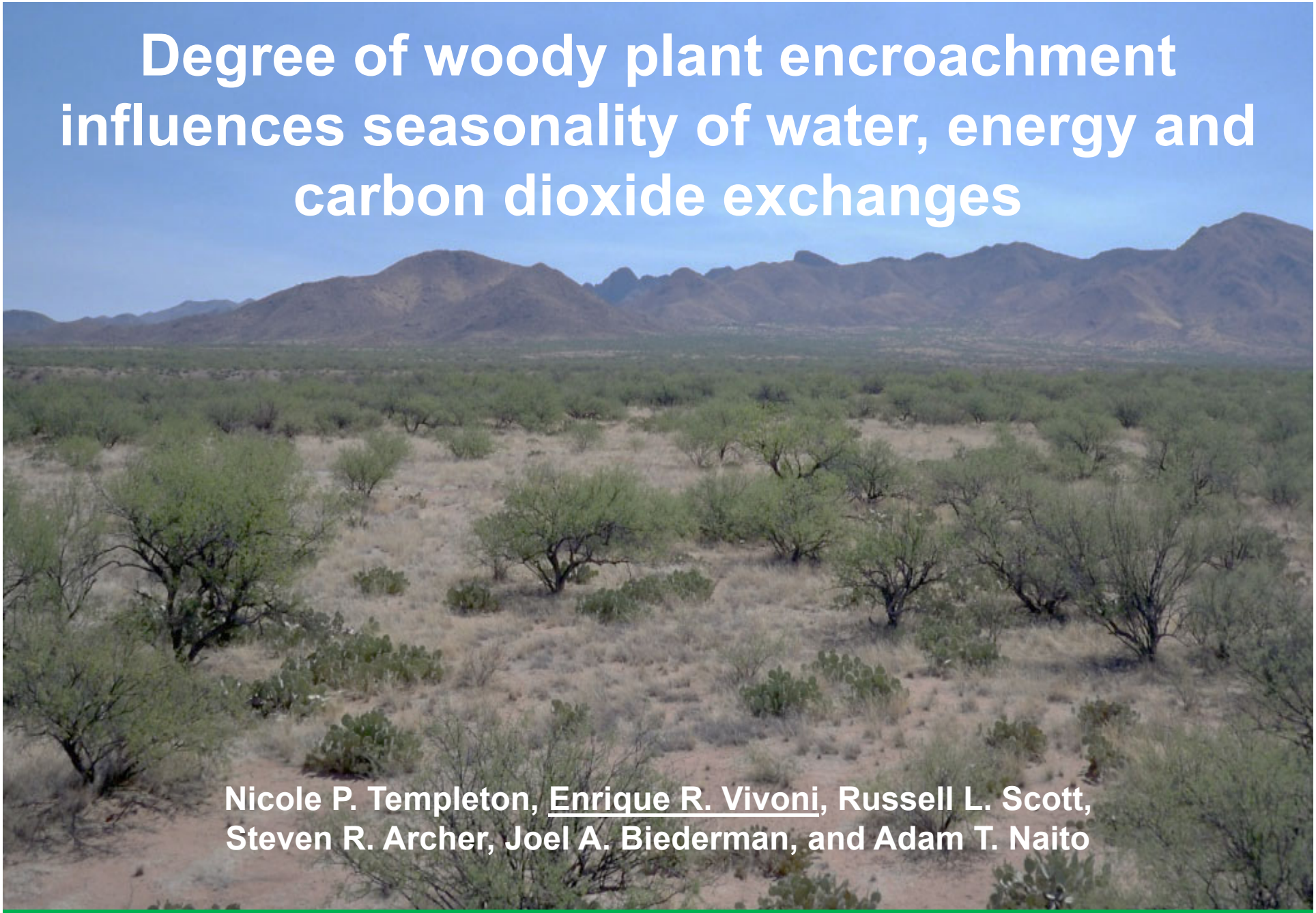
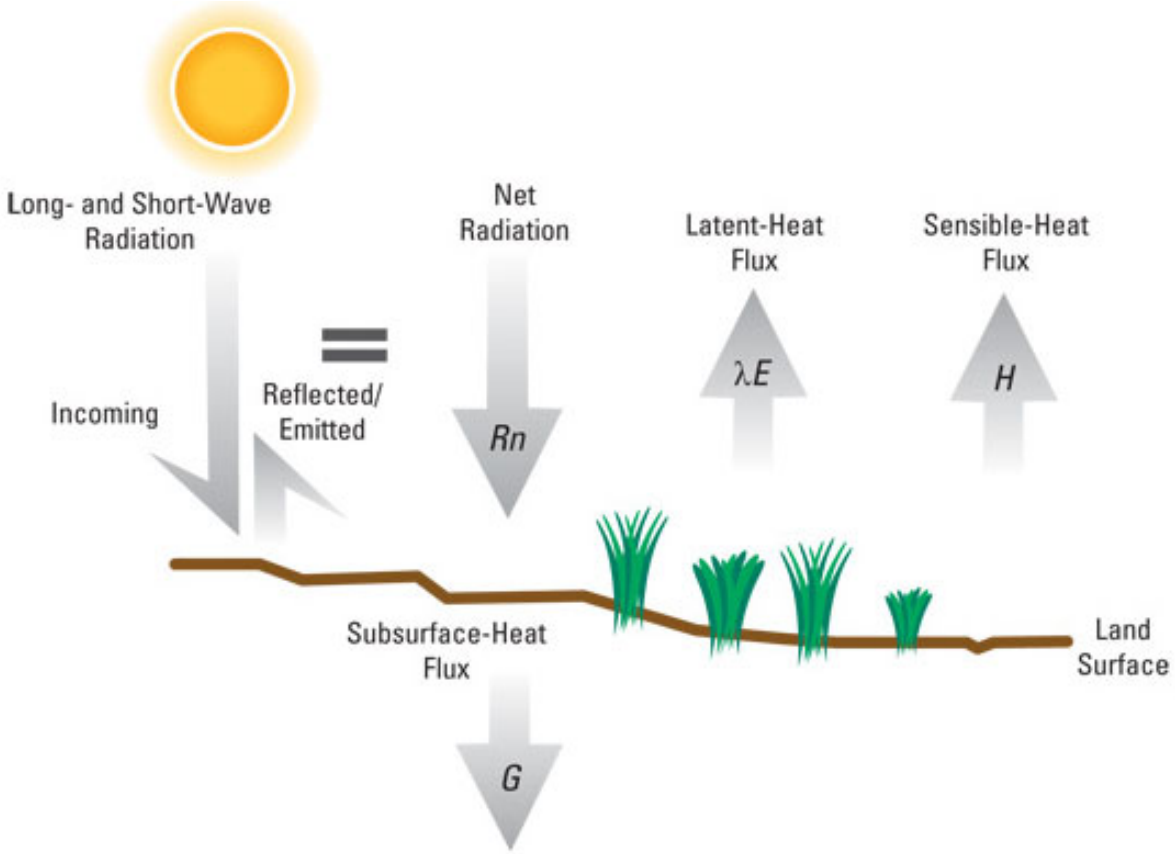
Degree of woody plant encroachment influences seasonality of water, energy and carbon dioxide exchanges



Nicole P. Templeton, Enrique R. Vivoni, Russell L. Scott,
Steven R. Archer, Joel A. Biederman, and Adam T. Naito

Energy Fluxes



$$R_n = SW_{in} + LW_{in} - SW_{out} - LW_{out}$$

$$R_n - G = H + LE$$

Radiative fluxes:

R_n = Net Radiation

$SW_{in/out}$ = Incoming/Outgoing Shortwave Radiation

$LW_{in/out}$ = Incoming/Outgoing Longwave Radiation

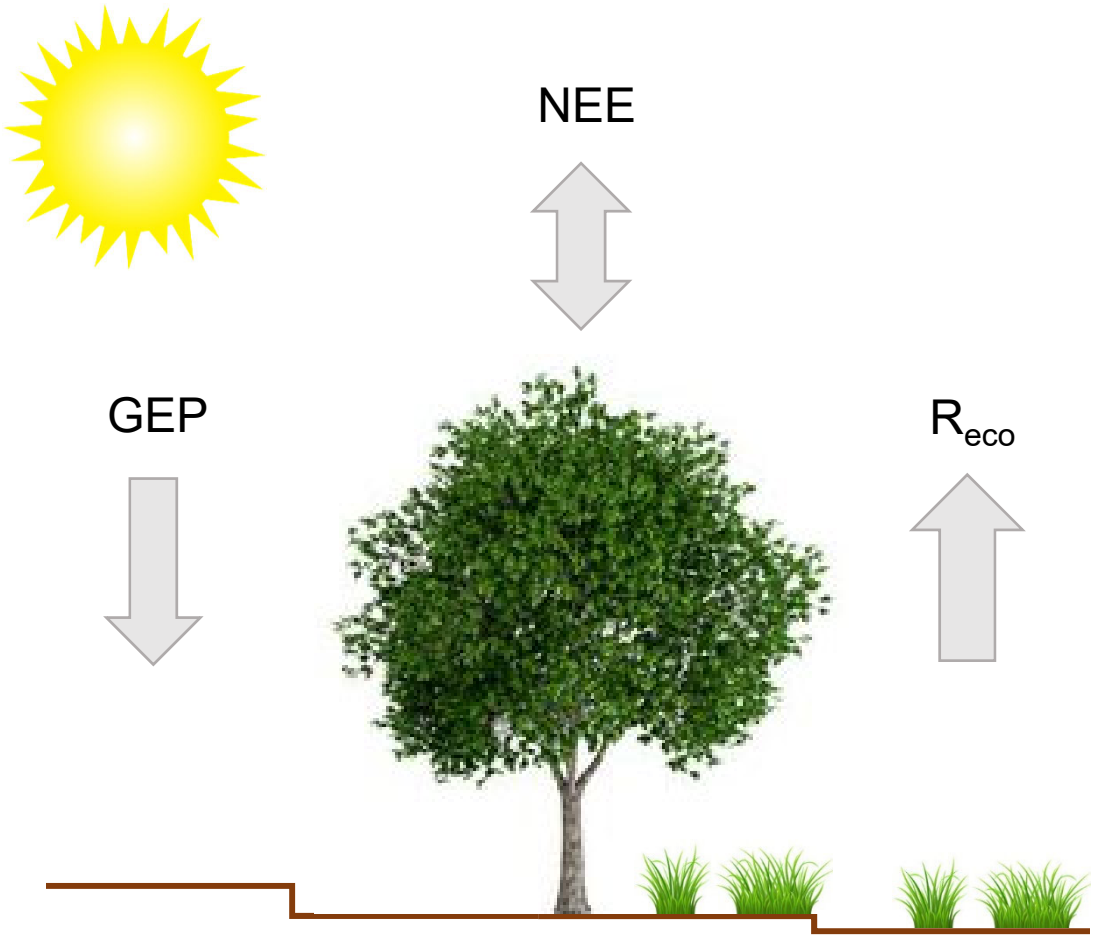
G = Ground Heat Flux

Turbulent fluxes:

H = Sensible Heat Flux

LE = Latent Heat Flux

Carbon Dioxide Fluxes



NEE = Net Ecosystem Exchange

R_{eco} = Ecosystem Respiration

GEP = Gross Ecosystem Production

$NEE = R_{eco} - GEP$

If NEE < 0, CO_2 uptake

If NEE > 0, CO_2 release

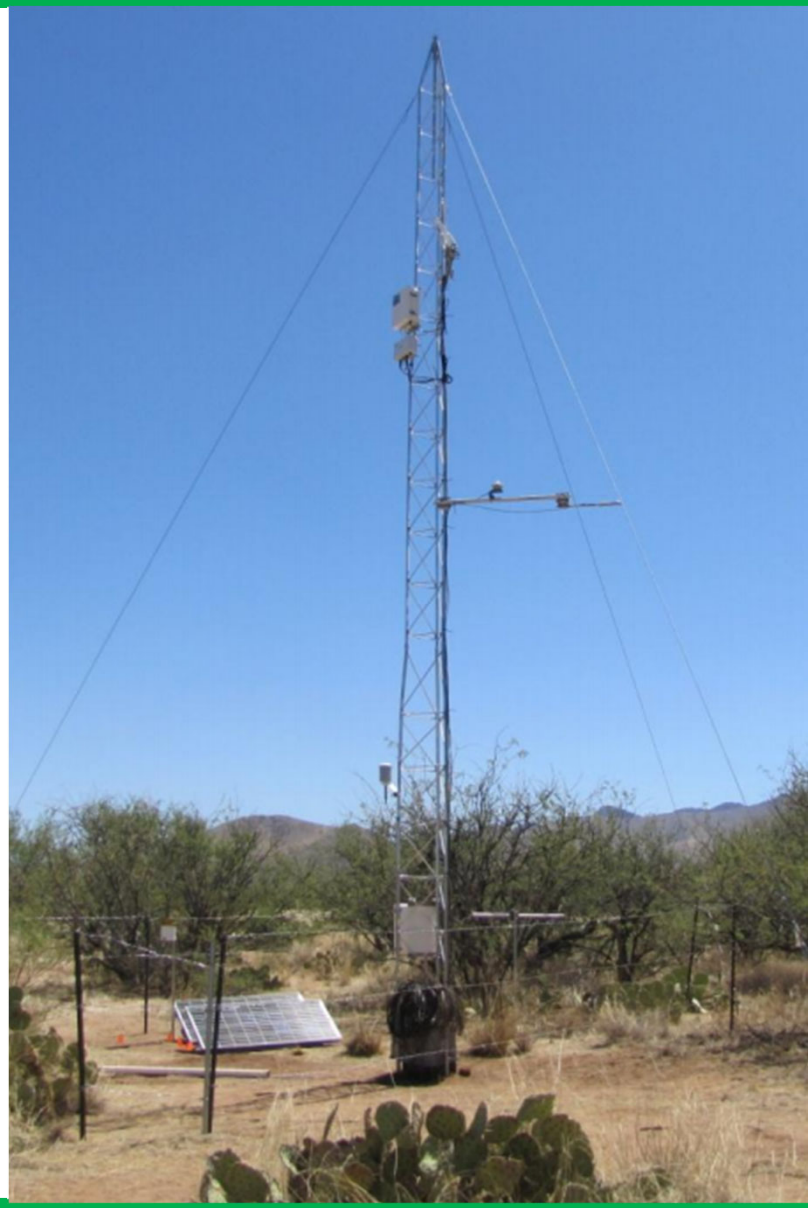
Eddy Covariance Method

Eddy Covariance Measurements:

- Infrared gas analyzer: Gas Concentrations (H_2O, CO_2)
- Sonic anemometer: 3D Wind Direction and Velocity (*u*, *v*, and *w*)
- Data is sampled at very high frequencies (10 to 20 Hz).

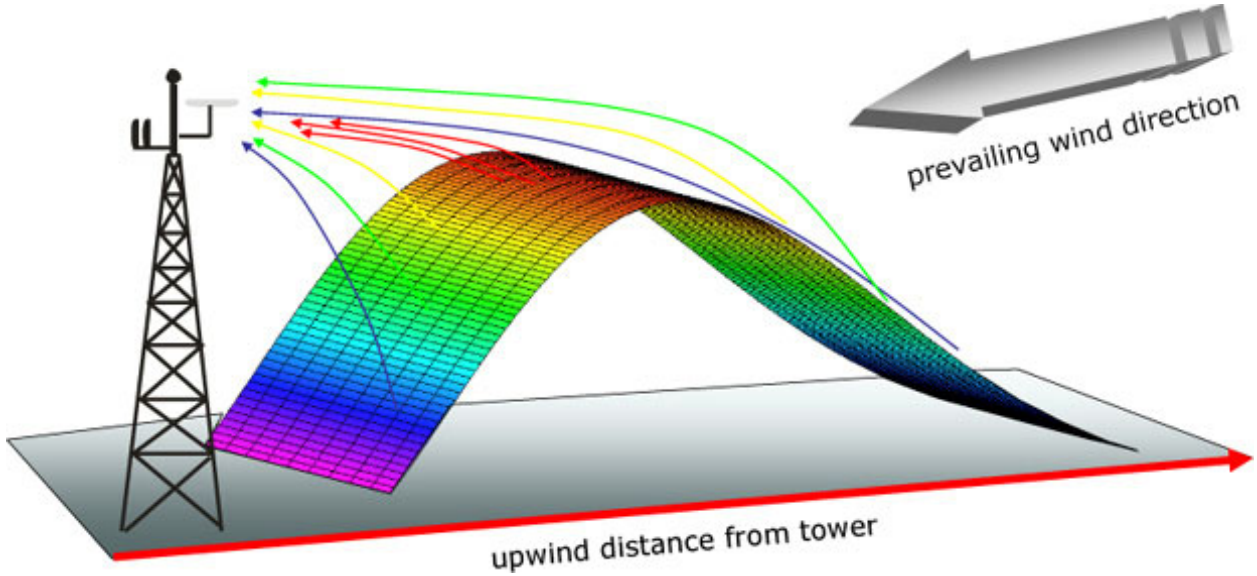
Meteorological Measurements (at 30 min):

- Air Temperature
- Relative Humidity
- Barometric Pressure
- Net Radiation
- Rainfall
- Surface Temperature
- Soil moisture
- Soil temperature
- Ground heat flux



Eddy Covariance Method

Eddy Covariance Technique: Calculate covariance between the concentration of interest and vertical wind speed (w') in the eddies



$$H = \rho_a C_P \overline{w'\theta'}$$

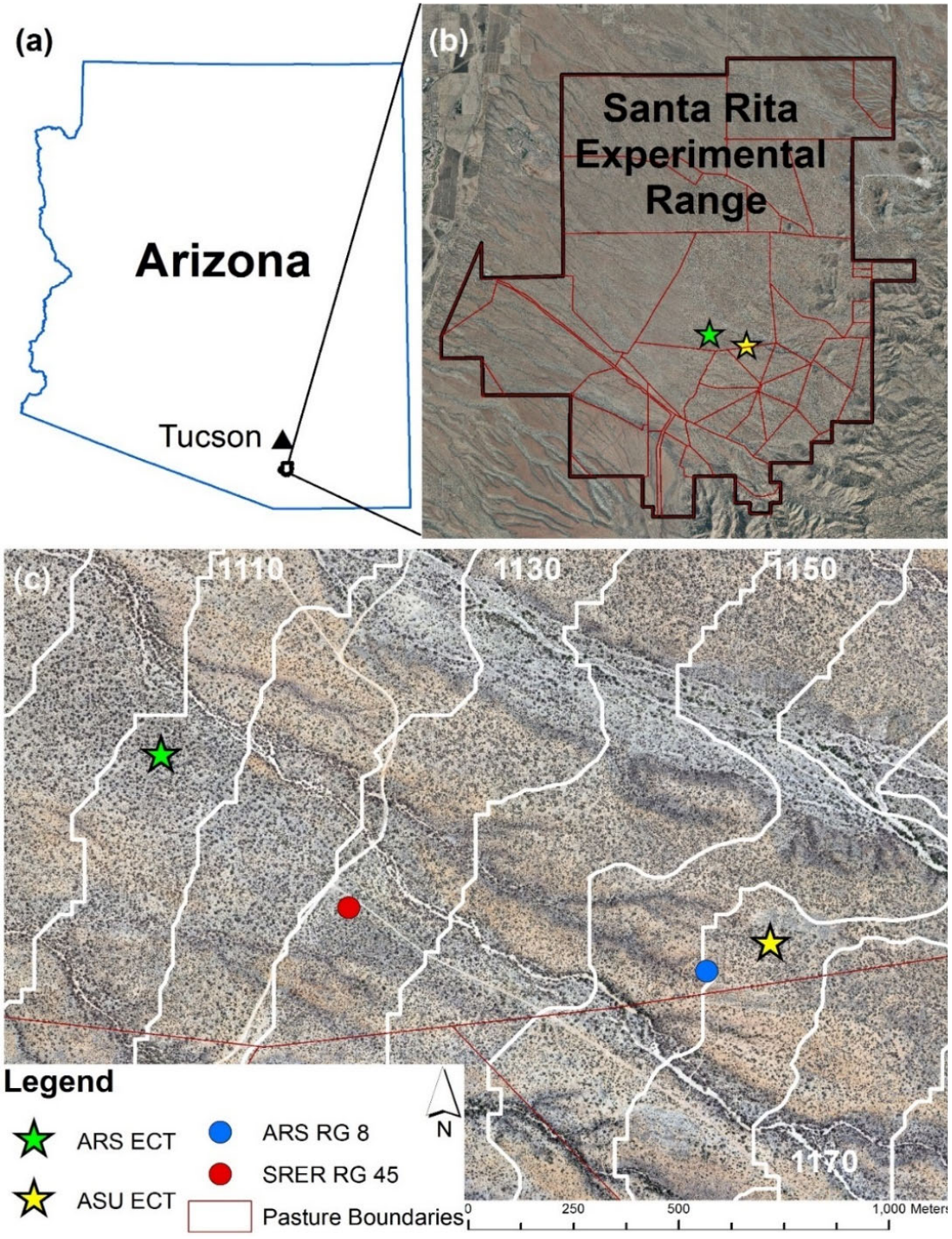
$$LE = \rho_a \lambda \overline{w'q'}$$

$$F_C = \overline{w'\rho_C'}$$

- The flux source area is an upwind area where the atmospheric flux measured by the instruments is generated.
- The flux source area depends on the height of the instruments, the surface roughness and thermal stability.

Site Descriptions

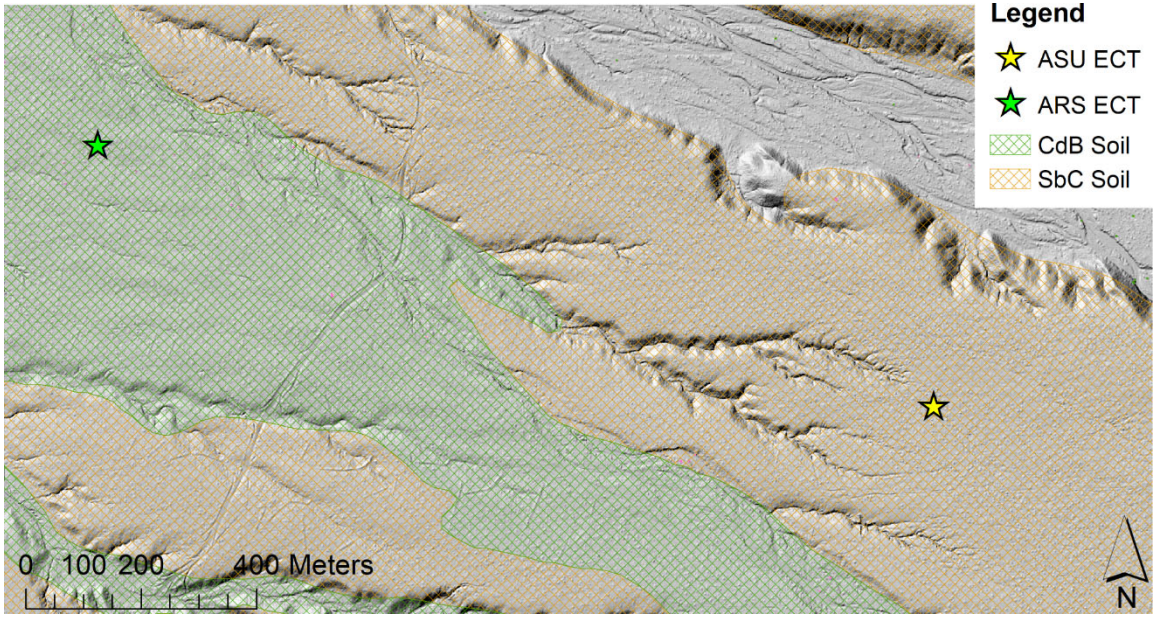
- ARS ECT established in 2004 (*Scott et al.*, 2009), elevation of 1,116 m.
- ASU ECT established in May 2011 (*Pierini et al.*, 2014), elevation of 1,168 m.
- Primary land use is grazing – both sites lie within the same pasture.
- Comparisons from July 1, 2011 to June 15, 2016.



Site Descriptions

Soil Differences:

- ARS: Combate-Diaspar complex (CdB) – drains well, sandy loam textures, alluvial channel deposits.
- ASU: Sasabe-Baboquivari complex (SdC) – less well drained sandy clay and sandy clay loam, characteristic of an alluvial fan terrace.



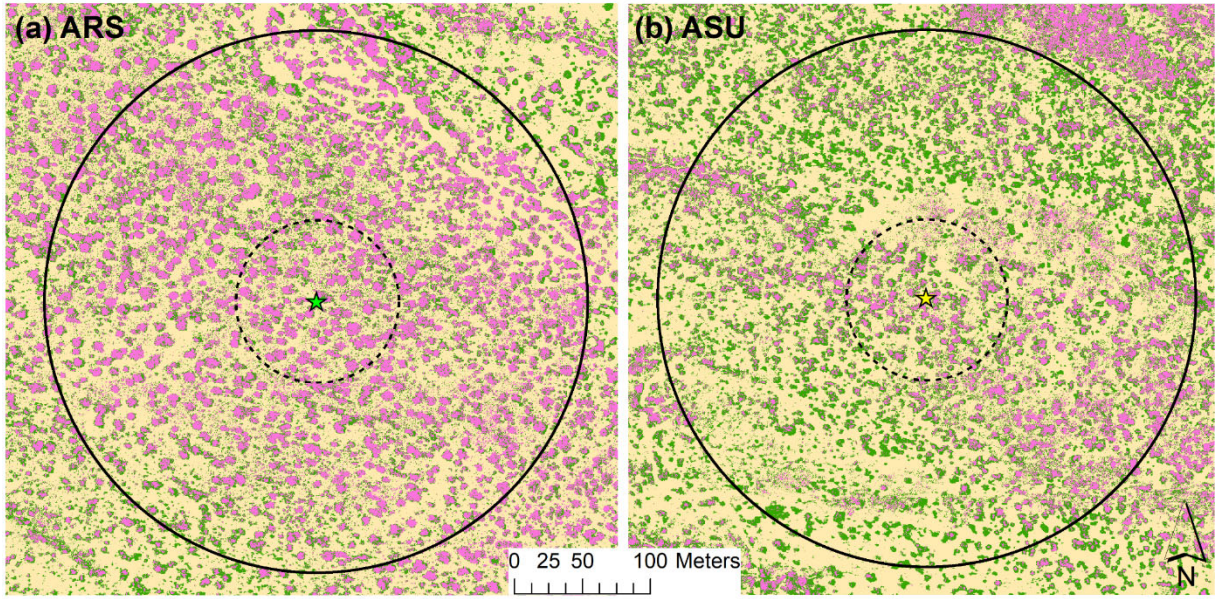
Soil Survey: Breckenfield and Robinett, 2003

Disturbance Histories:

- Area around ASU tower was treated for mesquite in 1974 via basal application of diesel oil.
- ASU tower was affected by a fire on June 2, 1994 that burned 4000 ha in SRER.
- ARS tower area remained undisturbed during these two events.

Image Classification and Vegetation Transects

LiDAR (Light Detection and Ranging) flight took place April 2011. Obtained a 1 foot resolution orthoimage.



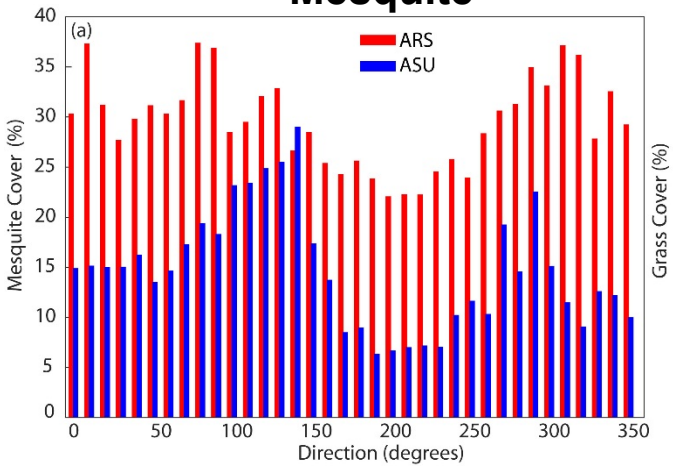
- Processed orthoimage using maximum likelihood classification method in ArcGIS 10.4.
- Verified classification with vegetation transect data from June 2014 (ARS) and November 2015 (ASU).

Vegetation Classification	ARS (%) *60 m*	ASU (%) *60 m*	ARS (%) *200 m*	ASU (%) *200 m*
Mesquite	34 (35)	20 (21)	**30**	15
Grass	17 (15)	23	18	**25**
Bare (Soil)	49 (50)	57	52	**60**

Mesquite Height Frequency Distribution	ARS (%)	ASU (%)
0 to 0.5 m	47	60
0.5 to 1.0 m	9	11
1.0 to 2.0 m	21	19
2.0 to 4.0 m	30	9
4.0 to 6.0 m	3	1

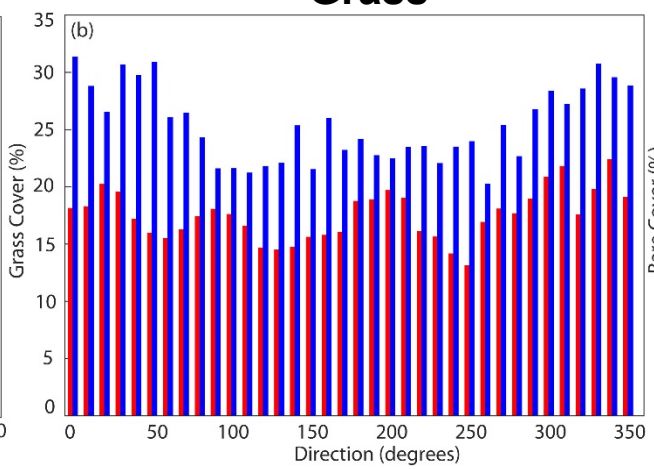
Vegetation Classification and Patterns

Mesquite



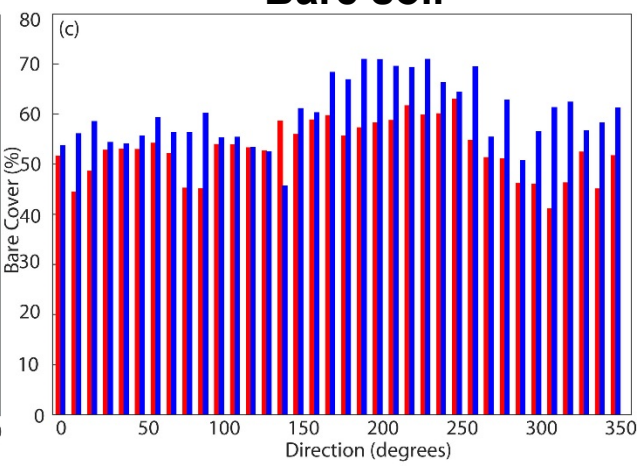
ARS CV = 15.2%
ASU CV = 40.2%

Grass



ARS CV = 12.4%
ASU CV = 12.9%

Bare soil

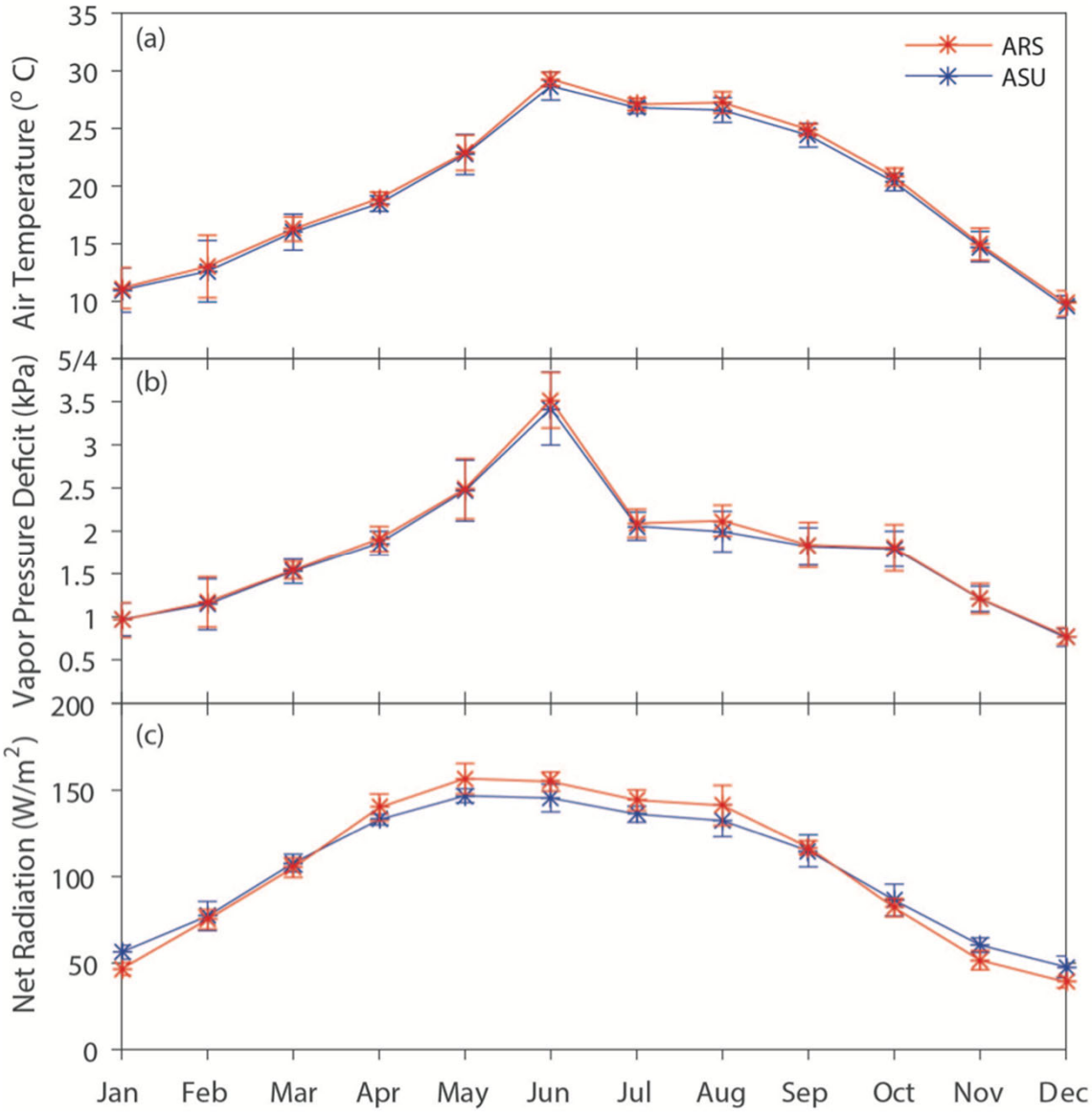


ARS CV = 10.4%
ASU CV = 10.8%

Evaluated spatial variation of vegetation distribution radially (200 m) around each tower in 10° bins, using coefficient of variation (CV).

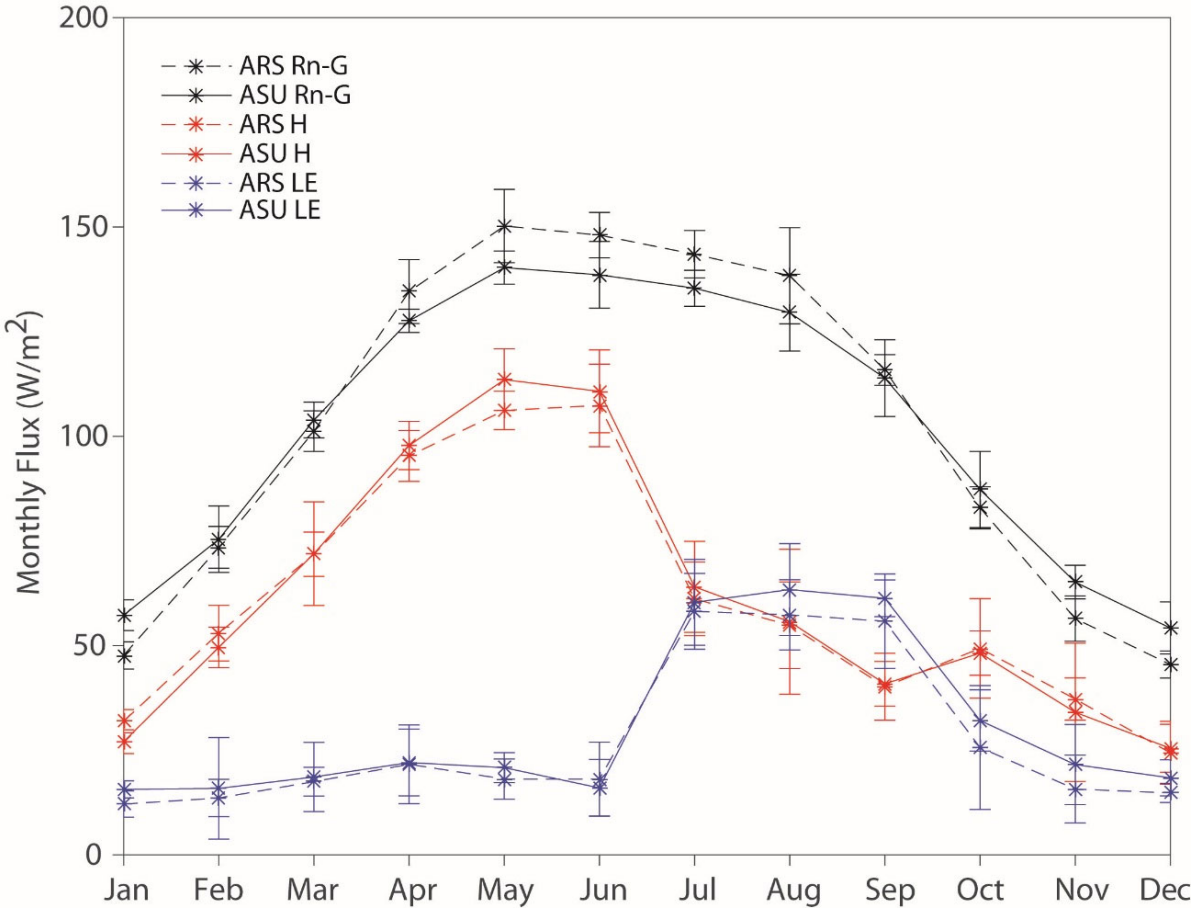
- Greater variability in mesquite cover.
- Lower amounts of mesquite at ASU ECT lead to higher grass and bare soil cover.
- Spatial heterogeneity is dominated by spatial patterns of mesquite trees.

Comparisons of Meteorological Variables



- Air temperature and VPD are similar between the two sites, with small elevation effect.
- Net radiation is larger at ARS ECT and there is a small shift.
- Warm season (April to August), ARS has higher net radiation, likely due to higher mesquite cover, which reduces albedo and shades the surface.
- In the cool season (October to March), grasses fill in bare soil areas, and Rn is greater at ASU ECT.

Turbulent Flux Comparisons



- Available energy (R_n – G) peaks in May, with higher amounts in ARS ECT.
- H peaks in May/June, while LE peaks during monsoon.
- LE is greater at ASU ECT, particularly from Aug. to Jan., due to higher grass cover.

Water Flux Differences

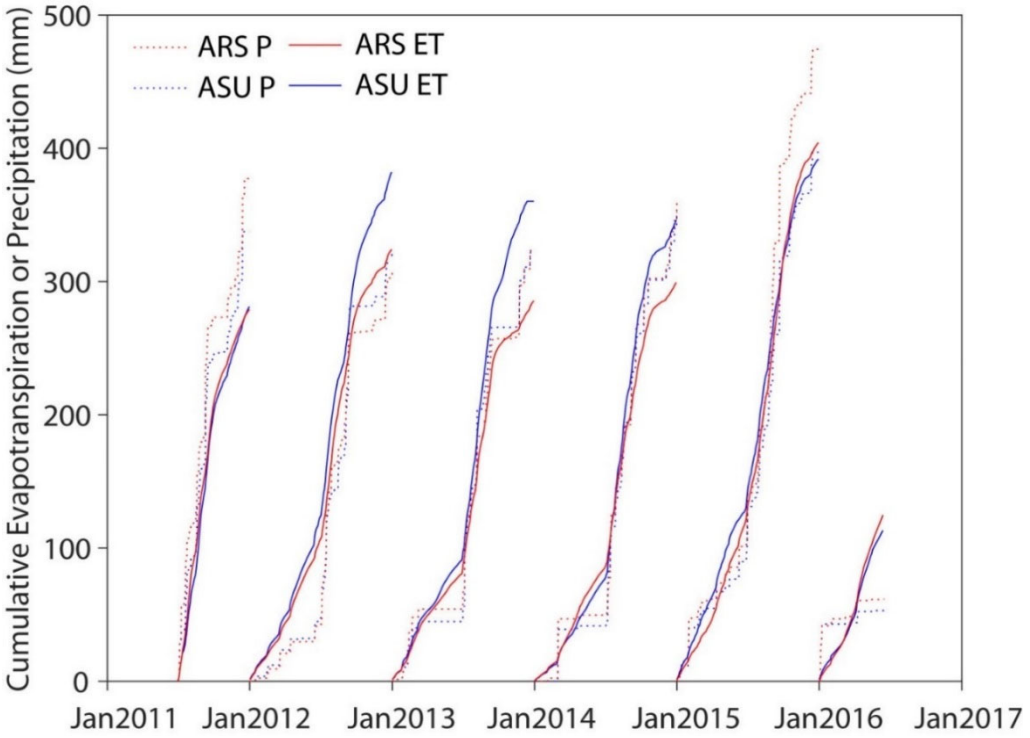
	Cumulative Precipitation (mm)	
	ARS ECT	**ASU ECT**
2011*	377.44	337.57
2012	307.08	322.28
2013	323.34	321.95
2014	359.42	352.04
2015	474.47	397.14
2016*	54.36	53.21

* Indicates partial year

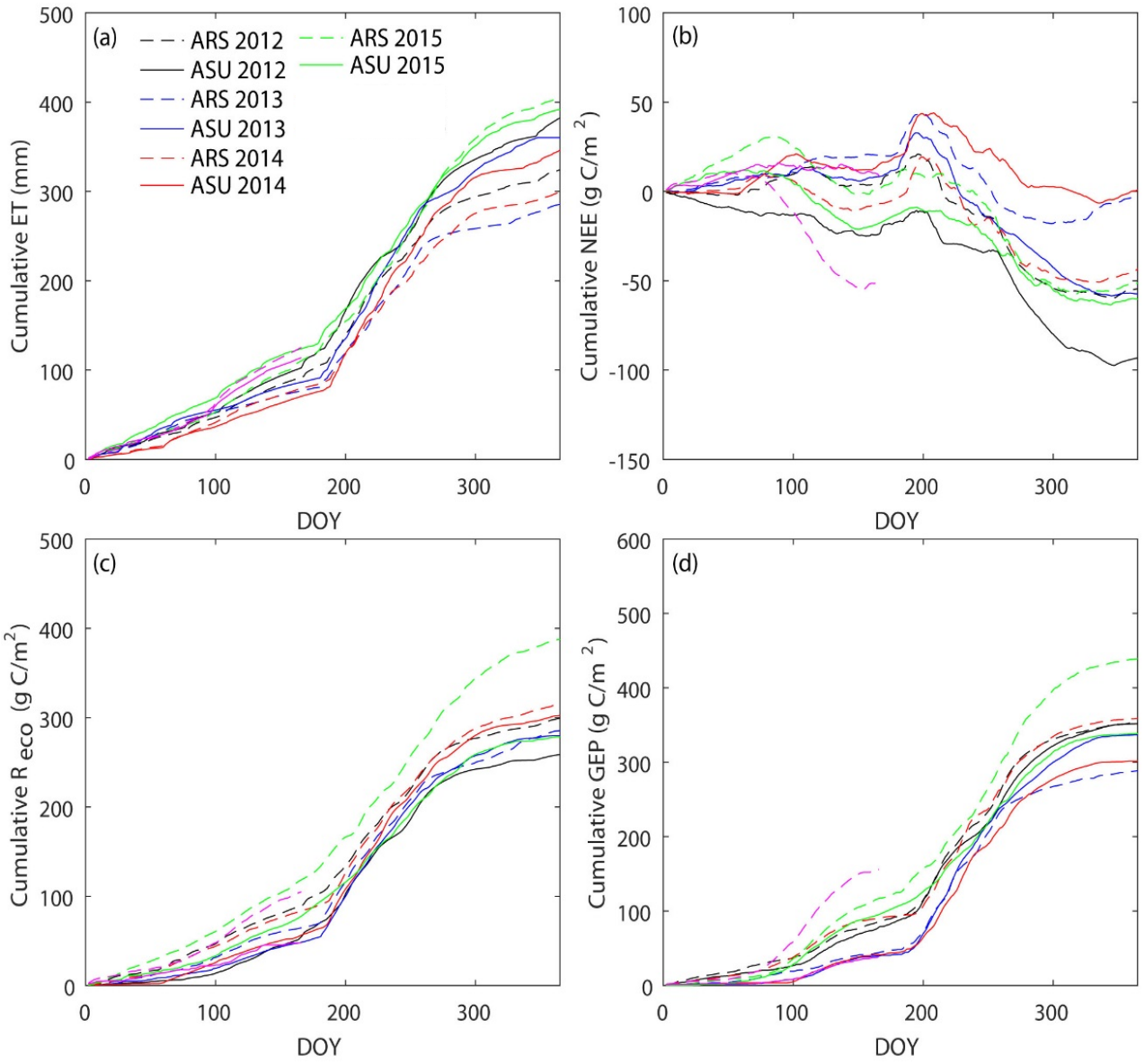
- Bimodal precipitation pattern: winter (longer duration, low intensity) and summer (more frequent, short duration, high intensity during monsoon)

- Generally, ASU ECT has higher annual ET, with the exception of 2015 (substantially more rain at ARS ECT).
- Differences occur after NAM onset, due to increased grass cover at ASU.

ET/P Ratio	**ARS**	**ASU**
2012	1.06	1.19
2013	0.90	1.12
2014	0.83	0.98
2015	0.85	0.99

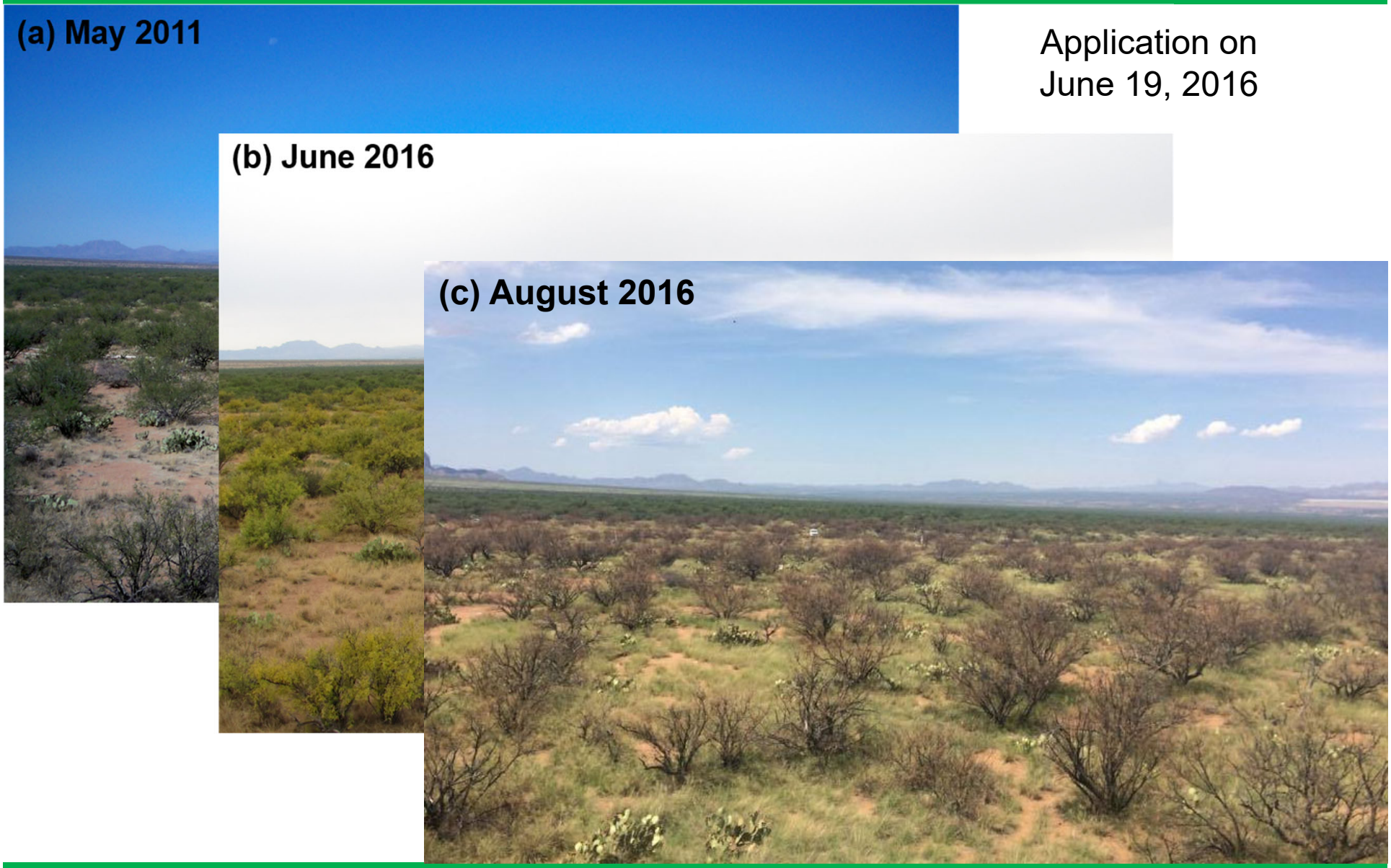


Carbon Flux Differences



- NEE patterns reflect mesquite putting on leaves in April (period of carbon uptake), onset of NAM in July (release of carbon), quickly followed by landscape greening and carbon uptake.
- Cumulative NEE varies from year to year.
- R_{eco} is always higher at ARS ECT.
- GEP is also always higher at ARS ECT, with the exception of 2013.

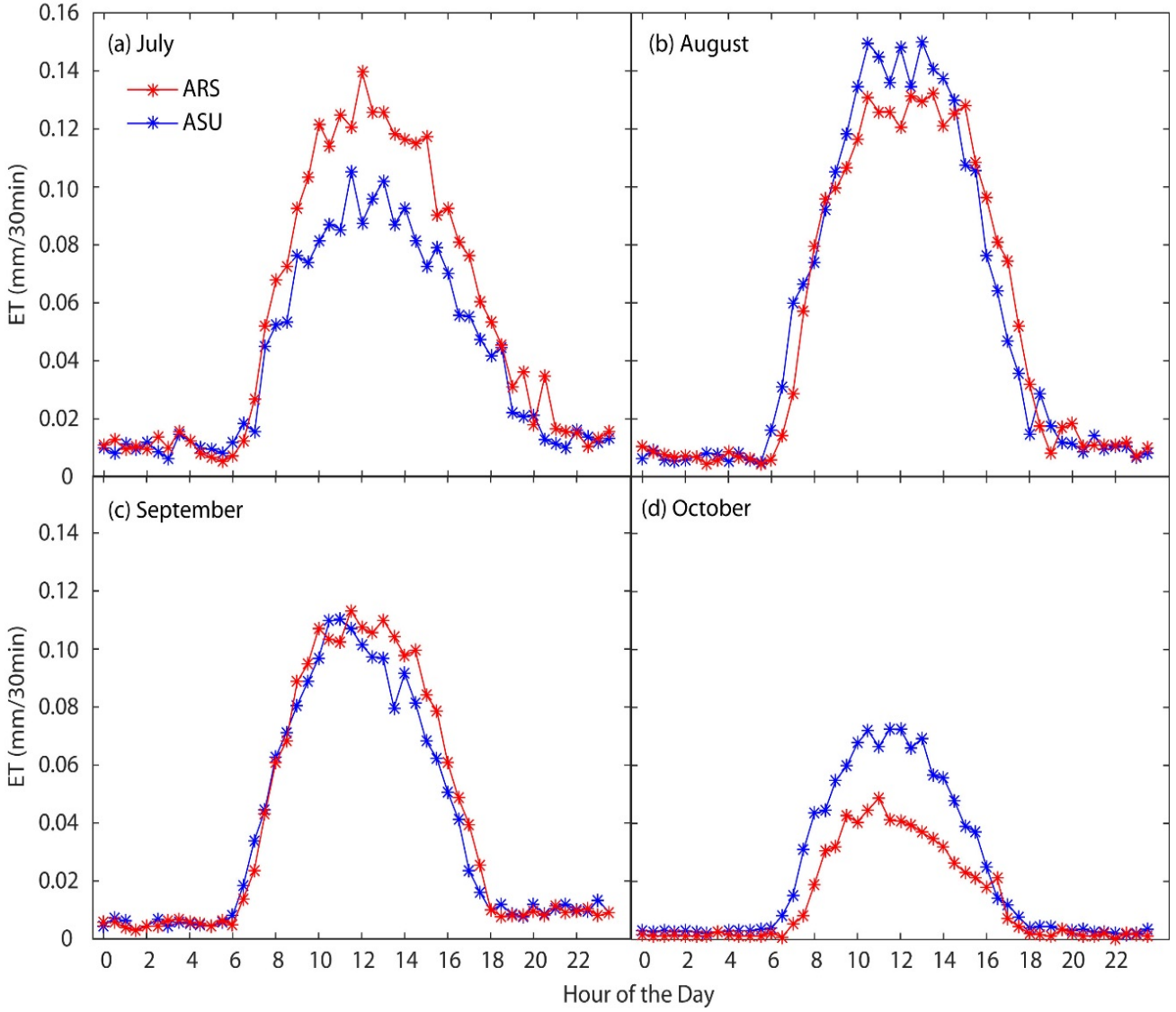
On-going Work: Long-term Effects of Herbicide Treatment



Application on
June 19, 2016

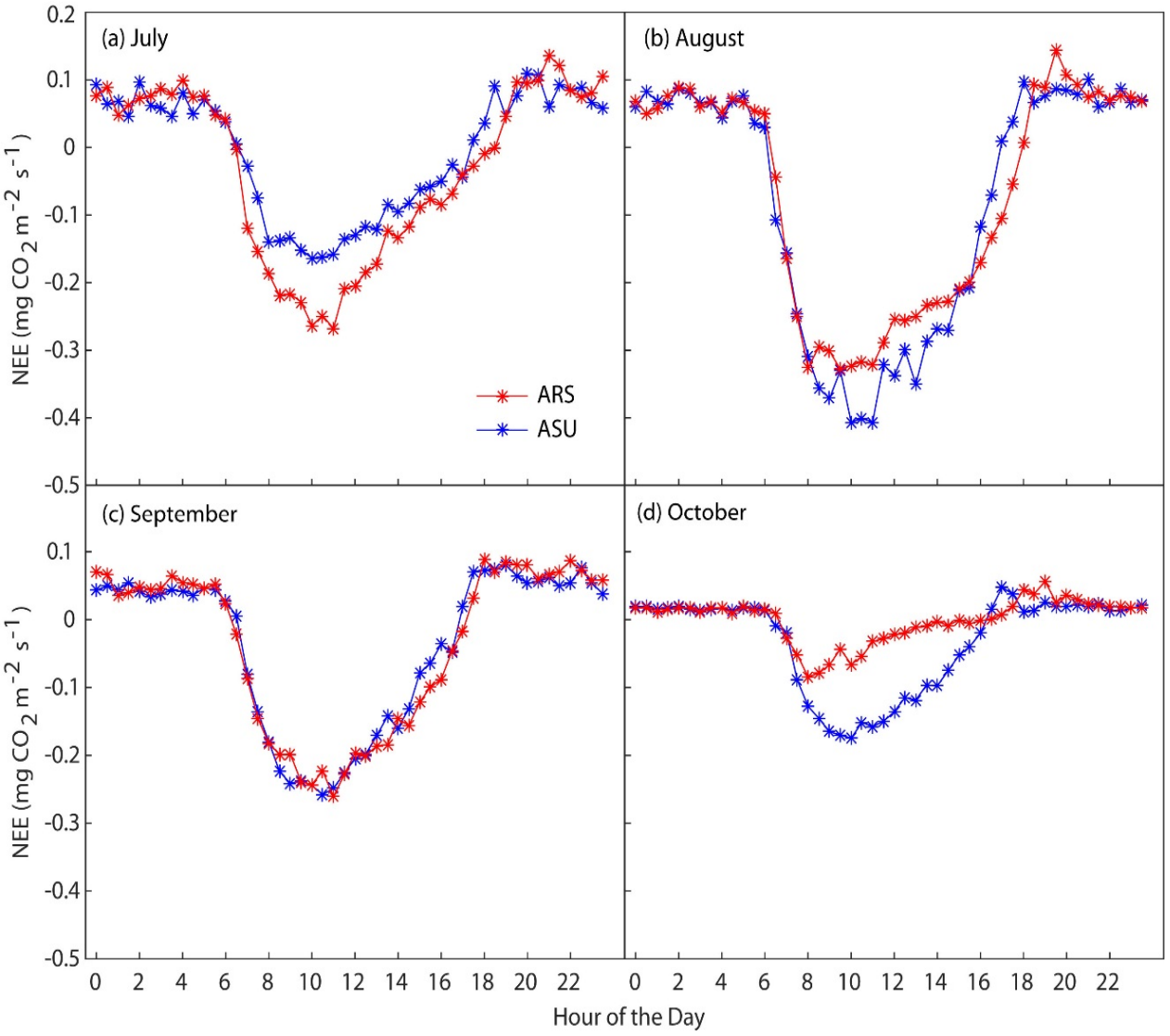
Diurnal Flux Variability, Post-Treatment in 2016

- ARS has higher ET in July, due to reduced mesquite at ASU but low grass cover.
- ET is similar in August and September 2016.
- ASU has higher ET in October, likely due to higher grass cover and mesquite leaves beginning to yellow.



Diurnal Flux Variability, Post-treatment in 2016

- ARS has more carbon uptake in July, likely due to greater mesquite cover.
- ASU and ARS have similar patterns in August and September.
- By October, ASU has more carbon uptake, likely due to higher grass cover and mesquite leaves beginning to yellow.



Annual Water and Carbon Flux Comparisons

	P (mm)		ET (mm)		NEE (g C/m^2)		R_{eco} (g C/m^2)		GEP (g C/m^2)	
	ARS	**ASU**	**ARS**	**ASU**	**ARS**	**ASU**	**ARS**	**ASU**	**ARS**	**ASU**
2011*	377.4	337.6	279.2	281.2	-80	-45	219	191	299	236
2012	304.8	322.3	324.1	382.2	-55	-93	299	259	354	352
2013	318.3	322.0	285.7	360.3	-3	-57	285	280	289	337
2014	359.4	352.0	299.4	346.4	-43	1	315	303	359	302
2015	**474.5**	**397.1**	404.3	391.8	-51	-60	388	278	439	338
2016	404.7	402.2	423.4	395.6	**-115**	**-117**	**420**	267	**535**	384

- Rainfall in 2015 was high, with +80 mm at ARS as compared to ASU.
- Contrary to previous patterns, ET is higher at ARS for 2015 and 2016.
- In 2016, treatment effect is mixed in with the effect of rainfall differences.

Conclusions

- **Vegetation differences:** ARS ECT has more mesquite and ASU ECT more grass, likely due to historical disturbances (past mesquite treatment and wildfire) and soil differences.
- **Meteorological differences:** Small differences in local air temperature; certain years can have >50 mm differences in total rainfall.
- **Energy balance differences:** Net radiation differences linked to mesquite and grass cover seasonality; evapotranspiration is greater at ASU ECT due to higher grass cover.
- **CO_2 exchange differences:** Gross ecosystem production is higher at ARS ECT due to the greater mesquite coverage (except 2013), difference is larger for wet years.

Conclusions

Did the mesquite treatment work?

1. Evaluation so far limited to year of treatment (up to December 2016).

2. Rainfall prior to the treatment favored more ET and GEP at ARS site.

3. Clear reduction in ET at ASU (treated site) in summer and fall 2016 relative to prior years; reduction in GEP at ASU also occurs in summer only.

4. Given the regrowth of mesquite trees, the treatment effect might have been limited to summer-fall 2016, but legacy effects still need to be studied.