Preliminary Work

Seasonal changes in surface exchange coefficient

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Outline

1. Introduction to the heat exchange coefficient
2. Landsat data for Connecticut
3. Landsat data for Arizona
4. Tower and MODIS data for Arizona
5. Conclusions

Goals

- Develop a satellite based method for estimating the surface-to-air heat exchange coefficient
- Map the spatial patterns and seasonal changes of the exchange coefficient. Identify the processes that alter the coefficient
- Compare the moist Connecticut region with an arid region in southern Arizona

Exchange Coefficient (K)

- Assumes a linear relationship between the total turbulent heat flux (sensible and latent) and the temperature difference between the surface and the air. $F=K\ (T_s-T_a)$
- Exchange coefficient is determined as the ratio of flux to temperature difference. $K=F/(T_s-T_a)$
- Coefficient varies with roughness and water availability
- Ts is the radiative "skin" temperature
- Neglects the effect of wind speed

Four Methods of K determination

A. Heat fluxes determined from eddy covariance. Temperature difference ΔT determined from tower Ts and Ta
B. Heat flux is determined from the tower net radiation. ΔT determined tower Ts and Ta
C. Heat flux determined from solar zenith angle and satellite derived Ts and albedo. Ta determined from tower.
D. Like C, but Ta determined from regional radiosondes. [No local data required]

Methods C and D

$$\bar{K} = [(S * T_R * (1 - a)\cos(\varphi) - (\epsilon_s - \epsilon_a)\sigma\bar{T}^4)]/\Delta T$$

$$\Delta T = Ts - Ta$$

Method C: Ts and albedo from satellite; Ta from tower
Method D: Ts and albedo from satellite; Ta from regional balloon soundings

Parameter	Meaning	Value	Variability
S	Solar Constant	1380 W/m2	constant
σ	Stefan-Boltzmann Const.	$5.67 * 10^{-8}$	constant
Tr	Atmos. Transmissivity	0.7	variable
ϵ_s	Surface emissivity	0.95	variable
ϵ_a	Atmos. emissivity	0.6	variable
a	Albedo	0.2	variable
φ	Solar zenith angle	30	variable
$\bar{T}$	Average temperature	288K	variable
G	Ground heat flux	0	variable

Compared sites

Annual Precipitation

Compared sites

- Connecticut (Koppen class Cfa):
  - Landsat data only (6 replicates)
  - Method D only
  - Major seasonal change: Deciduous phenology
- Arizona (Koppen class Bsa):
  - Landsat , MODIS and tower data
  - All methods (A,B,C,D)
  - Major seasonal change: July monsoon precipitation

Land cover types in Connecticut

1. Deciduous Forest
2. Mixed Forest
3. Grass
4. Urban

Landsat image table: Connecticut

Calendar Day	DOY	T925	T850	Wind Speed (925 hpa)	Dew Point (925 hpa)
2007_0117	17.000	-16.467	-15.267	22.500	-21.817
20030327.000	86.000	3.000	-0.750	21.500	-7.167
2005_0417	107.000	12.067	6.867	17.333	-10.433
2003_0428*	118.000	14.233	9.933	17.167	-5.600
2008_0511	132.000	8.600	5.033	12.833	-1.233
2007_0525	145.000	21.667	15.633	15.500	10.500
2001_0625 (some clouds)	176.000	16.267	12.733	9.833	11.000
1991_0716	197.000	0.000	13.400	13.000	1.067
2001_0727	208.000	11.367	6.567	16.167	2.867
2000_0825	238.000	14.833	10.900	12.167	9.067
2006_1013	286.000	1.700	-1.633	17.000	-7.800
1995_1116	320.000	-4.500	-8.967	16.833	-8.750

Deciduous Forest

Oak, Maple, Beech, etc.

Long Meadow Pond

July 2010

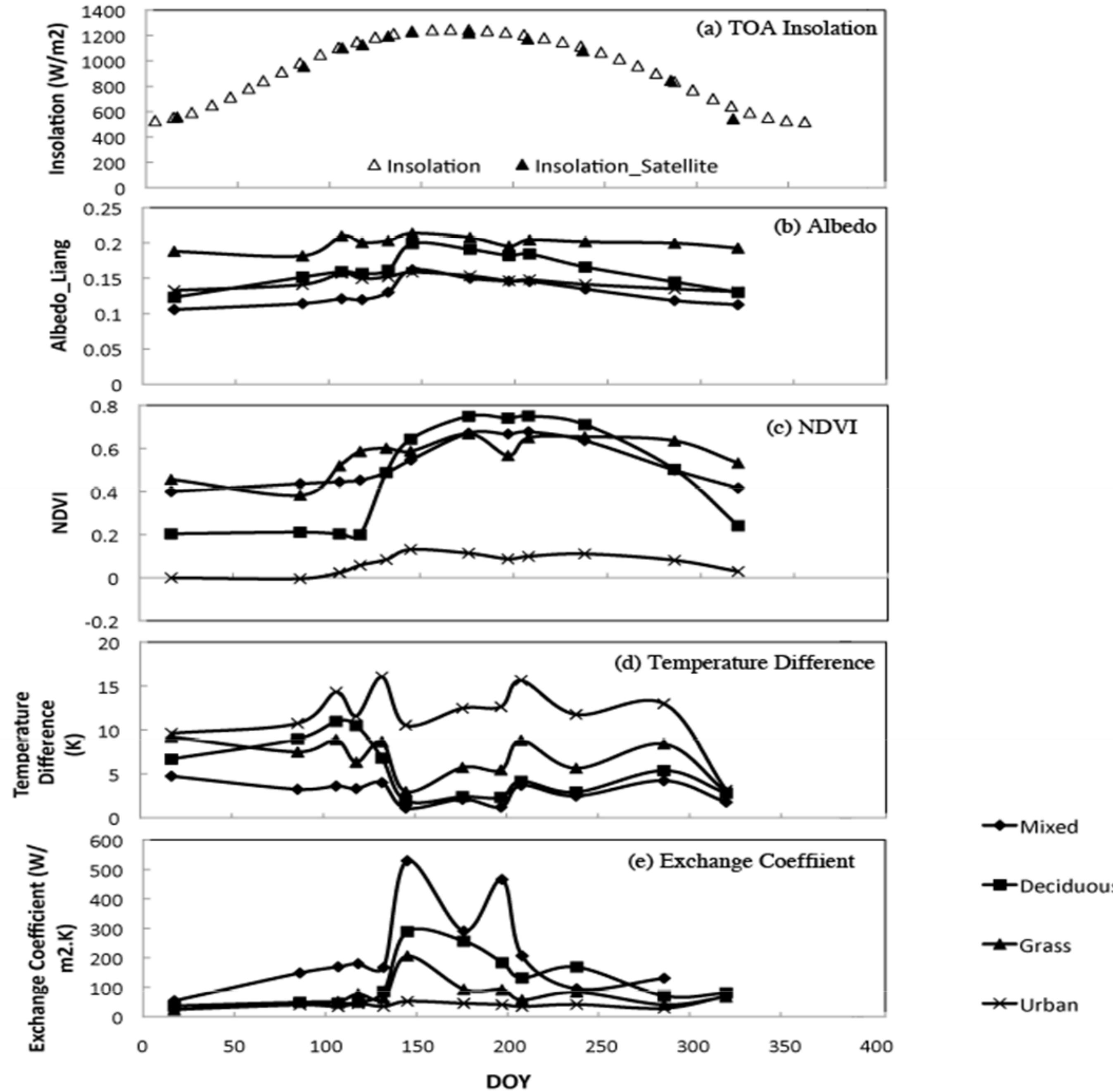
Mixed Forest

Oak, Maple, Beech, Spruce, Pine, etc.

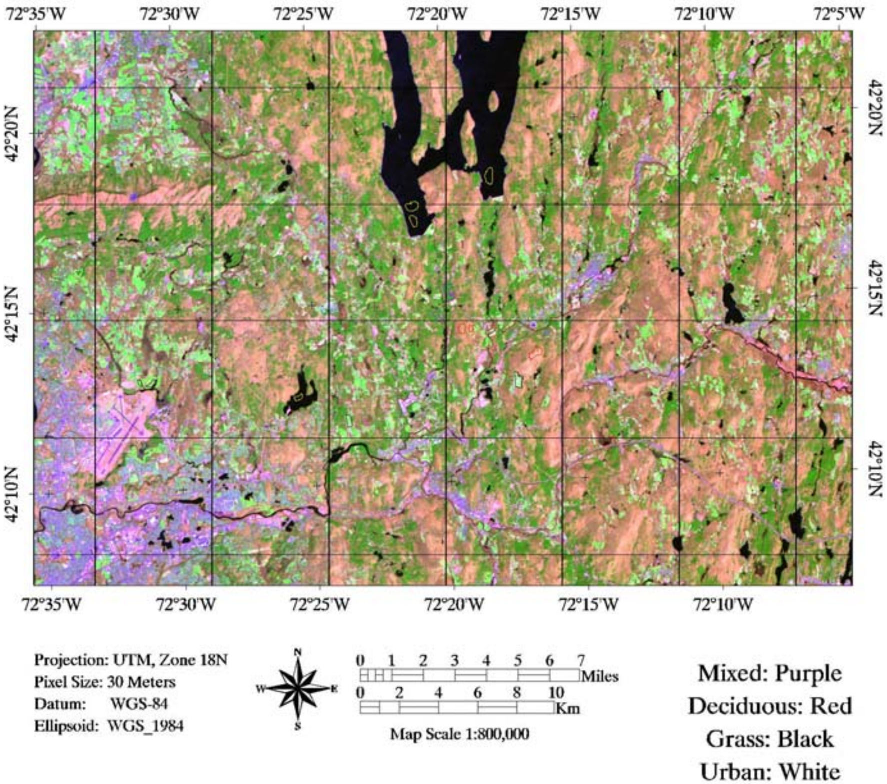
Lake Winchester

July 2010

Connecticut

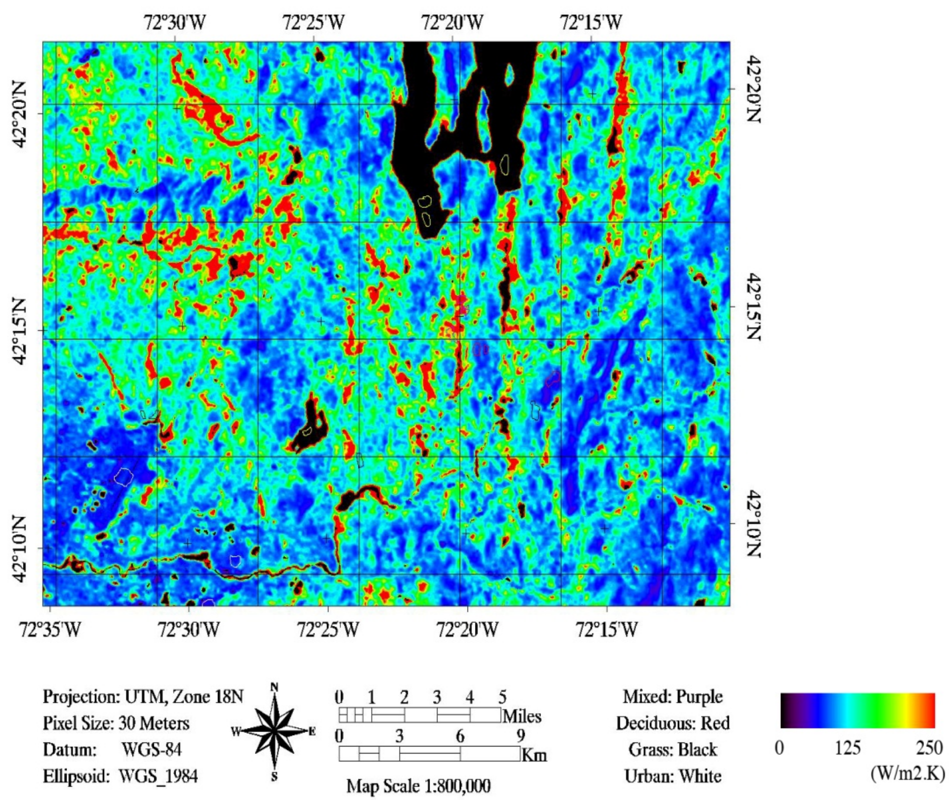


7-4-1 Landsat (20030428)

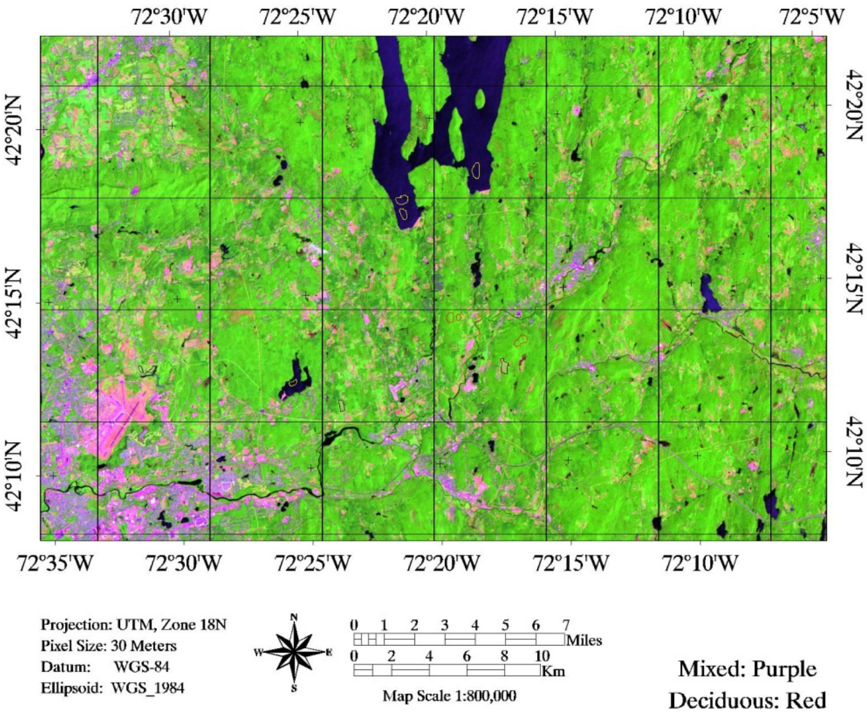


Connecticut
April 28, 2003
Before leaf-out

Exchange Coefficient (Apr)



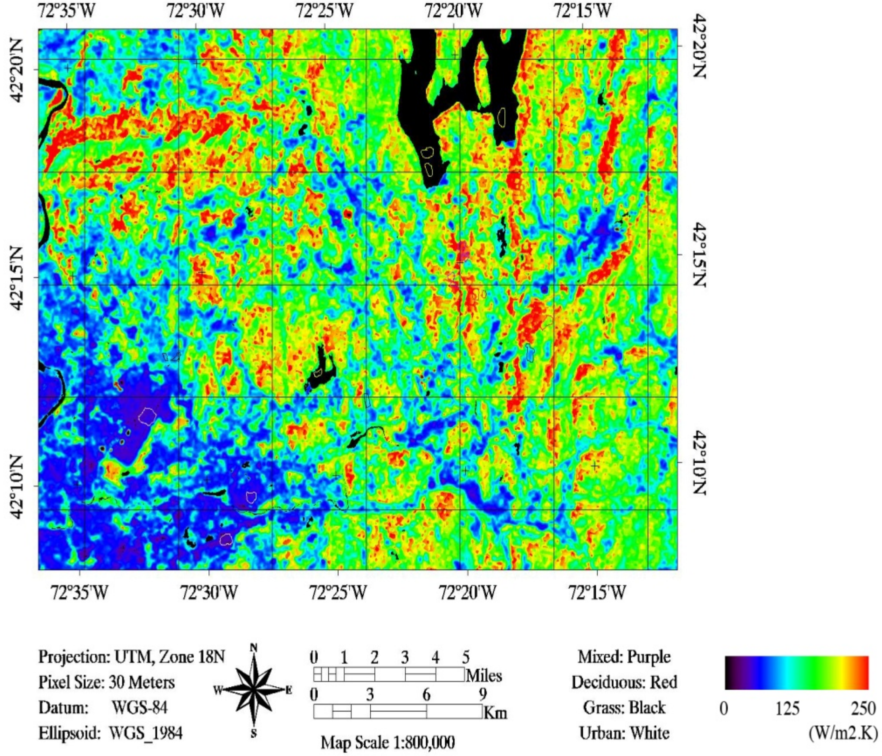
7-4-1 Landsat (20010727)



Mixed: Purple
Deciduous: Red
Grass: Black
Urban: White

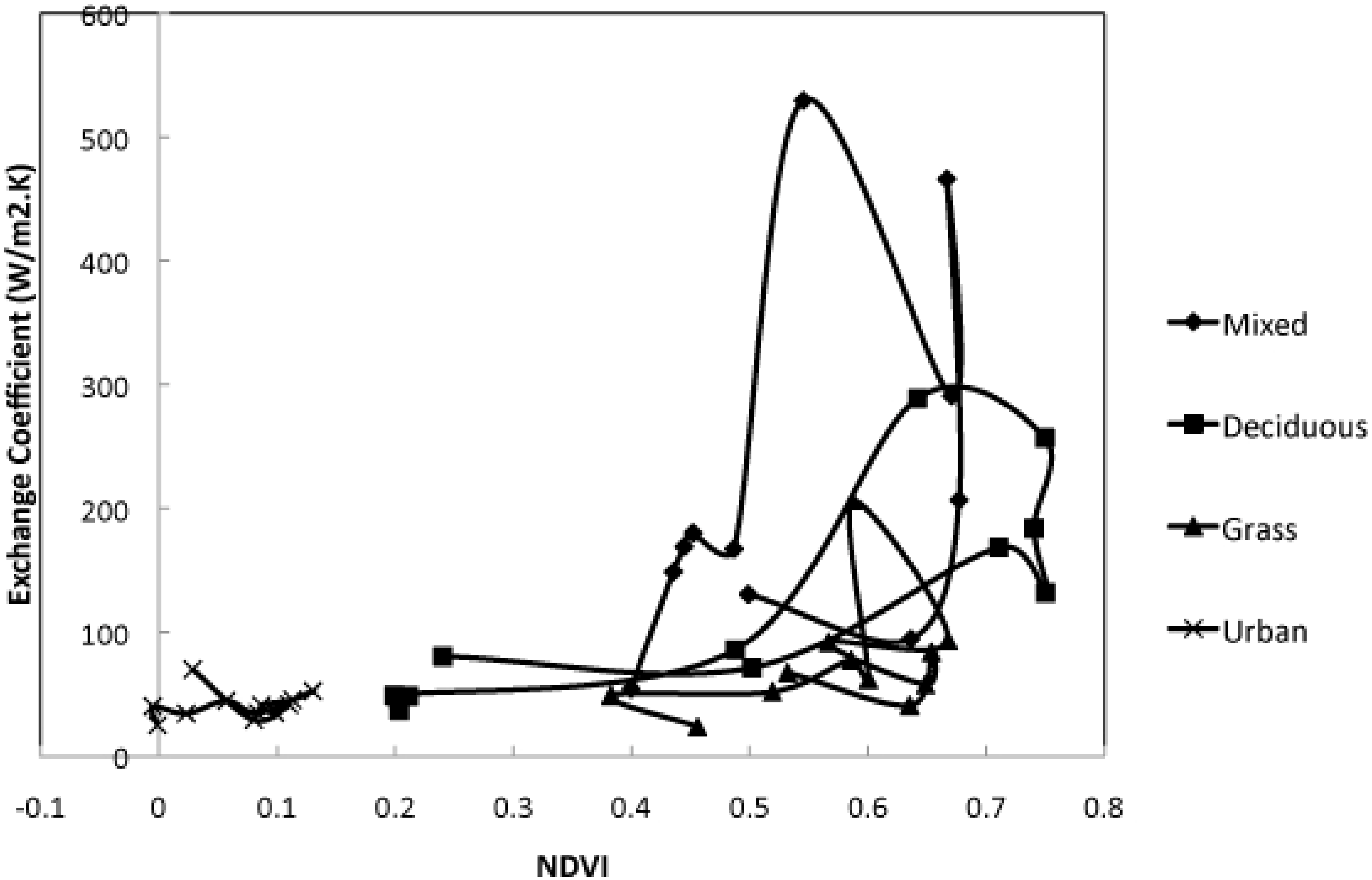
Connecticut
July 27, 2001
After leaf-out

Exchange Coefficient (July)



Connecticut Landsat data

Average of six replicates



Arizona Landsat Study

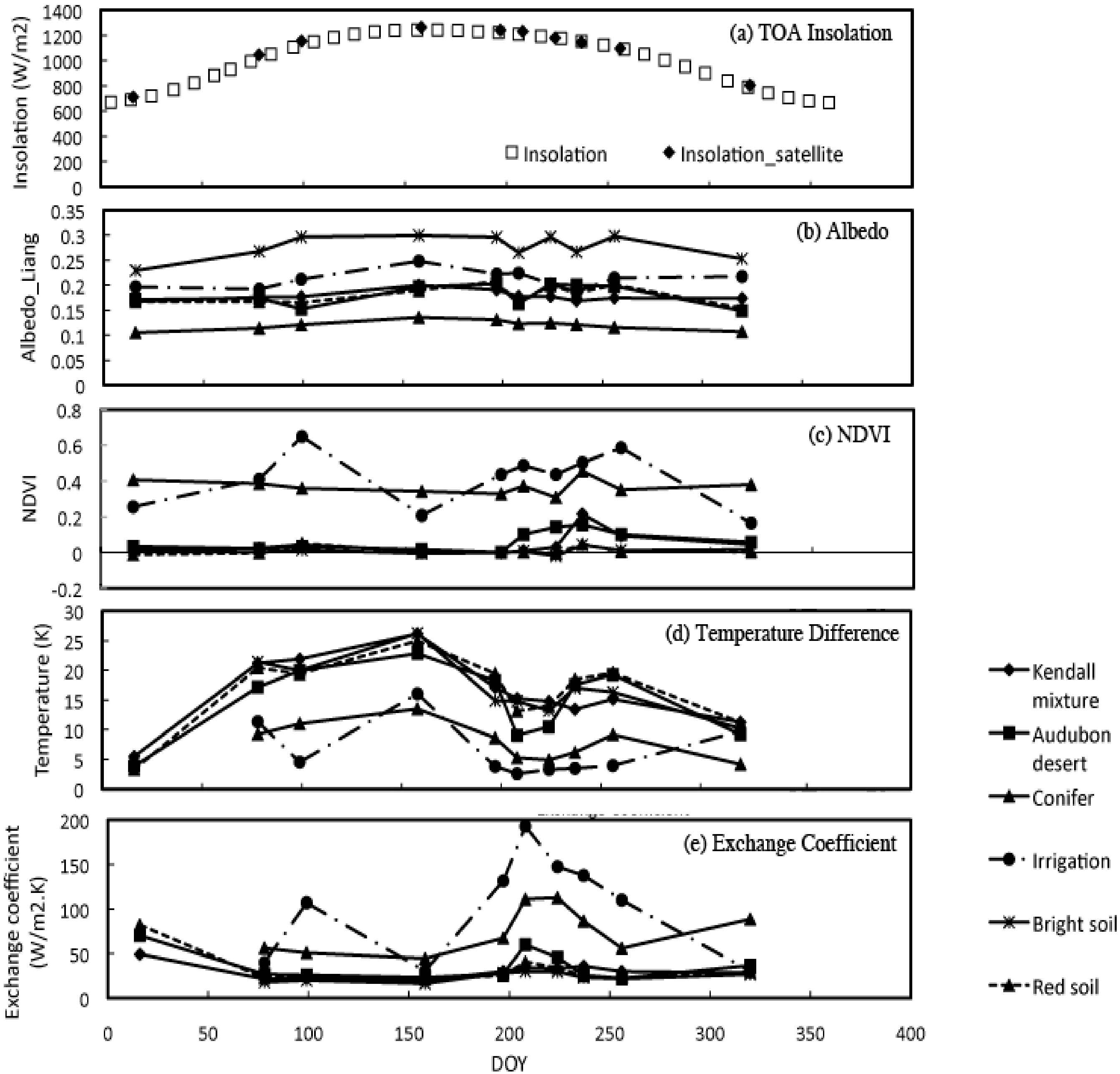
Land Cover types

1. Kendall grassland
2. Audubon barren desert
3. Conifer
4. Center-pivot irrigation
5. Bright soil
6. Dark soil

Table of Landsat images for Arizona

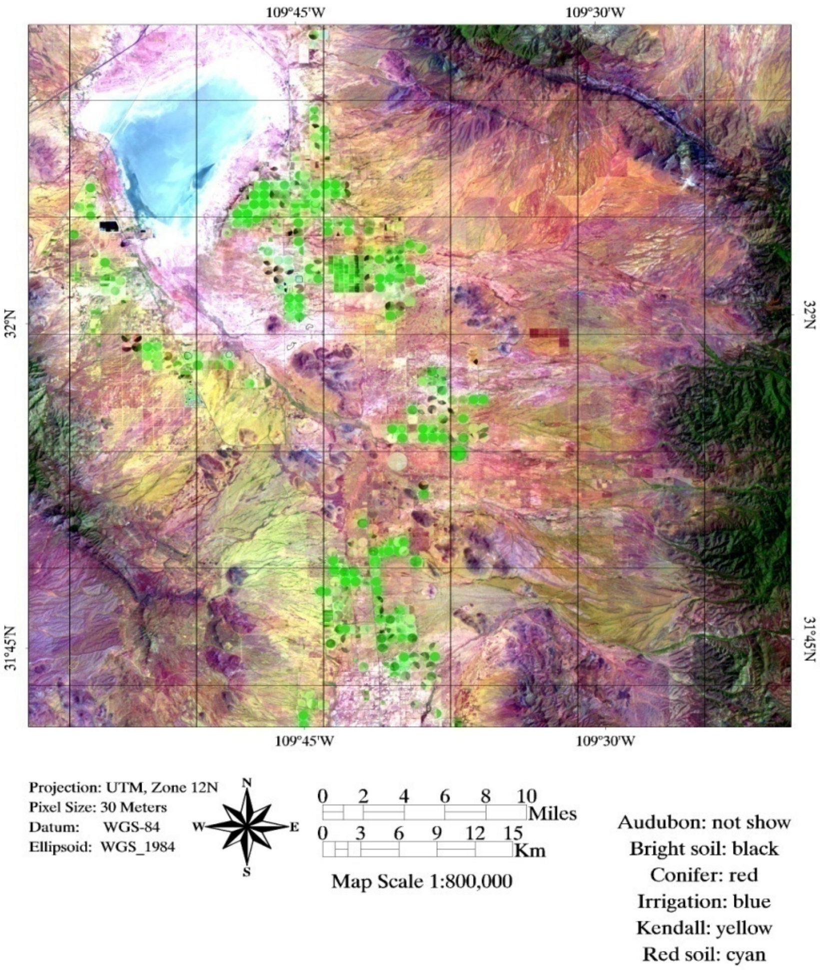
Calendar Day	DOY	T925	T850	Wind speed (850 hpa)	Dew Point (850 hpa)
2009_0116	16		15.7	10.5	-22.8
2008_0318	78		7.1	11	-5.4
2010_0409	99		17.9	7	-25.1
2008_0606	158		22.3	7.5	-8.2
2005_0716	197		29.7	11.5	9.2
2009_0727	208		29.7	14	2.7
2003_0812	224		29.5	7.5	10
2002_0825	237		28.7	8.5	6.2
2003_0913	256		25.8	5.5	0.3
2009_1116	320		12.2	15	-21.8

Arizona



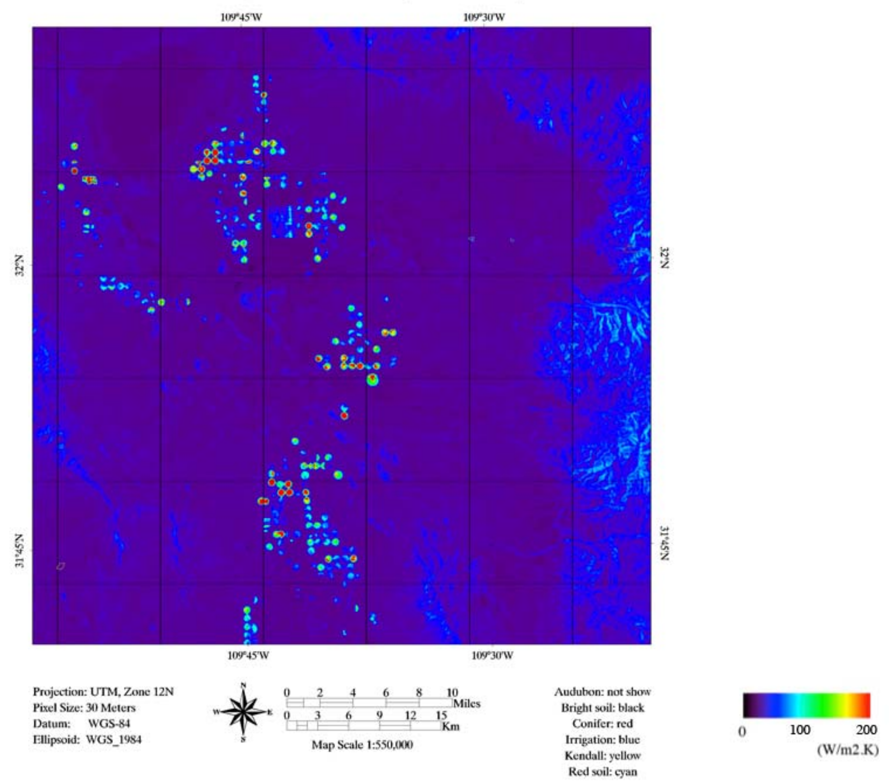
(a) TOA Insolation
Insolation (W/m2)
Insolation
Insolation_satellite
(b) Albedo
Albedo_Liang
(c) NDVI
NDVI
(d) Temperature Difference
Temperature (K)
(e) Exchange Coefficient
Exchange coefficient (W/m2.K)
DOY
Kendall mixture
Audubon desert
Conifer
Irrigation
Bright soil
Red soil

7-4-1 Landsat (20080606)

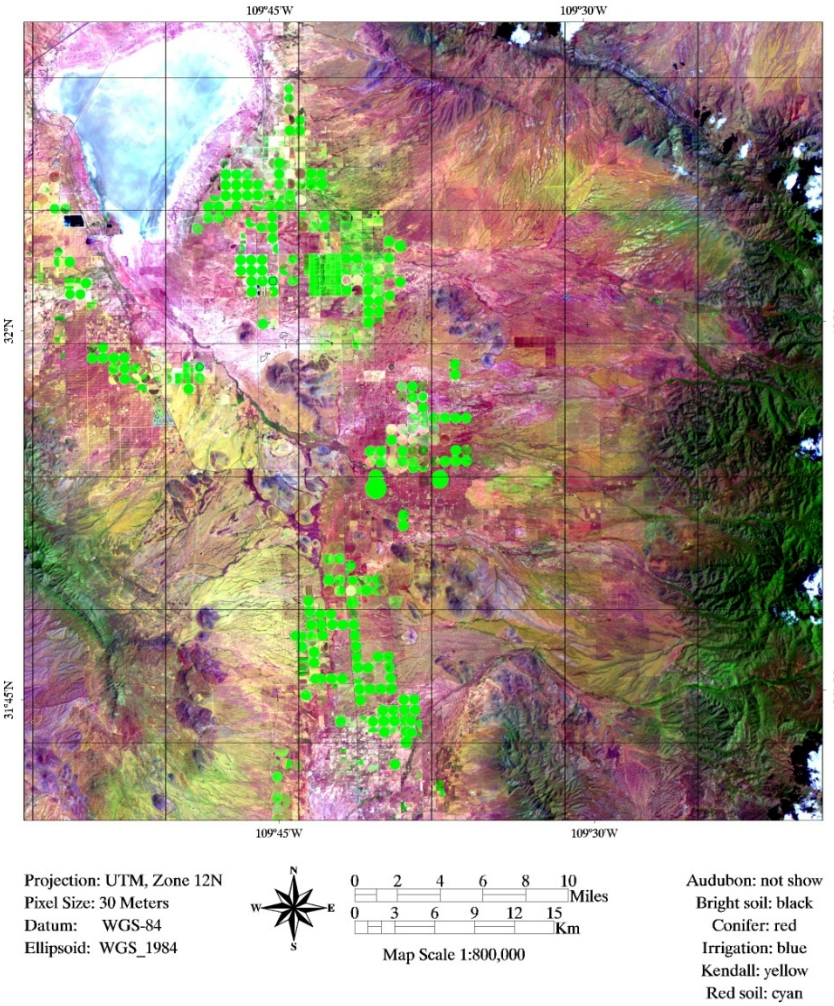


Arizona
June 6, 2008
Before monsoon

Exchange Coefficient (20080606)

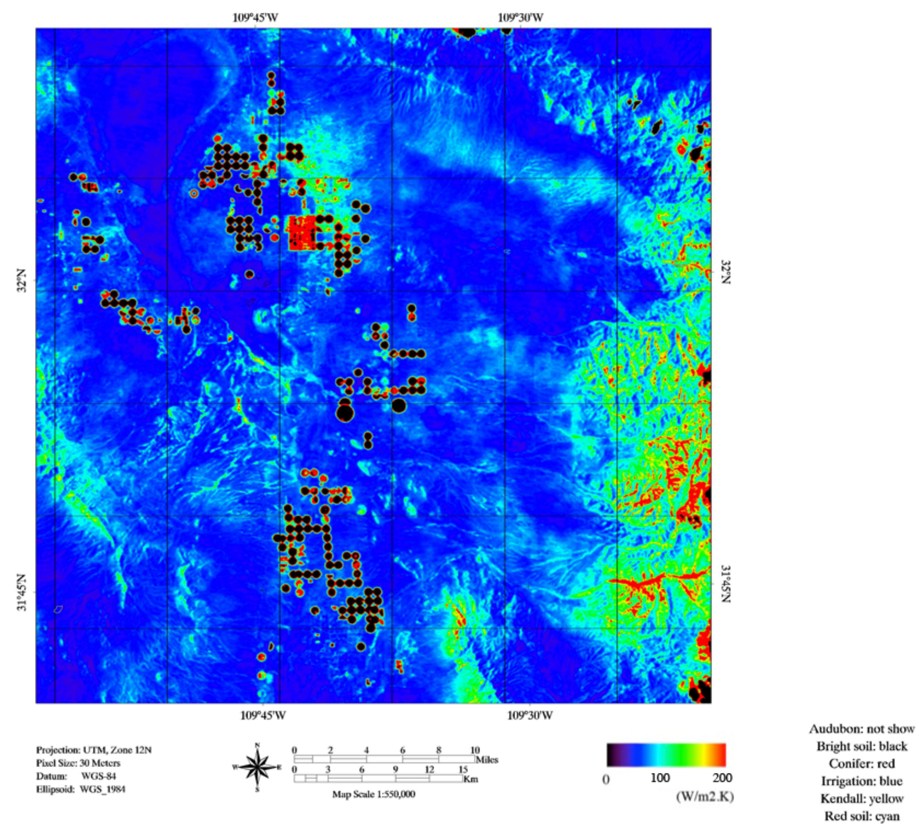


7-4-1 RGB Landsat (20090727)



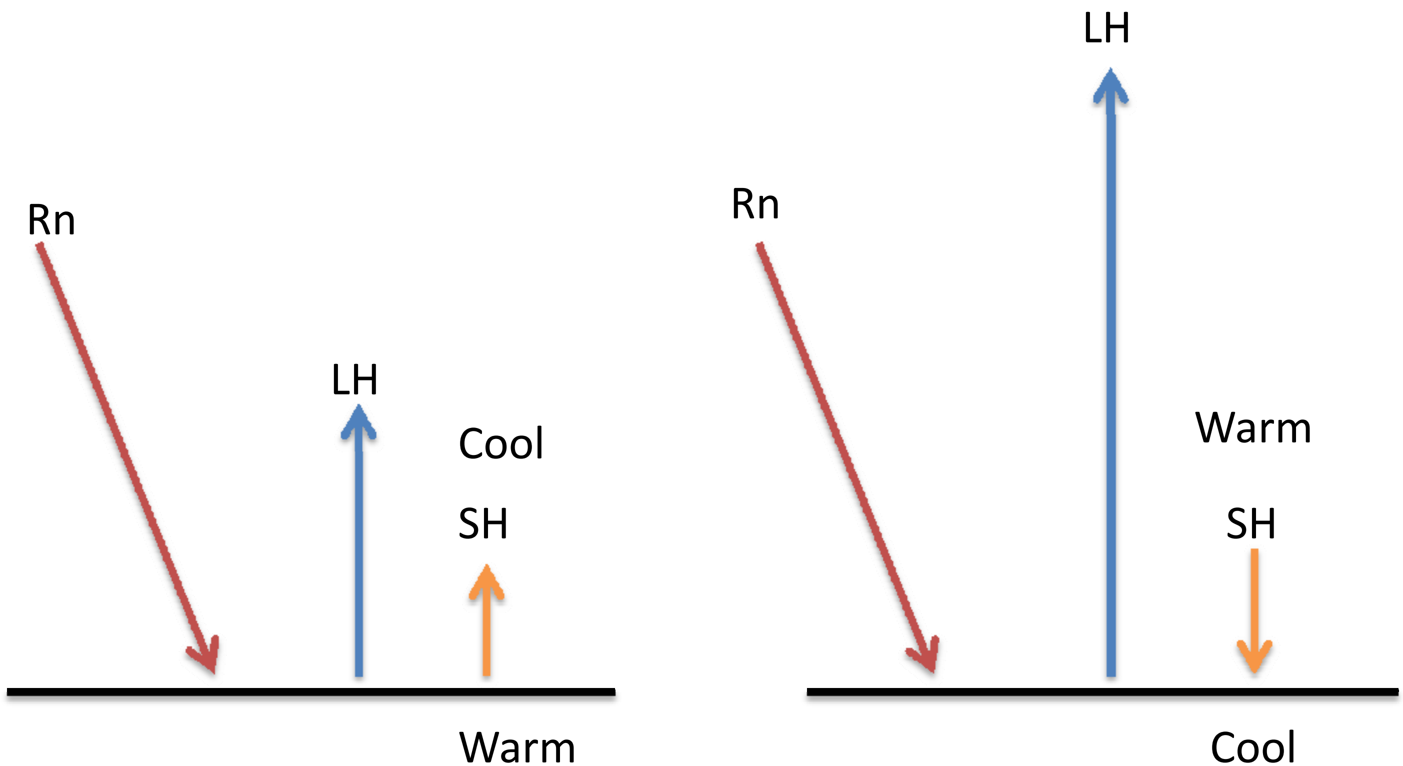
Arizona
July 27, 2009
During monsoon

Exchange Coefficient (20090727)



Negative ΔT and K are shown in black

Irrigated fields in arid landscapes

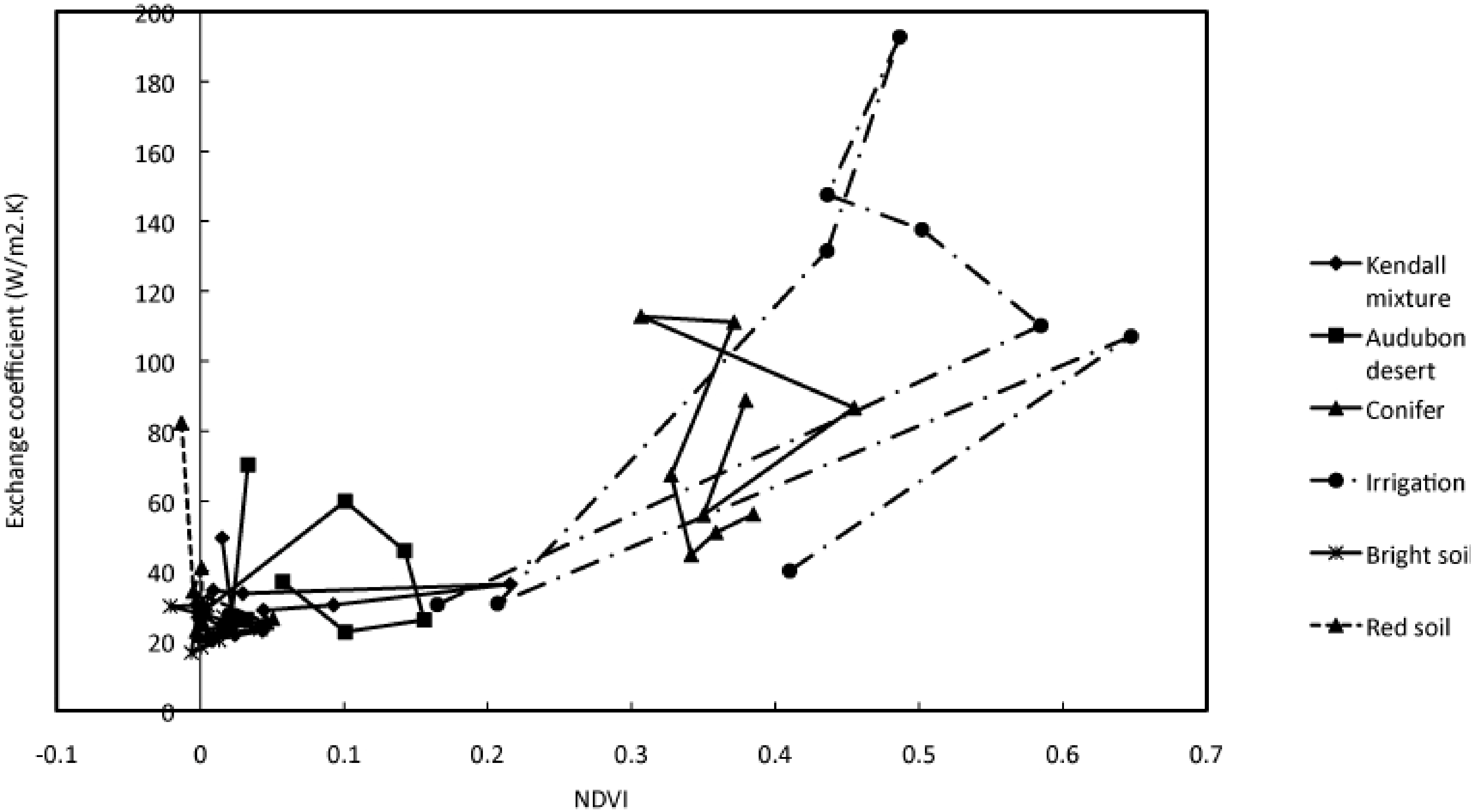


Strong evaporation
Large positive exchange coefficient

Very strong evaporation
Net counter-gradient heat flux
Negative temperature difference
Negative exchange coefficient

Note: sensible heat flux is down gradient in both cases.

Arizona Landsat data



Arizona Tower and MODIS data

1. Compare K methods
2. Continuous time series (8-day composites)
3. MODIS has better albedo, NDVI and Ts products than Landsat
4. MODIS has poorer spatial resolution than Landsat

Data

- Satellite
  - **MOD13Q1:** the Normalized Difference Vegetation Index (NDVI) 16-day composite with a 250-meter spatial resolution.
  - **MCD43A3:** an 8-day composite combined albedo product obtained by Terra and Aqua satellites. It has spatial resolution of 500 meters.
  - **MOD11A2**: an 8-day composite land surface temperature with spatial resolution of 1km.
- Towers (Ameriflux)
  - 30-minute averages

Methods

- Method *a*
  - Tower measured LE, H, dT

$$\overline{K} = \frac{LE + H}{R_{net}}$$

- Method *b*
  - Tower measured R_{net}, dT

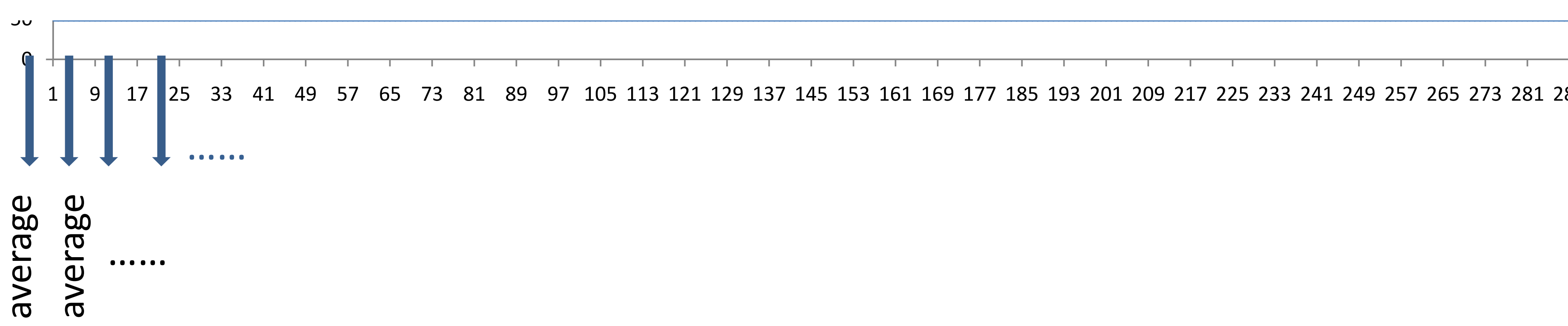
$$\overline{K} = \frac{R_{net}}{dT}$$

- Method *c*
  - Computed R_{net}
  - dT – computed using both satellite data and tower data

$$\overline{K} = \frac{S \cdot t_a (1 - \alpha) \cos\varphi - (\varepsilon_s - \varepsilon_a) \sigma \overline{T}^4}{dT}$$

Combining Satellite and Tower Data

- Time of day
  - Terra – flyover at 10:30am
  - Towers – every 30 minutes
- 8-day composites

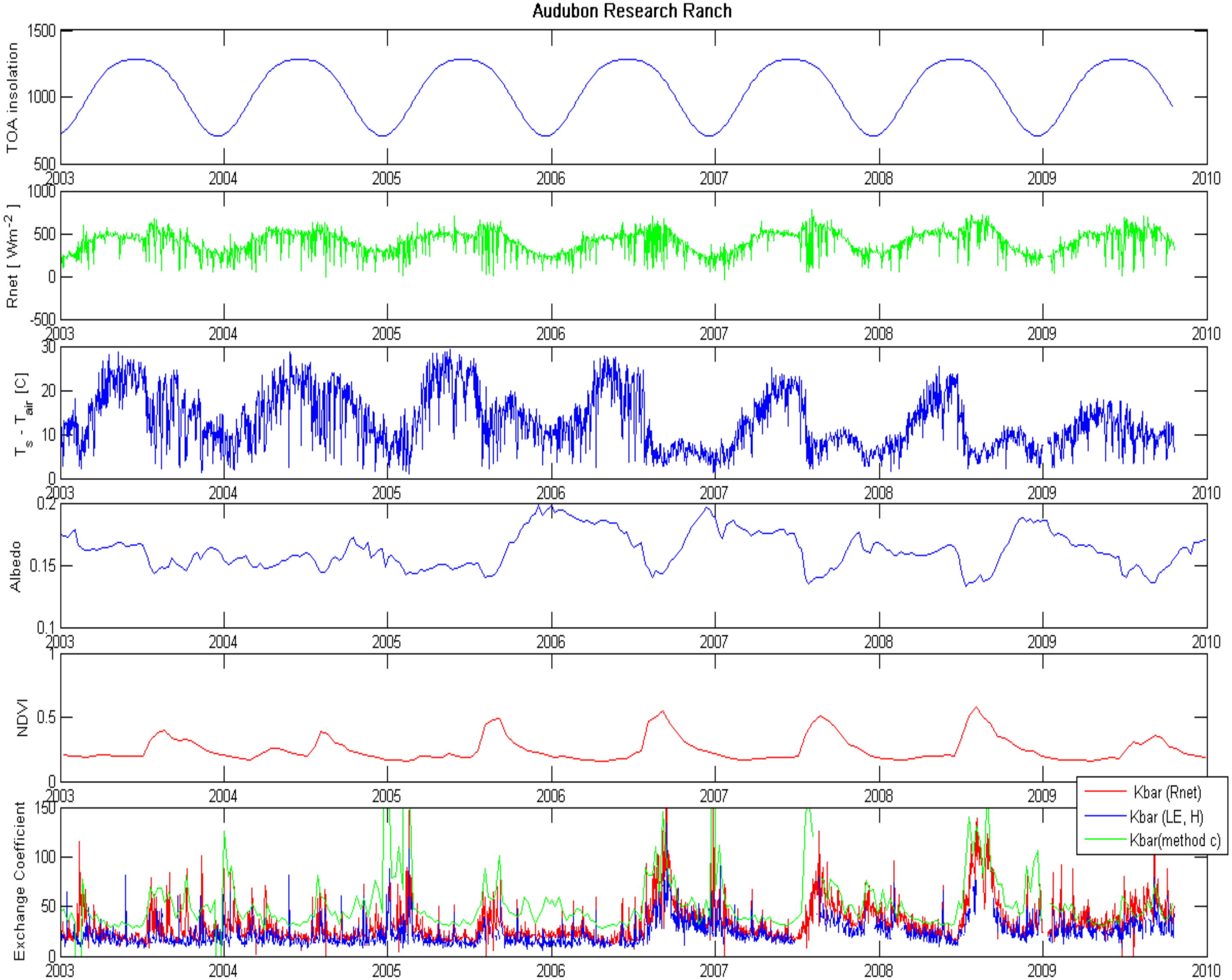


Arizona land cover types for tower and MODIS study

1. Audubon Research Ranch: barren
2. Santa Rita: mesquite
3. Kendall: grassland

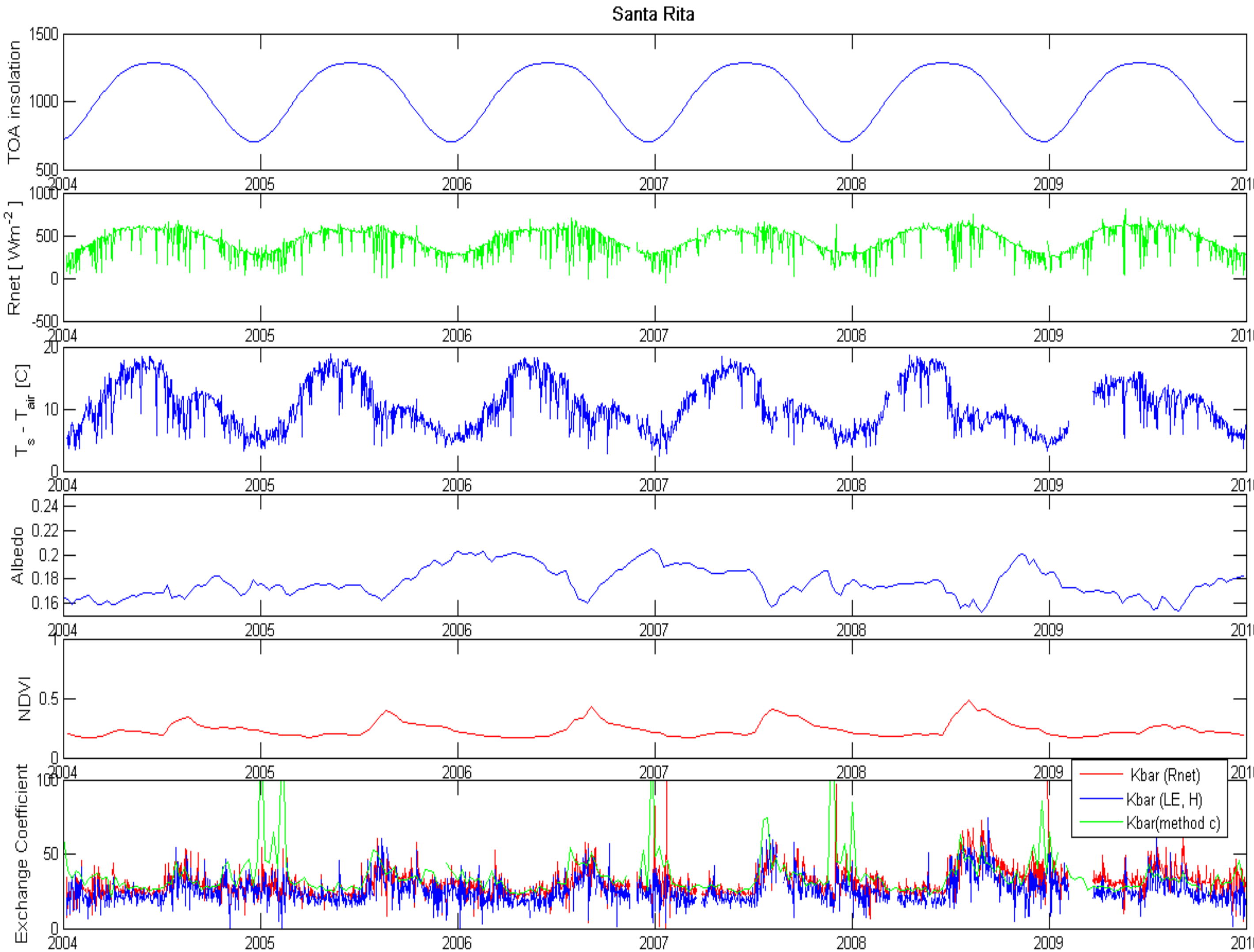
Audubon Research Ranch: Barren

Audubon Research Ranch: Barren



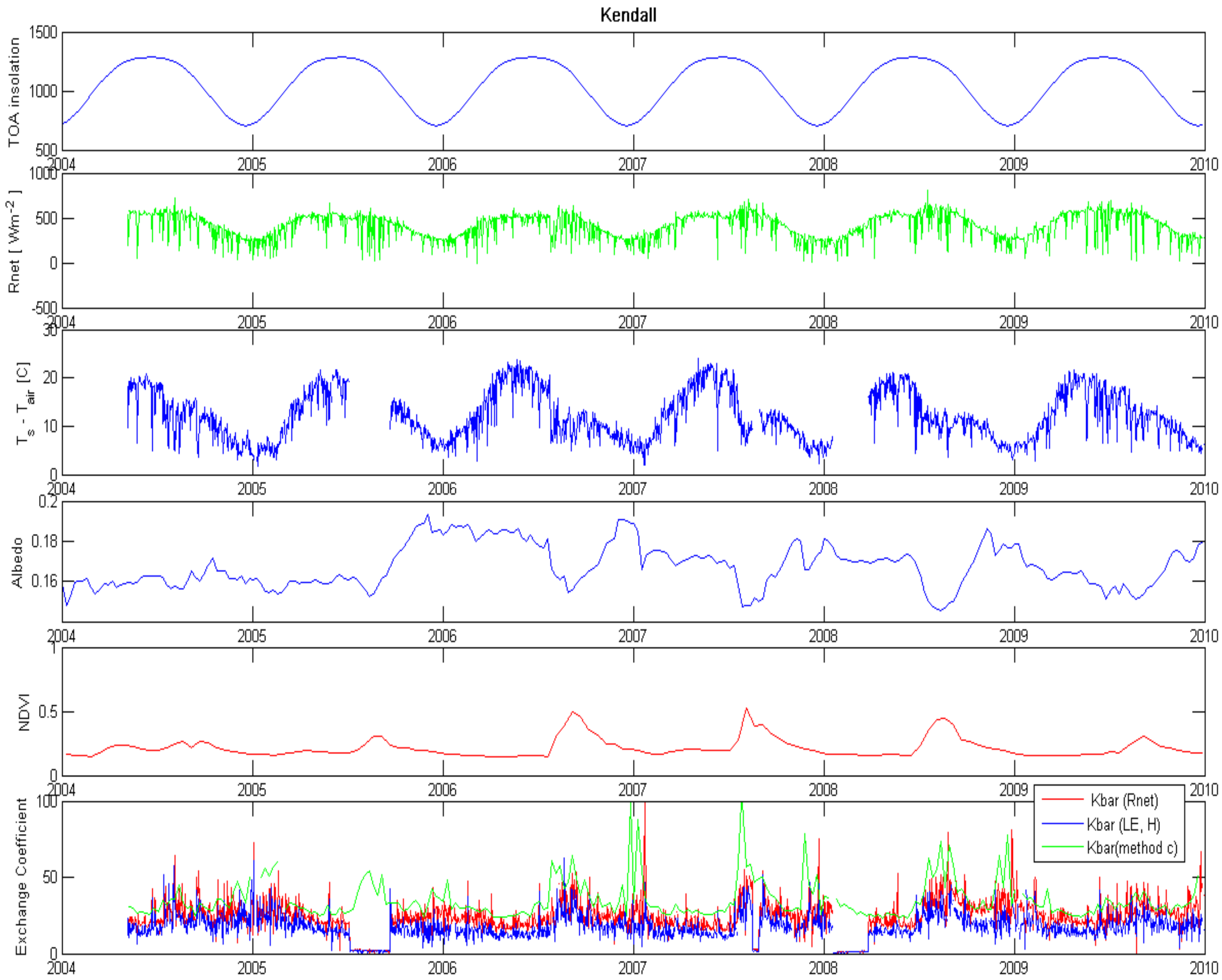
Santa Rita Mesquite

Santa Rita: mesquite



Kendall Grasslands

Kendall: Grasslands



General Conclusions

- Our K method removes the seasonal cycle in insolation and thus isolates the role of surface properties.
- The four methods agree well and give robust estimates of K except when DT<2C.
- Connecticut and Arizona have different seasonal changes in surface properties, but K is linked to NDVI in both places.
- Spatial pattern of K matches the complex spatial pattern of land cover.
- Neglect of wind effect is not too serious.
- Landsat compositing introduces noise.

Connecticut Landsat Study

1. Grass and forest increase their K strongly due to leaf-out in mid May. DT decreases, in spite of higher summer radiative forcing.
2. Only urban surfaces have a higher DT in summer due to the greater insolation
3. K for forests varies from about 30W/M2*K in winter to 250 in summer. Urban areas range only from 20 to 40.
4. Albedo rises slightly as NDVI increases

Arizona Landsat study

- Generally, DT varies with season following the insolation, reaching 25C in summer. K is less variable, so insolation dominates.
- K rises in July and August following the monsoon rains. K correlates with NDVI.
- Only irrigated land and conifer forests ever exceed K=100W/M2*K. More typical is K~30.
- Most center-pivot circles have a negative DT in July, indicating an upgradient net heat transport.
- Albedo drops as NDVI increases

Arizona tower and MODIS study

- Methods A, B and C agree well.
- ΔT follows the seasonal insolation cycle, but with a "notch" for the monsoon
- The seasonal cycle in K includes a (noisy) winter max and a robust July max due to the monsoon rains.
- The monsoon maximum in K varies between years and follows NDVI.
- Albedo drops with increasing NDVI

Future work

- Use MODIS and NARR with method D
- Compare results with the literature
- Compare observed K with model predictions