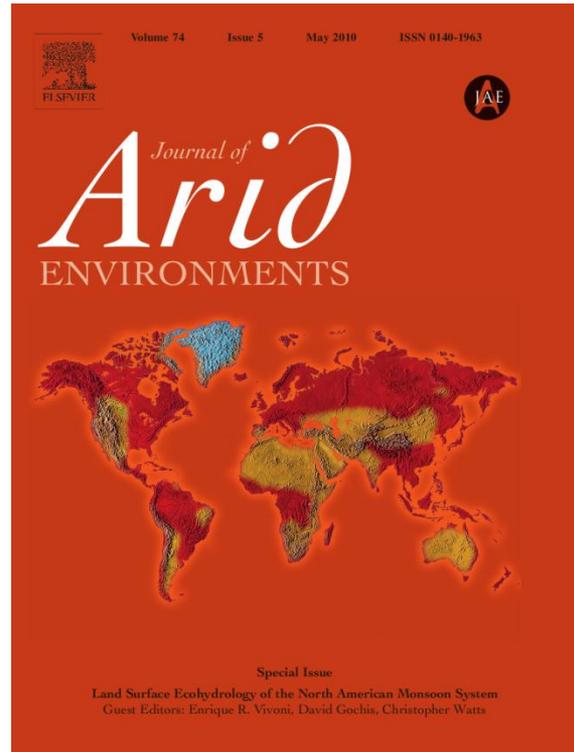


LAND SURFACE ECOHYDROLOGY OF THE NORTH AMERICAN MONSOON SYSTEM



Special Issue in Journal of Arid Environments, May 2010

Synthesis and Introduction by Enrique R. Vivoni
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BACKGROUND

- Ecohydrological studies in the southwest U.S. and northwest Mexico benefit from bi-national research programs (e.g., SALSA, NAME, SMEX04).
- Prior studies across the U.S.-Mexico border have highlighted the close interactions between water and ecosystems in determining land surface conditions.
- This special issue was designed to bring together U.S. and Mexico studies on ecohydrology initiated during NAME and SMEX04.

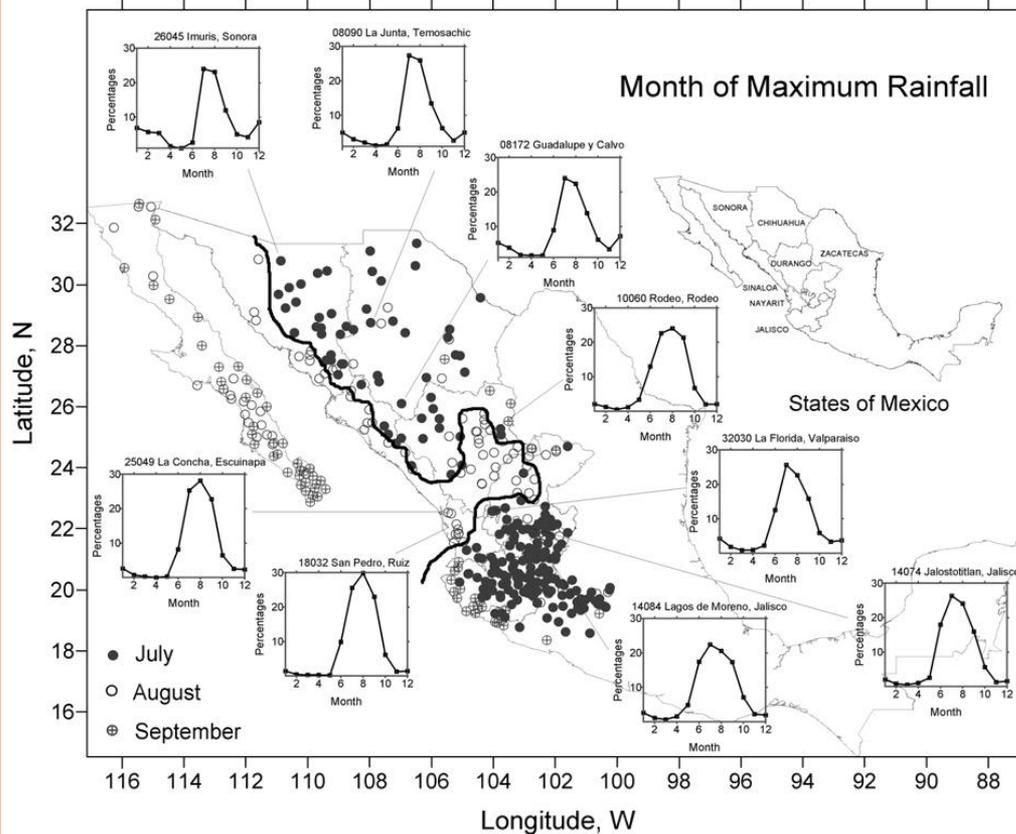


APPROACH TODAY

- Introduce and summarize the major findings from a selected number of the twelve papers.
- Proceed in an order that spans from the entire regions to specific sites and from observational to modeling.
 - Key included with **Study Area, Topics & Institutions**
- Present a synthesis of the special issue that points to future research paths.
- For more information, see preface article:
Vivoni, E.R., Watts, C.J. and Gochis, D.J. 2010. Land surface ecohydrology of the North American Monsoon system, *Journal of Arid Environments*, 74, 529-530.

BRITO-CASTILLO ET AL: AN ANOMALY IN THE OCCURRENCE OF THE MONTH OF MAXIMUM PRECIPITATION IN NORTHWEST MEXICO

Motivation: Rainfall in northwest Mexico reveals a disruption in the south to north progression. This study tests hypotheses explaining this rainfall anomaly.



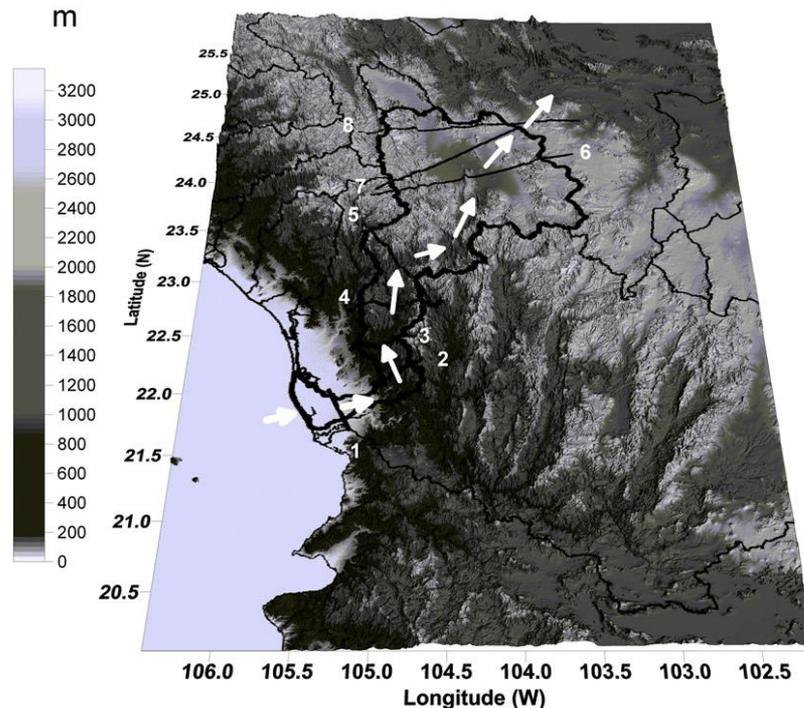
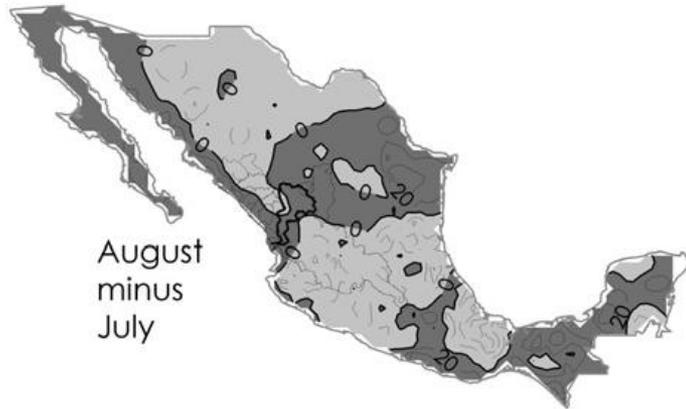
Question: *What factors control the peak rainfall activity in western Mexico and the Mexican Antiplano?*

Long-term rainfall and streamflow observations used to identify the rainfall anomaly and its hydrologic implications.

Sea-surface temperature and terrain distributions aid in testing a set of potential hypotheses.

Study Area: Northwest Mexico
Topics: Rainfall and Streamflow

BRITO-CASTILLO ET AL: AN ANOMALY IN THE OCCURRENCE OF THE MONTH OF MAXIMUM PRECIPITATION IN NORTHWEST MEXICO



Findings:

(1) Increases in August rainfall coincide with a system of canyons that could allow moisture transport into the continental interior.

(2) Streamflow also follows the disruption of the anticipated south-to-north pattern in the peak month, but delayed by 1 month.

(3) Atmosphere–ocean–land surface interactions in this particular region have implications for the rainfall delivered to the Mexican Antiplano.



LIZARRAGA ET AL: SPATIOTEMPORAL VARIATIONS IN SURFACE CHARACTERISTICS OVER THE NORTH AMERICAN MONSOON REGION

Motivation: The regional dynamics of summer greening have not been quantified. This study explores site-based vegetation dynamics using MODIS.



Question: *How does the NAM affect the seasonal ecosystem response along a gradient in summer rain?*

Ecosystem response quantified by: (1) greenness, (2) albedo and (3) land surface temperature.

Semimonthly MODIS observations from 2000-2008 utilized.

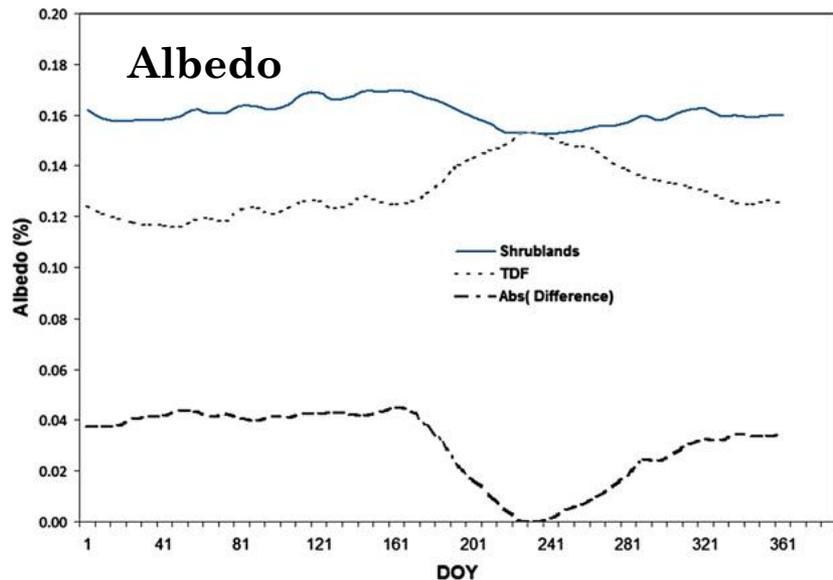
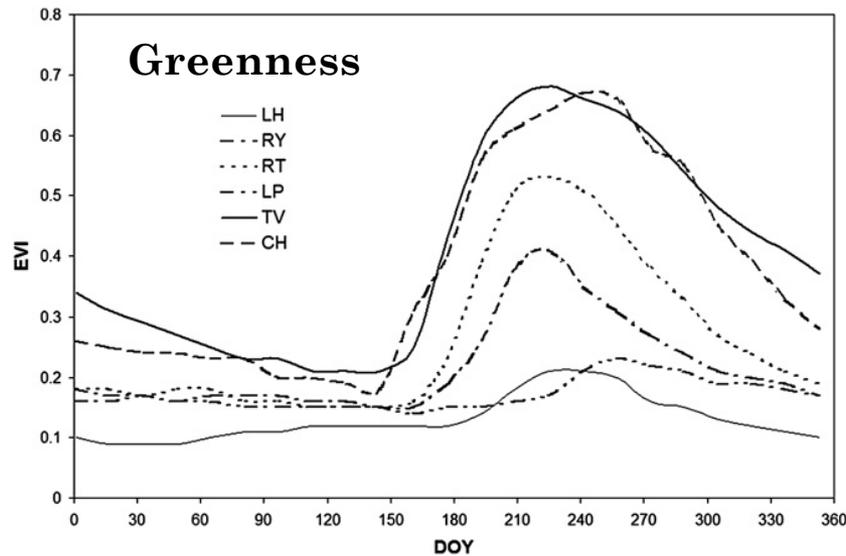
Study Area: Northwest Mexico, Walnut Gulch

Topics: Rainfall and Vegetation Dynamics

UNISON, ITSON, USDA/ARS



LIZARRAGA ET AL: SPATIOTEMPORAL VARIATIONS IN SURFACE CHARACTERISTICS OVER THE NORTH AMERICAN MONSOON REGION



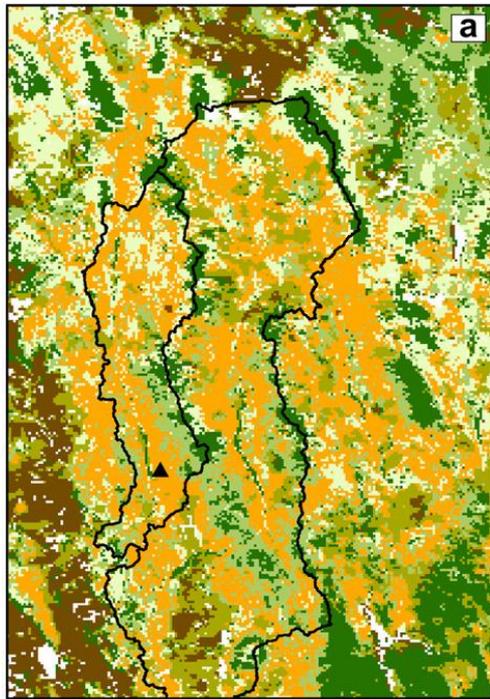
Findings:

- (1) Greater seasonal ecosystem response for southern sites with more intense greening, lasting a longer period, compared to northern areas.
- (2) Unexpected variations in albedo with tropical dry forests increasing while shrublands decrease in albedo during NAM. Likely due to role of open bare soil reflectivity.
- (3) Land surface cooling during NAM greatest at intermediate latitudes (~18 C decrease), while lower cooling at northern and southern sites.

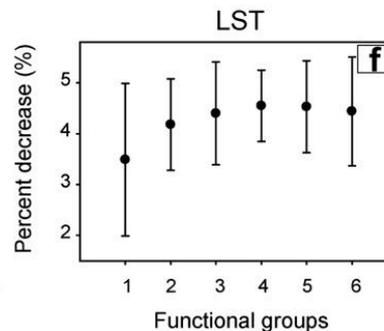
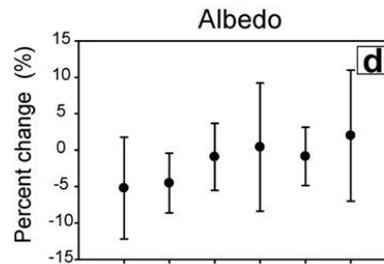
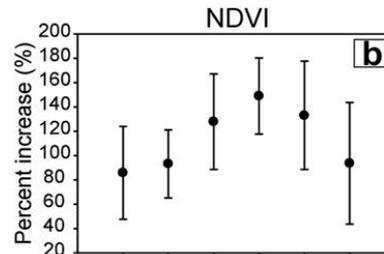


MENDEZ-BARROSO ET AL: OBSERVED SHIFTS IN LAND SURFACE CONDITIONS DURING THE NORTH AMERICAN MONSOON

Motivation: The role of summer greening on precipitation recycling is unknown. This study uses remote sensing and site observations to infer this.



- 1: Semidesert shrubland
- 2: Semidesert grassland
- 3: Mixed shrubland
- 4: Subtropical scrubland (low elevation)
- 5: Subtropical scrubland (high elevation)
- 6: Madrean evergreen woodland



Question: *Does vegetation greening lead to conditions that promote sustained rainfall conditions?*

Vegetation greening quantified by: (1) NDVI, (2) albedo and (3) surface temperature. Eddy covariance tower data used to test surface-rainfall feedback mechanism.

Remote-sensing data used to identify ecoregions in study area.

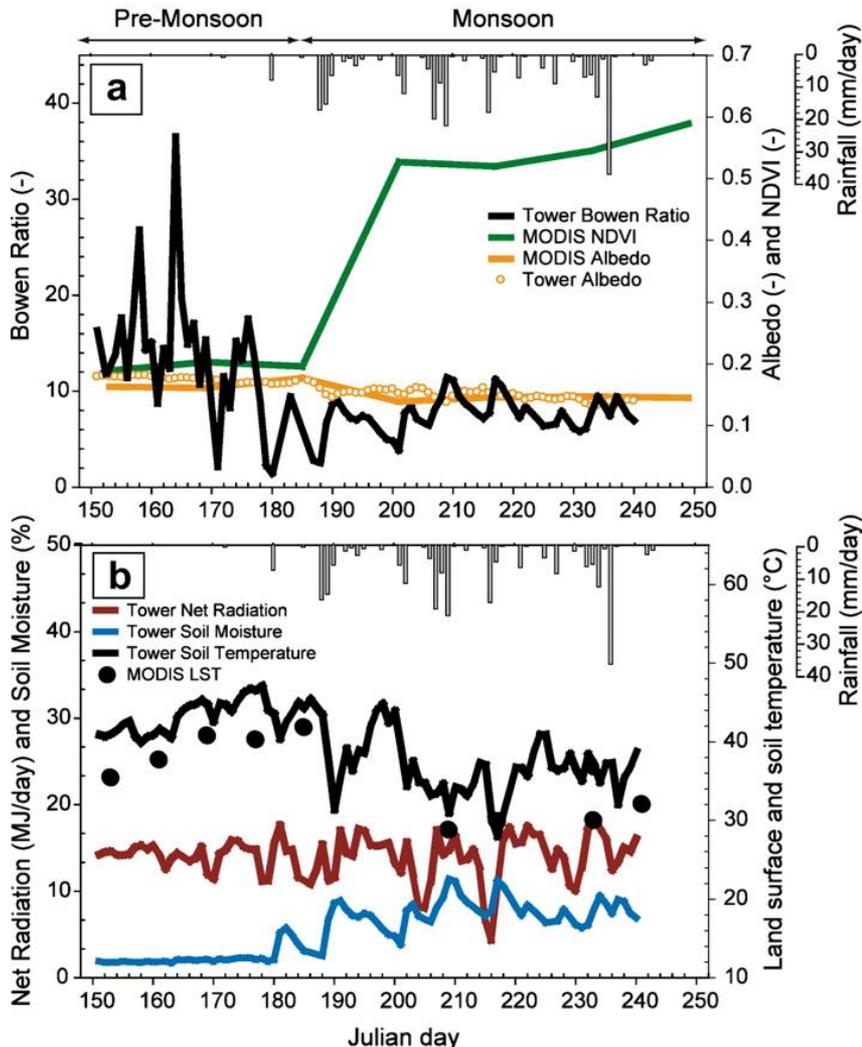
Study Area: Rio Sonora, MX

Topics: Vegetation and Land-Atmosphere Relation



MENDEZ-BARROSO ET AL: OBSERVED SHIFTS IN LAND SURFACE CONDITIONS DURING THE NORTH AMERICAN MONSOON

Seasonality of Ecosystem Conditions



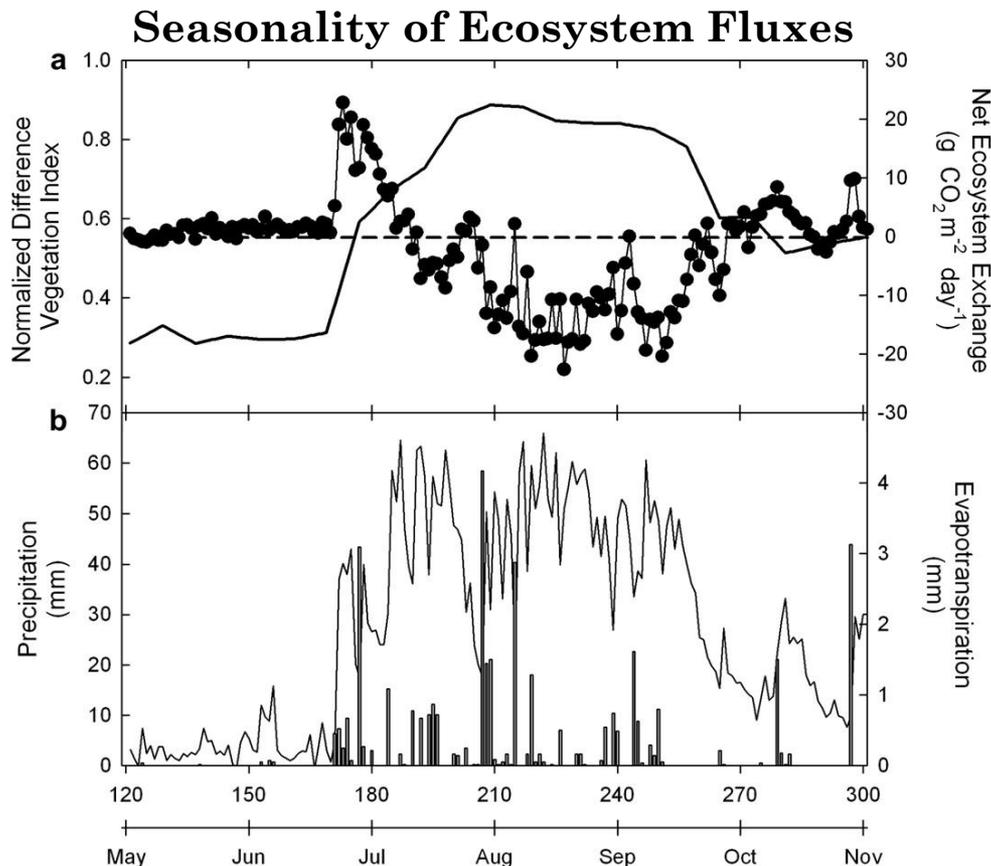
Findings:

- (1) Subtropical scrublands were the most dynamic ecosystems cover large areas. Thus, EC tower data are broadly representative.
- (2) Land and atmospheric variables during clear days follow a positive surface-rainfall feedback mechanism.
- (3) Unexpectedly, the feedback mechanism is weakened during cloudy days. The effects of remnant morning cloudiness identified for first time.



PEREZ-RUIZ ET AL: CO₂ AND WATER VAPOR EXCHANGE IN A TROPICAL DRY FOREST DURING THE NORTH AMERICAN MONSOON

Motivation: Ecosystem fluxes have not been quantified in tropical dry forests. This study uses eddy covariance observations to identify seasonality.



Question: *Are tropical dry forests net sinks or sources of CO₂ during the summer monsoon?*

Net ecosystem exchange measured by the eddy covariance method over 6-months in 2006. Four periods identified: pre-monsoon, early monsoon, late monsoon and post-monsoon, with differing dynamics.

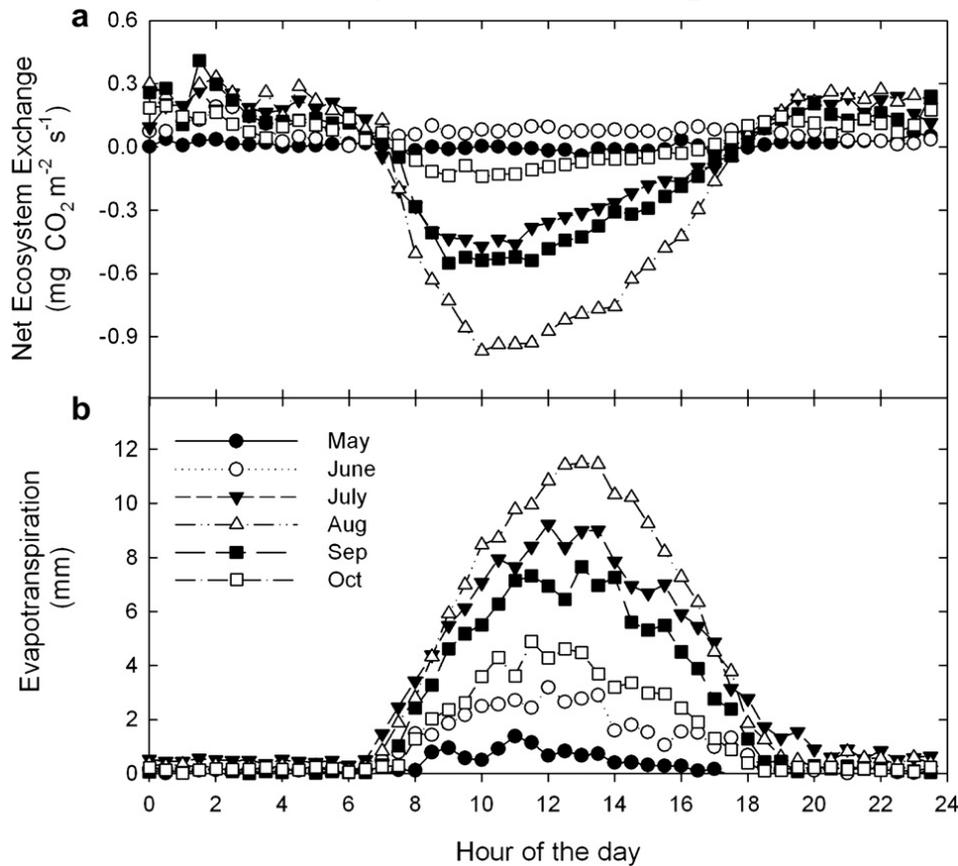
Study Area: Tesopaco, Sonora, MX

Topics: Ecosystem Fluxes

ITSON, UNISON, USDA/ARS

PEREZ-RUIZ ET AL: CO₂ AND WATER VAPOR EXCHANGE IN A TROPICAL DRY FOREST DURING THE NORTH AMERICAN MONSOON

Monthly-Average Diurnal Cycle of Net Ecosystem Exchange and ET



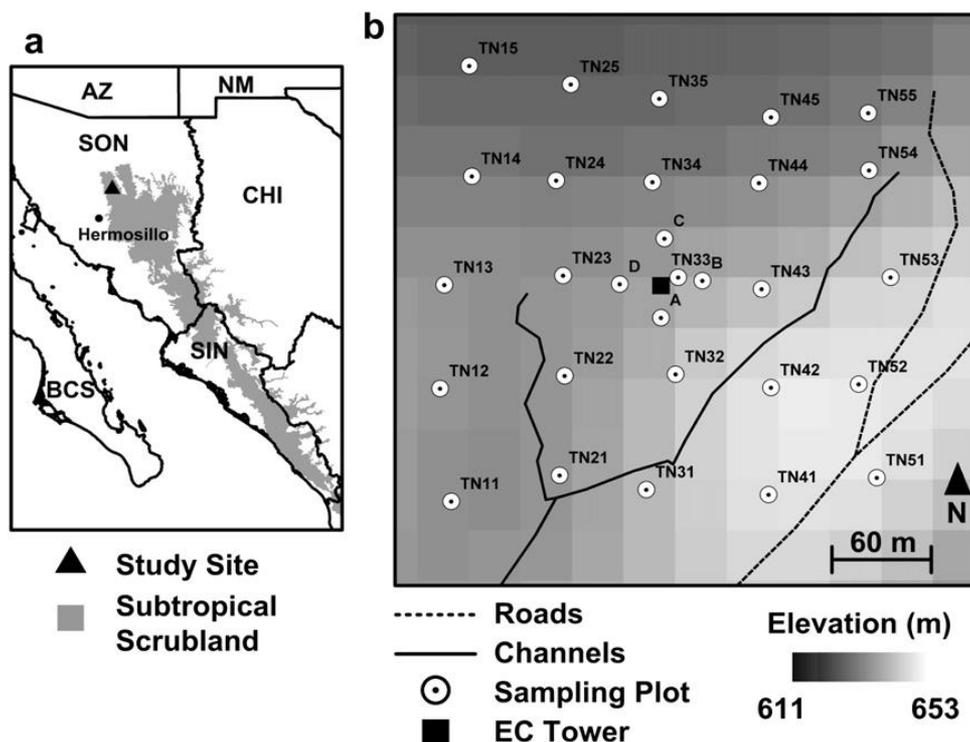
Findings:

- (1) Net ecosystem exchange varied from positive (microbial efflux,) to negative (canopy assimilation) and back to nearly zero (leaf senescence).
- (2) During the summer growing season of 2006, sustained rates of CO₂ gain amounted to 374 g CO₂/m², an upper limit for seasonally dry ecosystems.
- (3) Water use efficiencies for tropical dry forests were found comparable to other ecosystems with peak in August of 3.55 g CO₂/mm H₂O.



VIVONI ET AL: IMPROVED LAND-ATMOSPHERE RELATIONS THROUGH DISTRIBUTED SAMPLING IN A SUBTROPICAL SCRUBLAND

Motivation: Land-atmosphere studies typically ignore the footprint conditions around a tower. This study uses distributed soil sampling to address this.



Question: Do the surface conditions around a tower affect the relation of soil and atmospheric variables?

Surface conditions quantified by: (1) soil moisture and (2) temperature at 29 plots around 250-m by 250-m box surrounding EC tower.

Sampling during 2006-2008 summers (32 days) of coincident EC tower and footprint conditions.

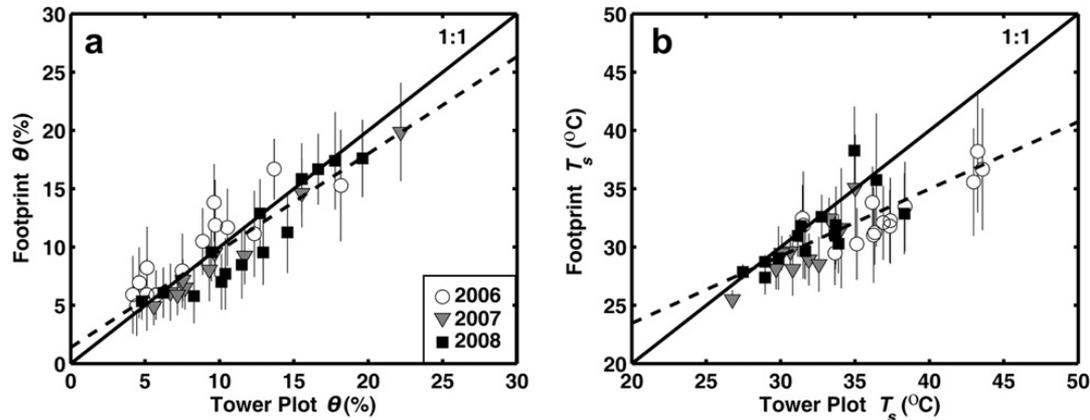
Study Area: Rayon, Sonora, MX

Topics: Land-Atmosphere Interactions

ASU, UNISON, ITSON

VIVONI ET AL: IMPROVED LAND-ATMOSPHERE RELATIONS THROUGH DISTRIBUTED SAMPLING IN A SUBTROPICAL SCRUBLAND

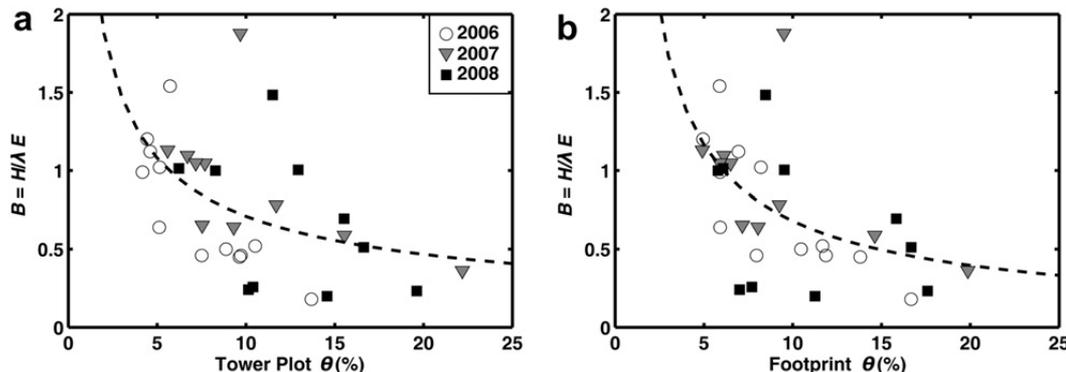
Relations Between Tower and Footprint Average Soil Moisture and Temperature



Findings:

- (1) Increase in footprint variability with higher soil moisture or temperature.
- (2) A mismatch between footprint averaged and tower point data primarily for soil temperature. Better match for soil moisture.

Soil Moisture Control on Bowen Ratio for Tower and Footprint Average

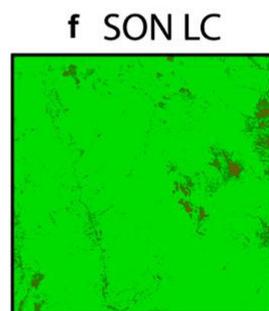
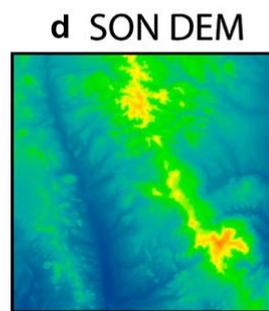
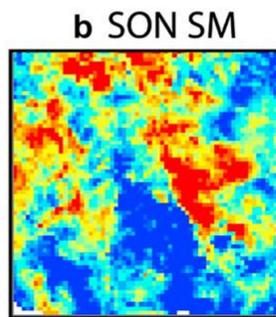
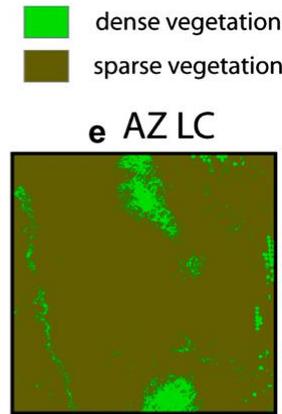
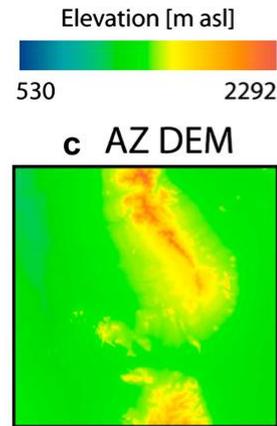
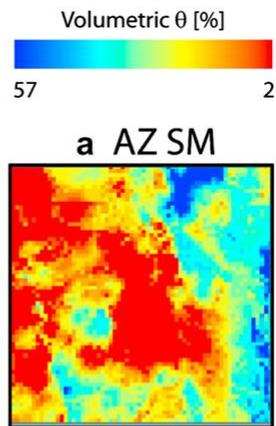
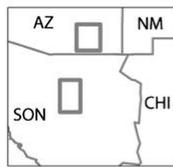


- (3) Improved relationship between soil moisture and surface flux partitioning (Bowen ratio) when using footprint average.



MASCARO ET AL: STATISTICAL AND SCALING PROPERTIES OF SOIL MOISTURE IN TWO NORTH AMERICAN MONSOON AREAS

Motivation: Soil moisture scaling properties are not well known in semiarid regions. This study uses aircraft retrievals to quantify soil moisture scaling.



51.2 km

51.2 km

Question: *How do land surface conditions affect spatial soil moisture patterns?*

Soil moisture obtained from aircraft (800-m) brightness temperature retrievals during SMEX04 for areas in Arizona (AZ) and Sonora (SON).

Digital elevation model (DEM), land cover and rainfall data used in the interpretation of soil moisture patterns.

Study Area: Rio Sonora, Walnut Gulch

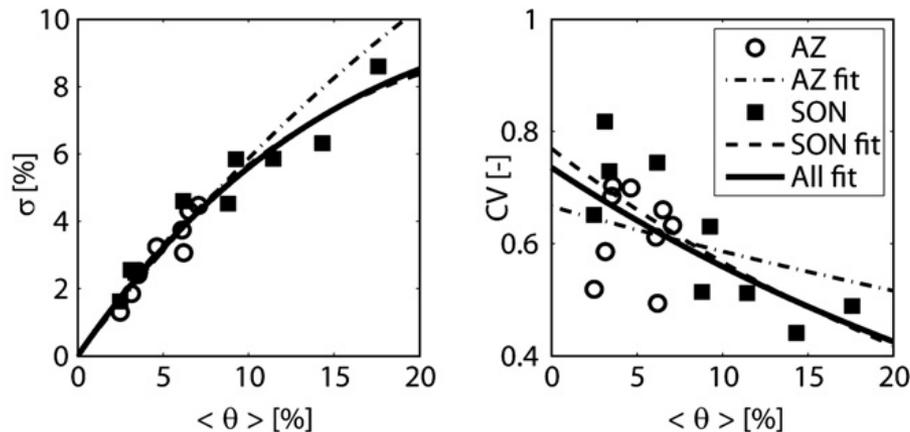
Topics: Soil Moisture



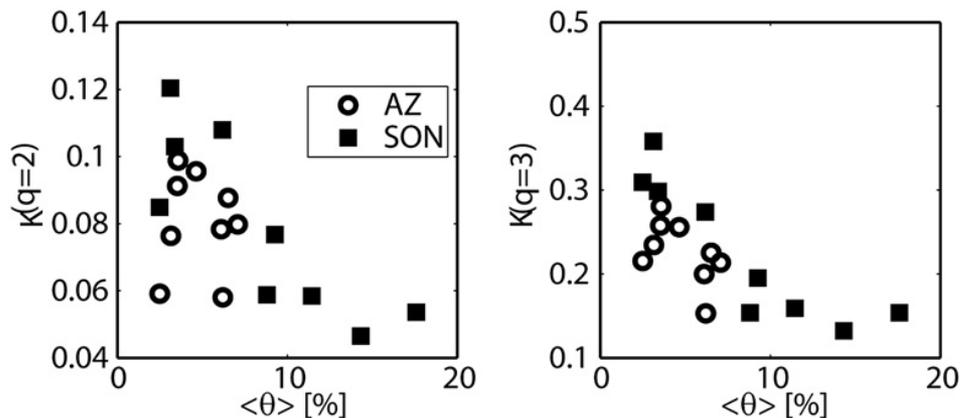
ASU

MASCARO ET AL: STATISTICAL AND SCALING PROPERTIES OF SOIL MOISTURE IN TWO NORTH AMERICAN MONSOON AREAS

Soil Moisture Spatial Variability as Function of Mean Soil Moisture Content



Multifractal Scaling Exponent as Function of Mean Soil Moisture Content



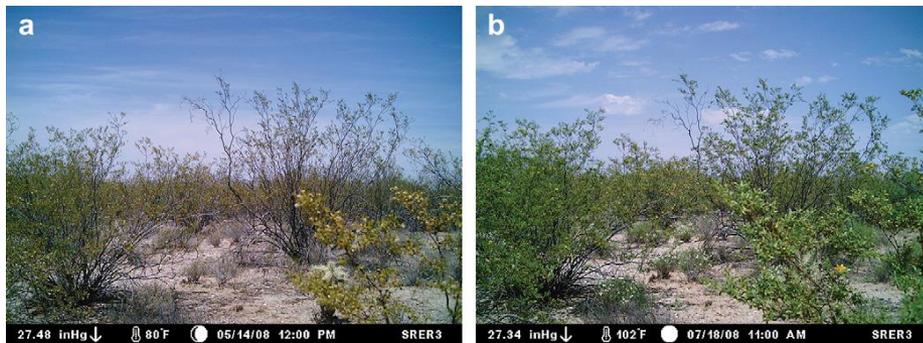
Findings:

- (1) Increase in spatial variability with higher soil moisture, though differing relations in each region.
- (2) Presence of scale invariance and multifractality detected from 800-m to 51.2 km resolutions.
- (3) Multifractal properties linked to mean soil moisture state for SON, but less so in AZ.
- (4) Differences among sites potentially related to variations in rainfall or land cover.



KURC ET AL: IMAGE-DERIVED GREENNESS LINKS DEEP SOIL MOISTURE TO CARBON UPTAKE IN A CREOSOTE BUSH SHRUBLAND

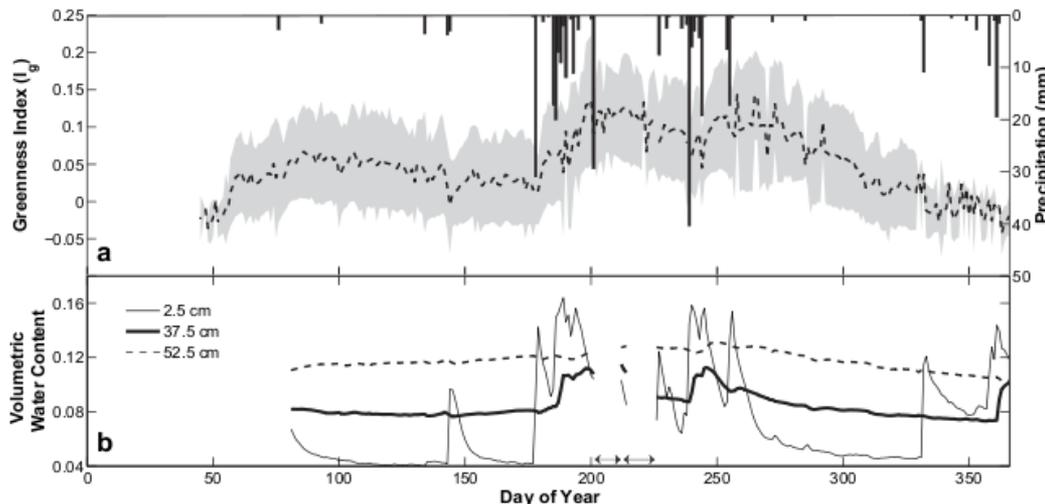
Motivation: Continuous phenology observations are infrequent in semiarid regions. This study develops an imaging technique for shrubland greenness.



Question: *What are the hydrologic triggers for vegetation greening in evergreen shrubs?*

Phenological cameras in an eddy covariance footprint and soil moisture profiles used to identify relations between precipitation pulses and greening.

Comparison of image-derived greenness to remotely-sensed MODIS estimate carried out.

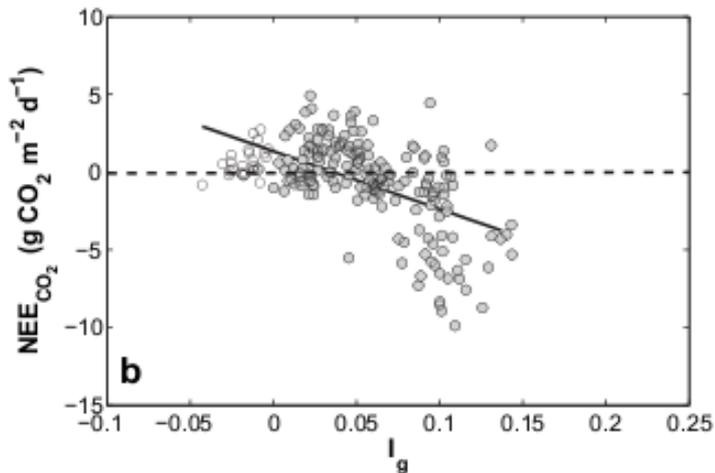
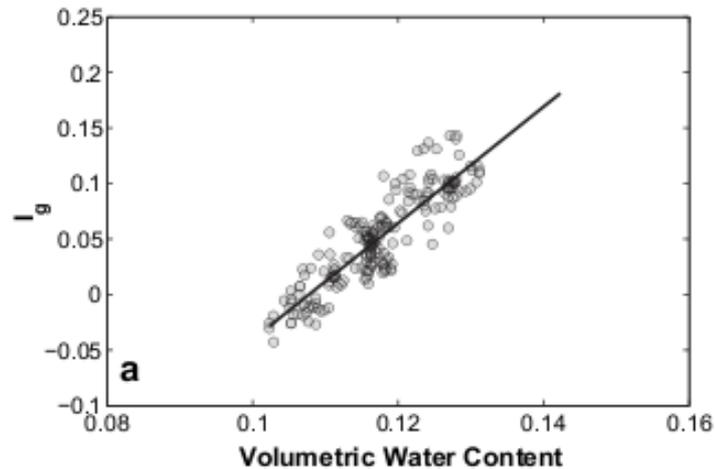


Study Area: Santa Rita Exp. Range
Topics: Vegetation and Soil Moisture



KURC ET AL: IMAGE-DERIVED GREENNESS LINKS DEEP SOIL MOISTURE TO CARBON UPTAKE IN A CREOSOTEBUSH SHRUBLAND

Soil Moisture and Net Ecosystem Exchange as Function of Greenness



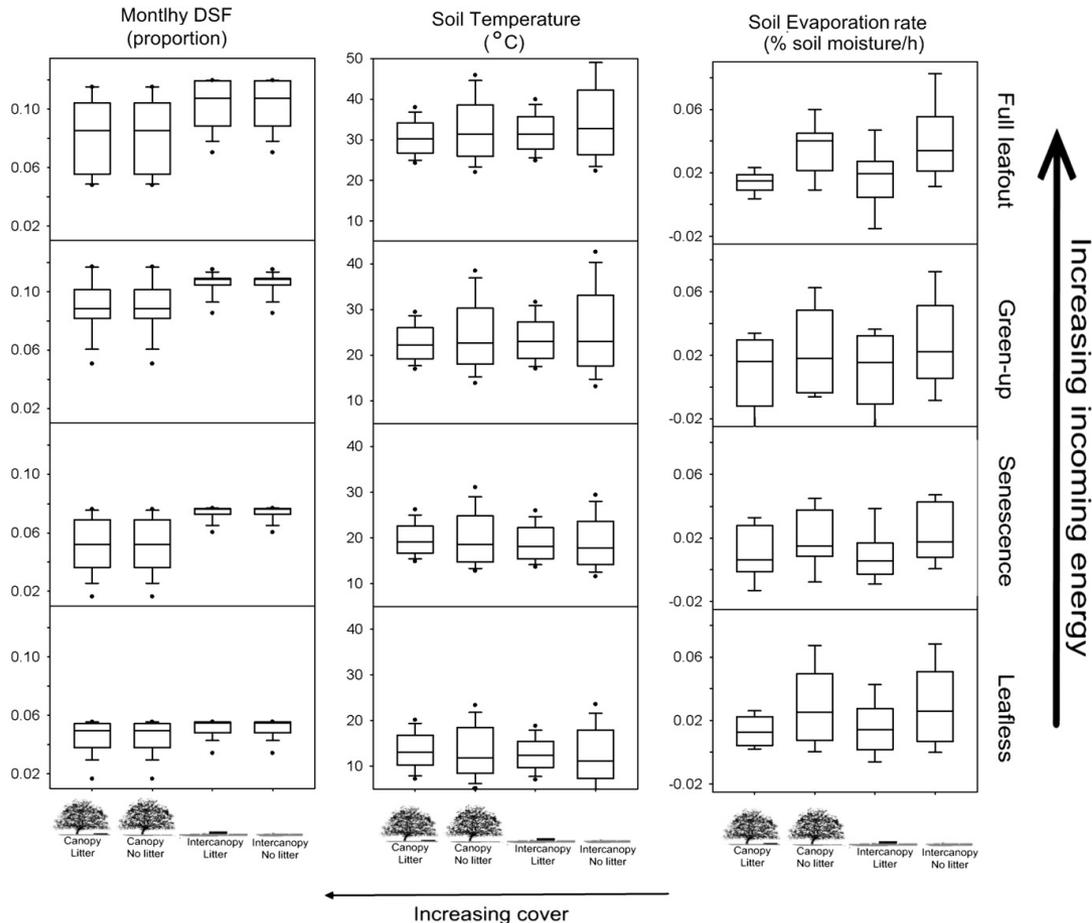
Findings:

- (1) Demonstrated the utility of time-lapse digital photography for quantifying dynamics of creosotebush systems using multiple cameras in a tower footprint.
- (2) The most effective precipitation pulses for creosotebush greenup were those leading to soil moisture increases at >30 cm depth.
- (3) Greenness index showed a moderate relation to net ecosystem exchange, allowing potential application for phenocams in carbon budget estimates.



VILLEGAS ET AL: ECOHYDROLOGICAL CONTROLS OF SOIL EVAPORATION IN DECIDUOUS DRYLANDS

Motivation: Controls on soil evaporation in semiarid areas are poorly known. This study measured soil evaporation across gradients in cover and phenology.



Question: *What are the major controls on soil evaporation in patchy woody savannas that experience seasonal greening?*

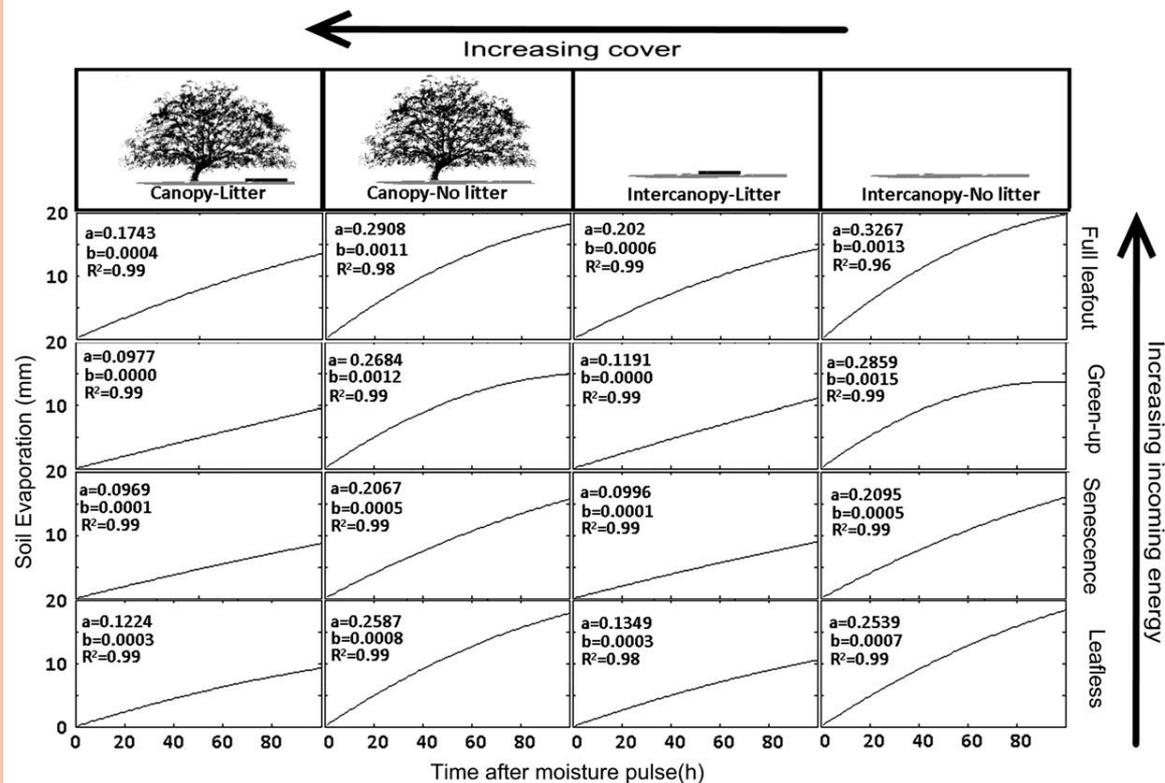
Soil evaporation was measured across a range of cover types (canopy, intercanopy, litter) using microlysimeters.

Solar radiation at the soil surface was measured using hemispherical photographs for each cover and season.

Study Area: Santa Rita Exp. Range
Topics: Vegetation and Soil Evaporation



VILLEGAS ET AL: ECOHYDROLOGICAL CONTROLS OF SOIL EVAPORATION IN DECIDUOUS DRYLANDS



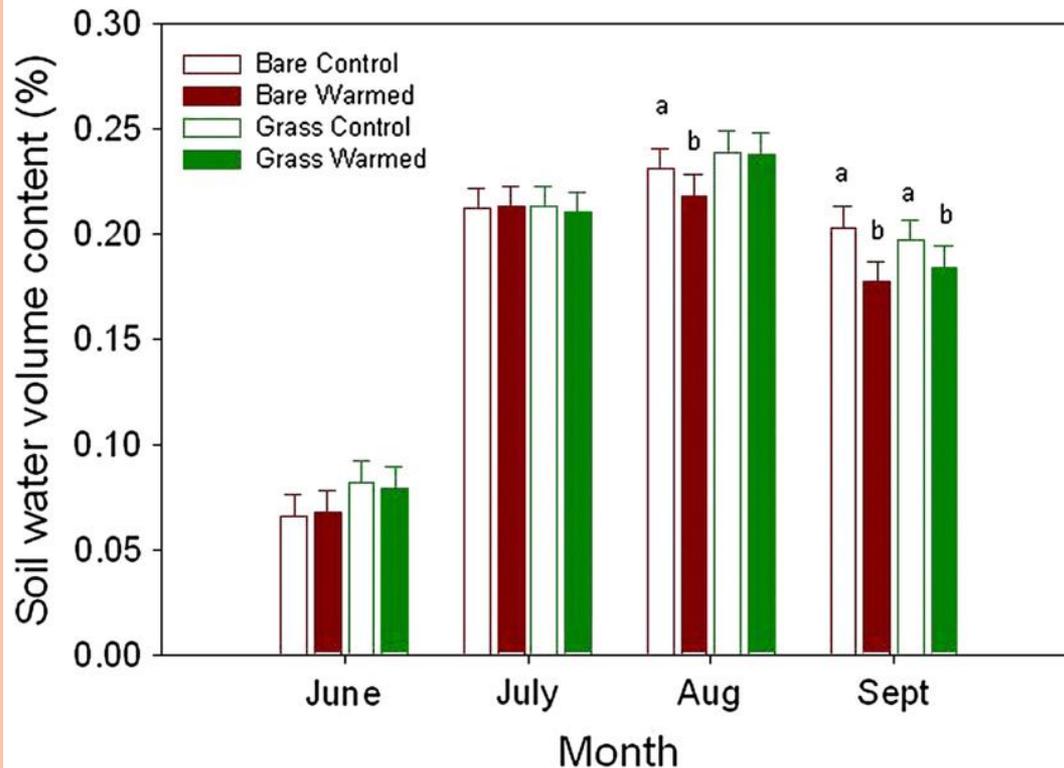
Findings:

- (1) The presence of a litter layer was found to be a major control on soil evaporation for all seasons.
- (2) When a litter layer was absent, patch and mosaic attributes influenced soil evaporation variably with season/phenology.
- (3) A hypothesis is provided for how energy and wind limitations influence soil evaporation for differences in vegetation hierarchy.

COLLINS ET AL: RAPID PLANT COMMUNITY RESPONSES TO NIGHTTIME WARMING IN A CHIHUAHUAN DESERT GRASSLAND

Motivation: Increased temperatures are expected to change grasslands. This study reports on manipulation experiments to isolate such effects.

Summertime Soil Moisture Response in Bare and Grass Areas with Warming



Question: *How will soil moisture and grassland cover respond to increased nighttime temperatures and nitrogen deposition?*

A manipulation experiment for 1 summer season was performed with nitrogen additions and night-time warming.

Soil moisture, temperature, $\text{NO}_3\text{-N}$ and plant cover (total and by species) measured in control, warmed, N-addition and warmed+N-addition plots.

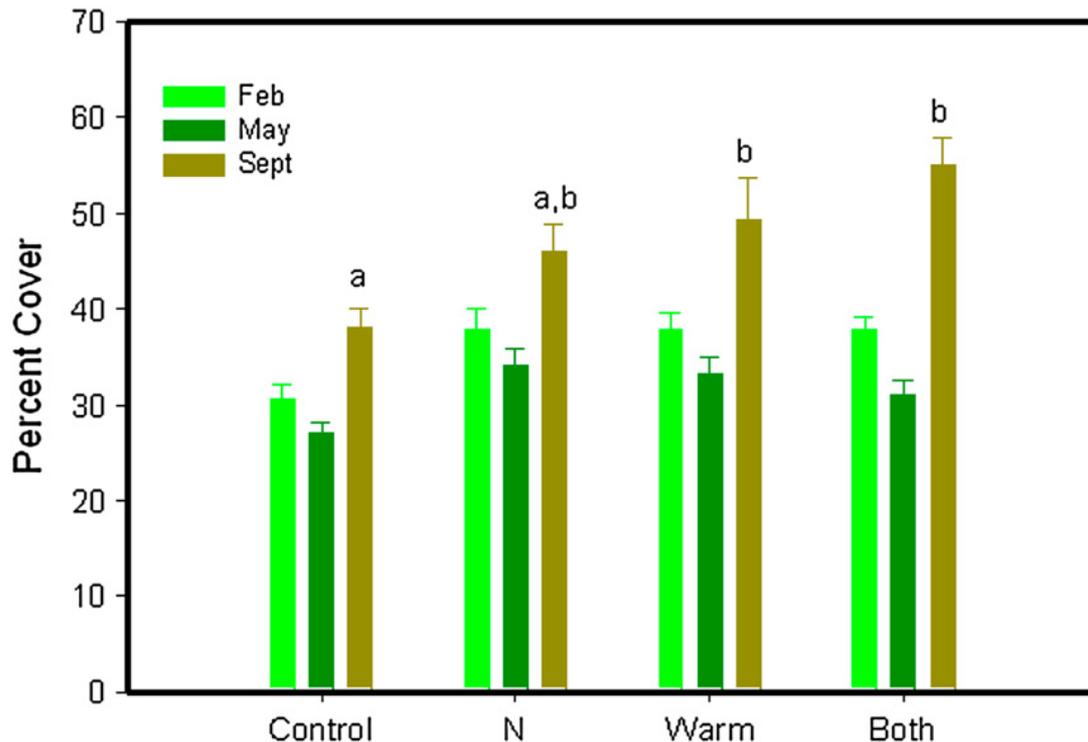
Study Area: Sevilleta LTER

Topics: Vegetation and Temperature



COLLINS ET AL: RAPID PLANT COMMUNITY RESPONSES TO NIGHTTIME WARMING IN A CHIHUAHUAN DESERT GRASSLAND

Total Grass Cover Response in Study Plots



Findings:

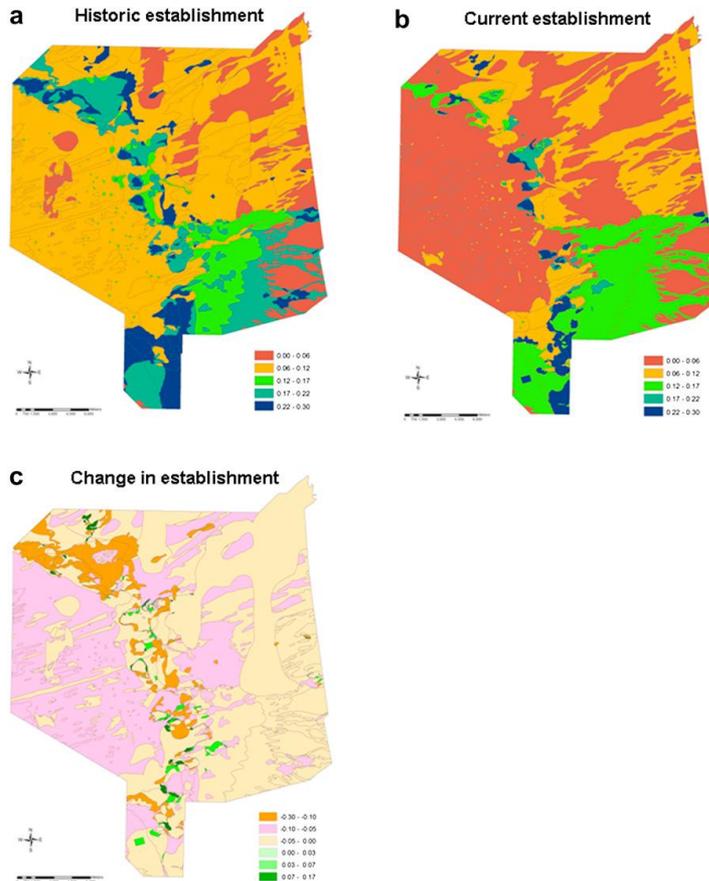
(1) After one monsoon season, warming significantly increased total plant cover.

(2) Warming had a significant drying effect on soil moisture first under interspace patches in August and then beneath both interspace patches and grass canopies in September.

(3) No significant effect of N on total cover, nor a warming by N interaction was found, but species specific responses varied among 3 grass species.

PETERS ET AL: SOIL-VEGETATION-CLIMATE INTERACTIONS: EFFECTS OF NORTH AMERICAN MONSOON ON GRASS RECRUITMENT

Motivation: Changes in summer precipitation are expected to alter grassland recruitment. This study simulates grass establishment for a range of scenarios.



Question: *How does recruitment of grass seedlings vary across a complex landscape where plants and soils control soil moisture availability?*

Numerical experiments are conducted using a soil water model applied to historical (1858) and current vegetation patterns over different landforms.

Simplified climate change scenarios (increased temperature by 3 C and +5, +10, +25% and -5, -10, -25% rainfall).

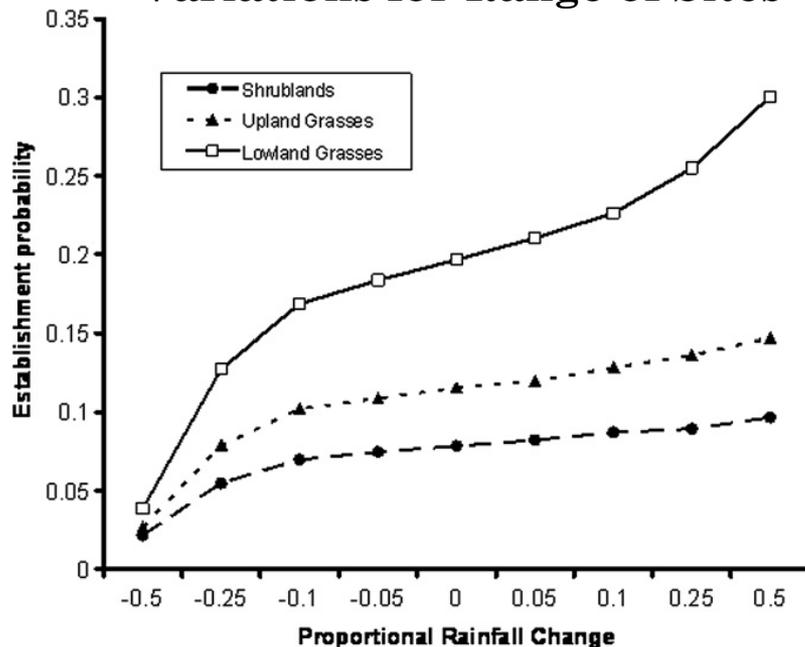
Study Area: Jornada LTER

Topics: Vegetation and Rainfall

NMSU, USDA/ARS

PETERS ET AL: SOIL-VEGETATION-CLIMATE INTERACTIONS: EFFECTS OF NORTH AMERICAN MONSOON ON GRASS RECRUITMENT

Grassland Establishment with Rainfall and Temperature Variations for Range of Sites



Findings:

- (1) Woody encroachment at the Jornada decreased simulated grass recruitment; the amount of reduction depended on site-specific soil properties.
- (2) Reductions in monsoon rainfall below 25% of current amounts would reduce recruitment to low levels across all vegetation types with significant impacts on the ability of black grama to persist.
- (3) Lowland grass sites (with clay soils) remain viable locations for grass recruitment under most scenarios, suggesting a path forward for restoration.



SYNTHESIS AND FORWARD THINKING

- We can identify a unifying theme of seasonal changes in ecosystem (CO₂, phenology) and hydrologic (soil moisture, ET) conditions across many studies.
 - *Systematic studies across ecosystems that represent the archetypes found in the North American monsoon region are needed.*
- Understanding of ecohydrologic conditions for climate change predictions motivated many studies.
 - *Experimentalists & modelers need to work together on defining data, manipulations and models that can address this difficult problem.*
- Leveraging existing field sites/collaborations in U.S. and Mexico would allow coordinated regional efforts. ●