Defining Temperature and Vegetation Connections at Neighborhood and Regional Scales in Phoenix, Arizona Using Remotely Sensed and Ground Based Measurements

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Abstract

Neighborhoods (1km^2 areas) in Phoenix, Arizona, USA have significant relationships between remotely-sensed vegetation abundance (SAVI) and surface temperatures. Significant differences were also found between SAVI and surface temperatures of low socioeconomic status (SES) neighborhoods and neighborhoods with high SES. Low SES neighborhoods have significantly higher temperatures and lower SAVI values.

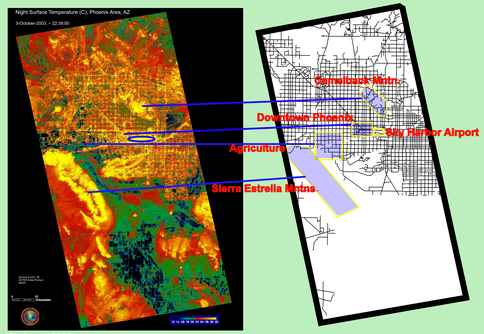
A second study was conducted on the regional relationship between SAVI and surface temperatures in Phoenix. It was hypothesized that these remotely sensed variables would be significantly related to ground-measured relative humidity values and air temperatures.

Remotely sensed SAVI and surface temperature values were collected for five dates, representing different seasons, along with weather station data taken at the time and date of the remote sensing scenes.

Linear regression analysis showed that SAVI and surface temperature do have a statistically strong relationship for the majority of the scenes. The analysis found no link between SAVI and relative humidity or surface temperature and air temperature. Since past studies have shown connections, although complex, between these variables it is likely that there is an error in the study. Possible reasons for this error are that the weather station sites do not accurately represent the land types of the region, wind effects may be influencing the station measurements, or that the differential heating of north and south facing slopes with the same SAVI values may be making the regression invalid.

Urban Heat Island in Phoenix

Phoenix is known to have an urban heat island that significantly increases minimum and maximum temperatures, which continue to climb as the city grows and becomes denser. These ASTER thermal images taken at ~11:00pm show the stored heat in the streets and other paved surfaces in the Phoenix metropolitan area. The hottest (brightest) location in the city is the Phoenix airport (blue box).



(Stefanov, 2003)

Coverage, Resolution and Details of Remote Sensors

MASTER	
# Bands	50 (Hyperspectral)
# Bands in TIR	10
Platform	Airborne
Temporal Coverage of Ground	None
Pixel Size on Ground	~12m for this scene
Nighttime Scenes Avalable	No

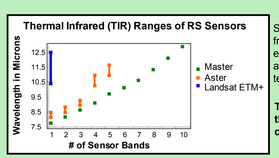
Landsat 7 ETM+	
# Bands	6
# Bands in TIR	1
Platform	Satellite
Temporal Coverage of Ground	Every 16 days
Pixel Size on Ground	VNIR: 30m TIR: 60m
Nighttime Scenes Avalable	No

ASTER	
# Bands	14
# Bands in TIR	5
Platform	Satellite
Temporal of Coverage of Ground	Possiblity for repeat coverage every 16 days but is limited
Pixel Size on Ground	VNIR: 15m TIR: 90m
Nighttime Scenes Avalable	Yes

High-resolution RS scenes were needed to analyze climate on a "neighborhood" scale. The three platforms chosen were from the Advance Spaceborne Thermal Emission and Reflection Radiometer (ASTER), Modis/ASTER airborne simulator (MASTER), and Landsat Enhanced Thematic Plus (ETM+) sensor.

RS Scene Data Processing: Surface Temperature and Vegetation Indices

Surface Surface kinetic temperatures and vegetation indices were obtained from the RS data.



Surface temperatures can be derived from Thermal Infrared (TIR) energy emitted from the ground and measured at the sensor as a brightness temperature.

The 3 sensors cover different portions of the TIR spectum. The Master sensor covers the TIR the most comprehensivley.

Soil Adjusted Vegetation Index (SAVI) = $\left(\frac{\text{NIR - Vis RED}}{\text{NIR + Vis RED + L}}\right)$ X 1+L

The L is a constant inserted to compensate for the high soil reflectance values seen in desert areas with sparse vegetation [Huete, 1988]. In the Phoenix area an L of .5 is used since the vegetation cover is approximately 20%.. The bands analyzed for the ASTER scenes were band 2 (vis red) and band 3 (NIR). The bands used for the Landsat scenes were band 3 (vis red) and band 4 (NIR).

Acknowledgements

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IGERT Integrative Graduate Education and Research Training in Urban Ecology

CAP LTER Central Arizona-Phoenix Long-Term Ecological Research

ASTER JAPAN / USA

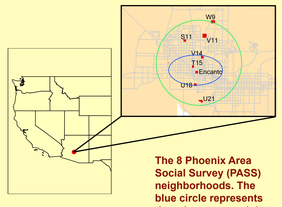
ASU

Surface Temperature Correlations with Socioeconomic and Vegetation Indices at the Neighborhood Scale

Mean measurements of SAVI and surface temperature were collected for the neighborhood boundaries. At this neighborhood scale, a strong correlation was found between SAVI values and surface temperatures. Significant differences were also found between SAVI values and surface temperatures of low socioeconomic status (SES) neighborhoods and neighborhoods with high SES. Low SES neighborhoods have significantly higher temperatures and lower SAVI values.

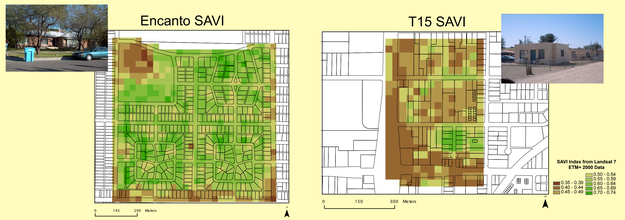
Neighborhood Study of Links Between Socioeconomics and Temperature

- **The study is located in the Phoenix, Arizona metropolitan area, a region of three million people that is growing rapidly and converting agricultural land and undeveloped native desert into upper- and middle-income residential neighborhoods on the urban fringe.**
- **The eight neighborhoods are approx. 1 km square defined by census block group boundaries.**
- **Neighborhoods represent different types of urban communities stratified by income, ethnicity, location and age of housing.**

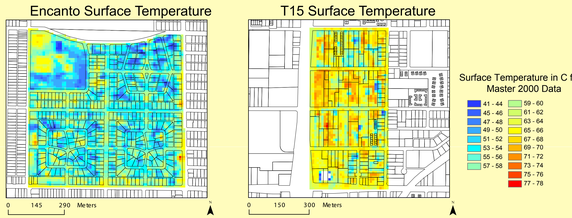


The 8 Phoenix Area Social Survey (PASS) neighborhoods. The blue circle represents the urban core and the green circle marks the outer fringe of Phoenix

Examples of SAVI derived from Landsat 7 ETM + and Master derived surface temperatures in the neighborhoods. The neighborhood on the left has a higher SES than the one on the right. Both are located in the Phoenix urban core.



The lowest income PASS neighborhood (T15) has a much lower vegetation density than one of the wealthier neighborhoods (Encanto).



The lowest income PASS neighborhood (T15) has a much higher surface temperature than one of the wealthier neighborhoods (Encanto).

Neighborhood correlations between socioeconomic variables and surface temperature

% people 25+ more than college	
MASTER 6/00	R= -.894
ASTER 1/03	not significant
ASTER 12/02	not significant
Landsat 2000	R= -.697
Landsat 2001	R= -.789

Median Household Income	
MASTER 6/00	R= -.689
ASTER 1/03	R= .272
ASTER 12/02	R= .328
Landsat 2000	R= -.427
Landsat 2001	R= -.590

% Hispanic	
MASTER 6/00	R= .390
ASTER 1/03	R= -.703
ASTER 12/02	R= -.644
Landsat 2000	not significant
Landsat 2001	R= .342

Increasing temperature is significantly correlated to decreasing educational attainment, decreasing income, and increasing % Hispanic in Phoenix neighborhoods.

Neighborhood correlations between variables controlled by amount of vegetation and surface temperature

Landsat 2000 SAVI	
MASTER 6/00	R= -.673
ASTER 1/03	R= -.536
ASTER 12/02	R= -.455
Landsat 2000	Used to create SAVI
Landsat 2001	R= -.641

Mesic Residential 1998	
MASTER 6/00	R= -0.553
ASTER 1/03	R= -0.534
ASTER 12/02	R= -0.468
Landsat 2000	R= -0.698
Landsat 2001	R= -0.589

Increasing vegetation abundance is significantly correlated to decreasing surface temperatures in Phoenix neighborhoods.

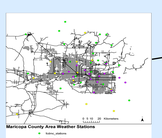
Neighborhood Scale Conclusions

- **The same positive correlation seen on a regional scale between high mean temperatures and low-income, Hispanic areas is observed on a neighborhood scale.**
- **There are positive correlations between high temperatures and low educational attainment and increasing population/ mile on the neighborhood scale.**
- **Temperature decrease in neighborhoods with high vegetation was seen across all 3 sensors. This suggests that temperature is influenced by vegetation consistently throughout the year and is relatively insensitive to resolution, within the range studied (12 - 90m/pixel).**
- **High resolution RS data can strengthen correlations between temperature, vegetation and social variables. The finest scale surface temperatures derived from Master RS data (12m/pixel) correlate to the neighborhood socioeconomic variables at least as strongly as the lower resolution Landsat 7 ETM+ (60m/ pixel) temperature correlations. Aster temperature data (90m/pixel) had the weakest correlations.**

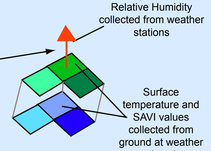
Regional Phoenix Analysis of Weather Station-Derived Air Data and Remotely Sensed Temperature and SAVI

Since significant correlations of SAVI and surface temperature were observed at the neighborhood scale it was hypothesized that this relationship would also be seen at a regional scale. Also, since air temperature has been shown to have a relationship with surface temperature and vegetation percentage with relative humidity, it was hypothesized that these variables would also have significant relationships [Laymon, C., et al., 1998; Voogt and Grimmond, 2000] This study sought to define these two relationships in order to predict air temperature from surface temperature and to predict relative humidity from SAVI values.

Procedure



Weather station locations in Phoenix area



Mean values of SAVI and surface temperature were taken at the locations of 35 weather stations to compare with that station's air temperature and relative humidity measurements.

Results of Linear Regression Analysis

Date of Scene	Comparison	R2	Anova Significance
ASTER	**SAVI vs Sur Temp**	**0.563**	**0**
9/22/2001	**Air Temp vs RH**	**0.168**	**0.091**
	Air Temp vs Sur Temp	0.01	0.693
	RH vs SAVI	**0.458**	**0.002**
ASTER			
12/14/2002	SAVI vs Sur Temp	0.003	0.794
	Air Temp vs RH	**0.468**	**0**
	Air Temp vs Sur Temp	0.029	0.415
	RH vs SAVI	0.02	0.501
ASTER			
3/20/2003	**SAVI vs Sur Temp**	**0.283**	**0.005**
	Air Temp vs RH	0.007	0.679
	Air Temp vs Sur Temp	0.001	0.881
	RH vs SAVI	0.037	0.346
Landsat ETM+			
5/21/2000	SAVI vs Sur Temp	0.051	0.223
	Air Temp vs RH	**0.613**	**0**
	Air Temp vs Sur Temp	0	0.95
	RH vs SAVI	0.022	0.429
Landsat ETM+			
6/9/2001	**SAVI vs Sur Temp**	**0.603**	**0**
	Air Temp vs RH	**0.505**	**0**
	Air Temp vs Sur Temp	0.007	0.654
	RH vs SAVI	0.063	0.16

- **SAVI vs Surface Temperature: significantly strong in the June, March, and September scenes.**
- **Air Temperature VS Relative Humidity: almost always strongly significant (except for 3/22/03)**
- **Air temperature VS Surface temperature / Relative Humidity VS SAVI: The regression analyses of air temperature versus surface temperature and relative humidity versus SAVI did not reveal significant relationships for any of the five scenes**

Reasons for Poor Ground - Air Data Correlations

- Remotely sensed data only represents one point in time (ie. the surface temperature and SAVI values recorded at exactly 10am) while the weather stations are continuously recording. Errors may be introduced when trying to connect these data types.
- Since significant results were obtained from the Phoenix neighborhood study, another approach would be to include only the stations that are in residential neighborhoods in the regression analysis. Possibly these relationships do not exist for commercial areas but do exist in neighborhoods.
- The weather stations may be influenced by surface temperature and SAVI values that are not directly under the station but from the downwind direction. It may be more accurate to get the SAVI and surface temperature values used in the regression from a buffered area upwind of the station.
- The elevated regions in the Phoenix may have similar SAVI values on north and south facing slopes but may have radically different surface temperatures due to differential heating. These may be skewing the regression analysis for the entire scene.
- Weather stations may be on sites that are unrepresentative of the Phoenix area as a whole.