Monitoring Alfalfa, Grass, Corn and Potato Water Use under Full and Deficit Irrigation using a Spatially Distributed Temperature Model

José L. Chávez
Civil and Environmental Engineering
Colorado State University

Project Members

- José L. Chávez, PhD, PI

Associate Professor
Civil and Environmental Engineering Department

- Karan Venayagamoorthy, PhD, co-PI

Associate Professor
Civil and Environmental Engineering Department

- Perry Cabot, PhD, co-PI

Extension Water Resources Specialist
Colorado Water Institute

- Mahmoud Soliman, MS,

Doctoral program graduate student
Civil and Environmental Engineering Department

Rational of the Study

- Water transfer from Ag (deficit) to other users
- Irrigation reductions in terms of crop actual water use must be monitored
- Vast region, covering numerous counties, demands an accurate estimate of reduced consumptive use (CU) using R.S.
- Need of reliable and consistent R.S. of ET model.

Objectives

1. To document fully and limited irrigated grass pastures, alfalfa, potato and corn fields seasonal water use, over multiple years, using soil water content sensors and micro-meteorological stations.
2. To determine irrigation efficiency by documenting water deliveries and the fate of water once it reaches the field. Where records are available.
3. To derive estimates of saved crop consumptive water use that may be credited to limited irrigated *alfalfa, grass, potato and corn* fields.
4. To employ digital airborne and/or satellite imagery remote sensing of evapotranspiration (ET) models to estimate ET rates from fully and limited irrigated fields.
5. To develop, calibrate, and validate a remote sensing energy balance model based on remote sensing (Taero) and weather data, using fluid dynamics, soil water content measurements (at multiple field sites), aerodynamic profile towers, and large aperture scintillometers.

Expected use to which the results will be put

- Results from the proposed project (remote sensing (RS) algorithm to monitor/manage crop water use or ET) are expected to be adopted by irrigation districts, water consultants, state engineers, and federal researchers to improve water management in the state and document water savings (e.g., to improve irrigation/application efficiencies, for water rights transfer and/or banking), and for general hydrologic applications (e.g., soil moisture monitoring, drought monitoring).

- Furthermore, the RS of ET algorithm will be included in the regular academic curriculum in Civil and Environmental Engineering at Colorado State University (CIVE 519 – Irrigation Water Management course) to educate new generation of students on the proper application of the algorithm and its advantages.

- Publication of research results will be pursued in journals and professional conferences as well as through Extension factsheets, Colorado Water Institute by-monthly Newsletter, and the Colorado Agricultural Experiment Station (CAES) annual report publications will help disseminate the findings of this project.

Objective 1

- Soil water content sensors will be used to monitor soil water status (deficit) in the crop root depth, LAS, EC, BR.
- The soil water data will be used in the soil water balance approach to estimate weekly and seasonal crop water use for fields managed under fully and limited irrigation strategies.
- With the help of participating farmers, technicians, students, a logbook will be maintained to document irrigation days, irrigation amounts (gross), and irrigation duration. Precipitation will be taken from the nearest weather station. Also, basic weather data to compute reference evapotranspiration (following ASCE-EWRI 2005 procedures) will be obtained from COAGMET weather stations.

Objective 2

- Flow meters will be used to document water deliveries to the fields, measured soil moisture data in the profile will be used to determine vertical fluxes of water passed the root zone and therefore deep percolation water movement. Estimates of ET using the EB and SWB methods will determine crop consumptive use (CU). Thus, we will be able to compute irrigation efficiencies as defined in Chapter 3 “Efficiency and Uniformity” by Heermann et al. (in Hoffman et al., 2007).

Objective 3

- Saved crop consumptive water use will be determined by relating the limited or reduced irrigation crops/fields to the fully irrigated fields seasonal (cumulative) ET measurements and estimates. Measurements will be represented by the results in objective 1 and estimates will be determined following the procedure outlined in Andales et al. (2011) using reference ET and appropriate non-stressed crop coefficients.

Objective 4

- Multispectral data composed of surface reflectance in the Red (R) and Near Infra-Red (NIR) bands and surface temperature from the Thermal Infra-Red (TIR) band of sensors mounted on airborne platforms will be used or acquired at very high spatial resolutions (sub meter). Data acquisition will happen every 16 days concurrently with the overpass of satellite Landsat 8.

- Satellite data corresponding to the same R, NIR and TIR bandwidths, with pixel spatial resolutions of 30-100 m, will be downloaded from the EROS and/or USGS Earth Explorer websites.

- RS of ET models as ReSET, SEBAL-A, SEBS, TSM will be applied.

Objective 5

- Past experience on modeling ET over different fully irrigated vegetated surfaces, using the energy balance and the aerodynamic temperature approach, in Colorado, will be documented and contrasted for conditions found under fully irrigated and the limited irrigation in Colorado for grass, alfalfa, corn and potato fields.

- Fluid dynamic principles will be applied to multispectral remote sensing data, airborne and/or satellite based) crop bio-physical characteristics (e.g., crop height, density, clumping index, surface roughness length, local leaf area index, surface resistance, etc.) to develop a robust energy balance-temperature model for the accurate estimation (monitoring) of actual crop water use and seasonal/spatial water savings along the crop growth period.

- The aerodynamic or with-in canopy air temperature (Taero) based algorithm will be developed by incorporating RS data and fluid dynamics characterized over the different vegetation architecture and density (homogeneity/heterogeneity) over different crop types and irrigation methods and strategies (full to limited). A grid of air temperature sensors to measure Taero will be deployed.

- The evaluation of the developed RS Taero based ET algorithm will be performed using large aperture scintillometers (LAS), BR, EC, lysimeters, SWB, and aerodynamic towers (APT).

Research Sites

- CO West slope:

Table 1: Site Location and Info by County

County	Delta	Gunnison	Mesa (GVWUA)	Mesa (CSU-AES)	Montezuma (CSU-AES)	Montrose (UVWUA)
Crop Type	Alfalfa	Grass Hay/Pasture	Alfalfa	Grass Hay/Pasture	Alfalfa	Alfalfa
Site Size (acres)	30	40	80	30	30	80
Plot Size (acres)	10	10	40	10	10	40
No. of Plots	3	4	2	3	3	2

GVWUA: Grand Valley Water Users Association; CSU-AES: Colorado State University Agricultural Experiment Station; UVWUA: Uncompahgre Valley Water Users Association

- CO East slope: Greeley, La Salle, CSU ARDEC Fort Collins, CSU AVRC Rocky Ford, CSU-ARS Akron. Crops: corn, alfalfa, sorghum.

- CO San Luis Valley: potatoes (Mountain King Potato Farms).

- Other States: Iowa (2002), Texas (2007, 2008). Crops: corn, soybeans, sorghum, cotton.

CO West Slope (2015, 2016)

Montrose County location:
Managed by Willie Frigetto @ about 8901-10445 6530 Rd in Montrose, CO where 6530 Rd and Dale Lane intersect, about 2000 feet north of Snyder Farm Supply at 1441 6530 Rd (8.2 acres and 6.3 acres for the treatment and reference fields, respectively). Parcel ID = 44106782. Master ID = 6519

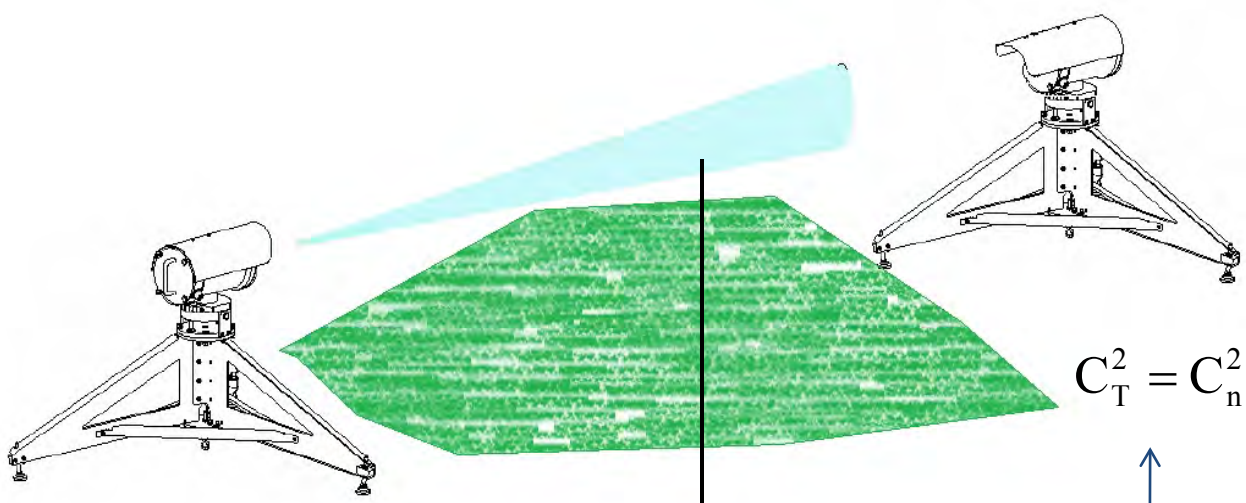
Field Notes

West (REFERENCE) = furrow irrigated → REFERENCE FIELD
East (PLOT #1) = furrow irrigated → STOP AFTER 1st CUTTING[1]

Large Aperture Scintillometer (LAS)

Picture provided by Dr. Cabot

Scintillometry for Sensible Heat Flux (H)



$$C_T^2 = C_n^2 \left(\frac{T^2}{-0.78 - 10^{-6} P} \right)^2 \left(1 + \frac{0.03}{\beta} \right)^{-2}$$

UC_n^2 (mV) ➔ C_n^2 + β, T, P, RH% → C_T^2 parameter

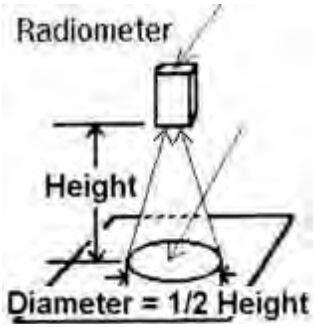
Z_{LAS}, Z_{crop}, U, Z_U + MOS theory + C_T^2 parameter

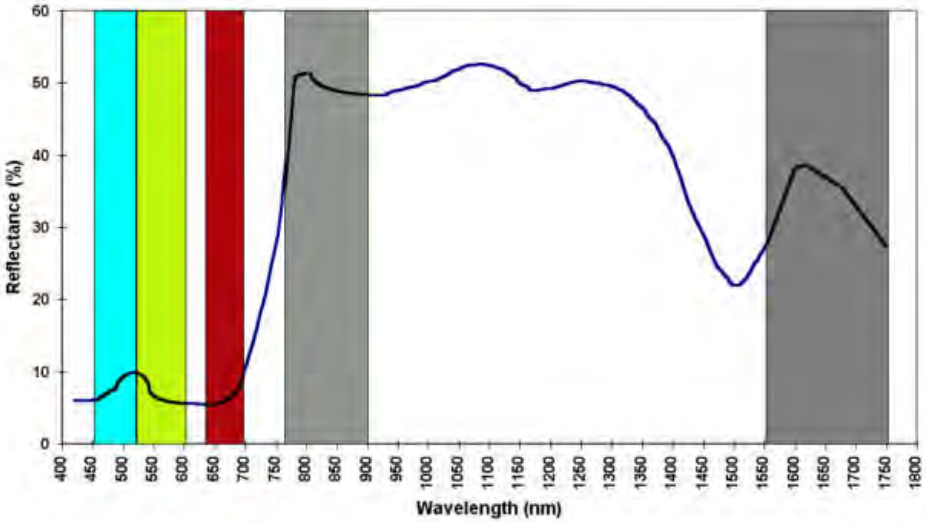
→ T_*, u_*, L_{mo}, H

LE = Rn – G - H

$$H = \rho C_p \, b(z-d) \sqrt{\frac{g}{T}} \left(C_T^2 \right)^{3/4}$$

Multispectral Radiometer (MSR5)





MSR5 data used for in-situ estimates of Rn, G, VI, LAI, fc, and calibration/verification of Satellite imagery.

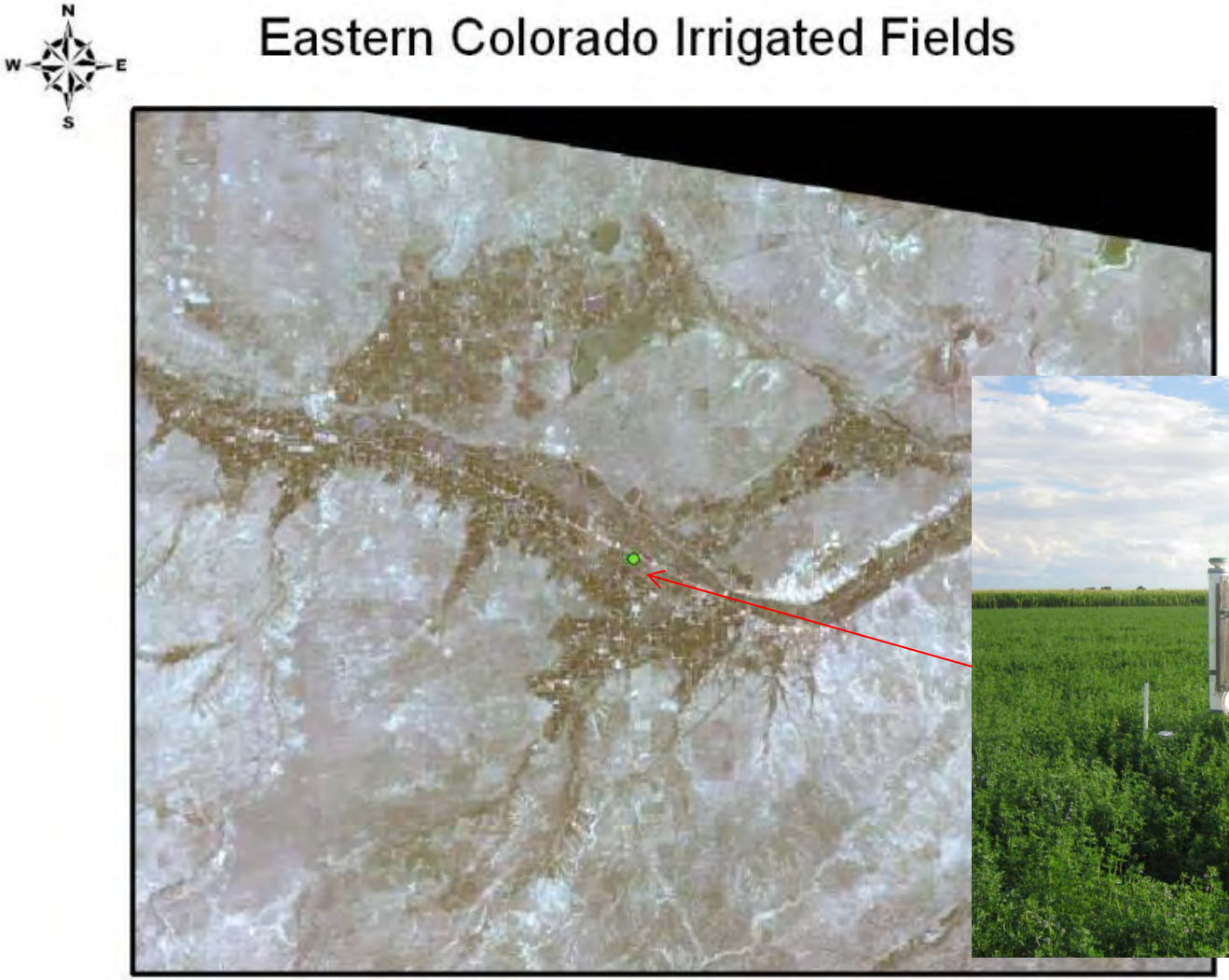
CO East Slope

Fields:

- AVRC, Rocky Ford
  - Corn, alfalfa

- ARS field, Greeley
  - Corn, beans, wheat

AVRC, Rocky Ford, CO



ET measurements using a large weighing lysimeter

Alfalfa on large lysimeter (2008-2012)

CSU
Arkansas Valley Research Center

Corn on large lysimeter (2013-2014)

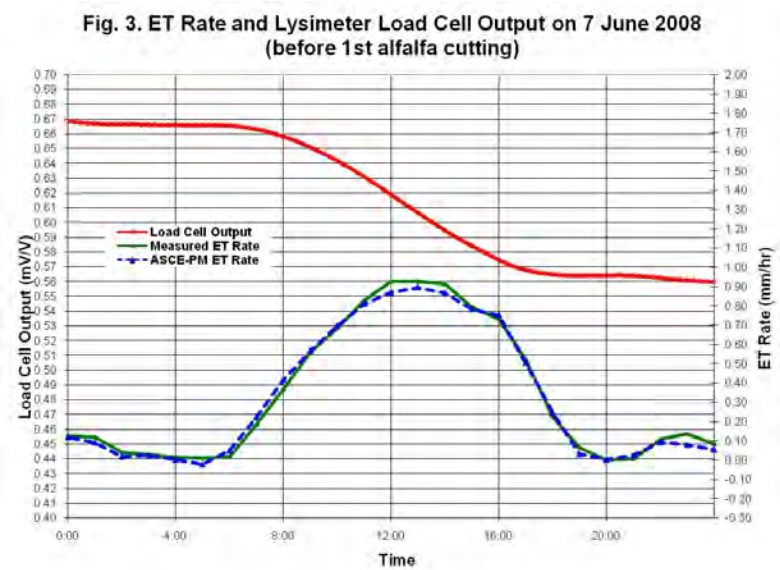
Measurements at lysimeter site: Ta, RH, U, RH%, Ts (IRT), Rn, G, VWC-SM, Rs, hc, PAR, pics.

Soil Water balance to obtain ET values with Lysimetric data

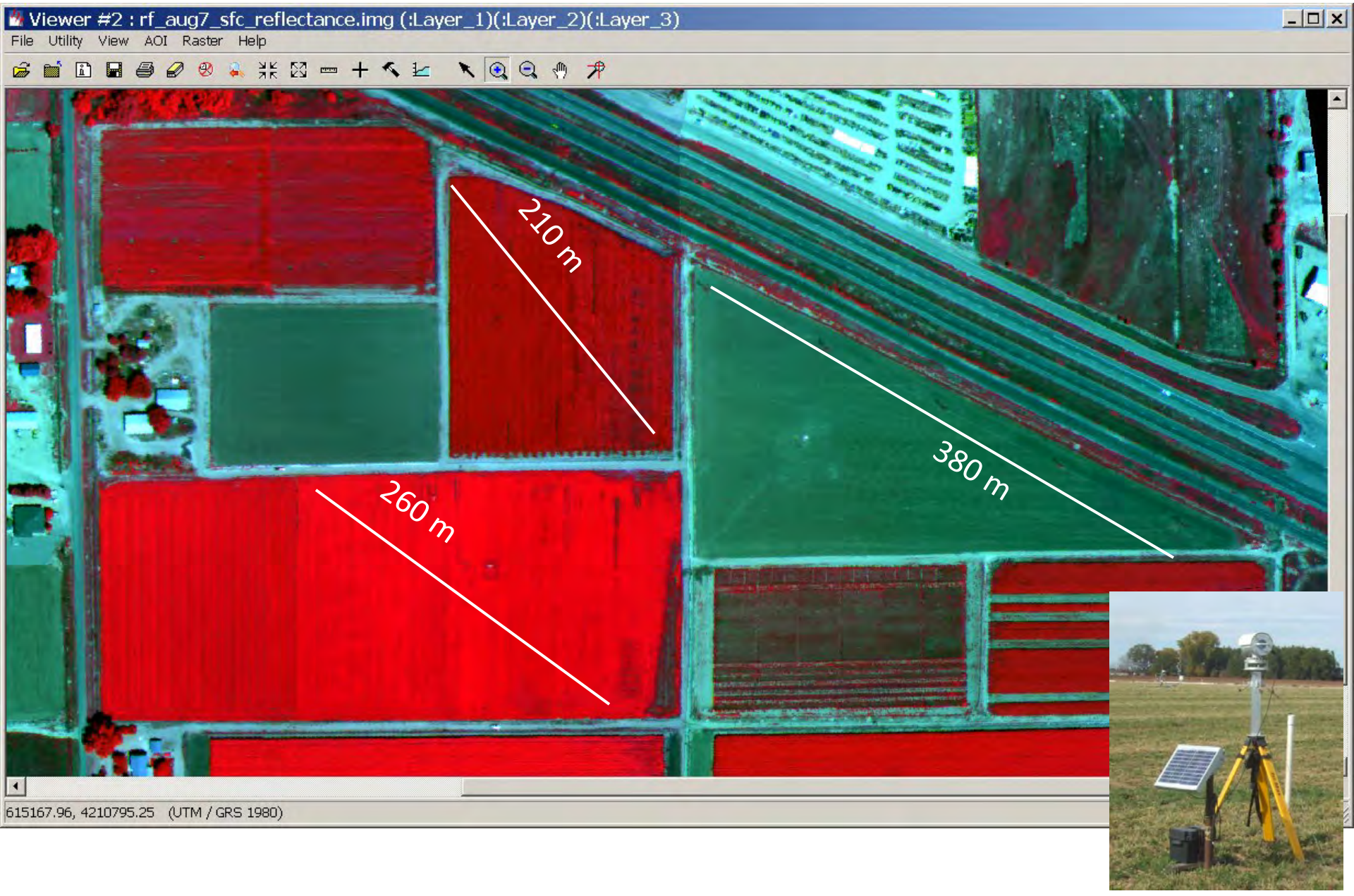
Water balance of the lysimeter is calculated based on the mass gain/loss recorded, using the equation:

$$ET = P + Irr - D - \Delta S$$

ET : Evapotranspiration rate (at the lysimeter box), mm
P : Precipitation, mm
Irr : Irrigation, mm
D : Drainage, mm
ΔS : Change in mass, mm



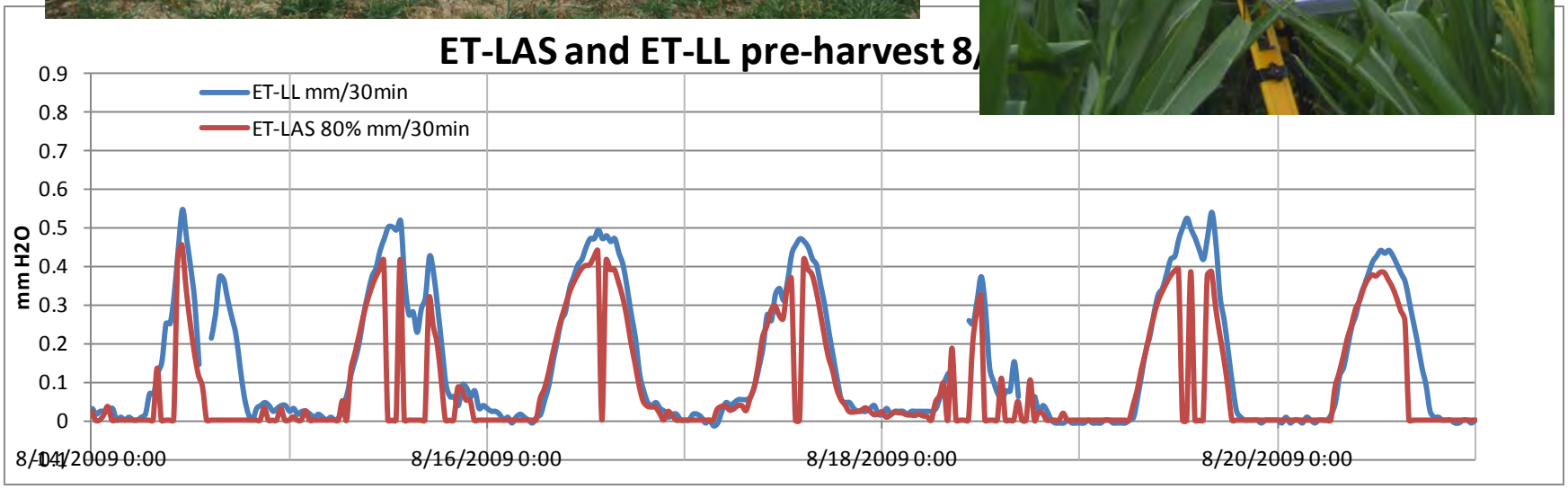
2010 LAS units



LAS systems at AVRC

(10/30/2010)

(7/14/2010)



Bowen Ratio Energy Balance (BREB) System near Greeley, CO

Crops: wheat, beans, corn
Years: 2008, 2009, 2010, 2011, 2012

$$LE = \frac{R_n - G}{1 + \beta}$$

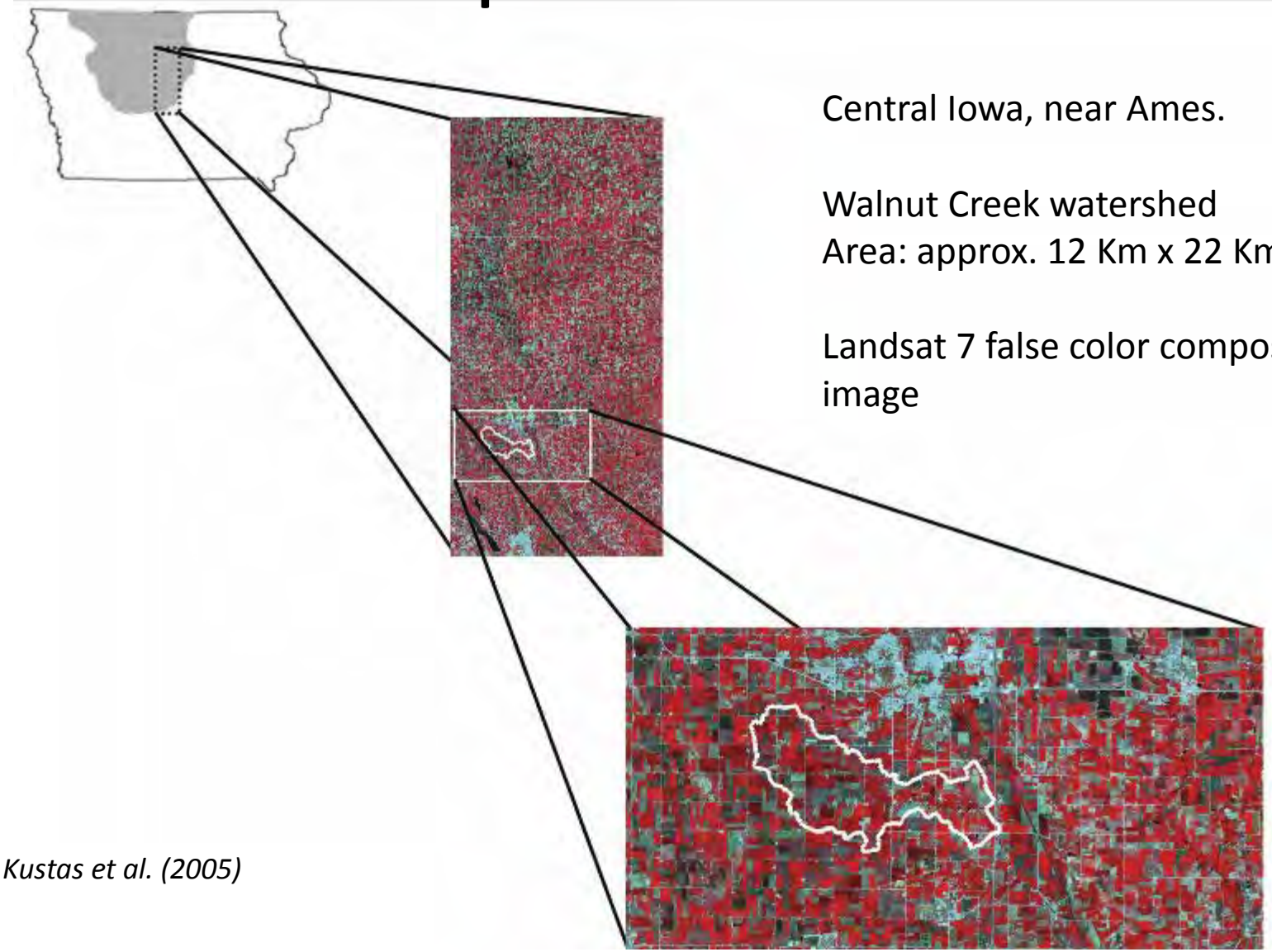
$$H = \frac{\beta}{1 + \beta}(R_n - G)$$

$$\beta = \frac{H}{LE} = \frac{-\rho_a C_p K_H \left(\frac{\Delta T}{\Delta z}\right)}{-\frac{\rho_a}{\gamma} C_p K_W \left(\frac{\Delta e}{\Delta z}\right)}$$

Iowa 2002 SMACEX Data

- Description of Experiment can be found at: *Kustas, W. P., J. L. Hatfield, and J. H. Prueger, 2005: The Soil Moisture–Atmosphere Coupling Experiment (**SMACEX**): Background, hydrometeorological conditions, and preliminary findings. J. Hydrometeor., **6,** 791–804.* Journal Site
- Intense data collection period: June 15 through July 9, 2002
- Surface type: corn and soybean fields
- Instruments, sensors: 12 heat flux EC towers, 2 weather stations, 20 rain guauges/Ta, Exotech Multispectrral radiometer, airborne and satellite data,
- Data type: LE, H, G, Rn, Rs, Ts, Ta, RH, U, u*, CO2, LAI, hc, VI, P, BP, SWC, Tsoil
- Airborne multispectral system flights/dates: doy 167, 169, 174, 182, 184, 189.
- Average field size: 25 ha

Iowa Experiment location



Central Iowa, near Ames.

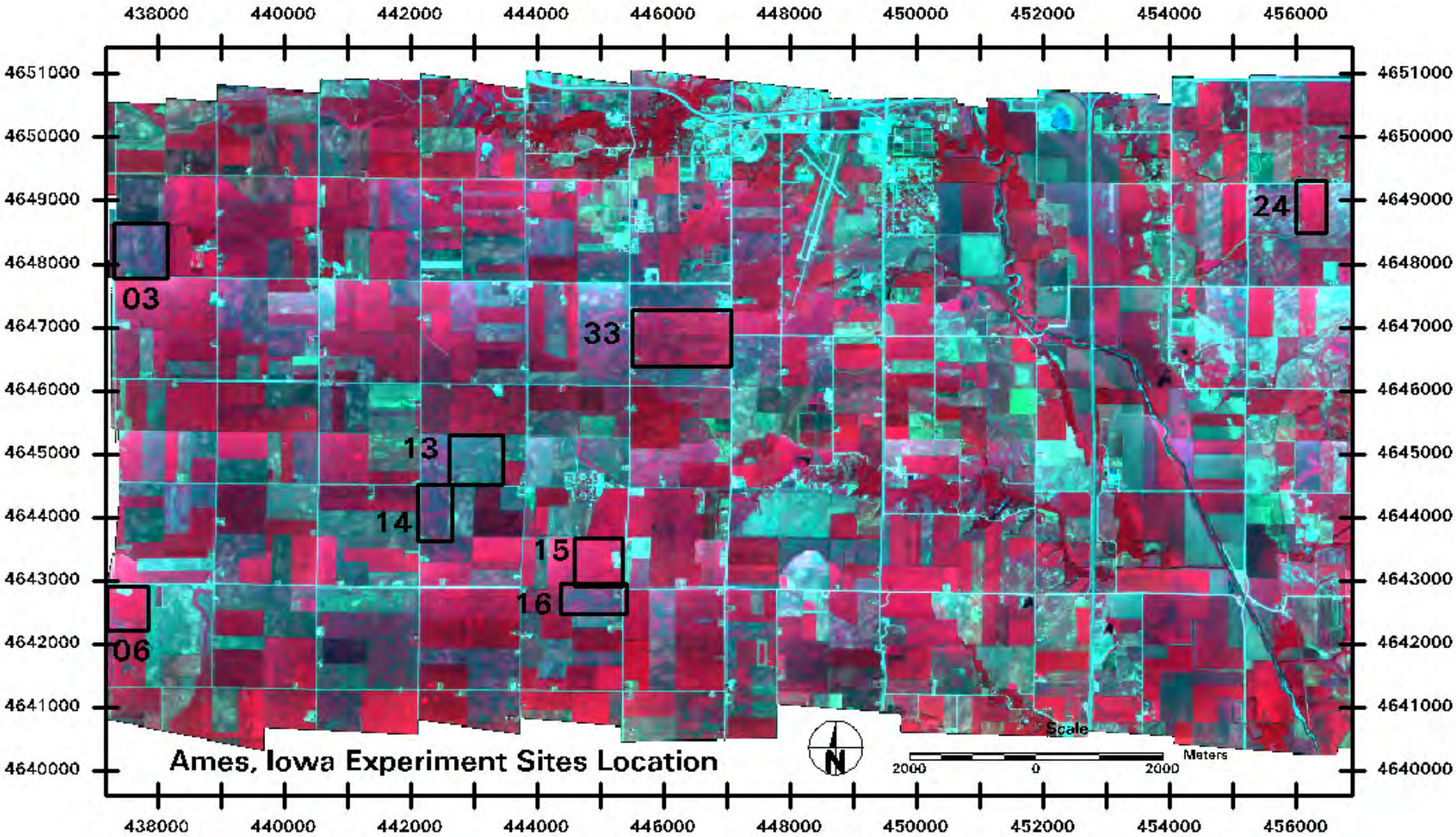
Walnut Creek watershed
Area: approx. 12 Km x 22 Km

Landsat 7 false color composite image

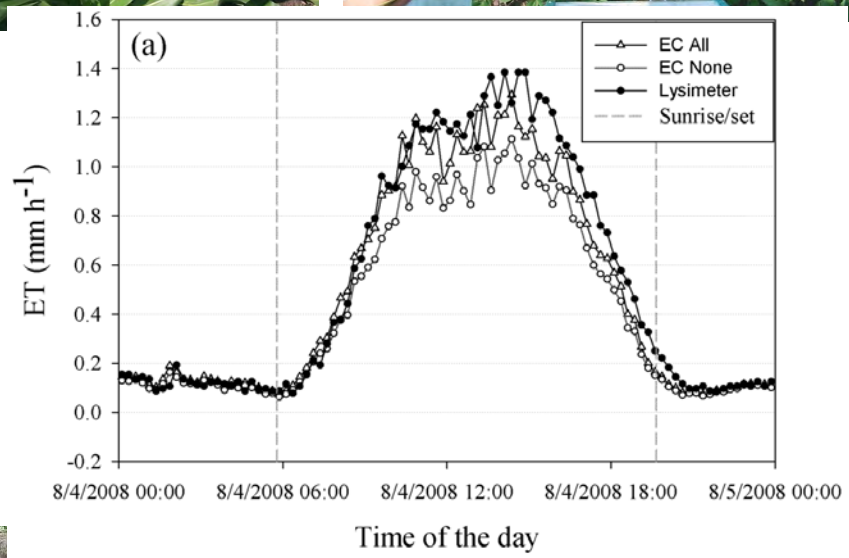
Kustas et al. (2005)

ET estimation over Corn and Soybean Fields (Iowa)

2002 NASA SMACEX – SMEX02



ET measured with Eddy covariance systems in Iowa

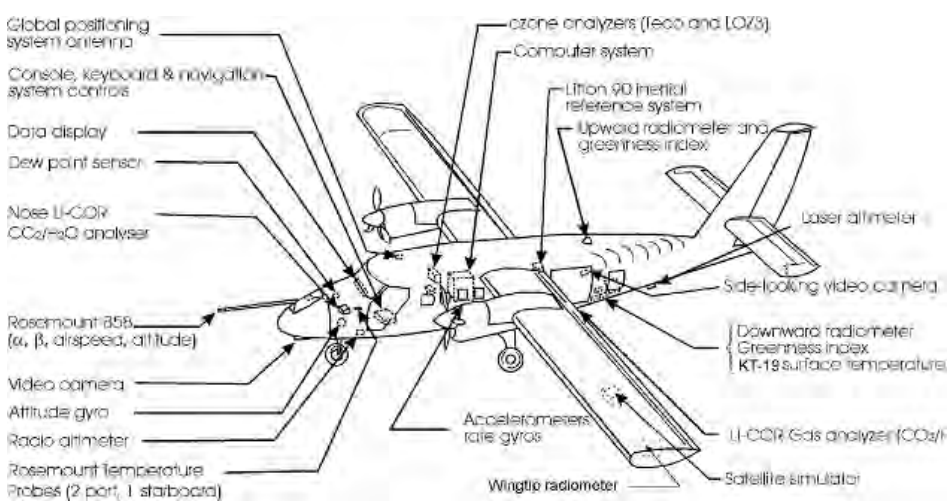


Iowa dataset example: 26 Flux x Remote sensing cases

Crop Type	Flight CST	DOY	Site #	R_n W m^{-2}	G W m^{-2}	LE W m^{-2}	H_{actual} W m^{-2}	LE_c W m^{-2}	H_c W m^{-2}	U m s^{-1}	wind dir. (degree)	u_* m s^{-1}
C	11:11	167	15.1	636	184	246	143	285.8	166.2	1.68	128.8	0.24
C	11:11	167	15.2	648	143	199	159	280.7	224.3	1.68	144.2	0.26
S	11:11	167	16.1	657	240	191	173	218.8	198.2	1.92	122.3	0.30
S	11:11	167	16.2	623	258	215	183	197.2	167.8	1.92	139.4	0.47
C	15:12	167	15.1	548	139	223	96	285.9	123.1	1.54	149.4	0.24
C	15:12	167	15.2	578	107	173	98	300.7	170.3	1.67	175.7	0.28
S	11:32	167	16.1	656	212	174	175	221.4	222.6	2.17	133.6	0.25
S	11:32	167	16.2	625	228	177	151	214.2	182.8	2.25	143.6	0.39
C	11:45	167	6	672	248	250	135	275.3	148.7	1.66	128.2	0.06
C	10:42	167	33	609	194	174	146	225.7	189.3	2.90	129.7	0.27
C	10:15	169	15.1	537	138	212	110	262.6	136.3	5.69	292.8	0.71
C	10:15	169	15.2	544	112	207	149	250.6	180.7	5.76	310.5	0.67
C	9:38	174	15.2	502	58	272	77	346.0	98.0	5.14	211.0	0.59
S	9:38	174	16.1	530	118	257	134	270.8	141.2	5.50	195.0	0.60
S	9:38	174	16.2	486	140	258	104	246.6	99.4	6.64	217.0	0.57
C	10:05	174	15.2	565	49	367	92	412.6	103.4	5.44	205.0	0.68
S	10:05	174	16.1	581	144	280	160	278.1	158.9	6.02	197.0	0.67
S	10:05	174	16.2	543	146	274	131	268.6	128.4	7.27	215.0	0.62
C	10:43	184	15.1	568	72	418	85	412.2	83.8	2.17	247.0	0.40
C	10:43	184	15.2	530	27	323	84	399.2	103.8	2.31	247.0	0.39
S	10:43	184	16.1	563	85	282	127	329.6	148.4	2.91	195.0	0.30
S	10:43	184	16.2	534	79	300	110	332.9	122.1	3.26	221.0	0.33
C	10:48	189	15.1	620	97	419	8	513.2	9.8	3.27	256.0	0.59
C	10:48	189	15.2	600	48	417	23	523.1	28.9	3.37	255.0	0.57
S	10:48	189	16.1	611	85	417	2	523.5	2.5	4.17	226.0	0.47
S	10:48	189	16.2	600	91	476	9	499.6	9.4	4.60	241.0	0.49

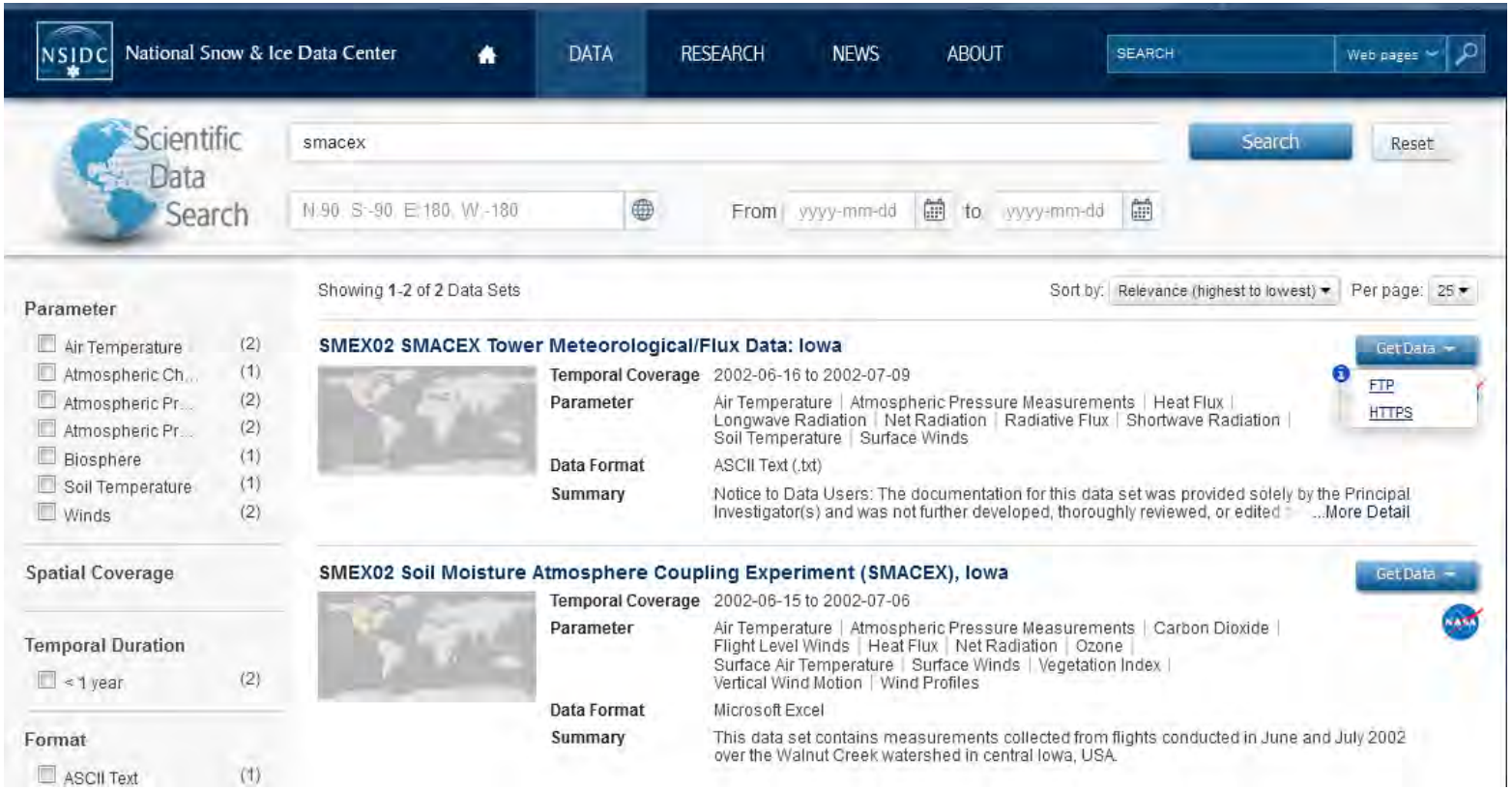
Iowa datasets sources (1)

- MacPherson, I. 2004. *SMEX02 Soil Moisture Atmosphere Coupling Experiment (SMACEX), Iowa*. [indicate subset used]. Boulder, Colorado USA: NASA National Snow and Ice Data Center Distributed Active Archive Center. doi: 10.5067/HX0S0ONCL8Y6.
- http://nsidc.org/data/docs/daac/nsidc0232_smex_smacex.gd.html
- Measurements: Air, dew point, and radiometric temperatures, greenness index, net radiation, CO_2 concentration, wind direction, wind speed, sensible heat flux, latent heat flux, CO_2 flux, friction velocity from momentum flux, and ozone flux



Iowa datasets sources (2)

- Flux tower data
- http://nsidc.org/data/search/#keywords=smacex/sortKeys=score,,desc/facetFilters=%257B%257D/pageNumber=1/itemsPerPage=25



Dataset on FTP site for download

Index of ftp://sidads.colorado.edu/pub/DATASETS/AVDM/data/soil_moisture/SMEX02/meteorological/SMACEX_tower/

Up to higher level directory

Name	Size	Last Modified	
00README.txt	3 KB	12/16/2009	12:00:00 AM
7500Letter.pdf	158 KB	7/18/2003	12:00:00 AM
AN03.txt	375 KB	3/9/2004	12:00:00 AM
AN06.txt	371 KB	3/9/2004	12:00:00 AM
AN13.txt	401 KB	3/9/2004	12:00:00 AM
AN14.txt	400 KB	3/9/2004	12:00:00 AM
AN151.txt	391 KB	3/15/2004	12:00:00 AM
AN152.txt	374 KB	3/9/2004	12:00:00 AM
AN161.txt	400 KB	3/9/2004	12:00:00 AM
AN162.txt	397 KB	3/9/2004	12:00:00 AM
AN23.txt	396 KB	3/9/2004	12:00:00 AM
AN24.txt	374 KB	3/9/2004	12:00:00 AM
AN25.txt	372 KB	3/9/2004	12:00:00 AM
AN33.txt	408 KB	3/9/2004	12:00:00 AM
EC03.txt	89 KB	3/9/2004	12:00:00 AM
EC06.txt	67 KB	3/9/2004	12:00:00 AM
EC13.txt	75 KB	3/9/2004	12:00:00 AM
EC14.txt	68 KB	3/9/2004	12:00:00 AM
EC151.txt	69 KB	3/9/2004	12:00:00 AM
EC152.txt	76 KB	3/9/2004	12:00:00 AM
EC161.txt	70 KB	3/9/2004	12:00:00 AM

Texas BEAREX

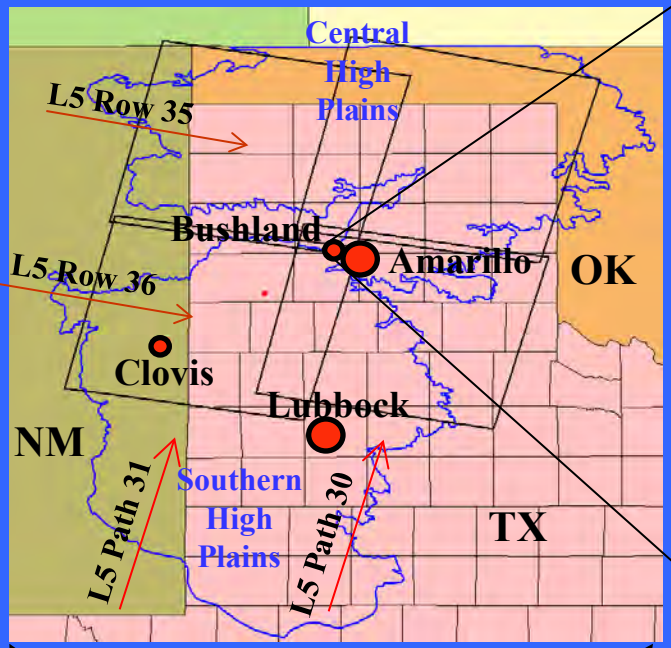
BEAREX 2008: Cotton fully irrigated and dryland fields (lysimeters, EC, BR, LAS, NP)

Advances in Water Resources
Volume 50, Pages 1-178 (December 2012), link:
http://www.sciencedirect.com/science/journal/03091708/50/supp/C

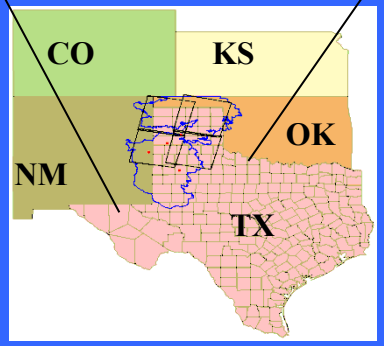
The Bushland Evapotranspiration and Agricultural Remote Sensing Experiment 2008 Edited by William Kustas, Susan Moran and Tilden Meyers

BEAREX 2007: Corn, sorghum fully irrigated and dryland fields (lysimeters, NP)

Study Area



Landsat Satellite Path and Rows for Texas Panhandle



Texas, USA

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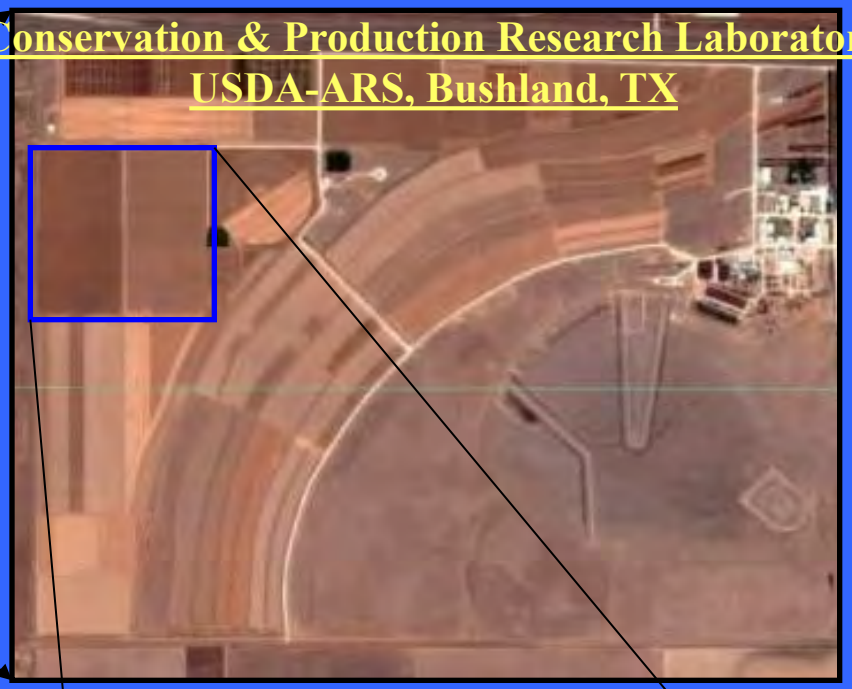
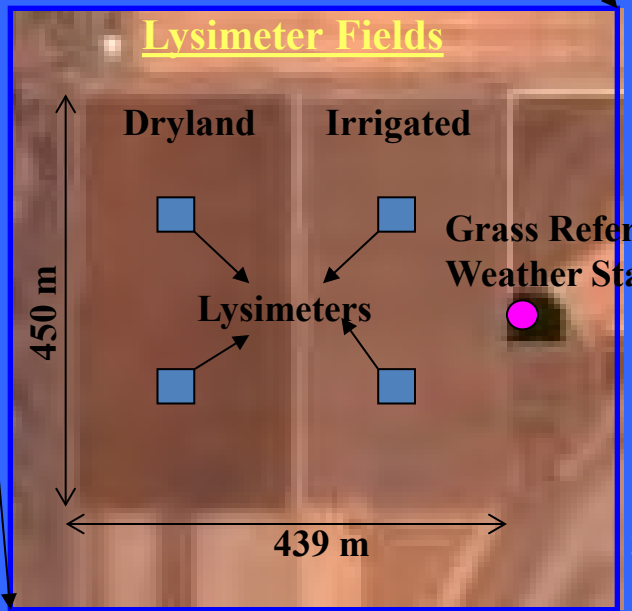
Conservation & Production Research Laboratory
USDA-ARS, Bushland, TX

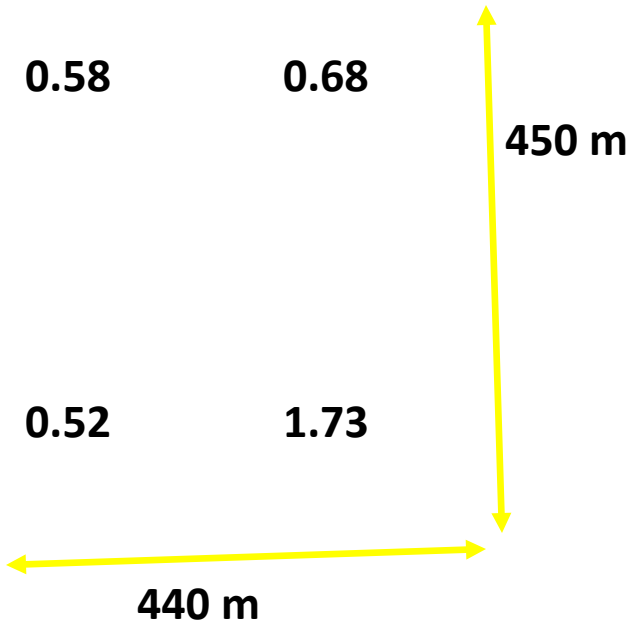




ARS-BUSHLAND Weighing Lysimeters

2007 Reflectance Imagery (0.5 m)

June 25, 2007, DOY 176



Reflectance image calibrated with Barium Sulfate panel data

Thermal image calibrated with MODTRAN 4 v3

DOY 176, 184, 191, 192, 207 and 223

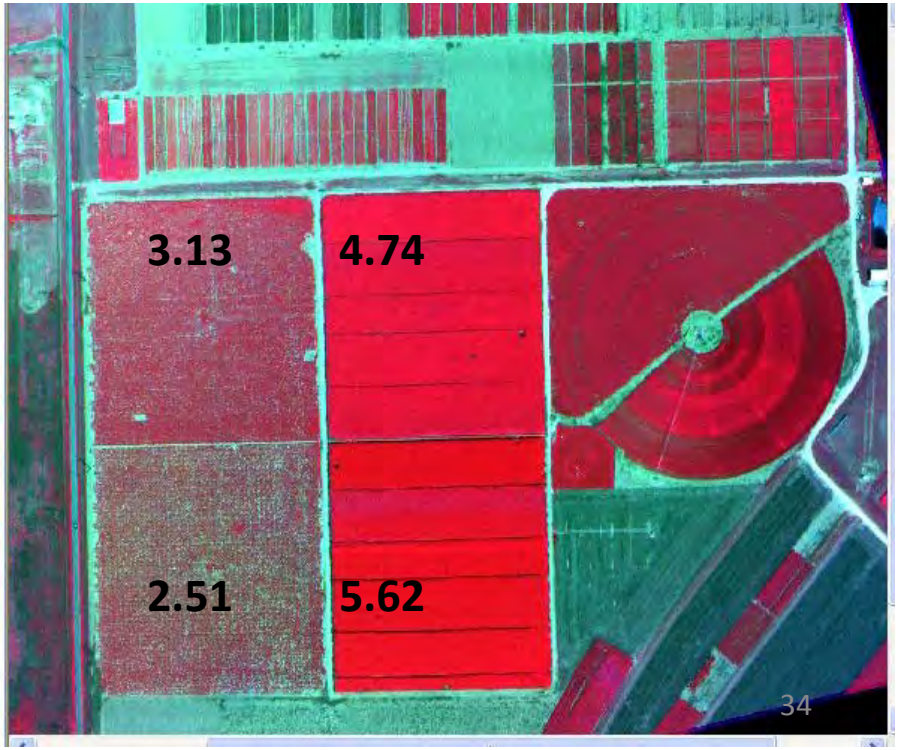
NE ➔ Sorghum (forage)

SE ➔ Corn (forage)

NW ➔ Sorghum (grain/rows)

SW ➔ Sorghum (grain/clumped)

July 26, 2007, DOY 207




SW Lysimeter
EC SW5
Shadow of the aerodynamic (wind/temperature/RH) profile tower
07/07/2008

Days with available EC data (per month)

Site	May	June	July	Aug	Sept	Oct
1 NE	19-30	11-30	1-7, 9-11, 15-31	1-14	6-30*	1-3*
2 SE	19-30	3-18, 23-30	1-11, 13-20, 22-31	1-**13**, 29-31	1-30	1-9
3 NW	19-30	5-30	1-7, 9-11, 13-31	1-14	13-30	1-6
4 Grass	20-30	4-18, 23-30	1-11, 13-31	1-14, 21-29	13-30	1-9
5 SW	19-30	5-18, 22-30	1-11, 13-31	1-15	5-30	1-9
6 Tower	22-30	4-18, 22-30	1-11, 13-31	1-31	1-10, 12-30	1-9
7 WW	21-30	8-30	1-11, 13-31	1-31	1-10, 27-30	1-9
8 NE	20-30	7-30	1-31	1-31	1-30	1-9
9 SE	20-30	20-26	1-31	1-31	1-30	1-9

*Flux mode only.

San Luis Valley, CO

- Potato field (Mountain King Potatoes Farm near Monte Vista, CO), center pivot irrigated, 2015-2016, SMS, LAS
- One quarter of field irrigated with CP, ¼ of field irrigated with drips,
- Collaborators: Dr. Samuel Essah and Dr. Allan Andales.

Methodology

- Obtaining T_{aero} from measured H,
- Understanding the influence of VI, density, arrangement, fc or % cover, wind speed/direction/deviation on H and T_{aero}.
- Modeling T_{aero} with in-situ (ground-based) and RS data.
- Verification of model with independent datasets.

Remote sensing models for ET

- ***Energy balance equation*** to estimate ET.

$$\mathbf{R_n - LE - G - H = 0}$$

- Modeling R_n, G and H, then determining **LE** as a residual,

- Several models have been developed; SEBAL, METRIC, ReSET, SAT, ALARM, Hybrid models, etc.

Net Radiation, R_n

$$R_n = (1 - \alpha)\, R_{sw\downarrow} + R_{L\downarrow} - R_{L\uparrow}$$

albedo , α

$R_{sw\downarrow}$

$R_{L\uparrow}$

reflectance, ρ_λ

ε_o

T_{sfc}

radiance, L_λ

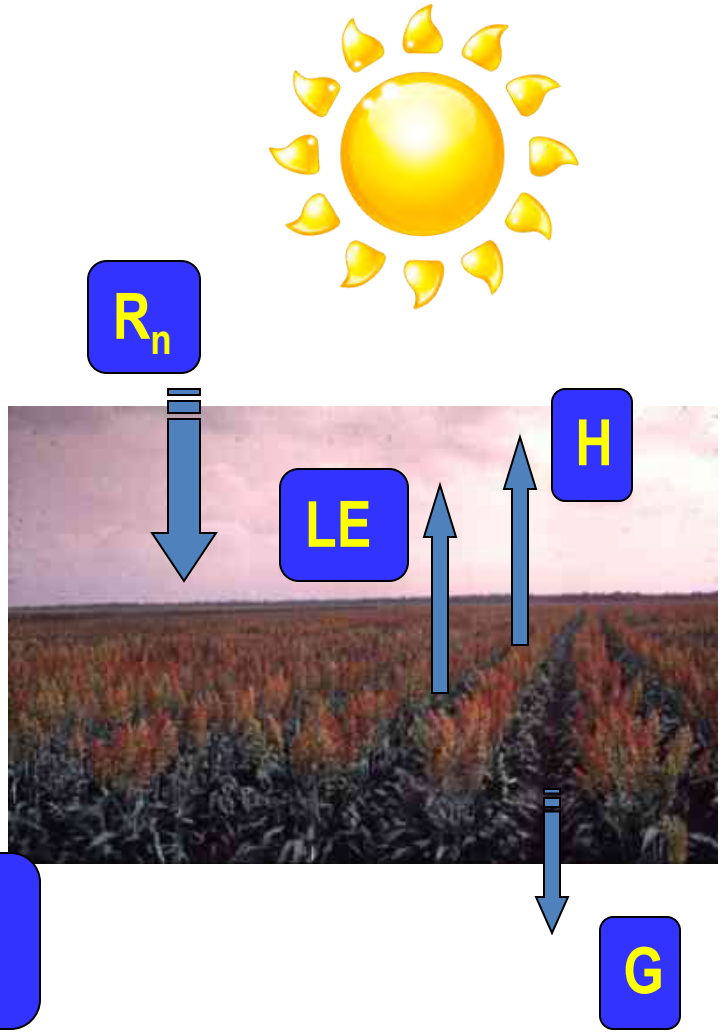
fc

T_{bb}

RED, NIR, VIS bands images

NDVI, OSAVI, LAI

Thermal image



Estimates of Rn are very accurate

Soil Heat Flux, G

$$G = 0.35\ \mathbf{R_{n,SOIL}}$$

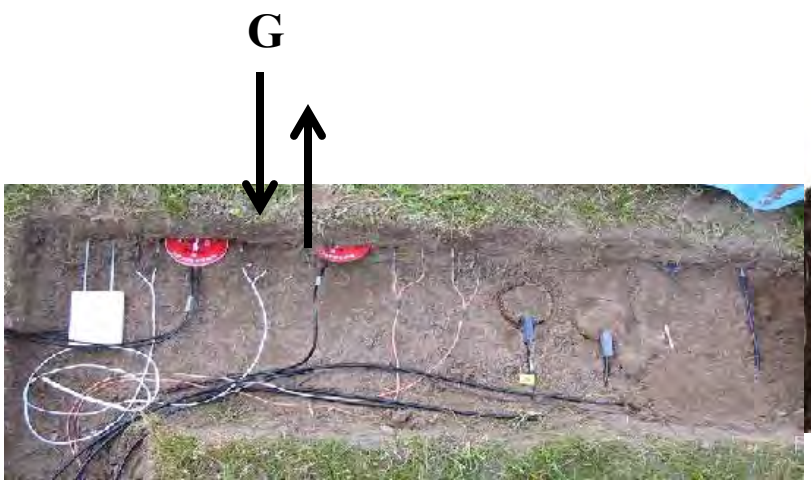
(Choudhury et al., 1987)

$$G = ((\mathbf{T_s} - 273.15)\ (0.0038 + 0.0074\ \boldsymbol{\alpha})\ (1 - 0.98\ \mathbf{NDVI}^4))\ \mathbf{R_n}$$

(Bastiaanssen, 2000)

$$G = [(0.3324 - 0.024\ \mathbf{LAI})\ (0.8155 - 0.3032\ \mathrm{Ln}(\mathbf{LAI})]\ \mathbf{R_n}$$

(Chávez et al., 2005)



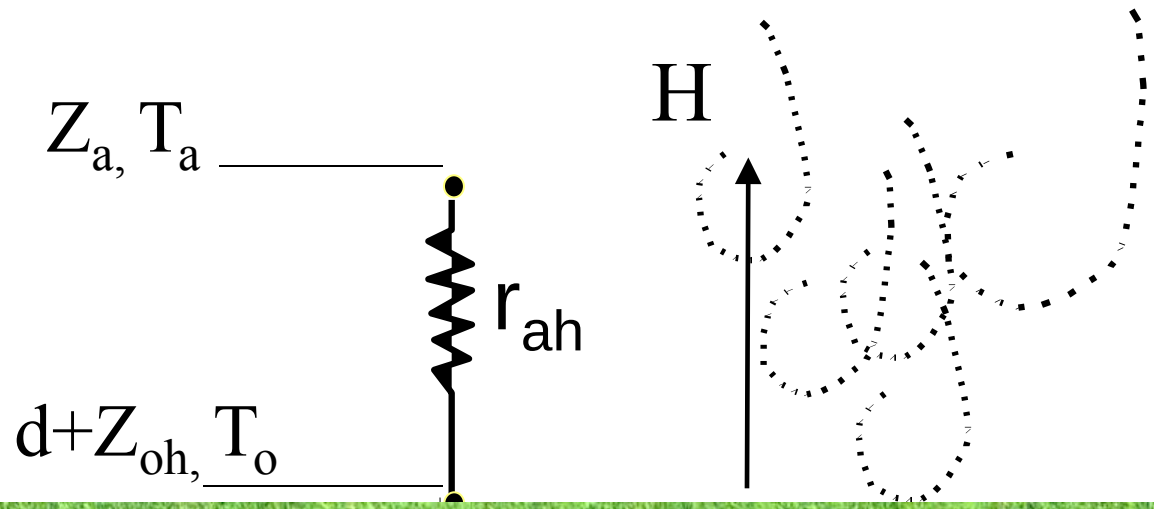
Performance evaluation, of several G models, over a range of percent vegetation covers is needed.

One Source: Sensible Heat Flux (H)

$$H = \rho \times c_p \times (T_o - T_a) / r_{ah}$$

r_{ah} = the aerodynamic resistance to heat transport (s/m),
c_p is the specific heat capacity of the air (1004 J/kg/K),
ρ is air density (kg/m^3),
T_o = surface aerodynamic temperature (K),
T_a = air temperature (K)

$$r_{ah} = \frac{\ln\left(\frac{z_a - d}{z_{om}}\right)\ln\left(\frac{z_a - d}{z_{oh}}\right)}{u \times k^2}$$



- Invert the equation for H and solve it for T_o
- Obtain friction velocity (u_*) and roughness length for momentum transfer (Z_{om}) from micro-met stations

Calendar of Activities

Objective	Fall 2015 (summer)	Spring 2016	Fall 2016 (summer)	Spring 2017	Fall 2017 (summer)	Spring 2018
1. Document ET seasonal	Part done	x	x		x	
2. Irrigation Efficiency		x				
3. Saved CU		x				
4. RS of ET			x	x	x	
5. ET modeling			x	x	x	x
Final Report						x

Tasks performed (Fall 2015)

Project Duration: July 1st, 2015 - June 30th, 2018

- Recruiting graduate student (PhD), GS6
- Crop ET models review and summary
- Training on remote sensing of ET (ReSET)
- Application of ReSET to potato field (SLV)

Graduate Student GS6

GS 6 Worksheet and Advising Form: CSU ID: 83[illegible]

Name: Mahmoud Osman

Semester Advised for: Sp 2016

Adviser signature: Jose J. Chavez

Degree: PhD

Required courses taken prior to admission:

Course	Cr.	Term to be taken

Required courses taken after admission:

Course	Cr.	Term to be taken		Course
CIVE 520	3	Fall 2015		
CIVE 625	3	Fall 2015		
GR 503	4	Fall 2015		
SOCR 522	3	Spring 2016		
CIVE 799J	4	Spring 2016		
CIVE 425	3	Spring 2016		
HORT 571	3	Spring 2016		

Thesis/Dissertation (Yes) or No

If a master's degree is to be used as part of the Ph.D.:

Year of Masters degree	Institution
2015	Faculty of Engineering - Cairo University

Transfer Courses:

Course No	Cr.	Term and Year Taken			Institution	

Committee Adviser: Jose Chavez

Dept. CEE

Spring Semester 2016

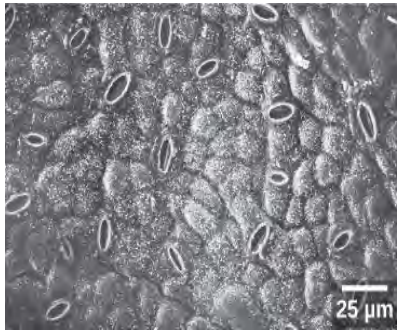
CRN	Course	Course Title	Credits	Level
12138	CIVE 425	Soil and Water Engineering	3.000	Graduate
12139	CIVE 425	Soil and Water Engineering - Lab	0.000	Graduate
26511	ENGR 522	Object-Oriented GIS Programming for Engineers	3.000	Graduate
25194	HORT 571	Soil-Plant-Water Relations/Water Stress	3.000	Graduate
26417	SOCR 500	Environmental Measurement Laboratory	1.000	Graduate
25407	SOCR 522	Micrometeorology	3.000	Graduate

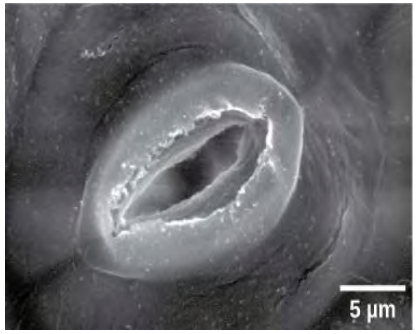
Fall Semester 2015

CRN	Course	Course Title	Credits	Level
62565	CIVE 520	Physical Hydrology	3.000	Graduate
75223	CIVE 625	Quantitative Eco-Hydrology	3.000	Graduate
70647	GR 503	Remote Sensing--Graduate	4.000	Graduate
75406	GR 503	Remote Sensing--Graduate	0.000	Graduate

Crop ET models review and summary

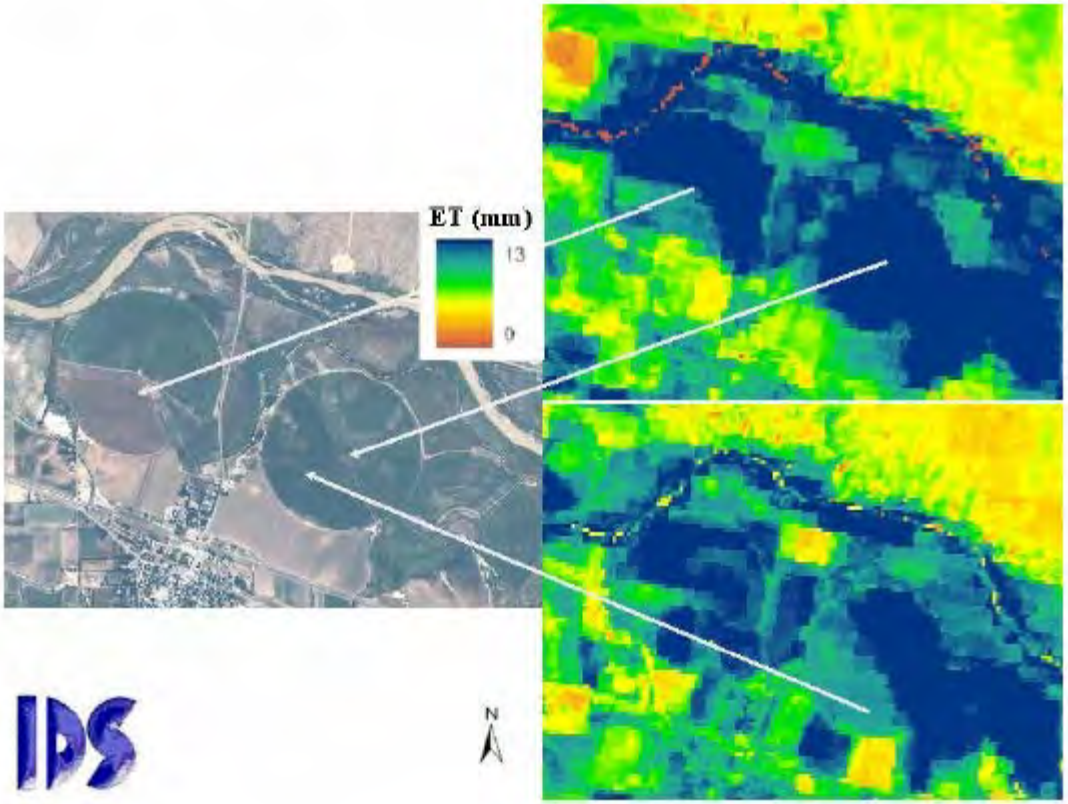
- Topics researched:
  - Plant transpiration
  - Evaporation
  - Evapotranspiration
  - Earth's energy balance
  - Ground heat flux
  - Net radiation flux
  - Sensible heat flux
  - Latent heat flux
  - Methods for potential ET estimation: pan evaporation, large aperture scintillometer, Thornwaite, Penman, Penman-Monteith, Hargreaves, Hargreaves-Samani, Priestley-Taylor, Blaney-Criddle, Turc.
  - Methods of RS of ET: SEBAL, METRIC, S-SEBI, TSM, ReSET, SAT.





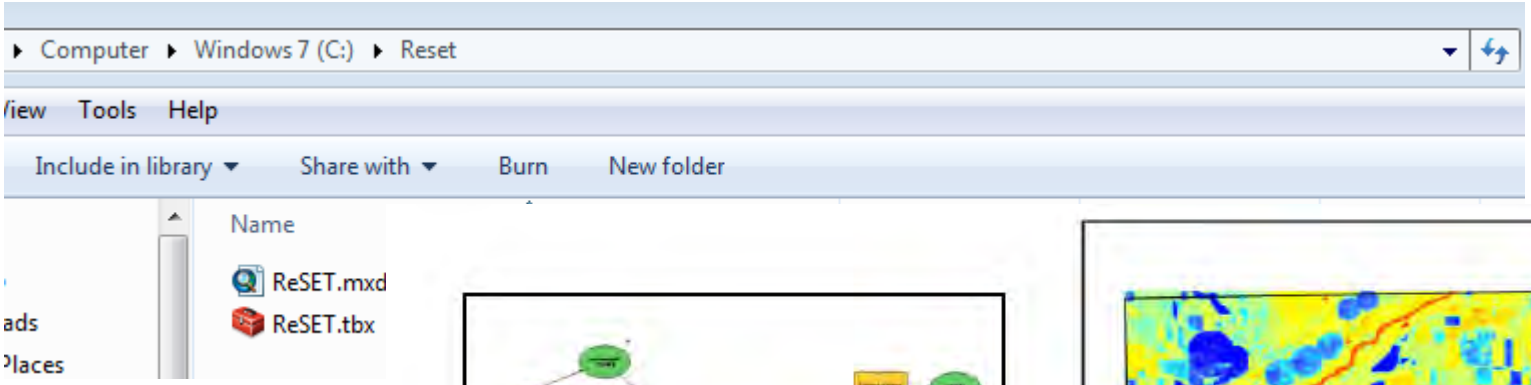
Training on remote sensing of ET (ReSET)

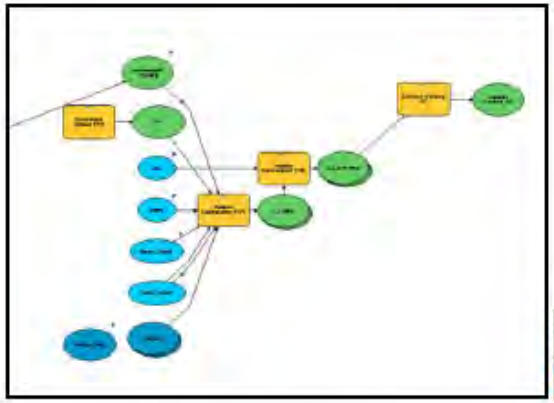
A Guide to Using ReSET for Estimating Evapotranspiration

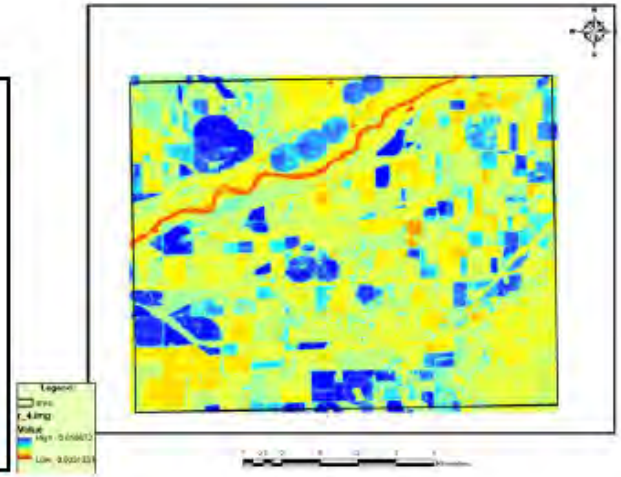


Integrated Decision Support Group (IDS)
Colorado State University

ReSET ArcGIS code (Tool Box)





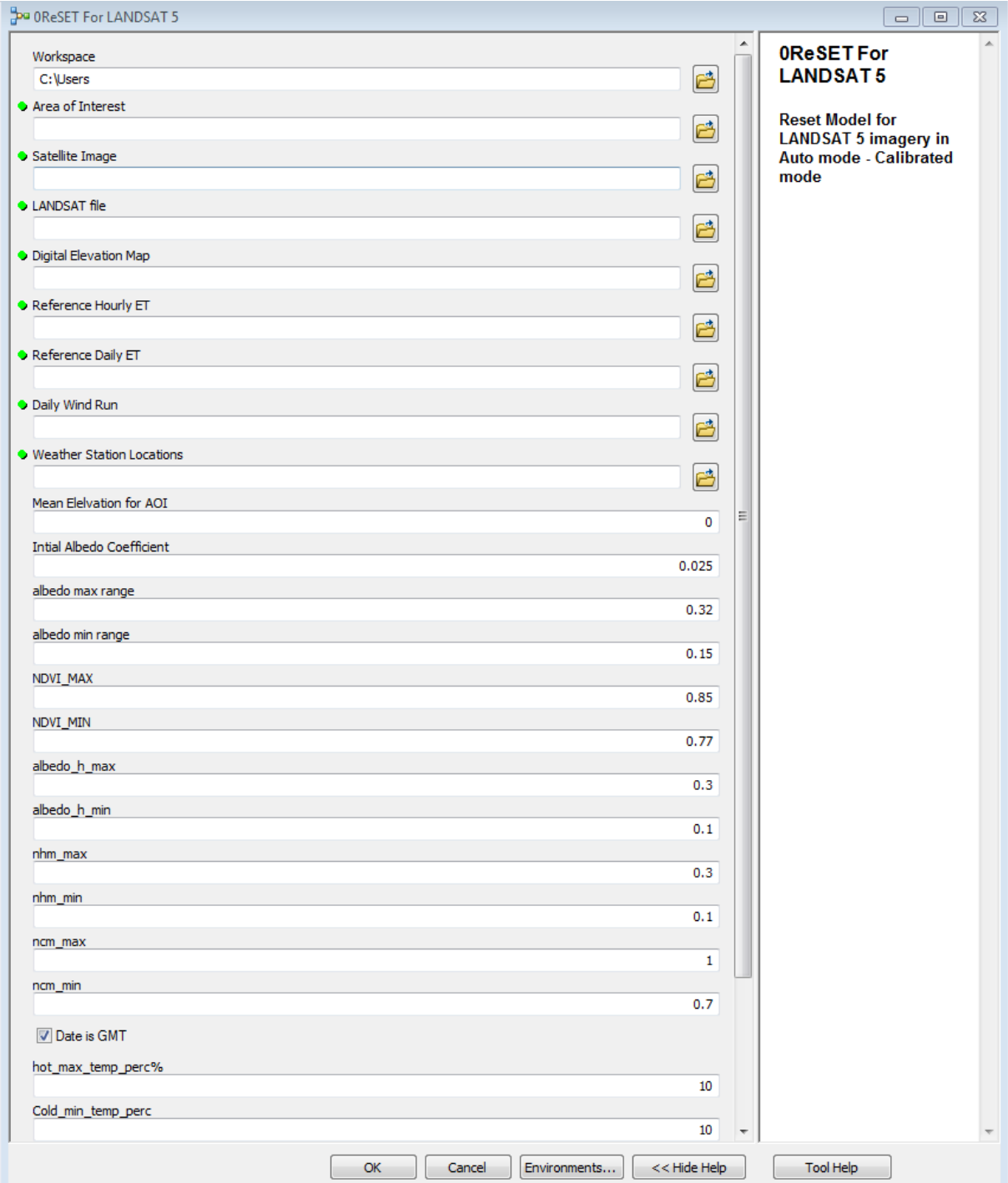


In this step, we will calculate the reflectance for all pixels in all bands except the thermal band (band 6). The band reflectance is computed by dividing the outgoing energy of the band (measured by the satellite sensor) by the incoming energy calculated from theoretical values of different wavelengths of the solar radiation.

The dr (**1.094299422**) is (The inverse relative distance between the earth and Sun) and is calculated in the model, dimensionless—this constant changes for every image because of the change of zenith angles.
Please note: Calibration constants are **different for each Landsat image type**.
For (most) Landsat 5 images:

- ref7 = (((-0.015 + (1.44 + .015) * $n1_image(7) / 255)) * PI) / (7.452 * $n2_cosine-theta * **1.094299422**)

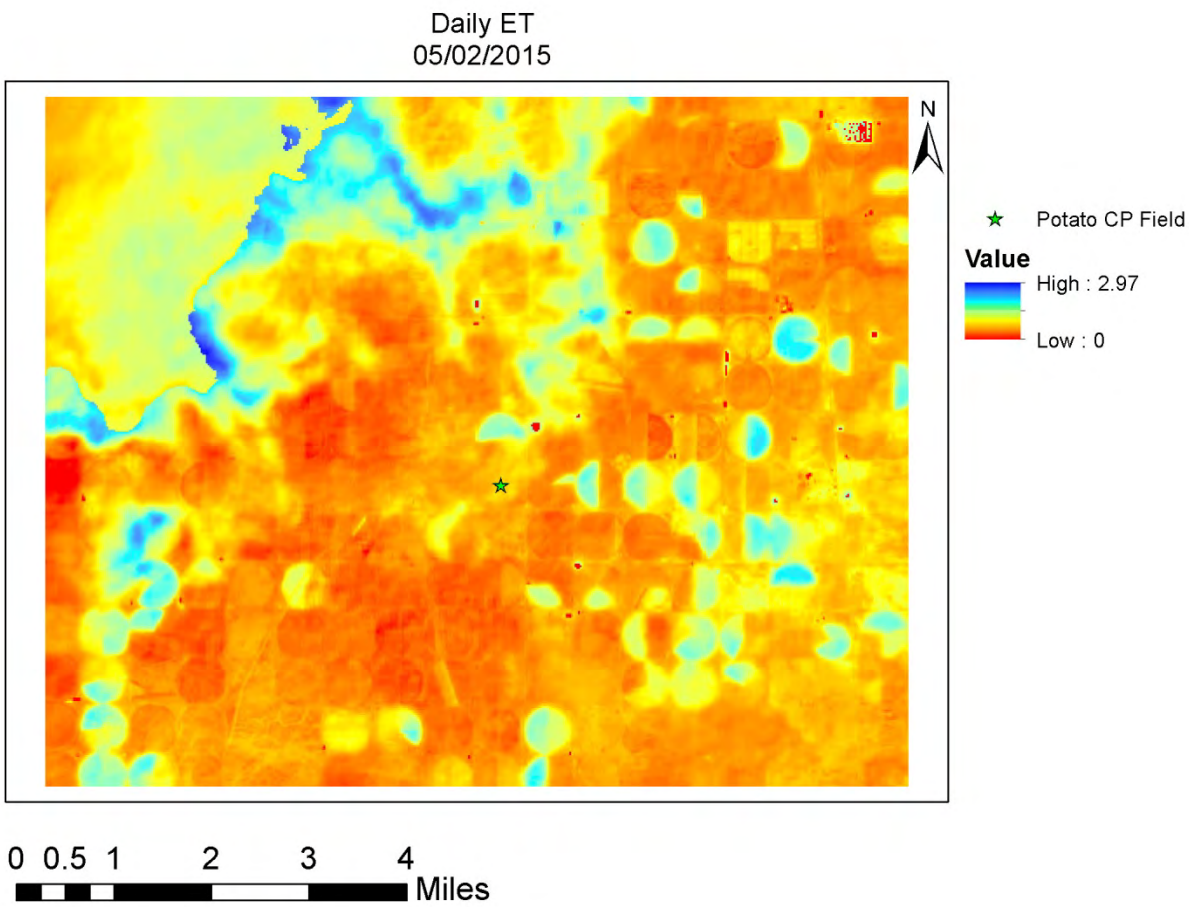
ReSET settings inputs



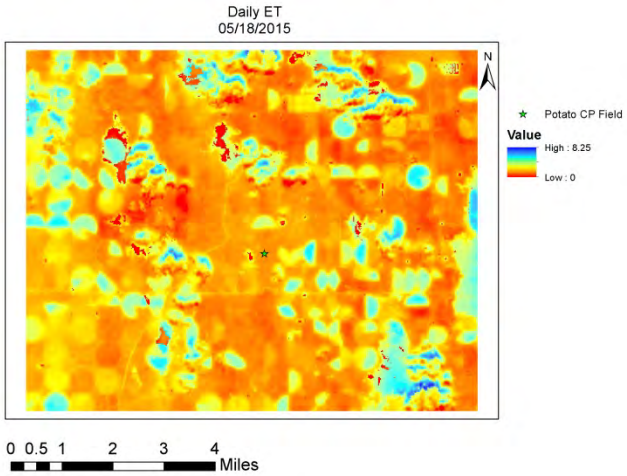
Application of ReSET to SLV-2015

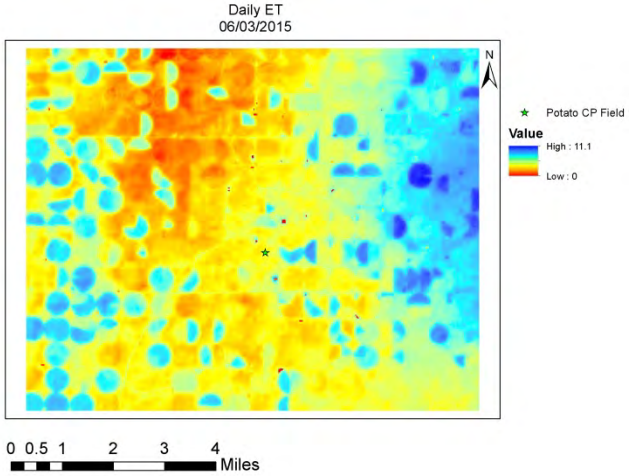
Landsat images processed (9) for: May 2, 18, June 3, 19, July 21, Aug 6, 22, Sept 7, 23.

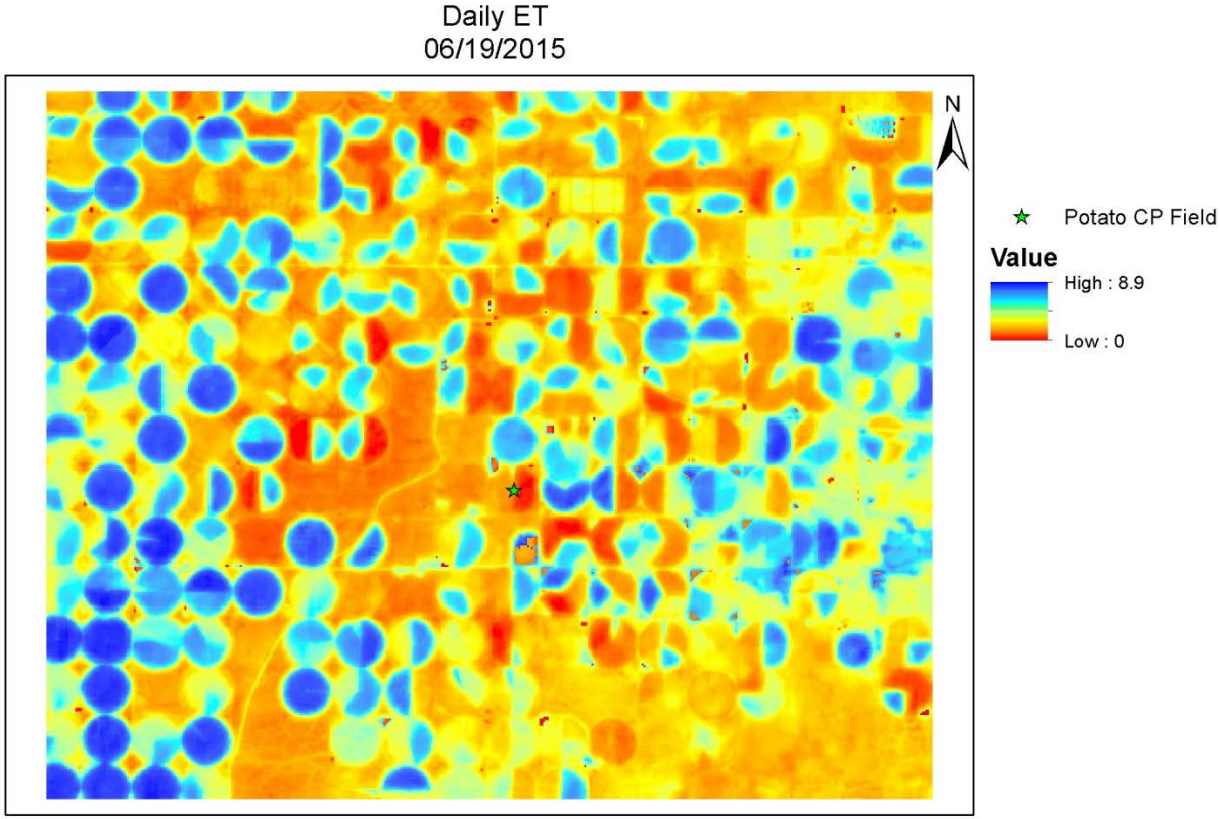
Planting: early May,
Potato chemical application to kill top part (desiccation): Sept 7. Senescence starting setting in by August 24th.
Harvest: Sept 30th.



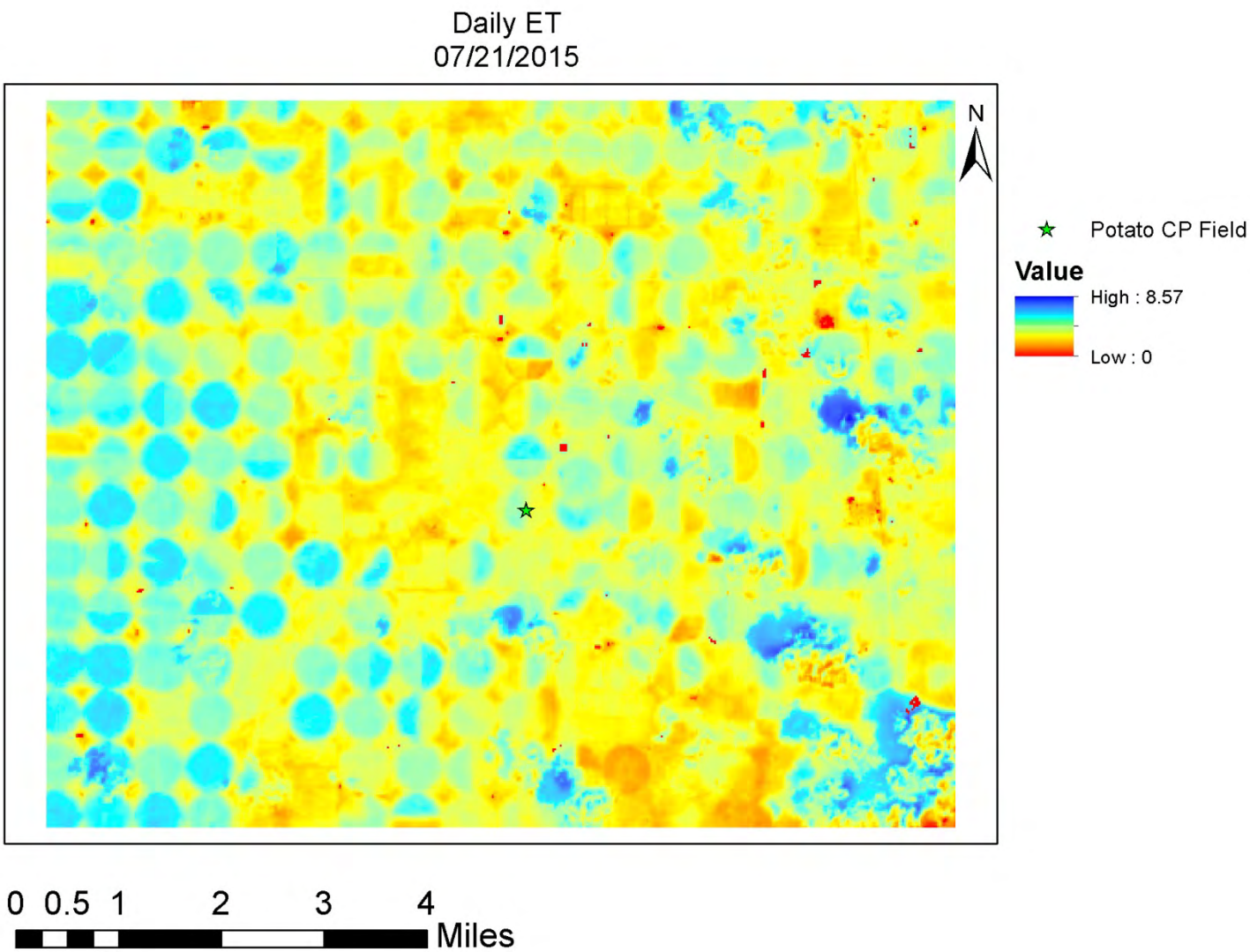
SLV-2015: daily ET, May/June



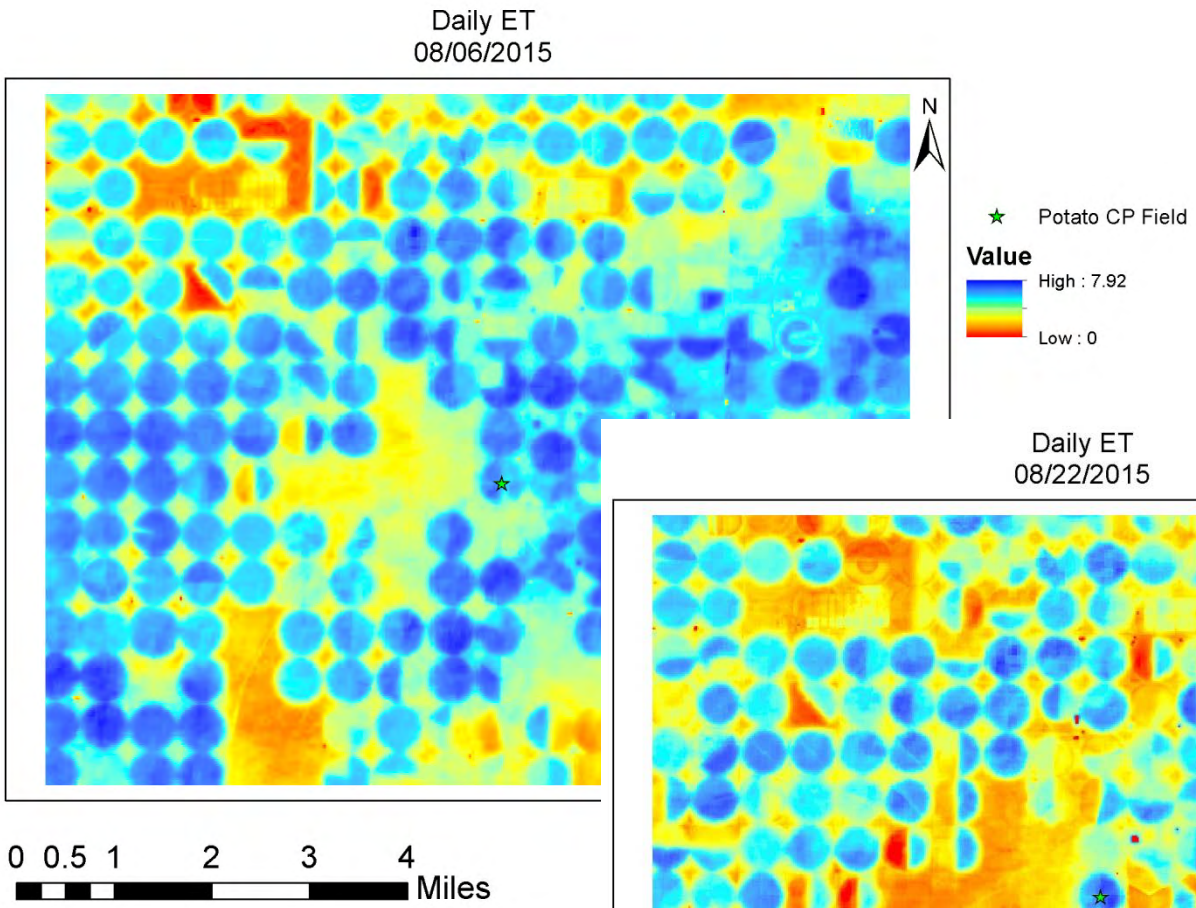


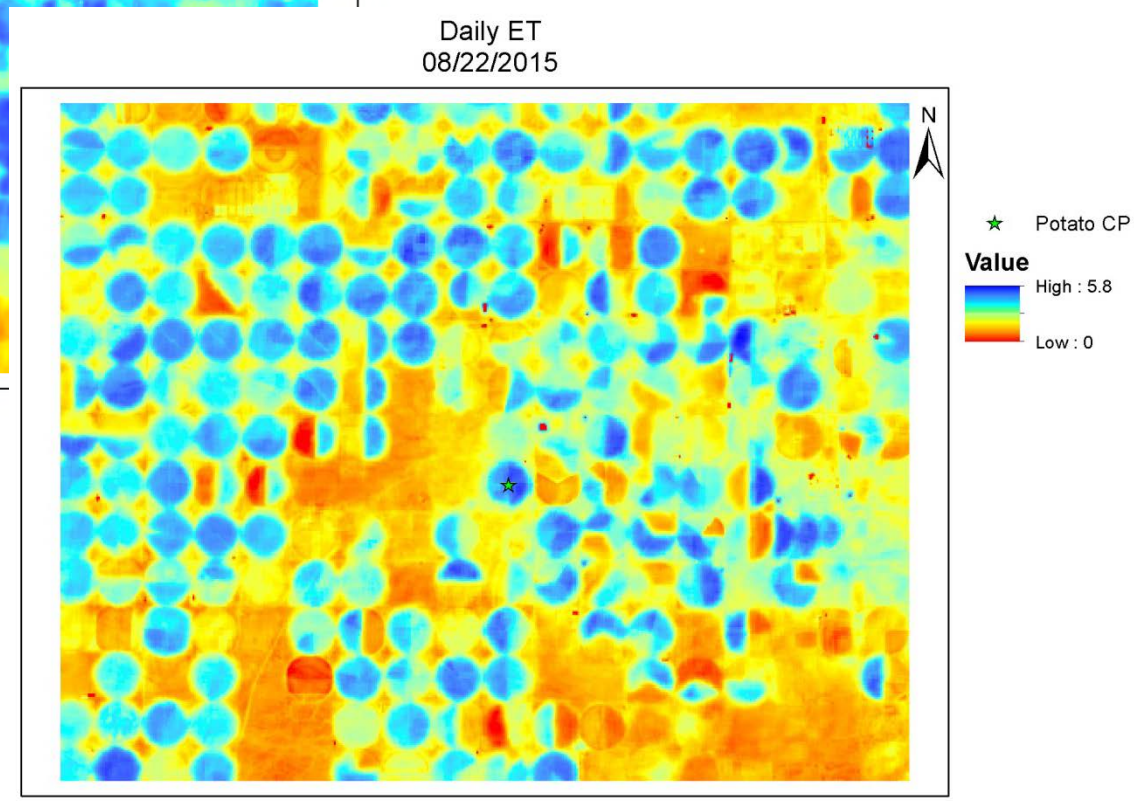


SLV-2015: daily ET, July

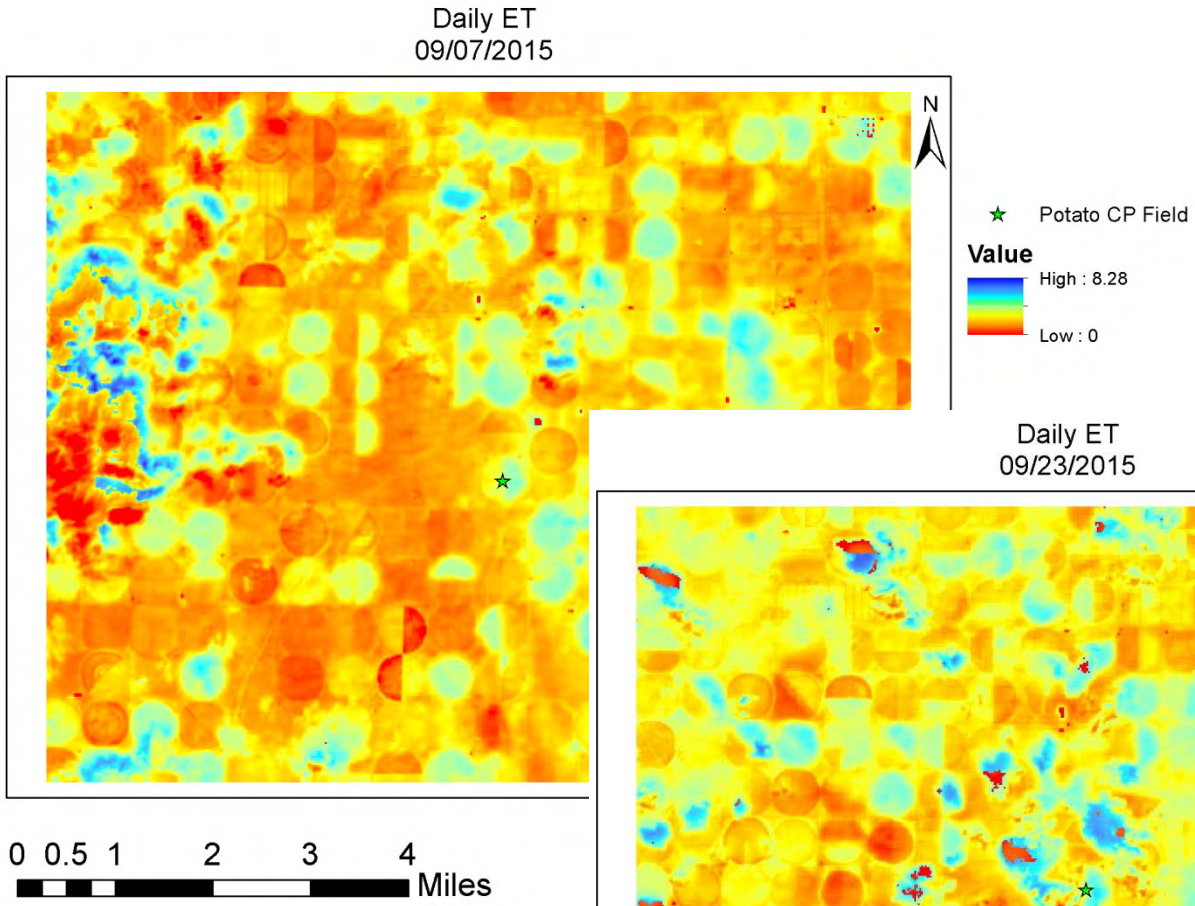


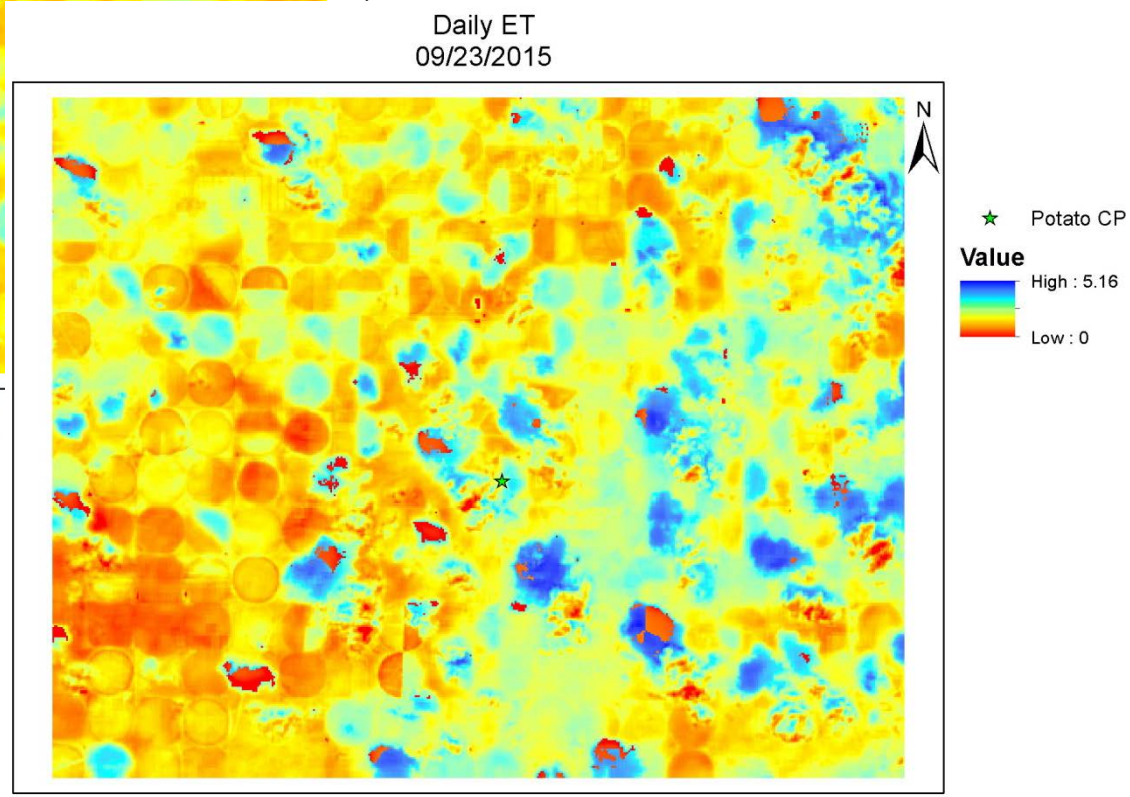
SLV-2015: daily ET, Aug 2015





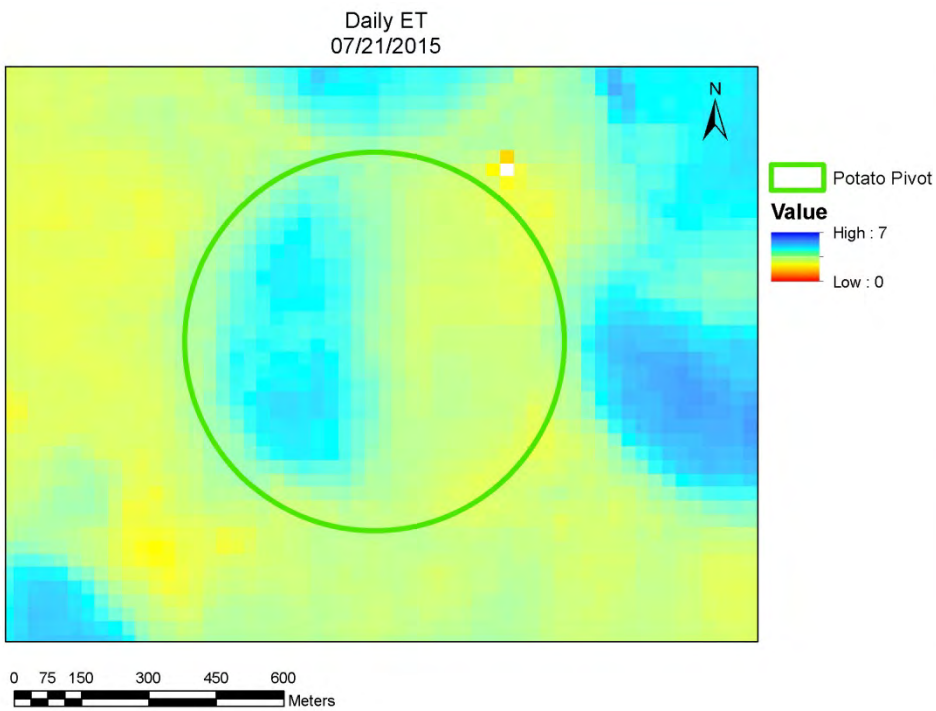
SLV-2015: daily ET, Sept 2015

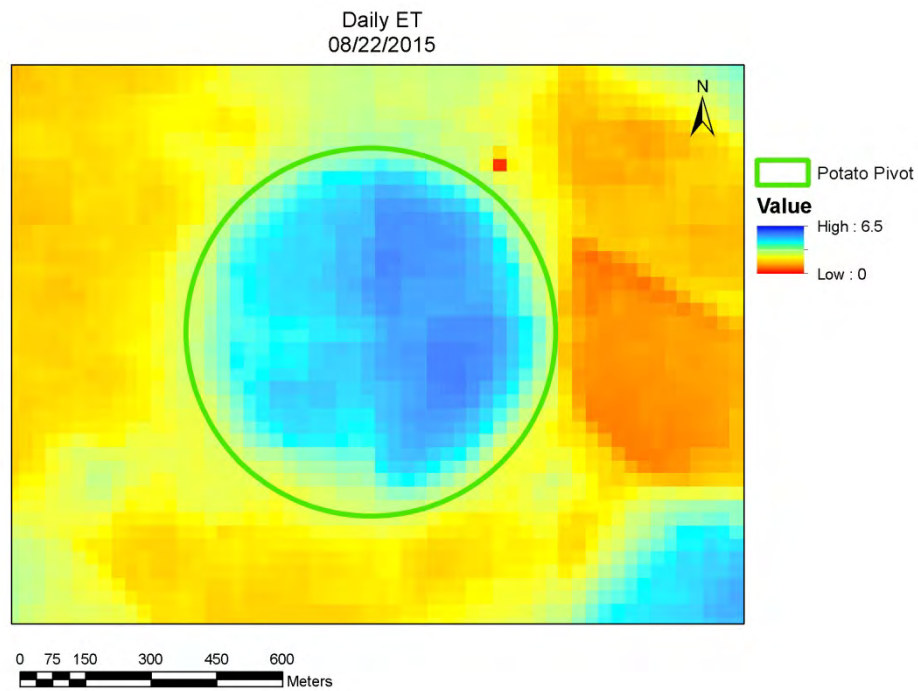




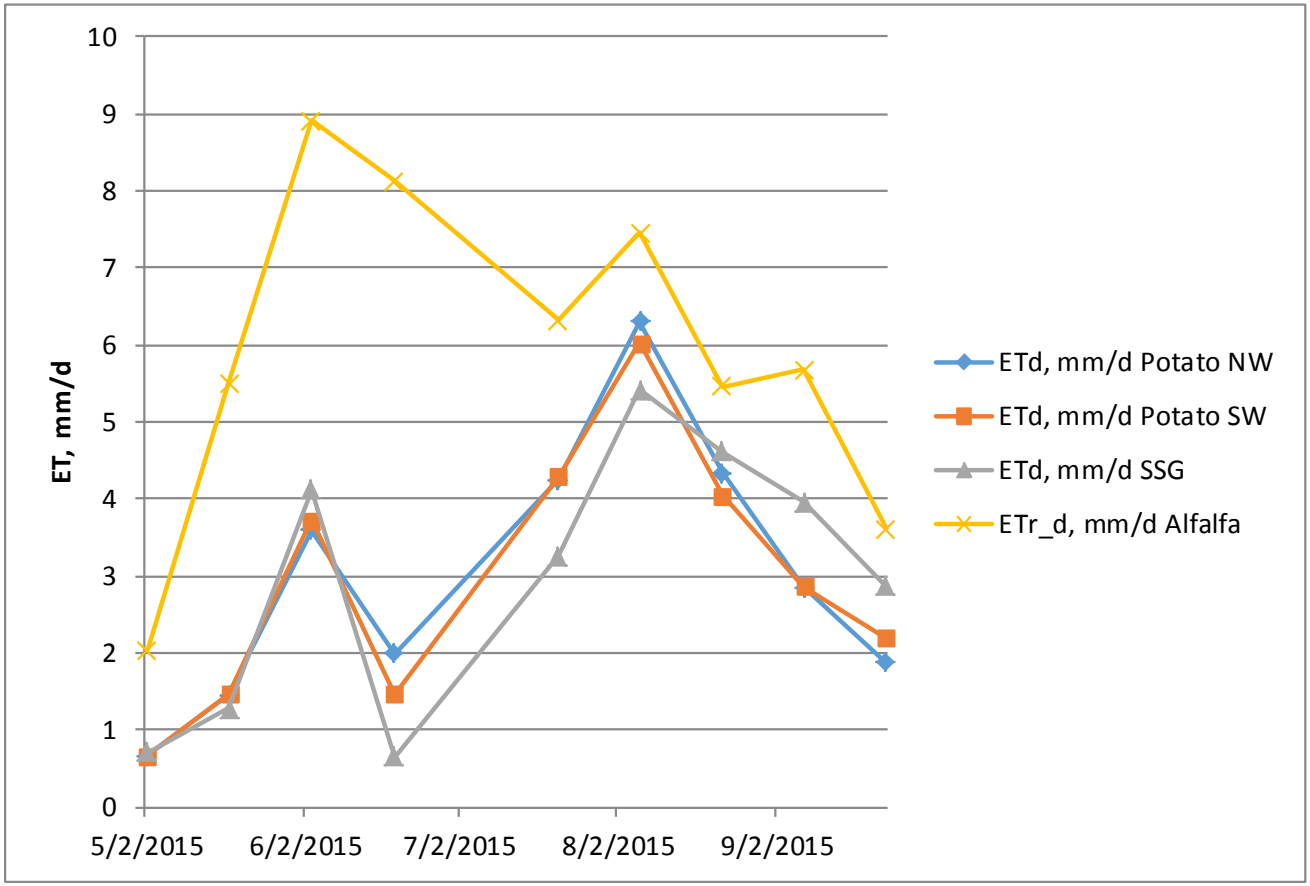
RS based actual ET for SLV CP

- Northwestern quarter of CP hourly and daily ET: CP irrigated
- Southwestern quarter of CP hourly and daily ET: drip irrigated
- Eastern CP half Sudan Sorghum grass hourly and daily ET: CP irrigated
- Hourly and daily alfalfa reference ET





RS based actual ET for SLV CP plots



a) No significant difference between ET NW and SW potato plots (sprinkler vs. drip)
b) Need to account for irrigation amounts (efficiency) and stored water in root zone in a full soil water balance to infer on water savings and crop water efficiency with each irrigation type.
c) Data to be included: irrigation/rainfall amounts and frequency, Rz, soil water content.
d) H from EB (RS) will be used to estimate Taero .