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

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Project Members

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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:

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<th>Mesa (GSU-AES)</th>
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GVWUA: Grand Valley Water Users Association; CSU-AES: Colorado State University Agricultural Experiment Station; UVWUA: Uncompahgre Valley Water Users Association


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

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
Large Aperture Scintillometer (LAS)

Picture provided by Dr. Cabot
Scintillometry for Sensible Heat Flux (H)

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

\[ LE = Rn - G - H \]

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

Eastern Colorado Irrigated Fields
ET measurements using a large weighing lysimeter

CSU
Arkansas Valley Research Center

Alfalfa on large lysimeter (2008-2012)

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

Corn on large lysimeter (2013-2014)
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

*\( \Delta S \)*: Change in mass, mm
2010 LAS units
(10/30/2010) LAS systems at AVRC

(7/14/2010)

ET-LAS and ET-LL pre-harvest 8/14-8/20

ET-LL mm/30min
ET-LAS 80% mm/30min
Bowen Ratio Energy Balance (BREB) System near Greeley, CO

Crops: wheat, beans, corn

\[
LE = \frac{R_n - G}{1 + \beta} \\
H = \frac{\beta}{1 + \beta} (R_n - G)
\]

\[
\beta = \frac{H}{LE} = \frac{-\rho_a C_p K_H \left( \frac{\Delta T}{\Delta Z} \right)}{-\frac{\rho_a}{\gamma} C_p K_W \left( \frac{\Delta e}{\Delta Z} \right)}
\]
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 gauges/Ta, Exotech Multispectral 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

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Iowa datasets sources (1)

- 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
  • [link](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/

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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)
ARS-BUSHLAND  Weighing Lysimeters
2007 Reflectance Imagery (0.5 m)

June 25, 2007, DOY 176

0.58  

0.68  

450 m

0.52  

1.73  

440 m

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
Shadow of the aerodynamic (wind/temperature/RH) profile tower
### Days with available EC data (per month)

<table>
<thead>
<tr>
<th>Site</th>
<th>May</th>
<th>June</th>
<th>July</th>
<th>Aug</th>
<th>Sept</th>
<th>Oct</th>
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<tbody>
<tr>
<td>1 NE</td>
<td>19-30</td>
<td>11-30</td>
<td>1-7, 9-11, 15-31</td>
<td>1-14</td>
<td>6-30*</td>
<td>1-3*</td>
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<td>2 SE</td>
<td>19-30</td>
<td>3-18, 23-30</td>
<td>1-11, 13-20, 22-31</td>
<td>1-13, 29-31</td>
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<td>3 NW</td>
<td>19-30</td>
<td>5-30</td>
<td>1-7, 9-11, 13-31</td>
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<td>13-30</td>
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<td>4 Grass</td>
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<td>4-18, 23-30</td>
<td>1-11, 13-31</td>
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<tr>
<td>5 SW</td>
<td>19-30</td>
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<td>1-11, 13-31</td>
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<tr>
<td>6 Tower</td>
<td>22-30</td>
<td>4-18, 22-30</td>
<td>1-11, 13-31</td>
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<td>21-30</td>
<td>8-30</td>
<td>1-11, 13-31</td>
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<td>1-10, 27-30</td>
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<tr>
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<tr>
<td>9 SE</td>
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<td>1-31</td>
<td>1-31</td>
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*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.

\[ R_n - LE - G - H = 0 \]

• 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, $\alpha$
- reflectance, $\rho_\lambda$
- radiance, $L_\lambda$
- RED, NIR, VIS bands images
- NDVI, OSAVI, LAI
- thermal image

Estimates of $R_n$ are very accurate
Soil Heat Flux, G

\[ G = 0.35 \, R_{n,SOIL} \]  
(Choudhury et al., 1987)

\[ G = ((T_s - 273.15) \, (0.0038+0.0074 \, \alpha) \, (1-0.98 \, NDVI^4)) \, R_n \]  
(Bastiaanssen, 2000)

\[ G = [(0.3324 - 0.024 \, LAI) \, (0.8155 - 0.3032 \, \ln(LAI))] \, R_n \]  
(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),
- \( \rho \) is air density (kg/m\(^3\)),
- \( T_o \) = surface aerodynamic temperature (K),
- \( T_a \) = air temperature (K)

\[
\ln\left(\frac{z_a - d}{z_{om}}\right) \ln\left(\frac{z_a - d}{z_{oh}}\right) = \frac{Z_a, T_a}{r_{ah}} \\
\]

- Invert the equation for \( H \) and solve it for \( T_o \)
- Obtain friction velocity (\( u_* \)) and roughness length for momentum transfer (\( Z_{om} \)) from micromet stations
## Calendar of Activities

<table>
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<th>Objective</th>
<th>Fall 2015 (summer)</th>
<th>Spring 2016</th>
<th>Fall 2016 (summer)</th>
<th>Spring 2017</th>
<th>Fall 2017 (summer)</th>
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Tasks performed (Fall 2015)

Project Duration: July 1\textsuperscript{st}, 2015 - June 30\textsuperscript{th}, 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)
### GS 6 Worksheet and Advising Form

**Name:** Mahmoud Osman  
**Degree:** PhD  
**Semester Advised for:** Spring 2016  
**Adviser Signature:**

<table>
<thead>
<tr>
<th>Course</th>
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<th>Term to be taken</th>
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<td>CIVE 625</td>
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**Spring Semester 2016**

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**Fall Semester 2015**

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**Thesis/Dissertation:** Yes  
**Year of Masters degree:** 2015  
**Institution:** Faculty of Engineering - Cairo University  

**Transfer Courses:**

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**Committee Adviser:** Jose Chavez  
**Dept.:** CEE
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 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
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:

- \( \text{ref7} = \left( \left( -0.015 + (1.44 + 0.15) \times \frac{n1\_image(7)}{255} \right) \times \text{PI} \right) / \left( 7.452 \times n2\_cosine-theta \times 1.094299422 \right) \)
ReSET settings inputs

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<td>Satellite Image</td>
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<td>LANDSAT file</td>
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<td>Digital Elevation Map</td>
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<td>Reference Hourly ET</td>
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<td>Reference Daily ET</td>
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<td>Daily Wind Run</td>
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<td>Weather Station Locations</td>
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Date: 01/06/2016
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.

SLV-2015: daily ET, May/June
SLV-2015: daily ET, July
SLV-2015: daily ET, Aug 2015

Daily ET
08/06/2015

Daily ET
08/22/2015

Value
High : 7.92
Low : 0

Potato CP Field

Value
High : 5.8
Low : 0

Potato CP
SLV-2015: daily ET, Sept 2015

Daily ET
09/07/2015

Daily ET
09/23/2015

Value
High : 8.28
Low : 0

Potato CP Field

Value
High : 5.16
Low : 0

Potato CP

Miles
0 0.5 1 2 3 4
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 \( \text{Tae}_\text{ro} \).