Monitoring Irrigation Water Use

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Drought Leadership Training

Crop Drought Management Workshop– CSU Extension

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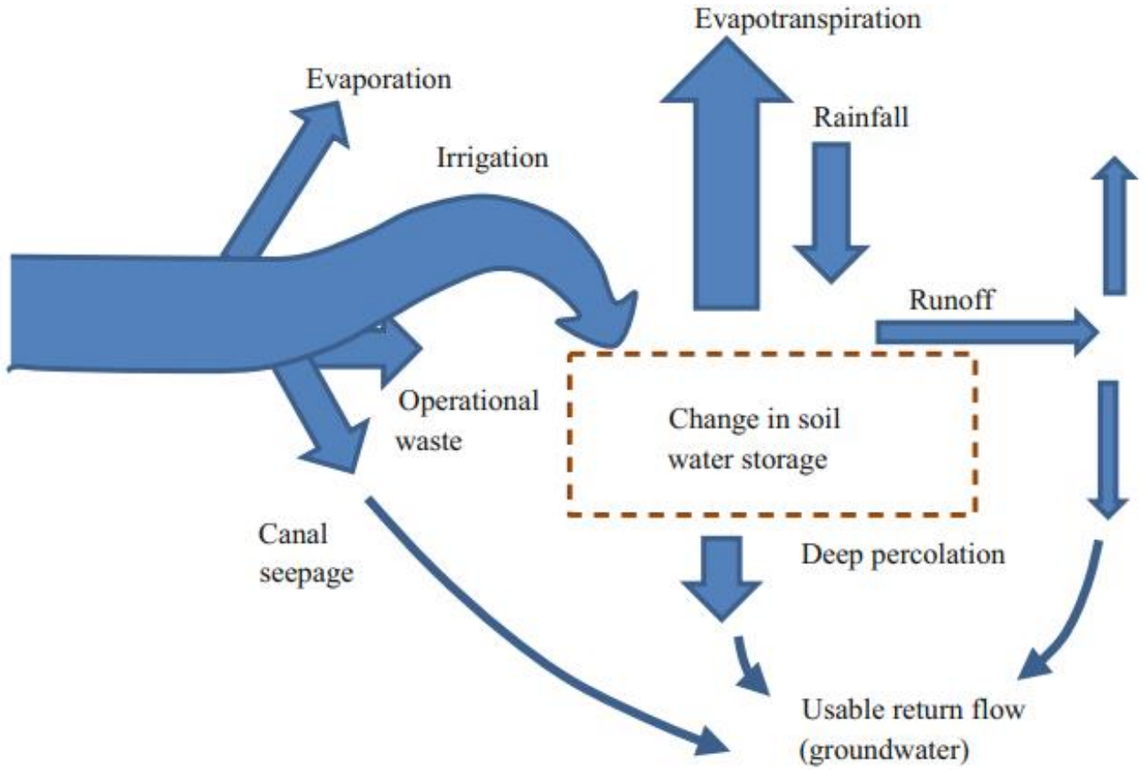
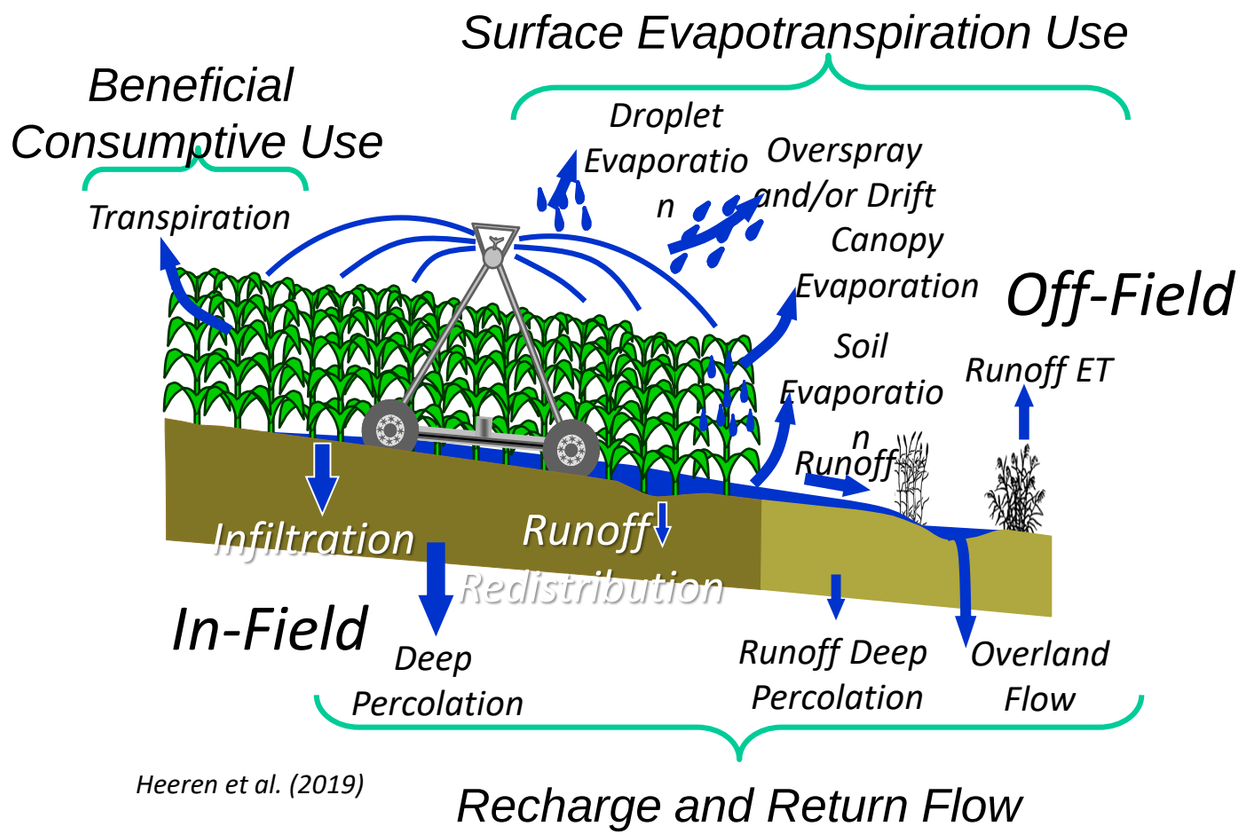
CIVIL AND ENVIRONMENTAL ENGINEERING

Farm irrigation hydrologic cycle



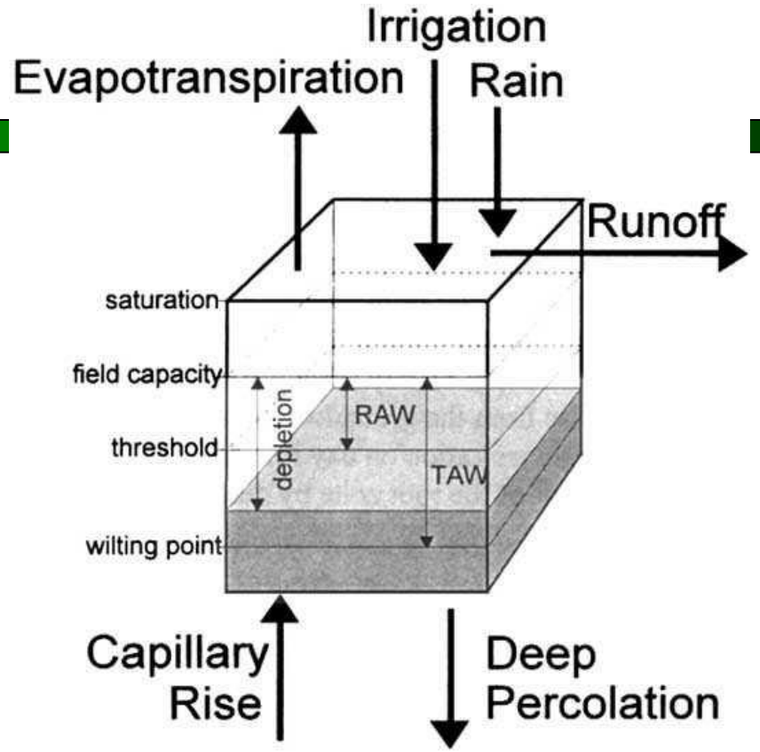
Farm scale irrigation water balance (After NRCS – NEH)



Heeren et al. (2019)

Inflow - Outflow = Change in storage

Soil Water Deficit-based (D_i) irrigation



$$D_i = D_{i-1} + ET_c - P - IR + DP$$

- Irrigate when the soil water deficit $\mathbf{D_i \sim d_{MAD}}$

$\mathbf{d_{MAD}}$ is the allowable water depletion depth

- $\mathbf{d_{MAD} = MAD \times TAW \times R_z}$

where

- MAD = management allowed or allowable depletion or deficit
- **Typical range: 0.15 < MAD < 0.5**

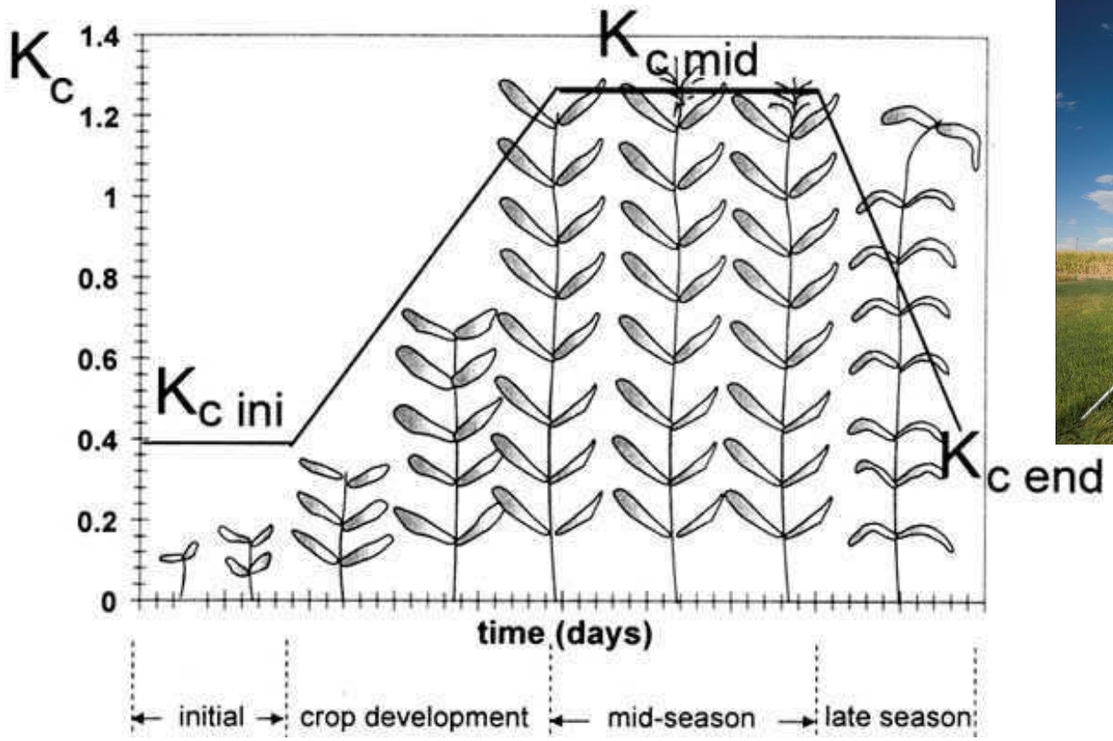
TAW = total available water, and $\mathbf{TAW = \theta_{FC} - \theta_{PWP}}$

Crop Coefficients to calculate crop ET or ETc

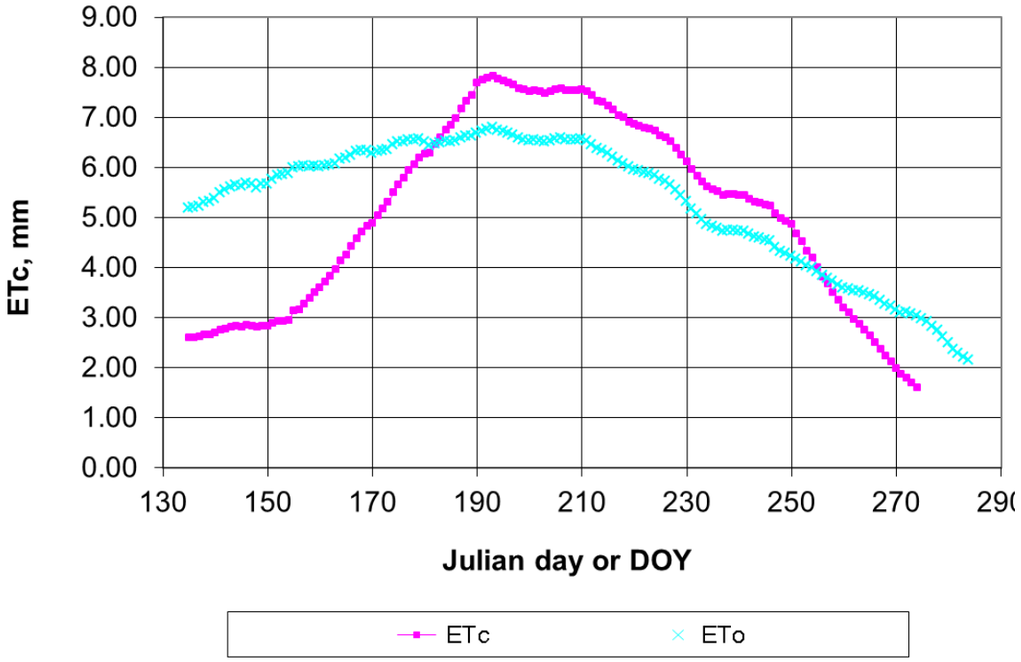
Kc = ETc / ET_ref

ETc with weighing lysimeters

ET_ref with lysimeters or equations



ETc = Kc x ET_ref



Irrigation Scheduling: The Water Balance Approach (alfalfa reference single crop coefficients)

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Irrigation Scheduling: The Water Balance Approach

Fact Sheet No. **4.707** Crop Series | **Irrigation**

by A. A. Andales, J. L. Chávez, T. A. Bauder*

The water requirement of a crop must be satisfied to achieve potential yields. The crop water requirement is also called crop evapotranspiration and is usually represented as ET_c. Evapotranspiration is a combination of two processes – evaporation of water from the ground surface or wet surfaces of plants; and transpiration of water through the stomata of leaves. The water requirement can be supplied by stored soil water, precipitation, that can be used by the plants. The *AWC* of soil is typically expressed in terms of inches of water per inch of soil depth. General values of *AWC* are provided in Table 1. Available water capacity values for specific soils can be obtained from county soil surveys or online at http://websoilsurvey.nrcs.usda.gov/app/.

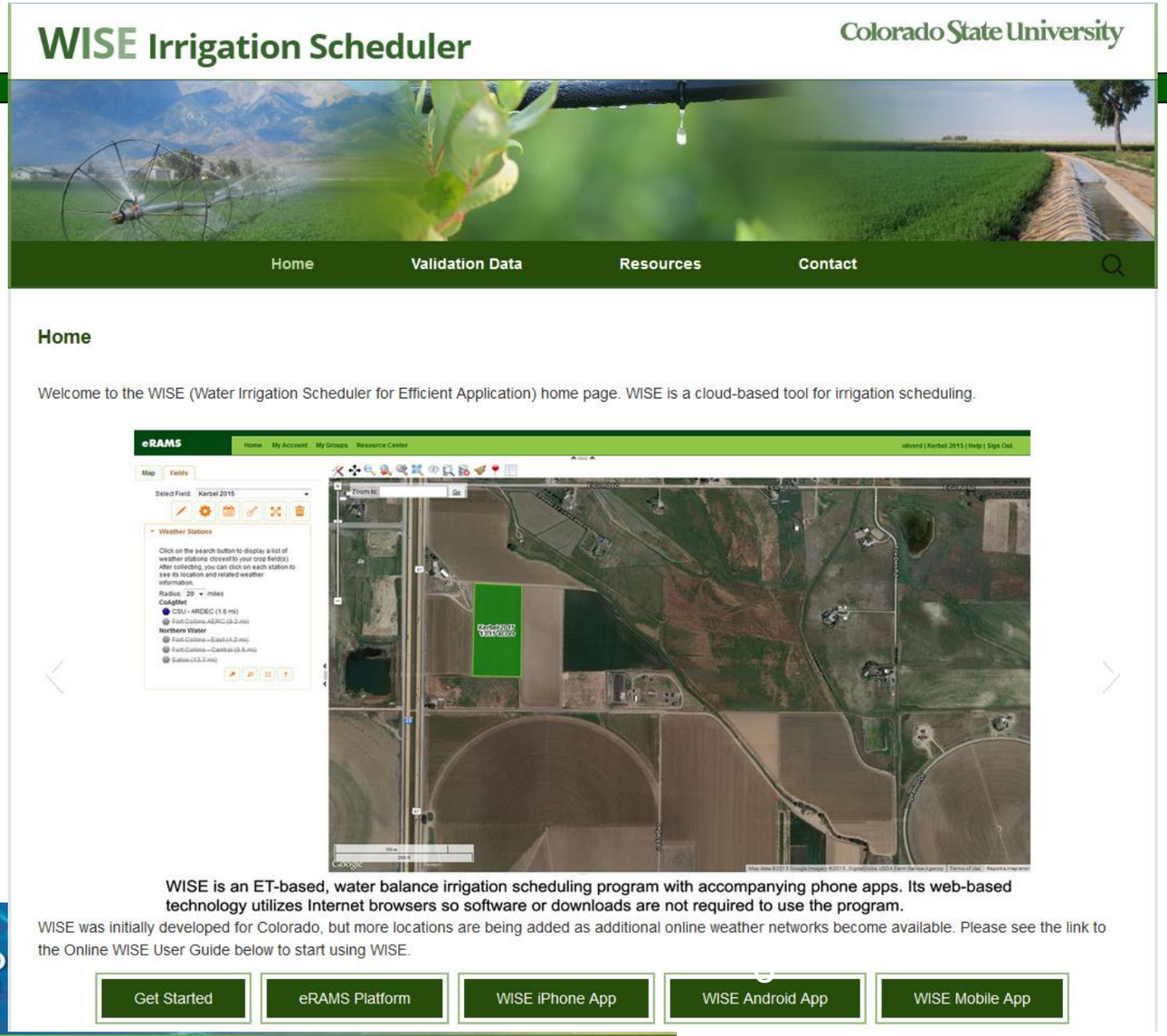
Water Balance Accounting

Quick Facts

- The water balance approach to irrigation scheduling keeps track of the soil water deficit by accounting for all water additions and subtractions from the soil root zone.

irrigation scheduling the water balance approach

Water Irrigation Scheduler for Efficient Application (WISE) for Colorado: http://wise.colostate.edu/



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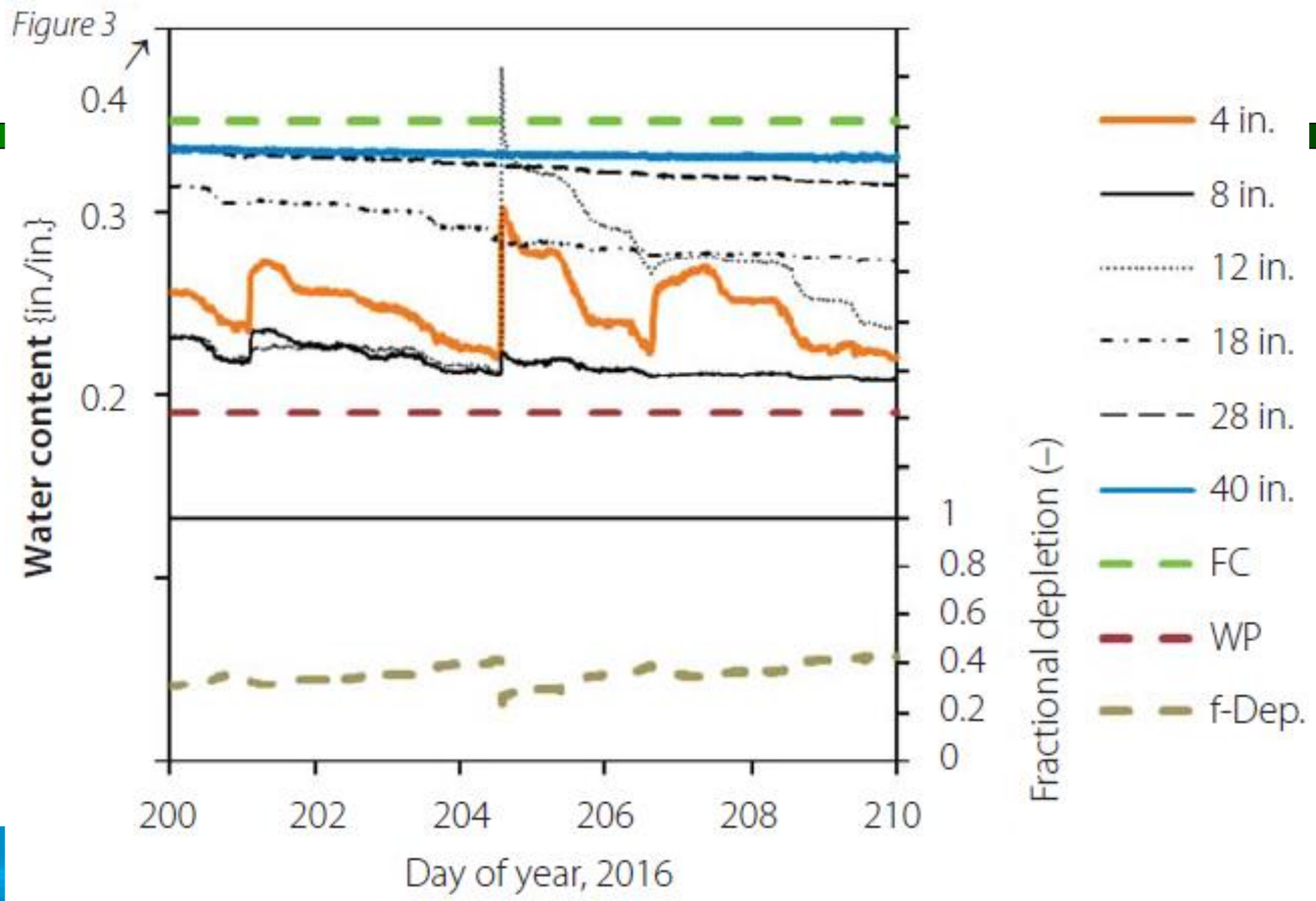
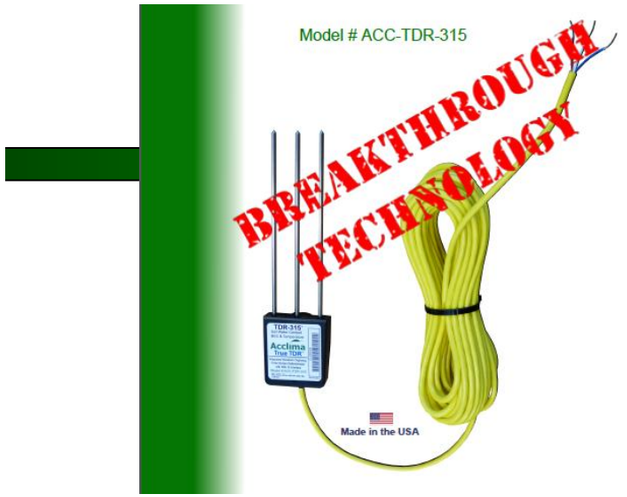
Soil water content sensors to manage irrigation



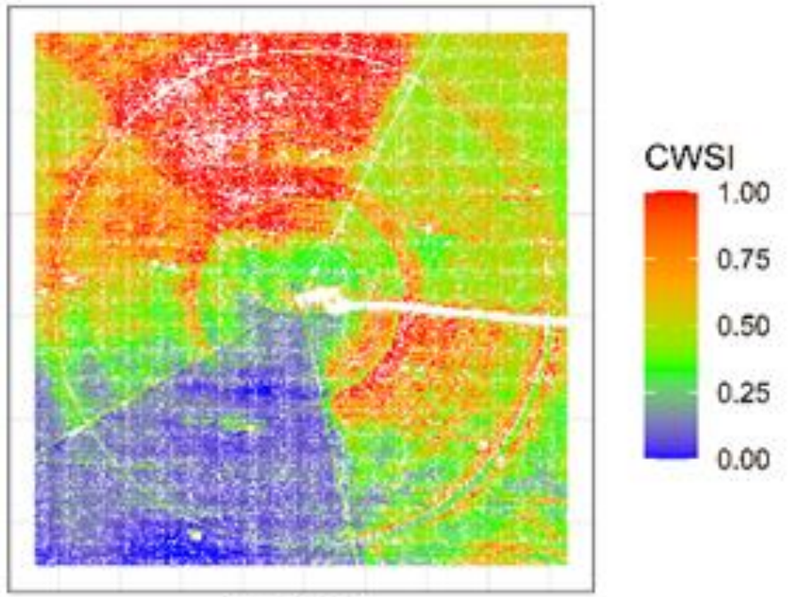


$$D_i = (\theta_{v_FC} - \theta_{v_i}) \times R_z$$

$$IR_n = \sum_{i=1}^{N} \frac{\theta_{fci} - \theta_{MADi}}{100} \times 1000 \times R_{zi}$$

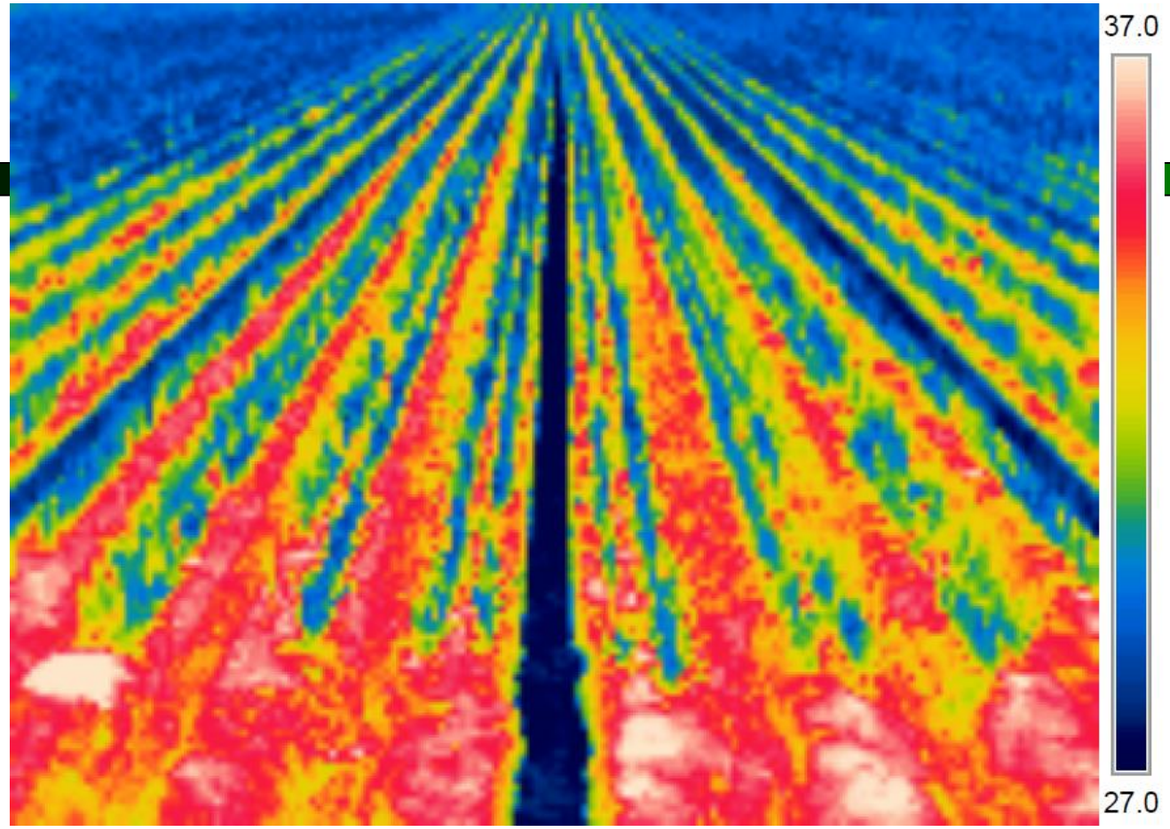
Crop Water Stress Index (CWSI) Approach using Infra-red Thermometer (IRT) data

- To detect crop water stress based on crop canopy temperature
- To calculate the level of stress and water use (reduction) on crops based on canopy temperature (**Tc**)



DOY207

Thermal picture of a furrow irrigated field near Greeley, CO



98.6 °F

80.6 °F

Obtaining "actual ET" (ET_a) from CWSI

$$CWSI = \frac{dT - dT_{mn}}{dT_{mx} - dT_{mn}}$$

CWSI range: 0-1,

where:

$$\boldsymbol{dT = T_c - T_a}$$

$dT_{mn} : f(\text{VPD}) = \text{a (VPD)} + \text{b}$

$dT_{mx} : f(\text{VPG}) = \text{a (VPG)} + \text{b}$

$$CWSI = 1 - \frac{ET_a}{ET_c}$$

$$ET_c = K_c \times ET_{ref}$$

$$ET_a = (1 - CWSI)\, ET_c$$

Example of lower limit dT functions

For Corn:

$dT_{min} = (Tc - Ta)_{min} = b + a\ VPD$

(Idso, 1982) Maricopa, AZ

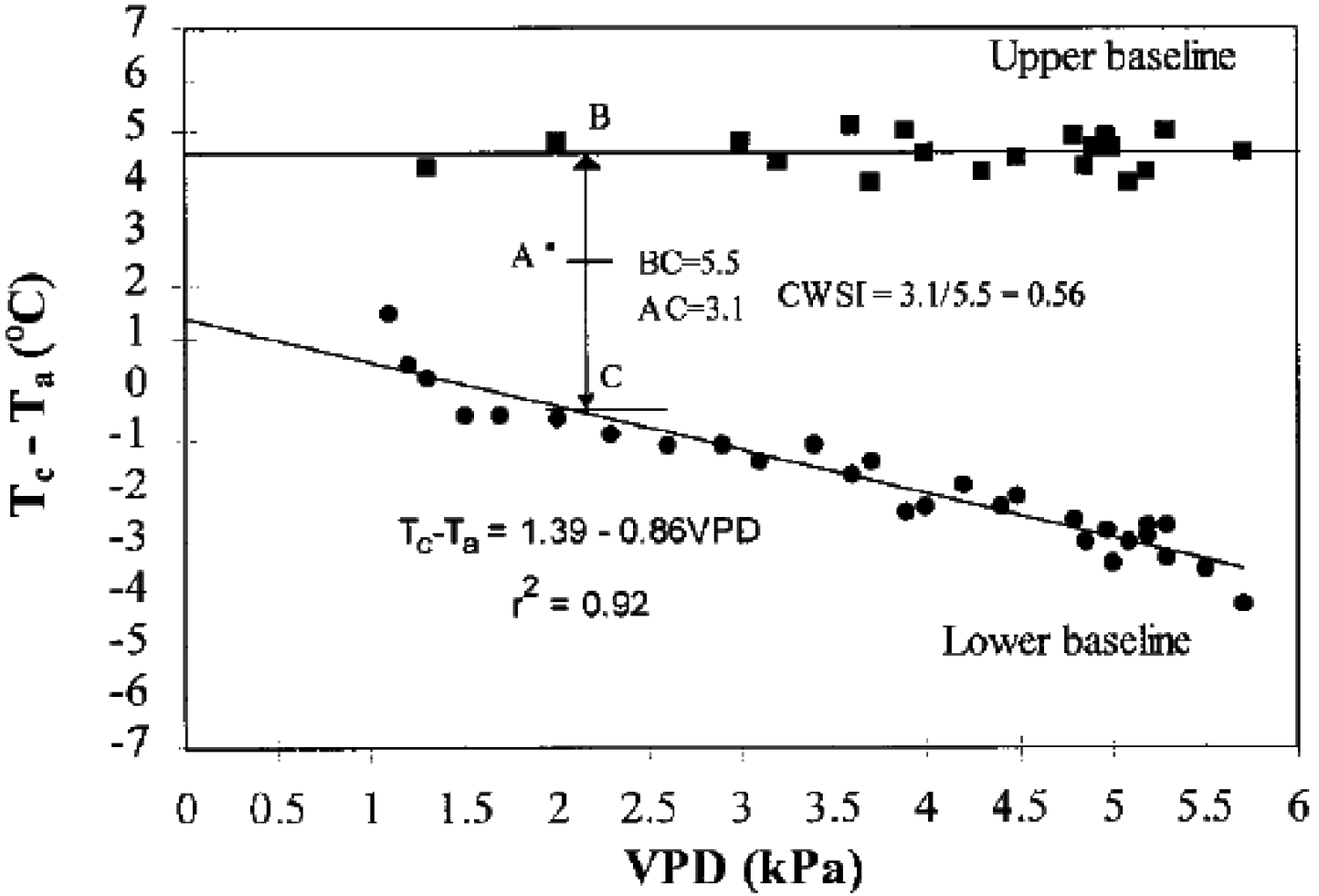
$dT_{min} = 3.11 - 1.97\ VPD,$

(Nielsen &Garden (1987) Akron, CO

$dT_{min} = 2.67 - 2.06\ VPD,$

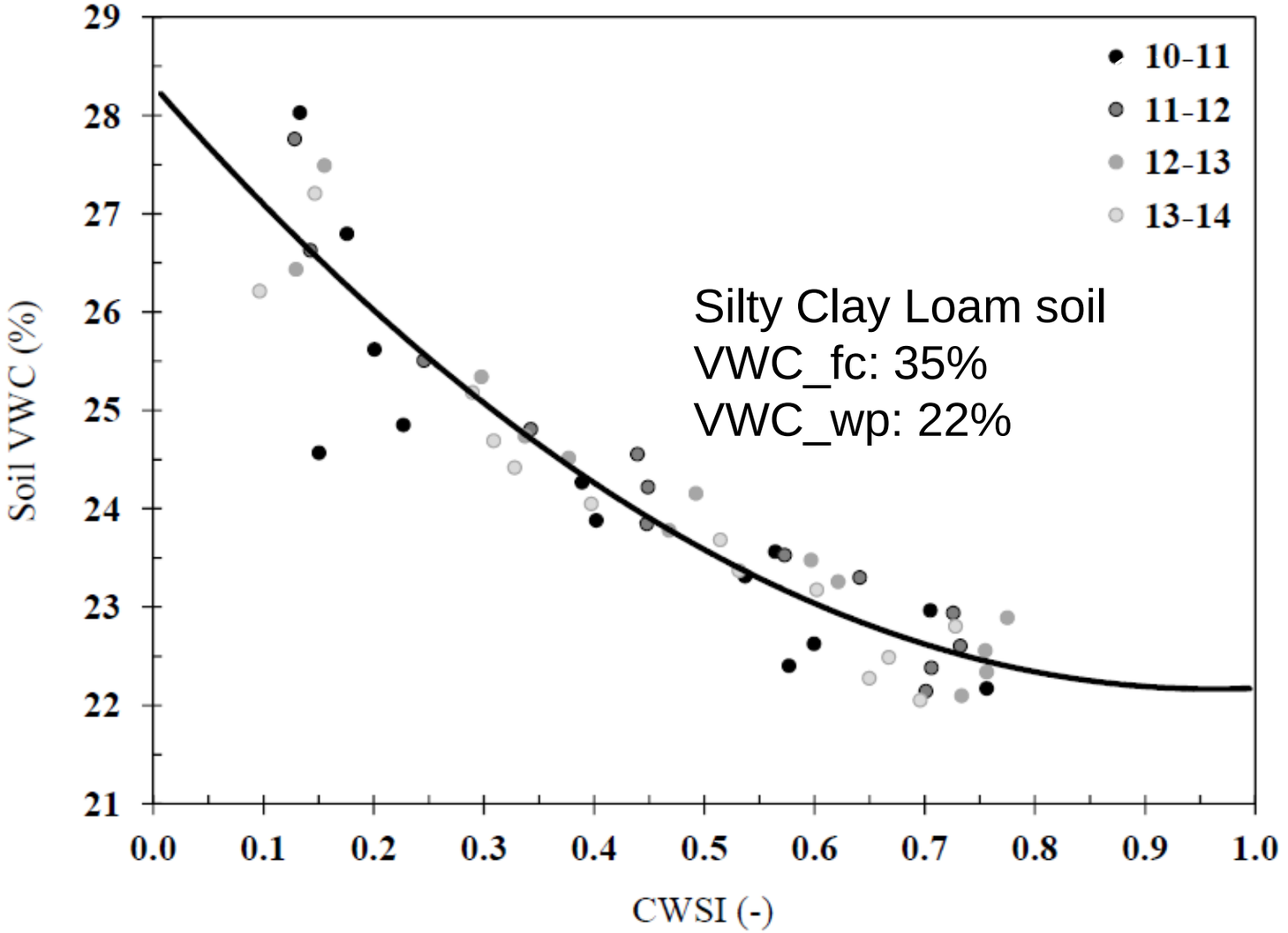
(Taghvaeian et al. 2012), For Iliff, CO:

$dT_{min} = 2.73 - 1.90 \times (VPD)$



Irmak et al. (2000)

CWSI *vs.* volumetric water content (VWC)



For MAD = 55%
Trigger irrigation when VWC_t ~ 28%
For a CWSI ~ 0.15 or 15%

Irrigation amount:
Di = (VWC_fc – VWC_i) x Rz
Di = (0.35 – 0.28) x 1000 mm/m x 1 m
= (0.07) x 1000 mm
= 70 mm or 2.75 in

CWSI and ET_a calculations: example

- **Input data**:
- Date: August 26th, 2010
- Location: Greeley, CO
- Crop: corn
- Sensor: IRT Apogee SI-111 (oblique), Time of reading: 2 pm,
- Tc = 28.9 °C (84 °F canopy temperature corrected for surface emissivity)
- ***In-situ*** weather data: Ta = 32.0 °C (89.6 °F), RH = 25.5%, ETc = 8.2 mm/d (0.32 in/d)
- **Output**:
- Compute the vapor pressure deficit (VPD): VPD = $e_s(Ta) – e_a(Td)$
- 0.6108*EXP(17.27 x Ta/(Ta+237.3)) - 0.6108 x EXP(17.27 x Ta/(Ta+237.3))x RH /100 = 3.54 kPa
- Compute the vapor pressure gradient (VPG): VPG =$e_s(Ta) – e_s(Ta + b)$
- 0.6108*EXP(17.27 x Ta/(Ta+237.3)) - 0.6108 x EXP(17.27 x (Ta+3.11)/((Ta+3.11)+237.3)) = -0.9 kPa

(Idso, 1982)

$dT_{min} = 3.11 – 1.97\ VPD,$

$dT_{min} = (Tc – Ta)_{min} = b + a\ VPD$

CWSI example cont'd

$$CWSI = \frac{dT - dT_{mn}}{dT_{mx} - dT_{mn}}$$

- **Output**:
- Compute the dTmin as: 3.11 - 1.97 x (3.54 kPa) = -3.86 °C
- Compute the dTmax as: 3.11 - 1.97 x (-0.9 kPa) = 4.89 °C
- Compute actual dT as: 28.9 – 32.0 = -3.1 °C
- Compute the CWSI:

- CWSI = [(-3.1) – (-3.86)] / [(4.89) – (-3.86)] = 0.09
- This result means 9% crop water stress.

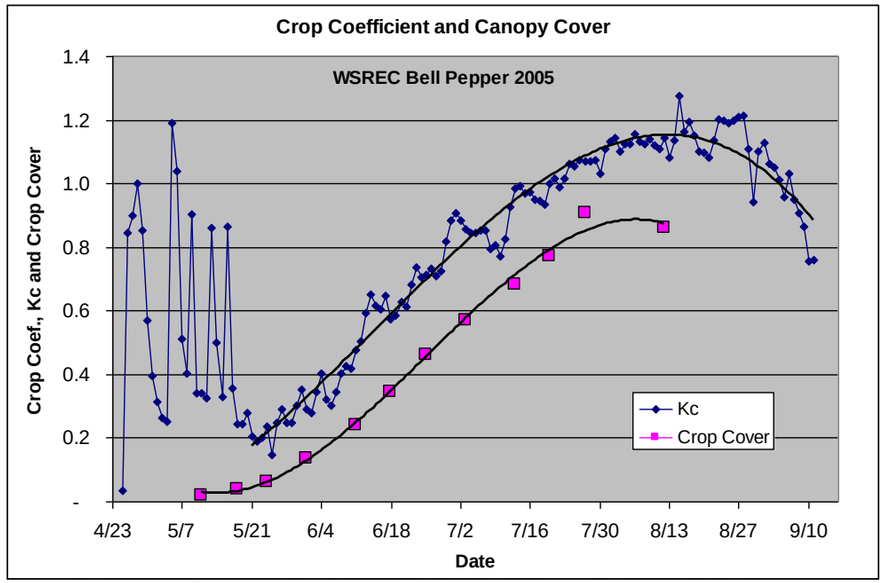
ETc = 8.2 mm/d (0.32 in/d)

- Then, $ET_a = (1 - 0.09) \times ET_c = 0.91 \times 8.2$ mm/d = 7.6 mm/d (0.3 in/d)

Vegetation fraction of ground cover based ET

NDVI → f_c → K_{cb} → ET_{cb} Approach

Trout et al.(2008)
Johnson & Trout (2012)



$$NDVI = (R_{NIR} - R_{RED}) / (R_{NIR} + R_{RED})$$

$$f_c = 1.22 \times NDVI - 0.21$$

$$K_{cb_o} = 1.13 \times f_c + 0.14$$

$$ET_a = K_{cb_o} \times ET_o$$

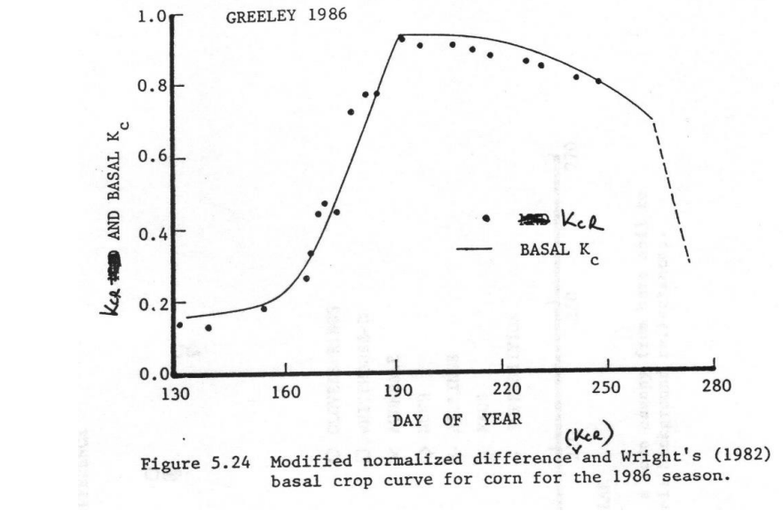
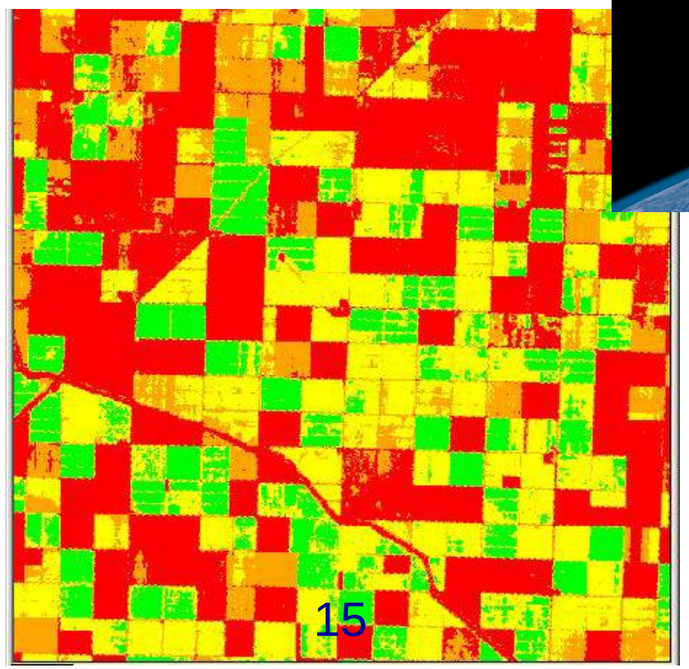
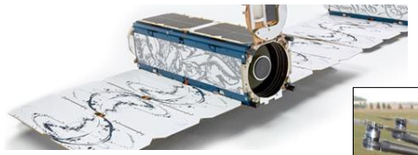


Figure 5.24 Modified normalized difference and Wright's (1982) basal crop curve for corn for the 1986 season.



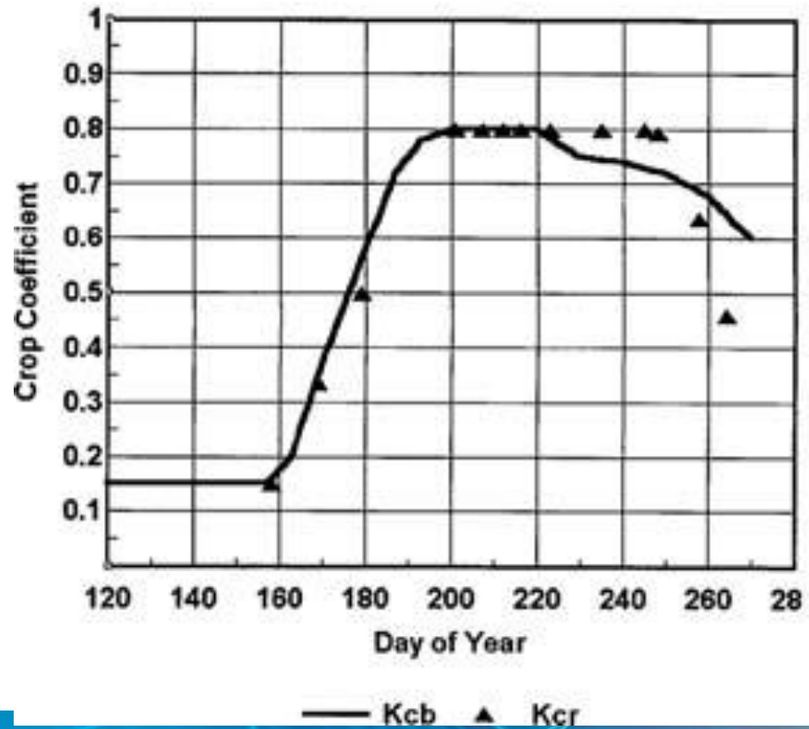


Reflectance-based Crop Coefficient ET

$$ET_a = K_{cr} \times ET_r$$

For **Potatoes**:

$K_{cr} = 1.085 * SAVI + 0.051$



For **Corn**: Neale et al. (1989)

$K_{cr} = 1.092 \times NDVI - 0.053$, for Fruita, CO

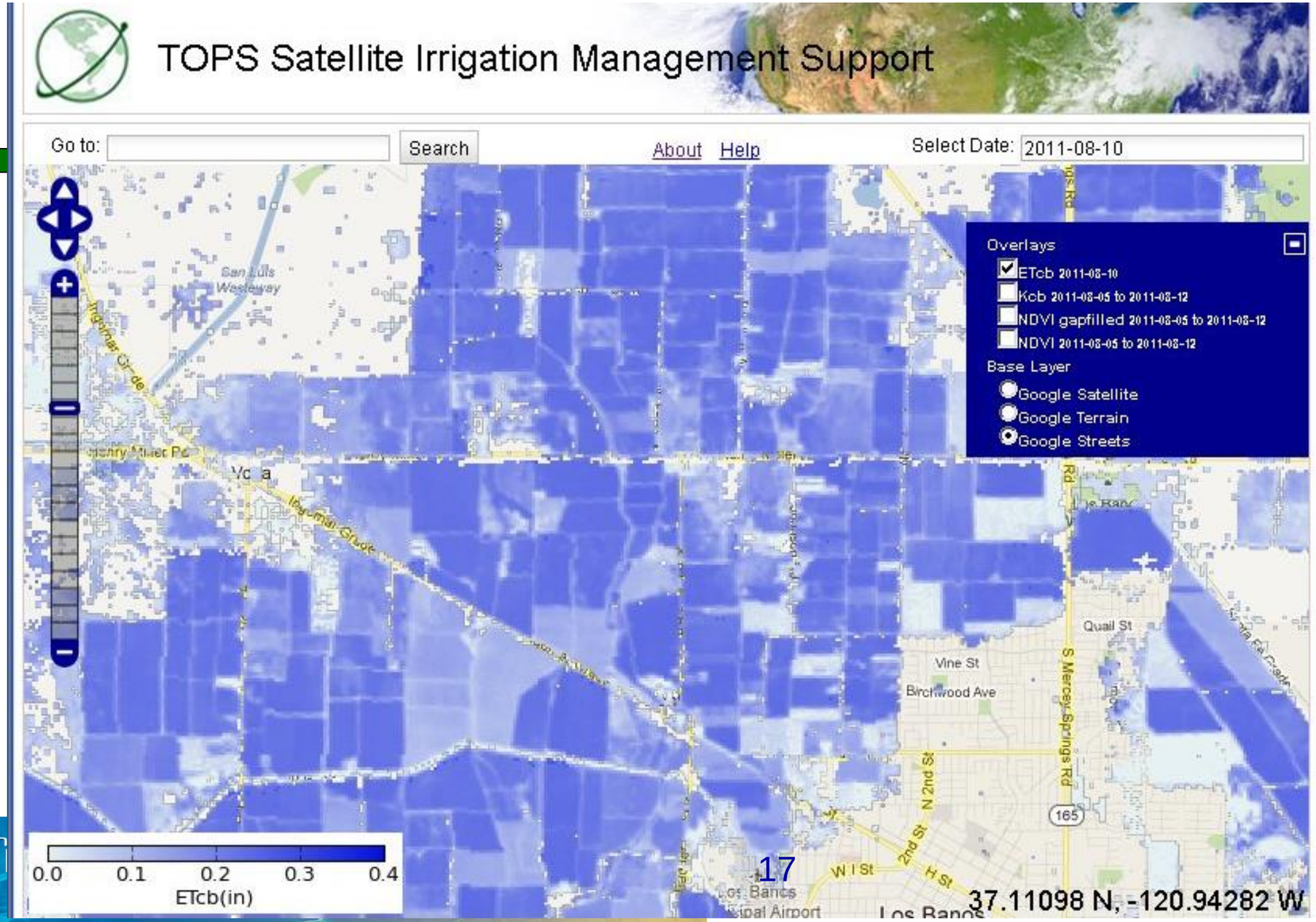
$K_{cr} = 1.181 \times NDVI - 0.026$, for Greeley, CO

Bausch (1993)

$K_{cr} = 1.416 \times SAVI + 0.017$

For **beans**: $K_{cr} = 1.326\ SAVI + 0.029$

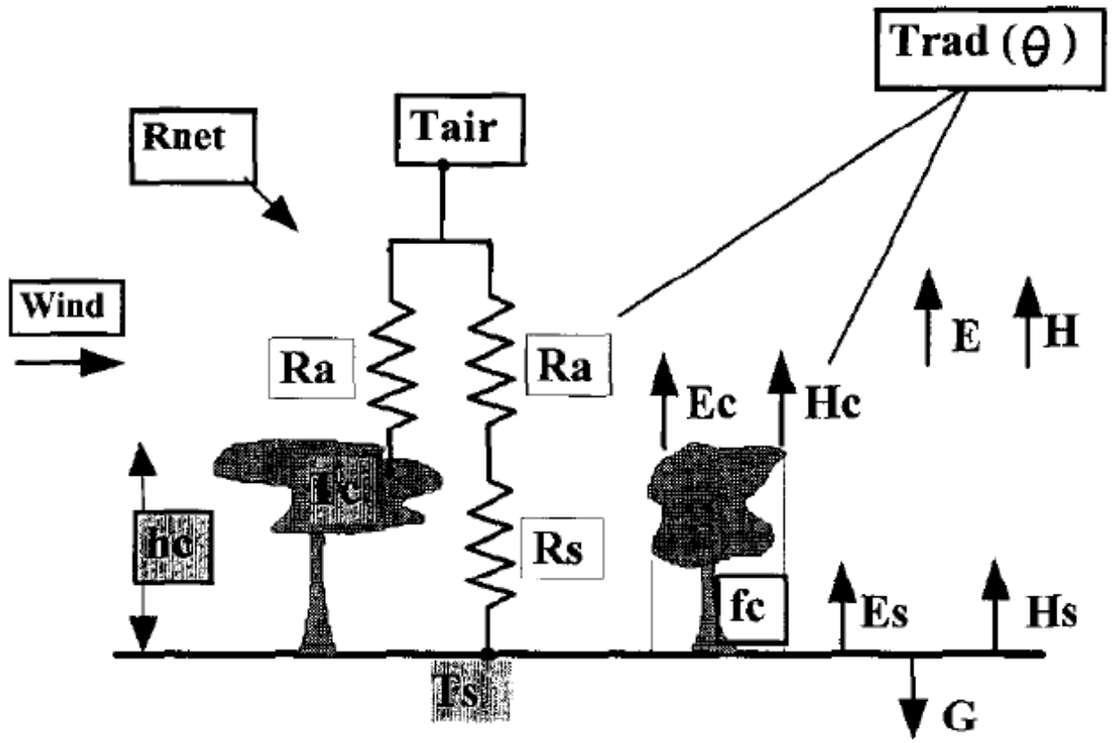
TOPS Satellite Irrigation Management Support: ET_{cb}



Two Source Model (TSM)

$$LE = R_n - G - H$$

J.M. Norman et al. / Agricultural and Forest Meteorology 77 (1995) 263–293



$$T_{RAD}(\theta) = \left[f(\theta) T_C^n + (1 - f(\theta)) T_S^n \right]^{1/n}$$

T_s

T_a

U

LAI

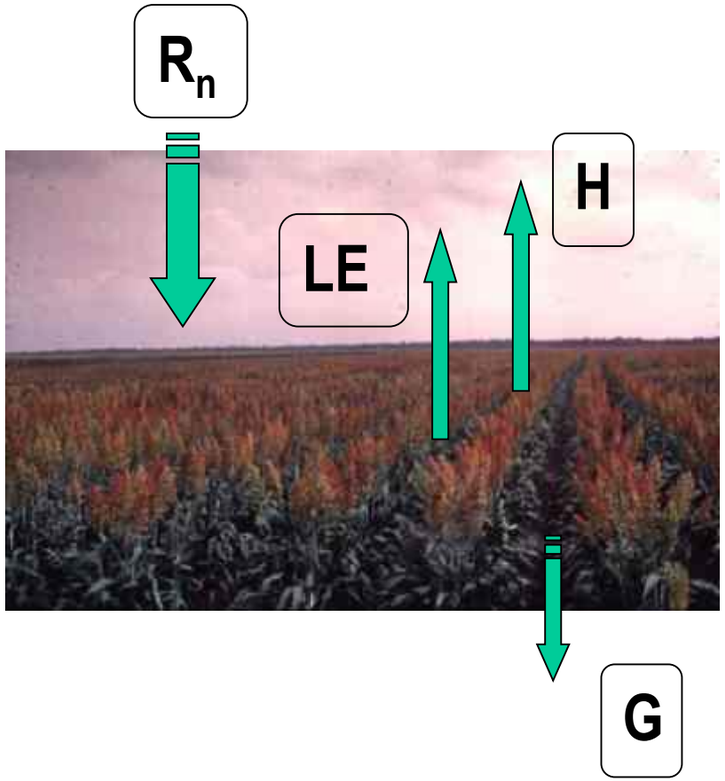
f_c

f_g

h_c

w

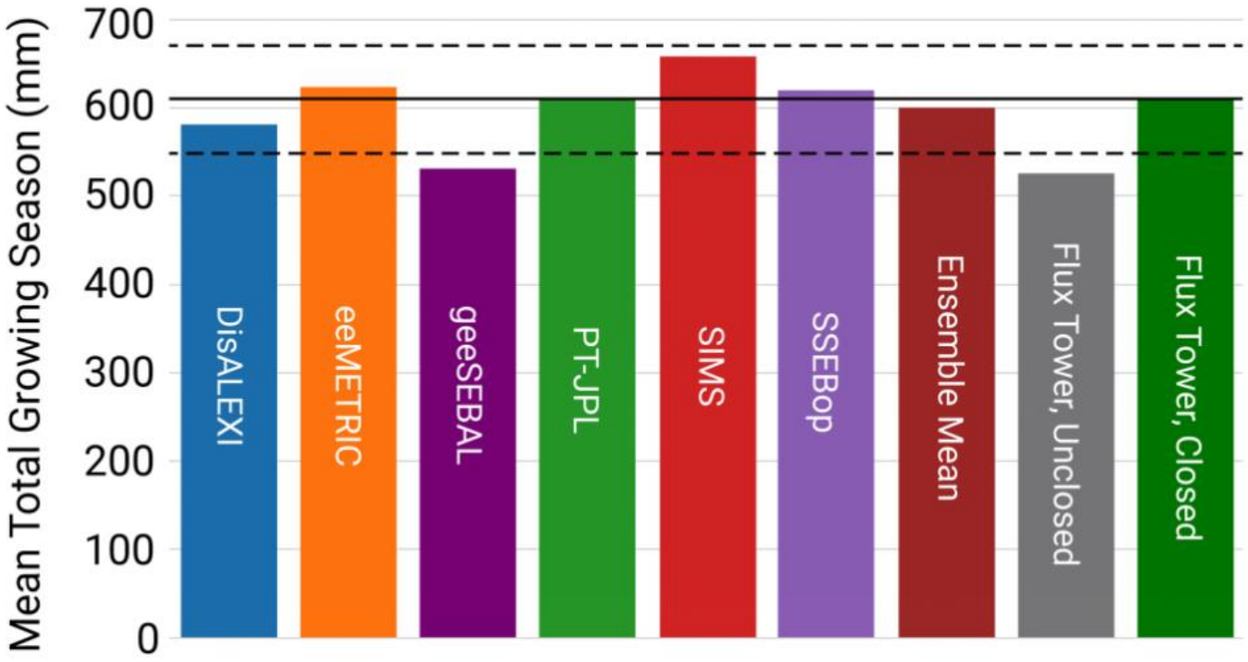
R_n



OPENET mapping of crop ET accuracy

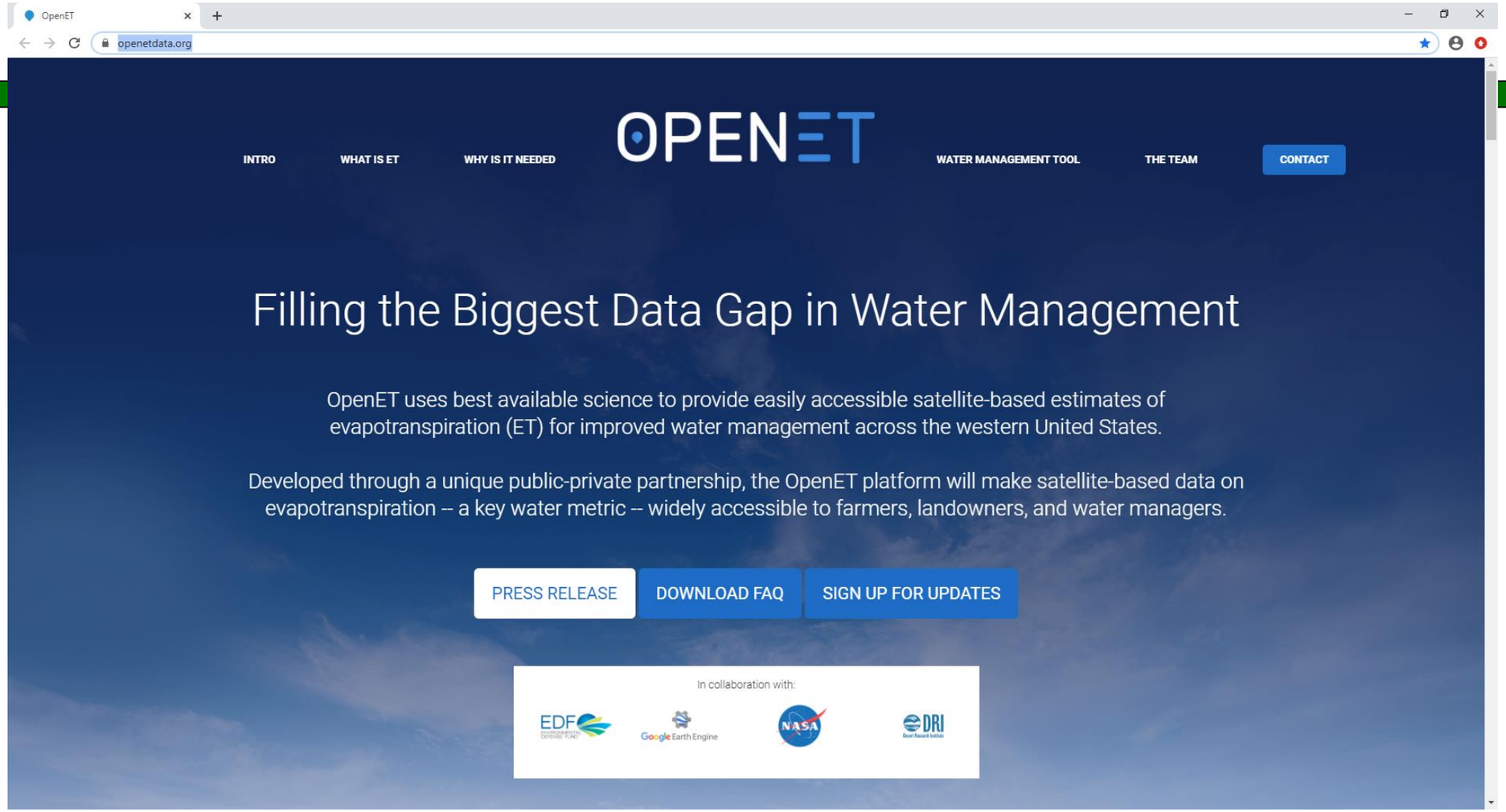
Accuracy Summary for Croplands for the OpenET Ensemble ET Value

Time Period	Slope	Mean Bias Error)	Mean Absolute Error	Root Mean Squared Error	r-squared	Mean flux tower ET
Water Year: 14 sites with 48 total water years	0.93	-71.6 mm (-7.0%)	91.3 mm (8.9%)	100.5 mm (9.8%)	0.90	1024 mm
Growing Season: 38 sites with 151 growing seasons	1.0	-10.1 mm (-1.7%)	80.3 mm (13.2%)	92.7 mm (15.2%)	0.88	609.5 mm
Monthly: 44 sites with 1,682 total months	0.95	-3.6 mm (-3.9%)	15.6 mm (16.6%)	20.0 mm (21.3%)	0.91	92.7 mm
Daily: 48 sites with 4,913 total Landsat overpass days	0.88	-0.3 mm (-7.4%)	0.8 mm (22.8%)	1. 1 mm (29.7%		



OPEN ET

https://openetdata.org/



Thank You

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