

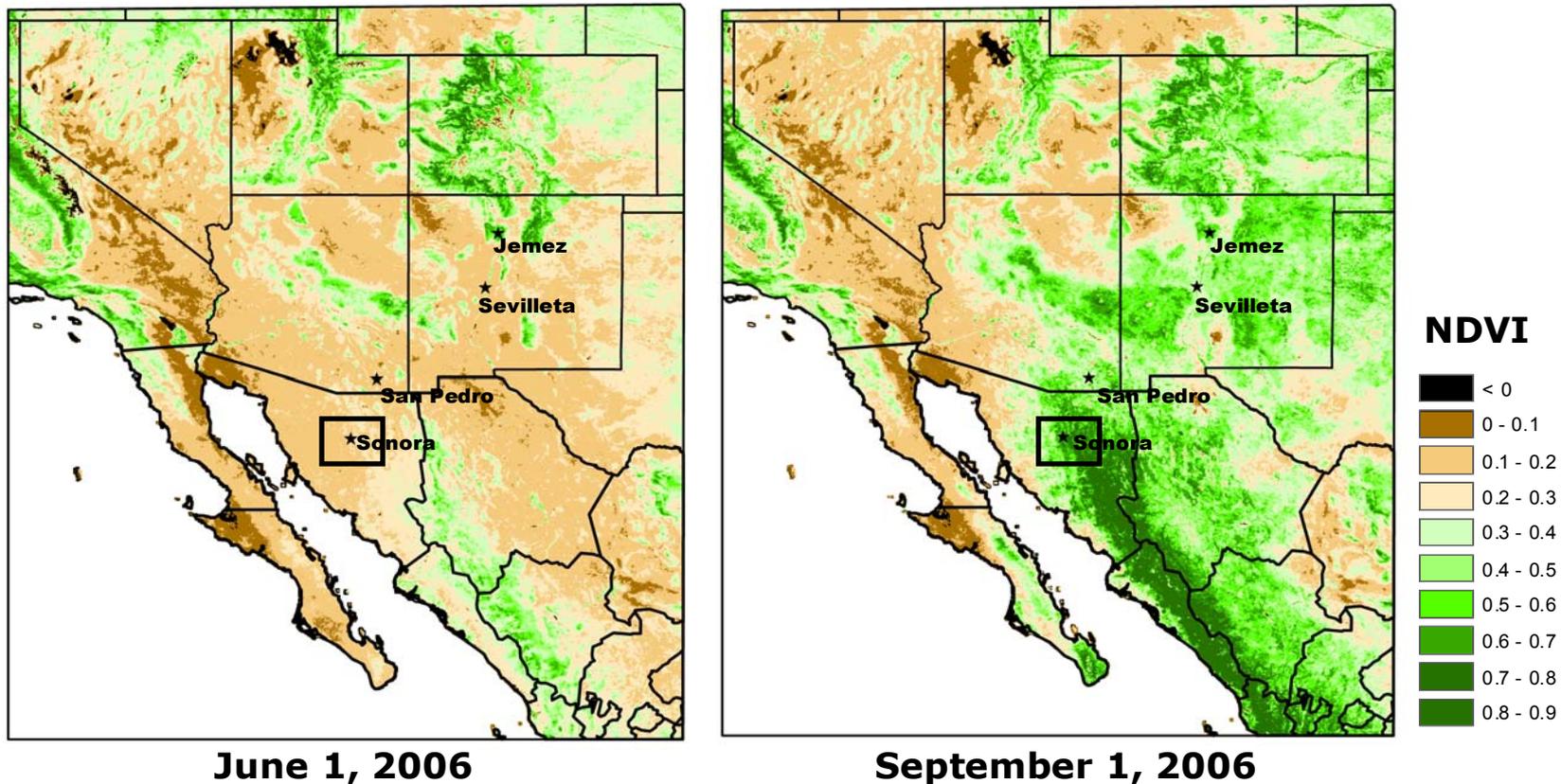
# Seasonal and interannual relations between precipitation, soil moisture and vegetation in the North American monsoon region

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# Motivation

*Precipitation during the NAMS leads to a strong vegetation response consisting of leaf-on of subtropical deciduous species over the complex topography in western Mexico.*

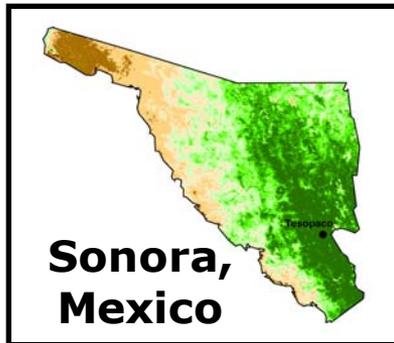


**June 1, 2006**

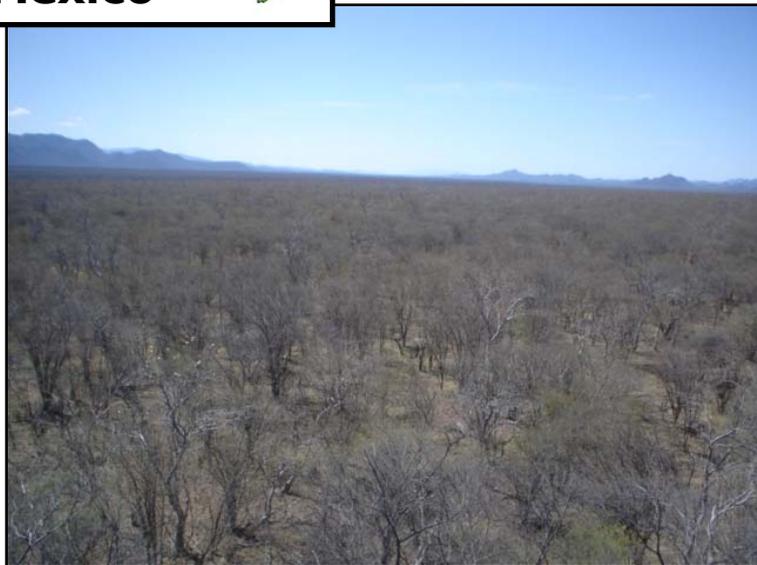
**September 1, 2006**

**SPOT VEGETATION 2 Product, 1-km resolution  
10-day composite, Normalized Difference Vegetation Index**

# Motivation



*Seasonality in precipitation and vegetation has potential impacts on land-atmosphere interactions, runoff production and groundwater recharge.*



**Winter Conditions**



**Summer Monsoon Conditions**

**Photographs from 15-m Eddy Covariance Tower in  
Deciduous Subtropical Forest in Tesopaco, Sonora, Mexico**



# Motivation

## **Motivating Questions:**

1. *Are dynamic vegetation patterns related to soil moisture and precipitation distributions?*
2. *Do inter-annual and intra-annual variations exist at the regional scale as well as in different ecosystems?*

## **Methods to Approach Questions:**

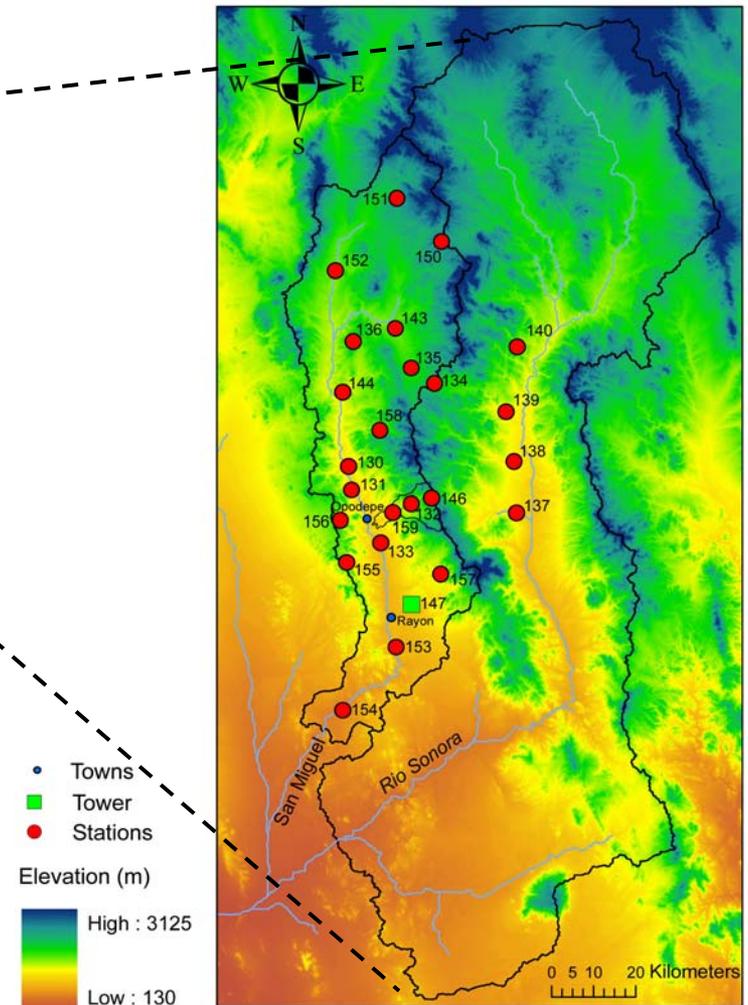
1. Remotely-sensed observations from MODIS.
2. Regional network of precipitation and soil moisture observations.
3. Spatial and temporal data analyses.

# Study Region



## Rio Sonora Study Basins

- A large-scale intensive study site has been established in the mountainous Rio Sonora basin ( $\sim 15,500 \text{ km}^2$ )
- Region characterized by north-to-south mountain ranges and two major rivers: **Rio San Miguel, Rio Sonora**.
- Complex topography with semiarid monsoon climate, seasonally-green vegetation and ephemeral streams.



**SMEX 2004:** Soil Moisture Field Campaign  
**NAME 2004:** Eddy Covariance Tower Network  
**Sonora IRES:** Expanded Hydromet Network  
**(2006-2008)** Eddy Covariance Experiments

# Regional Network

## Ecosystem Distribution and Continuous Stations

### Sonoran grassland



### Sinaloan thornscrub



### Madrean woodland



*Increasing Elevation* →

### **Stevens Hydra Probe SDI-12**



### **Texas Electronics 8" Tipping-bucket Rain Gauge**

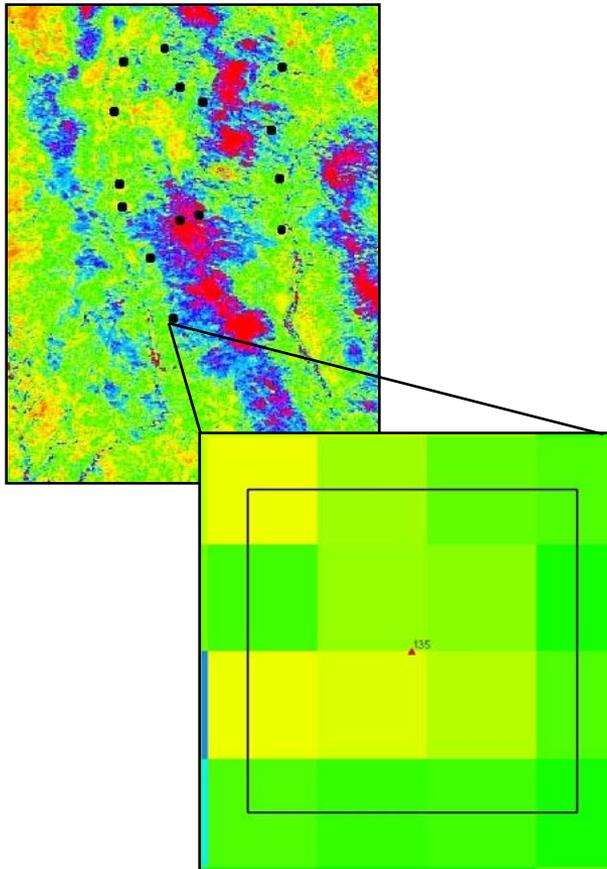


## Regional Hydrometeorological Network

- Network of 25 continuous measurement stations of precipitation and soil moisture (and 10 new stations to be installed in 2008).
- Represent different elevations, ecosystems types and soil/geological formations.
- Each continuous station has a tipping-bucket rain gauge (calibration performed) and two soil moisture sensors: 2.5 and 5-cm depths.

# Remote Sensing

## Extraction of Vegetation Dynamics at Regional Stations



*Polygon extraction area (3 x 3 pixels, 750-m by 750-m) centered on each station.*

## Remotely-Sensed Vegetation Dynamics From MODIS

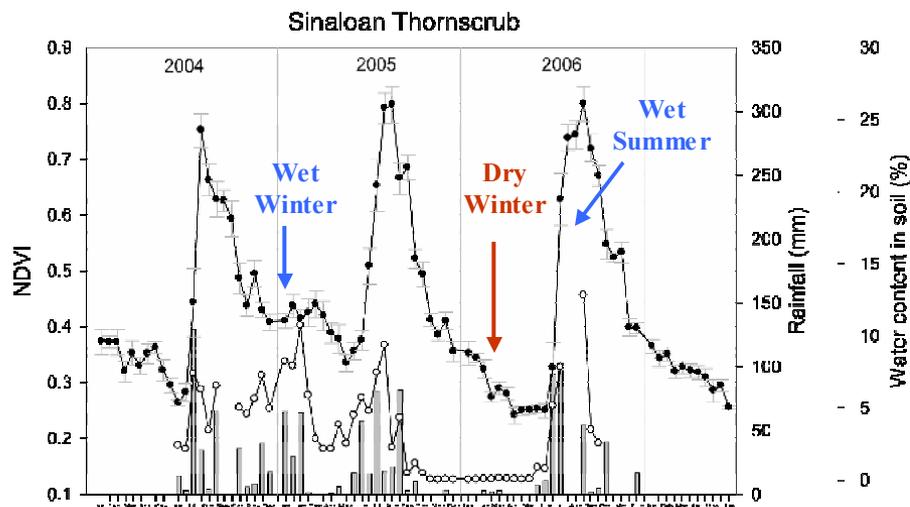
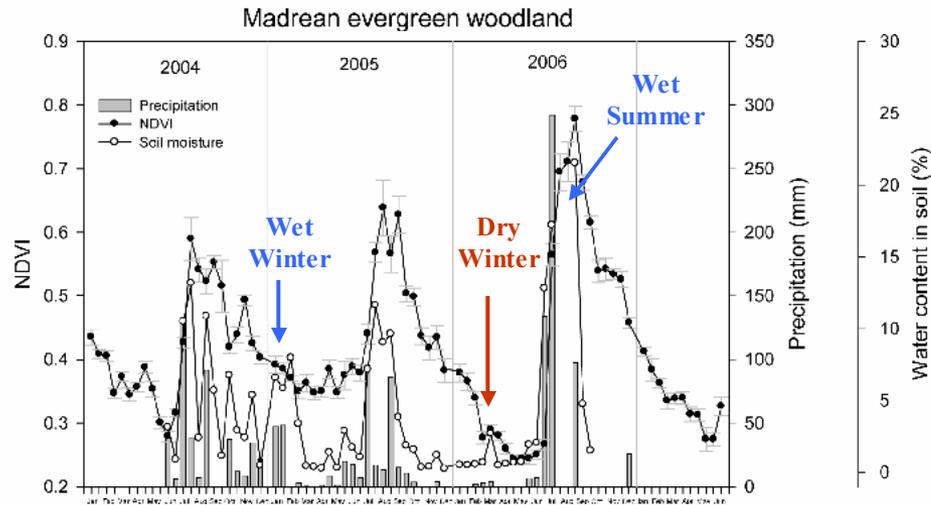
- MODIS AQUA Imagery Archive:
  - NDVI, EVI, Land surface temperature (LST), Leaf area index (LAI) and Albedo.
  - 8-day and 16-day image composites from period 2004-2007 (~180 images).
  - Spatial resolution of 250-m or 1-km, depending on product.
- Image Processing Procedures:
  - Reprojection and format conversion from native HDF-EOS to GEO Tiff.
  - Extraction of polygon around each regional station for each image.
  - Calculation of 3x3 pixel average value and standard deviation.
  - Time series analysis of zonal statistics.
- Normalized Difference Vegetation Index (NDVI):

$$NDVI = \frac{\rho_{NIR} - \rho_{red}}{\rho_{NIR} + \rho_{red}}$$

- 250-m resolution product, available at 16-day composites.

# Ecosystem-Scale Dynamics

## Temporal Dynamics of NDVI, Precipitation and Soil Moisture



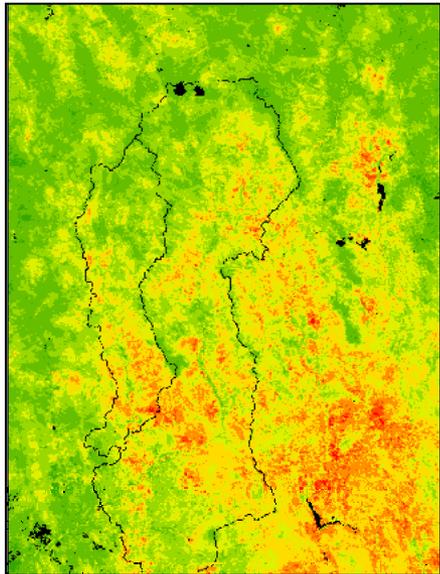
## Hydrologic Controls on Vegetation Dynamics

- In each ecosystem, we related MODIS and station observations:
- Three monsoons (2004-2007) had differences in vegetation dynamics linked to hydrologic conditions.
- Conifer ecosystems:
  - Smaller overall response to monsoon rainfall and sensitivity to winter precipitation.
  - Larger interannual differences in monsoon response.
- Subtropical ecosystems:
  - Consistent and significant greening during summer season.
  - Smaller interannual differences in monsoon response.
- *Drought and pluvial periods apparent in short-term records.*

# Regional-Scale Dynamics

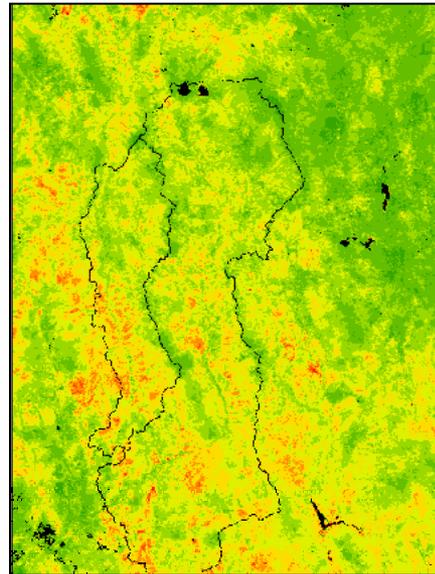
## Seasonal Changes in NDVI during NAMS over Region

**Summer 2004**



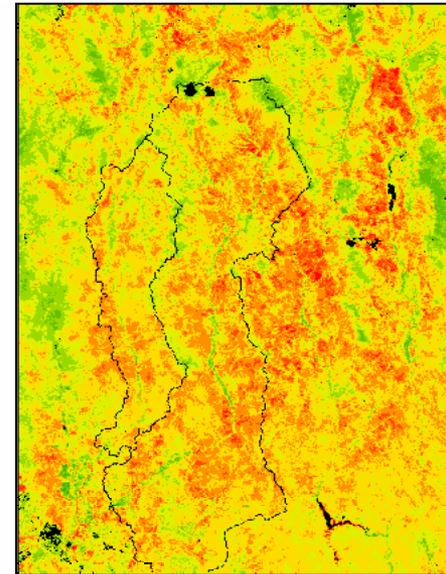
**$\langle R \rangle = 251$  mm**

**Summer 2005**

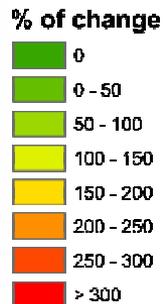


**$\langle R \rangle = 222$  mm**

**Summer 2006**



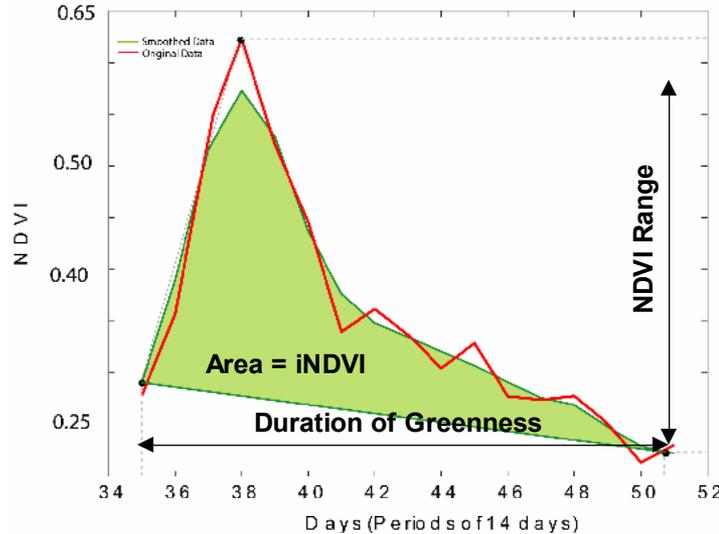
**$\langle R \rangle = 350$  mm**



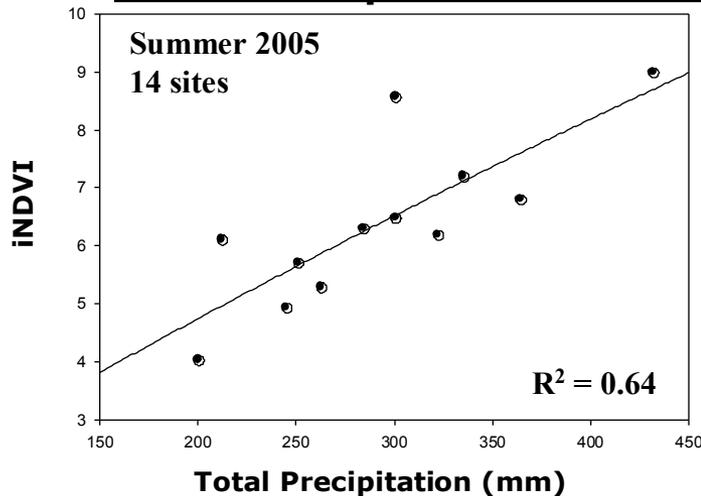
- Marked *NDVI* greenup for each summer monsoon, related to total season precipitation averaged over entire network,  $\langle R \rangle$ .
- Interannual differences in photosynthetic activity within various ecosystems.
- Interannual variability in the spatial organization of vegetation greenup, which can serve as a proxy for total season precipitation distribution in ungauged regions.

# Vegetation Metrics

## Vegetation Metrics for Seasonally-Green Ecosystems



## iNDVI-Precipitation Relation

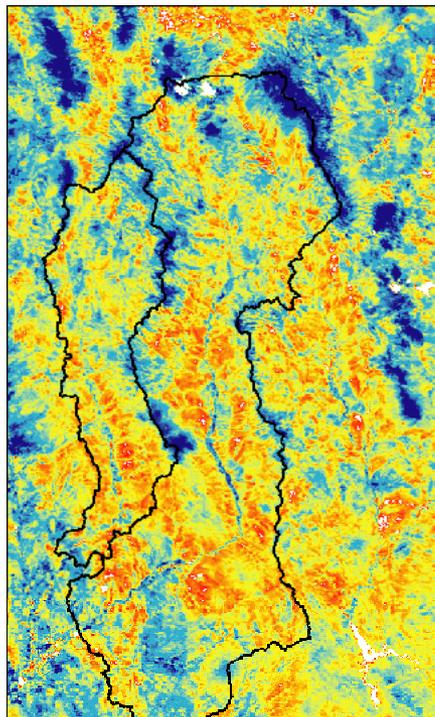


## Quantifying Seasonal Vegetation Dynamics at Regional Stations

- Ecosystem phenological metrics derived for each ecosystem using the methods of Reed et al. (1994):
  - Integrated NDVI (iNDVI) related to the net primary productivity (NPP).
  - Duration of Greenness related to the period of photosynthetic activity.
  - NDVI range is a measure of the change in the ecosystem biomass (photosynthesis).
- Based upon these vegetation metrics, we found the following:
  - Total annual precipitation is a strong control on the iNDVI (related to greenness and NPP) for each ecosystem.
  - Higher rainfall use efficiencies (REU) are found for the more arid ecosystems.
- Other metrics include Rate of Greenup and Rate of Senescence.

# Spatial and Temporal Stability

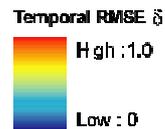
## Vegetation Dynamics used to Infer Ecosystem Dynamics in Time and Space using Stability Analysis



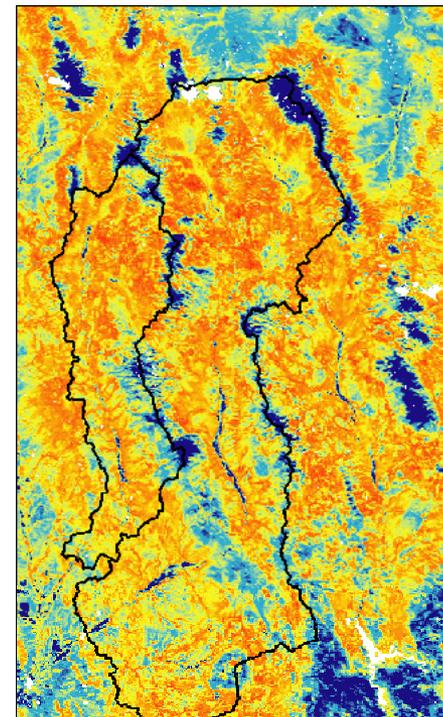
*Time stability captures sites that track closely the temporal mean.*

*Low RMSE  $\delta$  = Similar to the temporal mean*

*High RMSE  $\delta$  = Different from the temporal mean*



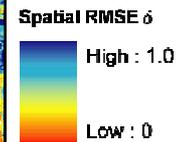
Temporal NDVI RMSE  $\delta$



*Spatial stability captures sites that consistently track the spatial mean.*

*Low RMSE  $\delta$  = Similar to the spatial mean*

*High RMSE  $\delta$  = Different from the spatial mean*

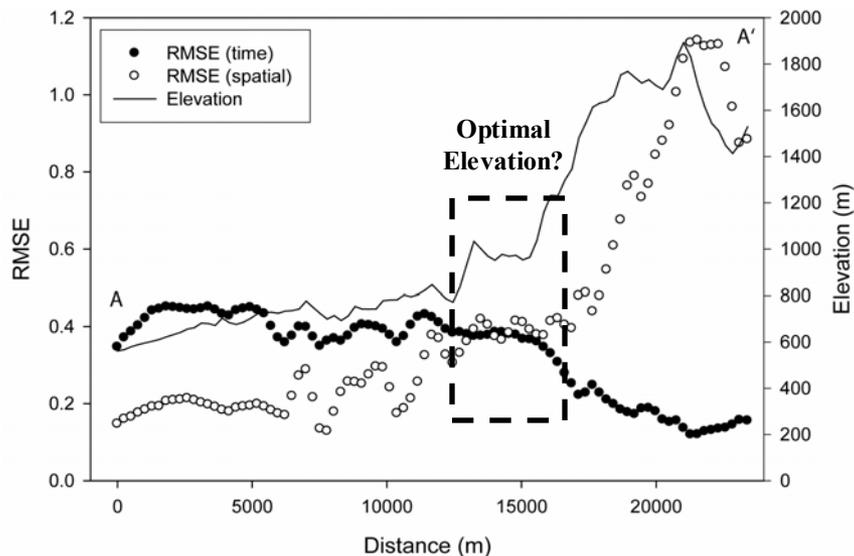
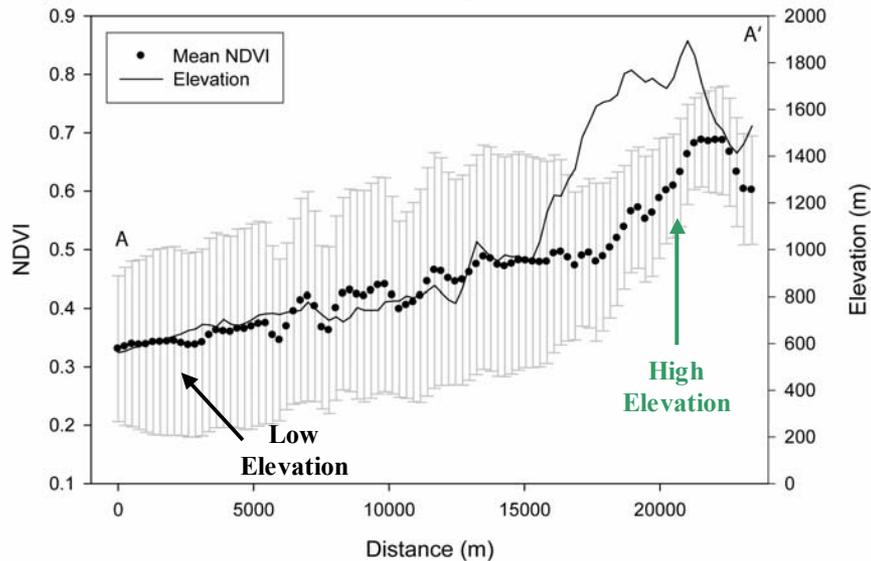


Spatial NDVI RMSE  $\delta$

- Analysis clearly delineates the stable and dynamic ecosystems in the region based on the temporal and spatial variability of NDVI (over all images in 2004-2007).
- Higher elevation conifers and riparian corridors relatively little in time and do not track the spatial dynamics in the region.
- Mid elevation subtropical deciduous species vary more in time and represent the regional scale mean behavior (since they capture more of the regional area).

# Topographic Controls

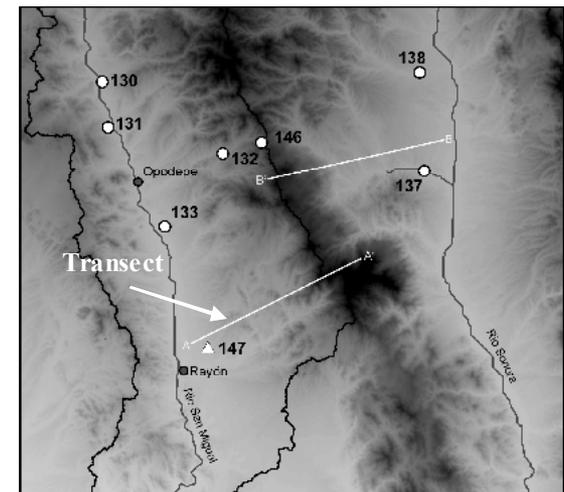
## Elevation Variation of NDVI and Stability Metrics



## Topographic Controls on Ecosystem Dynamics

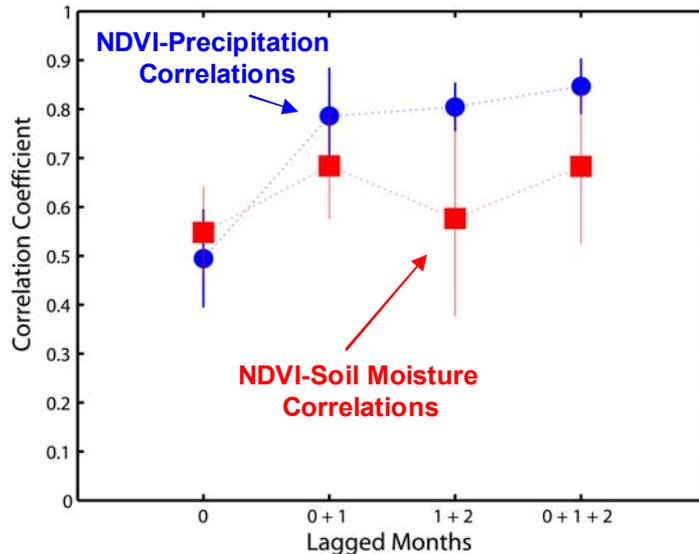
- Elevation dependence of ecosystem distribution and vegetation dynamics
  - Higher NDVI in high elevation, but complex relation for upper sites.
  - Higher sites track the spatial mean less than low sites and exhibit less variations in time than low sites.
  - An optimal region may exist where vegetation represents the spatial mean and has low temporal variability.

## Transect Location



# Vegetation-Hydrology Relations

## Lagged Correlation Coefficients at Monthly Time Scale



## Lagged Correlation Coefficients for Precipitation

Station ID	0	0+1	1+2	0+1+2
130	0.442	0.784	0.749	<b>0.843</b>
131	0.465	0.727	0.872	<b>0.874</b>
132	0.494	0.721	0.741	<b>0.805</b>
133	0.477	0.807	0.876	<b>0.885</b>
135	0.559	0.831	0.745	<b>0.847</b>
136	0.580	<b>0.900</b>	0.790	0.859
143	0.495	0.819	0.822	<b>0.903</b>
144	0.314	0.735	0.805	0.789
146	0.429	0.608	<b>0.844</b>	0.736
147	0.691	0.927	0.802	<b>0.928</b>

## Relations between Vegetation Dynamics and Hydrologic Variables

- Lagged correlations of monthly NDVI to monthly precipitation and soil moisture indicate the following:
  - Correlation between NDVI and hydrologic variables increases with accumulation time.
  - Concurrent correlation (lag=0) is greater with soil moisture than precipitation.
  - Prior correlations (lag=0+1+2) is greater with precipitation than soil moisture.
  - Represent regional mean (all stations as symbols) and standard deviations (bars).
- Significant correlations (bold values) at individual stations observed for:
  - Precipitation accumulation during monsoon (lag = 0+1+2).
  - Soil moisture accumulation during current month or previous month.



# Conclusions and Remarks

1. NAMS leads to spatial and temporal changes in vegetation as observed from MODIS remote sensing data.

*Vegetation greening varies within different ecosystems and demonstrates seasonal and interannual variations in response.*

2. Vegetation dynamics observed from remote sensing allow characterization of ecosystem properties.

*Spatiotemporal stability analyses allow delineation of regions of similar ecosystem response along complex topography.*

3. Hydrological conditions have a strong control on the vegetation dynamics in the NAMS region.

*Rainfall Use Efficiency (RUE) and monthly NDVI are correlated with soil moisture and precipitation accumulations.*

# A Seasonally-Green Desert Landscape



FIN

