 95 | 25 | 275 | 502 | 31 | 92 | 1020 |
| 4 | 85 | 208 | 127 | 1012 | 15 | 35 | 1482 |
| 5 | 27 | 206 | 431 | 277 | 117 | 23 | 1081 |
| 6 | 2 | 251 | 143 | 44 | 6 | 4336 | 4782 |
| Totals | 768 | 1278 | 1114 | 2896 | 256 | 4841 | 11153 |

Correct pixels: 6541
Percentage of correct pixels: 58.6 %

**Table 3.7:** Error matrix showing the comparison between the new functional groups map and a reference map (Land cover map generated by Yilmaz et al. (2008)). The classes shown horizontally represent the classes of the reference map; conversely, the classes shown vertically represent the classes in the generated map. The number of pixels shaded and shown diagonally represents the number of correctly classified pixels by category.

The monsoon transition in albedo has a strong dependence on the functional group. Low elevation FGs (1 to 3) exhibit a decrease in albedo, on average, while the high elevation FG 6 has an increase in albedo during the monsoon (Fig. 3.11d). This contrast is likely due to the dual roles of soil color and vegetation greenness on determining albedo (Sandholtz et al., 2002). In addition, large spatial variations occur in each FG due to the heterogeneous nature of the albedo response. LST exhibits a general decrease in all FGs, with a lower reduction for semidesert shrublands (FG 1). Other FGs exhibit decreases in LST from 3 to 5% and moderate spatial variations. This is due to a widespread effect of soil moisture, through evapotranspiration, on reducing surface temperatures during the monsoon transition. Comparing across the NDVI, albedo and LST changes, the subtropical scrublands (FG 4 and 5) show the largest increases in NDVI, large decreases in LST, and a decrease, on average, in albedo.

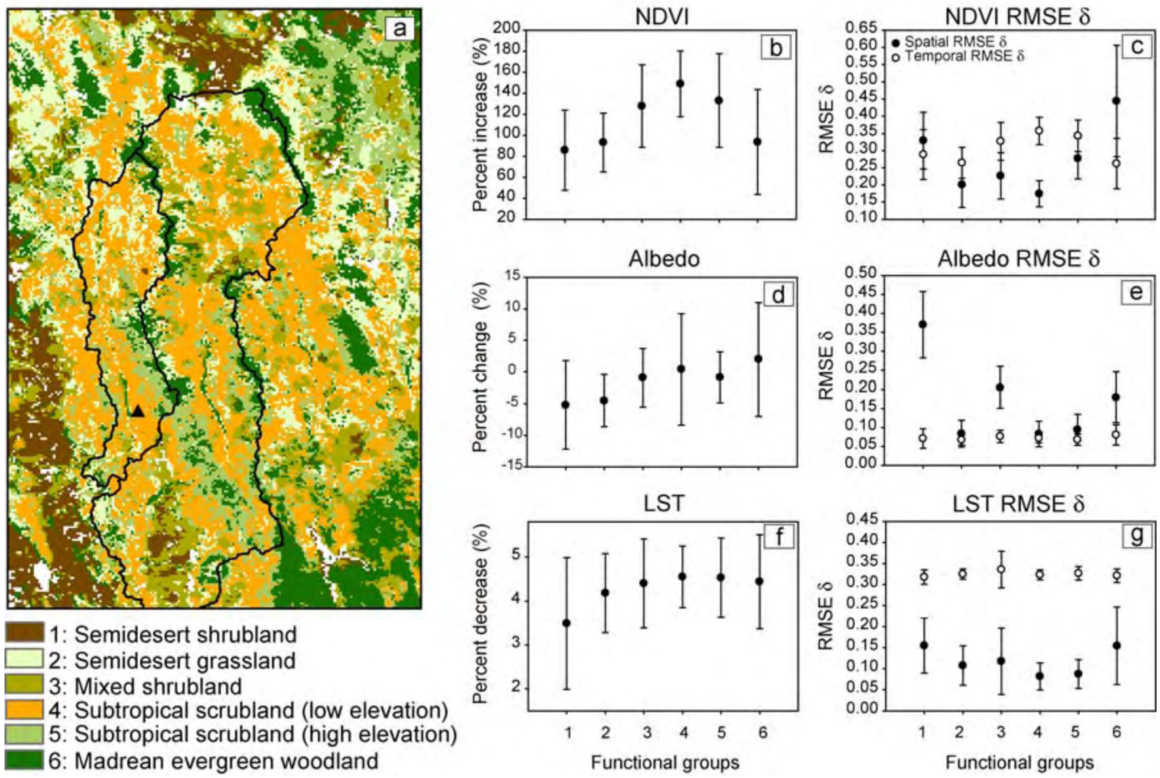


**Figure 3.11:** (a) Land surface response functional groups obtained from cluster analysis. Mean spatial percent change during NAM for each functional group for: (b) NDVI, (d) Albedo and (f) LST. Error bars represent ± 1 spatial standard deviation. Relation between mean spatial and temporal RMSE $\delta$ by functional group for: (c) NDVI, (e) Albedo and (g) LST. Functional groups are ordered with increasing elevation (see legend for functional group name).

Table 3.8 summarizes the overall behavior for all functional groups and the corresponding percentage of total area for each FG. Figs. 3.11c, e and g present the spatial and temporal RMSE $\delta$ averaged for each FG and its spatial variability. As discussed previously, FGs with low spatial RMSE $\delta$ represent well the regional mean, while FGs with low temporal RMSE $\delta$ exhibit low seasonality. We highlight the response in subtropical scrublands (FG 4 and FG 5) since this ecosystem is monitored at an eddy covariance tower site.

| Functional Group | Ecosystem Classification | Number of Pixels (Percent Area) | Direction of Change in Monsoon | | |
|---|---|---|---|---|---|
| | | | **NDVI** | **Albedo** | **LST** |
| 1 | Semidesert shrubland | 5213 (8.8%) | + | - | - |
| 2 | Semidesert grassland | 10290 (17.4%) | + | - | - |
| 3 | Mixed shrubland | 8675 (14.6%) | + | - | - |
| 4 | Subtropical scrubland (low elevation) | 15518 (26.2%) | + | ± | - |
| 5 | Subtropical scrubland (high elevation) | 9112 (15.4%) | + | - | - |
| 6 | Madrean evergreen woodland | 10450 (17.6%) | + | + | - |

**Table 3.8:** Functional group characteristics, including the direction of change in the spatially-average land surface property (NDVI, albedo, LST) during the monsoon transition: increase (+), decrease (-) and no net change (±). See Fig. 3 for the spatial variability. The number of pixels refers to the MODIS pixel resolution (~1 $km^2$), in parenthesis is the percent of the total area.

The large areas occupied by subtropical scrublands (~21,150 $km^2$) have high seasonality in NDVI and LST; and dominate the regional response in NDVI, albedo and LST. As a result, the tower site is representative of the land surface conditions in a broad region that responds vigorously to the NAM. The high representativeness extent of the tower site in subtropical scrublands fills a major observational gap in the Sonoran Desert (Yang et al., 2008).

### 3.7. Vegetation-Rainfall Feedback Mechanism in Subtropical Scrubland

Fig. 3.12 presents the land surface transitions at the eddy covariance tower during the 2007 monsoon. The monsoon onset, indicated by the precipitation pulses, occurred near Julian day 185 (July 4, 2007). Precipitation (*P*) led to high soil moisture in the surface layer, which increased from ~2% to 10%. Vegetation responded quickly to soil water, increasing from NDVI = 0.20 to 0.55. Vegetation greenup led to a decrease in albedo, consistent with estimates from MODIS. In addition, soil temperature decreased from ~43 to 37 ℃, which matched with the MODIS LST. Lower LST is a result of the cooling effects of evapotranspiration, as shown by the decreasing Bowen ratio.

The Bowen ratio (*B*) is the ratio of sensible to latent heat flux. Field data indicate a positive relation between NDVI and *P*, and a negative relation between LST and *P*. According to Brunsell (2006), these correlations indicate a positive vegetation-rainfall feedback, but do not imply direct causality. As a result, a close inspection of the tower data can help infer the sign and pathways of the feedback in the subtropical scrubland. Observed transitions are summarized in Table 3.9 by comparing the pre-monsoon and monsoon-averaged values. Fig. 3.12c illustrates a theoretical pathway through which positive anomalies in soil moisture and vegetation greening lead to more rainfall, adapted from Eltahir (1998). We test whether the positive vegetation-rainfall feedback holds based on the observations. The thick boxes indicate the data that supports Eltahir (1998), including: (a) an increase in vegetation greenness, (b) a decrease in albedo, (c) a decrease in *B*, (d) an increase in water vapor in the boundary layer, (e) a decrease in LST, and (f) an increase in net terrestrial radiation. The field data, however, do not support an increase in the net solar radiation (thick dashed box). In fact, a strong decrease occurs in net solar radiation (Table 3.9), primarily due to cloudiness.

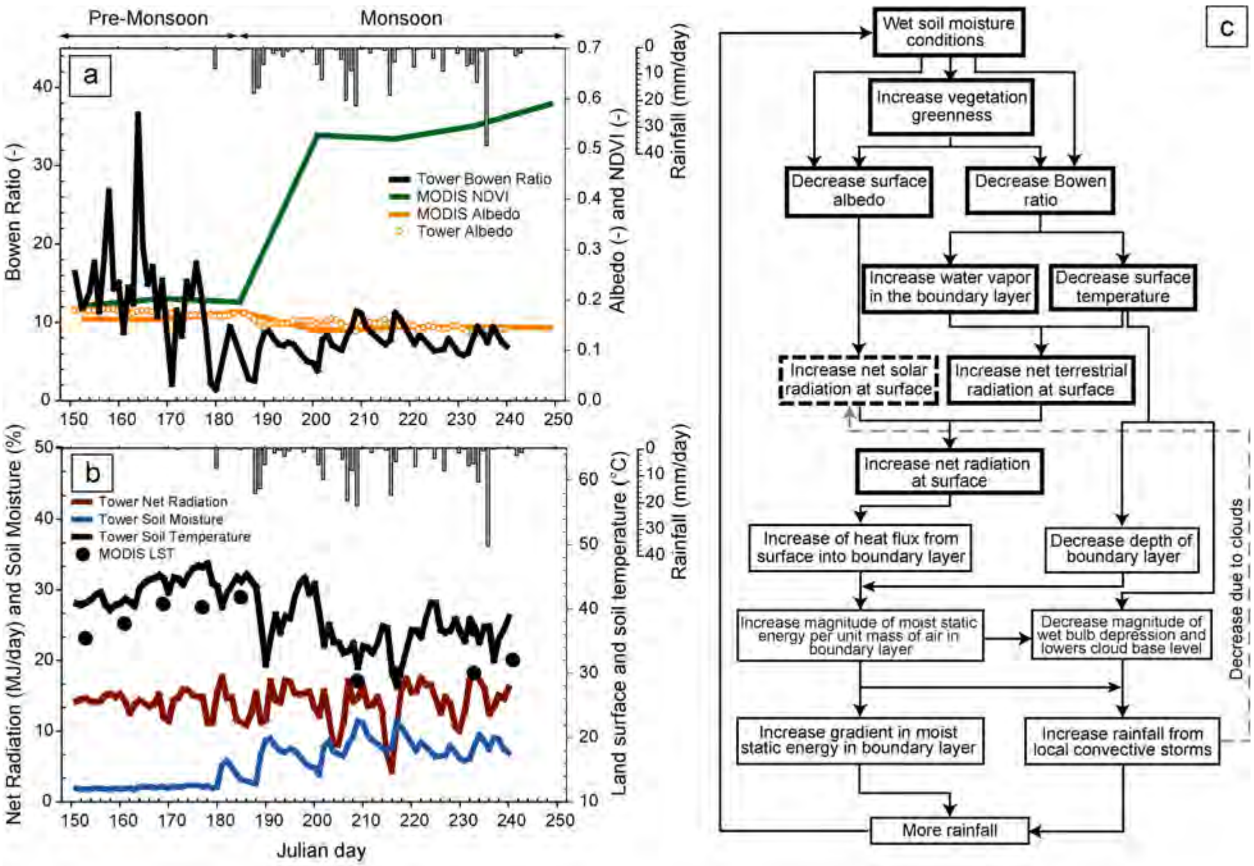


**Figure 3.12:** (a) Transition in NDVI, albedo, Bowen ratio and precipitation during the 2007 monsoon season. (b) Transition of soil temperature, net radiation, soil moisture and precipitation. Gaps in net radiation correspond to cloudy days not included in analysis. (c) Diagram relating changes in soil moisture and vegetation greenness with the subsequent effects in land-atmosphere interactions and rainfall, adapted from Eltahir (1998).

We capture this negative interaction by the dashed line linking the convective storms to net solar radiation. Overall, this negative interaction suppresses the increase in net terrestrial radiation and promotes only a small change in net radiation. For dry monsoon days, net radiation averages 13.35 MJ/day (N = 17), while for wet days it is 14.86 MJ/day (N = 33). This indicates that for days with wet soils, we observe a slight increase in net radiation relevant to the pre-monsoon period (13.98 MJ/day).

| Data Source | Land Surface Variable and Unit | Pre-Monsoon | Monsoon |
|---|---|---|---|
| Tower | Rainfall (mm) | 8.64 | 227.58 |
| | Albedo (-) | 0.17 | 0.15 |
| | Bowen Ratio (-) | 13.27 | 1.84 |
| | Net Radiation (MJ/day) | 13.98 | 13.70 |
| | Net Solar Radiation (MJ/day) | 25.82 | 18.62 |
| | Net Terrestrial Radiation (MJ/day) | -11.77 | -4.92 |
| | Soil Moisture (%) | 2.36 | 7.43 |
| | Soil Temperature (˚C) | 43.11 | 36.84 |
| | Vapor Pressure (mb) | 1.06 | 2.22 |
| MODIS | Albedo (-) | 0.17 | 0.14 |
| | NDVI (-) | 0.20 | 0.56 |
| | LST (˚C) | 39 | 30 |

**Table 3.9:** Comparison of ground-based and remotely-sensed variables tower. Before monsoon has 34 days: DOY 151 (May 31, 2007) to DOY 184 (July 3, 2007). During monsoon period has 56 days: DOY 185 (July 3, 2007) to DOY 240 (August 28, 2007).

How do we reconcile the observed trends in the monsoon transition with the proposed vegetation-rainfall feedback? As noted by Brunsell (2006), there is an important distinction between vegetation effects on the surface energy balance that enhance precipitation and those that suppress it. From this evidence, we infer that a positive vegetation-rainfall feedback exists only when the effects of clouds do not decrease net solar radiation. This would occur, for example, on sunny days following a precipitation pulse. Julian days 201-202 (July 19 to 20, 2007) demonstrate this sequence (Table 3.10). In this two-day period, land surface conditions can promote subsequent rainfall.

Persistent cloudy conditions can weaken the vegetation-rainfall feedback. For example, Julian days 215-216 (August 3 to 4, 2007) have sufficient cloudiness to decrease net radiation, interrupting the proposed pathway, despite having the other elements (Table 3.10). This comparison suggests that the negative interaction relating cloudiness to net solar radiation is important for the vegetation-rainfall feedback. This feedback mechanism operates at seasonally scale because the feedback mechanism proposed by Eltahir (1998) is based in two basic properties of the land surface that we have monitored in this thesis: 1) the albedo and 2) the Bowen ratio. The changes in these two variables occur at seasonal scale (three or four months). The transition between dry and wet conditions occurs rapidly, but the temporal persistence of these land surface properties stay for several months.

| **Vegetation-Rainfall Feedback** | **Land Surface Variable and Unit** | **Day 1** | **Day 2** |
|---|---|---|---|
| Positive feedback | Precipitation (mm/day) | 6.10 | 11.68 |
| Julian day 201 to 202 | Albedo (-) | 0.152 | 0.149 |
| | Bowen Ratio (-) | 4.97 | 0.75 |
| | Net Radiation (MJ/day) | 11.98 | 15.42 |
| | Net Solar Radiation (MJ/day) | 15.49 | 19.60 |
| | Net Terrestrial Radiation (MJ/day) | -3.51 | -4.17 |
| | Soil Moisture (%) | 3.85 | 7.75 |
| | Soil Temperature (˚C) | 39.2 | 34.3 |
| | Vapor Pressure (mb) | 2.12 | 2.28 |
| Weakened Feedback | Precipitation (mm/day) | 0.76 | 17.53 |
| Julian day 215 to 216 | Albedo (-) | 0.161 | 0.153 |
| | Bowen Ratio (-) | 0.83 | 0.08 |
| | Net Radiation (MJ/day) | 6.43 | 4.04 |
| | Net Solar Radiation (MJ/day) | 8.80 | 5.08 |
| | Net Terrestrial Radiation (MJ/day) | -2.37 | -1.04 |
| | Soil Moisture (%) | 7.18 | 7.76 |
| | Soil Temperature (˚C) | 36.9 | 30.2 |
| | Vapor Pressure (mb) | 2.37 | 2.53 |

**Table 3.10:** Comparison of changes in ground observations during two-day sequences exhibiting a positive vegetation-rainfall feedback (Day 1 and 2 = Julian days 201 and 202); and a weakened feedback due to the effects of cloudiness (Day 1 and 2 = Julian days 215 and 216).

# CHAPTER 4

# CONCLUSIONS AND FUTURE WORK

Vegetation dynamics in the North American monsoon region are closely linked to seasonal changes in precipitation (e.g., Salinas-Zavala et al., 2002; Matsui et al., 2005; Watts et al., 2007; Vivoni et al., 2007). To the authors' knowledge, however, the controls exerted by precipitation and soil moisture on seasonal vegetation greening have not been studied for the broader NAM region in northwest Mexico. Furthermore, the seasonal, interannual and spatial variations in vegetation response during the NAM are not well understood. Quantifying these spatiotemporal variations in a range of ecosystems is fundamental for assessing the degree of coupling between ecologic, hydrologic and atmospheric processes during the summer season. For example, Dominguez et al. (2008) found that the dynamics of evapotranspiration in the NAM ecosystems leads to a positive feedback on rainfall generation and to local precipitation recycling. Since the spatiotemporal variations of vegetation greening are directly linked to photosynthesis and evapotranspiration, quantifying vegetation dynamics using remote sensing observations represents an important step towards investigating ecohydrological processes in the NAM region. While vegetation greening should clearly be related to precipitation and soil moisture in the water-limited ecosystems, no prior attempts have been made to quantify the hydrologic controls on the vegetation dynamics. Also, it is important to evaluate land surface changes to understand their potential role in the precipitation processes during the NAM (e.g., Dominguez et al., 2008; Vivoni et al., 2008b).

In this thesis, we quantify the seasonal and interannual changes in vegetation greenness through the use of remotely-sensed vegetation index fields from the MODIS sensor over the period 2004 to 2006. We present the changes in land surface conditions occurring during the NAM though the combined use of remote sensing observations and ground-based data. Our regional analysis focuses on a large area in northern Sonora comprised by two major basins (Río San Miguel and Río Sonora) and parts of the Río Yaqui and San Pedro River basins in the Sierra Madre Occidental. The regional extent and the study duration were selected to take advantage of the regional instrument network with precipitation and soil moisture observations. By relating and interpreting the remotely-sensed and ground-based measurements, we identify the following characteristics of the regional vegetation dynamics in the Sierra Madre Occidental of northern Sonora and their relation to precipitation and soil moisture:

(1) Seasonal changes in vegetation greenness are dramatic in all the regional ecosystems and are related to hydrologic conditions and their spatial distribution during a particular monsoon season. As a result, interannual variability is observed in the seasonal vegetation greening and the metrics used to quantify biomass production. The vegetation response was most intense and extensive during the wet 2006 monsoon, reaching up to a 300% seasonal increase in NDVI.

(2) Vegetation responses to NAM precipitation and soil moisture depend strongly on the plant communities in each ecosystem. The ecosystem with consistently high monsoon greening is the mid elevation Sinaloan thornscrub, as suggested by Watts et al. (2007) and Vivoni et al. (2007). Other ecosystems in the region either exhibited lower seasonal changes in NDVI or less consistent year-to-year variations. Comparisons across

ecosystems indicate that different plant greenup strategies are utilized in response to interannual hydrologic variations.

(3) Spatial and temporal persistence of remotely-sensed NDVI fields reveal ecosystem patterns that are not observed using simple metrics. In particular, RMSE $\delta_s$ distinguishes between evergreen woodlands at high elevations and deciduous scrublands at mid elevations, while the temporal RMSE $\delta_t$ can more clearly separate different ecosystems at similar elevations. Analysis along two topographic transects indicate that elevation controls vegetation dynamics and serves to organize ecosystems into elevation bands, with high monsoonal response at mid elevations.

(4) Accumulated seasonal precipitation is a strong indicator of biomass production across the regional ecosystems, with Sinaloan thornscrub exhibiting the highest rainfall use efficiency. During the study period, differences between ecosystem responses were minimized during the wet 2006 monsoon and maximized during drier monsoons, in contrast to the common rainfall use efficiency found by Huxman et al. (2004) during drought years. Additional studies are required to quantify rainfall use efficiency in wet and dry periods in the regional ecosystems.

(5) Lagged correlation analysis indicates a strong degree of coupling between vegetation greening and the precipitation and soil moisture conditions at each regional station. Interestingly, concurrent correlations for monthly NDVI are higher with surface soil moisture, while lagged correlations are more significant for accumulated precipitation. This suggests that soil moisture plays an important intermediary role between NAM precipitation and vegetation response.

In addition, with the help of remote sensing observations, we identify areas exhibiting the potential for a vegetation-rainfall feedback, and then with the use of ground-based observations, we identify the sign, pathways, and interruptions in the feedback mechanism. From this analysis, we can also conclude:

(6) The spatial and temporal persistence of NDVI, albedo and LST identifies areas with strong seasonality that represents the regionally-averaged dynamics. Changes in land surface conditions for the areally-extensive subtropical scrublands exhibit the necessary trends in NDVI, albedo and LST for a positive vegetation-rainfall feedback.

(7) Observations at an eddy covariance tower site in the subtropical scrubland indicate that the necessary trends in land surface variables are exhibited for a positive vegetation-rainfall feedback if persistent cloudiness does not occur. The effects of clouds on net solar radiation can weaken or interrupt the positive feedback mechanism.

The observational analysis and interpretations conducted here show the importance of combining satellite remote sensing and ground networks for monitoring ecosystem dynamics and their link to hydrologic conditions. The use of multiple observation scales allows understanding the regional context in which detailed precipitation, soil moisture or surface flux measurements have been made (Gebremichael et al., 2007; Vivoni et al., 2007; Watts et al., 2007). In particular, it is clear that substantial interannual variations are present in monsoon vegetation greening. Clearly, the duration of our study is a limitation in our interannual analysis, primarily due to the recent establishment of the regional network. Additional analysis is desirable either by extending the work as new data sets become available or performing retrospective analysis with satellite data (though ground data would be limited).

Several additional questions have arisen through the analysis conducted in this thesis. While our focus has been on the summer season, the response to lower and more variable winter precipitation appears to be significant, in particular for Sonoran savanna grasslands during wet winters. The other regional ecosystems also appear to maintain greener conditions for longer periods when winter rainfall is available. Spring season growth is more common in higher latitude desert grasses (e.g., Pennington and Collins, 2007). As a result, the influence of winter precipitation on the annual hydrologic cycle and vegetation dynamics warrants further study.

The linkages between winter and summer ecohydrological processes are of considerable interest to understand the interannual variations in both the land surface conditions and the North American monsoon system. The interannual variability of NAM precipitation has been related to several factors, including sea surface temperature (e.g., Vera et al., 2006; Castro et al., 2007) and continental snow and soil moisture anomalies (e.g., Gutzler, 2000; Zhu et al., 2007). While the potential role of vegetation greening on the NAM has been proposed (Higgins et al., 2003), there is a lack of consensus regarding if vegetation dynamics impact the monsoon (Salinas-Zavala et al., 2002; Matsui et al., 2005; Dominguez et al., 2008). If a vegetation-atmosphere feedback exists in the NAM region, then understanding the spatiotemporal vegetation dynamics from remote sensing would be a critical link toward enhancing rainfall and streamflow predictability. The feedback approach used in this work is based on previous theoretical developments by Eltahir (1998) and Brunsell (2006). As a result, our contribution is to test the vegetation-rainfall feedback by inspecting remotely-sensed and ground-based land surface variables in a region with vegetation greening during the NAM. Through this test, we identify an important cloud interaction that interrupts the pathway and potentially leads to a negative feedback. Additional observations and model-based interpretations would be required to test the atmospheric portions of the feedback mechanism as these have not been addressed here. Additional attention is also merited on the potential effects of spatial gradients in land surface conditions on the vegetation-rainfall feedback, in particular along mountain fronts. Horizontal variations in NDVI, albedo and LST may induce local atmospheric circulations that could play a role in the feedback mechanism.

# CHAPTER 5

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# APPENDIX 1

## STATIONS DATASETS

STATION 130

| DOY | Year | EVI mean | EVI std | NDVI mean | NDVI std | Albedo | LST (K) | Rainfall (mm) | Soil moisture (%) |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 2004 | 0.136 | 0.008 | 0.284 | 0.006 | 0.120 | 299.000 | | |
| 17 | 2004 | 0.147 | 0.005 | 0.280 | 0.008 | 0.118 | 294.720 | | |
| 33 | 2004 | 0.143 | 0.009 | 0.280 | 0.005 | 0.120 | 300.840 | | |
| 49 | 2004 | 0.153 | 0.004 | 0.261 | 0.007 | 0.127 | 301.770 | | |
| 65 | 2004 | 0.159 | 0.017 | 0.296 | 0.020 | 0.129 | 309.740 | | |
| 81 | 2004 | 0.192 | 0.009 | 0.303 | 0.012 | 0.138 | 314.530 | | |
| 97 | 2004 | 0.211 | 0.019 | 0.334 | 0.023 | 0.135 | 311.180 | | |
| 113 | 2004 | 0.188 | 0.016 | 0.328 | 0.016 | 0.137 | 318.400 | | |
| 129 | 2004 | 0.158 | 0.011 | 0.281 | 0.010 | 0.138 | 320.860 | | |
| 145 | 2004 | 0.146 | 0.012 | 0.255 | 0.015 | 0.140 | 324.030 | | |
| 161 | 2004 | 0.137 | 0.007 | 0.221 | 0.012 | 0.143 | 324.340 | 6.1 | 0.3 |
| 177 | 2004 | 0.135 | 0.009 | 0.220 | 0.008 | 0.140 | 326.260 | 0.3 | 0.0 |
| 193 | 2004 | 0.403 | 0.029 | 0.662 | 0.036 | 0.153 | 273.000 | 99.1 | 6.8 |
| 209 | 2004 | 0.432 | 0.039 | 0.633 | 0.030 | 0.147 | 312.660 | 34.5 | 2.6 |
| 225 | 2004 | 0.315 | 0.031 | 0.473 | 0.027 | 0.147 | 315.970 | 32.5 | 1.4 |
| 241 | 2004 | 0.304 | 0.013 | 0.493 | 0.017 | 0.136 | 313.860 | 44.7 | 4.0 |
| 257 | 2004 | 0.278 | 0.012 | 0.491 | 0.012 | 0.140 | 311.000 | NA | NA |
| 273 | 2004 | 0.292 | 0.027 | 0.530 | 0.025 | 0.139 | 310.920 | NA | NA |
| 289 | 2004 | 0.238 | 0.012 | 0.385 | 0.015 | 0.147 | 305.920 | 40.6 | 3.4 |
| 305 | 2004 | 0.242 | 0.027 | 0.422 | 0.038 | 0.133 | 300.920 | 6.6 | 0.2 |
| 321 | 2004 | 0.216 | 0.013 | 0.390 | 0.018 | 0.126 | 296.520 | 5.6 | 0.4 |
| 337 | 2004 | 0.202 | 0.011 | 0.377 | 0.013 | 0.124 | 297.960 | 36.3 | 5.1 |
| 353 | 2004 | 0.194 | 0.009 | 0.352 | 0.012 | 0.129 | 295.000 | 13.0 | 0.9 |
| 1 | 2005 | 0.179 | 0.012 | 0.362 | 0.009 | 0.120 | 298.290 | 30.0 | 6.1 |
| 17 | 2005 | 0.178 | 0.009 | 0.340 | 0.012 | 0.118 | 297.570 | 18.3 | 4.2 |
| 33 | 2005 | 0.169 | 0.013 | 0.335 | 0.023 | 0.125 | 294.490 | 51.1 | 7.6 |
| 49 | 2005 | 0.192 | 0.022 | 0.358 | 0.023 | 0.126 | 302.010 | 0.5 | 1.8 |
| 65 | 2005 | 0.206 | 0.038 | 0.365 | 0.036 | 0.130 | 308.010 | 0.3 | 0.0 |
| 81 | 2005 | 0.201 | 0.035 | 0.331 | 0.036 | 0.135 | 310.820 | 0.0 | 0.0 |
| 97 | 2005 | 0.195 | 0.023 | 0.307 | 0.027 | 0.138 | 316.200 | 0.5 | 0.0 |
| 113 | 2005 | 0.178 | 0.026 | 0.296 | 0.035 | 0.138 | 313.530 | 5.3 | 0.3 |
| 129 | 2005 | 0.155 | 0.017 | 0.263 | 0.022 | 0.138 | 323.300 | 0.0 | 0.0 |
| 145 | 2005 | 0.150 | 0.014 | 0.255 | 0.016 | 0.137 | 320.930 | 5.3 | 0.2 |
| 161 | 2005 | 0.154 | 0.015 | 0.244 | 0.025 | 0.142 | 324.120 | 25.9 | 2.0 |
| 177 | 2005 | 0.164 | 0.007 | 0.278 | 0.006 | 0.139 | 325.360 | 6.9 | 0.7 |
| 193 | 2005 | 0.226 | 0.007 | 0.357 | 0.014 | 0.148 | 273.000 | 50.0 | 4.2 |
| 209 | 2005 | 0.394 | 0.020 | 0.551 | 0.019 | 0.152 | 288.840 | 118.1 | 8.0 |
| 225 | 2005 | 0.377 | 0.035 | 0.623 | 0.031 | 0.155 | 311.250 | 17.8 | 0.7 |
| 241 | 2005 | 0.337 | 0.029 | 0.521 | 0.035 | 0.136 | 310.890 | 39.6 | 3.6 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 257 | 2005 | 0.269 | 0.034 | 0.446 | 0.036 | 0.147 | 316.130 | 2.3 | 0.0 |
| 273 | 2005 | 0.219 | 0.019 | 0.340 | 0.025 | 0.143 | 311.970 | 1.5 | 0.0 |
| 289 | 2005 | 0.195 | 0.022 | 0.362 | 0.020 | 0.141 | 310.430 | 0.0 | 0.0 |
| 305 | 2005 | 0.190 | 0.019 | 0.337 | 0.020 | 0.142 | 309.480 | 0.0 | 0.0 |
| 321 | 2005 | 0.192 | 0.016 | 0.305 | 0.021 | 0.142 | 304.970 | 0.0 | 0.0 |
| 337 | 2005 | 0.177 | 0.018 | 0.329 | 0.017 | 0.146 | 299.760 | 2.3 | 0.0 |
| 353 | 2005 | 0.153 | 0.017 | 0.278 | 0.018 | 0.135 | 303.300 | 0.0 | 0.0 |
| 1 | 2006 | 0.147 | 0.016 | 0.274 | 0.016 | 0.139 | 305.000 | 0.0 | 0.0 |
| 17 | 2006 | 0.153 | 0.015 | 0.278 | 0.015 | 0.143 | 303.530 | 0.0 | 0.0 |
| 33 | 2006 | 0.138 | 0.014 | 0.251 | 0.013 | 0.138 | 308.390 | 5.8 | 0.0 |
| 49 | 2006 | 0.135 | 0.010 | 0.214 | 0.014 | 0.143 | 305.740 | 0.0 | 0.0 |
| 65 | 2006 | 0.126 | 0.012 | 0.230 | 0.015 | 0.139 | 309.030 | 6.4 | 0.0 |
| 81 | 2006 | 0.122 | 0.008 | 0.218 | 0.008 | 0.148 | 313.910 | 0.5 | 0.0 |
| 97 | 2006 | 0.135 | 0.016 | 0.199 | 0.017 | 0.155 | 319.820 | 0.0 | 0.0 |
| 113 | 2006 | 0.127 | 0.018 | 0.219 | 0.015 | 0.156 | 319.050 | 0.0 | 0.0 |
| 129 | 2006 | 0.123 | 0.014 | 0.203 | 0.016 | 0.153 | 325.970 | 0.0 | 0.0 |
| 145 | 2006 | 0.131 | 0.013 | 0.209 | 0.014 | 0.154 | 323.890 | 14.2 | 1.5 |
| 161 | 2006 | 0.134 | 0.016 | 0.207 | 0.021 | 0.148 | 327.120 | 7.4 | 0.2 |
| 177 | 2006 | 0.229 | 0.013 | 0.337 | 0.013 | 0.136 | 294.180 | 102.1 | 5.3 |
| 193 | 2006 | 0.275 | 0.014 | 0.380 | 0.013 | 0.135 | 320.910 | NA | NA |
| 209 | 2006 | 0.449 | 0.022 | 0.645 | 0.018 | 0.137 | 290.650 | 13.7 | 13.3 |
| 225 | 2006 | 0.432 | 0.028 | 0.623 | 0.026 | 0.153 | 308.060 | 26.4 | 6.2 |
| 241 | 2006 | 0.420 | 0.017 | 0.637 | 0.020 | 0.142 | 307.080 | 68.8 | 9.0 |
| 257 | 2006 | 0.396 | 0.017 | 0.584 | 0.031 | 0.140 | 309.980 | 0.0 | 0.4 |
| 273 | 2006 | 0.282 | 0.009 | 0.513 | 0.020 | 0.165 | 312.060 | 0.0 | 0.0 |
| 289 | 2006 | 0.208 | 0.006 | 0.380 | 0.006 | 0.142 | 305.730 | | |
| 305 | 2006 | 0.196 | 0.015 | 0.369 | 0.024 | 0.144 | 306.270 | | |
| 321 | 2006 | 0.186 | 0.015 | 0.353 | 0.011 | 0.138 | 302.030 | | |
| 337 | 2006 | 0.169 | 0.011 | 0.339 | 0.014 | 0.140 | 299.170 | | |
| 353 | 2006 | 0.155 | 0.007 | 0.282 | 0.014 | 0.155 | 296.450 | | |
| 9 | 2007 | 0.146 | 0.007 | 0.259 | 0.013 | 0.139 | 299.660 | | |
| 25 | 2007 | 0.121 | 0.003 | 0.232 | 0.003 | 0.133 | NA | | |
| 33 | 2007 | 0.127 | 0.004 | 0.237 | 0.004 | 0.138 | 303.800 | | |
| 49 | 2007 | 0.121 | 0.004 | 0.216 | 0.004 | 0.145 | 305.530 | | |
| 65 | 2007 | 0.127 | 0.013 | 0.248 | 0.023 | 0.148 | 314.680 | | |
| 81 | 2007 | 0.133 | 0.017 | 0.245 | 0.026 | 0.142 | 312.970 | | |
| 97 | 2007 | 0.138 | 0.020 | 0.233 | 0.025 | 0.150 | 313.370 | | |
| 113 | 2007 | 0.142 | 0.020 | 0.246 | 0.026 | 0.147 | 318.560 | | |
| 129 | 2007 | 0.131 | 0.014 | 0.219 | 0.020 | 0.148 | 322.670 | | |
| 145 | 2007 | 0.129 | 0.019 | 0.225 | 0.023 | 0.152 | 323.690 | | |
| 161 | 2007 | 0.137 | 0.011 | 0.196 | 0.012 | 0.151 | 328.220 | | |
| 177 | 2007 | 0.272 | 0.013 | 0.417 | 0.015 | 0.164 | 330.360 | | |
| 193 | 2007 | 0.429 | 0.021 | 0.684 | 0.013 | NA | NA | | |
| 209 | 2007 | 0.418 | 0.022 | 0.650 | 0.016 | 0.146 | NA | | |
| 225 | 2007 | 0.387 | 0.039 | 0.634 | 0.033 | 0.160 | NA | | |

STATION 131

| DOY | Year | EVI mean | EVI std | NDVI mean | NDVI std | Albedo | LST (K) | Rainfall (mm) | Soil moisture (%) |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 2004 | 0.116 | 0.012 | 0.262 | 0.022 | 0.130 | 299.320 | | |
| 17 | 2004 | 0.139 | 0.007 | 0.267 | 0.023 | 0.137 | 295.310 | | |
| 33 | 2004 | 0.137 | 0.019 | 0.278 | 0.028 | 0.137 | 300.600 | | |
| 49 | 2004 | 0.138 | 0.005 | 0.267 | 0.013 | 0.139 | 300.980 | | |
| 65 | 2004 | 0.164 | 0.011 | 0.317 | 0.019 | 0.141 | 309.850 | | |
| 81 | 2004 | 0.183 | 0.006 | 0.305 | 0.010 | 0.145 | 314.100 | | |
| 97 | 2004 | 0.180 | 0.008 | 0.309 | 0.012 | 0.153 | 310.260 | | |
| 113 | 2004 | 0.181 | 0.022 | 0.317 | 0.031 | 0.150 | 317.890 | | |
| 129 | 2004 | 0.153 | 0.021 | 0.283 | 0.031 | 0.151 | 320.680 | | |
| 145 | 2004 | 0.150 | 0.038 | 0.260 | 0.034 | 0.153 | 323.990 | | |
| 161 | 2004 | 0.134 | 0.015 | 0.224 | 0.020 | 0.156 | 323.320 | 4.3 | 2.4 |
| 177 | 2004 | 0.134 | 0.018 | 0.230 | 0.023 | 0.153 | 326.120 | 12.4 | 1.4 |
| 193 | 2004 | 0.383 | 0.157 | 0.384 | 0.061 | 0.170 | 276.590 | 131.8 | 0.8 |
| 209 | 2004 | 0.384 | 0.006 | 0.609 | 0.011 | 0.153 | 310.070 | 36.6 | 3.4 |
| 225 | 2004 | 0.415 | 0.010 | 0.583 | 0.016 | 0.151 | 314.860 | 30.0 | 3.2 |
| 241 | 2004 | 0.340 | 0.019 | 0.546 | 0.019 | 0.160 | 314.030 | 48.8 | 4.2 |
| 257 | 2004 | 0.318 | 0.011 | 0.573 | 0.016 | 0.145 | 309.310 | NA | NA |
| 273 | 2004 | 0.314 | 0.014 | 0.580 | 0.013 | 0.148 | 309.480 | NA | NA |
| 289 | 2004 | 0.264 | 0.005 | 0.449 | 0.012 | 0.147 | 303.500 | 17.8 | 2.9 |
| 305 | 2004 | 0.222 | 0.007 | 0.435 | 0.011 | 0.141 | 301.550 | 3.0 | 1.2 |
| 321 | 2004 | 0.201 | 0.006 | 0.381 | 0.008 | 0.137 | 296.590 | 2.0 | 0.8 |
| 337 | 2004 | 0.190 | 0.011 | 0.369 | 0.011 | 0.134 | 297.320 | 37.3 | 5.1 |
| 353 | 2004 | 0.186 | 0.013 | 0.361 | 0.008 | 0.138 | 294.750 | 10.9 | 1.4 |
| 1 | 2005 | 0.167 | 0.010 | 0.367 | 0.013 | 0.131 | 297.850 | 36.8 | 4.2 |
| 17 | 2005 | 0.173 | 0.006 | 0.360 | 0.009 | 0.129 | 296.340 | 17.8 | 3.5 |
| 33 | 2005 | 0.185 | 0.011 | 0.368 | 0.022 | 0.120 | 296.320 | 44.5 | 4.4 |
| 49 | 2005 | 0.192 | 0.008 | 0.376 | 0.016 | 0.145 | 300.010 | 1.5 | 1.7 |
| 65 | 2005 | 0.190 | 0.020 | 0.380 | 0.018 | 0.136 | 306.090 | 1.3 | 0.4 |
| 81 | 2005 | 0.202 | 0.015 | 0.345 | 0.026 | 0.143 | 309.860 | 0.0 | 0.5 |
| 97 | 2005 | 0.207 | 0.022 | 0.330 | 0.035 | 0.150 | 313.320 | 0.3 | 0.7 |
| 113 | 2005 | 0.156 | 0.020 | 0.285 | 0.020 | 0.148 | 314.380 | 5.6 | 1.1 |
| 129 | 2005 | 0.157 | 0.025 | 0.278 | 0.030 | 0.154 | 321.330 | 0.8 | 1.0 |
| 145 | 2005 | 0.132 | 0.026 | 0.255 | 0.026 | 0.151 | 322.010 | 4.6 | 1.9 |
| 161 | 2005 | 0.145 | 0.016 | 0.244 | 0.028 | 0.154 | 322.940 | 59.7 | 5.2 |
| 177 | 2005 | 0.233 | 0.022 | 0.391 | 0.016 | 0.150 | 322.370 | 7.1 | 3.8 |
| 193 | 2005 | 0.249 | 0.028 | 0.378 | 0.031 | 0.167 | 316.870 | 59.2 | 8.0 |
| 209 | 2005 | 0.393 | 0.047 | 0.542 | 0.079 | 0.149 | 304.460 | 1.0 | 1.9 |
| 225 | 2005 | 0.465 | 0.010 | 0.700 | 0.015 | 0.150 | 308.760 | 11.2 | 4.7 |
| 241 | 2005 | 0.320 | 0.017 | 0.543 | 0.022 | 0.145 | 311.190 | 41.7 | 5.3 |
| 257 | 2005 | 0.271 | 0.010 | 0.519 | 0.012 | 0.147 | 315.290 | 15.5 | 4.1 |
| 273 | 2005 | 0.257 | 0.010 | 0.442 | 0.012 | 0.139 | 309.100 | 31.0 | 4.6 |
| 289 | 2005 | 0.200 | 0.012 | 0.415 | 0.008 | 0.146 | 308.730 | 0.3 | 2.3 |
| 305 | 2005 | 0.194 | 0.017 | 0.358 | 0.019 | 0.147 | 308.350 | 0.0 | 1.8 |
| 321 | 2005 | 0.183 | 0.011 | 0.321 | 0.021 | 0.148 | 304.110 | 0.3 | 1.3 |
| 337 | 2005 | 0.153 | 0.012 | 0.325 | 0.013 | 0.143 | 298.220 | 2.0 | 1.1 |
| 353 | 2005 | 0.143 | 0.010 | 0.286 | 0.023 | 0.147 | 302.520 | 0.0 | 0.8 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 2006 | 0.127 | 0.005 | 0.275 | 0.014 | 0.149 | 303.930 | 0.0 | 0.7 |
| 17 | 2006 | 0.137 | 0.015 | 0.274 | 0.018 | 0.155 | 302.790 | 0.0 | 0.9 |
| 33 | 2006 | 0.125 | 0.016 | 0.253 | 0.015 | 0.148 | 307.590 | 4.1 | 2.0 |
| 49 | 2006 | 0.128 | 0.006 | 0.225 | 0.013 | 0.149 | 306.730 | 0.5 | 1.4 |
| 65 | 2006 | 0.120 | 0.016 | 0.233 | 0.026 | 0.159 | 307.510 | 1.5 | 1.0 |
| 81 | 2006 | 0.116 | 0.003 | 0.220 | 0.005 | 0.161 | 311.170 | 0.0 | 3.4 |
| 97 | 2006 | 0.132 | 0.014 | 0.208 | 0.022 | 0.158 | 319.370 | 0.0 | 1.5 |
| 113 | 2006 | 0.139 | 0.023 | 0.220 | 0.025 | 0.168 | 317.920 | 0.0 | 1.3 |
| 129 | 2006 | 0.121 | 0.020 | 0.222 | 0.023 | 0.168 | 324.470 | 0.0 | 1.7 |
| 145 | 2006 | 0.153 | 0.020 | 0.223 | 0.025 | 0.168 | 321.510 | 20.8 | 4.0 |
| 161 | 2006 | 0.144 | 0.008 | 0.229 | 0.013 | 0.163 | 325.740 | 3.0 | 4.4 |
| 177 | 2006 | 0.202 | 0.006 | 0.317 | 0.011 | 0.151 | 314.600 | 66.3 | 10.5 |
| 193 | 2006 | 0.335 | 0.039 | 0.521 | 0.035 | 0.144 | 318.790 | NA | NA |
| 209 | 2006 | 0.457 | 0.005 | 0.678 | 0.013 | 0.150 | 289.790 | NA | NA |
| 225 | 2006 | 0.408 | 0.031 | 0.624 | 0.018 | 0.153 | 307.540 | 5.6 | 4.2 |
| 241 | 2006 | 0.398 | 0.006 | 0.669 | 0.010 | 0.143 | 307.650 | 54.1 | 5.7 |
| 257 | 2006 | 0.390 | 0.006 | 0.601 | 0.006 | 0.139 | 309.420 | 0.0 | 1.7 |
| 273 | 2006 | 0.225 | 0.009 | 0.373 | 0.018 | 0.156 | 311.480 | 0.0 | 1.2 |
| 289 | 2006 | 0.182 | 0.011 | 0.370 | 0.022 | 0.137 | 305.040 | | |
| 305 | 2006 | 0.193 | 0.012 | 0.367 | 0.024 | 0.135 | 304.960 | | |
| 321 | 2006 | 0.183 | 0.020 | 0.382 | 0.015 | 0.139 | 301.800 | | |
| 337 | 2006 | 0.149 | 0.008 | 0.334 | 0.018 | 0.144 | 299.300 | | |
| 353 | 2006 | 0.147 | 0.008 | 0.303 | 0.017 | 0.140 | 296.350 | | |
| 9 | 2007 | 0.140 | 0.008 | 0.268 | 0.014 | 0.134 | 297.170 | | |
| 25 | 2007 | 0.116 | 0.007 | 0.249 | 0.019 | 0.131 | NA | | |
| 33 | 2007 | 0.127 | 0.010 | 0.258 | 0.019 | 0.134 | 303.690 | | |
| 49 | 2007 | 0.135 | 0.015 | 0.252 | 0.019 | 0.138 | 303.500 | | |
| 65 | 2007 | 0.134 | 0.014 | 0.254 | 0.022 | 0.142 | 314.800 | | |
| 81 | 2007 | 0.138 | 0.027 | 0.258 | 0.042 | 0.140 | 312.490 | | |
| 97 | 2007 | 0.130 | 0.030 | 0.239 | 0.040 | 0.148 | 313.120 | | |
| 113 | 2007 | 0.141 | 0.030 | 0.235 | 0.035 | 0.148 | 318.040 | | |
| 129 | 2007 | 0.139 | 0.033 | 0.231 | 0.040 | 0.150 | 322.160 | | |
| 145 | 2007 | 0.142 | 0.029 | 0.228 | 0.038 | 0.150 | 322.610 | | |
| 161 | 2007 | 0.145 | 0.022 | 0.219 | 0.028 | 0.149 | 327.020 | | |
| 177 | 2007 | 0.360 | 0.009 | 0.498 | 0.010 | 0.162 | 329.930 | | |
| 193 | 2007 | 0.400 | 0.005 | 0.683 | 0.008 | NA | NA | | |
| 209 | 2007 | 0.345 | 0.008 | 0.606 | 0.007 | 0.146 | 307.520 | | |
| 225 | 2007 | 0.296 | 0.016 | 0.559 | 0.009 | 0.149 | NA | | |

STATION 132

| DOY | Year | EVI mean | EVI std | NDVI mean | NDVI std | Albedo | LST (K) | Rainfall (mm) | Soil moisture (%) |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 2004 | 0.171 | 0.010 | 0.373 | 0.022 | 0.126 | 296.380 | | |
| 17 | 2004 | 0.161 | 0.006 | 0.372 | 0.010 | 0.123 | 293.520 | | |
| 33 | 2004 | 0.162 | 0.004 | 0.372 | 0.023 | 0.126 | 298.180 | | |
| 49 | 2004 | 0.167 | 0.010 | 0.319 | 0.018 | 0.136 | 297.330 | | |
| 65 | 2004 | 0.167 | 0.010 | 0.352 | 0.022 | 0.131 | 308.860 | | |
| 81 | 2004 | 0.187 | 0.006 | 0.330 | 0.015 | 0.140 | 312.350 | | |
| 97 | 2004 | 0.200 | 0.014 | 0.352 | 0.018 | 0.140 | 309.520 | | |
| 113 | 2004 | 0.188 | 0.007 | 0.362 | 0.011 | 0.141 | 315.530 | | |
| 129 | 2004 | 0.161 | 0.006 | 0.321 | 0.019 | 0.145 | 318.610 | | |
| 145 | 2004 | 0.148 | 0.007 | 0.295 | 0.013 | 0.142 | 321.270 | | |
| 161 | 2004 | 0.142 | 0.003 | 0.264 | 0.006 | 0.146 | 322.280 | 14.5 | 2.4 |
| 177 | 2004 | 0.162 | 0.008 | 0.282 | 0.016 | 0.145 | 321.990 | 2.5 | 2.1 |
| 193 | 2004 | 0.282 | 0.052 | 0.443 | 0.061 | 0.145 | 308.160 | 129.3 | 7.3 |
| 209 | 2004 | 0.533 | 0.045 | 0.751 | 0.029 | 0.155 | 306.710 | 34.3 | 6.2 |
| 225 | 2004 | 0.470 | 0.029 | 0.662 | 0.028 | 0.151 | 313.710 | 3.6 | 3.4 |
| 241 | 2004 | 0.375 | 0.018 | 0.627 | 0.032 | 0.149 | 311.770 | 65.3 | 6.5 |
| 257 | 2004 | 0.350 | 0.021 | 0.625 | 0.019 | 0.139 | 308.040 | NA | NA |
| 273 | 2004 | 0.301 | 0.018 | 0.593 | 0.032 | 0.140 | 310.380 | NA | NA |
| 289 | 2004 | 0.233 | 0.008 | 0.486 | 0.028 | 0.136 | 300.350 | 35.3 | 5.0 |
| 305 | 2004 | 0.205 | 0.006 | 0.437 | 0.019 | 0.127 | 299.630 | 5.3 | 4.5 |
| 321 | 2004 | 0.204 | 0.011 | 0.494 | 0.024 | 0.124 | 294.770 | 8.4 | 5.6 |
| 337 | 2004 | 0.193 | 0.018 | 0.430 | 0.014 | 0.124 | 297.500 | 39.6 | 7.2 |
| 353 | 2004 | 0.194 | 0.015 | 0.408 | 0.014 | 0.129 | 294.640 | 18.0 | 4.9 |
| 1 | 2005 | 0.196 | 0.008 | 0.410 | 0.014 | 0.123 | 295.510 | 64.3 | 8.2 |
| 17 | 2005 | 0.201 | 0.006 | 0.437 | 0.021 | 0.122 | 294.510 | 29.5 | 7.9 |
| 33 | 2005 | 0.229 | 0.006 | 0.415 | 0.016 | 0.122 | 293.040 | 63.8 | 10.7 |
| 49 | 2005 | 0.221 | 0.005 | 0.425 | 0.025 | 0.131 | 297.450 | 1.3 | 5.9 |
| 65 | 2005 | 0.219 | 0.011 | 0.440 | 0.024 | 0.134 | 304.000 | 0.0 | 2.8 |
| 81 | 2005 | 0.222 | 0.010 | 0.419 | 0.026 | 0.135 | 306.540 | 0.0 | 2.1 |
| 97 | 2005 | 0.210 | 0.008 | 0.388 | 0.018 | 0.143 | 311.250 | 0.5 | 2.1 |
| 113 | 2005 | 0.194 | 0.013 | 0.378 | 0.025 | 0.140 | 309.790 | 5.8 | 3.8 |
| 129 | 2005 | 0.186 | 0.011 | 0.335 | 0.015 | 0.149 | 319.320 | 0.0 | 2.5 |
| 145 | 2005 | 0.176 | 0.007 | 0.356 | 0.015 | 0.143 | 316.670 | 17.5 | 4.5 |
| 161 | 2005 | 0.197 | 0.010 | 0.375 | 0.018 | 0.145 | 319.050 | 57.9 | 5.7 |
| 177 | 2005 | 0.291 | 0.019 | 0.508 | 0.032 | 0.146 | 319.070 | 16.8 | 4.8 |
| 193 | 2005 | 0.396 | 0.040 | 0.653 | 0.047 | 0.142 | 313.020 | 80.8 | 7.4 |
| 209 | 2005 | 0.448 | 0.037 | 0.791 | 0.029 | 0.152 | 303.050 | 18.8 | 9.3 |
| 225 | 2005 | 0.484 | 0.036 | 0.797 | 0.033 | 0.158 | 306.750 | 21.8 | 2.2 |
| 241 | 2005 | 0.411 | 0.075 | 0.665 | 0.028 | 0.151 | 307.910 | 81.3 | 4.3 |
| 257 | 2005 | 0.375 | 0.021 | 0.685 | 0.022 | 0.150 | 312.500 | 2.8 | 0.5 |
| 273 | 2005 | 0.311 | 0.009 | 0.521 | 0.017 | 0.142 | 309.540 | 10.2 | 1.1 |
| 289 | 2005 | 0.233 | 0.013 | 0.493 | 0.023 | 0.143 | 307.290 | 0.3 | 0.5 |
| 305 | 2005 | 0.203 | 0.016 | 0.412 | 0.012 | 0.144 | 307.150 | 0.0 | 0.0 |
| 321 | 2005 | 0.190 | 0.027 | 0.385 | 0.010 | 0.143 | 303.220 | 0.0 | 0.0 |
| 337 | 2005 | 0.183 | 0.014 | 0.410 | 0.016 | 0.138 | 297.610 | 3.0 | 0.0 |
| 353 | 2005 | 0.162 | 0.010 | 0.355 | 0.019 | 0.140 | 301.620 | 0.0 | 0.0 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 2006 | 0.159 | 0.009 | 0.352 | 0.022 | 0.142 | 302.070 | 0.0 | 0.0 |
| 17 | 2006 | 0.156 | 0.008 | 0.344 | 0.009 | 0.144 | 301.300 | 0.0 | 0.0 |
| 33 | 2006 | 0.145 | 0.009 | 0.324 | 0.017 | 0.142 | 303.580 | 2.5 | 0.0 |
| 49 | 2006 | 0.150 | 0.008 | 0.274 | 0.009 | 0.147 | 303.610 | 2.0 | 0.0 |
| 65 | 2006 | 0.140 | 0.006 | 0.290 | 0.011 | 0.155 | 303.070 | 2.5 | 0.1 |
| 81 | 2006 | 0.137 | 0.007 | 0.279 | 0.011 | 0.155 | 309.210 | 0.0 | 0.1 |
| 97 | 2006 | 0.147 | 0.007 | 0.241 | 0.014 | 0.158 | 315.150 | 0.0 | 0.0 |
| 113 | 2006 | 0.146 | 0.008 | 0.250 | 0.008 | 0.155 | 316.120 | 0.0 | 0.0 |
| 129 | 2006 | 0.132 | 0.004 | 0.250 | 0.008 | 0.160 | 322.390 | 0.0 | 0.0 |
| 145 | 2006 | 0.141 | 0.008 | 0.252 | 0.007 | 0.161 | 322.070 | 6.6 | 0.9 |
| 161 | 2006 | 0.138 | 0.009 | 0.250 | 0.013 | 0.161 | 324.760 | 10.7 | 0.8 |
| 177 | 2006 | 0.185 | 0.030 | 0.326 | 0.045 | 0.144 | 318.110 | 93.5 | 5.1 |
| 193 | 2006 | 0.394 | 0.022 | 0.627 | 0.046 | 0.154 | 312.750 | 96.8 | 7.8 |
| 209 | 2006 | 0.488 | 0.026 | 0.738 | 0.024 | 0.150 | 288.160 | NA | NA |
| 225 | 2006 | 0.496 | 0.027 | 0.743 | 0.025 | 0.156 | 302.470 | NA | NA |
| 241 | 2006 | 0.504 | 0.035 | 0.799 | 0.031 | 0.142 | 302.050 | 54.4 | 12.8 |
| 257 | 2006 | 0.502 | 0.022 | 0.719 | 0.025 | 0.143 | 305.670 | 2.0 | 3.4 |
| 273 | 2006 | 0.366 | 0.009 | 0.669 | 0.018 | 0.146 | 307.660 | 0.0 | 2.5 |
| 289 | 2006 | 0.278 | 0.015 | 0.547 | 0.026 | 0.136 | 302.970 | | |
| 305 | 2006 | 0.252 | 0.013 | 0.523 | 0.008 | 0.131 | 303.650 | | |
| 321 | 2006 | 0.246 | 0.015 | 0.533 | 0.019 | 0.133 | 300.210 | | |
| 337 | 2006 | 0.213 | 0.016 | 0.398 | 0.015 | 0.130 | 298.060 | | |
| 353 | 2006 | 0.193 | 0.019 | 0.397 | 0.009 | 0.134 | 294.500 | | |
| 9 | 2007 | 0.187 | 0.008 | 0.365 | 0.012 | 0.130 | 295.480 | | |
| 25 | 2007 | 0.158 | 0.007 | 0.343 | 0.015 | 0.129 | NA | | |
| 33 | 2007 | 0.166 | 0.006 | 0.351 | 0.012 | 0.133 | 301.290 | | |
| 49 | 2007 | 0.155 | 0.004 | 0.319 | 0.012 | 0.136 | 301.200 | | |
| 65 | 2007 | 0.159 | 0.006 | 0.327 | 0.012 | 0.144 | 312.390 | | |
| 81 | 2007 | 0.164 | 0.009 | 0.321 | 0.012 | 0.140 | 308.640 | | |
| 97 | 2007 | 0.164 | 0.010 | 0.318 | 0.012 | 0.145 | 309.910 | | |
| 113 | 2007 | 0.169 | 0.008 | 0.308 | 0.017 | 0.145 | 314.320 | | |
| 129 | 2007 | 0.157 | 0.009 | 0.285 | 0.020 | 0.148 | 319.090 | | |
| 145 | 2007 | 0.153 | 0.005 | 0.294 | 0.010 | 0.151 | 320.730 | | |
| 161 | 2007 | 0.168 | 0.001 | 0.255 | 0.003 | 0.148 | 323.060 | | |
| 177 | 2007 | 0.397 | 0.037 | 0.677 | 0.031 | 0.151 | 327.040 | | |
| 193 | 2007 | 0.461 | 0.027 | 0.753 | 0.030 | 0.148 | NA | | |
| 209 | 2007 | 0.428 | 0.018 | 0.687 | 0.020 | 0.148 | 305.990 | | |
| 225 | 2007 | 0.399 | 0.021 | 0.697 | 0.033 | 0.145 | NA | | |

STATION 133

| DOY | Year | EVI mean | EVI std | NDVI mean | NDVI std | Albedo | LST (K) | Rainfall (mm) | Soil moisture (%) |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 2004 | 0.161 | 0.002 | 0.294 | 0.004 | 0.157 | 298.660 | | |
| 17 | 2004 | 0.168 | 0.011 | 0.302 | 0.003 | 0.147 | 295.740 | | |
| 33 | 2004 | 0.159 | 0.003 | 0.303 | 0.005 | 0.155 | 300.930 | | |
| 49 | 2004 | 0.155 | 0.009 | 0.255 | 0.011 | 0.153 | 298.320 | | |
| 65 | 2004 | 0.177 | 0.019 | 0.301 | 0.024 | 0.154 | 309.110 | | |
| 81 | 2004 | 0.178 | 0.013 | 0.278 | 0.015 | 0.164 | 313.600 | | |
| 97 | 2004 | 0.188 | 0.030 | 0.288 | 0.046 | 0.163 | 312.360 | | |
| 113 | 2004 | 0.173 | 0.019 | 0.267 | 0.027 | 0.167 | 319.470 | | |
| 129 | 2004 | 0.147 | 0.013 | 0.240 | 0.014 | 0.174 | 322.250 | | |
| 145 | 2004 | 0.147 | 0.017 | 0.225 | 0.022 | 0.177 | 324.780 | | |
| 161 | 2004 | 0.141 | 0.015 | 0.212 | 0.017 | 0.180 | 325.030 | 5.6 | 0.1 |
| 177 | 2004 | 0.146 | 0.013 | 0.210 | 0.016 | 0.171 | 328.320 | 0.8 | 0.0 |
| 193 | 2004 | 0.220 | 0.087 | 0.286 | 0.113 | 0.180 | 298.770 | 113.5 | 8.0 |
| 209 | 2004 | 0.357 | 0.027 | 0.525 | 0.034 | 0.176 | 309.080 | 39.4 | 4.4 |
| 225 | 2004 | 0.379 | 0.028 | 0.515 | 0.028 | 0.184 | 309.830 | 4.1 | 0.4 |
| 241 | 2004 | 0.298 | 0.016 | 0.468 | 0.019 | 0.186 | 314.030 | 45.5 | 5.8 |
| 257 | 2004 | 0.305 | 0.014 | 0.487 | 0.013 | 0.162 | 311.320 | NA | NA |
| 273 | 2004 | 0.251 | 0.010 | 0.421 | 0.014 | 0.177 | 312.690 | NA | NA |
| 289 | 2004 | 0.223 | 0.015 | 0.361 | 0.022 | 0.175 | 304.890 | 33.8 | 6.1 |
| 305 | 2004 | 0.224 | 0.005 | 0.382 | 0.007 | 0.161 | 301.440 | 2.8 | 1.8 |
| 321 | 2004 | 0.212 | 0.007 | 0.347 | 0.007 | 0.163 | 297.640 | 2.8 | 1.7 |
| 337 | 2004 | 0.223 | 0.018 | 0.364 | 0.010 | 0.159 | 299.080 | 31.8 | 8.4 |
| 353 | 2004 | 0.214 | 0.006 | 0.368 | 0.010 | 0.154 | 296.050 | 10.4 | 0.8 |
| 1 | 2005 | 0.206 | 0.016 | 0.365 | 0.019 | 0.151 | 297.940 | 40.4 | 11.4 |
| 17 | 2005 | 0.200 | 0.011 | 0.365 | 0.015 | 0.148 | 297.400 | 26.9 | 10.5 |
| 33 | 2005 | 0.200 | 0.012 | 0.369 | 0.017 | 0.153 | 297.310 | 58.2 | 14.0 |
| 49 | 2005 | 0.235 | 0.045 | 0.396 | 0.044 | 0.154 | 298.960 | 1.8 | 7.2 |
| 65 | 2005 | 0.235 | 0.025 | 0.393 | 0.021 | 0.159 | 306.290 | 0.0 | 0.5 |
| 81 | 2005 | 0.223 | 0.015 | 0.371 | 0.017 | 0.162 | 309.390 | 0.0 | 0.0 |
| 97 | 2005 | 0.206 | 0.011 | 0.321 | 0.014 | 0.167 | 314.750 | 0.3 | 0.0 |
| 113 | 2005 | 0.187 | 0.015 | 0.278 | 0.019 | 0.164 | 315.210 | 3.8 | 0.8 |
| 129 | 2005 | 0.168 | 0.021 | 0.271 | 0.017 | 0.176 | 322.620 | 0.0 | 0.0 |
| 145 | 2005 | 0.159 | 0.011 | 0.242 | 0.010 | 0.176 | 322.660 | 0.8 | 0.0 |
| 161 | 2005 | 0.153 | 0.013 | 0.248 | 0.016 | 0.180 | 323.360 | 62.0 | 3.7 |
| 177 | 2005 | 0.195 | 0.007 | 0.283 | 0.013 | 0.181 | 324.530 | 0.0 | 0.1 |
| 193 | 2005 | 0.223 | 0.011 | 0.302 | 0.010 | 0.200 | 317.600 | 35.8 | 0.0 |
| 209 | 2005 | 0.473 | 0.018 | 0.696 | 0.017 | 0.177 | 288.950 | 121.7 | 14.9 |
| 225 | 2005 | 0.487 | 0.028 | 0.676 | 0.017 | 0.172 | 312.150 | 17.5 | 9.1 |
| 241 | 2005 | 0.315 | 0.034 | 0.496 | 0.020 | 0.166 | 313.320 | 8.4 | 4.7 |
| 257 | 2005 | 0.258 | 0.009 | 0.440 | 0.013 | 0.177 | 317.230 | 2.3 | 2.5 |
| 273 | 2005 | 0.236 | 0.009 | 0.356 | 0.007 | 0.163 | 313.700 | 15.5 | 4.7 |
| 289 | 2005 | 0.206 | 0.010 | 0.369 | 0.015 | 0.173 | 309.760 | 0.0 | 3.3 |
| 305 | 2005 | 0.188 | 0.008 | 0.319 | 0.013 | 0.175 | 308.970 | 0.0 | 1.2 |
| 321 | 2005 | 0.188 | 0.010 | 0.310 | 0.011 | 0.181 | 305.510 | 0.0 | 0.3 |
| 337 | 2005 | 0.182 | 0.005 | 0.315 | 0.007 | 0.187 | 298.880 | 1.5 | 0.5 |
| 353 | 2005 | 0.171 | 0.005 | 0.287 | 0.007 | 0.179 | 304.090 | 0.0 | 0.3 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 2006 | 0.164 | 0.004 | 0.282 | 0.008 | 0.180 | 304.010 | 0.0 | 0.1 |
| 17 | 2006 | 0.171 | 0.008 | 0.284 | 0.009 | 0.187 | 303.430 | 0.0 | 0.1 |
| 33 | 2006 | 0.157 | 0.010 | 0.263 | 0.015 | 0.184 | 307.650 | 3.6 | 0.9 |
| 49 | 2006 | 0.155 | 0.023 | 0.230 | 0.029 | 0.183 | 309.540 | 1.5 | 0.7 |
| 65 | 2006 | 0.146 | 0.013 | 0.232 | 0.019 | 0.182 | 309.990 | 4.6 | 1.6 |
| 81 | 2006 | 0.134 | 0.006 | 0.220 | 0.010 | 0.185 | 314.540 | 0.0 | 2.4 |
| 97 | 2006 | 0.139 | 0.019 | 0.218 | 0.017 | 0.195 | 320.270 | 0.0 | 0.5 |
| 113 | 2006 | 0.144 | 0.010 | 0.206 | 0.020 | 0.196 | 319.520 | 0.0 | 0.4 |
| 129 | 2006 | 0.138 | 0.019 | 0.205 | 0.025 | 0.198 | 325.650 | 0.0 | 0.4 |
| 145 | 2006 | 0.142 | 0.013 | 0.203 | 0.014 | 0.199 | 325.360 | 6.6 | 2.4 |
| 161 | 2006 | 0.132 | 0.012 | 0.205 | 0.011 | 0.192 | 329.130 | 9.4 | 2.9 |
| 177 | 2006 | 0.248 | 0.018 | 0.314 | 0.023 | 0.191 | 296.010 | 141.0 | 12.4 |
| 193 | 2006 | 0.291 | 0.029 | 0.422 | 0.021 | 0.180 | 316.500 | 51.1 | 7.9 |
| 209 | 2006 | 0.430 | 0.021 | 0.605 | 0.020 | 0.178 | 291.460 | 36.6 | 13.4 |
| 225 | 2006 | 0.433 | 0.015 | 0.523 | 0.019 | 0.167 | 309.220 | 20.1 | 7.6 |
| 241 | 2006 | 0.436 | 0.021 | 0.620 | 0.022 | 0.159 | 307.310 | 101.6 | 12.3 |
| 257 | 2006 | 0.423 | 0.009 | 0.600 | 0.011 | 0.167 | 310.010 | 0.0 | 5.4 |
| 273 | 2006 | 0.304 | 0.009 | 0.492 | 0.010 | 0.189 | 311.110 | | |
| 289 | 2006 | 0.231 | 0.012 | 0.398 | 0.013 | 0.167 | 305.170 | | |
| 305 | 2006 | 0.243 | 0.015 | 0.429 | 0.020 | 0.157 | 305.950 | | |
| 321 | 2006 | 0.228 | 0.011 | 0.407 | 0.012 | 0.165 | 302.040 | | |
| 337 | 2006 | 0.197 | 0.013 | 0.343 | 0.018 | 0.173 | 298.630 | | |
| 353 | 2006 | 0.186 | 0.004 | 0.310 | 0.003 | 0.178 | 296.330 | | |
| 9 | 2007 | 0.177 | 0.004 | 0.287 | 0.006 | 0.156 | 298.320 | | |
| 25 | 2007 | 0.148 | 0.006 | 0.260 | 0.008 | 0.151 | NA | | |
| 33 | 2007 | 0.155 | 0.007 | 0.270 | 0.015 | 0.154 | 303.260 | | |
| 49 | 2007 | 0.142 | 0.008 | 0.240 | 0.009 | 0.158 | 304.010 | | |
| 65 | 2007 | 0.152 | 0.015 | 0.252 | 0.021 | 0.158 | 313.050 | | |
| 81 | 2007 | 0.146 | 0.021 | 0.247 | 0.033 | 0.157 | 311.030 | | |
| 97 | 2007 | 0.150 | 0.022 | 0.240 | 0.028 | 0.166 | 313.020 | | |
| 113 | 2007 | 0.149 | 0.026 | 0.219 | 0.028 | 0.165 | 318.180 | | |
| 129 | 2007 | 0.138 | 0.015 | 0.214 | 0.019 | 0.165 | 322.530 | | |
| 145 | 2007 | 0.139 | 0.011 | 0.217 | 0.016 | 0.169 | 323.920 | | |
| 161 | 2007 | 0.145 | 0.006 | 0.193 | 0.007 | 0.164 | 327.580 | | |
| 177 | 2007 | 0.351 | 0.032 | 0.491 | 0.035 | 0.176 | 330.630 | | |
| 193 | 2007 | 0.411 | 0.019 | 0.621 | 0.021 | NA | NA | | |
| 209 | 2007 | 0.421 | 0.018 | 0.626 | 0.021 | 0.162 | 309.630 | | |
| 225 | 2007 | 0.409 | 0.016 | 0.633 | 0.018 | 0.155 | NA | | |

STATION 134

| DOY | Year | EVI mean | EVI std | NDVI mean | NDVI std | Albedo | LST (K) | Rainfall (mm) | Soil moisture (%) |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 2004 | 0.112 | 0.015 | 0.286 | 0.025 | 0.133 | 297.490 | | |
| 17 | 2004 | 0.115 | 0.007 | 0.267 | 0.022 | 0.126 | 294.720 | | |
| 33 | 2004 | 0.110 | 0.008 | 0.274 | 0.031 | 0.130 | 298.980 | | |
| 49 | 2004 | 0.125 | 0.008 | 0.236 | 0.015 | 0.133 | 297.370 | | |
| 65 | 2004 | 0.116 | 0.006 | 0.253 | 0.025 | 0.132 | 308.220 | | |
| 81 | 2004 | 0.147 | 0.007 | 0.254 | 0.016 | 0.142 | 312.240 | | |
| 97 | 2004 | 0.151 | 0.007 | 0.276 | 0.014 | 0.134 | 310.800 | | |
| 113 | 2004 | 0.169 | 0.008 | 0.308 | 0.011 | 0.140 | 314.900 | | |
| 129 | 2004 | 0.156 | 0.013 | 0.312 | 0.017 | 0.143 | 319.910 | | |
| 145 | 2004 | 0.165 | 0.022 | 0.291 | 0.004 | 0.141 | 322.310 | | |
| 161 | 2004 | 0.155 | 0.006 | 0.272 | 0.012 | 0.145 | 321.580 | | |
| 177 | 2004 | 0.179 | 0.011 | 0.297 | 0.011 | 0.145 | 320.030 | | |
| 193 | 2004 | 0.225 | 0.009 | 0.357 | 0.015 | 0.139 | 312.780 | | |
| 209 | 2004 | 0.316 | 0.011 | 0.479 | 0.017 | 0.137 | 309.800 | | |
| 225 | 2004 | 0.272 | 0.014 | 0.473 | 0.040 | 0.136 | 310.510 | | |
| 241 | 2004 | 0.245 | 0.009 | 0.493 | 0.025 | 0.141 | 313.300 | | |
| 257 | 2004 | 0.229 | 0.012 | 0.409 | 0.018 | 0.132 | 308.910 | | |
| 273 | 2004 | 0.215 | 0.014 | 0.416 | 0.027 | 0.135 | 308.980 | | |
| 289 | 2004 | 0.193 | 0.011 | 0.360 | 0.017 | 0.130 | 304.100 | | |
| 305 | 2004 | 0.158 | 0.020 | 0.360 | 0.015 | 0.132 | 298.550 | | |
| 321 | 2004 | 0.161 | 0.020 | 0.358 | 0.016 | 0.128 | 294.060 | | |
| 337 | 2004 | 0.139 | 0.014 | 0.323 | 0.025 | 0.129 | 294.620 | | |
| 353 | 2004 | 0.146 | 0.017 | 0.299 | 0.020 | 0.135 | 293.280 | | |
| 1 | 2005 | 0.111 | 0.019 | 0.312 | 0.033 | 0.124 | 296.690 | | |
| 17 | 2005 | 0.119 | 0.010 | 0.294 | 0.030 | 0.124 | 295.860 | | |
| 33 | 2005 | 0.115 | 0.008 | 0.281 | 0.034 | 0.122 | 295.180 | | |
| 49 | 2005 | 0.133 | 0.009 | 0.260 | 0.021 | 0.125 | 296.650 | | |
| 65 | 2005 | 0.146 | 0.009 | 0.298 | 0.026 | 0.129 | 304.490 | | |
| 81 | 2005 | 0.151 | 0.008 | 0.305 | 0.028 | 0.134 | 307.810 | | |
| 97 | 2005 | 0.168 | 0.012 | 0.320 | 0.013 | 0.137 | 312.540 | | |
| 113 | 2005 | 0.169 | 0.007 | 0.350 | 0.013 | 0.137 | 310.230 | | |
| 129 | 2005 | 0.178 | 0.010 | 0.335 | 0.011 | 0.143 | 318.650 | | |
| 145 | 2005 | 0.165 | 0.005 | 0.314 | 0.014 | 0.140 | 318.340 | | |
| 161 | 2005 | 0.179 | 0.009 | 0.314 | 0.013 | 0.141 | 321.320 | | |
| 177 | 2005 | 0.200 | 0.010 | 0.335 | 0.009 | 0.138 | 321.830 | | |
| 193 | 2005 | 0.218 | 0.011 | 0.319 | 0.014 | 0.139 | 298.780 | | |
| 209 | 2005 | 0.283 | 0.012 | 0.470 | 0.017 | 0.128 | 305.870 | | |
| 225 | 2005 | 0.260 | 0.020 | 0.531 | 0.029 | 0.143 | 309.660 | | |
| 241 | 2005 | 0.247 | 0.017 | 0.523 | 0.026 | 0.138 | 310.260 | | |
| 257 | 2005 | 0.216 | 0.017 | 0.429 | 0.023 | 0.138 | 314.810 | | |
| 273 | 2005 | 0.181 | 0.019 | 0.355 | 0.014 | 0.139 | 311.650 | | |
| 289 | 2005 | 0.165 | 0.017 | 0.396 | 0.014 | 0.144 | 306.650 | | |
| 305 | 2005 | 0.160 | 0.028 | 0.349 | 0.009 | 0.147 | 306.070 | | |
| 321 | 2005 | 0.148 | 0.026 | 0.340 | 0.012 | 0.147 | 302.430 | | |
| 337 | 2005 | 0.146 | 0.024 | 0.366 | 0.018 | 0.154 | 297.410 | | |
| 353 | 2005 | 0.136 | 0.016 | 0.302 | 0.011 | 0.146 | 301.000 | | |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 1 | 2006 | 0.130 | 0.018 | 0.303 | 0.013 | 0.150 | 301.440 |
| 17 | 2006 | 0.128 | 0.017 | 0.284 | 0.009 | 0.152 | 300.940 |
| 33 | 2006 | 0.125 | 0.010 | 0.289 | 0.015 | 0.149 | 304.280 |
| 49 | 2006 | 0.134 | 0.005 | 0.254 | 0.015 | 0.151 | 305.120 |
| 65 | 2006 | 0.126 | 0.003 | 0.271 | 0.014 | 0.159 | 304.930 |
| 81 | 2006 | 0.127 | 0.005 | 0.257 | 0.011 | 0.162 | 309.720 |
| 97 | 2006 | 0.137 | 0.003 | 0.226 | 0.009 | 0.161 | 316.790 |
| 113 | 2006 | 0.131 | 0.005 | 0.241 | 0.009 | 0.161 | 317.640 |
| 129 | 2006 | 0.134 | 0.009 | 0.247 | 0.009 | 0.165 | 322.120 |
| 145 | 2006 | 0.130 | 0.007 | 0.244 | 0.009 | 0.163 | 322.470 |
| 161 | 2006 | 0.132 | 0.006 | 0.249 | 0.009 | 0.161 | 324.310 |
| 177 | 2006 | 0.188 | 0.018 | 0.291 | 0.028 | 0.135 | 312.750 |
| 193 | 2006 | 0.205 | 0.014 | 0.344 | 0.023 | 0.141 | 319.040 |
| 209 | 2006 | 0.297 | 0.020 | 0.504 | 0.022 | 0.136 | 290.460 |
| 225 | 2006 | 0.343 | 0.025 | 0.582 | 0.022 | 0.133 | 306.500 |
| 241 | 2006 | 0.311 | 0.058 | 0.523 | 0.037 | 0.146 | 304.950 |
| 257 | 2006 | 0.309 | 0.028 | 0.521 | 0.030 | 0.141 | 306.210 |
| 273 | 2006 | 0.258 | 0.017 | 0.438 | 0.018 | 0.143 | 306.990 |
| 289 | 2006 | 0.192 | 0.024 | 0.440 | 0.024 | 0.130 | 304.330 |
| 305 | 2006 | 0.172 | 0.034 | 0.401 | 0.020 | 0.130 | 304.080 |
| 321 | 2006 | 0.170 | 0.027 | 0.412 | 0.026 | 0.137 | 299.960 |
| 337 | 2006 | 0.147 | 0.029 | 0.362 | 0.020 | 0.141 | 297.250 |
| 353 | 2006 | 0.139 | 0.024 | 0.308 | 0.016 | 0.135 | 293.720 |
| 9 | 2007 | 0.134 | 0.013 | 0.263 | 0.009 | 0.1405 | 295.54 |
| 25 | 2007 | 0.117 | 0.011 | 0.287 | 0.023 | 0.1365 | NA |
| 33 | 2007 | 0.123 | 0.011 | 0.282 | 0.026 | 0.131 | 301.1 |
| 49 | 2007 | 0.120 | 0.007 | 0.254 | 0.019 | 0.142 | 302.28 |
| 65 | 2007 | 0.129 | 0.003 | 0.269 | 0.026 | 0.144 | 312.56 |
| 81 | 2007 | 0.132 | 0.006 | 0.286 | 0.020 | 0.144 | 308.22 |
| 97 | 2007 | 0.139 | 0.008 | 0.268 | 0.016 | 0.146 | 310.22 |
| 113 | 2007 | 0.152 | 0.010 | 0.294 | 0.014 | 0.1475 | 315.27 |
| 129 | 2007 | 0.158 | 0.010 | 0.276 | 0.014 | 0.149 | 319.77 |
| 145 | 2007 | 0.139 | 0.008 | 0.275 | 0.006 | 0.149 | 321.72 |
| 161 | 2007 | 0.181 | 0.007 | 0.372 | 0.013 | 0.154 | 323.89 |
| 177 | 2007 | 0.288 | 0.020 | 0.489 | 0.033 | 0.146 | 321.84 |
| 193 | 2007 | 0.343 | 0.031 | 0.522 | 0.041 | 0.144 | 312.41 |
| 209 | 2007 | 0.336 | 0.036 | 0.589 | 0.036 | 0.141 | 307.24 |
| 225 | 2007 | 0.294 | 0.030 | 0.613 | 0.026 | 0.14 | NA |

STATION 135

| DOY | Year | EVI mean | EVI std | NDVI mean | NDVI std | Albedo | LST (K) | Rainfall (mm) | Soil moisture (%) |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 2004 | 0.106 | 0.005 | 0.243 | 0.008 | 0.120 | 298.520 | | |
| 17 | 2004 | 0.101 | 0.005 | 0.226 | 0.007 | 0.113 | 295.030 | | |
| 33 | 2004 | 0.101 | 0.004 | 0.213 | 0.007 | 0.119 | 300.460 | | |
| 49 | 2004 | 0.098 | 0.004 | 0.225 | 0.007 | 0.125 | 301.510 | | |
| 65 | 2004 | 0.122 | 0.002 | 0.248 | 0.004 | 0.121 | 309.810 | | |
| 81 | 2004 | 0.146 | 0.003 | 0.251 | 0.005 | 0.135 | 314.290 | | |
| 97 | 2004 | 0.189 | 0.011 | 0.324 | 0.018 | 0.140 | 311.750 | | |
| 113 | 2004 | 0.203 | 0.012 | 0.355 | 0.021 | 0.137 | 317.030 | | |
| 129 | 2004 | 0.190 | 0.012 | 0.346 | 0.021 | 0.140 | 321.310 | | |
| 145 | 2004 | 0.180 | 0.012 | 0.328 | 0.023 | 0.140 | 323.610 | | |
| 161 | 2004 | 0.175 | 0.010 | 0.298 | 0.017 | 0.141 | 324.350 | 30.5 | 33.8 |
| 177 | 2004 | 0.201 | 0.013 | 0.323 | 0.022 | 0.144 | 322.620 | 13.2 | 11.9 |
| 193 | 2004 | 0.285 | 0.028 | 0.423 | 0.033 | 0.160 | 316.040 | 56.9 | 27.1 |
| 209 | 2004 | 0.320 | 0.013 | 0.579 | 0.013 | 0.155 | 291.450 | 34.3 | 20.9 |
| 225 | 2004 | 0.315 | 0.016 | 0.468 | 0.020 | 0.139 | 316.390 | 15.0 | 14.7 |
| 241 | 2004 | 0.275 | 0.015 | 0.440 | 0.022 | 0.137 | 315.970 | 24.9 | 21.6 |
| 257 | 2004 | 0.216 | 0.005 | 0.429 | 0.007 | 0.132 | 310.620 | NA | NA |
| 273 | 2004 | 0.227 | 0.010 | 0.444 | 0.017 | 0.142 | 309.630 | NA | NA |
| 289 | 2004 | 0.233 | 0.003 | 0.393 | 0.005 | 0.153 | 303.820 | 2.3 | 36.9 |
| 305 | 2004 | 0.202 | 0.010 | 0.393 | 0.013 | 0.137 | 298.800 | 2.5 | 23.9 |
| 321 | 2004 | 0.183 | 0.007 | 0.362 | 0.012 | 0.134 | 295.380 | 9.9 | 25.9 |
| 337 | 2004 | 0.148 | 0.008 | 0.296 | 0.013 | 0.132 | 295.740 | 35.3 | 32.8 |
| 353 | 2004 | 0.139 | 0.007 | 0.280 | 0.010 | 0.136 | 294.960 | 11.7 | 25.9 |
| 1 | 2005 | 0.128 | 0.013 | 0.278 | 0.019 | 0.125 | 295.740 | 25.1 | 34.6 |
| 17 | 2005 | 0.148 | 0.018 | 0.308 | 0.032 | 0.125 | 295.230 | 22.4 | 35.3 |
| 33 | 2005 | 0.166 | 0.027 | 0.345 | 0.045 | 0.123 | 295.400 | 65.8 | 37.9 |
| 49 | 2005 | 0.195 | 0.032 | 0.366 | 0.044 | 0.126 | 298.460 | 2.3 | 34.2 |
| 65 | 2005 | 0.245 | 0.035 | 0.408 | 0.048 | 0.134 | 306.400 | 0.0 | 17.3 |
| 81 | 2005 | 0.236 | 0.036 | 0.390 | 0.042 | 0.139 | 309.780 | 0.0 | 8.6 |
| 97 | 2005 | 0.208 | 0.013 | 0.349 | 0.019 | 0.141 | 313.420 | 0.0 | 2.8 |
| 113 | 2005 | 0.215 | 0.011 | 0.387 | 0.016 | 0.143 | 310.330 | 12.7 | 7.9 |
| 129 | 2005 | 0.217 | 0.013 | 0.367 | 0.021 | 0.146 | 320.350 | 0.0 | 0.8 |
| 145 | 2005 | 0.195 | 0.009 | 0.332 | 0.017 | 0.140 | 316.630 | 7.1 | 5.3 |
| 161 | 2005 | 0.198 | 0.010 | 0.340 | 0.019 | 0.145 | 324.150 | 5.8 | 1.8 |
| 177 | 2005 | 0.186 | 0.015 | 0.327 | 0.023 | 0.140 | 326.620 | 1.8 | 0.6 |
| 193 | 2005 | 0.190 | 0.012 | 0.315 | 0.020 | 0.152 | 299.070 | 56.9 | 18.9 |
| 209 | 2005 | 0.383 | 0.021 | 0.593 | 0.026 | 0.136 | 305.390 | 93.2 | 32.3 |
| 225 | 2005 | 0.443 | 0.027 | 0.733 | 0.018 | 0.143 | 307.590 | 57.7 | 29.8 |
| 241 | 2005 | 0.388 | 0.013 | 0.701 | 0.012 | 0.149 | 307.460 | 42.7 | 33.7 |
| 257 | 2005 | 0.343 | 0.016 | 0.581 | 0.022 | 0.147 | 313.540 | 8.9 | 25.9 |
| 273 | 2005 | 0.223 | 0.008 | 0.415 | 0.017 | 0.149 | 308.260 | 30.0 | 26.9 |
| 289 | 2005 | 0.213 | 0.006 | 0.448 | 0.012 | 0.150 | 308.040 | 0.3 | 21.8 |
| 305 | 2005 | 0.195 | 0.005 | 0.376 | 0.012 | 0.157 | 306.310 | 0.0 | 17.8 |
| 321 | 2005 | 0.184 | 0.009 | 0.339 | 0.010 | 0.158 | 302.310 | 0.0 | 15.6 |
| 337 | 2005 | 0.167 | 0.004 | 0.331 | 0.012 | 0.165 | 297.640 | 2.0 | 14.5 |
| 353 | 2005 | 0.151 | 0.005 | 0.292 | 0.008 | 0.158 | 300.550 | 0.0 | 14.2 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 2006 | 0.140 | 0.005 | 0.275 | 0.007 | 0.163 | 302.410 | 0.0 | 13.6 |
| 17 | 2006 | 0.139 | 0.005 | 0.263 | 0.009 | 0.169 | 301.540 | 0.0 | 12.5 |
| 33 | 2006 | 0.130 | 0.005 | 0.255 | 0.009 | 0.166 | 306.260 | 1.8 | 12.6 |
| 49 | 2006 | 0.135 | 0.004 | 0.227 | 0.004 | 0.165 | 306.590 | 2.3 | 12.7 |
| 65 | 2006 | 0.134 | 0.005 | 0.238 | 0.007 | 0.168 | 307.370 | 12.2 | 13.7 |
| 81 | 2006 | 0.129 | 0.003 | 0.237 | 0.006 | 0.170 | 310.560 | 0.0 | 19.8 |
| 97 | 2006 | 0.154 | 0.011 | 0.235 | 0.014 | 0.174 | 318.550 | 0.0 | 16.0 |
| 113 | 2006 | 0.165 | 0.021 | 0.252 | 0.027 | 0.174 | 319.080 | 0.0 | 11.4 |
| 129 | 2006 | 0.160 | 0.016 | 0.263 | 0.021 | 0.172 | 322.530 | 0.0 | 9.2 |
| 145 | 2006 | 0.162 | 0.015 | 0.265 | 0.024 | 0.170 | 322.410 | 3.6 | 7.9 |
| 161 | 2006 | 0.175 | 0.016 | 0.246 | 0.016 | 0.164 | 326.240 | 13.7 | 7.7 |
| 177 | 2006 | 0.324 | 0.037 | 0.454 | 0.042 | 0.144 | 313.450 | 95.5 | 33.1 |
| 193 | 2006 | 0.326 | 0.026 | 0.551 | 0.065 | 0.142 | 316.690 | 32.5 | 25.6 |
| 209 | 2006 | 0.489 | 0.033 | 0.705 | 0.025 | 0.145 | 289.790 | 12.4 | 38.0 |
| 225 | 2006 | 0.481 | 0.056 | 0.685 | 0.038 | 0.147 | 307.180 | 47.5 | 36.1 |
| 241 | 2006 | 0.278 | 0.036 | 0.601 | 0.052 | 0.146 | 303.960 | 52.1 | 32.6 |
| 257 | 2006 | 0.357 | 0.011 | 0.570 | 0.008 | 0.142 | 308.980 | 0.0 | 28.1 |
| 273 | 2006 | 0.247 | 0.005 | 0.499 | 0.005 | 0.142 | 310.260 | | |
| 289 | 2006 | 0.175 | 0.004 | 0.372 | 0.007 | 0.136 | 305.230 | | |
| 305 | 2006 | 0.153 | 0.004 | 0.349 | 0.009 | 0.134 | 305.520 | | |
| 321 | 2006 | 0.155 | 0.002 | 0.345 | 0.007 | 0.139 | 300.900 | | |
| 337 | 2006 | 0.141 | 0.005 | 0.312 | 0.012 | 0.144 | 298.980 | | |
| 353 | 2006 | 0.137 | 0.004 | 0.272 | 0.007 | 0.142 | 295.070 | | |
| 9 | 2007 | 0.127 | 0.004 | 0.234 | 0.008 | 0.142 | 297.64 | | |
| 25 | 2007 | 0.107 | 0.003 | 0.216 | 0.009 | 0.14 | NA | | |
| 33 | 2007 | 0.108 | 0.003 | 0.217 | 0.007 | 0.141 | 304.59 | | |
| 49 | 2007 | 0.121 | 0.003 | 0.209 | 0.007 | 0.144 | 305.24 | | |
| 65 | 2007 | 0.117 | 0.004 | 0.209 | 0.007 | 0.15 | 314.67 | | |
| 81 | 2007 | 0.122 | 0.005 | 0.231 | 0.009 | 0.139 | 312.86 | | |
| 97 | 2007 | 0.157 | 0.014 | 0.272 | 0.021 | 0.1435 | 313.5 | | |
| 113 | 2007 | 0.183 | 0.018 | 0.299 | 0.024 | 0.141 | 318.01 | | |
| 129 | 2007 | 0.172 | 0.012 | 0.287 | 0.020 | 0.145 | 323.39 | | |
| 145 | 2007 | 0.174 | 0.014 | 0.302 | 0.025 | 0.149 | 323.96 | | |
| 161 | 2007 | 0.203 | 0.024 | 0.356 | 0.067 | 0.145 | 327.18 | | |
| 177 | 2007 | 0.483 | 0.057 | 0.640 | 0.046 | 0.152 | 330.58 | | |
| 193 | 2007 | 0.518 | 0.040 | 0.680 | 0.029 | NA | 311.38 | | |
| 209 | 2007 | 0.467 | 0.027 | 0.706 | 0.021 | 0.1705 | 308.65 | | |
| 225 | 2007 | 0.354 | 0.018 | 0.649 | 0.016 | 0.144 | NA | | |

STATION 136

| DOY | Year | EVI mean | EVI std | NDVI mean | NDVI std | Albedo | LST (K) | Rainfall (mm) | Soil moisture (%) |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 2004 | 0.127 | 0.005 | 0.269 | 0.020 | 0.130 | 296.120 | | |
| 17 | 2004 | 0.129 | 0.007 | 0.274 | 0.024 | 0.121 | 293.980 | | |
| 33 | 2004 | 0.131 | 0.004 | 0.279 | 0.027 | 0.127 | 301.080 | | |
| 49 | 2004 | 0.129 | 0.003 | 0.258 | 0.015 | 0.127 | 300.000 | | |
| 65 | 2004 | 0.140 | 0.005 | 0.292 | 0.018 | 0.127 | 307.210 | | |
| 81 | 2004 | 0.171 | 0.006 | 0.294 | 0.017 | 0.135 | 312.170 | | |
| 97 | 2004 | 0.177 | 0.007 | 0.321 | 0.019 | 0.134 | 309.020 | | |
| 113 | 2004 | 0.166 | 0.012 | 0.294 | 0.015 | 0.136 | 315.790 | 0.0 | 0.0 |
| 129 | 2004 | 0.142 | 0.012 | 0.277 | 0.020 | 0.141 | 319.610 | 0.0 | 0.0 |
| 145 | 2004 | 0.129 | 0.009 | 0.249 | 0.019 | 0.138 | 322.280 | 0.0 | 0.0 |
| 161 | 2004 | 0.124 | 0.009 | 0.229 | 0.016 | 0.141 | 322.300 | 5.6 | 0.8 |
| 177 | 2004 | 0.131 | 0.007 | 0.238 | 0.010 | 0.136 | 322.410 | 0.5 | 1.0 |
| 193 | 2004 | 0.270 | 0.013 | 0.424 | 0.018 | 0.146 | 315.340 | 12.7 | 6.6 |
| 209 | 2004 | 0.411 | 0.019 | 0.575 | 0.017 | 0.147 | 306.850 | 8.4 | 6.3 |
| 225 | 2004 | 0.375 | 0.008 | 0.553 | 0.014 | 0.142 | 314.620 | 21.3 | 2.2 |
| 241 | 2004 | 0.329 | 0.012 | 0.598 | 0.017 | 0.139 | 314.460 | 27.2 | 2.2 |
| 257 | 2004 | 0.302 | 0.019 | 0.556 | 0.014 | 0.136 | 310.720 | NA | NA |
| 273 | 2004 | 0.312 | 0.010 | 0.594 | 0.016 | 0.139 | 308.750 | NA | NA |
| 289 | 2004 | 0.274 | 0.007 | 0.461 | 0.015 | 0.141 | 302.220 | 1.3 | 3.4 |
| 305 | 2004 | 0.251 | 0.009 | 0.476 | 0.022 | 0.133 | 299.450 | 5.8 | 0.6 |
| 321 | 2004 | 0.219 | 0.008 | 0.455 | 0.025 | 0.131 | 294.270 | 8.9 | 1.3 |
| 337 | 2004 | 0.197 | 0.009 | 0.396 | 0.026 | 0.129 | 295.330 | 31.8 | 2.5 |
| 353 | 2004 | 0.198 | 0.010 | 0.377 | 0.021 | 0.130 | 294.540 | 14.5 | 1.0 |
| 1 | 2005 | 0.186 | 0.009 | 0.394 | 0.025 | 0.127 | 297.310 | 16.5 | 5.0 |
| 17 | 2005 | 0.182 | 0.010 | 0.372 | 0.019 | 0.123 | 297.250 | 25.4 | 3.6 |
| 33 | 2005 | 0.171 | 0.007 | 0.347 | 0.018 | 0.121 | 295.490 | 39.1 | 4.4 |
| 49 | 2005 | 0.188 | 0.006 | 0.362 | 0.012 | 0.126 | 297.390 | 7.1 | 2.5 |
| 65 | 2005 | 0.199 | 0.009 | 0.364 | 0.018 | 0.130 | 304.880 | 4.1 | 0.3 |
| 81 | 2005 | 0.187 | 0.009 | 0.348 | 0.016 | 0.132 | 309.050 | 0.0 | 0.0 |
| 97 | 2005 | 0.171 | 0.011 | 0.314 | 0.021 | 0.140 | 312.970 | 0.5 | 0.0 |
| 113 | 2005 | 0.170 | 0.012 | 0.311 | 0.035 | 0.139 | 311.750 | 6.4 | 0.1 |
| 129 | 2005 | 0.153 | 0.011 | 0.292 | 0.009 | 0.141 | 319.560 | 0.0 | 0.0 |
| 145 | 2005 | 0.202 | 0.009 | 0.377 | 0.016 | 0.136 | 317.370 | 50.8 | 1.1 |
| 161 | 2005 | 0.187 | 0.009 | 0.352 | 0.011 | 0.137 | 321.230 | 5.8 | 0.3 |
| 177 | 2005 | 0.176 | 0.006 | 0.334 | 0.013 | 0.138 | 324.870 | 0.0 | 0.0 |
| 193 | 2005 | 0.237 | 0.073 | 0.405 | 0.117 | 0.131 | 317.210 | 77.5 | 2.8 |
| 209 | 2005 | 0.420 | 0.037 | 0.623 | 0.050 | 0.144 | 306.610 | 100.6 | 1.2 |
| 225 | 2005 | 0.433 | 0.012 | 0.727 | 0.018 | 0.138 | 310.490 | 29.7 | 0.0 |
| 241 | 2005 | 0.283 | 0.013 | 0.570 | 0.026 | 0.136 | 306.900 | 23.1 | 0.0 |
| 257 | 2005 | 0.259 | 0.022 | 0.480 | 0.017 | 0.136 | 315.110 | 23.9 | 0.0 |
| 273 | 2005 | 0.222 | 0.013 | 0.404 | 0.029 | 0.138 | 311.110 | 15.2 | 0.0 |
| 289 | 2005 | 0.189 | 0.014 | 0.393 | 0.036 | 0.139 | 308.540 | 0.3 | 0.0 |
| 305 | 2005 | 0.185 | 0.011 | 0.354 | 0.038 | 0.137 | 307.640 | 0.0 | 0.0 |
| 321 | 2005 | 0.169 | 0.012 | 0.316 | 0.034 | 0.141 | 303.170 | 0.0 | 0.0 |
| 337 | 2005 | 0.160 | 0.012 | 0.336 | 0.030 | 0.144 | 299.070 | 0.8 | 0.0 |
| 353 | 2005 | 0.149 | 0.011 | 0.294 | 0.023 | 0.138 | 301.290 | 0.0 | 0.0 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 2006 | 0.140 | 0.007 | 0.291 | 0.022 | 0.143 | 303.410 | 0.0 | 0.0 |
| 17 | 2006 | 0.139 | 0.007 | 0.286 | 0.024 | 0.145 | 300.500 | 0.0 | 0.0 |
| 33 | 2006 | 0.128 | 0.007 | 0.264 | 0.016 | 0.140 | 306.450 | 2.3 | 0.0 |
| 49 | 2006 | 0.136 | 0.006 | 0.234 | 0.014 | 0.143 | 306.130 | 0.0 | 0.0 |
| 65 | 2006 | 0.126 | 0.009 | 0.249 | 0.016 | 0.148 | 305.760 | 5.6 | 0.0 |
| 81 | 2006 | 0.120 | 0.006 | 0.238 | 0.012 | 0.147 | 311.080 | 0.0 | 0.0 |
| 97 | 2006 | 0.131 | 0.004 | 0.209 | 0.010 | 0.149 | 317.420 | 0.0 | 0.0 |
| 113 | 2006 | 0.124 | 0.012 | 0.218 | 0.008 | 0.154 | 317.750 | 0.0 | 0.0 |
| 129 | 2006 | 0.117 | 0.006 | 0.213 | 0.009 | 0.151 | 323.530 | 0.0 | 0.0 |
| 145 | 2006 | 0.132 | 0.008 | 0.213 | 0.007 | 0.152 | 323.560 | 3.6 | 0.0 |
| 161 | 2006 | 0.125 | 0.012 | 0.213 | 0.006 | 0.150 | 324.990 | 10.2 | 0.0 |
| 177 | 2006 | 0.230 | 0.012 | 0.368 | 0.022 | 0.128 | 314.160 | 100.6 | 2.4 |
| 193 | 2006 | 0.249 | 0.017 | 0.431 | 0.014 | 0.142 | 318.400 | 31.2 | 6.8 |
| 209 | 2006 | 0.481 | 0.015 | 0.711 | 0.016 | 0.152 | 286.450 | 33.0 | 10.9 |
| 225 | 2006 | 0.387 | 0.015 | 0.628 | 0.028 | 0.148 | 306.960 | 20.8 | 7.8 |
| 241 | 2006 | 0.367 | 0.048 | 0.453 | 0.054 | 0.133 | 303.720 | 112.0 | 9.2 |
| 257 | 2006 | 0.405 | 0.006 | 0.632 | 0.018 | 0.136 | 307.030 | 0.0 | 6.0 |
| 273 | 2006 | 0.295 | 0.010 | 0.562 | 0.019 | 0.146 | 309.550 | | |
| 289 | 2006 | 0.227 | 0.005 | 0.461 | 0.025 | 0.135 | 303.550 | | |
| 305 | 2006 | 0.215 | 0.007 | 0.452 | 0.025 | 0.134 | 304.870 | | |
| 321 | 2006 | 0.192 | 0.005 | 0.399 | 0.016 | 0.137 | 300.740 | | |
| 337 | 2006 | 0.174 | 0.009 | 0.351 | 0.018 | 0.143 | 298.400 | | |
| 353 | 2006 | 0.158 | 0.007 | 0.318 | 0.019 | 0.138 | 294.820 | | |
| 9 | 2007 | 0.143 | 0.005 | 0.284 | 0.016 | 0.1355 | 296.81 | | |
| 25 | 2007 | 0.130 | 0.004 | 0.275 | 0.022 | 0.1385 | NA | | |
| 33 | 2007 | 0.132 | 0.002 | 0.271 | 0.017 | 0.1325 | 301.34 | | |
| 49 | 2007 | 0.126 | 0.006 | 0.243 | 0.016 | 0.1355 | 302.3 | | |
| 65 | 2007 | 0.120 | 0.006 | 0.257 | 0.021 | 0.1395 | 312.98 | | |
| 81 | 2007 | 0.133 | 0.005 | 0.278 | 0.014 | 0.136 | 309.34 | | |
| 97 | 2007 | 0.138 | 0.008 | 0.256 | 0.019 | 0.14 | 310.68 | | |
| 113 | 2007 | 0.128 | 0.005 | 0.258 | 0.020 | 0.1415 | 315.53 | | |
| 129 | 2007 | 0.123 | 0.003 | 0.233 | 0.015 | 0.1415 | 320.99 | | |
| 145 | 2007 | 0.118 | 0.006 | 0.238 | 0.016 | 0.1425 | 322.06 | | |
| 161 | 2007 | 0.221 | 0.006 | 0.450 | 0.014 | 0.1385 | 324.45 | | |
| 177 | 2007 | 0.436 | 0.039 | 0.633 | 0.055 | 0.1405 | 328.81 | | |
| 193 | 2007 | 0.510 | 0.016 | 0.771 | 0.011 | 0.15 | 311.18 | | |
| 209 | 2007 | 0.358 | 0.011 | 0.616 | 0.017 | 0.143 | 306.71 | | |
| 225 | 2007 | 0.306 | 0.018 | 0.594 | 0.016 | 0.132 | NA | | |

STATION 137

| DOY | Year | EVI mean | EVI std | NDVI mean | NDVI std | Albedo | LST (K) | Rainfall (mm) | Soil moisture (%) |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 2004 | 0.144 | 0.008 | 0.255 | 0.007 | 0.152 | 300.580 | | |
| 17 | 2004 | 0.134 | 0.003 | 0.233 | 0.004 | 0.134 | 297.280 | | |
| 33 | 2004 | 0.130 | 0.006 | 0.224 | 0.003 | 0.143 | 302.520 | | |
| 49 | 2004 | 0.130 | 0.003 | 0.209 | 0.002 | 0.146 | 301.170 | | |
| 65 | 2004 | 0.125 | 0.004 | 0.212 | 0.003 | 0.144 | 311.170 | | |
| 81 | 2004 | 0.133 | 0.004 | 0.207 | 0.003 | 0.149 | 318.300 | | |
| 97 | 2004 | 0.139 | 0.009 | 0.214 | 0.005 | 0.148 | 316.280 | | |
| 113 | 2004 | 0.129 | 0.007 | 0.207 | 0.006 | 0.154 | 321.150 | | |
| 129 | 2004 | 0.126 | 0.006 | 0.208 | 0.004 | 0.157 | 323.650 | | |
| 145 | 2004 | 0.119 | 0.003 | 0.200 | 0.003 | 0.158 | 326.150 | | |
| 161 | 2004 | 0.118 | 0.005 | 0.194 | 0.003 | 0.157 | 326.270 | | |
| 177 | 2004 | 0.133 | 0.004 | 0.202 | 0.006 | 0.161 | 328.320 | 3.3 | 3.4 |
| 193 | 2004 | 0.203 | 0.014 | 0.279 | 0.020 | 0.178 | 316.030 | 97.3 | 7.1 |
| 209 | 2004 | 0.353 | 0.043 | 0.517 | 0.036 | 0.160 | 312.940 | 37.1 | 3.4 |
| 225 | 2004 | 0.283 | 0.027 | 0.408 | 0.030 | 0.156 | 317.170 | 28.4 | 7.5 |
| 241 | 2004 | 0.273 | 0.012 | 0.414 | 0.023 | 0.158 | 316.120 | 43.4 | 9.5 |
| 257 | 2004 | 0.229 | 0.009 | 0.362 | 0.012 | 0.157 | 312.860 | NA | NA |
| 273 | 2004 | 0.192 | 0.006 | 0.323 | 0.008 | 0.158 | 314.780 | NA | NA |
| 289 | 2004 | 0.166 | 0.003 | 0.291 | 0.003 | 0.163 | 307.400 | 52.6 | 9.4 |
| 305 | 2004 | 0.176 | 0.006 | 0.292 | 0.009 | 0.146 | 300.710 | 20.8 | 6.0 |
| 321 | 2004 | 0.184 | 0.007 | 0.329 | 0.010 | 0.139 | 295.860 | 7.9 | 15.0 |
| 337 | 2004 | 0.189 | 0.007 | 0.321 | 0.010 | 0.140 | 296.650 | 24.9 | 19.0 |
| 353 | 2004 | 0.185 | 0.006 | 0.307 | 0.005 | 0.150 | 284.500 | 21.8 | 12.6 |
| 1 | 2005 | 0.185 | 0.017 | 0.330 | 0.019 | 0.140 | 297.150 | 28.4 | 24.1 |
| 17 | 2005 | 0.204 | 0.028 | 0.350 | 0.042 | 0.143 | 298.130 | 21.8 | 22.3 |
| 33 | 2005 | 0.205 | 0.030 | 0.355 | 0.040 | 0.141 | 296.510 | 70.1 | 25.4 |
| 49 | 2005 | 0.219 | 0.030 | 0.337 | 0.038 | 0.151 | 297.410 | 4.3 | 20.4 |
| 65 | 2005 | 0.215 | 0.026 | 0.350 | 0.030 | 0.153 | 307.860 | 0.3 | 2.7 |
| 81 | 2005 | 0.205 | 0.014 | 0.322 | 0.018 | 0.152 | 310.920 | 0.0 | 0.0 |
| 97 | 2005 | 0.192 | 0.007 | 0.293 | 0.013 | 0.158 | 315.430 | 0.0 | 0.0 |
| 113 | 2005 | 0.170 | 0.006 | 0.286 | 0.006 | 0.152 | 314.850 | 7.4 | 1.6 |
| 129 | 2005 | 0.164 | 0.007 | 0.269 | 0.007 | 0.163 | 323.990 | NA | NA |
| 145 | 2005 | 0.170 | 0.011 | 0.260 | 0.003 | 0.158 | 322.370 | NA | NA |
| 161 | 2005 | 0.157 | 0.006 | 0.232 | 0.006 | 0.159 | 325.240 | NA | NA |
| 177 | 2005 | 0.156 | 0.005 | 0.230 | 0.004 | 0.158 | 329.360 | NA | NA |
| 193 | 2005 | 0.145 | 0.002 | 0.218 | 0.004 | 0.190 | 322.560 | NA | NA |
| 209 | 2005 | 0.315 | 0.016 | 0.512 | 0.040 | 0.166 | 310.550 | NA | NA |
| 225 | 2005 | 0.361 | 0.023 | 0.564 | 0.017 | 0.153 | 312.700 | NA | NA |
| 241 | 2005 | 0.311 | 0.020 | 0.423 | 0.021 | 0.143 | 314.460 | NA | NA |
| 257 | 2005 | 0.233 | 0.007 | 0.400 | 0.008 | 0.153 | 318.280 | NA | NA |
| 273 | 2005 | 0.226 | 0.004 | 0.320 | 0.003 | 0.158 | 315.830 | NA | NA |
| 289 | 2005 | 0.175 | 0.006 | 0.299 | 0.004 | 0.166 | 311.990 | NA | NA |
| 305 | 2005 | 0.178 | 0.007 | 0.278 | 0.007 | 0.166 | 309.410 | NA | NA |
| 321 | 2005 | 0.173 | 0.006 | 0.268 | 0.006 | 0.168 | 305.850 | 0.0 | 0.0 |
| 337 | 2005 | 0.161 | 0.006 | 0.270 | 0.006 | 0.167 | 300.920 | 1.5 | 0.0 |
| 353 | 2005 | 0.159 | 0.006 | 0.253 | 0.005 | 0.166 | 302.950 | 0.0 | 0.0 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 2006 | 0.144 | 0.005 | 0.244 | 0.003 | 0.168 | 305.160 | 0.0 | 0.0 |
| 17 | 2006 | 0.150 | 0.006 | 0.240 | 0.004 | 0.168 | 302.890 | 0.0 | 0.0 |
| 33 | 2006 | 0.136 | 0.004 | 0.225 | 0.004 | 0.166 | 309.200 | 0.0 | 0.0 |
| 49 | 2006 | 0.140 | 0.004 | 0.207 | 0.003 | 0.166 | 307.940 | 2.5 | 0.0 |
| 65 | 2006 | 0.146 | 0.003 | 0.211 | 0.001 | 0.169 | 308.610 | 5.1 | 0.0 |
| 81 | 2006 | 0.127 | 0.004 | 0.203 | 0.003 | 0.170 | 315.250 | 0.0 | 0.0 |
| 97 | 2006 | 0.134 | 0.005 | 0.189 | 0.002 | 0.174 | 319.790 | 0.0 | 0.0 |
| 113 | 2006 | 0.132 | 0.003 | 0.187 | 0.002 | 0.176 | 319.540 | 0.0 | 0.0 |
| 129 | 2006 | 0.123 | 0.003 | 0.190 | 0.004 | 0.177 | 326.100 | 0.0 | 0.0 |
| 145 | 2006 | 0.126 | 0.006 | 0.184 | 0.002 | 0.185 | 325.610 | 3.6 | 0.0 |
| 161 | 2006 | 0.125 | 0.002 | 0.189 | 0.003 | 0.174 | 328.660 | 8.9 | 0.0 |
| 177 | 2006 | 0.235 | 0.031 | 0.303 | 0.029 | 0.160 | 316.890 | 108.5 | 13.8 |
| 193 | 2006 | 0.364 | 0.029 | 0.520 | 0.020 | 0.167 | 316.280 | NA | NA |
| 209 | 2006 | 0.443 | 0.016 | 0.634 | 0.011 | 0.155 | 290.200 | NA | NA |
| 225 | 2006 | 0.429 | 0.025 | 0.599 | 0.018 | 0.162 | 307.640 | 44.7 | 22.9 |
| 241 | 2006 | 0.407 | 0.018 | 0.618 | 0.022 | 0.151 | 306.870 | 82.0 | 29.0 |
| 257 | 2006 | 0.410 | 0.010 | 0.580 | 0.007 | 0.151 | 310.050 | 0.0 | 21.2 |
| 273 | 2006 | 0.253 | 0.014 | 0.435 | 0.030 | 0.152 | 310.570 | | |
| 289 | 2006 | 0.211 | 0.009 | 0.374 | 0.009 | 0.145 | 305.320 | | |
| 305 | 2006 | 0.203 | 0.009 | 0.370 | 0.009 | 0.144 | 305.850 | | |
| 321 | 2006 | 0.198 | 0.008 | 0.363 | 0.007 | 0.147 | 301.740 | | |
| 337 | 2006 | 0.171 | 0.007 | 0.322 | 0.007 | 0.151 | 299.110 | | |
| 353 | 2006 | 0.173 | 0.006 | 0.296 | 0.007 | 0.146 | 295.540 | | |
| 9 | 2007 | 0.158 | 0.009 | 0.270 | 0.010 | 0.147 | 298.060 | | |
| 25 | 2007 | 0.128 | 0.007 | 0.240 | 0.009 | 0.138 | NA | | |
| 33 | 2007 | 0.137 | 0.006 | 0.237 | 0.006 | 0.142 | 303.780 | | |
| 49 | 2007 | 0.137 | 0.004 | 0.225 | 0.004 | 0.148 | 305.560 | | |
| 65 | 2007 | 0.125 | 0.003 | 0.229 | 0.003 | 0.148 | 314.950 | | |
| 81 | 2007 | 0.145 | 0.007 | 0.242 | 0.006 | 0.146 | 313.240 | | |
| 97 | 2007 | 0.148 | 0.009 | 0.230 | 0.007 | 0.153 | 314.660 | | |
| 113 | 2007 | 0.150 | 0.008 | 0.230 | 0.004 | 0.152 | 318.930 | | |
| 129 | 2007 | 0.139 | 0.006 | 0.217 | 0.005 | 0.155 | 323.890 | | |
| 145 | 2007 | 0.158 | 0.006 | 0.261 | 0.009 | 0.159 | 324.760 | | |
| 161 | 2007 | 0.179 | 0.002 | 0.237 | 0.002 | 0.159 | 326.210 | | |
| 177 | 2007 | 0.321 | 0.019 | 0.471 | 0.022 | 0.163 | 329.790 | | |
| 193 | 2007 | 0.338 | 0.012 | 0.540 | 0.013 | NA | 320.290 | | |
| 209 | 2007 | 0.340 | 0.020 | 0.520 | 0.022 | 0.156 | 310.390 | | |
| 225 | 2007 | 0.284 | 0.011 | 0.474 | 0.018 | 0.159 | NA | | |

STATION 138

| DOY | Year | EVI mean | EVI std | NDVI mean | NDVI std | Albedo | LST (K) | Rainfall (mm) | Soil moisture (%) |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 2004 | 0.149 | 0.009 | 0.284 | 0.019 | 0.143 | 299.020 | | |
| 17 | 2004 | 0.136 | 0.010 | 0.254 | 0.018 | 0.137 | 295.440 | | |
| 33 | 2004 | 0.135 | 0.009 | 0.247 | 0.012 | 0.142 | 301.880 | | |
| 49 | 2004 | 0.112 | 0.004 | 0.227 | 0.009 | 0.153 | 299.410 | | |
| 65 | 2004 | 0.123 | 0.005 | 0.230 | 0.010 | 0.143 | 312.510 | | |
| 81 | 2004 | 0.131 | 0.006 | 0.216 | 0.013 | 0.146 | 314.350 | | |
| 97 | 2004 | 0.159 | 0.013 | 0.259 | 0.019 | 0.149 | 313.180 | | |
| 113 | 2004 | 0.158 | 0.015 | 0.253 | 0.021 | 0.154 | 321.320 | | |
| 129 | 2004 | 0.145 | 0.013 | 0.243 | 0.017 | 0.159 | 323.810 | | |
| 145 | 2004 | 0.146 | 0.013 | 0.209 | 0.019 | 0.161 | 326.490 | | |
| 161 | 2004 | 0.137 | 0.013 | 0.218 | 0.017 | 0.162 | 326.970 | 25.1 | 21.1 |
| 177 | 2004 | 0.149 | 0.009 | 0.234 | 0.008 | 0.161 | 327.230 | 7.1 | 13.4 |
| 193 | 2004 | 0.184 | 0.010 | 0.276 | 0.014 | 0.183 | 324.050 | 69.6 | 19.0 |
| 209 | 2004 | 0.259 | 0.018 | 0.417 | 0.031 | 0.173 | 295.400 | 3.8 | 14.8 |
| 225 | 2004 | 0.213 | 0.013 | 0.300 | 0.019 | 0.157 | 319.370 | 7.9 | 8.8 |
| 241 | 2004 | 0.217 | 0.024 | 0.319 | 0.024 | 0.155 | 319.090 | 42.7 | 13.9 |
| 257 | 2004 | 0.214 | 0.010 | 0.362 | 0.021 | 0.152 | 316.080 | NA | NA |
| 273 | 2004 | 0.196 | 0.015 | 0.334 | 0.019 | 0.154 | 314.890 | NA | NA |
| 289 | 2004 | 0.181 | 0.010 | 0.314 | 0.015 | 0.148 | 306.800 | 48.0 | 8.8 |
| 305 | 2004 | 0.193 | 0.013 | 0.320 | 0.022 | 0.141 | 301.690 | 18.0 | 16.6 |
| 321 | 2004 | 0.189 | 0.012 | 0.327 | 0.024 | 0.136 | 296.100 | 6.4 | 20.0 |
| 337 | 2004 | 0.163 | 0.009 | 0.301 | 0.015 | 0.137 | 297.680 | 26.4 | 20.9 |
| 353 | 2004 | 0.156 | 0.009 | 0.285 | 0.011 | 0.144 | 296.330 | 20.3 | 17.5 |
| 1 | 2005 | 0.160 | 0.014 | 0.304 | 0.005 | 0.134 | 298.250 | 24.9 | 22.4 |
| 17 | 2005 | 0.167 | 0.010 | 0.310 | 0.021 | 0.135 | 297.880 | 17.0 | 21.6 |
| 33 | 2005 | 0.170 | 0.015 | 0.327 | 0.022 | 0.135 | 297.450 | 68.3 | 24.1 |
| 49 | 2005 | 0.201 | 0.017 | 0.333 | 0.025 | 0.148 | 302.260 | 0.8 | 19.3 |
| 65 | 2005 | 0.209 | 0.019 | 0.335 | 0.023 | 0.147 | 308.860 | 1.0 | 11.6 |
| 81 | 2005 | 0.202 | 0.014 | 0.326 | 0.018 | 0.155 | 310.600 | 0.0 | 8.3 |
| 97 | 2005 | 0.187 | 0.013 | 0.295 | 0.018 | 0.156 | 316.000 | 0.0 | 7.0 |
| 113 | 2005 | 0.181 | 0.013 | 0.293 | 0.012 | 0.157 | 314.030 | 8.1 | 10.6 |
| 129 | 2005 | 0.167 | 0.011 | 0.275 | 0.013 | 0.163 | 322.110 | 1.3 | 6.8 |
| 145 | 2005 | 0.157 | 0.013 | 0.260 | 0.016 | 0.160 | 324.750 | 0.0 | 6.5 |
| 161 | 2005 | 0.152 | 0.011 | 0.243 | 0.016 | 0.164 | 326.550 | 1.5 | 6.5 |
| 177 | 2005 | 0.159 | 0.009 | 0.250 | 0.017 | 0.161 | 330.300 | 0.5 | 7.4 |
| 193 | 2005 | 0.146 | 0.013 | 0.221 | 0.014 | 0.185 | 300.490 | 43.4 | 10.7 |
| 209 | 2005 | 0.215 | 0.009 | 0.408 | 0.018 | 0.154 | 292.580 | 82.0 | 22.9 |
| 225 | 2005 | 0.368 | 0.029 | 0.579 | 0.028 | 0.149 | 313.330 | 61.7 | 17.2 |
| 241 | 2005 | 0.316 | 0.029 | 0.555 | 0.042 | 0.155 | 312.270 | 46.5 | 17.7 |
| 257 | 2005 | 0.271 | 0.020 | 0.456 | 0.020 | 0.157 | 317.450 | 3.3 | 10.3 |
| 273 | 2005 | 0.217 | 0.012 | 0.325 | 0.016 | 0.160 | 314.540 | 1.3 | 7.6 |
| 289 | 2005 | 0.192 | 0.012 | 0.333 | 0.012 | 0.164 | 311.260 | 0.0 | 6.9 |
| 305 | 2005 | 0.182 | 0.017 | 0.301 | 0.019 | 0.163 | 309.950 | NA | NA |
| 321 | 2005 | 0.183 | 0.008 | 0.295 | 0.014 | 0.163 | 305.330 | 0.0 | 5.0 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 337 | 2005 | 0.172 | 0.013 | 0.293 | 0.012 | 0.162 | 300.920 | 1.0 | 4.7 |
| 353 | 2005 | 0.153 | 0.007 | 0.260 | 0.010 | 0.161 | 302.680 | 0.0 | 4.8 |
| 1 | 2006 | 0.145 | 0.008 | 0.255 | 0.007 | 0.164 | 304.230 | 0.0 | 4.6 |
| 17 | 2006 | 0.142 | 0.006 | 0.240 | 0.007 | 0.160 | 302.980 | 0.0 | 4.2 |
| 33 | 2006 | 0.131 | 0.008 | 0.228 | 0.011 | 0.167 | 308.900 | 0.0 | 4.6 |
| 49 | 2006 | 0.131 | 0.006 | 0.207 | 0.011 | 0.166 | 310.390 | 3.0 | 5.4 |
| 65 | 2006 | 0.127 | 0.008 | 0.212 | 0.012 | 0.166 | 310.800 | 3.0 | 4.9 |
| 81 | 2006 | 0.122 | 0.006 | 0.209 | 0.009 | 0.172 | 315.520 | 0.0 | 5.3 |
| 97 | 2006 | 0.135 | 0.009 | 0.206 | 0.010 | 0.179 | 321.430 | 0.0 | 5.0 |
| 113 | 2006 | 0.131 | 0.008 | 0.199 | 0.011 | 0.181 | 321.130 | 0.0 | 4.8 |
| 129 | 2006 | 0.122 | 0.007 | 0.195 | 0.007 | 0.178 | 327.780 | 0.0 | 5.0 |
| 145 | 2006 | 0.132 | 0.010 | 0.193 | 0.013 | 0.177 | 327.270 | 3.6 | 5.2 |
| 161 | 2006 | 0.123 | 0.011 | 0.191 | 0.015 | 0.177 | 330.980 | 6.4 | 5.7 |
| 177 | 2006 | 0.274 | 0.040 | 0.355 | 0.042 | 0.156 | 318.750 | 100.8 | 19.4 |
| 193 | 2006 | 0.357 | 0.088 | 0.520 | 0.096 | 0.156 | 316.120 | 78.5 | 16.9 |
| 209 | 2006 | 0.463 | 0.044 | 0.666 | 0.047 | 0.155 | 305.340 | 86.6 | 20.6 |
| 225 | 2006 | 0.490 | 0.048 | 0.652 | 0.050 | 0.159 | 309.430 | 30.2 | 17.2 |
| 241 | 2006 | 0.426 | 0.050 | 0.634 | 0.059 | 0.155 | 307.350 | 108.5 | 20.9 |
| 257 | 2006 | 0.392 | 0.033 | 0.577 | 0.039 | 0.155 | 309.840 | 1.8 | 15.4 |
| 273 | 2006 | 0.309 | 0.024 | 0.526 | 0.036 | 0.152 | 311.100 | 5.3 | 11.4 |
| 289 | 2006 | 0.234 | 0.015 | 0.434 | 0.030 | 0.138 | 306.210 | | |
| 305 | 2006 | 0.212 | 0.011 | 0.401 | 0.029 | 0.142 | 304.980 | | |
| 321 | 2006 | 0.205 | 0.012 | 0.390 | 0.024 | 0.142 | 301.540 | | |
| 337 | 2006 | 0.174 | 0.006 | 0.343 | 0.014 | 0.144 | 298.460 | | |
| 353 | 2006 | 0.159 | 0.005 | 0.298 | 0.010 | 0.144 | 294.960 | | |
| 9 | 2007 | 0.137 | 0.003 | 0.243 | 0.006 | 0.157 | 296.380 | | |
| 25 | 2007 | 0.104 | 0.005 | 0.212 | 0.008 | 0.148 | NA | | |
| 33 | 2007 | 0.115 | 0.009 | 0.215 | 0.008 | 0.146 | 303.170 | | |
| 49 | 2007 | 0.115 | 0.005 | 0.203 | 0.006 | 0.150 | 304.170 | | |
| 65 | 2007 | 0.131 | 0.007 | 0.253 | 0.013 | 0.156 | 314.100 | | |
| 81 | 2007 | 0.159 | 0.015 | 0.280 | 0.013 | 0.154 | 310.970 | | |
| 97 | 2007 | 0.165 | 0.021 | 0.270 | 0.028 | 0.158 | 313.370 | | |
| 113 | 2007 | 0.166 | 0.019 | 0.267 | 0.026 | 0.160 | 318.000 | | |
| 129 | 2007 | 0.168 | 0.014 | 0.249 | 0.020 | 0.160 | 322.670 | | |
| 145 | 2007 | 0.163 | 0.015 | 0.255 | 0.015 | 0.167 | 324.480 | | |
| 161 | 2007 | 0.168 | 0.015 | 0.227 | 0.016 | 0.162 | 327.950 | | |
| 177 | 2007 | 0.304 | 0.023 | 0.468 | 0.028 | 0.165 | 329.970 | | |
| 193 | 2007 | 0.409 | 0.030 | 0.603 | 0.031 | NA | NA | | |
| 209 | 2007 | 0.392 | 0.037 | 0.602 | 0.038 | 0.156 | 312.680 | | |
| 225 | 2007 | 0.349 | 0.027 | 0.560 | 0.020 | 0.151 | NA | | |

STATION 139

| DOY | Year | EVI mean | EVI std | NDVI mean | NDVI std | Albedo | LST (K) | Rainfall (mm) | Soil moisture (%) |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 2004 | 0.119 | 0.008 | 0.229 | 0.016 | 0.142 | 298.060 | | |
| 17 | 2004 | 0.112 | 0.015 | 0.205 | 0.021 | 0.136 | 296.490 | | |
| 33 | 2004 | 0.112 | 0.013 | 0.199 | 0.018 | 0.139 | 300.500 | | |
| 49 | 2004 | 0.111 | 0.012 | 0.199 | 0.016 | 0.135 | 298.080 | | |
| 65 | 2004 | 0.113 | 0.008 | 0.200 | 0.013 | 0.136 | 308.450 | | |
| 81 | 2004 | 0.120 | 0.007 | 0.191 | 0.011 | 0.142 | 317.630 | | |
| 97 | 2004 | 0.149 | 0.007 | 0.222 | 0.014 | 0.144 | 314.390 | | |
| 113 | 2004 | 0.143 | 0.006 | 0.236 | 0.011 | 0.148 | 320.020 | | |
| 129 | 2004 | 0.139 | 0.010 | 0.223 | 0.010 | 0.154 | 321.320 | | |
| 145 | 2004 | 0.129 | 0.009 | 0.183 | 0.009 | 0.151 | 326.160 | | |
| 161 | 2004 | 0.117 | 0.003 | 0.169 | 0.007 | 0.153 | 325.580 | 17.5 | 15.2 |
| 177 | 2004 | 0.136 | 0.008 | 0.185 | 0.011 | 0.141 | 326.780 | 8.6 | 8.2 |
| 193 | 2004 | 0.166 | 0.019 | 0.239 | 0.028 | 0.178 | 318.890 | 132.8 | 12.2 |
| 209 | 2004 | 0.255 | 0.027 | 0.390 | 0.037 | 0.162 | 312.230 | 40.4 | 10.1 |
| 225 | 2004 | 0.264 | 0.037 | 0.394 | 0.053 | 0.155 | 311.680 | 24.4 | 9.1 |
| 241 | 2004 | 0.250 | 0.028 | 0.392 | 0.039 | 0.153 | 317.190 | 37.1 | 9.5 |
| 257 | 2004 | 0.237 | 0.026 | 0.372 | 0.038 | 0.144 | 313.870 | NA | NA |
| 273 | 2004 | 0.199 | 0.012 | 0.341 | 0.024 | 0.155 | 313.250 | NA | NA |
| 289 | 2004 | 0.174 | 0.007 | 0.299 | 0.012 | 0.143 | 305.600 | 15.7 | 16.4 |
| 305 | 2004 | 0.159 | 0.011 | 0.275 | 0.018 | 0.136 | 301.710 | 12.4 | 7.4 |
| 321 | 2004 | 0.168 | 0.014 | 0.286 | 0.020 | 0.133 | 295.830 | 2.5 | 7.9 |
| 337 | 2004 | 0.145 | 0.019 | 0.258 | 0.032 | 0.132 | 296.240 | 28.2 | 11.1 |
| 353 | 2004 | 0.145 | 0.019 | 0.250 | 0.032 | 0.130 | 297.030 | 16.8 | 6.5 |
| 1 | 2005 | 0.132 | 0.028 | 0.246 | 0.030 | 0.130 | 295.730 | 37.8 | 14.5 |
| 17 | 2005 | 0.151 | 0.024 | 0.272 | 0.035 | 0.130 | 297.190 | 13.0 | 11.8 |
| 33 | 2005 | 0.153 | 0.028 | 0.299 | 0.038 | 0.129 | 296.980 | 71.9 | 15.3 |
| 49 | 2005 | 0.195 | 0.028 | 0.329 | 0.040 | 0.142 | 299.230 | 1.5 | 9.5 |
| 65 | 2005 | 0.221 | 0.026 | 0.351 | 0.032 | 0.141 | 306.540 | 0.3 | 5.3 |
| 81 | 2005 | 0.213 | 0.015 | 0.341 | 0.019 | 0.143 | 310.310 | 0.0 | 3.8 |
| 97 | 2005 | 0.190 | 0.006 | 0.292 | 0.013 | 0.148 | 315.660 | 0.0 | 3.1 |
| 113 | 2005 | 0.168 | 0.014 | 0.278 | 0.028 | 0.145 | 314.090 | 4.1 | 4.0 |
| 129 | 2005 | 0.160 | 0.009 | 0.264 | 0.011 | 0.152 | 323.420 | 0.0 | 2.9 |
| 145 | 2005 | 0.152 | 0.011 | 0.260 | 0.021 | 0.149 | 322.160 | 2.3 | 3.2 |
| 161 | 2005 | 0.153 | 0.012 | 0.255 | 0.021 | 0.151 | 326.220 | 1.8 | 3.0 |
| 177 | 2005 | 0.151 | 0.005 | 0.229 | 0.010 | 0.147 | 326.500 | 3.6 | 3.2 |
| 193 | 2005 | 0.135 | 0.004 | 0.213 | 0.006 | 0.174 | 310.810 | 64.3 | 7.8 |
| 209 | 2005 | 0.230 | 0.031 | 0.394 | 0.050 | 0.162 | 273.000 | 54.4 | 8.7 |
| 225 | 2005 | 0.232 | 0.021 | 0.368 | 0.026 | 0.141 | 314.830 | 29.0 | 6.6 |
| 241 | 2005 | 0.254 | 0.019 | 0.452 | 0.032 | 0.144 | 313.360 | 42.4 | 6.7 |
| 257 | 2005 | 0.215 | 0.015 | 0.359 | 0.014 | 0.148 | 317.960 | 3.6 | 3.5 |
| 273 | 2005 | 0.187 | 0.014 | 0.278 | 0.017 | 0.147 | 314.070 | 4.6 | 2.6 |
| 289 | 2005 | 0.161 | 0.012 | 0.289 | 0.015 | 0.147 | 310.850 | 0.0 | 4.3 |
| 305 | 2005 | 0.171 | 0.009 | 0.272 | 0.015 | 0.150 | 309.810 | NA | NA |
| 321 | 2005 | 0.168 | 0.012 | 0.266 | 0.017 | 0.152 | 304.830 | 0.0 | 1.1 |
| 337 | 2005 | 0.145 | 0.014 | 0.266 | 0.014 | 0.162 | 300.510 | 1.0 | 0.9 |
| 353 | 2005 | 0.135 | 0.007 | 0.234 | 0.014 | 0.151 | 303.740 | 0.0 | 0.9 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 2006 | 0.130 | 0.009 | 0.229 | 0.012 | 0.153 | 304.010 | 0.0 | 0.8 |
| 17 | 2006 | 0.129 | 0.006 | 0.232 | 0.012 | 0.155 | 302.720 | 0.0 | 0.7 |
| 33 | 2006 | 0.119 | 0.006 | 0.210 | 0.010 | 0.150 | 308.370 | 0.0 | 0.9 |
| 49 | 2006 | 0.084 | 0.018 | 0.185 | 0.010 | 0.159 | 308.610 | 1.3 | 1.2 |
| 65 | 2006 | 0.115 | 0.008 | 0.200 | 0.012 | 0.157 | 308.060 | 6.1 | 1.4 |
| 81 | 2006 | 0.113 | 0.008 | 0.198 | 0.010 | 0.161 | 313.570 | 0.0 | 2.6 |
| 97 | 2006 | 0.133 | 0.015 | 0.211 | 0.014 | 0.165 | 320.130 | 0.0 | 1.4 |
| 113 | 2006 | 0.121 | 0.009 | 0.207 | 0.017 | 0.167 | 320.980 | 0.0 | 1.2 |
| 129 | 2006 | 0.118 | 0.008 | 0.194 | 0.010 | 0.167 | 326.390 | 0.0 | 1.5 |
| 145 | 2006 | 0.116 | 0.011 | 0.187 | 0.015 | 0.166 | 326.630 | 1.3 | 1.6 |
| 161 | 2006 | 0.121 | 0.011 | 0.194 | 0.013 | 0.164 | 329.430 | 10.2 | 2.7 |
| 177 | 2006 | 0.178 | 0.020 | 0.258 | 0.027 | 0.160 | 316.750 | 125.2 | 14.1 |
| 193 | 2006 | 0.253 | 0.041 | 0.383 | 0.049 | 0.151 | 315.750 | 61.7 | 11.0 |
| 209 | 2006 | 0.489 | 0.053 | 0.654 | 0.041 | 0.155 | 307.700 | 50.8 | 18.1 |
| 225 | 2006 | 0.463 | 0.054 | 0.631 | 0.050 | 0.151 | 305.790 | 69.6 | 13.1 |
| 241 | 2006 | 0.419 | 0.045 | 0.614 | 0.046 | 0.148 | 305.480 | 100.6 | 14.1 |
| 257 | 2006 | 0.428 | 0.024 | 0.594 | 0.029 | 0.147 | 307.810 | 0.3 | 5.1 |
| 273 | 2006 | 0.303 | 0.014 | 0.511 | 0.020 | 0.147 | 309.330 | 0.5 | 3.4 |
| 289 | 2006 | 0.221 | 0.009 | 0.420 | 0.021 | 0.133 | 302.930 | | |
| 305 | 2006 | 0.201 | 0.016 | 0.393 | 0.029 | 0.130 | 303.620 | | |
| 321 | 2006 | 0.197 | 0.006 | 0.385 | 0.014 | 0.133 | 300.150 | | |
| 337 | 2006 | 0.158 | 0.011 | 0.332 | 0.018 | 0.137 | 298.380 | | |
| 353 | 2006 | 0.161 | 0.009 | 0.296 | 0.012 | 0.135 | 295.290 | | |
| 9 | 2007 | 0.139 | 0.008 | 0.244 | 0.014 | 0.141 | 297.020 | | |
| 25 | 2007 | 0.111 | 0.008 | 0.226 | 0.013 | 0.134 | NA | | |
| 33 | 2007 | 0.114 | 0.008 | 0.220 | 0.011 | 0.134 | 302.890 | | |
| 49 | 2007 | 0.117 | 0.006 | 0.210 | 0.012 | 0.139 | 304.990 | | |
| 65 | 2007 | 0.149 | 0.003 | 0.249 | 0.008 | 0.140 | 314.610 | | |
| 81 | 2007 | 0.155 | 0.012 | 0.285 | 0.007 | 0.139 | 310.970 | | |
| 97 | 2007 | 0.159 | 0.008 | 0.271 | 0.013 | 0.144 | 312.150 | | |
| 113 | 2007 | 0.162 | 0.009 | 0.268 | 0.016 | 0.150 | 318.110 | | |
| 129 | 2007 | 0.157 | 0.011 | 0.257 | 0.016 | 0.152 | 322.440 | | |
| 145 | 2007 | 0.156 | 0.011 | 0.255 | 0.021 | 0.151 | 324.500 | | |
| 161 | 2007 | 0.149 | 0.005 | 0.273 | 0.010 | 0.151 | 327.770 | | |
| 177 | 2007 | 0.229 | 0.027 | 0.364 | 0.032 | 0.156 | 331.530 | | |
| 193 | 2007 | 0.385 | 0.026 | 0.533 | 0.031 | NA | NA | | |
| 209 | 2007 | 0.430 | 0.038 | 0.640 | 0.035 | 0.158 | 309.170 | | |
| 225 | 2007 | 0.390 | 0.025 | 0.620 | 0.021 | 0.151 | NA | | |

STATION 140

| DOY | Year | EVI mean | EVI std | NDVI mean | NDVI std | Albedo | LST (K) | Rainfall (mm) | Soil moisture (%) |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 2004 | 0.129 | 0.007 | 0.289 | 0.017 | 0.102 | 297.510 | | |
| 17 | 2004 | 0.130 | 0.006 | 0.288 | 0.021 | 0.098 | 295.340 | | |
| 33 | 2004 | 0.134 | 0.012 | 0.280 | 0.025 | 0.105 | 299.330 | | |
| 49 | 2004 | 0.112 | 0.006 | 0.241 | 0.018 | 0.104 | 297.950 | | |
| 65 | 2004 | 0.136 | 0.011 | 0.285 | 0.015 | 0.106 | 308.850 | | |
| 81 | 2004 | 0.150 | 0.008 | 0.266 | 0.014 | 0.108 | 313.530 | | |
| 97 | 2004 | 0.159 | 0.006 | 0.277 | 0.013 | 0.112 | 313.690 | | |
| 113 | 2004 | 0.152 | 0.008 | 0.277 | 0.013 | 0.117 | 319.290 | | |
| 129 | 2004 | 0.124 | 0.003 | 0.256 | 0.011 | 0.117 | 321.830 | | |
| 145 | 2004 | 0.119 | 0.009 | 0.244 | 0.012 | 0.116 | 325.550 | | |
| 161 | 2004 | 0.114 | 0.003 | 0.241 | 0.013 | 0.115 | 326.360 | 8.6 | 21.6 |
| 177 | 2004 | 0.119 | 0.004 | 0.231 | 0.010 | 0.109 | 324.690 | 23.4 | 12.8 |
| 193 | 2004 | 0.241 | 0.028 | 0.387 | 0.049 | 0.126 | 314.890 | 100.8 | 23.3 |
| 209 | 2004 | 0.374 | 0.028 | 0.604 | 0.038 | 0.135 | 310.210 | 112.0 | 22.3 |
| 225 | 2004 | 0.354 | 0.035 | 0.571 | 0.049 | 0.133 | 312.010 | 20.1 | 19.6 |
| 241 | 2004 | 0.284 | 0.029 | 0.518 | 0.062 | 0.125 | 317.570 | 12.2 | 13.5 |
| 257 | 2004 | 0.256 | 0.017 | 0.483 | 0.022 | 0.117 | 312.230 | NA | NA |
| 273 | 2004 | 0.245 | 0.014 | 0.469 | 0.034 | 0.118 | 311.660 | NA | NA |
| 289 | 2004 | 0.215 | 0.010 | 0.374 | 0.019 | 0.122 | 304.380 | 0.3 | 29.9 |
| 305 | 2004 | 0.184 | 0.011 | 0.374 | 0.030 | 0.109 | 300.230 | 46.0 | 18.0 |
| 321 | 2004 | 0.187 | 0.017 | 0.372 | 0.017 | 0.107 | 295.790 | 0.3 | 22.2 |
| 337 | 2004 | 0.166 | 0.007 | 0.364 | 0.028 | 0.106 | 296.370 | 28.4 | 25.6 |
| 353 | 2004 | 0.172 | 0.009 | 0.339 | 0.024 | 0.111 | 294.660 | 19.3 | 17.2 |
| 1 | 2005 | 0.151 | 0.017 | 0.344 | 0.025 | 0.103 | 296.010 | 55.4 | 9.0 |
| 17 | 2005 | 0.161 | 0.010 | 0.344 | 0.023 | 0.103 | 296.940 | 40.6 | 11.8 |
| 33 | 2005 | 0.167 | 0.012 | 0.351 | 0.025 | 0.102 | 291.500 | 83.8 | 17.0 |
| 49 | 2005 | 0.178 | 0.013 | 0.360 | 0.025 | 0.107 | 298.890 | 0.0 | 0.5 |
| 65 | 2005 | 0.192 | 0.011 | 0.367 | 0.023 | 0.111 | 305.790 | 0.0 | 0.6 |
| 81 | 2005 | 0.194 | 0.010 | 0.355 | 0.009 | 0.119 | 309.930 | 0.0 | 3.1 |
| 97 | 2005 | 0.187 | 0.015 | 0.336 | 0.013 | 0.122 | 313.670 | 0.3 | 1.6 |
| 113 | 2005 | 0.170 | 0.007 | 0.347 | 0.019 | 0.121 | 312.660 | 4.6 | 2.8 |
| 129 | 2005 | 0.159 | 0.005 | 0.318 | 0.009 | 0.124 | 322.280 | 0.0 | 1.4 |
| 145 | 2005 | 0.153 | 0.015 | 0.289 | 0.012 | 0.120 | 319.770 | 3.0 | 2.2 |
| 161 | 2005 | 0.149 | 0.004 | 0.299 | 0.015 | 0.122 | 324.190 | 20.3 | 3.9 |
| 177 | 2005 | 0.168 | 0.009 | 0.298 | 0.017 | 0.117 | 325.440 | 0.8 | 2.7 |
| 193 | 2005 | 0.144 | 0.004 | 0.265 | 0.016 | 0.120 | 299.110 | 19.6 | 10.6 |
| 209 | 2005 | 0.241 | 0.016 | 0.489 | 0.036 | 0.115 | 309.300 | 51.1 | 24.5 |
| 225 | 2005 | 0.317 | 0.023 | 0.563 | 0.053 | 0.128 | 312.280 | 16.0 | 17.6 |
| 241 | 2005 | 0.286 | 0.027 | 0.486 | 0.019 | 0.121 | 311.850 | 12.7 | 18.4 |
| 257 | 2005 | 0.228 | 0.015 | 0.484 | 0.031 | 0.119 | 316.640 | 1.5 | 9.3 |
| 273 | 2005 | 0.198 | 0.012 | 0.336 | 0.013 | 0.115 | 312.350 | 0.0 | 7.5 |
| 289 | 2005 | 0.157 | 0.004 | 0.356 | 0.020 | 0.114 | 309.010 | 0.0 | 11.2 |
| 305 | 2005 | 0.150 | 0.004 | 0.324 | 0.010 | 0.117 | 308.370 | NA | NA |
| 321 | 2005 | 0.157 | 0.011 | 0.301 | 0.012 | 0.115 | 303.530 | 0.0 | 4.6 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 337 | 2005 | 0.137 | 0.003 | 0.304 | 0.014 | 0.115 | 299.730 | 0.0 | 4.4 |
| 353 | 2005 | 0.137 | 0.009 | 0.279 | 0.014 | 0.113 | 302.060 | 0.0 | 4.5 |
| 1 | 2006 | 0.127 | 0.005 | 0.275 | 0.013 | 0.115 | 302.660 | 0.0 | 4.1 |
| 17 | 2006 | 0.127 | 0.007 | 0.261 | 0.019 | 0.114 | 301.850 | 0.0 | 3.9 |
| 33 | 2006 | 0.119 | 0.004 | 0.264 | 0.015 | 0.114 | 307.300 | 0.0 | 4.0 |
| 49 | 2006 | 0.123 | 0.006 | 0.225 | 0.012 | 0.115 | 307.970 | 0.0 | 4.2 |
| 65 | 2006 | 0.112 | 0.005 | 0.238 | 0.011 | 0.118 | 306.890 | 0.0 | 4.2 |
| 81 | 2006 | 0.110 | 0.004 | 0.228 | 0.013 | 0.123 | 313.510 | 0.0 | 4.7 |
| 97 | 2006 | 0.123 | 0.003 | 0.209 | 0.010 | 0.121 | 319.010 | 0.0 | 4.0 |
| 113 | 2006 | 0.123 | 0.006 | 0.211 | 0.011 | 0.123 | 319.730 | 0.0 | 3.7 |
| 129 | 2006 | 0.114 | 0.007 | 0.209 | 0.013 | 0.121 | 326.980 | 0.0 | 3.6 |
| 145 | 2006 | 0.119 | 0.007 | 0.216 | 0.012 | 0.119 | 325.900 | 0.0 | 3.6 |
| 161 | 2006 | 0.110 | 0.004 | 0.214 | 0.010 | 0.121 | 326.460 | 0.0 | 8.8 |
| 177 | 2006 | 0.267 | 0.029 | 0.410 | 0.046 | 0.122 | 312.290 | 24.9 | 24.0 |
| 193 | 2006 | 0.334 | 0.033 | 0.615 | 0.054 | 0.127 | 313.380 | 0.5 | 26.9 |
| 209 | 2006 | 0.477 | 0.062 | 0.688 | 0.063 | 0.140 | 306.550 | NA | NA |
| 225 | 2006 | 0.420 | 0.064 | 0.649 | 0.076 | 0.143 | 305.970 | 2.5 | 32.8 |
| 241 | 2006 | 0.408 | 0.077 | 0.643 | 0.089 | 0.137 | 305.800 | 98.0 | 33.2 |
| 257 | 2006 | 0.333 | 0.057 | 0.547 | 0.080 | 0.129 | 310.510 | 26.9 | 16.6 |
| 273 | 2006 | 0.245 | 0.019 | 0.476 | 0.033 | 0.119 | 310.120 | 0.0 | 13.3 |
| 289 | 2006 | 0.183 | 0.018 | 0.381 | 0.037 | 0.115 | 305.230 | | |
| 305 | 2006 | 0.177 | 0.013 | 0.367 | 0.024 | 0.116 | 304.960 | | |
| 321 | 2006 | 0.167 | 0.013 | 0.356 | 0.027 | 0.117 | 301.160 | | |
| 337 | 2006 | 0.158 | 0.013 | 0.342 | 0.028 | 0.121 | 298.100 | | |
| 353 | 2006 | 0.161 | 0.010 | 0.317 | 0.029 | 0.113 | 293.810 | | |
| 9 | 2007 | 0.144 | 0.010 | 0.286 | 0.021 | 0.120 | 297.130 | | |
| 25 | 2007 | 0.125 | 0.009 | 0.274 | 0.022 | 0.114 | NA | | |
| 33 | 2007 | 0.132 | 0.010 | 0.280 | 0.024 | 0.115 | 302.080 | | |
| 49 | 2007 | 0.123 | 0.009 | 0.255 | 0.023 | 0.117 | 304.180 | | |
| 65 | 2007 | 0.114 | 0.003 | 0.278 | 0.015 | 0.119 | 313.240 | | |
| 81 | 2007 | 0.126 | 0.005 | 0.272 | 0.018 | 0.117 | 311.820 | | |
| 97 | 2007 | 0.132 | 0.005 | 0.260 | 0.017 | 0.122 | 312.520 | | |
| 113 | 2007 | 0.129 | 0.004 | 0.252 | 0.015 | 0.123 | 318.260 | | |
| 129 | 2007 | 0.136 | 0.008 | 0.243 | 0.014 | 0.123 | 322.310 | | |
| 145 | 2007 | 0.118 | 0.005 | 0.238 | 0.009 | 0.120 | 324.290 | | |
| 161 | 2007 | 0.162 | 0.005 | 0.360 | 0.019 | 0.122 | 325.800 | | |
| 177 | 2007 | 0.325 | 0.020 | 0.539 | 0.030 | 0.111 | 330.000 | | |
| 193 | 2007 | 0.409 | 0.025 | 0.601 | 0.025 | 0.134 | 315.920 | | |
| 209 | 2007 | 0.394 | 0.043 | 0.626 | 0.040 | 0.137 | 307.570 | | |
| 225 | 2007 | 0.370 | 0.040 | 0.637 | 0.046 | 0.138 | NA | | |

STATION 143

| DOY | Year | EVI mean | EVI std | NDVI mean | NDVI std | Albedo | LST (K) | Rainfall (mm) | Soil moisture (%) |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 2004 | 0.103 | 0.003 | 0.227 | 0.005 | 0.136 | 297.900 | | |
| 17 | 2004 | 0.096 | 0.005 | 0.208 | 0.008 | 0.121 | 295.990 | | |
| 33 | 2004 | 0.102 | 0.004 | 0.201 | 0.005 | 0.132 | 301.250 | | |
| 49 | 2004 | 0.108 | 0.004 | 0.215 | 0.007 | 0.135 | 301.720 | | |
| 65 | 2004 | 0.159 | 0.013 | 0.294 | 0.018 | 0.133 | 307.650 | | |
| 81 | 2004 | 0.165 | 0.010 | 0.272 | 0.013 | 0.143 | 315.680 | | |
| 97 | 2004 | 0.208 | 0.011 | 0.332 | 0.019 | 0.142 | 311.840 | | |
| 113 | 2004 | 0.215 | 0.011 | 0.347 | 0.018 | 0.147 | 318.240 | | |
| 129 | 2004 | 0.198 | 0.009 | 0.339 | 0.012 | 0.152 | 321.910 | | |
| 145 | 2004 | 0.179 | 0.008 | 0.309 | 0.009 | 0.148 | 324.810 | | |
| 161 | 2004 | 0.184 | 0.010 | 0.291 | 0.013 | 0.152 | 324.700 | 15.7 | 6.3 |
| 177 | 2004 | 0.180 | 0.011 | 0.283 | 0.013 | 0.150 | 324.720 | 2.8 | 7.9 |
| 193 | 2004 | 0.246 | 0.017 | 0.349 | 0.019 | 0.161 | 317.330 | 87.1 | 18.6 |
| 209 | 2004 | 0.363 | 0.020 | 0.579 | 0.028 | 0.167 | 311.600 | 20.6 | 12.0 |
| 225 | 2004 | 0.311 | 0.022 | 0.459 | 0.023 | 0.153 | 316.730 | 17.8 | 13.6 |
| 241 | 2004 | 0.265 | 0.030 | 0.405 | 0.033 | 0.142 | 317.570 | 25.9 | 11.1 |
| 257 | 2004 | 0.237 | 0.022 | 0.396 | 0.021 | 0.142 | 312.850 | NA | 0.0 |
| 273 | 2004 | 0.247 | 0.011 | 0.418 | 0.022 | 0.144 | 311.750 | 0.0 | 0.0 |
| 289 | 2004 | 0.235 | 0.013 | 0.372 | 0.014 | 0.127 | 302.350 | 1.3 | 1.5 |
| 305 | 2004 | 0.182 | 0.004 | 0.349 | 0.008 | 0.138 | 299.480 | 5.8 | 2.0 |
| 321 | 2004 | 0.165 | 0.009 | 0.326 | 0.013 | 0.131 | 296.020 | 8.9 | 3.1 |
| 337 | 2004 | 0.137 | 0.008 | 0.275 | 0.011 | 0.132 | 295.930 | 31.8 | 4.1 |
| 353 | 2004 | 0.134 | 0.004 | 0.258 | 0.010 | 0.131 | 295.930 | 14.5 | 2.6 |
| 1 | 2005 | 0.130 | 0.012 | 0.284 | 0.009 | 0.126 | 297.880 | 16.5 | 15.0 |
| 17 | 2005 | 0.161 | 0.015 | 0.311 | 0.026 | 0.127 | 297.700 | 18.5 | 25.6 |
| 33 | 2005 | 0.180 | 0.020 | 0.350 | 0.034 | 0.128 | 297.240 | 46.0 | 29.9 |
| 49 | 2005 | 0.223 | 0.022 | 0.382 | 0.027 | 0.136 | 298.050 | 9.4 | 21.6 |
| 65 | 2005 | 0.257 | 0.025 | 0.415 | 0.037 | 0.141 | 306.550 | 3.6 | 11.2 |
| 81 | 2005 | 0.233 | 0.023 | 0.380 | 0.019 | 0.146 | 311.910 | 0.0 | 8.6 |
| 97 | 2005 | 0.194 | 0.010 | 0.323 | 0.012 | 0.152 | 314.460 | 0.3 | 7.1 |
| 113 | 2005 | 0.226 | 0.013 | 0.319 | 0.015 | 0.148 | 311.120 | 7.4 | 9.4 |
| 129 | 2005 | 0.213 | 0.011 | 0.337 | 0.014 | 0.156 | 320.700 | 0.0 | 7.4 |
| 145 | 2005 | 0.213 | 0.014 | 0.331 | 0.015 | 0.148 | 319.030 | 18.3 | 12.9 |
| 161 | 2005 | 0.203 | 0.010 | 0.328 | 0.014 | 0.153 | 323.420 | 1.8 | 7.6 |
| 177 | 2005 | 0.188 | 0.009 | 0.321 | 0.014 | 0.151 | 326.750 | 0.0 | 7.3 |
| 193 | 2005 | 0.194 | 0.010 | 0.311 | 0.010 | 0.165 | 300.070 | 67.1 | 16.5 |
| 209 | 2005 | 0.315 | 0.056 | 0.493 | 0.066 | 0.118 | 291.400 | 94.0 | 24.8 |
| 225 | 2005 | 0.376 | 0.053 | 0.566 | 0.057 | 0.152 | 312.680 | 49.0 | 21.7 |
| 241 | 2005 | 0.365 | 0.024 | 0.574 | 0.033 | 0.146 | 308.820 | 36.3 | 25.8 |
| 257 | 2005 | 0.353 | 0.032 | 0.577 | 0.031 | 0.140 | 314.570 | 9.7 | 16.7 |
| 273 | 2005 | 0.240 | 0.014 | 0.387 | 0.026 | 0.146 | 311.330 | 1.0 | 11.9 |
| 289 | 2005 | 0.204 | 0.004 | 0.386 | 0.007 | 0.150 | 309.770 | 0.3 | 9.6 |
| 305 | 2005 | 0.199 | 0.008 | 0.353 | 0.011 | 0.153 | 308.320 | 0.0 | 8.0 |
| 321 | 2005 | 0.186 | 0.008 | 0.311 | 0.013 | 0.154 | 304.160 | 0.0 | 6.7 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 337 | 2005 | 0.163 | 0.007 | 0.292 | 0.006 | 0.164 | 299.820 | 1.5 | 6.2 |
| 353 | 2005 | 0.141 | 0.007 | 0.256 | 0.008 | 0.154 | 301.870 | 0.0 | 6.3 |
| 1 | 2006 | 0.134 | 0.003 | 0.250 | 0.007 | 0.156 | 303.490 | 0.0 | 6.0 |
| 17 | 2006 | 0.135 | 0.004 | 0.242 | 0.007 | 0.159 | 303.310 | 0.0 | 5.6 |
| 33 | 2006 | 0.127 | 0.004 | 0.240 | 0.006 | 0.155 | 308.120 | 4.1 | 7.1 |
| 49 | 2006 | 0.134 | 0.003 | 0.213 | 0.005 | 0.164 | 308.510 | 0.0 | 7.7 |
| 65 | 2006 | 0.133 | 0.004 | 0.227 | 0.004 | 0.161 | 309.020 | 11.4 | 7.4 |
| 81 | 2006 | 0.129 | 0.003 | 0.225 | 0.004 | 0.166 | 312.540 | 0.0 | 10.9 |
| 97 | 2006 | 0.132 | 0.005 | 0.219 | 0.006 | 0.168 | 319.350 | 0.5 | 7.3 |
| 113 | 2006 | 0.166 | 0.011 | 0.241 | 0.015 | 0.171 | 319.730 | 0.0 | 6.5 |
| 129 | 2006 | 0.170 | 0.012 | 0.256 | 0.014 | 0.170 | 324.840 | 0.0 | 6.5 |
| 145 | 2006 | 0.163 | 0.010 | 0.253 | 0.012 | 0.171 | 324.700 | 1.8 | 6.4 |
| 161 | 2006 | 0.167 | 0.007 | 0.260 | 0.008 | 0.163 | 326.810 | 9.7 | 9.6 |
| 177 | 2006 | 0.231 | 0.021 | 0.363 | 0.028 | 0.154 | 313.790 | 86.1 | 24.6 |
| 193 | 2006 | 0.258 | 0.019 | 0.348 | 0.026 | 0.152 | 321.510 | 20.3 | 10.9 |
| 209 | 2006 | 0.492 | 0.037 | 0.687 | 0.037 | 0.145 | 289.950 | 38.9 | 31.6 |
| 225 | 2006 | 0.490 | 0.027 | 0.677 | 0.023 | 0.143 | 306.190 | 53.3 | 26.6 |
| 241 | 2006 | 0.506 | 0.052 | 0.682 | 0.023 | 0.142 | 306.150 | 60.5 | 26.3 |
| 257 | 2006 | 0.388 | 0.039 | 0.586 | 0.043 | 0.137 | 308.970 | 0.0 | 13.9 |
| 273 | 2006 | 0.277 | 0.015 | 0.482 | 0.024 | 0.141 | 310.580 | 0.3 | 9.6 |
| 289 | 2006 | 0.192 | 0.006 | 0.374 | 0.013 | 0.138 | 305.920 | | |
| 305 | 2006 | 0.148 | 0.006 | 0.316 | 0.013 | 0.136 | 305.420 | | |
| 321 | 2006 | 0.145 | 0.006 | 0.303 | 0.011 | 0.140 | 301.540 | | |
| 337 | 2006 | 0.129 | 0.005 | 0.271 | 0.009 | 0.149 | 299.610 | | |
| 353 | 2006 | 0.129 | 0.003 | 0.261 | 0.006 | 0.141 | 290.000 | | |
| 9 | 2007 | 0.121 | 0.003 | 0.218 | 0.008 | 0.144 | 297.440 | | |
| 25 | 2007 | 0.098 | 0.003 | 0.202 | 0.007 | 0.140 | NA | | |
| 33 | 2007 | 0.099 | 0.004 | 0.198 | 0.007 | 0.149 | 303.260 | | |
| 49 | 2007 | 0.118 | 0.005 | 0.198 | 0.009 | 0.145 | 303.810 | | |
| 65 | 2007 | 0.111 | 0.005 | 0.206 | 0.007 | 0.143 | 314.600 | | |
| 81 | 2007 | 0.122 | 0.007 | 0.229 | 0.009 | 0.135 | 311.540 | | |
| 97 | 2007 | 0.145 | 0.007 | 0.250 | 0.006 | 0.143 | 311.330 | | |
| 113 | 2007 | 0.184 | 0.015 | 0.307 | 0.018 | 0.145 | 317.730 | | |
| 129 | 2007 | 0.177 | 0.010 | 0.289 | 0.012 | 0.146 | 321.590 | | |
| 145 | 2007 | 0.184 | 0.007 | 0.320 | 0.010 | 0.145 | 322.830 | | |
| 161 | 2007 | 0.307 | 0.022 | 0.515 | 0.026 | 0.147 | 325.160 | | |
| 177 | 2007 | 0.472 | 0.042 | 0.634 | 0.045 | 0.151 | 322.860 | | |
| 193 | 2007 | 0.482 | 0.049 | 0.656 | 0.023 | 0.161 | 308.320 | | |
| 209 | 2007 | 0.417 | 0.028 | 0.634 | 0.028 | 0.145 | 307.500 | | |
| 225 | 2007 | 0.322 | 0.022 | 0.584 | 0.025 | 0.135 | NA | | |

STATION 144

| DOY | Year | EVI mean | EVI std | NDVI mean | NDVI std | Albedo | LST (K) | Rainfall (mm) | Soil moisture (%) |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 2004 | 0.114 | 0.005 | 0.281 | 0.007 | 0.102 | 297.67 | | |
| 17 | 2004 | 0.114 | 0.006 | 0.276 | 0.008 | 0.102 | 295.40 | | |
| 33 | 2004 | 0.110 | 0.005 | 0.277 | 0.013 | 0.107 | 300.77 | | |
| 49 | 2004 | 0.110 | 0.003 | 0.253 | 0.011 | 0.107 | 301.38 | | |
| 65 | 2004 | 0.120 | 0.007 | 0.278 | 0.015 | 0.111 | 311.00 | | |
| 81 | 2004 | 0.146 | 0.005 | 0.277 | 0.007 | 0.122 | 314.70 | | |
| 97 | 2004 | 0.181 | 0.017 | 0.334 | 0.020 | 0.121 | 312.24 | | |
| 113 | 2004 | 0.174 | 0.014 | 0.349 | 0.018 | 0.124 | 318.13 | | |
| 129 | 2004 | 0.160 | 0.019 | 0.321 | 0.024 | 0.126 | 320.28 | | |
| 145 | 2004 | 0.164 | 0.026 | 0.303 | 0.024 | 0.120 | 324.16 | | |
| 161 | 2004 | 0.154 | 0.025 | 0.287 | 0.029 | 0.125 | 325.25 | 5.6 | 5.7 |
| 177 | 2004 | 0.142 | 0.016 | 0.261 | 0.017 | 0.123 | 325.19 | 30.2 | 4.4 |
| 193 | 2004 | 0.242 | 0.007 | 0.402 | 0.009 | 0.131 | 292.68 | 71.6 | 9.7 |
| 209 | 2004 | 0.316 | 0.035 | 0.409 | 0.082 | 0.148 | 312.01 | 29.5 | 6.8 |
| 225 | 2004 | 0.389 | 0.016 | 0.595 | 0.013 | 0.131 | 313.39 | 91.7 | 10.2 |
| 241 | 2004 | 0.324 | 0.019 | 0.548 | 0.015 | 0.125 | 315.30 | 17.3 | 7.4 |
| 257 | 2004 | 0.298 | 0.016 | 0.572 | 0.035 | 0.123 | 312.14 | NA | NA |
| 273 | 2004 | 0.286 | 0.024 | 0.590 | 0.036 | 0.122 | 310.51 | NA | NA |
| 289 | 2004 | 0.248 | 0.009 | 0.437 | 0.012 | 0.126 | 302.86 | 36.8 | 7.9 |
| 305 | 2004 | 0.228 | 0.016 | 0.456 | 0.021 | 0.117 | 300.86 | 3.6 | 9.5 |
| 321 | 2004 | 0.215 | 0.012 | 0.438 | 0.017 | 0.113 | 296.40 | 13.7 | 9.7 |
| 337 | 2004 | 0.178 | 0.015 | 0.393 | 0.031 | 0.109 | 296.75 | 29.0 | 11.5 |
| 353 | 2004 | 0.176 | 0.010 | 0.362 | 0.025 | 0.116 | 295.18 | 13.5 | 8.5 |
| 1 | 2005 | 0.150 | 0.020 | 0.371 | 0.038 | 0.106 | 298.43 | 16.8 | 11.7 |
| 17 | 2005 | 0.148 | 0.012 | 0.346 | 0.027 | 0.107 | 298.35 | 20.3 | 11.7 |
| 33 | 2005 | 0.148 | 0.011 | 0.332 | 0.016 | 0.109 | 296.66 | 42.4 | 13.1 |
| 49 | 2005 | 0.156 | 0.011 | 0.341 | 0.021 | 0.107 | 299.95 | 3.6 | 10.7 |
| 65 | 2005 | 0.178 | 0.005 | 0.364 | 0.011 | 0.118 | 308.26 | 0.0 | 7.5 |
| 81 | 2005 | 0.176 | 0.007 | 0.347 | 0.010 | 0.121 | 310.63 | 0.0 | 5.5 |
| 97 | 2005 | 0.185 | 0.019 | 0.341 | 0.025 | 0.126 | 314.69 | 1.8 | 5.1 |
| 113 | 2005 | 0.177 | 0.019 | 0.366 | 0.027 | 0.126 | 310.67 | 7.4 | 7.1 |
| 129 | 2005 | 0.176 | 0.022 | 0.334 | 0.024 | 0.131 | 321.54 | 0.0 | 5.7 |
| 145 | 2005 | 0.202 | 0.007 | 0.386 | 0.010 | 0.120 | 318.57 | 48.5 | 12.2 |
| 161 | 2005 | 0.192 | 0.016 | 0.353 | 0.010 | 0.127 | 322.67 | 11.7 | 8.0 |
| 177 | 2005 | 0.173 | 0.011 | 0.343 | 0.011 | 0.129 | 326.10 | 4.1 | 8.2 |
| 193 | 2005 | 0.169 | 0.009 | 0.306 | 0.013 | 0.138 | 316.44 | 64.5 | 13.3 |
| 209 | 2005 | 0.361 | 0.010 | 0.579 | 0.013 | 0.130 | 298.65 | 172.5 | 25.5 |
| 225 | 2005 | 0.412 | 0.014 | 0.715 | 0.017 | 0.130 | 311.36 | 31.5 | 20.3 |
| 241 | 2005 | 0.392 | 0.024 | 0.659 | 0.015 | 0.137 | 311.80 | 34.0 | 16.2 |
| 257 | 2005 | 0.296 | 0.017 | 0.576 | 0.012 | 0.127 | 316.46 | 11.7 | 13.9 |
| 273 | 2005 | 0.249 | 0.008 | 0.434 | 0.009 | 0.125 | 312.30 | 27.4 | 15.5 |
| 289 | 2005 | 0.223 | 0.007 | 0.497 | 0.010 | 0.127 | 309.27 | 0.3 | 12.6 |
| 305 | 2005 | 0.189 | 0.011 | 0.408 | 0.023 | 0.121 | 308.32 | 0.0 | 10.1 |
| 321 | 2005 | 0.174 | 0.013 | 0.367 | 0.016 | 0.123 | 303.66 | 0.0 | 8.6 |
| 337 | 2005 | 0.166 | 0.007 | 0.377 | 0.012 | 0.127 | 299.59 | 0.5 | 7.9 |
| 353 | 2005 | 0.157 | 0.005 | 0.364 | 0.009 | 0.123 | 302.28 | 0.0 | 7.9 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 2006 | 0.149 | 0.005 | 0.332 | 0.006 | 0.125 | 303.52 | 0.5 | 7.7 |
| 17 | 2006 | 0.141 | 0.006 | 0.307 | 0.006 | 0.125 | 302.10 | 0.0 | 7.3 |
| 33 | 2006 | 0.134 | 0.003 | 0.306 | 0.008 | 0.120 | 306.01 | 9.9 | 8.7 |
| 49 | 2006 | 0.136 | 0.002 | 0.253 | 0.002 | 0.125 | 307.74 | 0.0 | 10.5 |
| 65 | 2006 | 0.120 | 0.002 | 0.264 | 0.007 | 0.128 | 308.09 | 7.6 | 8.9 |
| 81 | 2006 | 0.121 | 0.002 | 0.253 | 0.006 | 0.135 | 312.45 | 0.0 | 10.0 |
| 97 | 2006 | 0.136 | 0.006 | 0.224 | 0.007 | 0.136 | 320.15 | 0.0 | 9.1 |
| 113 | 2006 | 0.128 | 0.008 | 0.253 | 0.011 | 0.139 | 319.18 | 1.0 | 8.7 |
| 129 | 2006 | 0.127 | 0.007 | 0.243 | 0.009 | 0.136 | 324.27 | 0.0 | 9.0 |
| 145 | 2006 | 0.140 | 0.004 | 0.243 | 0.008 | 0.139 | 323.31 | 25.7 | 12.9 |
| 161 | 2006 | 0.143 | 0.007 | 0.275 | 0.011 | 0.132 | 326.11 | 14.2 | 15.1 |
| 177 | 2006 | 0.321 | 0.012 | 0.477 | 0.020 | 0.127 | 311.80 | 101.9 | 26.0 |
| 193 | 2006 | 0.342 | 0.021 | 0.643 | 0.028 | 0.131 | 318.38 | NA | NA |
| 209 | 2006 | 0.421 | 0.017 | 0.652 | 0.016 | 0.136 | 290.65 | 17.8 | 12.4 |
| 225 | 2006 | 0.421 | 0.017 | 0.599 | 0.020 | 0.138 | 308.42 | 65.0 | 10.7 |
| 241 | 2006 | 0.420 | 0.012 | 0.648 | 0.019 | 0.133 | 306.66 | 101.6 | 16.5 |
| 257 | 2006 | 0.357 | 0.022 | 0.678 | 0.032 | 0.126 | 310.00 | 0.0 | 9.3 |
| 273 | 2006 | 0.252 | 0.006 | 0.422 | 0.005 | 0.139 | 310.86 | 0.0 | 7.3 |
| 289 | 2006 | 0.209 | 0.009 | 0.414 | 0.017 | 0.120 | 307.09 | | |
| 305 | 2006 | 0.197 | 0.009 | 0.432 | 0.012 | 0.118 | 306.77 | | |
| 321 | 2006 | 0.182 | 0.007 | 0.414 | 0.012 | 0.119 | 302.13 | | |
| 337 | 2006 | 0.163 | 0.007 | 0.355 | 0.012 | 0.121 | 299.29 | | |
| 353 | 2006 | 0.147 | 0.004 | 0.312 | 0.006 | 0.118 | 291.27 | | |
| 9 | 2007 | 0.135 | 0.007 | 0.292 | 0.011 | 0.117 | 297.85 | | |
| 25 | 2007 | 0.123 | 0.009 | 0.283 | 0.015 | 0.116 | NA | | |
| 33 | 2007 | 0.123 | 0.006 | 0.274 | 0.019 | 0.116 | 303.20 | | |
| 49 | 2007 | 0.119 | 0.006 | 0.242 | 0.011 | 0.122 | 303.63 | | |
| 65 | 2007 | 0.118 | 0.002 | 0.271 | 0.010 | 0.126 | 314.75 | | |
| 81 | 2007 | 0.149 | 0.016 | 0.316 | 0.027 | 0.125 | 311.44 | | |
| 97 | 2007 | 0.145 | 0.014 | 0.294 | 0.024 | 0.131 | 312.23 | | |
| 113 | 2007 | 0.149 | 0.019 | 0.306 | 0.022 | 0.132 | 317.03 | | |
| 129 | 2007 | 0.144 | 0.017 | 0.273 | 0.017 | 0.134 | 321.46 | | |
| 145 | 2007 | 0.139 | 0.017 | 0.280 | 0.027 | 0.134 | 323.09 | | |
| 161 | 2007 | 0.170 | 0.015 | 0.372 | 0.018 | 0.131 | 325.85 | | |
| 177 | 2007 | 0.366 | 0.027 | 0.581 | 0.031 | 0.134 | 330.18 | | |
| 193 | 2007 | 0.461 | 0.027 | 0.745 | 0.027 | 0.138 | 312.32 | | |
| 209 | 2007 | 0.404 | 0.010 | 0.657 | 0.009 | 0.146 | 308.18 | | |
| 225 | 2007 | 0.351 | 0.025 | 0.630 | 0.025 | 0.139 | NA | | |

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| DOY | Year | EVI mean | EVI std | NDVI mean | NDVI std | Albedo | LST (K) | Rainfall (mm) | Soil moisture (%) |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 2004 | 0.228 | 0.011 | 0.435 | 0.013 | 0.124 | 293.200 | | |
| 17 | 2004 | 0.206 | 0.011 | 0.408 | 0.007 | 0.120 | 291.040 | | |
| 33 | 2004 | 0.200 | 0.012 | 0.405 | 0.009 | 0.128 | 295.300 | | |
| 49 | 2004 | 0.188 | 0.008 | 0.347 | 0.007 | 0.134 | 296.770 | | |
| 65 | 2004 | 0.195 | 0.009 | 0.373 | 0.007 | 0.134 | 304.910 | | |
| 81 | 2004 | 0.213 | 0.005 | 0.345 | 0.010 | 0.141 | 311.220 | | |
| 97 | 2004 | 0.214 | 0.004 | 0.357 | 0.007 | 0.143 | 307.470 | | |
| 113 | 2004 | 0.217 | 0.005 | 0.388 | 0.009 | 0.145 | 313.590 | | |
| 129 | 2004 | 0.202 | 0.004 | 0.353 | 0.013 | 0.152 | 316.610 | | |
| 145 | 2004 | 0.175 | 0.009 | 0.301 | 0.009 | 0.156 | 319.000 | | |
| 161 | 2004 | 0.175 | 0.007 | 0.279 | 0.009 | 0.162 | 320.000 | 43.43 | 3.12 |
| 177 | 2004 | 0.220 | 0.005 | 0.316 | 0.006 | 0.162 | 318.500 | 5.84 | 0.87 |
| 193 | 2004 | 0.306 | 0.007 | 0.427 | 0.008 | 0.150 | 308.340 | 128.52 | 10.49 |
| 209 | 2004 | 0.420 | 0.044 | 0.589 | 0.033 | 0.149 | 307.210 | 38.61 | 13.16 |
| 225 | 2004 | 0.401 | 0.022 | 0.541 | 0.019 | 0.150 | 311.890 | 6.86 | 2.39 |
| 241 | 2004 | 0.327 | 0.024 | 0.523 | 0.020 | 0.146 | 309.420 | 91.69 | 10.87 |
| 257 | 2004 | 0.331 | 0.028 | 0.552 | 0.010 | 0.139 | 306.710 | 0.00 | 5.68 |
| 273 | 2004 | 0.305 | 0.011 | 0.515 | 0.041 | 0.142 | 308.470 | 0.00 | 1.13 |
| 289 | 2004 | 0.263 | 0.010 | 0.419 | 0.010 | 0.148 | 297.190 | 37.34 | 6.74 |
| 305 | 2004 | 0.237 | 0.015 | 0.439 | 0.013 | 0.131 | 298.560 | 11.94 | 2.91 |
| 321 | 2004 | 0.250 | 0.017 | 0.493 | 0.009 | 0.122 | 291.800 | 8.64 | 2.40 |
| 337 | 2004 | 0.228 | 0.013 | 0.425 | 0.012 | 0.123 | 294.460 | 34.54 | 5.35 |
| 353 | 2004 | 0.230 | 0.012 | 0.403 | 0.010 | 0.131 | 291.890 | 21.59 | 0.46 |
| 1 | 2005 | 0.224 | 0.016 | 0.392 | 0.013 | 0.122 | 294.060 | 47.24 | 6.56 |
| 17 | 2005 | 0.202 | 0.012 | 0.385 | 0.009 | 0.122 | 293.320 | 48.26 | 5.84 |
| 33 | 2005 | 0.229 | 0.009 | 0.370 | 0.005 | 0.121 | 292.730 | 70.00 | 7.95 |
| 49 | 2005 | 0.207 | 0.007 | 0.350 | 0.012 | 0.125 | 296.610 | 2.79 | 3.37 |
| 65 | 2005 | 0.192 | 0.011 | 0.363 | 0.014 | 0.136 | 302.140 | 0.51 | 0.42 |
| 81 | 2005 | 0.200 | 0.011 | 0.348 | 0.011 | 0.142 | 305.660 | 0.00 | 0.36 |
| 97 | 2005 | 0.213 | 0.009 | 0.350 | 0.008 | 0.146 | 309.640 | 1.27 | 0.26 |
| 113 | 2005 | 0.223 | 0.011 | 0.384 | 0.015 | 0.152 | 307.500 | 8.64 | 1.38 |
| 129 | 2005 | 0.216 | 0.011 | 0.348 | 0.010 | 0.156 | 317.770 | 1.27 | 0.30 |
| 145 | 2005 | 0.231 | 0.011 | 0.375 | 0.023 | 0.156 | 315.700 | 19.81 | 2.86 |
| 161 | 2005 | 0.247 | 0.009 | 0.389 | 0.013 | 0.163 | 318.410 | 17.53 | 1.70 |
| 177 | 2005 | 0.215 | 0.019 | 0.379 | 0.013 | 0.160 | 320.580 | 6.86 | 1.04 |
| 193 | 2005 | 0.275 | 0.012 | 0.440 | 0.016 | 0.160 | 318.190 | 95.25 | 7.14 |
| 209 | 2005 | 0.405 | 0.019 | 0.568 | 0.015 | 0.146 | 303.340 | 16.76 | 11.62 |
| 225 | 2005 | 0.383 | 0.045 | 0.638 | 0.044 | 0.157 | 304.390 | 13.21 | 9.03 |
| 241 | 2005 | 0.388 | 0.035 | 0.566 | 0.029 | 0.158 | 306.330 | 85.85 | 9.62 |
| 257 | 2005 | 0.372 | 0.035 | 0.627 | 0.029 | 0.151 | 308.890 | 14.99 | 3.82 |
| 273 | 2005 | 0.350 | 0.013 | 0.503 | 0.012 | 0.148 | 307.140 | 10.67 | 1.85 |
| 289 | 2005 | 0.273 | 0.013 | 0.498 | 0.014 | 0.149 | 304.520 | 3.56 | 1.57 |
| 305 | 2005 | 0.249 | 0.012 | 0.437 | 0.014 | 0.149 | 304.500 | 0.00 | 0.33 |
| 321 | 2005 | 0.254 | 0.013 | 0.418 | 0.018 | 0.148 | 300.020 | 0.00 | 0.37 |
| 337 | 2005 | 0.235 | 0.006 | 0.435 | 0.019 | 0.141 | 294.110 | 4.06 | 1.18 |
| 353 | 2005 | 0.215 | 0.006 | 0.382 | 0.018 | 0.145 | 299.590 | 0.00 | 0.22 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 2006 | 0.208 | 0.005 | 0.379 | 0.014 | 0.149 | 299.320 | 0.00 | 0.51 |
| 17 | 2006 | 0.199 | 0.004 | 0.365 | 0.014 | 0.151 | 298.320 | 0.00 | 0.48 |
| 33 | 2006 | 0.189 | 0.005 | 0.339 | 0.011 | 0.154 | 301.450 | 1.78 | 0.53 |
| 49 | 2006 | 0.177 | 0.003 | 0.277 | 0.010 | 0.160 | 301.730 | 3.05 | 0.67 |
| 65 | 2006 | 0.167 | 0.001 | 0.290 | 0.008 | 0.169 | 302.270 | 3.81 | 2.69 |
| 81 | 2006 | 0.165 | 0.003 | 0.280 | 0.007 | 0.168 | 306.560 | 0.00 | 0.46 |
| 97 | 2006 | 0.154 | 0.009 | 0.259 | 0.008 | 0.168 | 313.140 | 0.00 | 0.57 |
| 113 | 2006 | 0.165 | 0.007 | 0.243 | 0.008 | 0.178 | 314.710 | 0.25 | 0.65 |
| 129 | 2006 | 0.149 | 0.004 | 0.243 | 0.006 | 0.179 | 320.130 | 0.00 | 0.72 |
| 145 | 2006 | 0.153 | 0.004 | 0.244 | 0.008 | 0.180 | 318.620 | 6.35 | 1.91 |
| 161 | 2006 | 0.161 | 0.003 | 0.250 | 0.007 | 0.183 | 322.350 | 6.86 | 2.03 |
| 177 | 2006 | 0.175 | 0.006 | 0.267 | 0.008 | 0.164 | 314.880 | 134.11 | 12.80 |
| 193 | 2006 | 0.414 | 0.014 | 0.564 | 0.018 | 0.164 | 308.790 | 292.10 | 17.20 |
| 209 | 2006 | 0.505 | 0.036 | 0.695 | 0.029 | 0.162 | 287.540 | NA | NA |
| 225 | 2006 | 0.511 | 0.042 | 0.711 | 0.031 | 0.158 | 300.900 | NA | NA |
| 241 | 2006 | 0.548 | 0.034 | 0.778 | 0.020 | 0.142 | 300.640 | 97.79 | 21.52 |
| 257 | 2006 | 0.489 | 0.016 | 0.678 | 0.012 | 0.147 | 302.700 | 0.25 | 4.74 |
| 273 | 2006 | 0.356 | 0.014 | 0.615 | 0.010 | 0.140 | 304.530 | 0.00 | 1.50 |
| 289 | 2006 | 0.290 | 0.015 | 0.539 | 0.018 | 0.134 | 301.840 | | |
| 305 | 2006 | 0.296 | 0.025 | 0.542 | 0.017 | 0.131 | 301.060 | | |
| 321 | 2006 | 0.274 | 0.019 | 0.534 | 0.008 | 0.131 | 298.110 | | |
| 337 | 2006 | 0.266 | 0.014 | 0.526 | 0.012 | 0.135 | 294.750 | | |
| 353 | 2006 | 0.240 | 0.021 | 0.457 | 0.009 | 0.134 | 290.890 | | |
| 9 | 2007 | 0.246 | 0.007 | 0.412 | 0.007 | 0.151 | 293.270 | | |
| 25 | 2007 | 0.199 | 0.004 | 0.384 | 0.018 | 0.141 | NA | | |
| 33 | 2007 | 0.205 | 0.007 | 0.363 | 0.008 | 0.142 | 297.510 | | |
| 49 | 2007 | 0.188 | 0.004 | 0.335 | 0.013 | 0.149 | 299.710 | | |
| 65 | 2007 | 0.196 | 0.008 | 0.339 | 0.009 | 0.154 | 310.310 | | |
| 81 | 2007 | 0.193 | 0.003 | 0.339 | 0.009 | 0.150 | 307.140 | | |
| 97 | 2007 | 0.191 | 0.008 | 0.314 | 0.012 | 0.154 | 308.250 | | |
| 113 | 2007 | 0.195 | 0.004 | 0.312 | 0.010 | 0.155 | 312.510 | | |
| 129 | 2007 | 0.176 | 0.008 | 0.275 | 0.018 | 0.160 | 317.780 | | |
| 145 | 2007 | 0.183 | 0.006 | 0.274 | 0.011 | 0.169 | 319.210 | | |
| 161 | 2007 | 0.176 | 0.008 | 0.326 | 0.014 | 0.172 | 321.980 | | |
| 177 | 2007 | 0.321 | 0.013 | 0.570 | 0.019 | 0.169 | 323.650 | | |
| 193 | 2007 | 0.404 | 0.025 | 0.656 | 0.022 | NA | 311.210 | | |
| 209 | 2007 | 0.407 | 0.018 | 0.630 | 0.031 | 0.136 | 305.380 | | |
| 225 | 2007 | 0.386 | 0.026 | 0.638 | 0.021 | 0.148 | NA | | |

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| DOY | Year | EVI mean | EVI stdev | NDVI mean | NDVI stdev | Albedo | LST (K) | Rainfall (mm) | Soil moisture (%) |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 2004 | 0.144 | 0.005 | 0.270 | 0.008 | 0.156 | 301.470 | | |
| 17 | 2004 | 0.136 | 0.007 | 0.247 | 0.006 | 0.150 | 296.560 | | |
| 33 | 2004 | 0.128 | 0.003 | 0.245 | 0.005 | 0.154 | 301.820 | | |
| 49 | 2004 | 0.118 | 0.004 | 0.222 | 0.004 | 0.168 | 301.230 | | |
| 65 | 2004 | 0.131 | 0.003 | 0.238 | 0.004 | 0.154 | 311.270 | | |
| 81 | 2004 | 0.152 | 0.004 | 0.244 | 0.006 | 0.160 | 313.140 | | |
| 97 | 2004 | 0.156 | 0.007 | 0.256 | 0.006 | 0.157 | 314.270 | | |
| 113 | 2004 | 0.146 | 0.006 | 0.251 | 0.007 | 0.160 | 319.660 | | |
| 129 | 2004 | 0.128 | 0.005 | 0.223 | 0.007 | 0.164 | 321.580 | | |
| 145 | 2004 | 0.122 | 0.007 | 0.205 | 0.004 | 0.159 | 324.200 | | |
| 161 | 2004 | 0.120 | 0.004 | 0.199 | 0.005 | 0.167 | 325.230 | | |
| 177 | 2004 | 0.121 | 0.003 | 0.192 | 0.004 | 0.160 | 328.070 | | |
| 193 | 2004 | 0.338 | 0.063 | 0.459 | 0.100 | 0.183 | NA | | |
| 209 | 2004 | 0.348 | 0.013 | 0.536 | 0.020 | 0.176 | 309.770 | 69.6 | 8.4 |
| 225 | 2004 | 0.339 | 0.007 | 0.483 | 0.011 | 0.159 | 315.400 | 12.7 | 4.2 |
| 241 | 2004 | 0.306 | 0.013 | 0.531 | 0.023 | 0.168 | 315.200 | 40.9 | 6.9 |
| 257 | 2004 | 0.232 | 0.005 | 0.394 | 0.013 | 0.157 | 314.780 | 14.2 | 4.5 |
| 273 | 2004 | 0.199 | 0.006 | 0.334 | 0.006 | 0.161 | 314.950 | 0.0 | 1.1 |
| 289 | 2004 | 0.165 | 0.004 | 0.302 | 0.007 | 0.171 | 306.910 | 30.5 | 5.4 |
| 305 | 2004 | 0.172 | 0.003 | 0.312 | 0.006 | 0.150 | 305.190 | 2.3 | 3.2 |
| 321 | 2004 | 0.164 | 0.006 | 0.321 | 0.004 | 0.151 | 297.720 | 4.8 | 4.0 |
| 337 | 2004 | 0.170 | 0.007 | 0.305 | 0.006 | 0.147 | 300.200 | 31.0 | 7.6 |
| 353 | 2004 | 0.167 | 0.004 | 0.301 | 0.006 | 0.156 | 296.700 | 15.5 | 2.6 |
| 1 | 2005 | 0.165 | 0.004 | 0.297 | 0.006 | 0.150 | 297.640 | 34.0 | 9.1 |
| 17 | 2005 | 0.172 | 0.006 | 0.360 | 0.009 | 0.145 | 298.810 | 27.7 | 7.8 |
| 33 | 2005 | 0.175 | 0.008 | 0.326 | 0.011 | 0.146 | 294.200 | 66.3 | 11.3 |
| 49 | 2005 | 0.188 | 0.009 | 0.318 | 0.012 | 0.154 | 300.260 | 2.8 | 6.1 |
| 65 | 2005 | 0.198 | 0.013 | 0.342 | 0.014 | 0.151 | 305.580 | 9.7 | 4.0 |
| 81 | 2005 | 0.191 | 0.007 | 0.320 | 0.008 | 0.155 | 310.640 | 0.0 | 1.5 |
| 97 | 2005 | 0.175 | 0.006 | 0.282 | 0.006 | 0.162 | 315.730 | 0.0 | 0.8 |
| 113 | 2005 | 0.158 | 0.011 | 0.272 | 0.007 | 0.157 | 315.450 | 8.6 | 2.0 |
| 129 | 2005 | 0.138 | 0.005 | 0.245 | 0.005 | 0.162 | 321.460 | 0.0 | 0.9 |
| 145 | 2005 | 0.136 | 0.004 | 0.234 | 0.005 | 0.158 | 319.800 | 14.2 | 4.0 |
| 161 | 2005 | 0.133 | 0.002 | 0.235 | 0.002 | 0.163 | 323.410 | 6.1 | 1.6 |
| 177 | 2005 | 0.142 | 0.003 | 0.219 | 0.005 | 0.164 | 327.380 | 0.5 | 1.0 |
| 193 | 2005 | 0.174 | 0.030 | 0.279 | 0.047 | 0.194 | 319.970 | 79.0 | 5.1 |
| 209 | 2005 | 0.414 | 0.021 | 0.661 | 0.019 | 0.176 | NA | 135.4 | 7.3 |
| 225 | 2005 | 0.377 | 0.016 | 0.616 | 0.022 | 0.163 | 309.900 | 6.6 | 0.9 |
| 241 | 2005 | 0.279 | 0.010 | 0.457 | 0.016 | 0.151 | 315.320 | 13.2 | 0.8 |
| 257 | 2005 | 0.208 | 0.005 | 0.380 | 0.010 | 0.158 | 317.490 | 0.5 | 0.3 |
| 273 | 2005 | 0.189 | 0.010 | 0.316 | 0.008 | 0.159 | 314.900 | 13.0 | 2.0 |
| 289 | 2005 | 0.178 | 0.013 | 0.300 | 0.006 | 0.162 | 311.650 | 0.3 | 1.4 |
| 305 | 2005 | 0.158 | 0.006 | 0.267 | 0.006 | 0.168 | 310.470 | 0.0 | 0.2 |
| 321 | 2005 | 0.155 | 0.004 | 0.259 | 0.007 | 0.165 | 306.000 | 0.0 | 0.1 |
| 337 | 2005 | 0.141 | 0.007 | 0.260 | 0.005 | 0.175 | 301.010 | 2.3 | 0.2 |
| 353 | 2005 | 0.132 | 0.003 | 0.239 | 0.005 | 0.166 | 304.740 | 0.0 | 0.1 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 2006 | 0.123 | 0.004 | 0.234 | 0.006 | 0.170 | 305.780 | 0.0 | 0.0 |
| 17 | 2006 | 0.123 | 0.004 | 0.229 | 0.005 | 0.174 | 304.160 | 0.0 | 0.1 |
| 33 | 2006 | 0.115 | 0.002 | 0.215 | 0.002 | 0.170 | 309.280 | 0.0 | 0.1 |
| 49 | 2006 | 0.122 | 0.003 | 0.201 | 0.004 | 0.169 | 310.340 | 1.5 | 0.2 |
| 65 | 2006 | 0.122 | 0.002 | 0.208 | 0.003 | 0.177 | 309.690 | 3.3 | 0.2 |
| 81 | 2006 | 0.115 | 0.001 | 0.205 | 0.002 | 0.175 | 313.840 | 0.0 | 0.3 |
| 97 | 2006 | 0.112 | 0.003 | 0.195 | 0.002 | 0.179 | 319.910 | 0.0 | 0.4 |
| 113 | 2006 | 0.127 | 0.002 | 0.191 | 0.003 | 0.180 | 320.250 | 0.0 | 0.5 |
| 129 | 2006 | 0.110 | 0.001 | 0.189 | 0.001 | 0.178 | 323.860 | 0.0 | 0.6 |
| 145 | 2006 | 0.121 | 0.002 | 0.191 | 0.003 | 0.181 | 324.410 | 1.8 | 0.7 |
| 161 | 2006 | 0.113 | 0.002 | 0.196 | 0.003 | 0.179 | 328.670 | 19.8 | 1.5 |
| 177 | 2006 | 0.177 | 0.016 | 0.285 | 0.013 | 0.175 | 315.460 | 110.7 | 10.4 |
| 193 | 2006 | 0.336 | 0.008 | 0.492 | 0.023 | 0.159 | 318.430 | 51.6 | 6.9 |
| 209 | 2006 | 0.448 | 0.010 | 0.618 | 0.014 | 0.158 | 306.570 | 179.6 | 9.5 |
| 225 | 2006 | 0.444 | 0.017 | 0.611 | 0.024 | 0.161 | 307.640 | 72.6 | 7.7 |
| 241 | 2006 | 0.439 | 0.021 | 0.665 | 0.025 | 0.156 | 306.240 | 78.7 | 9.4 |
| 257 | 2006 | 0.397 | 0.011 | 0.581 | 0.014 | 0.153 | 309.190 | 0.3 | 3.6 |
| 273 | 2006 | 0.300 | 0.008 | 0.521 | 0.014 | 0.159 | 312.060 | | |
| 289 | 2006 | 0.229 | 0.005 | 0.414 | 0.011 | 0.153 | 307.720 | | |
| 305 | 2006 | 0.238 | 0.007 | 0.419 | 0.008 | 0.149 | 307.970 | | |
| 321 | 2006 | 0.203 | 0.004 | 0.384 | 0.010 | 0.154 | 304.230 | | |
| 337 | 2006 | 0.178 | 0.010 | 0.329 | 0.012 | 0.158 | 300.730 | | |
| 353 | 2006 | 0.165 | 0.005 | 0.296 | 0.005 | 0.160 | 298.000 | | |
| 9 | 2007 | 0.146 | 0.007 | 0.266 | 0.004 | 0.149 | 299.780 | | |
| 25 | 2007 | 0.135 | 0.005 | 0.260 | 0.010 | 0.148 | NA | | |
| 33 | 2007 | 0.145 | 0.002 | 0.248 | 0.004 | 0.155 | 305.210 | | |
| 49 | 2007 | 0.140 | 0.002 | 0.237 | 0.004 | 0.152 | 306.120 | | |
| 65 | 2007 | 0.124 | 0.002 | 0.217 | 0.004 | 0.156 | 315.280 | | |
| 81 | 2007 | 0.123 | 0.005 | 0.219 | 0.008 | 0.157 | 314.110 | | |
| 97 | 2007 | 0.125 | 0.004 | 0.207 | 0.008 | 0.159 | 314.690 | | |
| 113 | 2007 | 0.126 | 0.007 | 0.197 | 0.007 | 0.160 | 319.280 | | |
| 129 | 2007 | 0.122 | 0.006 | 0.190 | 0.009 | 0.162 | 323.080 | | |
| 145 | 2007 | 0.115 | 0.004 | 0.189 | 0.007 | 0.163 | 324.250 | | |
| 161 | 2007 | 0.117 | 0.004 | 0.203 | 0.005 | 0.161 | 327.340 | | |
| 177 | 2007 | 0.138 | 0.004 | 0.196 | 0.006 | 0.177 | 328.450 | | |
| 193 | 2007 | 0.361 | 0.014 | 0.527 | 0.017 | 0.139 | NA | | |
| 209 | 2007 | 0.372 | 0.008 | 0.520 | 0.011 | 0.146 | 309.830 | | |
| 225 | 2007 | 0.347 | 0.008 | 0.545 | 0.011 | 0.147 | NA | | |

## APPENDIX 2

## GLOSSARY OF TERMS

ANNP: Aboveground Net Primary Production.

BMA: Backward Moving Average.

BRDF: bidirectional Reflectance Distribution Function.

CAPE: Convective Available Energy.

ENSO: El Niño Southern Oscillation.

EVI: Enhanced Vegetation Index.

FG: Functional group.

FMA: Forward Moving Average

GPR: Greenness Precipitation Ratio.

HDF: Hierarchical Data Format.

iNDVI: Time integrated Normalized Difference Vegetation Index.

ITCZ: Inter-tropical Convergence Zone.

LST: Land Surface Temperature.

MODIS: Moderate Resolution Imaging Spectroradiometer.

MVC: Maximum Value Composite.

NAM: North American Monsoon.

NDVI: Normalized Difference Vegetation Index.

NPP: Net Primary Production.

$RMSE_{\delta}$: Root Mean Square Error of the Difference.

RUE: Rain Use Efficiency.

SST: Sea Surface Temperature.

# APPENDIX 3

## MATLAB SCRIPTS

The following MATLAB™ script was used to estimate the Forward Moving Average (FMA) and the Backward Moving Average (BMA) in the original EVI time series. Theses two lagged time series are used to estimate the staring and ending point of vegetation activity.

```
clear;
close all;
load stat130.txt
x= [stat130(:,1)];
y= [stat130(:,2)];
plot(x,y,'.-k');
hold on;
sm = smooth(y,'sgolay',3);
plot (x,sm,'LineWidth',2);
xlabel('Days');
ylabel('EVI');
title('EVI Time Series for Station 130')
hold on;
[xxl,yyl]=getmoving(x,y,3,0);
[xxr,yyr]=getmoving(x,y,3,1);
plot(xxl,yyl,'-r',xxr,yyr,'-g');
xyarray=[x y]
smarray=[x y]
legend('original data','FMA','BMA')
hold off
```

The “getmoving” function is defined with the following MATLAB™ script.

```
function[xa,ya]=getmoving(x,y,w,dir)

%if dir =1 it will do it to the right, if dir =0 the it will do it to
the
%left
if (dir==1)
    ya= 1:(length(x)-(w-1));
    xa= 1:(length(x)-(w-1));
    for (i=1:(length(x)-(w-1)))
        ya(i)=mean(y(i:i+w-1));
        xa(i)=x(i);
    end
else
    ya= 1:(length(x)-(w-1));
    xa= 1:(length(x)-(w-1));
    for (i=w:length(x))
        ya(i-(w-1))=mean(y(i-(w-1):i));
        xa(i-(w-1))=x(i);
```

```
    end
end
```

Once the starting and ending point of vegetation activity are established, we use the 16-time periods as input to calculate the vegetation metrics for the different years used in the analysis. In this case, we used the station 130 as an example.

```
clear;
close all;
load stat130.txt
x= [stat130(:,1)];
y= [stat130(:,2)];
plot(x,y,'.-k');
hold on;
sm = smooth(y,'sgolay',3)
plot (x,sm,'LineWidth',2);
xlabel('Days');
ylabel('EVI');
title('EVI Time Series for Station 130')
hold on;
xyarray=[x y]
smarray=[x sm]

figure(2)%Figure for vegetation metrics for year 2004
t= y(12:25);
u= x(12:25);
plot(u,t,'-g');
area_04=trapz(u,t)
evimax_04=max(t)
evimin_04=min(t)
RtUp_04=(evimax_04-xyarray(12,2))/(xyarray(14,1)-xyarray(12,1))
RtDn_04=(xyarray(25,2)-evimax_04)/(xyarray(25,1)- xyarray(14,1))
RanVeg_04=evimax_04-evimin_04
Durgreen_04= xyarray(25,1)-xyarray(12,1)
Timemax_04= xyarray(14,1)- xyarray(12,1)

figure(3)%figure for vegetation metrics for year 2005
tt= y(34:51);
uu= x(34:51);
plot(uu,tt,'-g');
area_05=trapz(uu,tt)
evimax_05=max(tt)
evimin_05=min(tt)
RtUp_05=(evimax_05-xyarray(34,2))/(xyarray(37,1)-xyarray(34,1))
RtDn_05=(xyarray(51,2)-evimax_05)/(xyarray(51,1)- xyarray(37,1))
RanVeg_05= evimax_05-evimin_05
Durgreen_05= xyarray(51,1)-xyarray(34,1)
Timemax_05= xyarray(37,1)- xyarray(34,1)

figure (4)%figure for vegetation metrics for year 2006
ttt= y(56:71);
uuu= x(56:71);
plot(uuu,ttt,'-g');
```

```
area_06=trapz(uuu,ttt)
evimax_06=max(ttt)
evimin_06=min(ttt)
RtUp_06=(evimax_06-xyarray(56,2))/(xyarray(60,1)-xyarray(56,1))
RtDn_06=(xyarray(71,2)-evimax_06)/(xyarray(71,1)- xyarray(60,1))
RanVeg_06=evimax_06-evimin_06
Durgreen_06= xyarray(71,1)-xyarray(56,1)
Timemax_06= xyarray(60,1)- xyarray(56,1)
```