Preliminary Work

Seasonal changes in surface exchange coefficient

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Help from Tamara Machac, Aaron Judah, Larry Bonneau, Xuhui Lee
Support from YCEI
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. $F = K \times (T_s - T_a)$

• 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

• $T_s$ 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 $\Delta T$ determined from tower $T_s$ and $T_a$

B. Heat flux is determined from the tower net radiation. $\Delta T$ determined tower $T_s$ and $T_a$

C. Heat flux determined from solar zenith angle and satellite derived $T_s$ and albedo. $T_a$ determined from tower.

D. Like C, but $T_a$ determined from regional radiosondes. [No local data required]
Methods C and D

\[
\bar{K} = \left[ (S \ast T_R \ast (1 - \alpha) \cos(\varphi) - (\varepsilon_s - \varepsilon_\alpha) \sigma \bar{T}^4) \right] / \Delta T
\]

\[
\Delta T = T_s - T_\alpha
\]

Method C: \( T_s \) and albedo from satellite; \( T_\alpha \) from tower
Method D: \( T_s \) and albedo from satellite; \( T_\alpha \) from regional balloon soundings

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Meaning</th>
<th>Value</th>
<th>Variability</th>
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<tr>
<td>( S )</td>
<td>Solar Constant</td>
<td>1380 W/m²</td>
<td>constant</td>
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<td>( \sigma )</td>
<td>Stefan-Boltzmann Const.</td>
<td>5.67 \times 10^{-8}</td>
<td>constant</td>
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<td>( T_R )</td>
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<td>( \varepsilon_s )</td>
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<td>( \varphi )</td>
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<td>( \bar{T} )</td>
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<tr>
<td>G</td>
<td>Ground heat flux</td>
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Compared sites

Annual Precipitation

Map showing the annual precipitation in the United States, with a legend indicating the average annual precipitation in inches. Highlighted areas in Nevada and Hawaii indicate lower and higher precipitation levels, respectively.
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

<table>
<thead>
<tr>
<th>Calendar Day</th>
<th>DOY</th>
<th>T925</th>
<th>T850</th>
<th>Wind Speed (925 hpa)</th>
<th>Dew Point (925 hpa)</th>
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Deciduous Forest

Oak, Maple, Beech, etc.
Long Meadow Pond

July 2010
Mixed Forest
Oak, Maple, Beech, Spruce, Pine, etc.
Lake Winchester

July 2010
Connecticut
April 28, 2003
Before leaf-out

7-4-1 Landsat (20030428)

Exchange Coefficient (Apr)
Connecticut
July 27, 2001
After leaf-out
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

<table>
<thead>
<tr>
<th>Calendar Day</th>
<th>DOY</th>
<th>T925</th>
<th>T850</th>
<th>Wind speed (850 hpa)</th>
<th>Dew Point (850 hpa)</th>
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Arizona

(a) TOA Insolation

(b) Albedo

(c) NDVI

(d) Temperature Difference

(e) Exchange Coefficient

Legend:
- Kendall mixture
- Audubon desert
- Conifer
- Irrigation
- Bright soil
- Red soil
Arizona
June 6, 2008
Before monsoon
Arizona
July 27, 2009
During monsoon

Negative $\Delta T$ 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

• **Method b**
  – Tower measured $R_{net}$, dT

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

\[
\bar{K} = \frac{LE + H}{R_{net}}
\]

\[
\bar{K} = \frac{R_{net}}{dT}
\]

\[
\bar{K} = \frac{S \cdot t_a (1 - \alpha) \cos \varphi - (\varepsilon_s - \varepsilon_a) \sigma \bar{T}^4}{dT}
\]
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
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.
• $\Delta T$ 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