Deficit Irrigation in Colorado and Need for ET Monitoring

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- Colorado Northern Water Conservancy District (Northern Water)
- USDA ARS, Water Management Systems Research Unit
- West Greeley Conservation District Central Colorado Water Conservancy District
- USDA NRCS (CIG program)

CO DNR Colorado Water Conservation Board

Northern Water The Northern Colorado Water Conservancy District

WEST GREELEY CONSERVATION DISTRICT

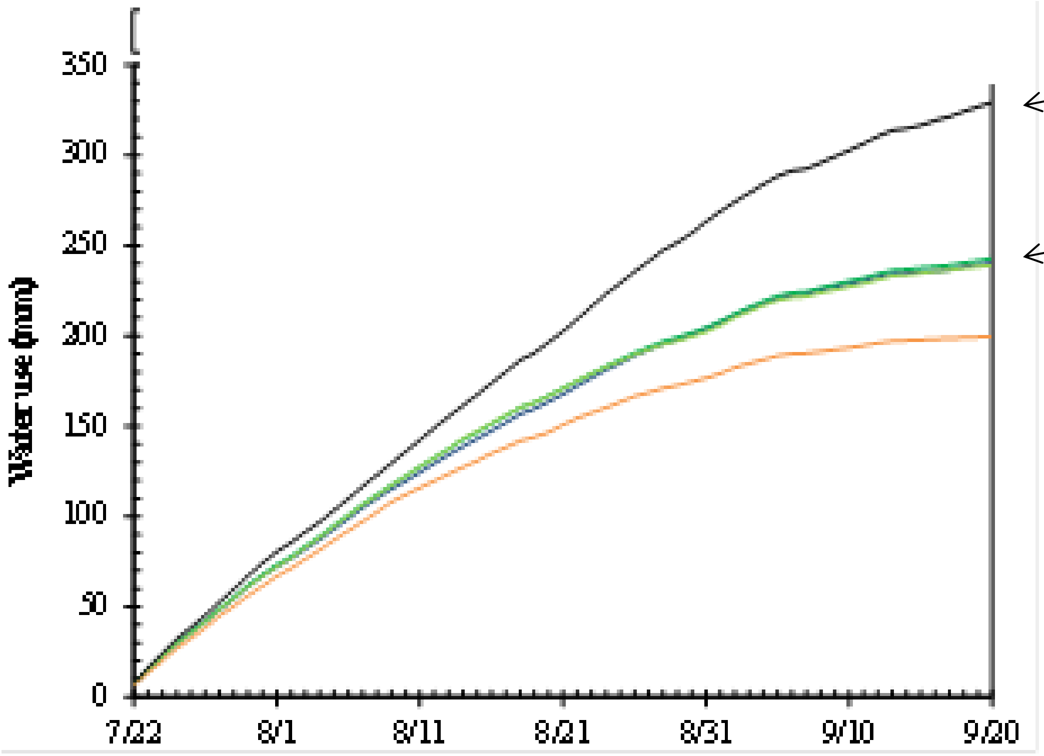
CCWCD WHERE THE FUTURE FLOWS Central Colorado Water Conservancy District

USDA ars United States Department of Agriculture Agricultural Research Service

USDA Natural Resource Conservation Service United States Department of Agriculture

How to monitor crop water stress?

- When stressed, plants use less water than the maximum amount possible for well water conditions.



13.8 in

Well water corn

8.8 in

Water stressed corn

Crop Water Stress

- “Stress,” in the context of plants, is a broad term used to describe some type of adversity that, if prolonged, can result in economic yield loss (Jackson, 1982).
- “Water stress” then describes a condition where the supply of water in plant leaves is insufficient to carry out photosynthesis and respiration using all available energy.
- Under water stress conditions, a greater amount of available energy must be converted to sensible heat compared with what would have occurred for non-water-stressed conditions. The result is that the temperature of the plant canopy increases over the temperature that would have resulted for no shortages in water.

How to monitor crop water stress?

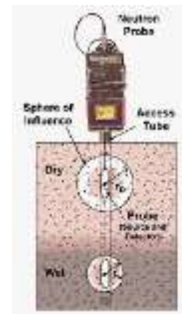
- By measuring or estimating crop water use and comparing resulting values to non-stress crop water use
- Crop water use = crop evapotranspiration = E + T = ET

  where: E = evaporation and T = transpiration
- ET = (Kcb Ks + Ke) ETref
- ET from a soil water balance (soil water sensors)
- ET from remote sensing sensors
- ET from micro-meteorological heat flux towers (e.g., EC)
- ET from lysimeters
- ET from plant heat balance or heat pulse techniques

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

Soil Moisture Measurements to infer on ET through the SWB

SWB = soil water balance



Gravimetric/volumetric

Tensiometer

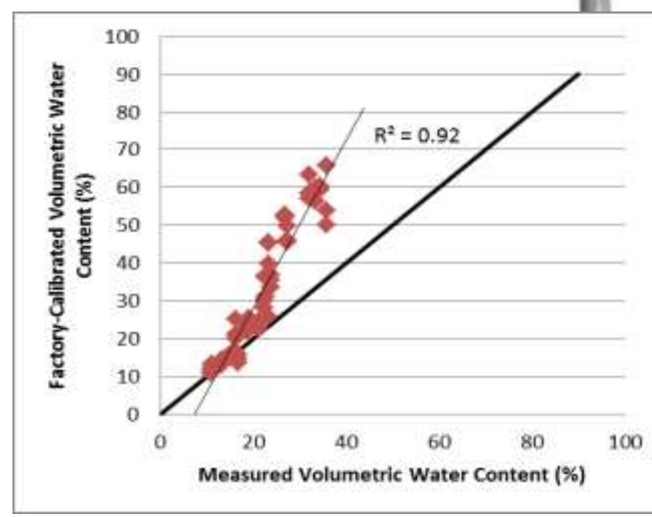
Resistance

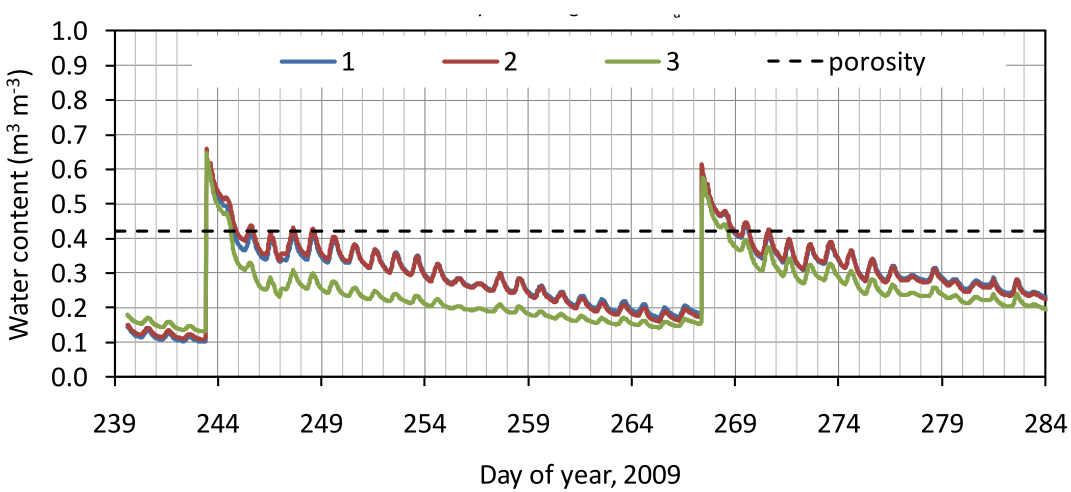
Capacitance

TDR

Neutron Probe

$$ETa = Pe + In - \Delta S$$

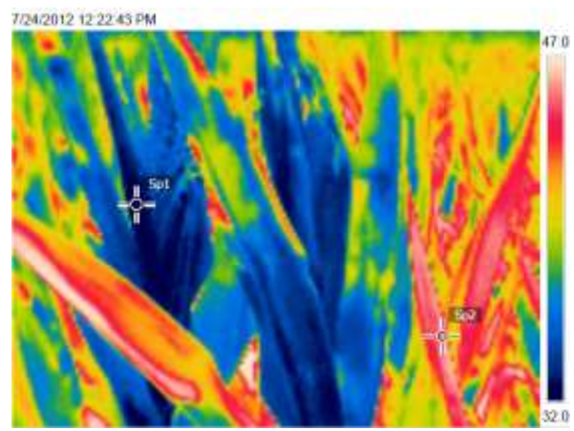


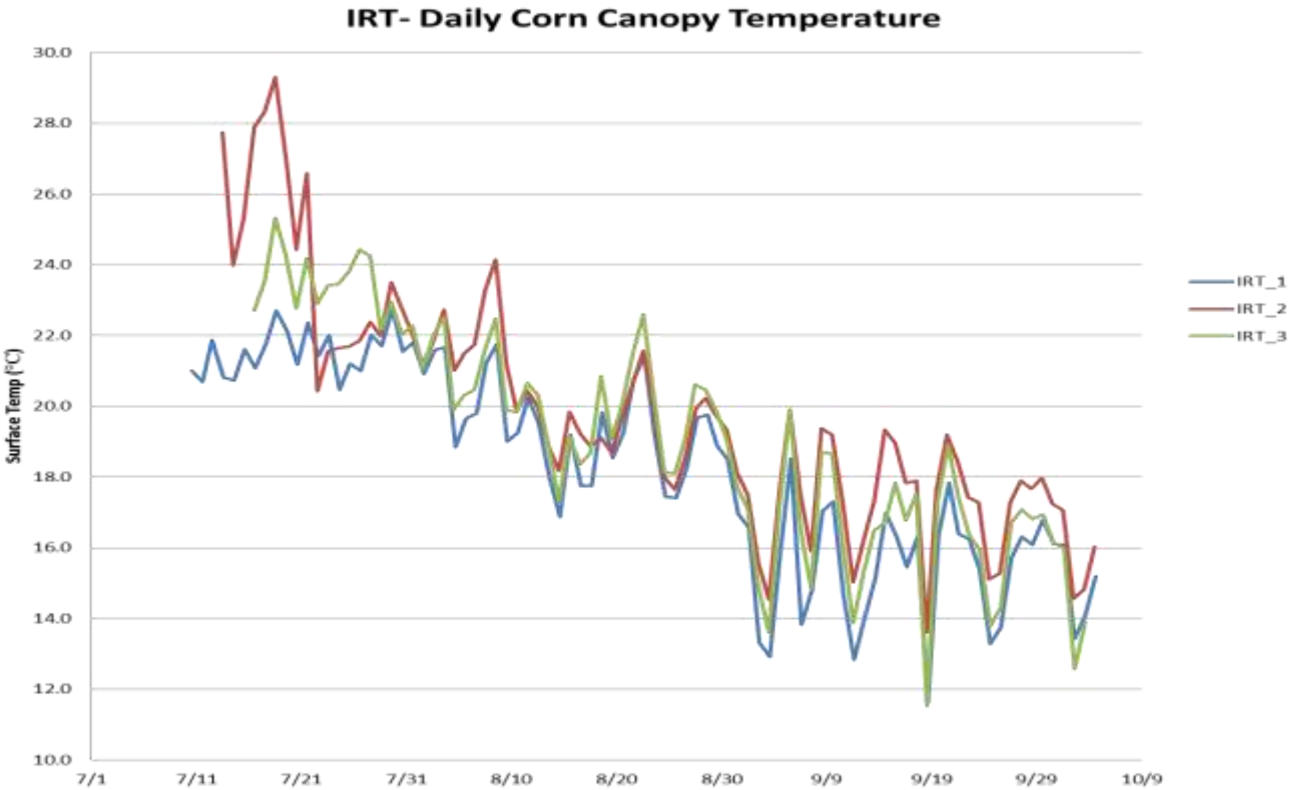


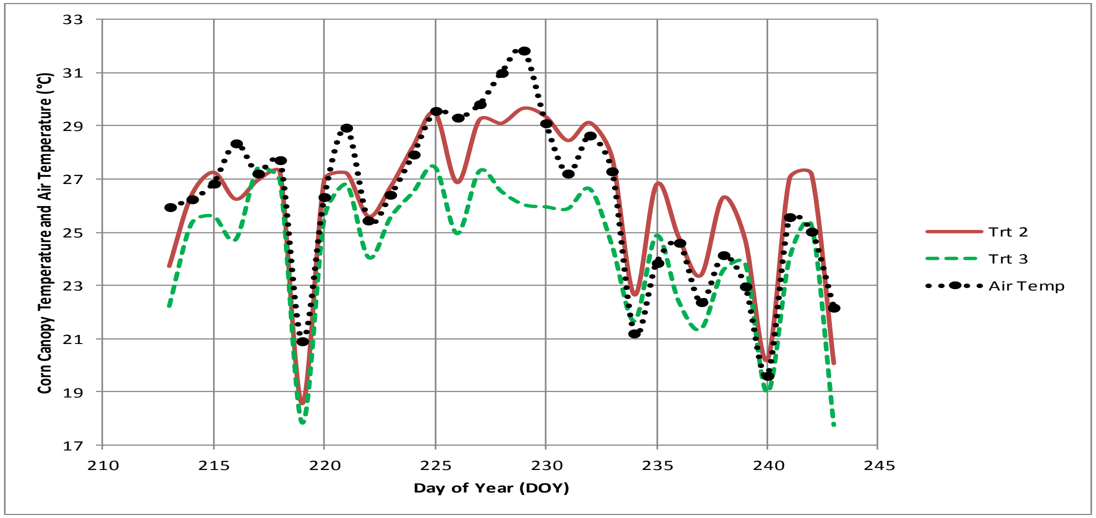
Using plant canopy temperature to detect stress

IRT

- Related to water status of plant and soil
  - ET process cools the plant
  - If ETa < ETp then the plant heats up
  - ETa = actual crop ET
  - ETp = potential crop ET
- Can be measured by non-contact infrared thermometers (IRTs)




IRT- Daily Corn Canopy Temperature
Surface Temp (°C)
30.0
28.0
26.0
24.0
22.0
20.0
18.0
16.0
14.0
12.0
10.0
7/1
7/11
7/21
7/31
8/10
8/20
8/30
9/9
9/19
9/29
10/9
IRT_1
IRT_2
IRT_3


Corn Canopy Temperature and Air Temperature (°C)
33
31
29
27
25
23
21
19
17
210
215
220
225
230
235
240
245
Day of Year (DOY)
Trt 2
Trt 3
Air Temp

Obtaining ET_a from CWSI

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

$$ET_a = (1 - CWSI)ET_P$$

where:

$dT = T_c - T_a$

$dT_{mn} = a\,(VPD) + b$

$dT_{mx} = a\,(VPG) + b$

ETa = actual crop ET, mm/d or in/d
ETp = potential crop ET, mm/d
Kcr = potential crop coefficient,
Kcb = basal crop coefficient,
Ks = stress coefficient,
Ke = evaporation coefficient

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

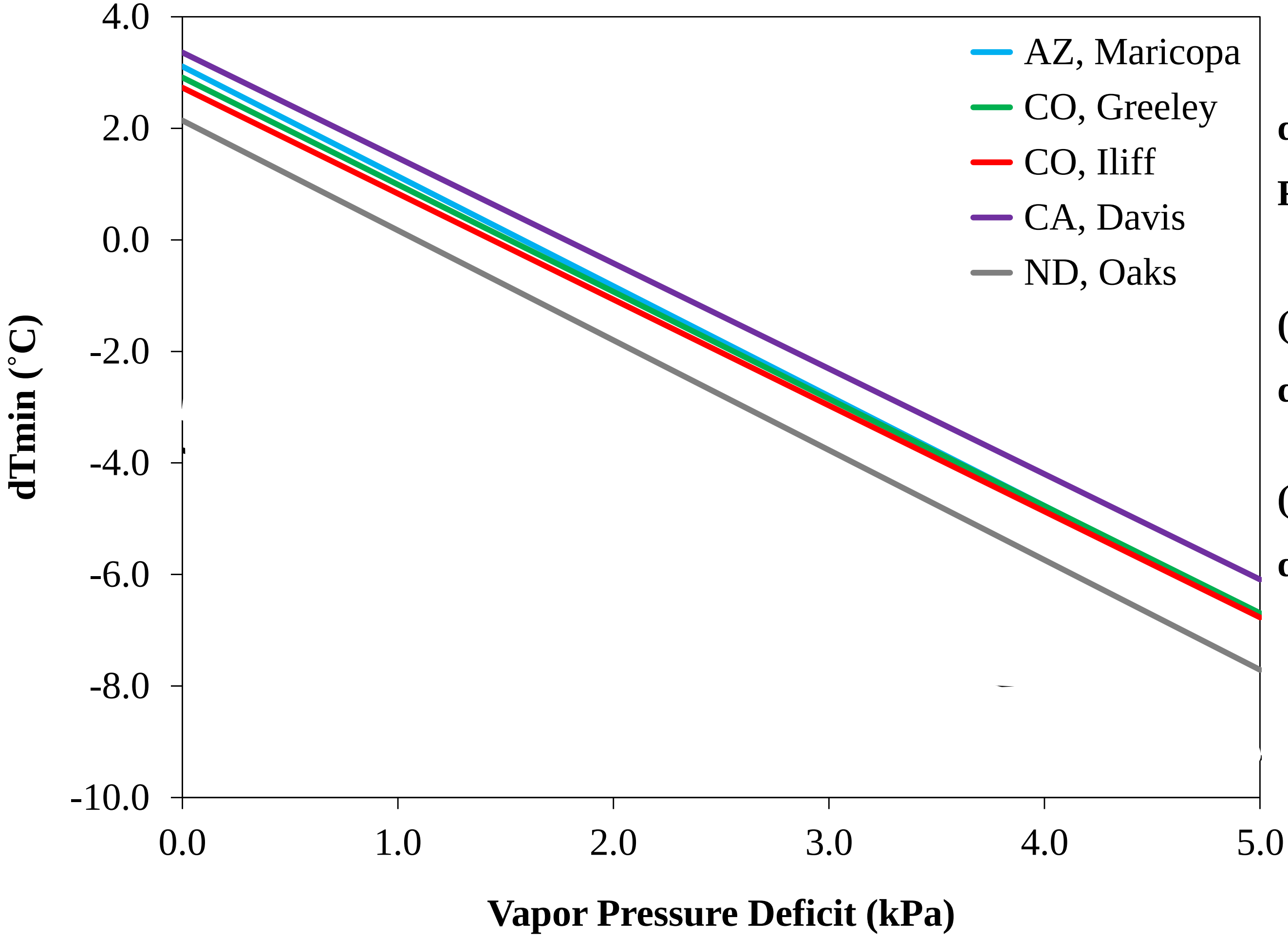
$$ET_a = (K_{cb}\,K_s) \times ET_r$$

$$K_s = (1 - CWSI)$$

Lower limit or boundary of dT (for corn)

$dT = T_c - T_a$

dT_{min} : 2.73 – 1.90 × VPD; Developed w/ data from Iliff, CO



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

For Corn:

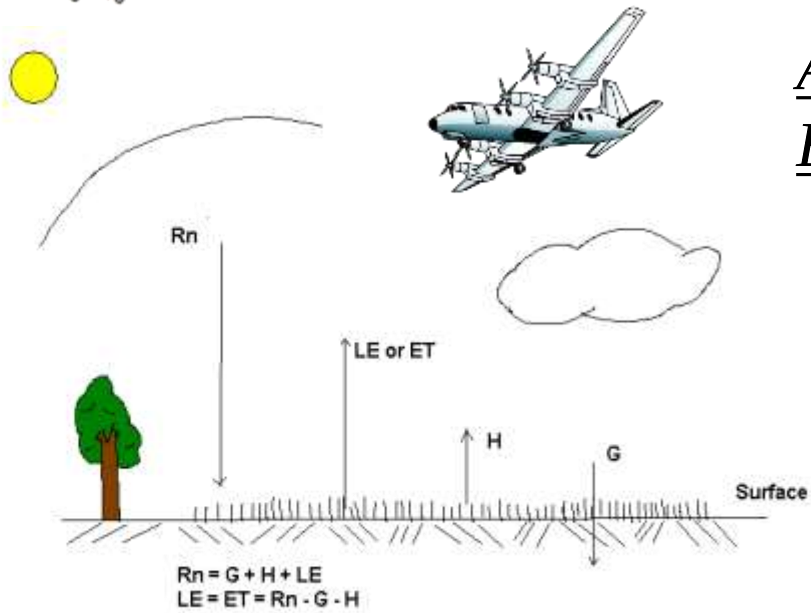
(Idso, 1982)

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

(Nielsen &Garden (1987)

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

SURFACE ENERGY BALANCE (EB)



Applied to evaluate the CWSI IRT ETa values.

$$LE = R_n - G - H$$

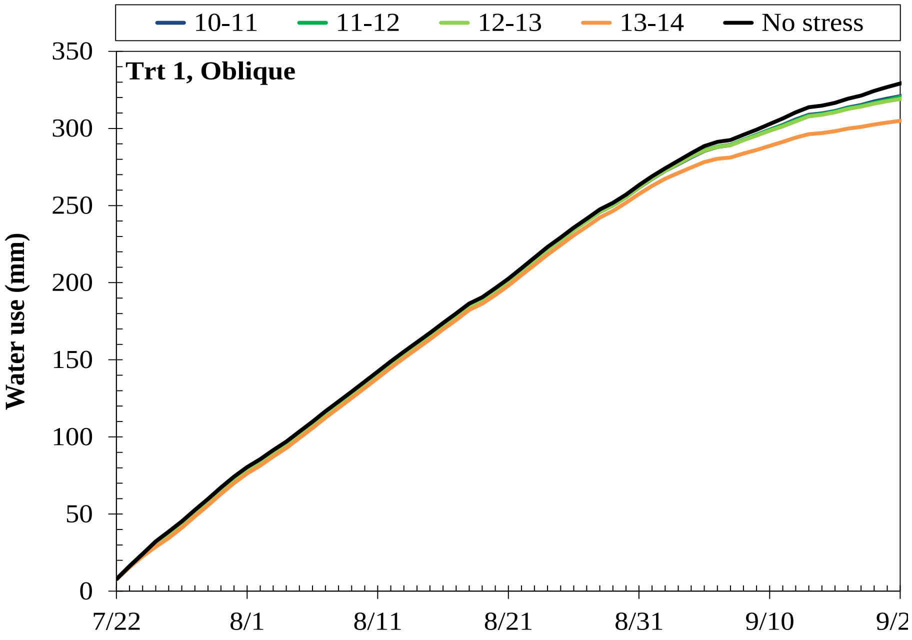
$$R_n = (1-\alpha)R_s + \varepsilon_a \sigma T_a^4 - \varepsilon_s \sigma T_s^4$$

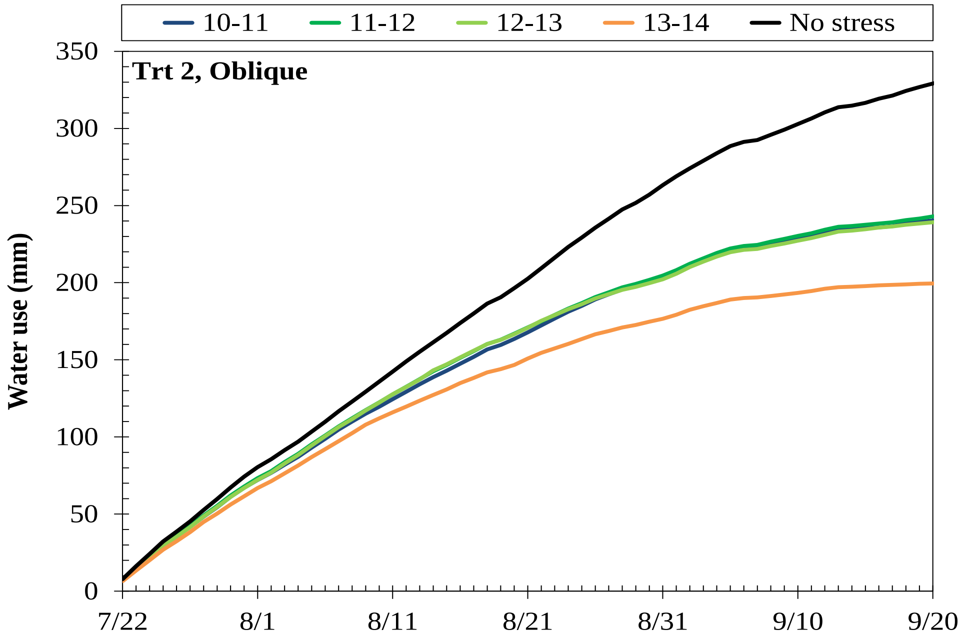
$$G = \{(0.3324 - 0.024\ LAI) \times (0.8155 - 0.3032\ \ln(LAI))\} \times R_n$$

$$H = \rho_a\ c_{pa}\ (T_{aero} - T_a) / r_{ah}$$

$$T_{aero} = 0.49\ T_s + 0.23\ T_a - 0.13\ LAI - 0.28\ U + 2.02\ h_c - 1.87\ Z_m + 0.04\ RH + 10.49$$

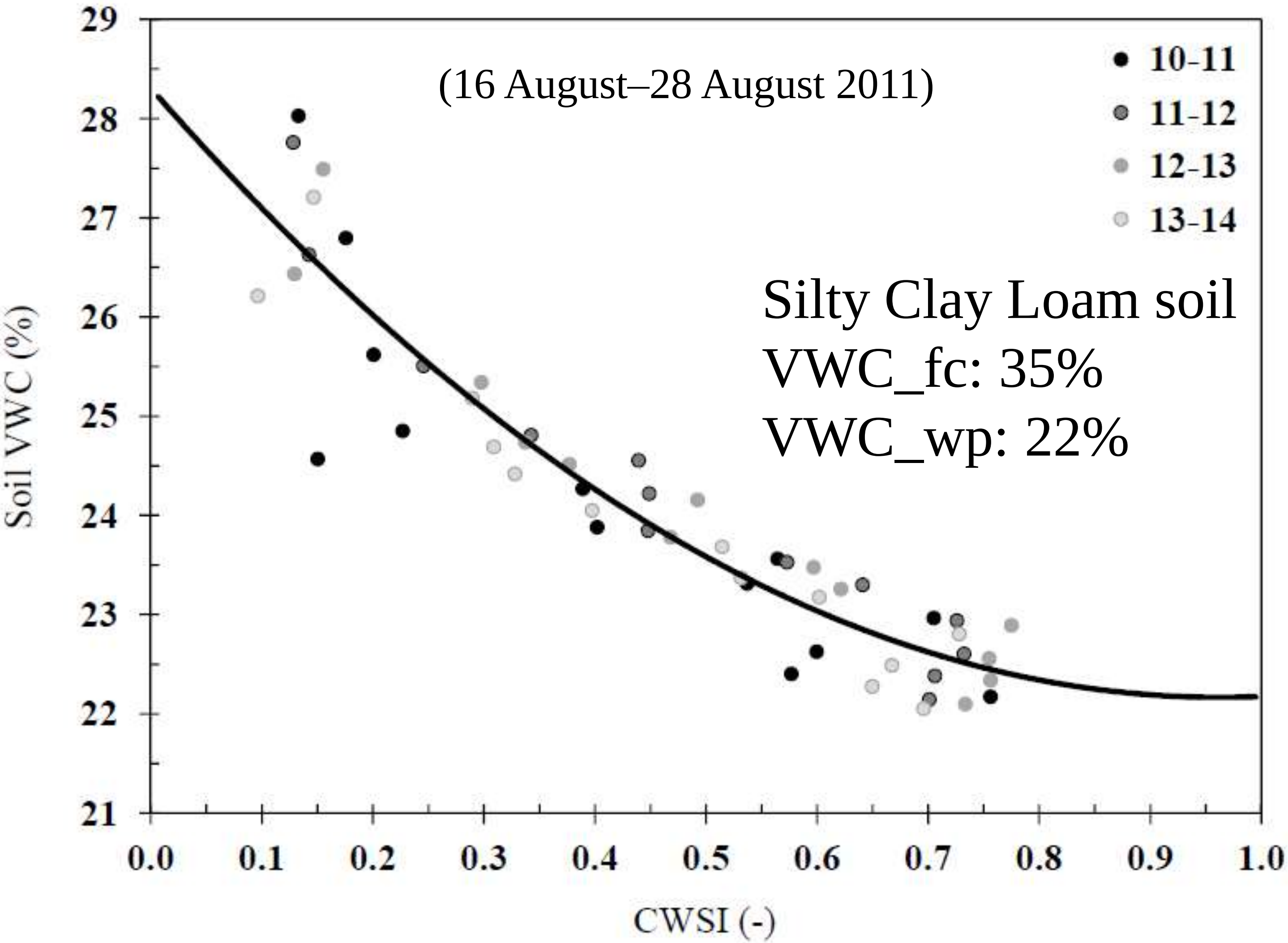
Estimated water use based on canopy temperatures collected by oblique IRTs: TrT 1 and 2





Error	Trt1		Trt2		Trt3	
	OIRTs	NIRTs	OIRTs	NIRTs	OIRTs	NIRTs
T_{aero}	-6.3%	-13.4%	5.8%	-15.6%	8.1%	-26.7%

CWSI *vs.* volumetric water content (VWC)



$$VWC = 6.63\ CWSI^2 - 12.76\ CWSI + 28.31\ (R^2 = 0.89)$$

Models tested

- TSM

$$T_s = \sqrt[4]{\frac{T_{sfc}^4 - (f_c \times T_c)^4}{1 - f_c}}$$

$$LE_s = R_{n\_s} - H_s - G$$

$$LE_c = R_{n\_c} - H_c - G$$

- SAT

$$H = \frac{\rho_a \times Cp_a \times (T_o - T_a)}{r_{ah}}$$

$$LE = R_n - G - H$$

$$T_o = (0.534 \times T_{sfc}) + (0.39 \times T_a) - (0.224 \times LAI) - (0.192 \times U) - 1.67$$

- CWSI

$$CWSI = \frac{dT - dT_{ll}}{dT_{ul} - dT_{ll}}$$

$$ET_a = (1 - CWSI) \times ET_p$$

- Kcr

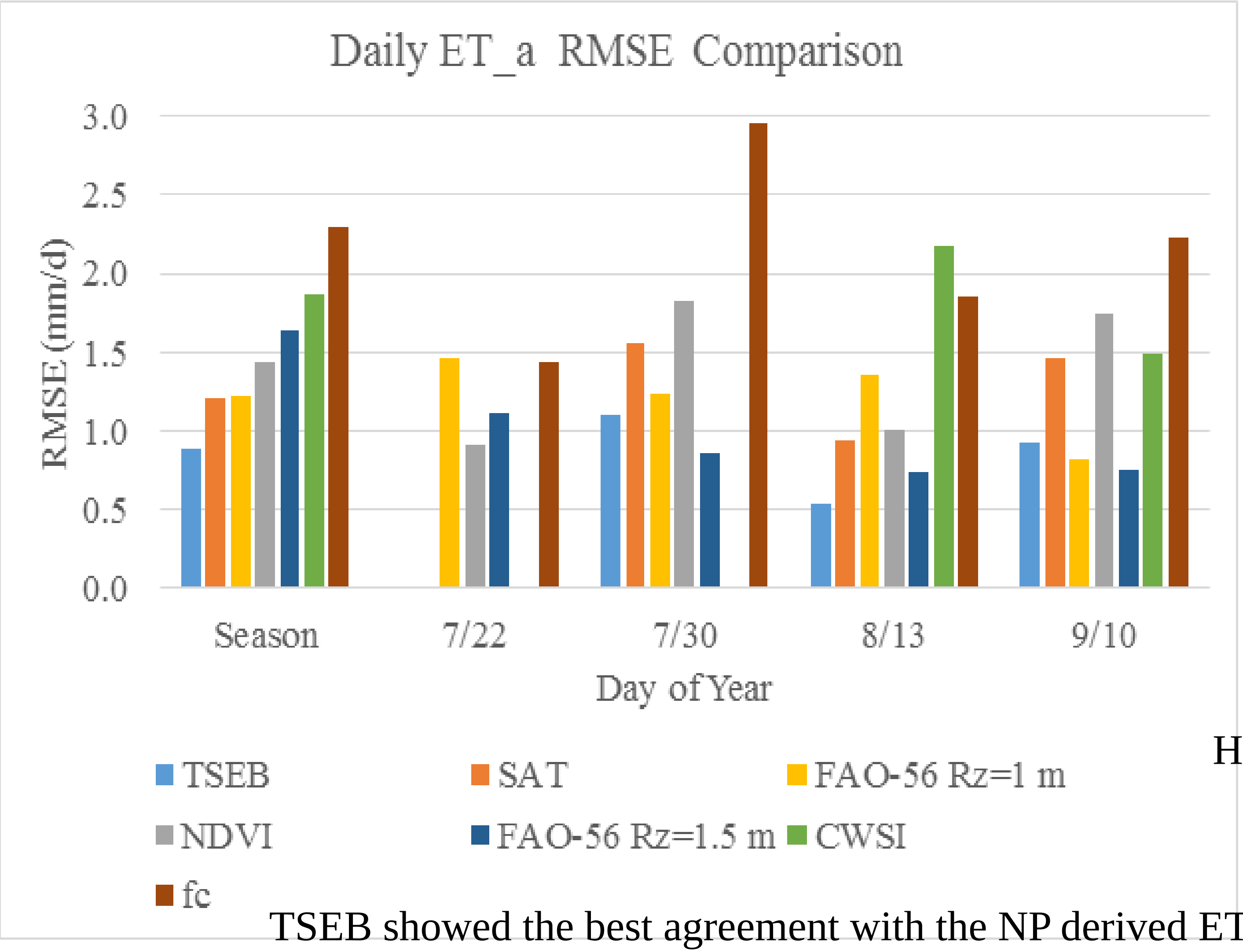
$$ET_a = k_{cbrf} \times ET_{ref}$$

For corn

$$k_{cbrf} = 1.181(NDVI) - 0.026$$

$$k_{cbrf} = 1.13 \times f_c + 0.14$$

Summary of the statistics from the daily ET_a derived from the 2015 Tempest UAS RS campaign



Hathaway (2016)

TSEB showed the best agreement with the NP derived ET_a, with a MBE of 0.29 mm/d, RMSE of 0.89 mm/d

ETa estimated using ReSET and other reflectance (VI) based models

Other model **1**: Reflectance-based crop coefficient (grass ref.), kcbo.
$Kcbo = 1.13 \times fc + 0.14$, $fc = 1.22 \times NDVI - 0.21$.

$$ETa = Kcbo \times ETo$$

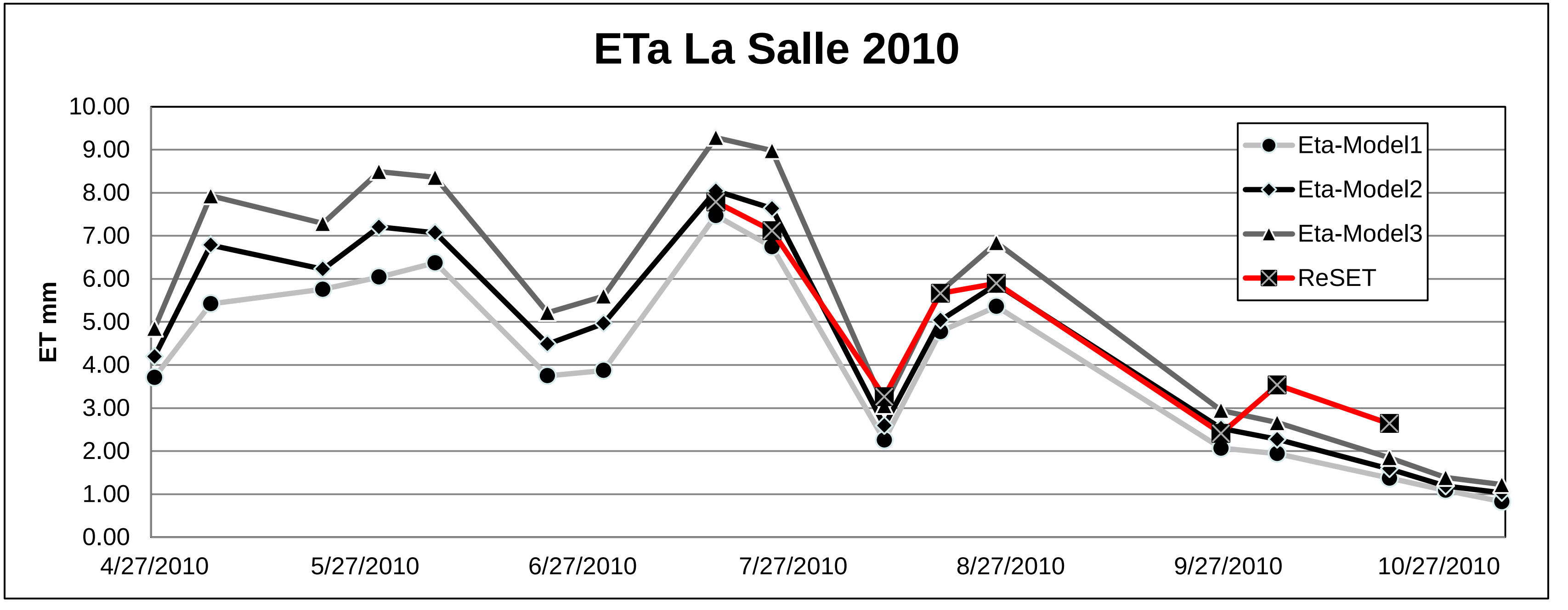
Other model **2**: Reflectance-based crop coefficient (alfalfa ref.), Kcr1:
$Kcr1 = 1.184 \times NDVI - 0.026$

$$ETa = Kcr1 \times ETr$$

Other model **3**: Reflectance-based crop coefficient (alfalfa ref.), Kcr2:
$Kcr2 = 1.416 \times SAVI + 0.017$

$$ETa = Kcr2 \times ETr$$

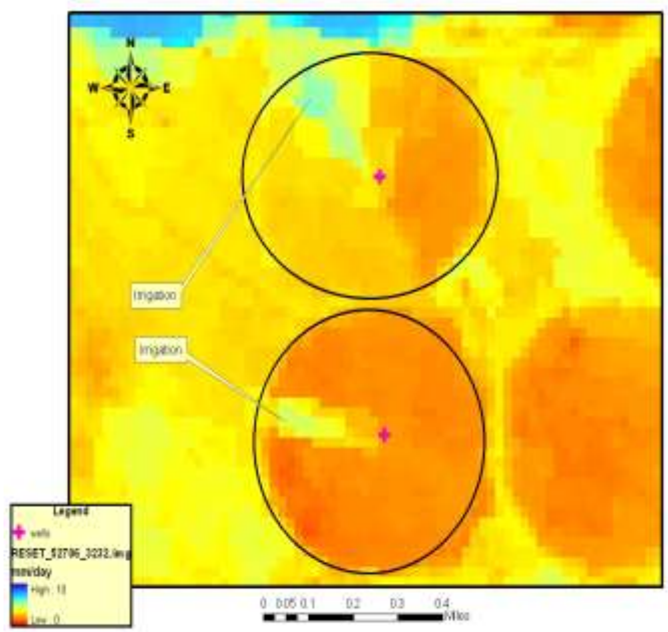
ETa at La Salle, CO field 2010 Using ReSET and other VI models



Irrigated corn, center pivot

Surface Energy Balance Model(ReSET-Raster)

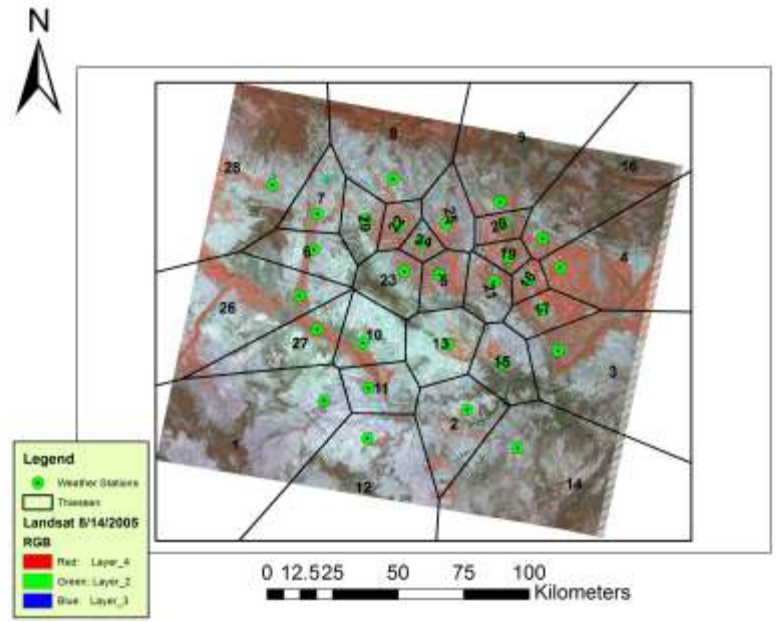
- The ReSET-Raster model uses Surface Energy Balance to calculate actual ET for every pixel.
- ReSET uses a full raster approach so a unique spatially based calibration is applied to each grid cell. The model is developed under several platforms (ArcGIS model builder (Python), ERDAS model maker and MATLAB)



Advantages of ReSET Raster over similar SEB models.

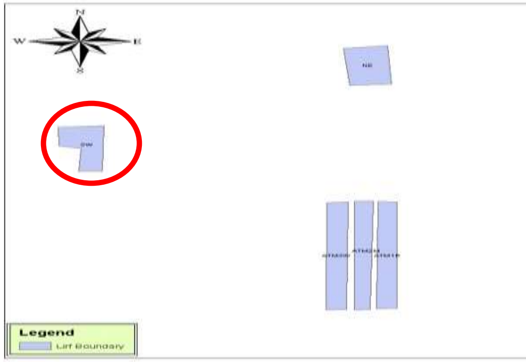
ReSET is developed on the same theoretical basis of several other SEB models except that its native environment is raster which makes it stand out compared to similar models.

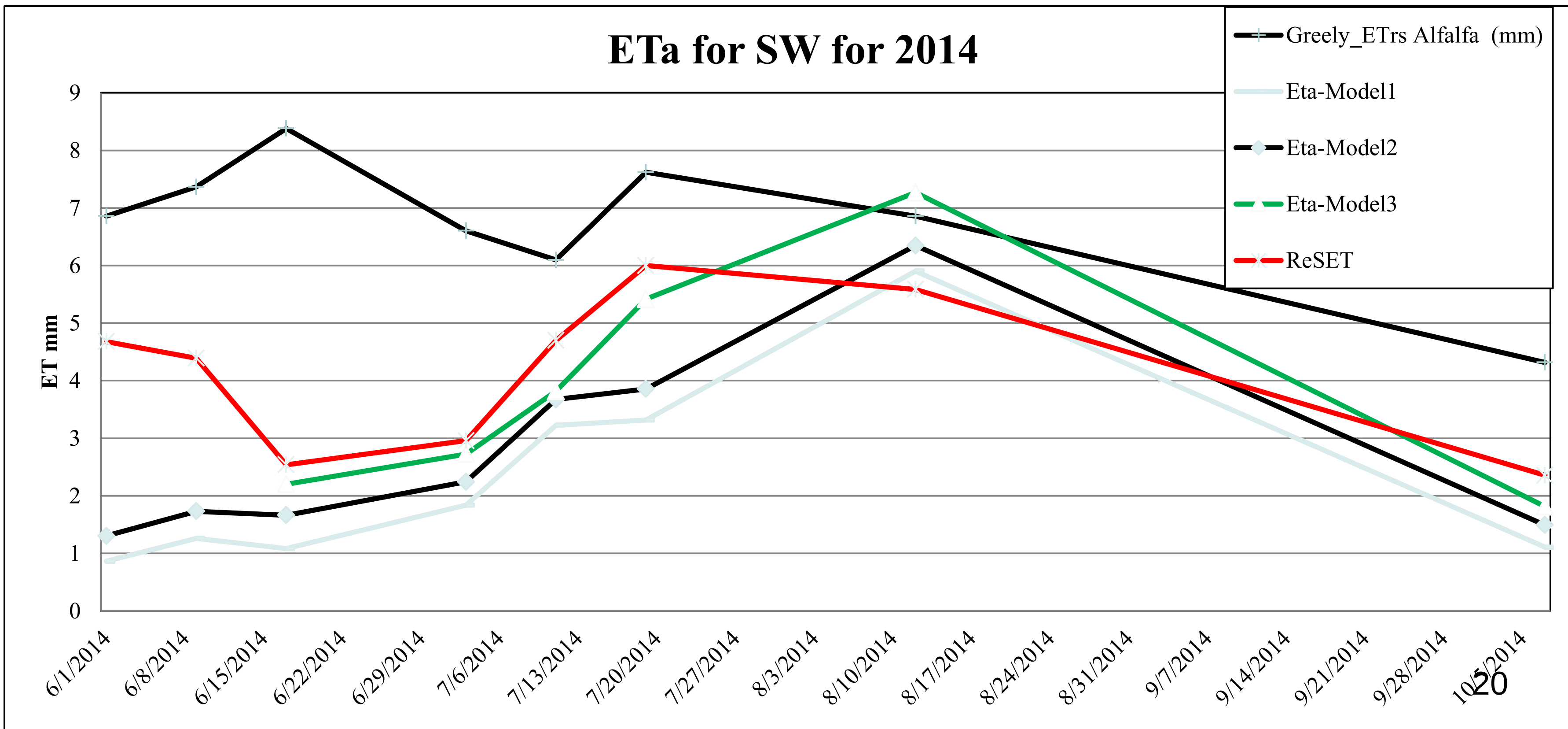
One of the main advantages of the SEB models is estimating ET for large areas that will usually contain several weather stations that should be used to accurately calibrate the model.



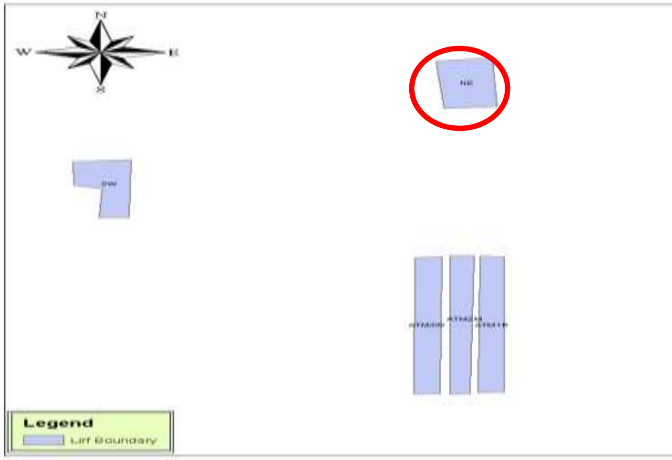
Point based (non raster) SEB models will use either one weather station or an average point value from several weather stations for calibration. The second option for point based models is dividing the area to several sub areas (thiessen polygons) and assign each area to a close by weather station then run the model for each area independently. Even with thiessen polygon solution there will be an abnormal discontinuity in the developed ET grid at the borders of the polygons due to the change of the reference points.

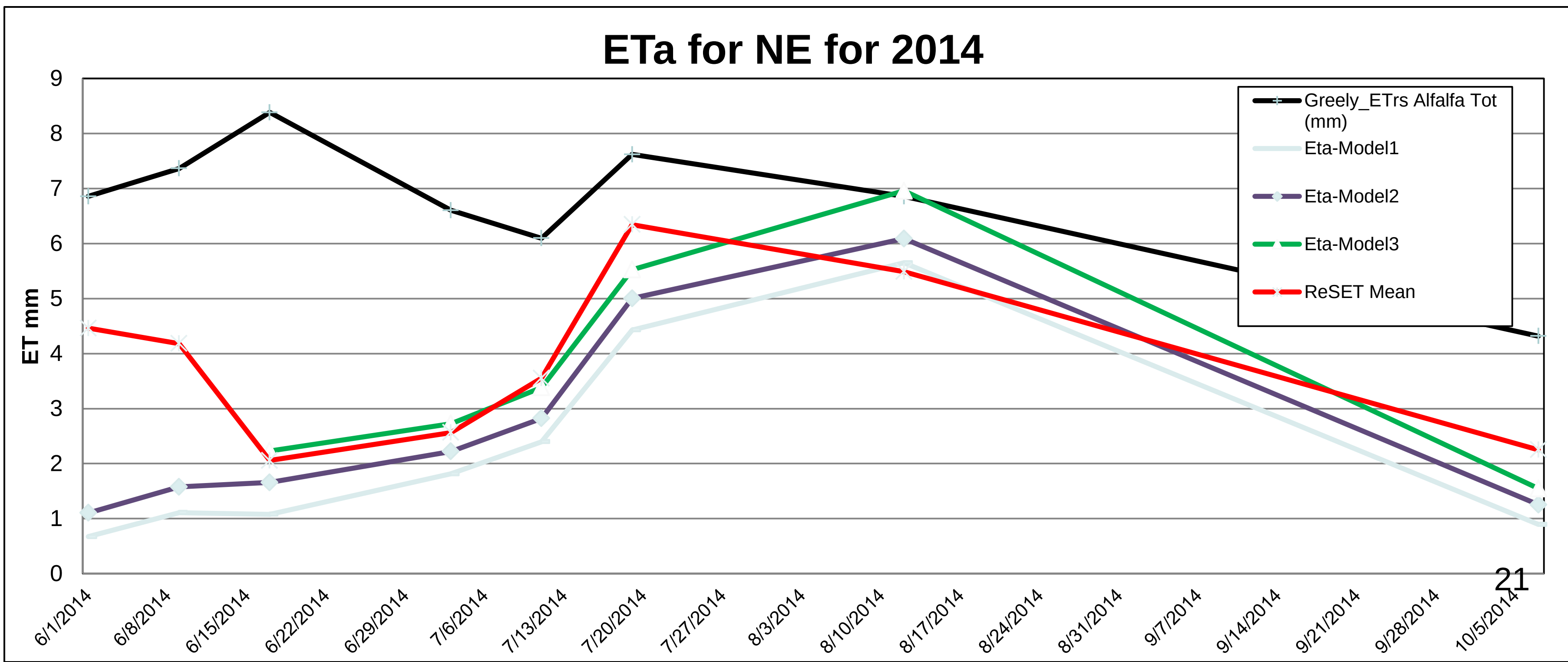
ETa at the ATM location on 2014





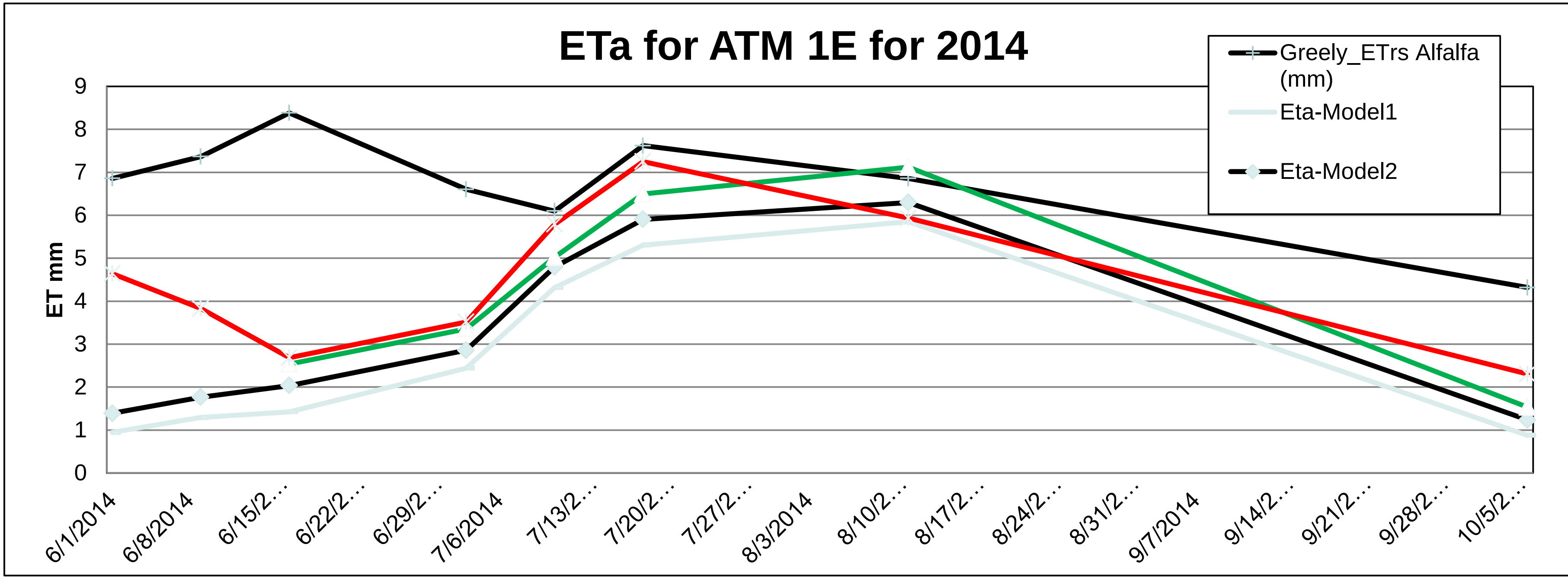
ETa at the ATM location on 2014

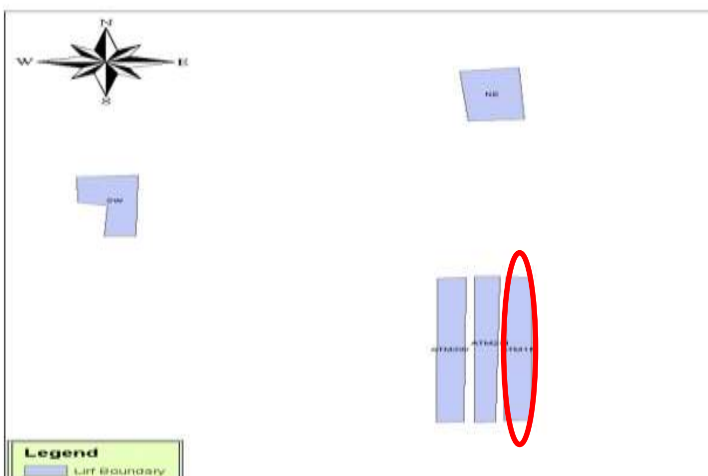




ETa at the ATM location on 2014

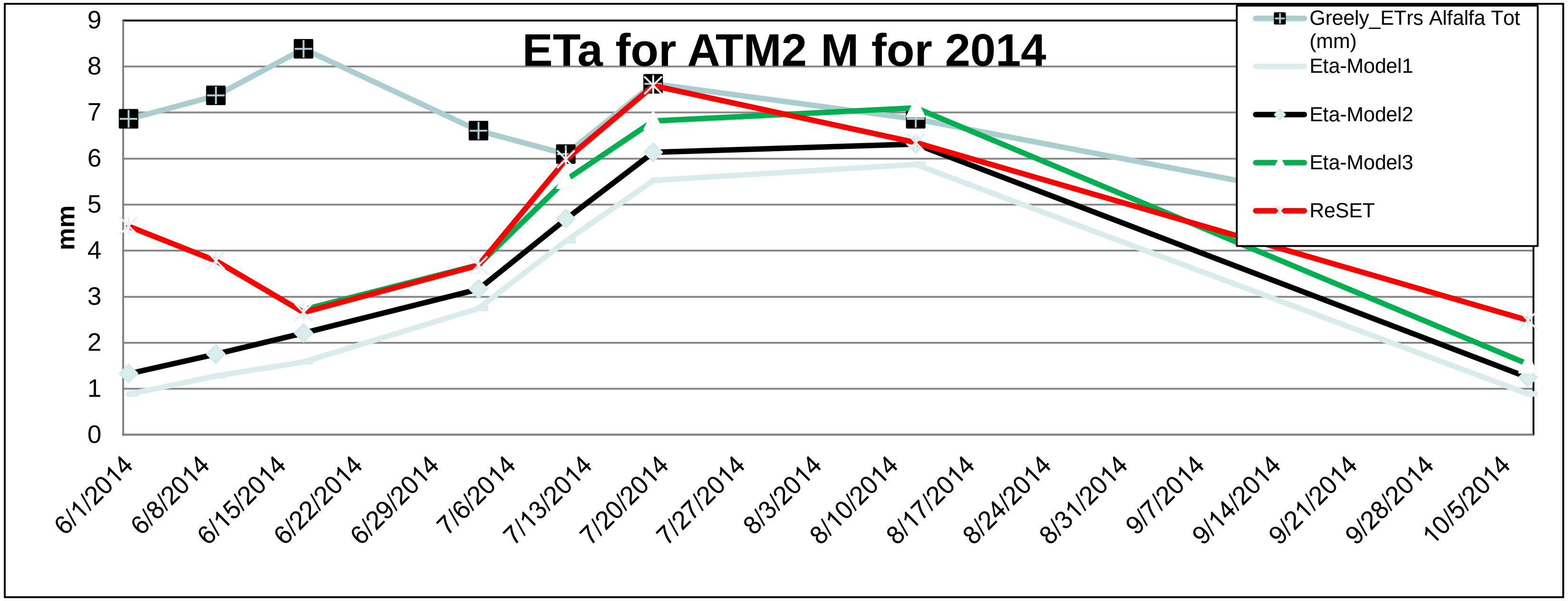
deficit

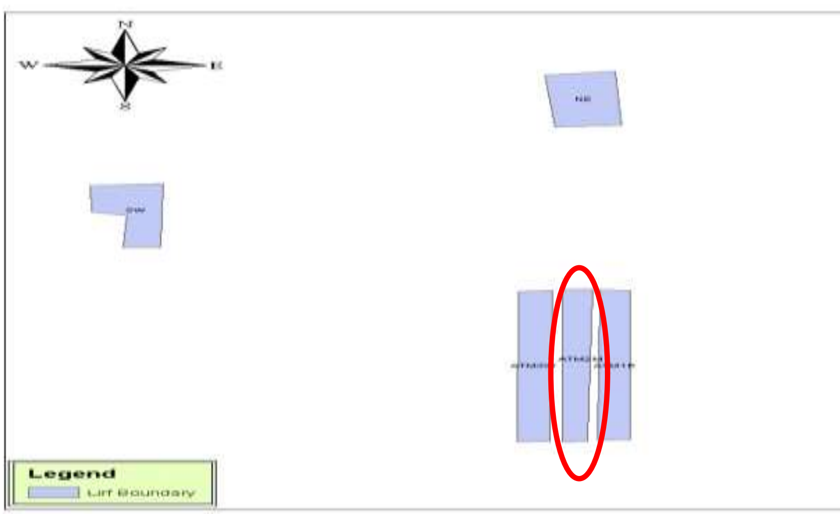




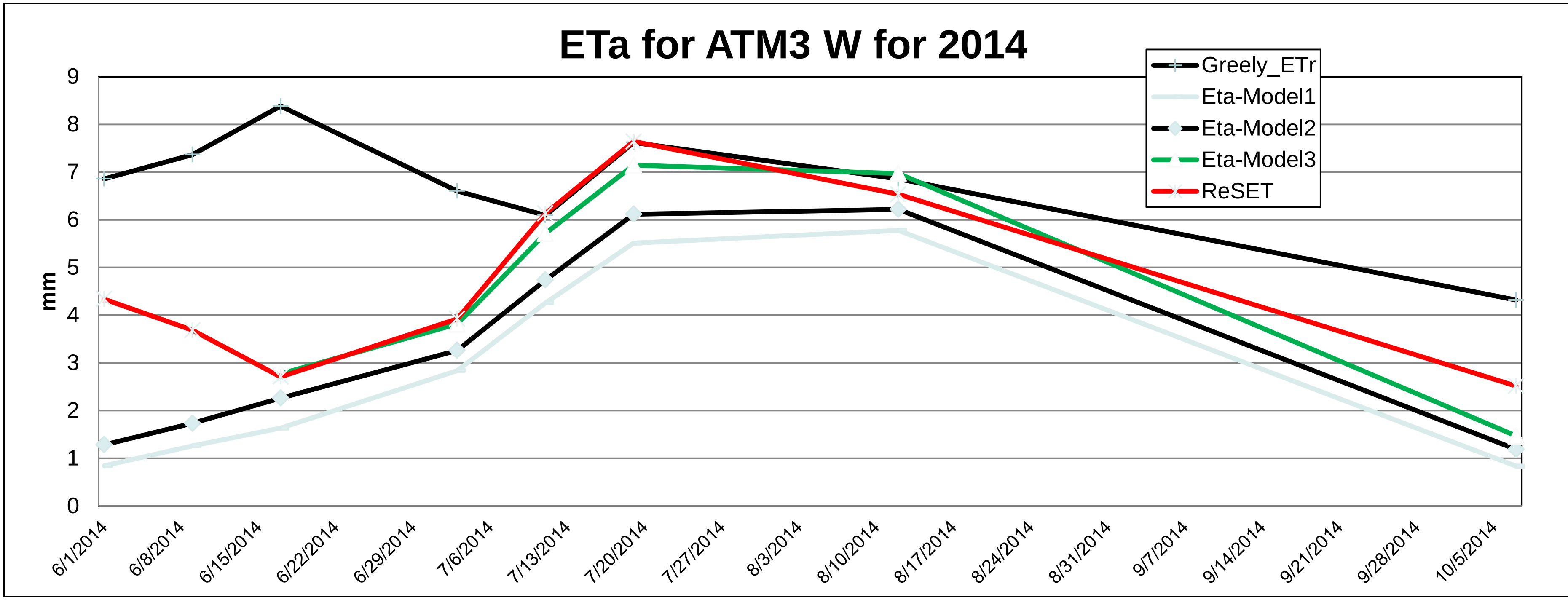
ETa at the ATM location on 2014

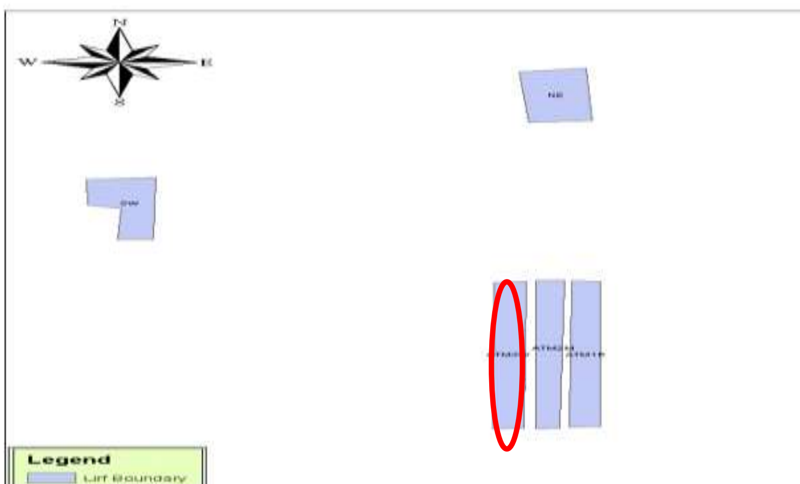
Full



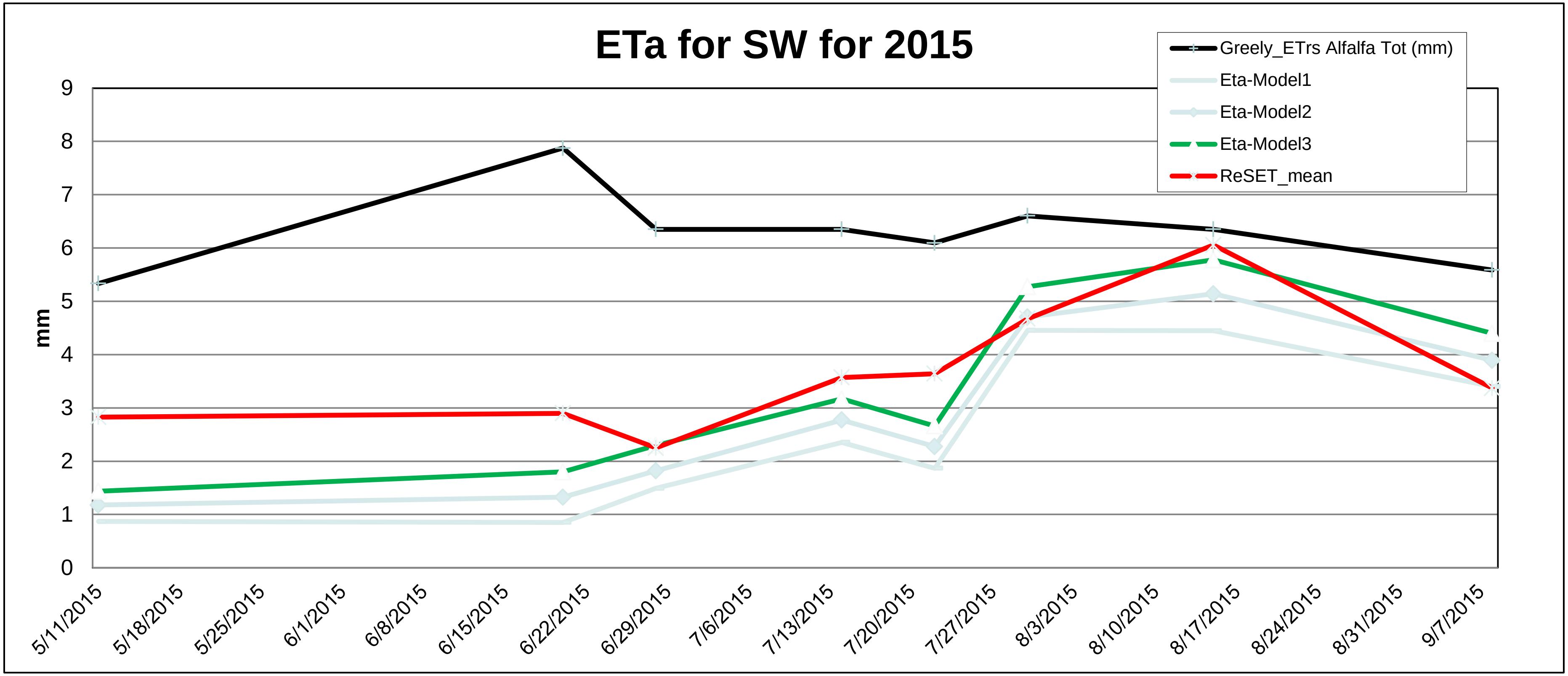


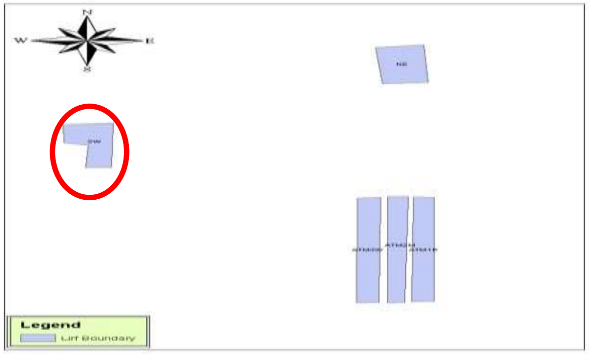
ETa at the ATM location on 2014 drought



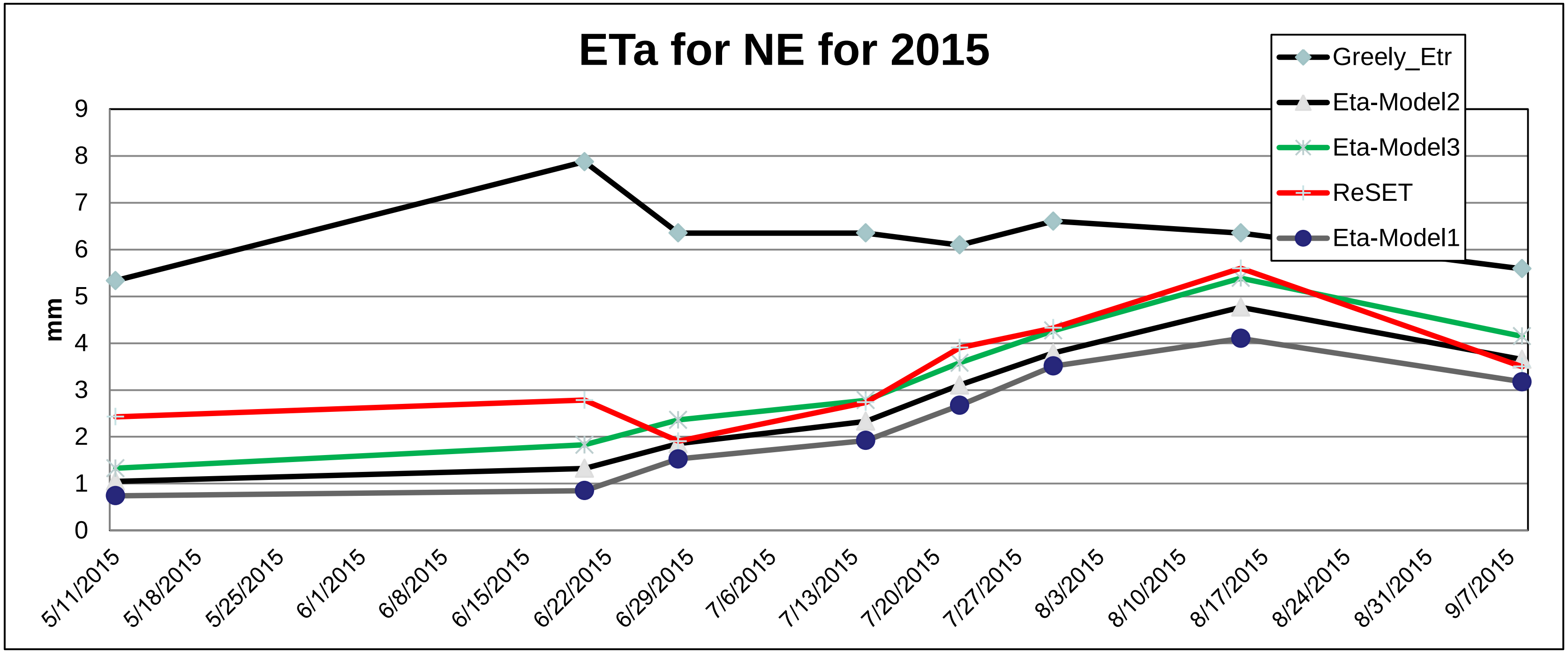


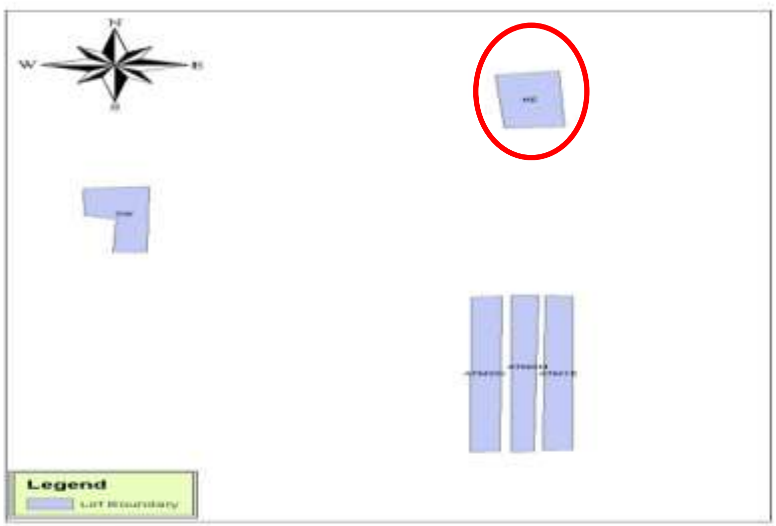
ETa at the ATM location on 2015





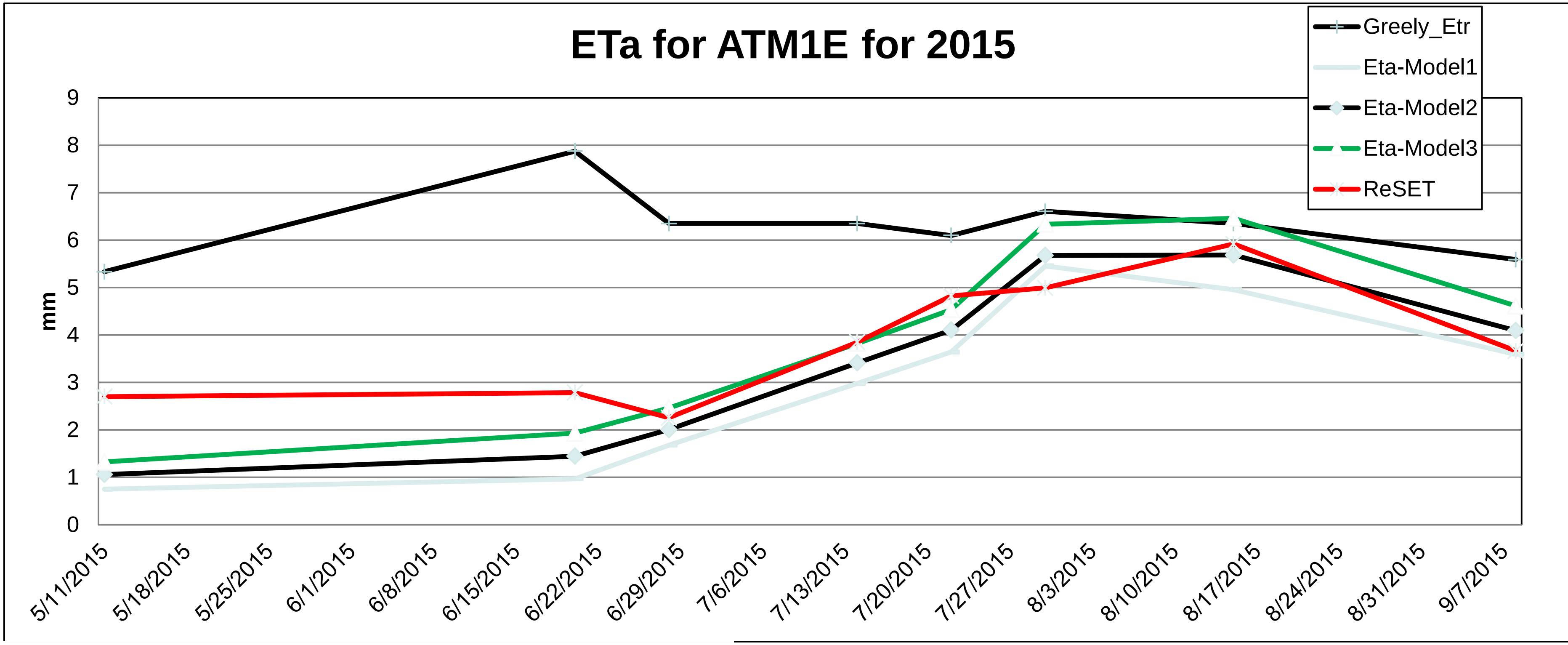
ETa at the ATM location on 2015

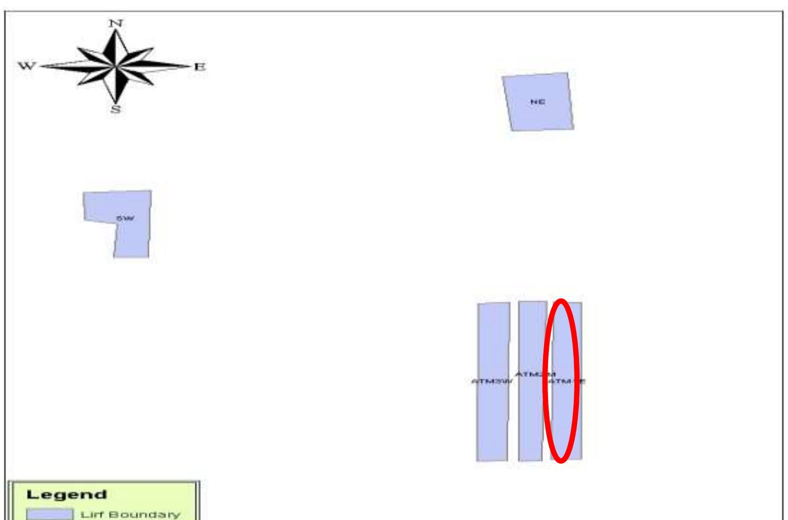




ETa at the ATM location on 2015

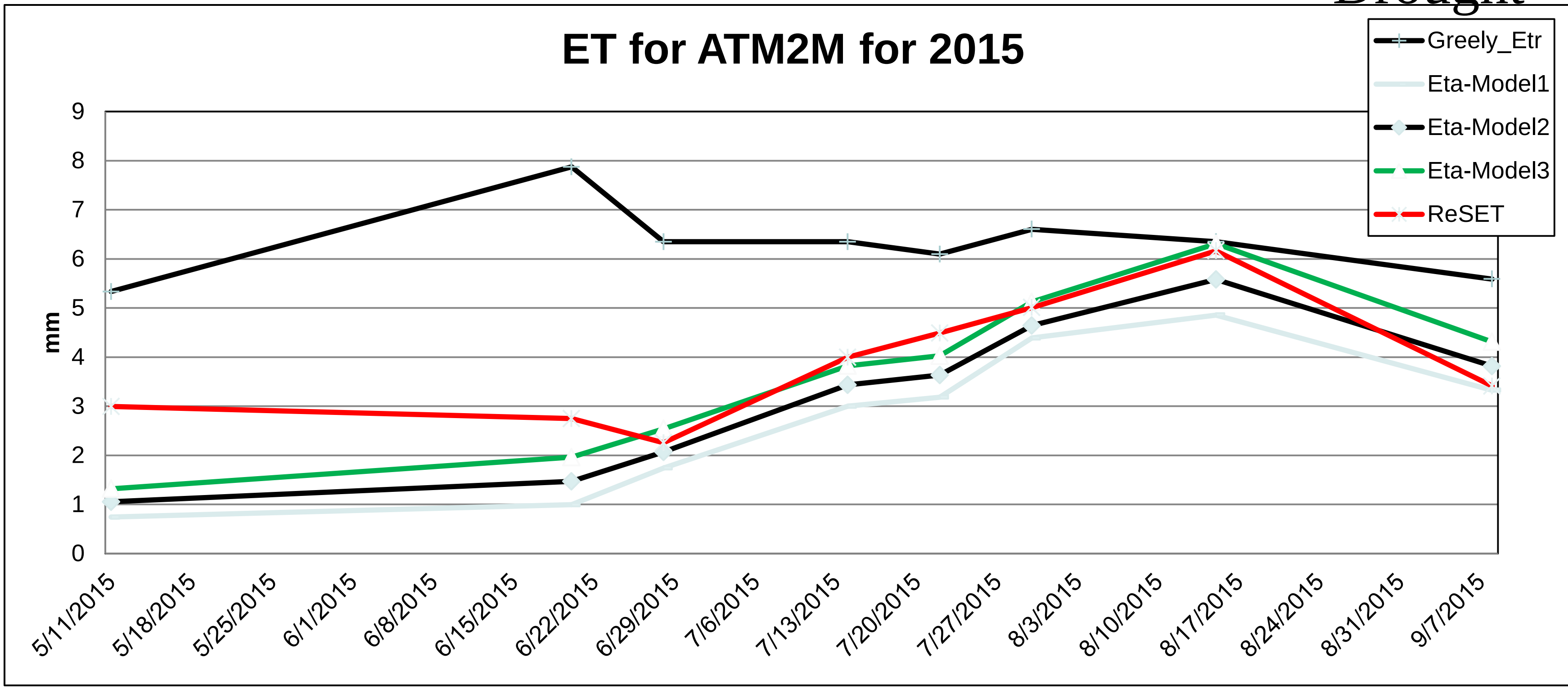
Full

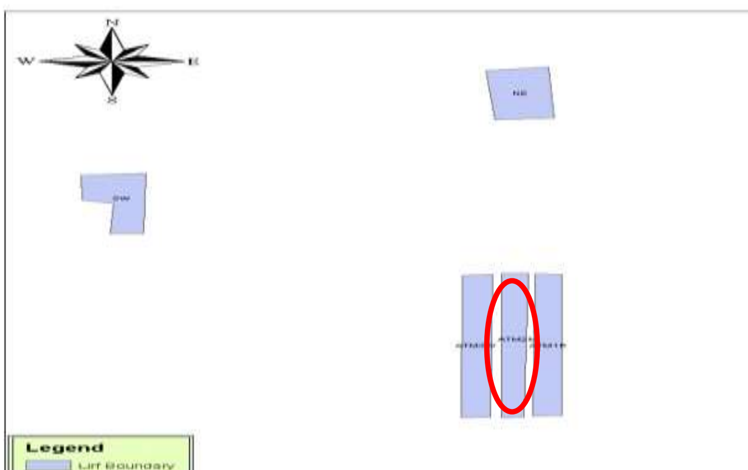




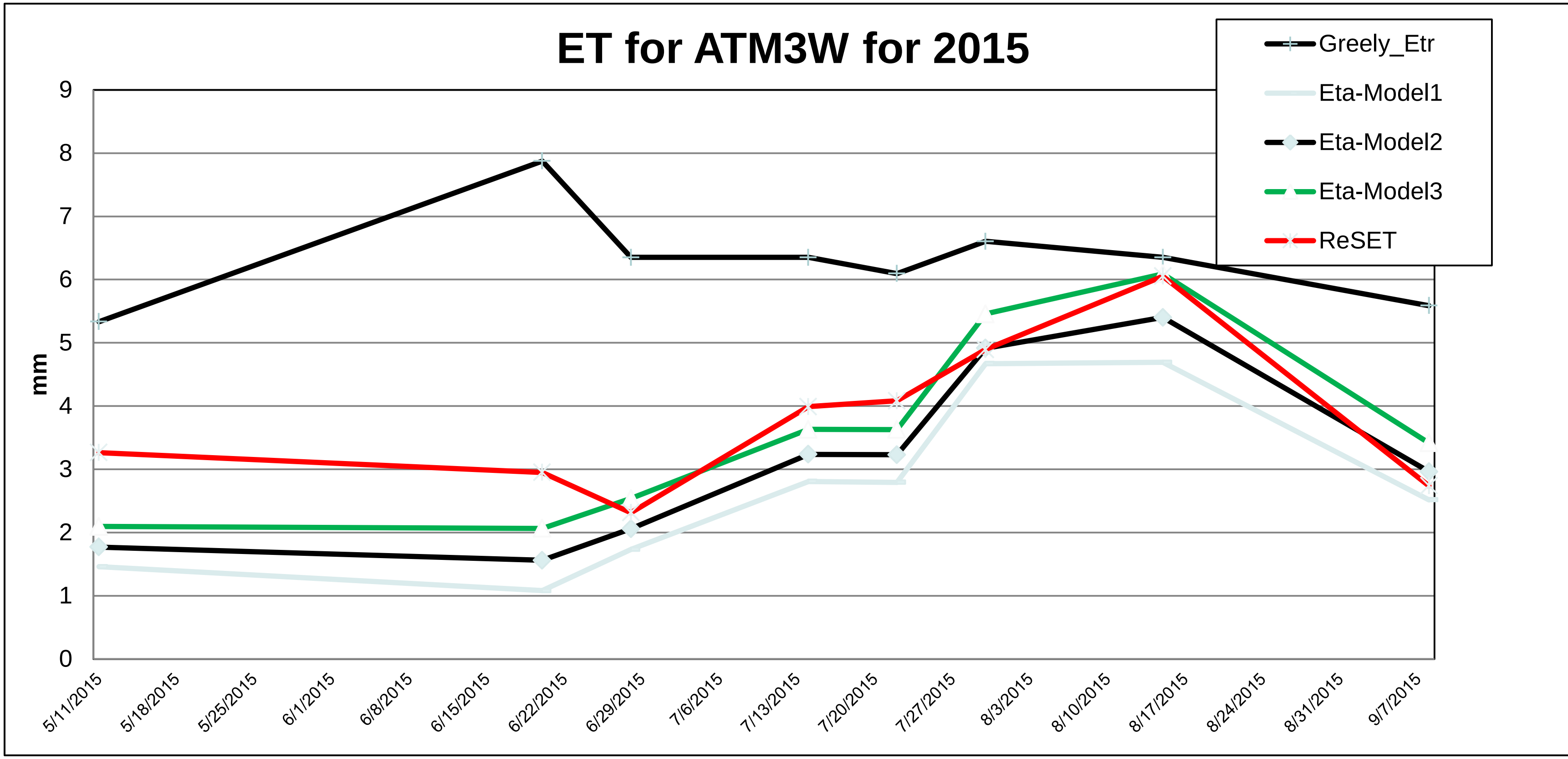
ET at the ATM location on 2015

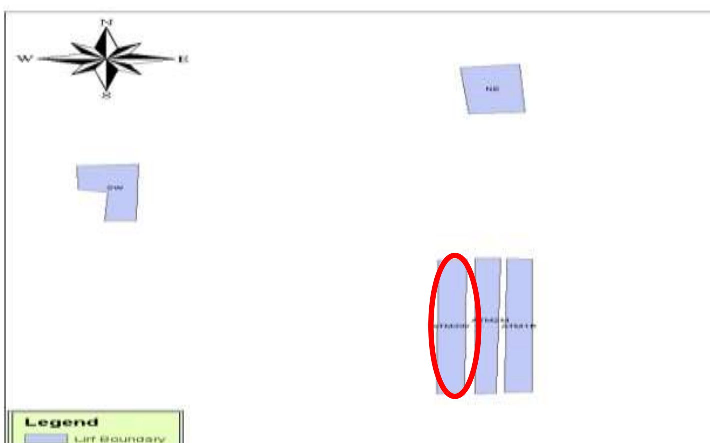
Drought



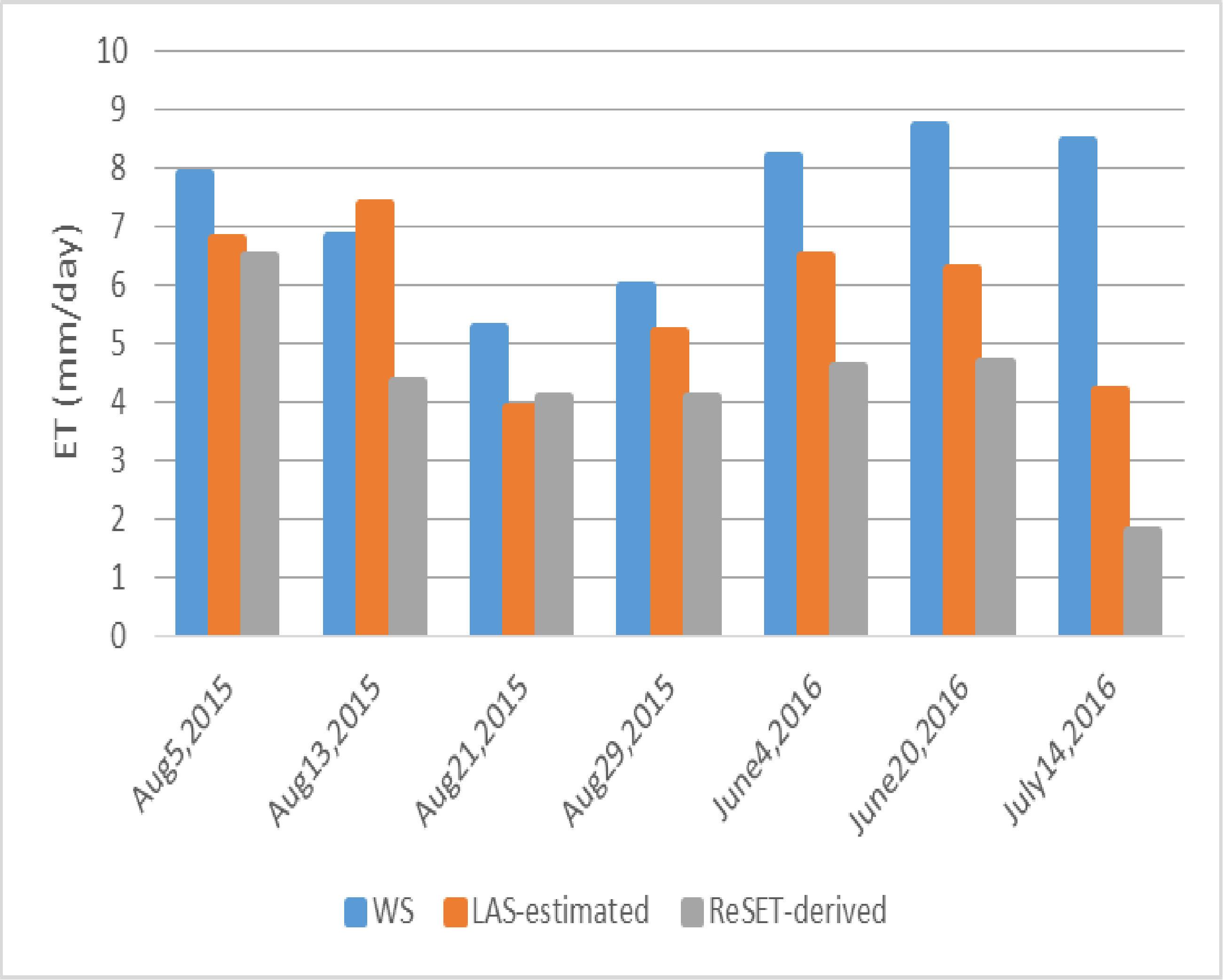


ET at the ATM location on 2015 Deficit





Montrose, CO 2015-2016



ETa comparison among reference Weather Station (WS), LAS-estimated and ReSET-derived