Relation between Surface Flux Measurements and Hydrologic Conditions in a Subtropical Scrubland during the North American Monsoon

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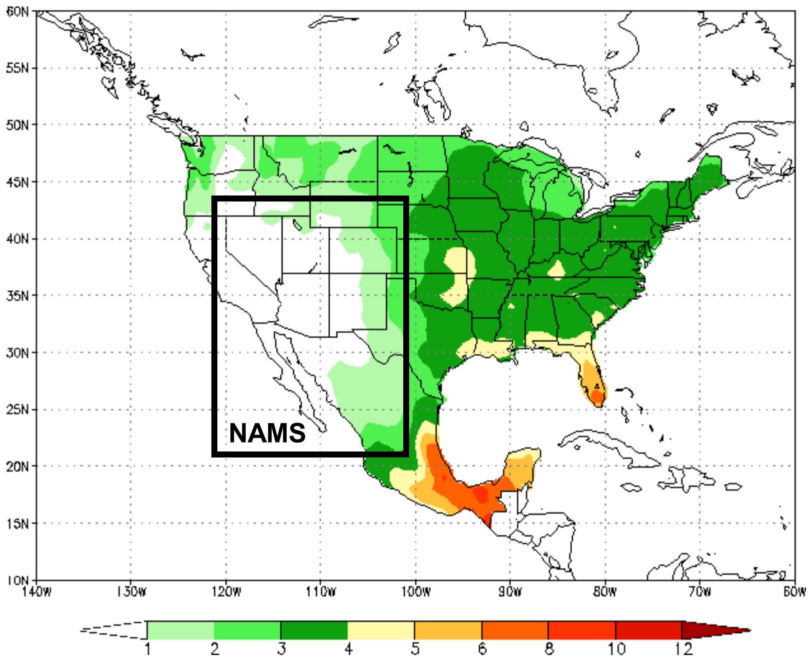
Motivation

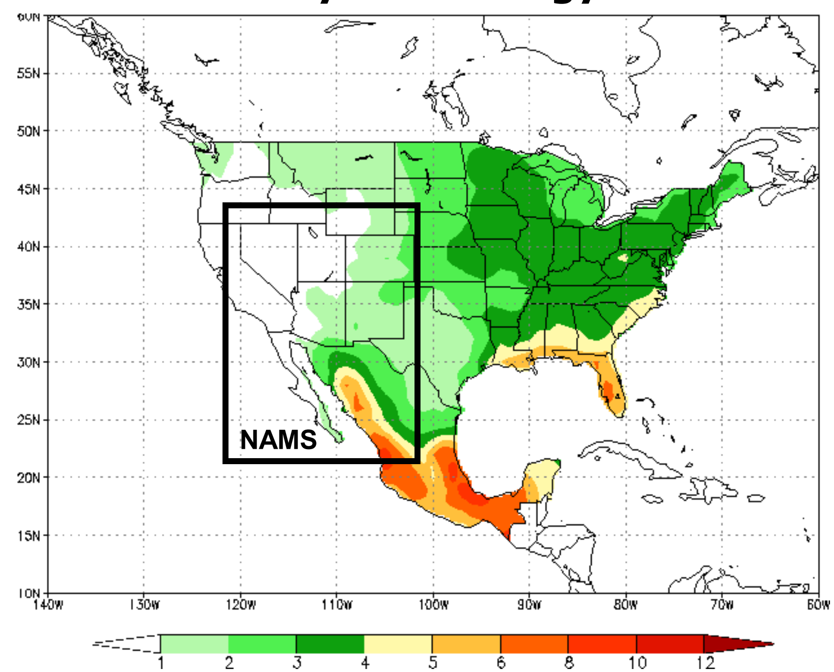
The North American Monsoon System (NAMS) is a seasonal change in atmospheric circulation leading to increased summer precipitation (July, August, September) in the southwestern US and northwestern Mexico.

June Climatology



Rainfall (mm/day)

July Climatology

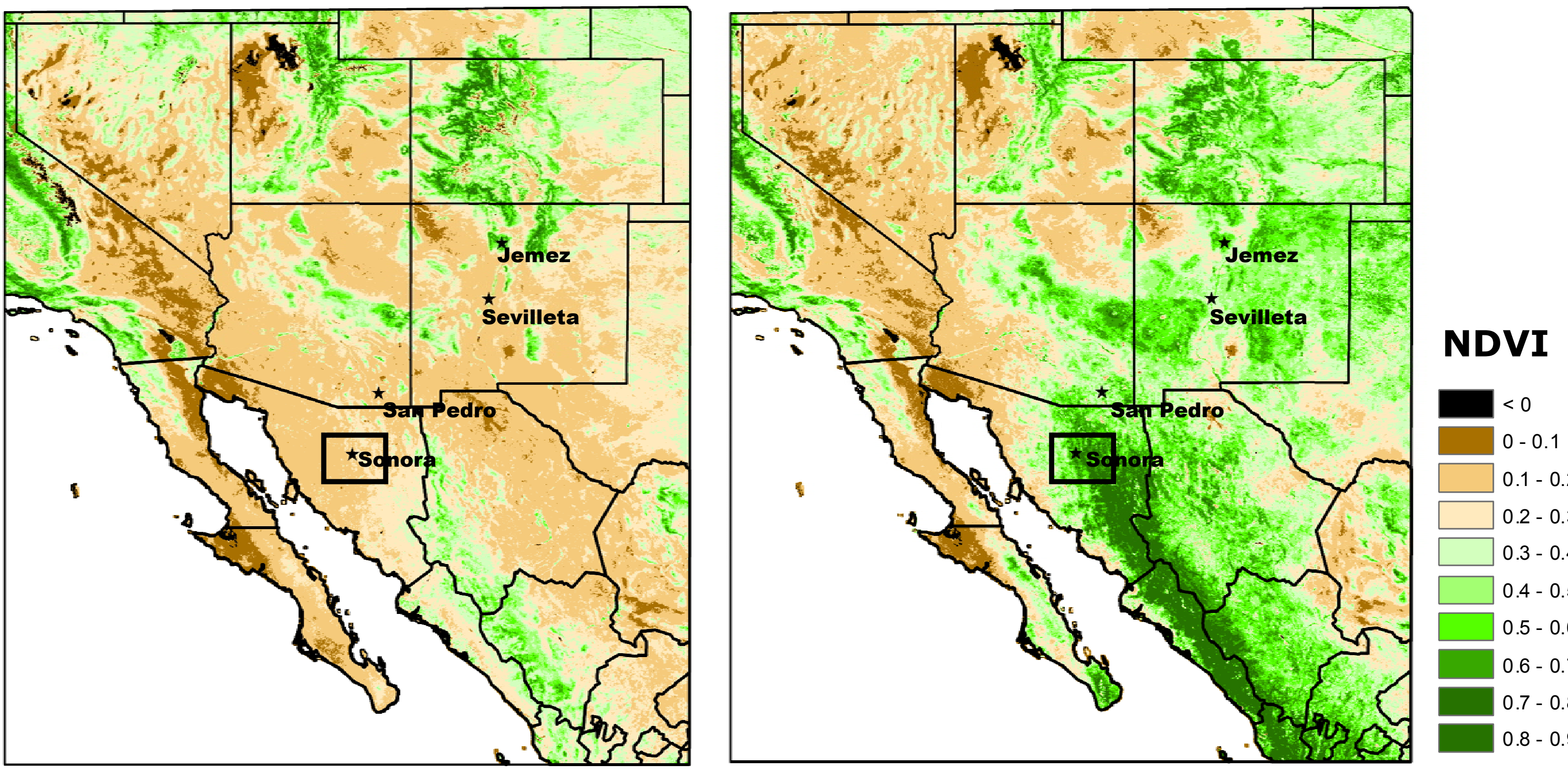


Rainfall (mm/day)

CPC Daily Gridded Precipitation Analysis for US and Mexico
1 degree by 1 degree, Monthly Climatology, 1970-1999

Motivation

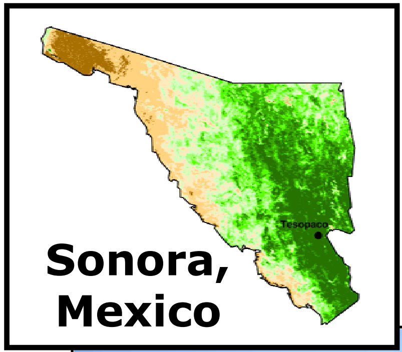
Precipitation during the NAMS leads to a strong vegetation response consisting of leaf-on of subtropical deciduous species over the complex topography in western Mexico.



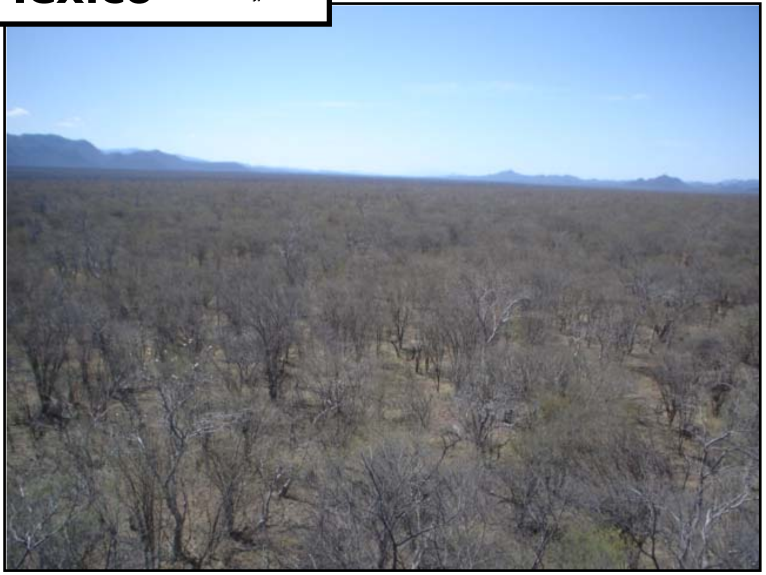
June 1, 2006 **September 1, 2006**

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

Outline

Hydrology and Surface Fluxes in NAMS Ecosystem:

1. **Seasonally-Green Study Site and Field Campaign:**

   Experiment design, instrumentation and observations.

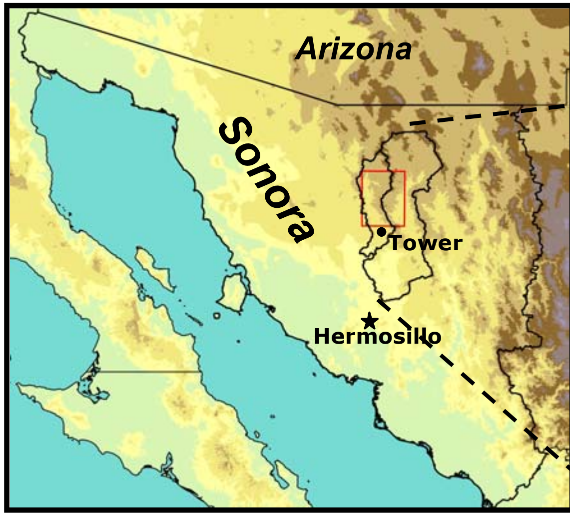
2. **Surface Turbulent Fluxes and Footprint Conditions:**

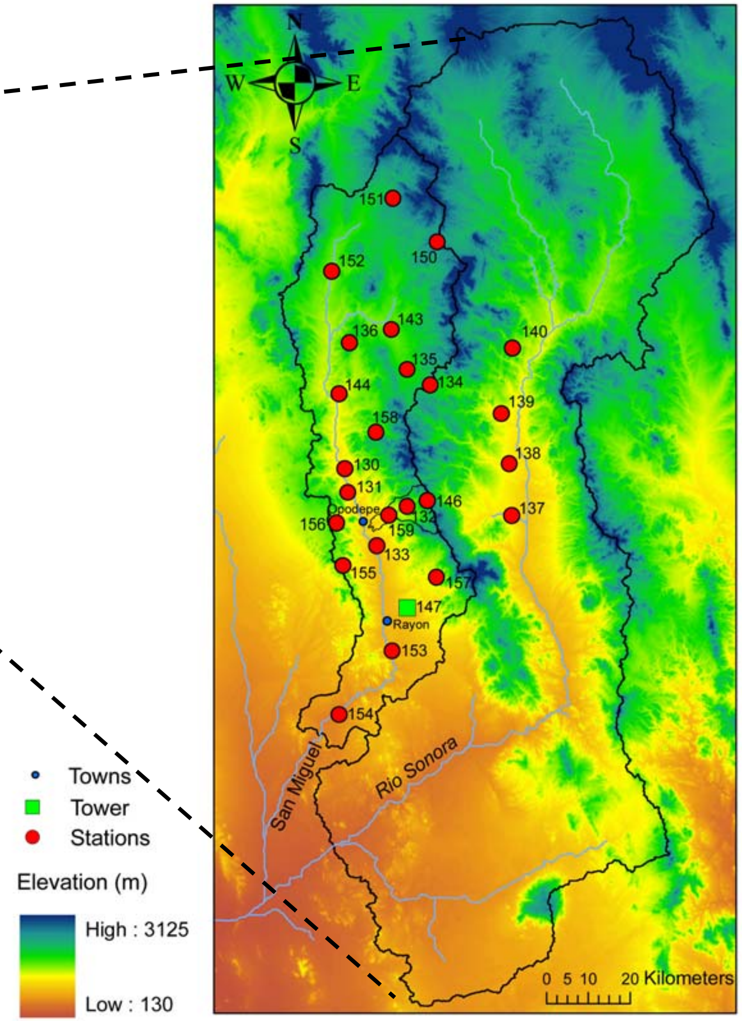
   Ground and remotely-sensed hydrological fluxes.

3. **Evapotranspiration Controls and Partitioning:**

   Relation between ET and footprint soil moisture.

Study Region





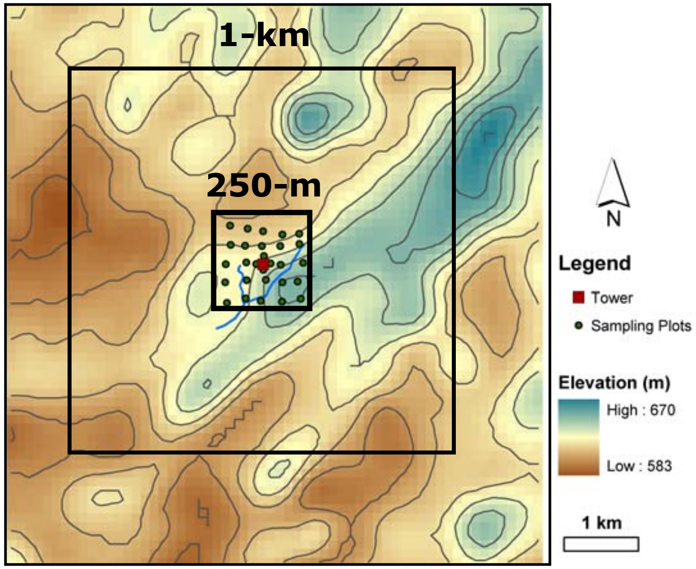
Rio Sonora Study Basins

- A large-scale intensive study site has been established in the mountainous Rio Sonora basin (~15,500 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

Study Region

ASTER 30-m DEM and Sampling Plot Locations at Tower Site



Vegetation Changes at Tower Site

June Period

July Period

Eddy Covariance Tower Site in Subtropical Scrubland

- We installed an EC tower in 2004 in Rayon, Sonora as part of a network of precipitation and soil moisture stations.

- Measurements at EC tower include:
    - Precipitation (2 sensor types)
    - Soil moisture (3 depths at 1 site)
    - Net Radiation and components
    - Ground and Sensible Heat Fluxes
    - Latent Heat Flux
    - Water vapor and CO_2 Profiler (4 heights)

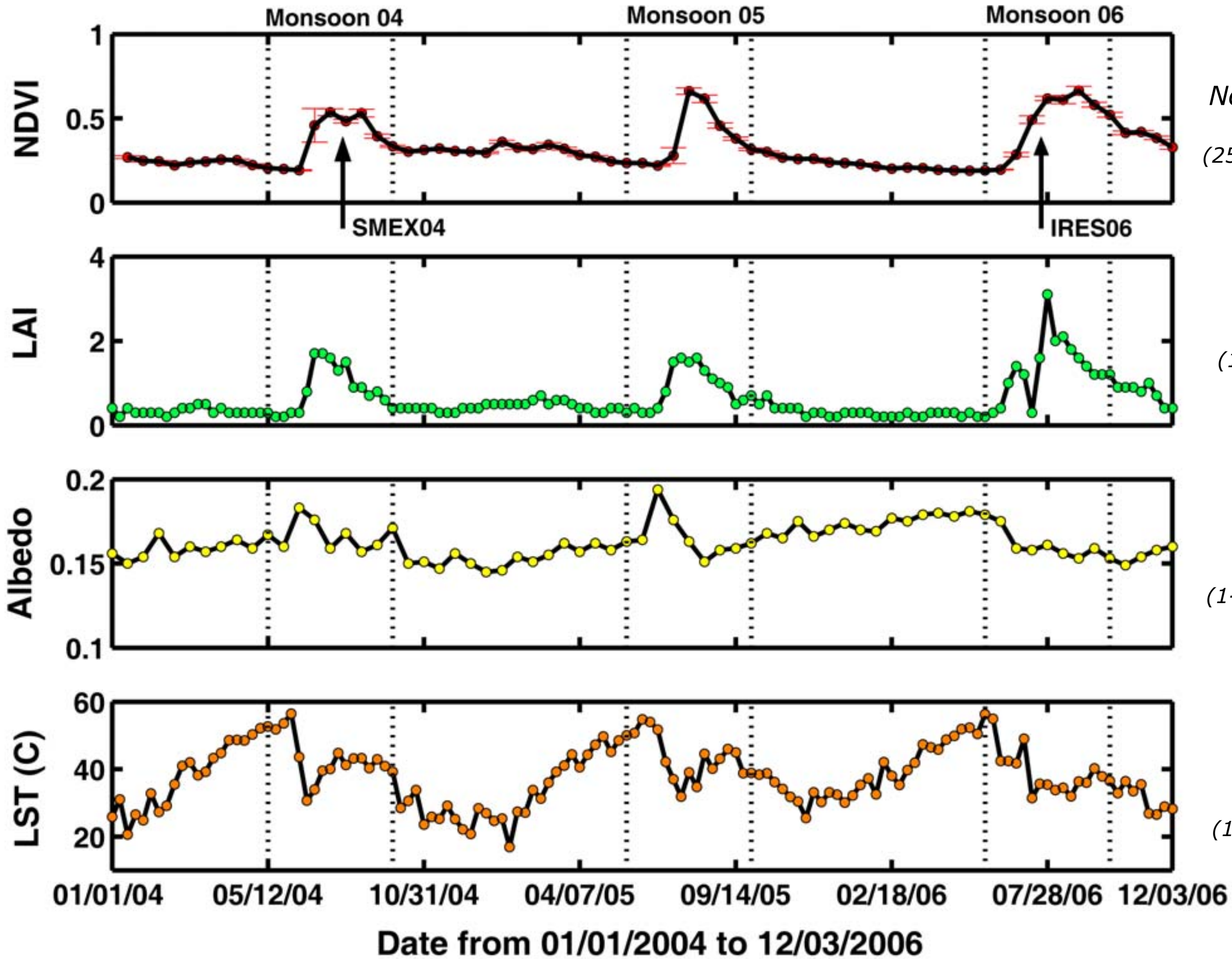
- Soil profile characteristics from pit:
    - Loamy sand (0 – 20 cm)
    - Sandy loam (20 – 50 cm)

- Subtropical scrubland ecosystem, known as *Sinaloan Thornscrub*, at site occupies large regions in northern Mexico.

- Cactus, shrub and tree species include:
    - Mesquite (*Prosopis juliflora*)
    - Tree Ocotillo (*Fouquieria macdougalii*)
    - Palo Verde (*Cercidium sonorae*)
    - Whiteball Acacia (*Acacia angustissima*)

Field Campaigns

Land Surface Changes Observed From MODIS at Tower Site (250-m or 1-km pixels)



Normalized Difference Vegetation Index *(250-m, 16-day composites)*

Leaf Area Index *(1-km, 8-day composites)*

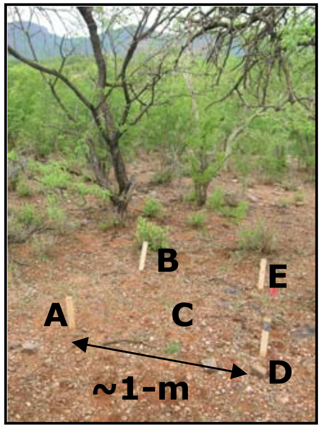
Broadband White-Sky Albedo *(1-km, 16-day composites)*

Land Surface Temperature *(1-km, 8-day composites)*

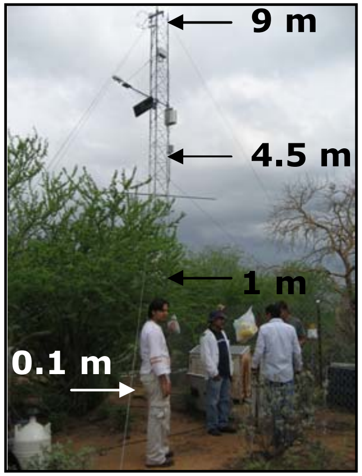
- NDVI and LAI exhibit strong signature of *monsoonal vegetation greening*.
- Albedo and LST *decrease during monsoon* in response to rainfall and greening.
- *Interannual variations* observed in the three monsoon responses.

Field Campaigns

Thirty Soil Sampling Plots in 250-m Pixel



Isotopic Sampling at Eddy Covariance Site

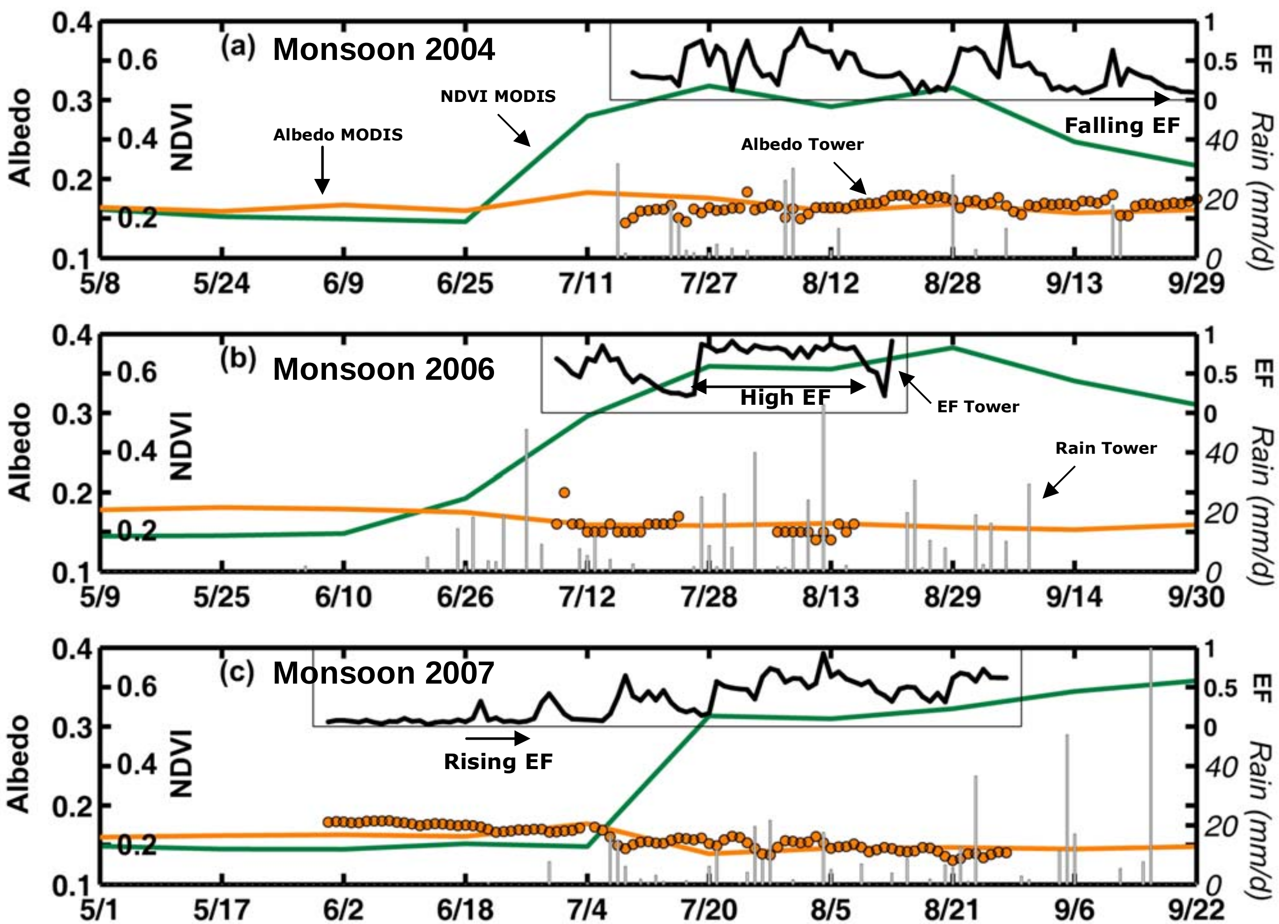


Ground Sampling at Eddy Covariance Tower Site

- Thirty (30) sampling plots in 250-m by 250-m area around tower selected and characterized including:
  - Slope, Aspect, Elevation
  - Vegetation and Soils
  - Landscape Position
- Daily sampling at five (5) locations in each sampling plot:
  - Volumetric soil moisture at 0-6 cm using portable Theta Probe.
  - Soil temperature using thermometer and IRT probe at 1, 5, 10 cm depths.
- Three to five half-hourly samplings of vapor, soil and vegetation for isotopic composition and ET partitioning:
  - Water vapor extracted from four (4) eddy covariance tower heights.
  - Soil sampled from 5, 10, 15 cm depths at five locations around tower.
  - Vegetation (stem, leaf) sampled from three major species around tower.

Surface Fluxes

EC Tower Fluxes and States During Monsoons



Decreasing EF toward end of Monsoon Season

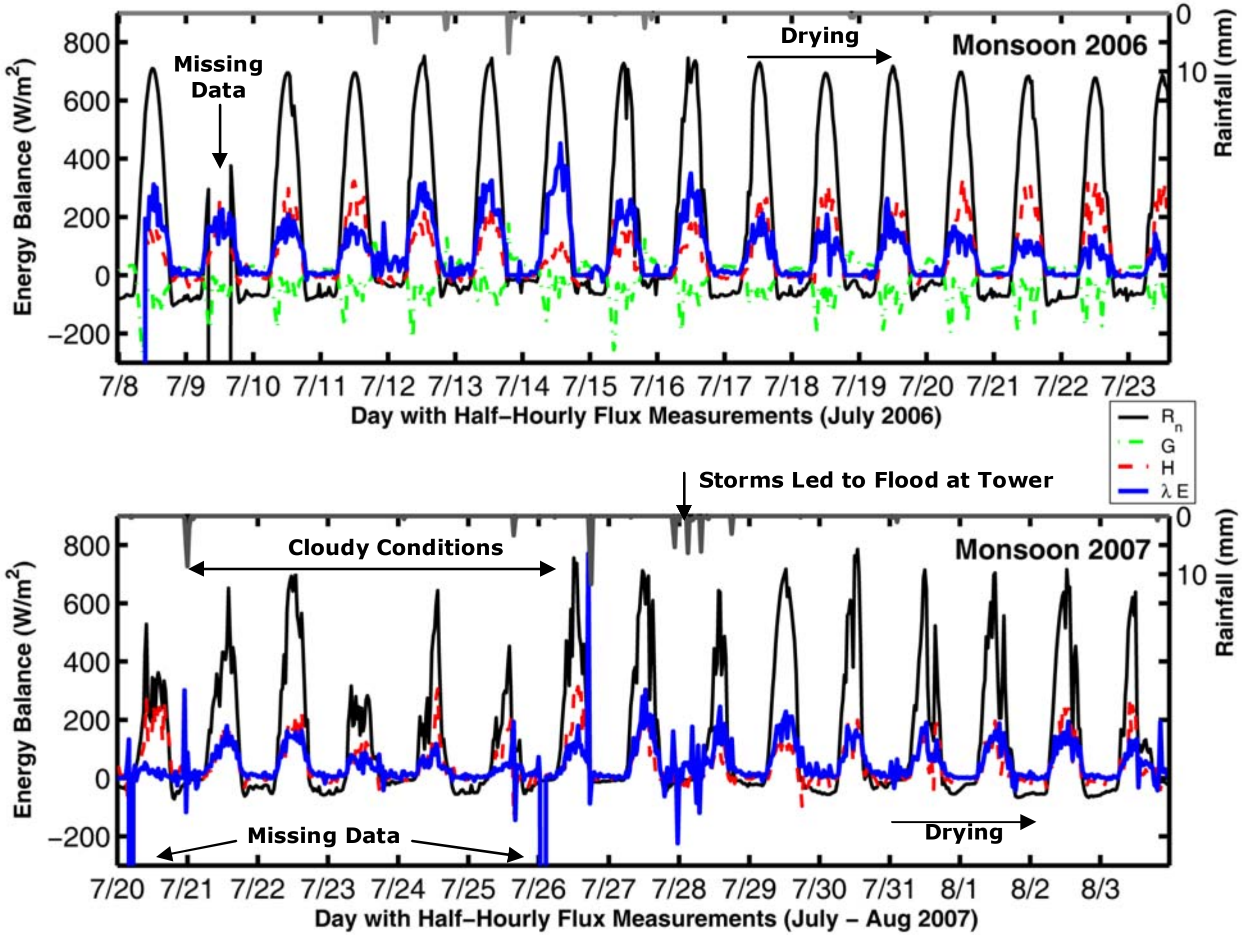
Sustained high EF due to Prolonged Rainfall Events

Increasing EF during start of Monsoon Season

- Marked *NDVI* greenup tied directly to precipitation temporal distribution.
- Good agreement between MODIS and Tower *albedo*, with decrease during monsoon.
- Evaporative Fraction (*EF*) sensitive to greenup and precipitation pulses.

Surface Fluxes

EC Tower Fluxes During Field Campaigns



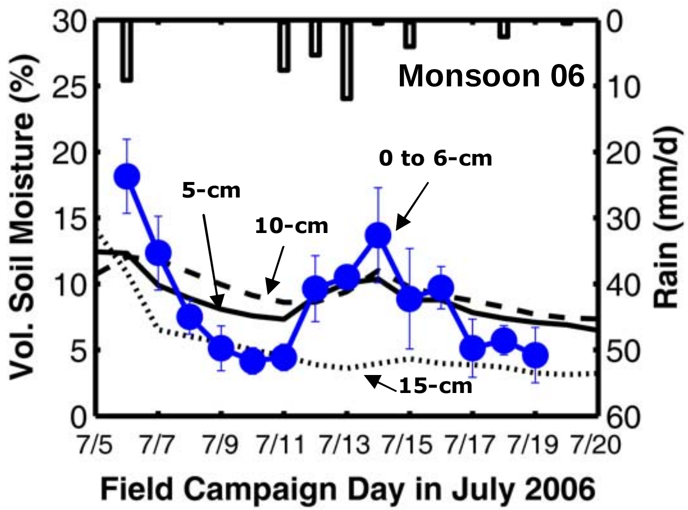
Convective Rainfall Occurring after Radiation Peak

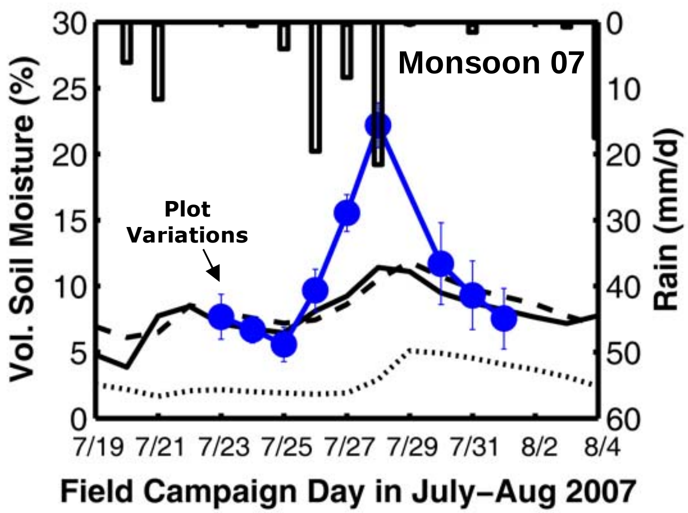
Stratiform Rainfall Occurring at Night or Early Morning

- Diurnal fluxes follow typical patterns for desert conditions with variable moisture.
- Increasing λE and decreasing H after precipitation pulses (vice-versa during drying).
- R_n, λE and H highly sensitive to cloudier conditions during 2007 period.

Tower Conditions

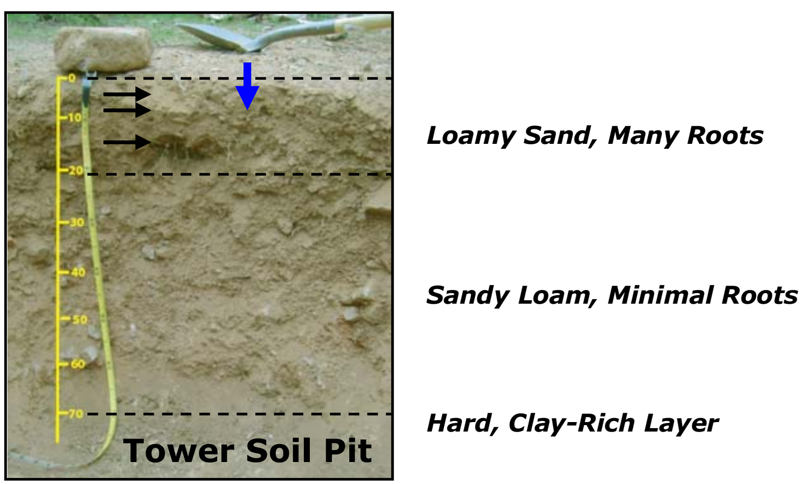
Comparison of Soil Moisture Estimates at Tower





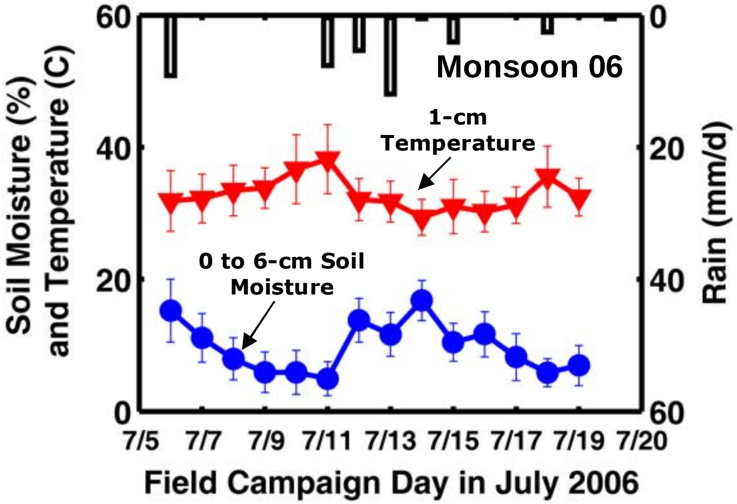
Soil Moisture Conditions at Eddy Covariance Tower Site

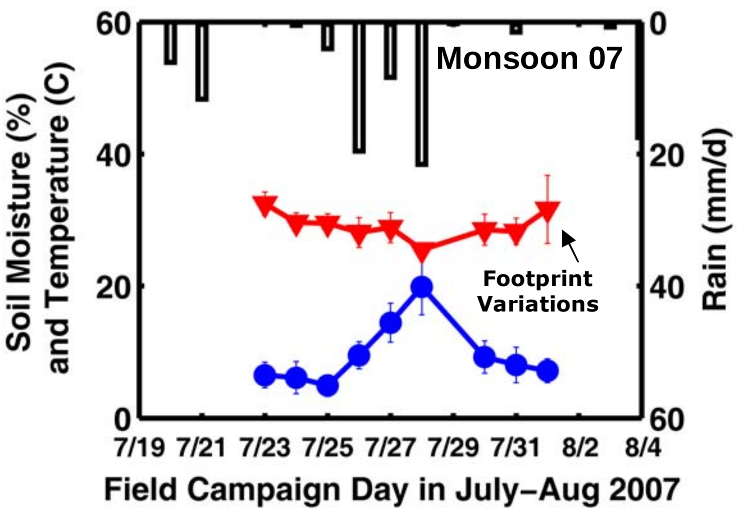
- Good agreement between continuous soil moisture estimates (Vitel sensor) and daily sampling (Theta probe).
  - 0-6 cm Theta probe
  - 5, 10 and 15 cm Vitel Hydra sensors
- Soil moisture variations with depth at the EC tower site suggest:
  - More dynamic surface layer (0 to 6 cm) captured by the Theta probe.
  - Less dynamic soil moisture for soil layers at depths of 15 cm and greater.



Footprint Conditions

Footprint-Averaged Soil Moisture and Temperature

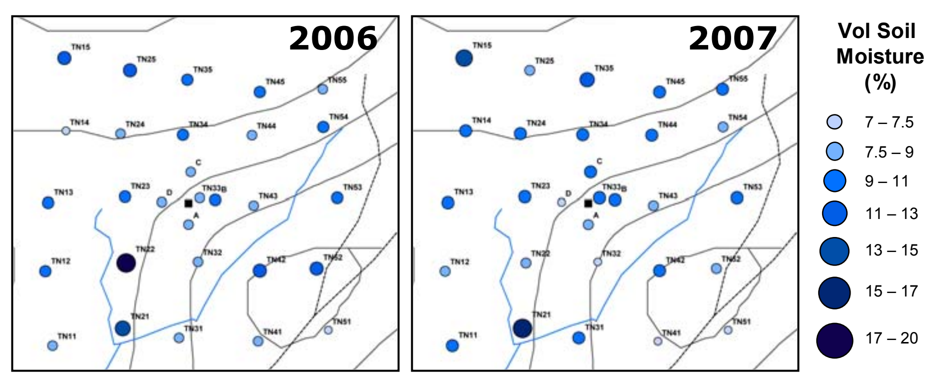




Footprint-Averaged Conditions at Eddy Covariance Tower Site

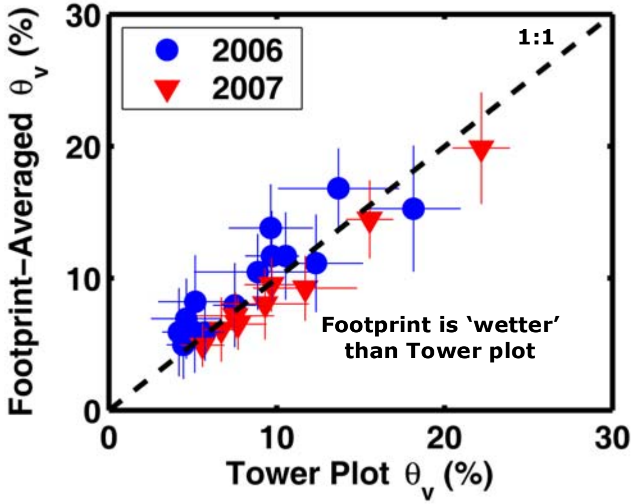
- Soil temperature and moisture in footprint follows rainfall forcing:
  - Greater spatial variation during 2006 due to stronger radiation forcing.
  - Large response to consecutive storms in 2007 lead to runoff production.
- Soil moisture and temperature exhibit spatial variations within footprint.
  - High soil moisture near channel and along steep, north-facing boundary.
  - Low soil moisture immediately around tower and along road.

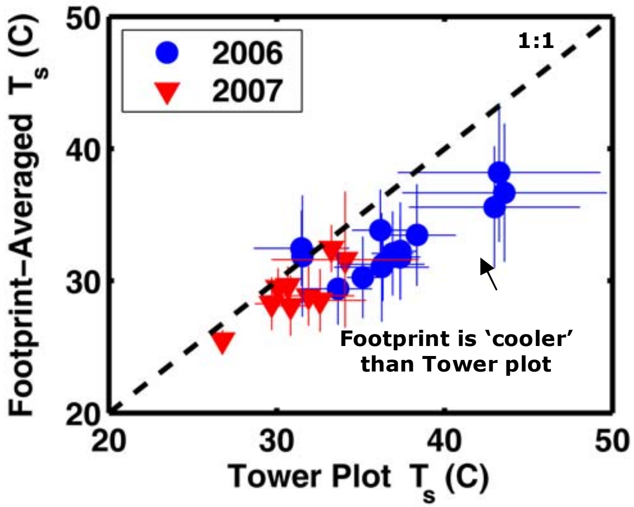
Temporal Mean Soil Moisture Field



Footprint Conditions

Comparison of Tower Plot and Footprint-Averages

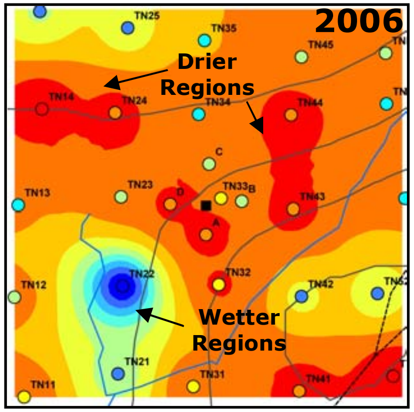


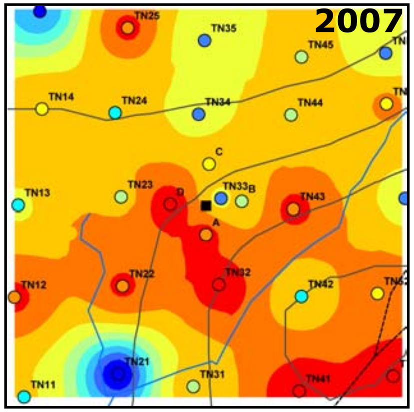


Land Surface Conditions in EC Tower Footprint and Tower Plot

- Footprint and tower plot surface states compared over range of conditions:
    - Footprint-average soil moisture is well represented at the tower site, but slightly higher values observed in 2006 at tower.
    - Footprint-average soil temperature deviates from tower site, exhibiting lower temperatures for both 2006 and 2007.
- Indicates that footprint 'averages' over sites exhibiting varying surface states.

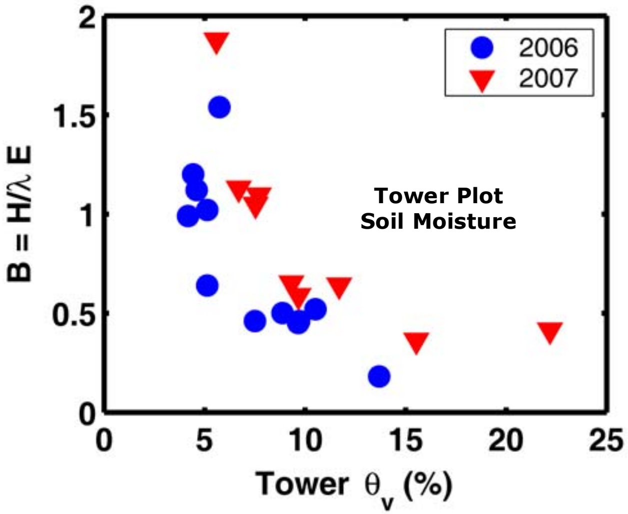
Soil Moisture Anomalies in Footprint

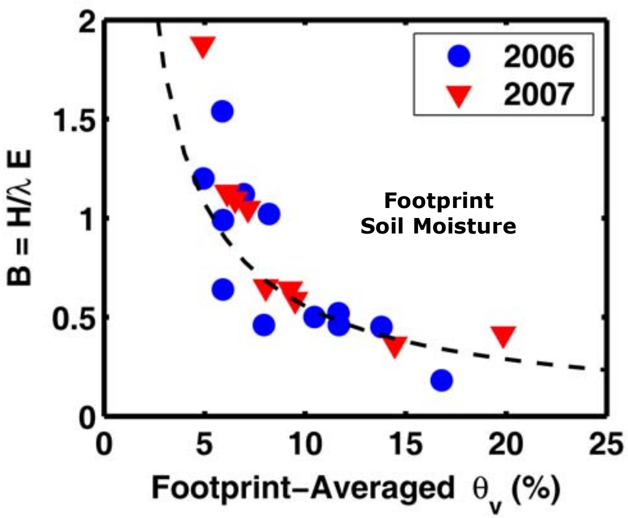




Evapotranspiration Controls

Relations Between Bowen Ratio and Soil Moisture Conditions





Soil Moisture Control on Radiation Partitioning at EC Tower

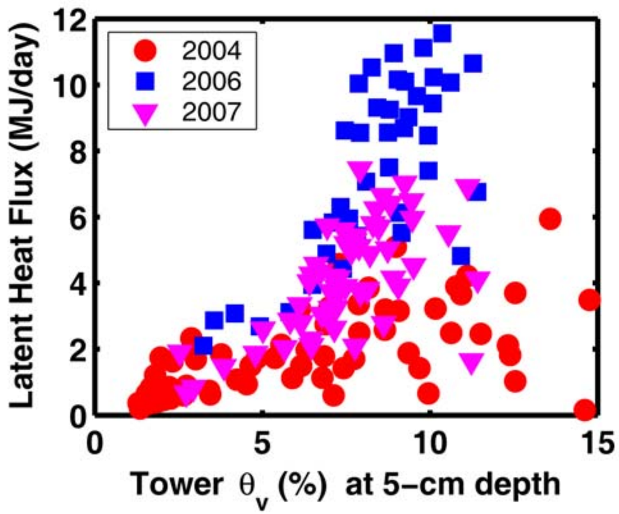
- Strong impact of soil moisture on the measured Bowen Ratio ($B = H/\lambda E$).
  - Decrease in *B* with increasing soil moisture, implying more evapotranspiration.
- Footprint-average conditions capture the relation better than tower plot observations
  - Implies that soil moisture in the footprint is more directly related to the turbulent fluxes.
  - Power-law relation suggested between *B* and footprint-averaged θ: $B = 4.95\theta^{-0.95}$ ($R^2 = 0.6$)

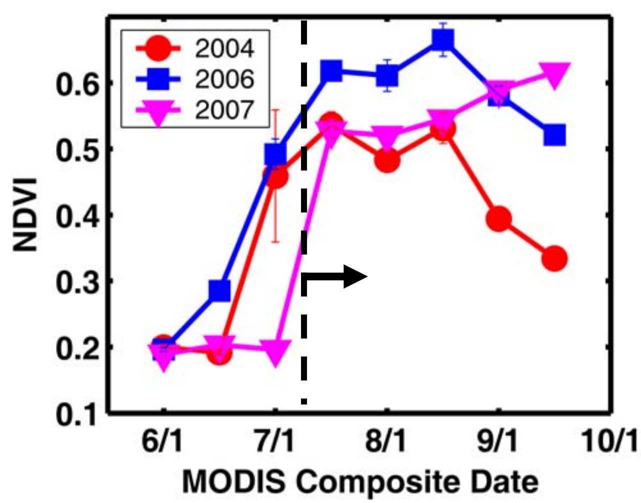
Bowen Ratio Statistics at EC Tower

	2004 JD 199-276	2006 JD 189-228	2007 JD 186-240
B_{mean}	3.21	0.82	1.84
B_{std}	3.30	0.97	2.42
B_{max}	18.16	3.58	12.95
B_{min}	0.03	0.10	0.08

Evapotranspiration Controls

Phenological Controls on ET-Soil Moisture Relation





ET-Soil Moisture Relation varies over different Monsoon Seasons

- ET-soil moisture relation computed for 2004, 2006 and 2007 based upon:
  - Tower soil moisture sensor (surface, 5-cm depth) and EC measurements over periods:
    - 2004: JD 205 – 275 (July 23 – Sept 31)
    - 2006: JD 189 – 228 (July 8 – Aug 16)
    - 2007: JD 186 – 240 (July 6 – Aug 28)
- Functional form of the ET-soil moisture relation varies in this ecosystem.
  - Years with high greeness (2006) show more *ET* for a soil moisture value. Higher ET_{max}.
  - Years with low greeness (2004) show less *ET* for a soil moisture amount. Lower ET_{max}.
- ET-soil moisture relations that vary with plant phenology would be useful for:
  - Understanding plant-water interactions
  - Land surface model parameterizations
  - Using vegetation indices as a ET predictor

Conclusions and Remarks

<u>Hydrology and Surface Fluxes in NAMS Ecosystem:</u>

1. NAMS leads to large changes in surface characteristics as observed at EC tower and from remote sensing data.

   Vegetation greening impacts the albedo and partitioning of surface turbulent fluxes over a range of monsoon seasons.

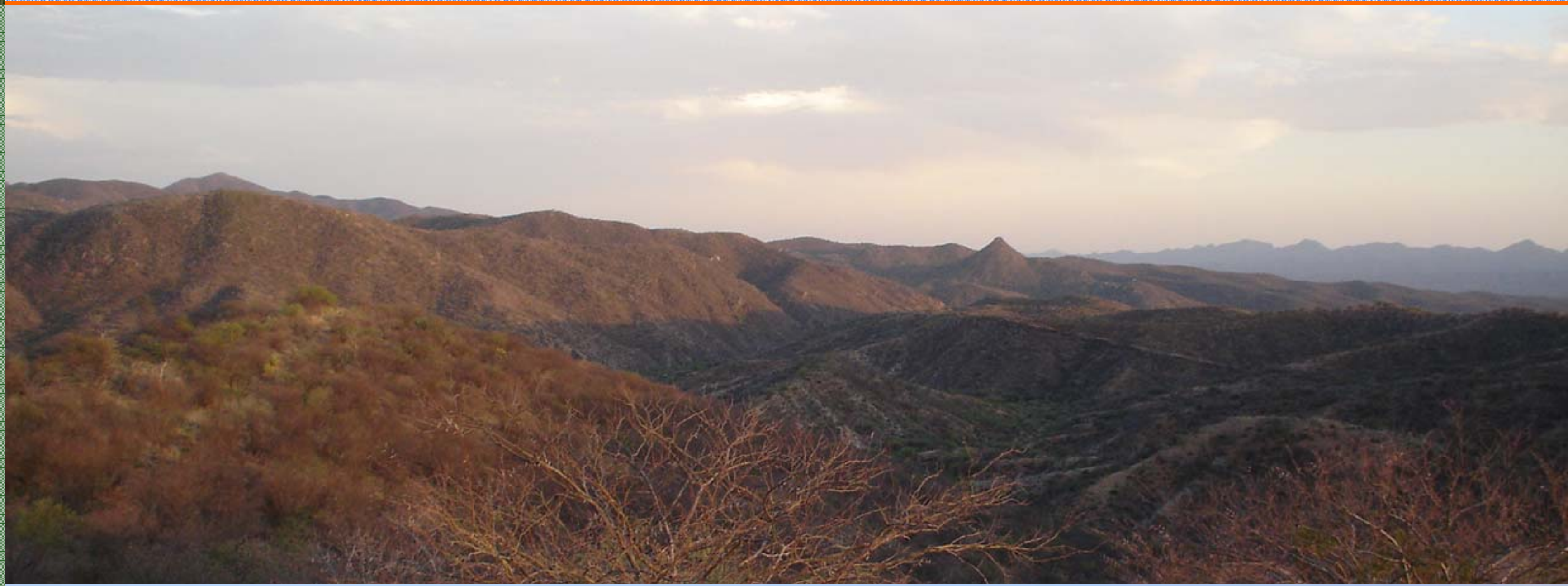
2. Land surface conditions in eddy covariance tower footprint vary from those measured directly at the tower site.

   Footprint sampling allows estimation of the spatiotemporal variations in soil moisture and temperature impacting fluxes.

3. Partitioning of surface fluxes is dependent on the footprint average soil moisture and varies with vegetation phenology.

   Interannual variations in vegetation phenology and soil moisture conditions greatly impact ET and Bowen Ratio.

A Seasonally-Green Desert Landscape



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