Adapting Crop Coefficients for Local Conditions

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University of Idaho

Discussion Points

- Transferability and Standardization of Reference ET
- Transferability of Crop Coefficients
- Impact of crop density and architecture
- Review of the Dual Crop Coefficient – Reference ET approach of FAO56
- Application at Mead, Nebraska with comparisons against Ameriflux Eddy Covariance
- Sensitivites of ET estimates to settings for Dual K_c parameters

The Dual K_c Approach

- $ET_c = K_c \, ET_{ref}$
- $K_c = K_s \, K_{cb} + K_e$
  - K_s = stress coefficient (0 – 1)
  - K_{cb} = 'basal' coefficient representing ET with dry surface soil layer (primarily transpiration)
  - K_e = evaporation from wet soil surface
- $K_e = K_r \, (K_{c\ max\ r} - K_s K_{cb})$ *(Transpiration (K_{cb}) has priority over E)*
- $K_{c\ max\ r} = \max[K_{c\ max\ bare}, (K_{cb} + 0.05)]$

Reference ET

ASCE Reference ET:
A Living Evaporation Index

30 s m^{-1}
(daytime hourly)

45 s m^{-1}
(24-hr)
for alfalfa

50 s m^{-1}
(daytime hourly)

70 s m^{-1}
(24-hr)
for grass

full Penman-Monteith

$$ET = \left(\frac{\Delta(R_n - G) + K_{time}\,\rho_a\, c_p \frac{(e_s - e_a)}{r_a}}{\Delta + \gamma\left(1 + \frac{r_s}{r_a}\right)} \right) / \lambda$$

C_n and C_d are constants

Standardized FAO56/ASCE Penman-Monteith

$$ET_{ref} = \frac{0.408\,\Delta(R_n - G) + \gamma \frac{C_n}{T+273} u_2 (e_s - e_a)}{\Delta + \gamma(1 + C_d u_2)}$$

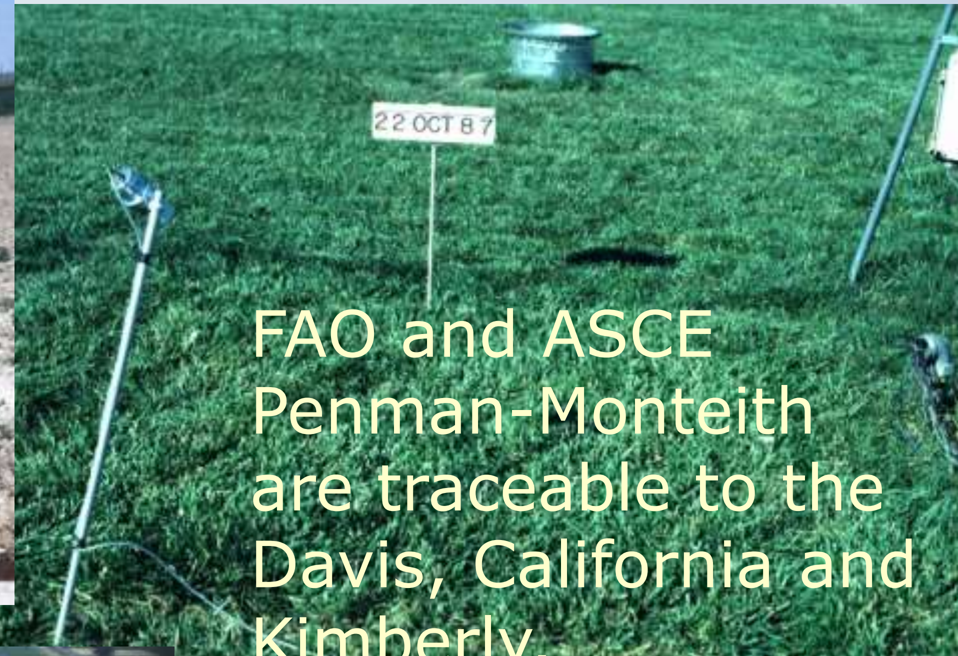
f (Solar Radiation)

f (Temperature)

Wind Speed

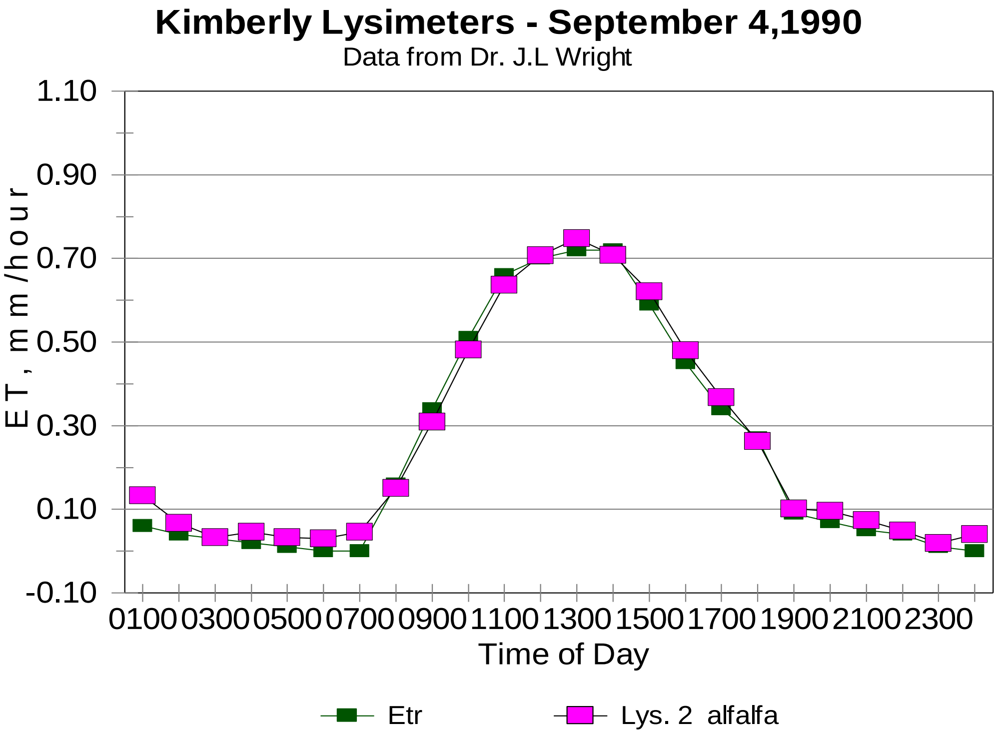
f (Humidity)

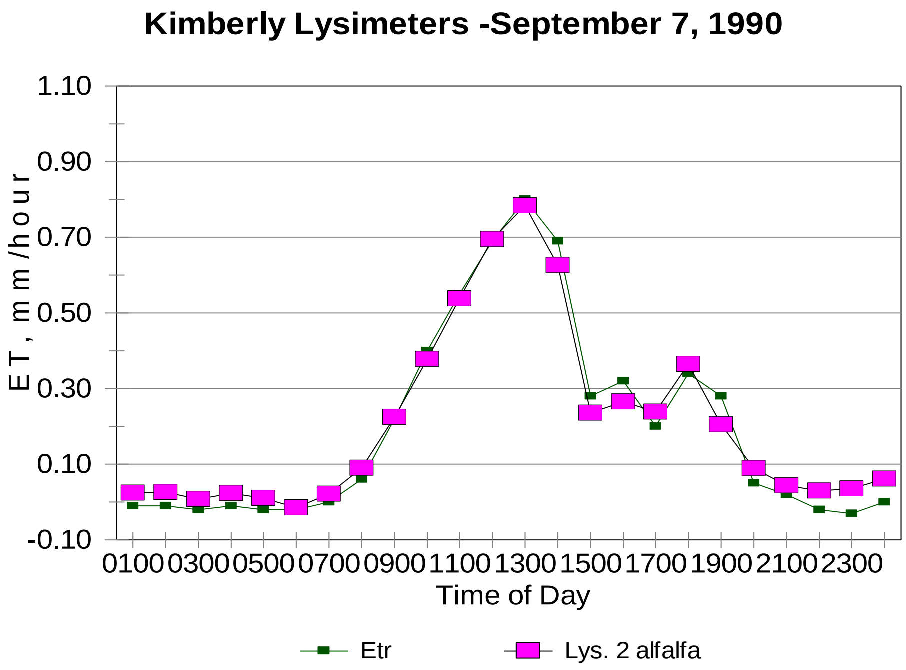
ASCE PM can be applied to clipped grass and to 0.5 m tall alfalfa



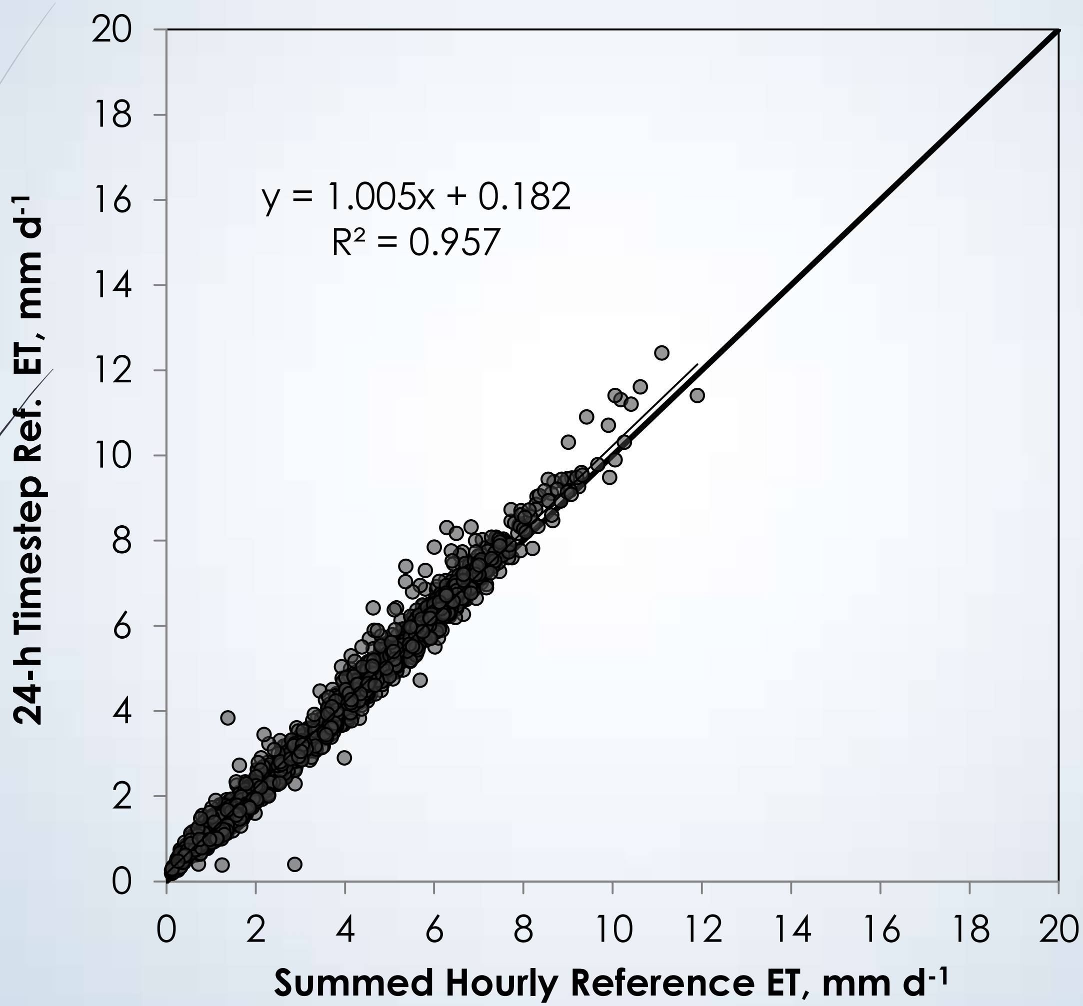
FAO and ASCE Penman-Monteith are traceable to the Davis, California and Kimberly, Idaho (USDA) Lysimeters

ASCE Standardized Penman-Monteith
(alfalfa reference) at Kimberly, Idaho
- hourly time step





ASCE/FAO PM -- Daily vs. Hourly Timesteps -- Both are good



Davis, California
CIMIS Station
2008 – 2012

Grass Reference

Conclusion: You can use hourly or daily weather data. Hourly estimates may be a "few percent" more accurate.

The FAO-56 hourly PM was applied using 50 s/m surface resistance as recommended in Allen et al. 2005

QAQC of Weather Data -- Correct biases before use

- FAO-56 and ASCE (2005) standardizations and guidelines encourage the use of a graphical assessment of hourly or daily weather data
- Graphical views of data and contrasts benefit from
  - Relatively quick and automated assessments
  - Scans of entire data series
  - Enables the use of the human brain's integrating and conclusion-drawing capabilities
- Recommended to complement Weather Network QAQC programs

ET

R E F - E T

Reference Evapotranspiration Calculator

For Support of ASCE Manual 70 (1990,2016) and 2005 ASCE Standardization
and
FAO Irrigation and Drainage Paper No. 56: CROP EVAPOTRANSPIRATION

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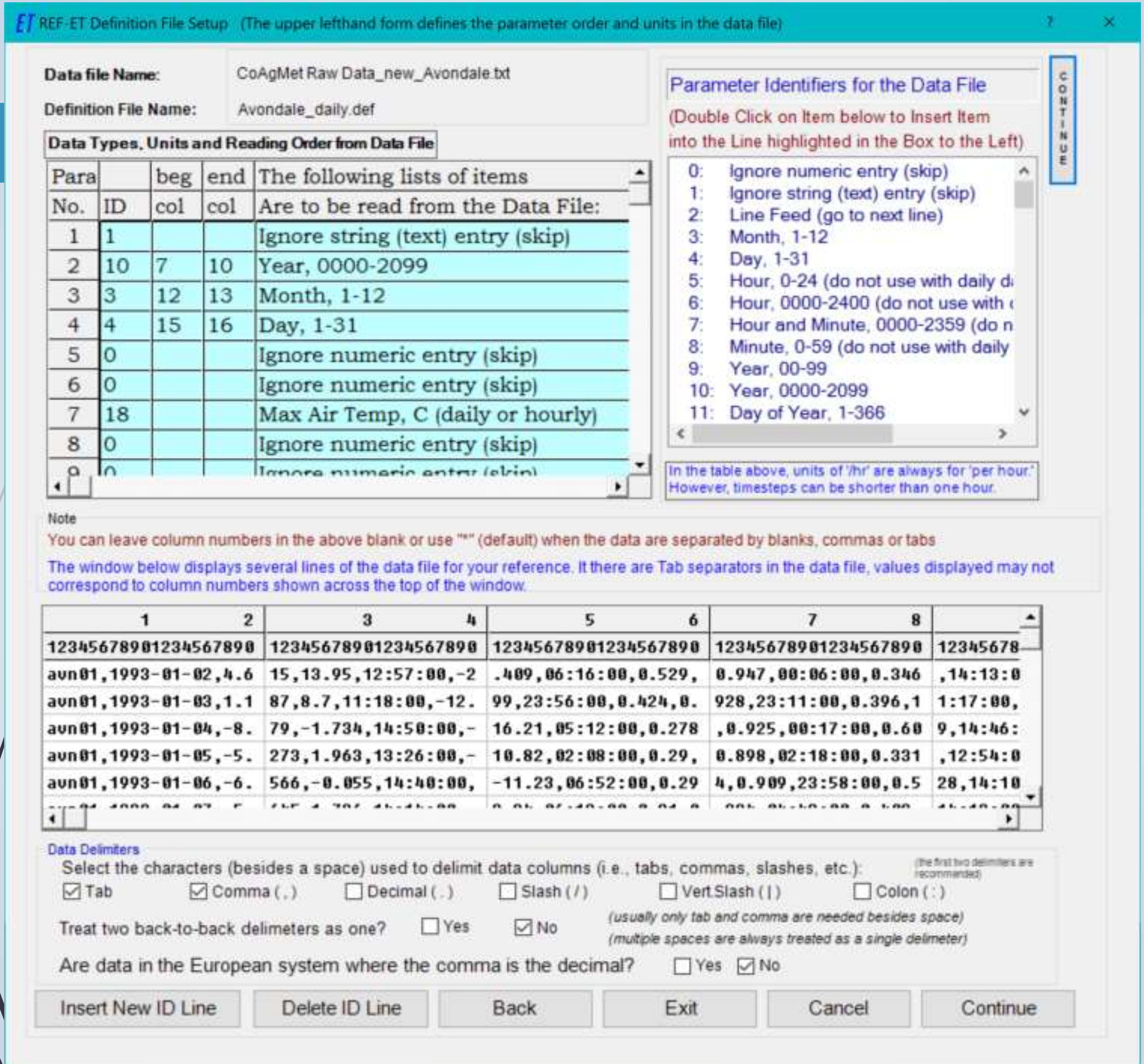
Version 6.0.9.22.2016

This is not an Official, Registered Copy. If not the original registrant, Please consider supporting our Development Costs by Obtaining a Registration Form from *http://extension.uidaho.edu/kimberly/tag/reference-evapotranspiration/* ***and submitting $49. payment plus costs for shipping and handling.***

About Ref-ET

Proceed



REF-ET Definition File Setup (The upper lefthand form defines the parameter order and units in the data file)

Data file Name: CoAgMet Raw Data_new_Avondale.txt

Definition File Name: Avondale_daily.def

Data Types, Units and Reading Order from Data File

Para No.	ID	beg col	end col	The following lists of items Are to be read from the Data File:
1	1			Ignore string (text) entry (skip)
2	10	7	10	Year, 0000-2099
3	3	12	13	Month, 1-12
4	4	15	16	Day, 1-31
5	0			Ignore numeric entry (skip)
6	0			Ignore numeric entry (skip)
7	18			Max Air Temp, C (daily or hourly)
8	0			Ignore numeric entry (skip)

Parameter Identifiers for the Data File

(Double Click on Item below to Insert Item into the Line highlighted in the Box to the Left)

0: Ignore numeric entry (skip)
1: Ignore string (text) entry (skip)
2: Line Feed (go to next line)
3: Month, 1-12
4: Day, 1-31
5: Hour, 0-24 (do not use with daily d
6: Hour, 0000-2400 (do not use with
7: Hour and Minute, 0000-2359 (do n
8: Minute, 0-59 (do not use with daily
9: Year, 00-99
10: Year, 0000-2099
11: Day of Year, 1-366

CONTINUE

In the table above, units of '/hr' are always for 'per hour.' However, timesteps can be shorter than one hour.

Note

You can leave column numbers in the above blank or use "*" (default) when the data are separated by blanks, commas or tabs

The window below displays several lines of the data file for your reference. It there are Tab separators in the data file, values displayed may not correspond to column numbers shown across the top of the window.

```
                   1                  2                   3                  4                   5                  6                   7                  8
12345678901234567890 12345678901234567890 12345678901234567890 12345678901234567890 12345678
avn01,1993-01-02,4.6 15,13.95,12:57:00,-2 .409,06:16:00,0.529, 0.947,00:06:00,0.346 ,14:13:0
avn01,1993-01-03,1.1 87,8.7,11:18:00,-12. 99,23:56:00,0.424,0. 928,23:11:00,0.396,1 1:17:00,
avn01,1993-01-04,-8. 79,-1.734,14:50:00,- 16.21,05:12:00,0.278 ,0.925,00:17:00,0.60 9,14:46:
avn01,1993-01-05,-5. 273,1.963,13:26:00,- 10.82,02:08:00,0.29, 0.898,02:18:00,0.331 ,12:54:0
avn01,1993-01-06,-6. 566,-0.055,14:40:00, -11.23,06:52:00,0.29 4,0.909,23:58:00,0.5 28,14:10
```

Data Delimiters

Select the characters (besides a space) used to delimit data columns (i.e., tabs, commas, slashes, etc.): (the first two delimiters are recommended)

☑ Tab ☑ Comma (,) ☐ Decimal (.) ☐ Slash (/) ☐ Vert.Slash (|) ☐ Colon (:)

Treat two back-to-back delimeters as one? ☐ Yes ☑ No

(usually only tab and comma are needed besides space)
(multiple spaces are always treated as a single delimeter)

Are data in the European system where the comma is the decimal? ☐ Yes ☑ No

Insert New ID Line | Delete ID Line | Back | Exit | Cancel | Continue

ET Description of the Weather Station and Data File

DataFile: CoAgMet Raw Data_new_Avondale.txt

DefinitionFile: Avondale_daily.def

CONTINUE

The anemometer height is: 2 meters (6.5) ft

The temperature/RH height is: 2 meters (6.5) ft

The weather station elevation is: 1396 meters (4580.0) ft

The weather station latitude is: 38.2166 degrees (- for Southern)

(Parameters in the next two lines are Required only for Hourly or shorter time period data)

The weather station longitude is: 104.341 degrees** W (E or W**)

Center of time zone longitude is: 105 degrees** W (E or W**) <----- (Hint : 105 W)

-- Eastern Time Zone = 75 deg.; Central = 90; Mountain = 105; Pacific = 120 deg.

(The time zone longitude must be in multiples of 15 degrees for North America) **Req. only for ~hourly data.

The weather site vegetation height : .12 m (0 if same as ref. or as ht. specified in the data file)

Initial Lines of the Data file to be skipped: 0 Code for missing data (e.g. -999) -999

Description of the station and data (No more than 1000 characters)

Avondale daily weather data for period of record, from COAGMET Raw Data - 'new database'

How "hourly" time stamps are defined**

- (•) Time represents time at the end of the period (most common and the default)
- ( ) Time represents time at the start of the period (uncommon)
- ( ) Time represents time at the center of the period (uncommon)

☐ For "hourly" data in U.S.A., Daylight Savings Time is Observed in Data Set (check if true)**

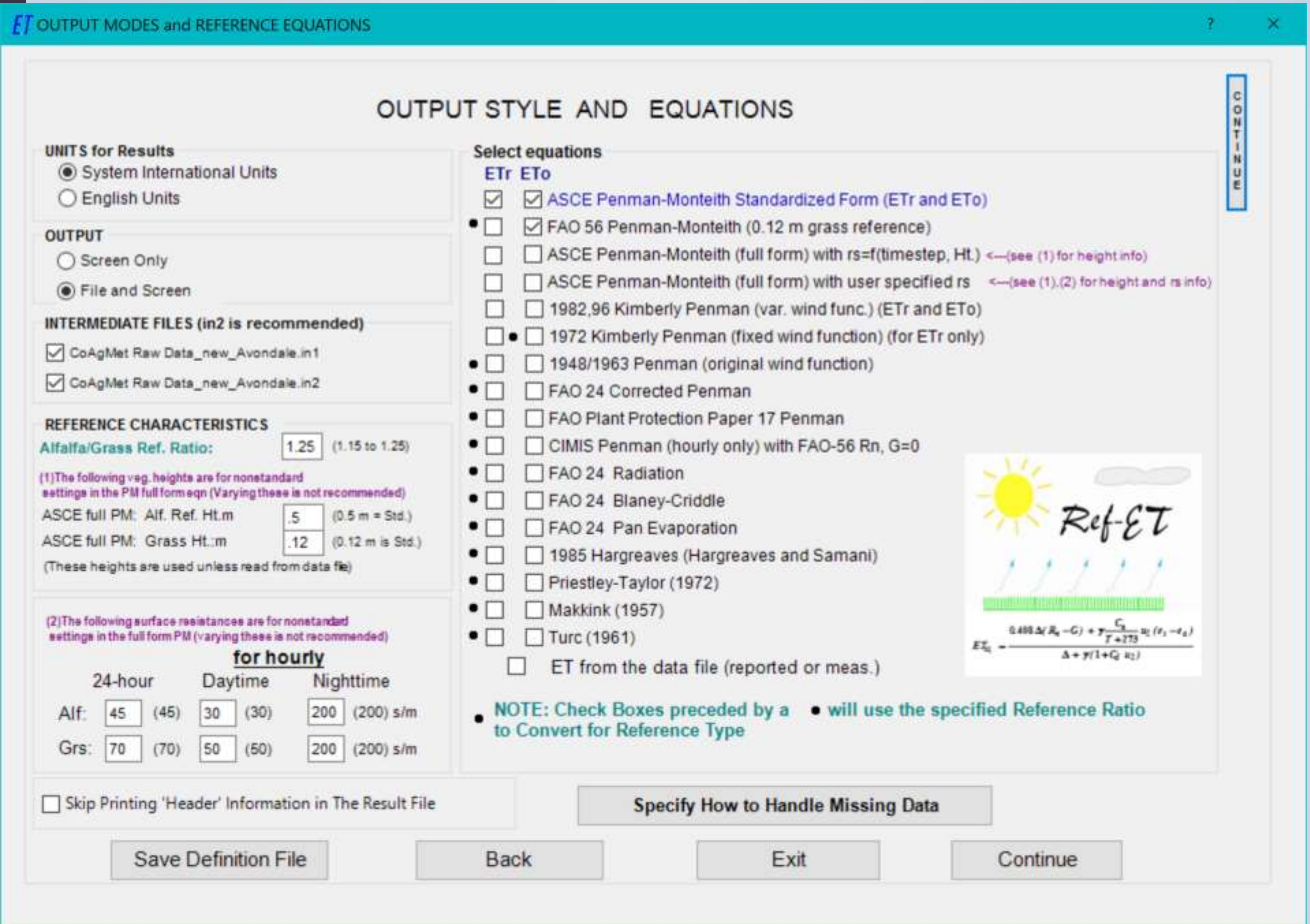
Note: For daily time steps, REF-ET presumes that the data represent the period from midnight to midnight.
The "Hourly" data term applies to any timestep shorter than 24 hours.

The following Data are required only for FAO-24 Eqns.

The default Day/Night wind ratio is : 2 (2 if unknown*)

The green fetch on the Class A Pan : 1000 m (1000 if unknown*)

Back | Cancel | Exit | Continue



OUTPUT MODES and REFERENCE EQUATIONS
OUTPUT STYLE AND EQUATIONS
UNITS for Results
System International Units
English Units
OUTPUT
Screen Only
File and Screen
INTERMEDIATE FILES (in2 is recommended)
CoAgMet Raw Data_new_Avondale.in1
CoAgMet Raw Data_new_Avondale.in2
REFERENCE CHARACTERISTICS
Alfalfa/Grass Ref. Ratio: 1.25 (1.15 to 1.25)
(1)The following veg. heights are for nonstandard settings in the PM full form eqn (Varying these is not recommended)
ASCE full PM: Alf. Ref. Ht.m .5 (0.5 m = Std.)
ASCE full PM: Grass Ht.:m .12 (0.12 m is Std.)
(These heights are used unless read from data file)
(2)The following surface resistances are for nonstandard settings in the full form PM (varying these is not recommended)
for hourly
24-hour Daytime Nighttime
Alf: 45 (45) 30 (30) 200 (200) s/m
Grs: 70 (70) 50 (50) 200 (200) s/m
Skip Printing 'Header' Information in The Result File
Select equations
ETr ETo
ASCE Penman-Monteith Standardized Form (ETr and ETo)
FAO 56 Penman-Monteith (0.12 m grass reference)
ASCE Penman-Monteith (full form) with rs=f(timestep, Ht.) <---(see (1) for height info)
ASCE Penman-Monteith (full form) with user specified rs <---(see (1),(2) for height and rs info)
1982,96 Kimberly Penman (var. wind func.) (ETr and ETo)
1972 Kimberly Penman (fixed wind function) (for ETr only)
1948/1963 Penman (original wind function)
FAO 24 Corrected Penman
FAO Plant Protection Paper 17 Penman
CIMIS Penman (hourly only) with FAO-56 Rn, G=0
FAO 24 Radiation
FAO 24 Blaney-Criddle
FAO 24 Pan Evaporation
1985 Hargreaves (Hargreaves and Samani)
Priestley-Taylor (1972)
Makkink (1957)
Turc (1961)
ET from the data file (reported or meas.)
Ref-ET
NOTE: Check Boxes preceded by a • will use the specified Reference Ratio to Convert for Reference Type
Specify How to Handle Missing Data
Save Definition File
Back
Exit
Continue
CONTINUE

Out screen:D:\Documents\ET\REFET_QAQC\Avondale\CoAgMet Raw Data_new_Avondale2.out

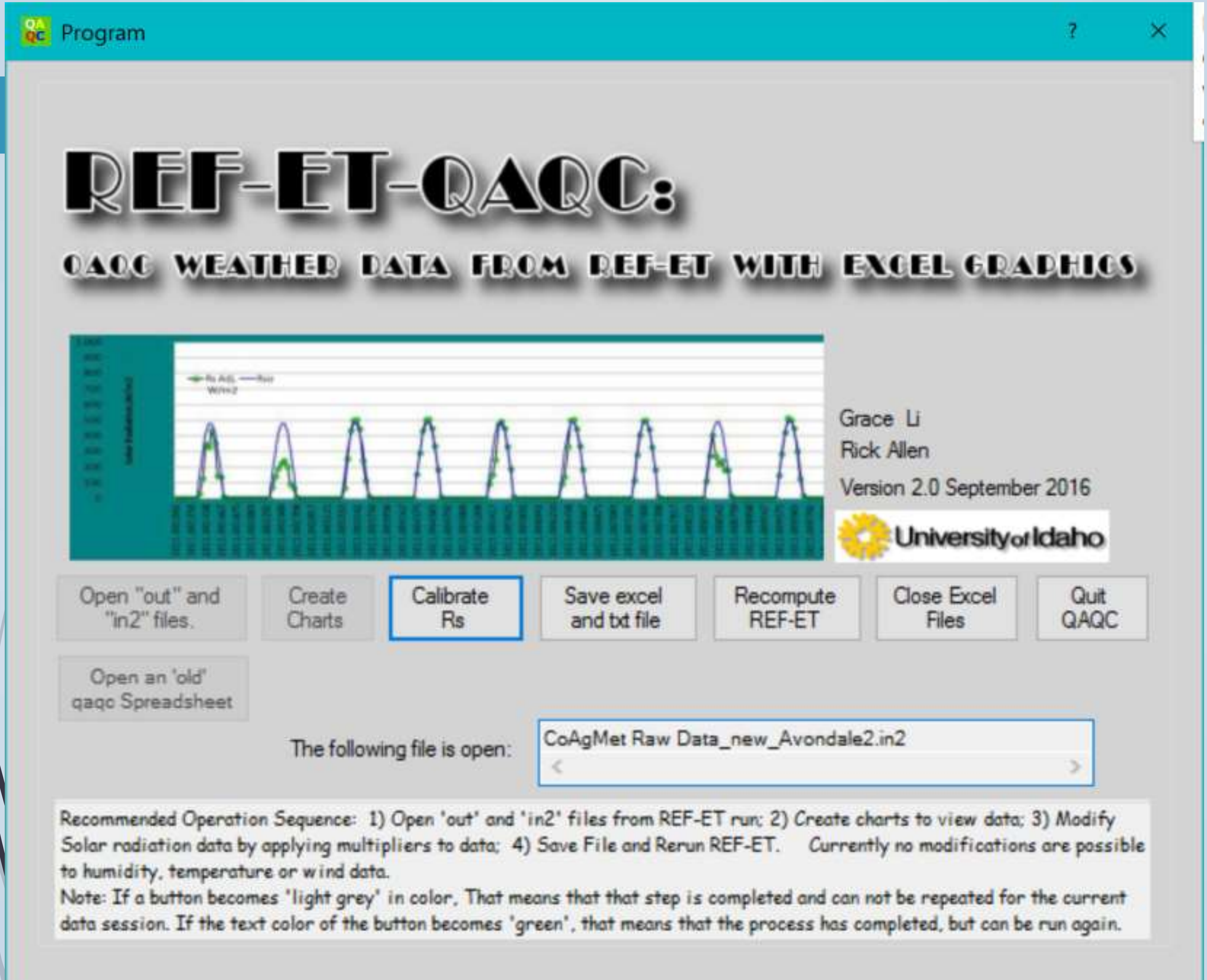
Mo	Day	Yr	Tmax C	Tmin C	Rs MJ/m2	Wind m/s	DewP C	ASCE StPM ETr mm/d	ASCE StPM ETo mm/d	FAO 56PM ETo mm/d	Precip mm
1	2	1993	13.95	-2.41	5.28	2.99	-1.96	3.02	1.88	1.93	.0
1	3	1993	8.7	-13.0	5.00	4.46	-4.91	2.13	1.34	1.37	.0
1	4	1993	-1.7	-16.2	6.12	1.07	-10.3	.48	.37	.40	.76
1	5	1993	2.0	-10.8	6.62	1.48	-9.81	1.03	.70	.73	.0
1	6	1993	-.1	-11.2	7.61	1.13	-9.64	.72	.52	.55	.0
1	7	1993	1.80	-9.84	7.04	1.95	-8.96	1.12	.75	.78	.0
1	8	1993	-4.38	-9.48	1.22	3.05	-7.75	.24	.16	.16	.0
1	9	1993	-8.6	-15.7	8.20	2.21	-14.8	.51	.37	.38	.0
1	10	1993	-9.9	-16.1	5.29	1.23	-16.4	.43	.33	.34	.0
1	11	1993	1.8	-17.7	8.74	2.38	-13.7	1.47	.95	.97	.76
1	12	1993	-2.7	-17.4	9.38	2.97	-13.5	.96	.64	.66	.0
1	13	1993	-5.6	-18.7	6.27	1.13	-15.4	.53	.40	.41	.0
1	14	1993	.0	-16.4	8.94	1.06	-12.6	.80	.57	.60	.0
1	15	1993	12.6	-12.7	9.48	1.19	-7.23	1.82	1.18	1.24	.25

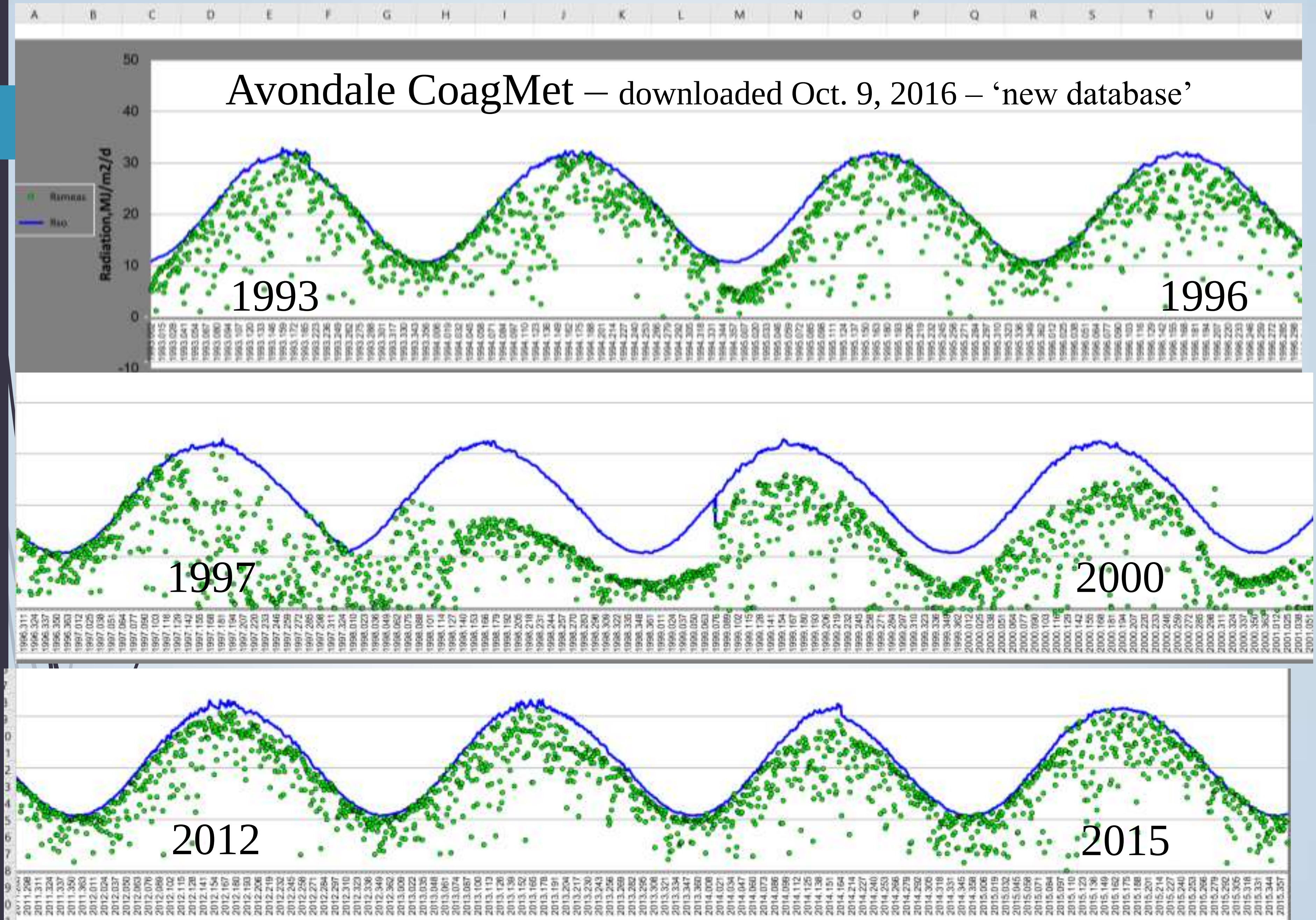
Run Ref-ET again

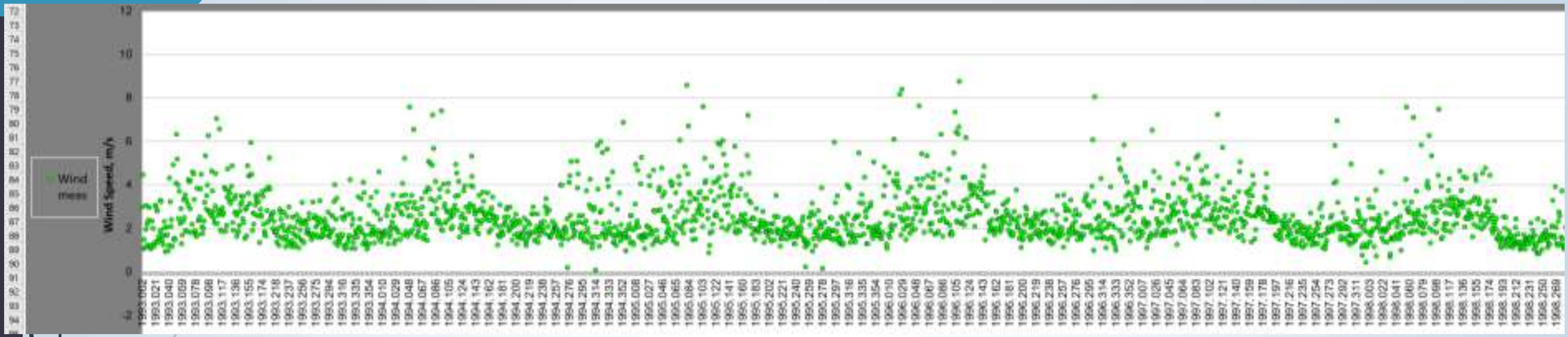
Run QAQC (manually)

Run QAQC (in background)

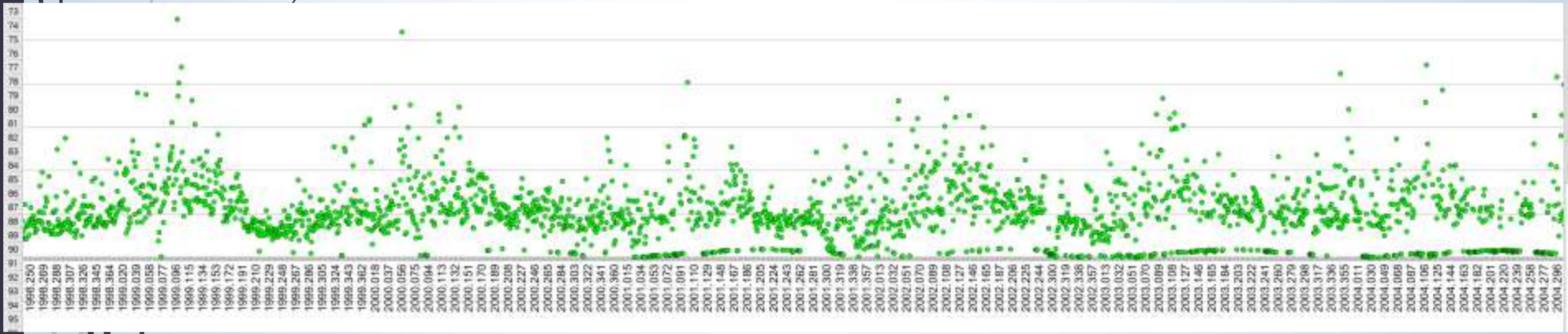
End


Program
REF-ET-QAQC:
QAQC WEATHER DATA FROM REF-ET WITH EXCEL GRAPHICS
Grace Li
Rick Allen
Version 2.0 September 2016
University of Idaho
Open "out" and "in2" files.
Create Charts
Calibrate Rs
Save excel and txt file
Recompute REF-ET
Close Excel Files
Quit QAQC
Open an 'old' qaqc Spreadsheet
The following file is open:
CoAgMet Raw Data_new_Avondale2.in2
Recommended Operation Sequence: 1) Open 'out' and 'in2' files from REF-ET run; 2) Create charts to view data; 3) Modify Solar radiation data by applying multipliers to data; 4) Save File and Rerun REF-ET. Currently no modifications are possible to humidity, temperature or wind data.
Note: If a button becomes 'light grey' in color, That means that that step is completed and can not be repeated for the current data session. If the text color of the button becomes 'green', that means that the process has completed, but can be run again.


Avondale CoagMet – downloaded Oct. 9, 2016 – 'new database'
Radiation, MJ/m2/d
Rsmeas
Rso
1993
1996
1997
2000
2012
2015

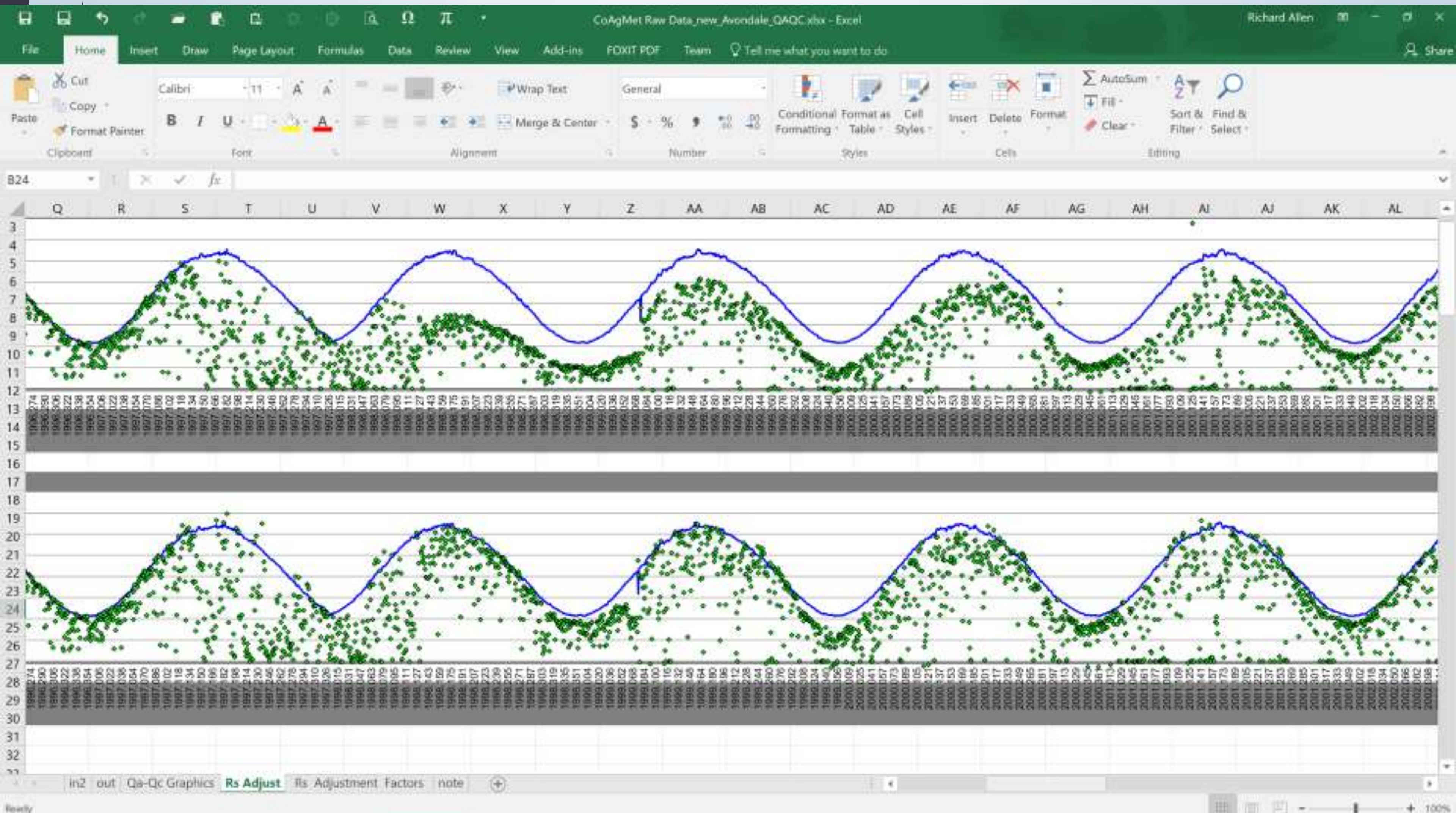


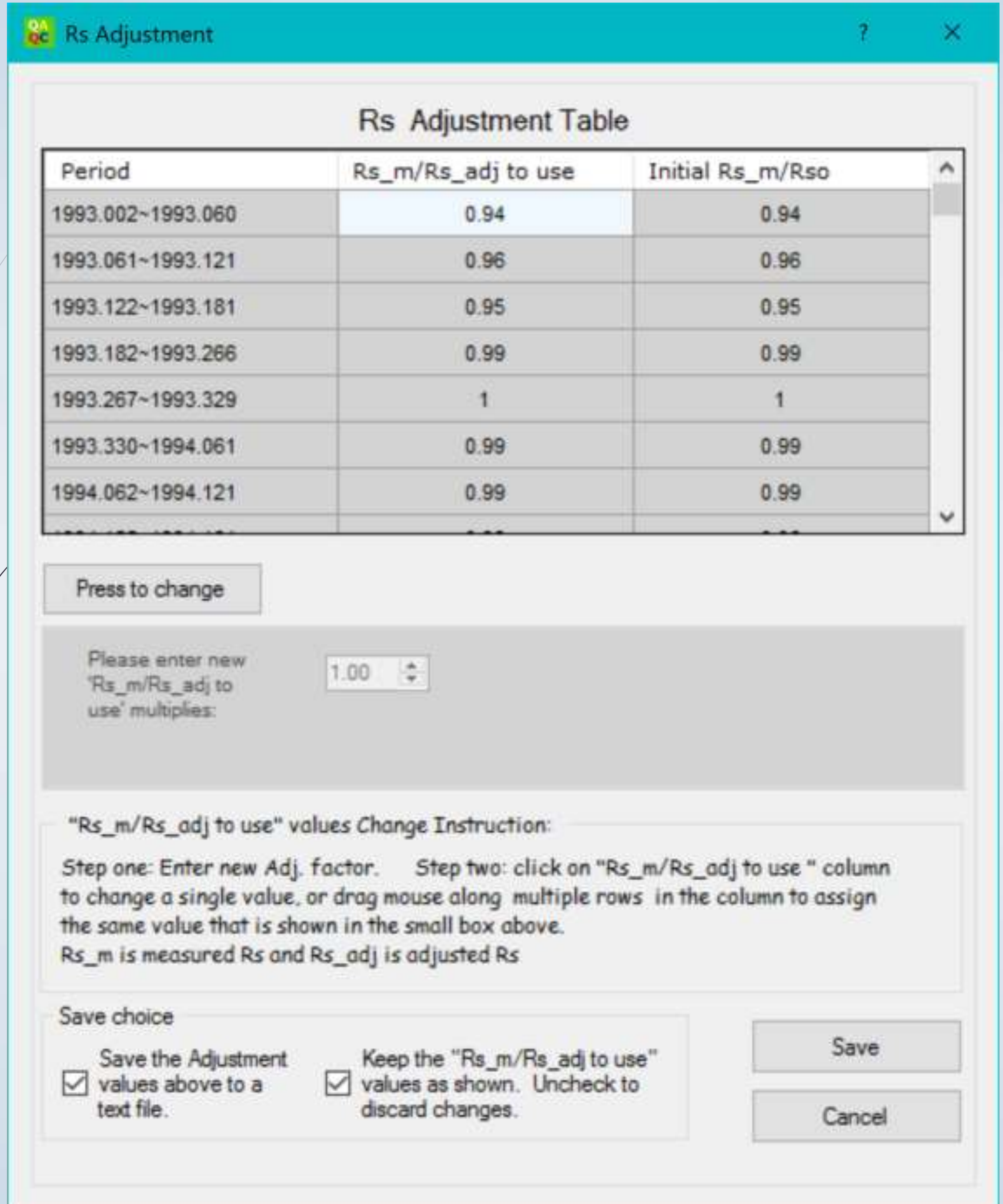
Wind meas
Wind Speed, m/s



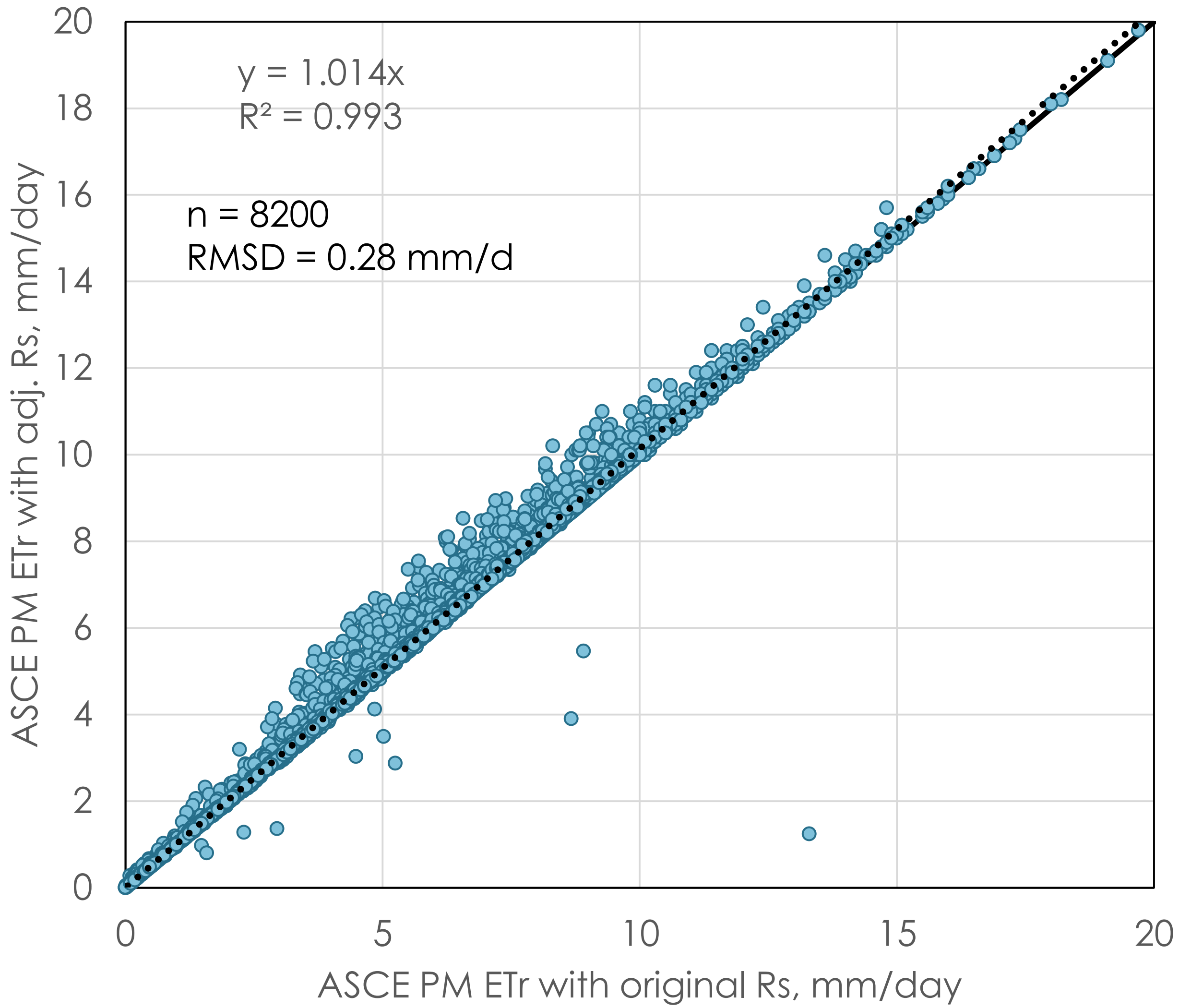
Observed R_s (top) and Auto-Adjusted R_s (bottom)

Avondale CoagMet for years 1997 - 2001

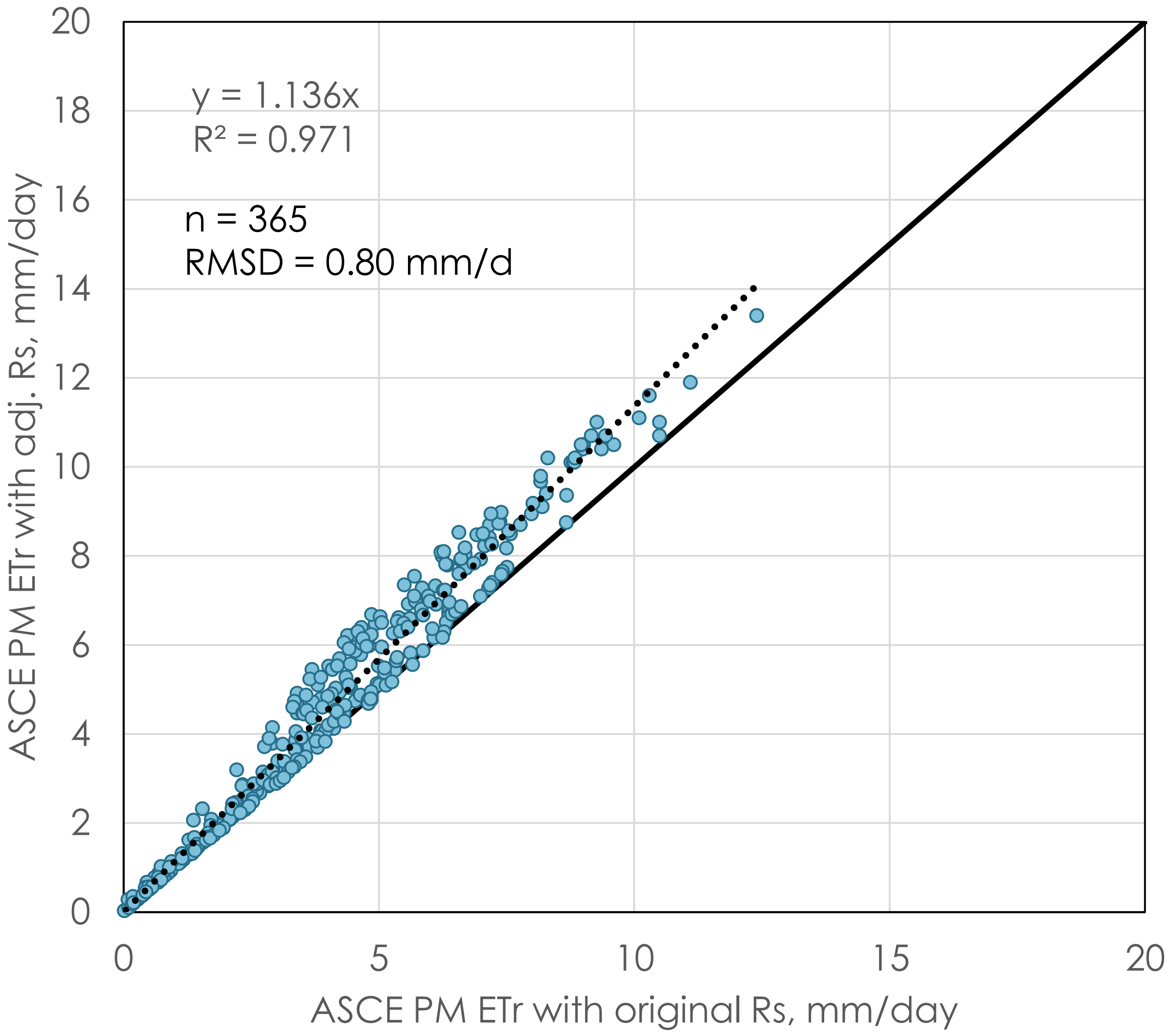



Rs Adjustment
Rs Adjustment Table
Period
Rs_m/Rs_adj to use
Initial Rs_m/Rso
1993.002~1993.060 0.94 0.94
1993.061~1993.121 0.96 0.96
1993.122~1993.181 0.95 0.95
1993.182~1993.266 0.99 0.99
1993.267~1993.329 1 1
1993.330~1994.061 0.99 0.99
1994.062~1994.121 0.99 0.99
Press to change
Please enter new 'Rs_m/Rs_adj to use' multiplies:
1.00
"Rs_m/Rs_adj to use" values Change Instruction:
Step one: Enter new Adj. factor. Step two: click on "Rs_m/Rs_adj to use " column to change a single value, or drag mouse along multiple rows in the column to assign the same value that is shown in the small box above.
Rs_m is measured Rs and Rs_adj is adjusted Rs
Save choice
Save the Adjustment values above to a text file.
Keep the "Rs_m/Rs_adj to use" values as shown. Uncheck to discard changes.
Save
Cancel

Avondale CoagMet - Period of Record
1993 - 2015
Adjustment of Solar Radiation, only

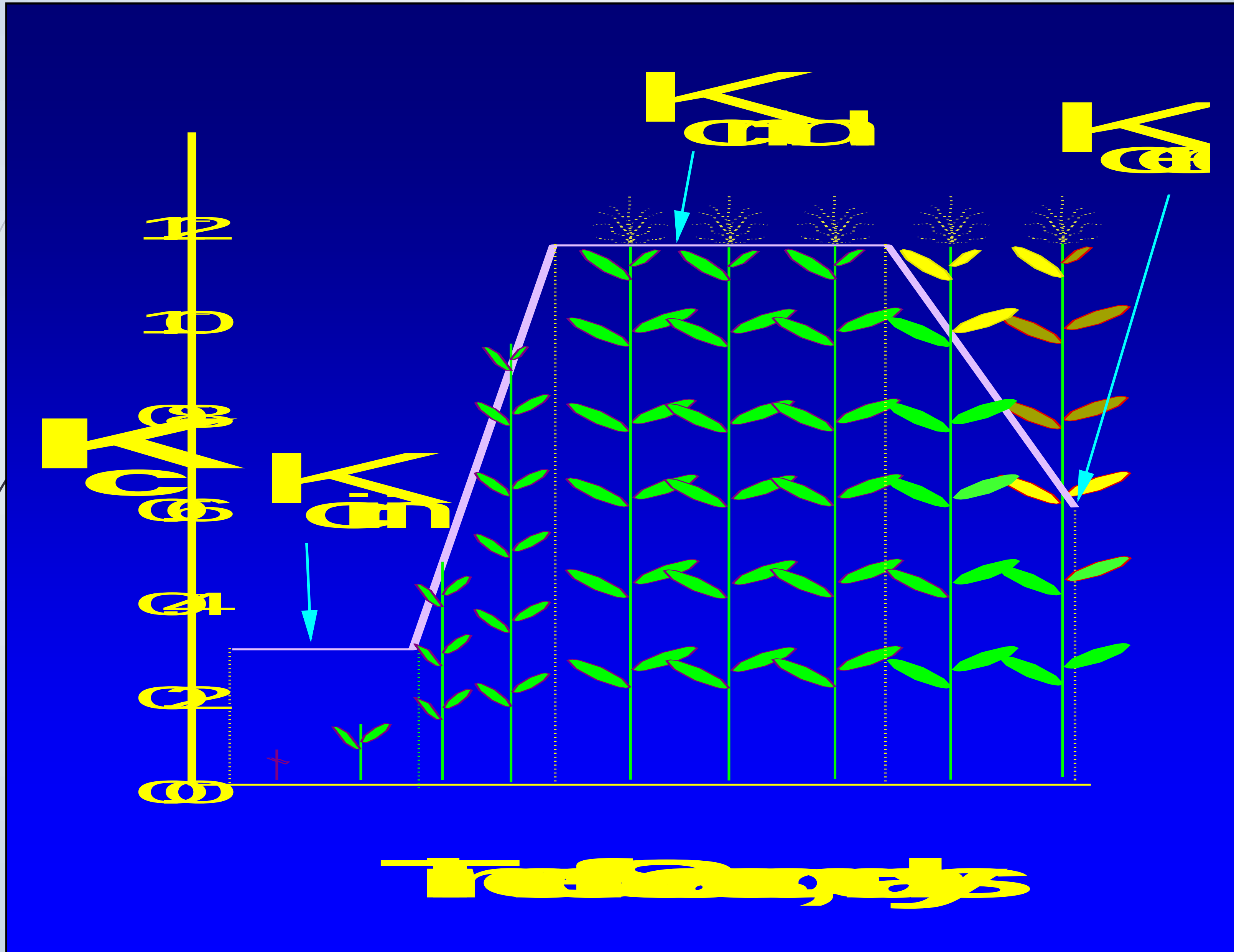


Avondale CoagMet - Period of Record
1998
Adjustment of Solar Radiation, only

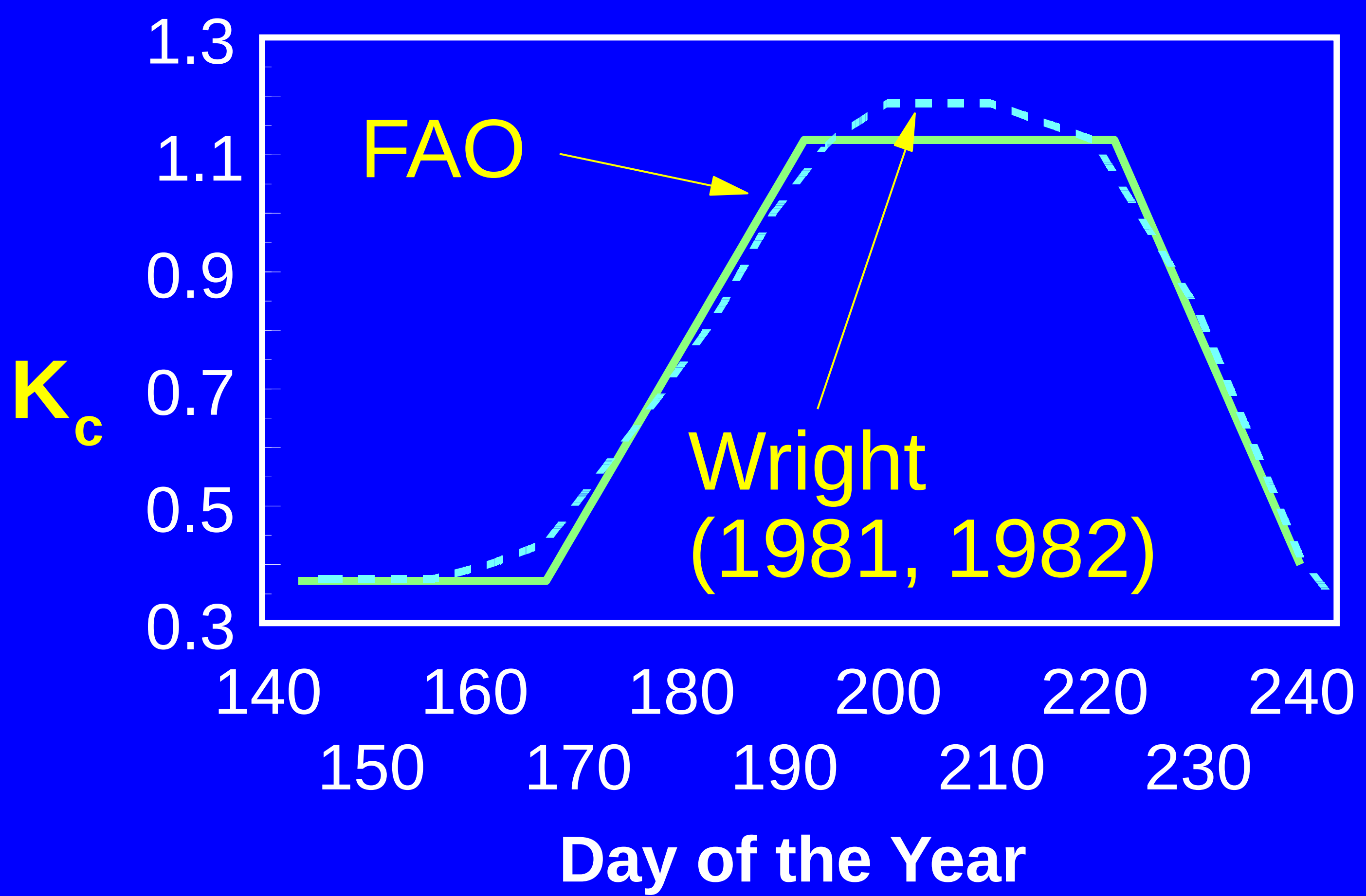


Crop Coefficients

Crop Coefficient = ET/ET_{ref}



Crop Coefficient Curve Types



Single or Dual K_c

Which should we use? ---- *(Dual)*

For highest accuracy field-by-field and year-to-year:

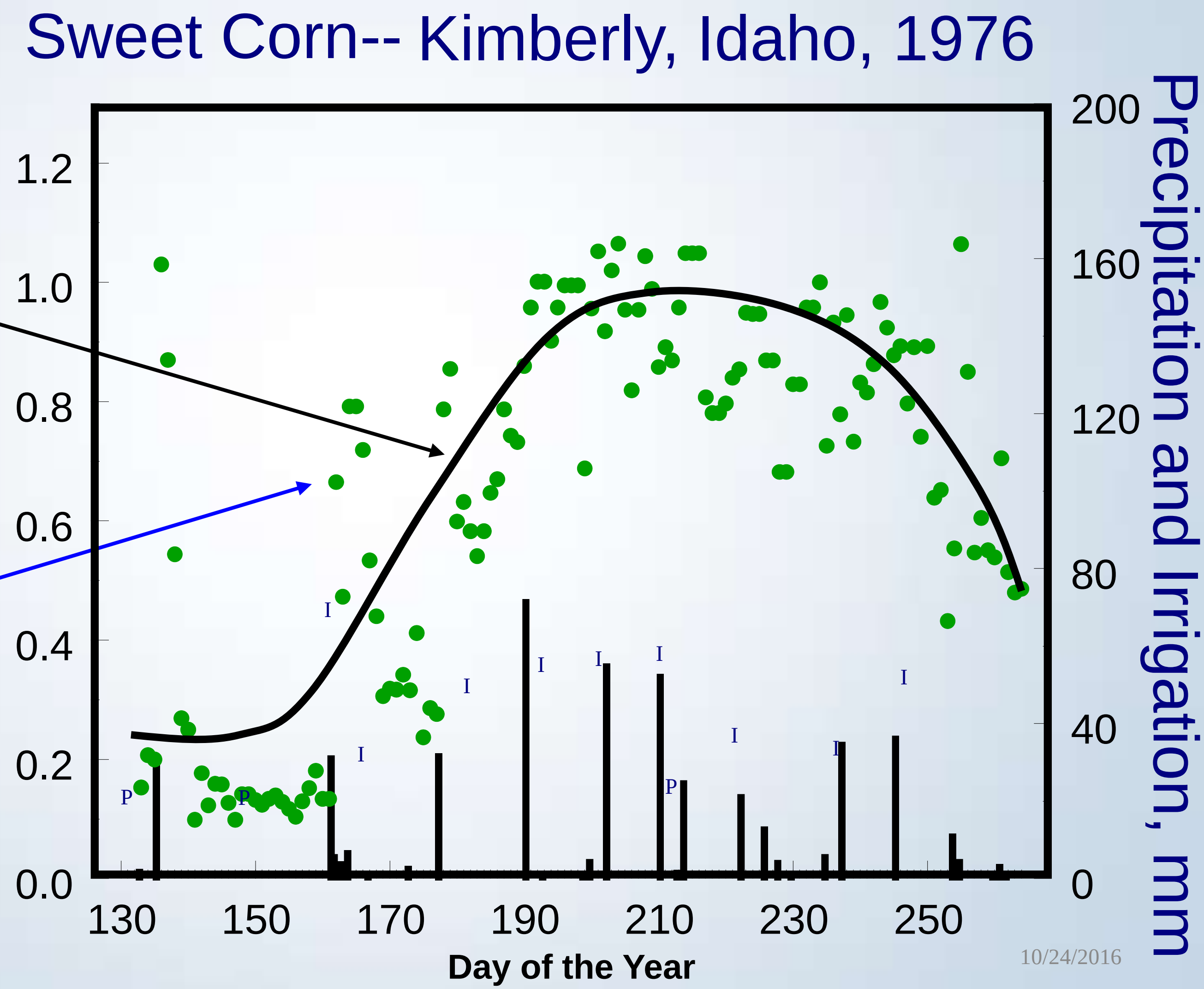
- It is best to account for impacts of increased ET caused by evaporation from soil
  - During the initial and development periods when ground cover is low
  - To account for the impacts of frequency of wetting
    - Precipitation (year to year variation)
    - Irrigation system type and management
  - To account for the degree of surface wetting by the irrigation system

K_c measured by Lysimeter

each dot is one day

"Single" Curve averaging evaporation "Spikes"

Wet Soil Evaporation "Spikes" (K_e)



10/24/2016

data courtesy of Dr. J.L. Wright, USDA-ARS

The "Dual K_c" method Splits Soil Evaporation from Transpiration

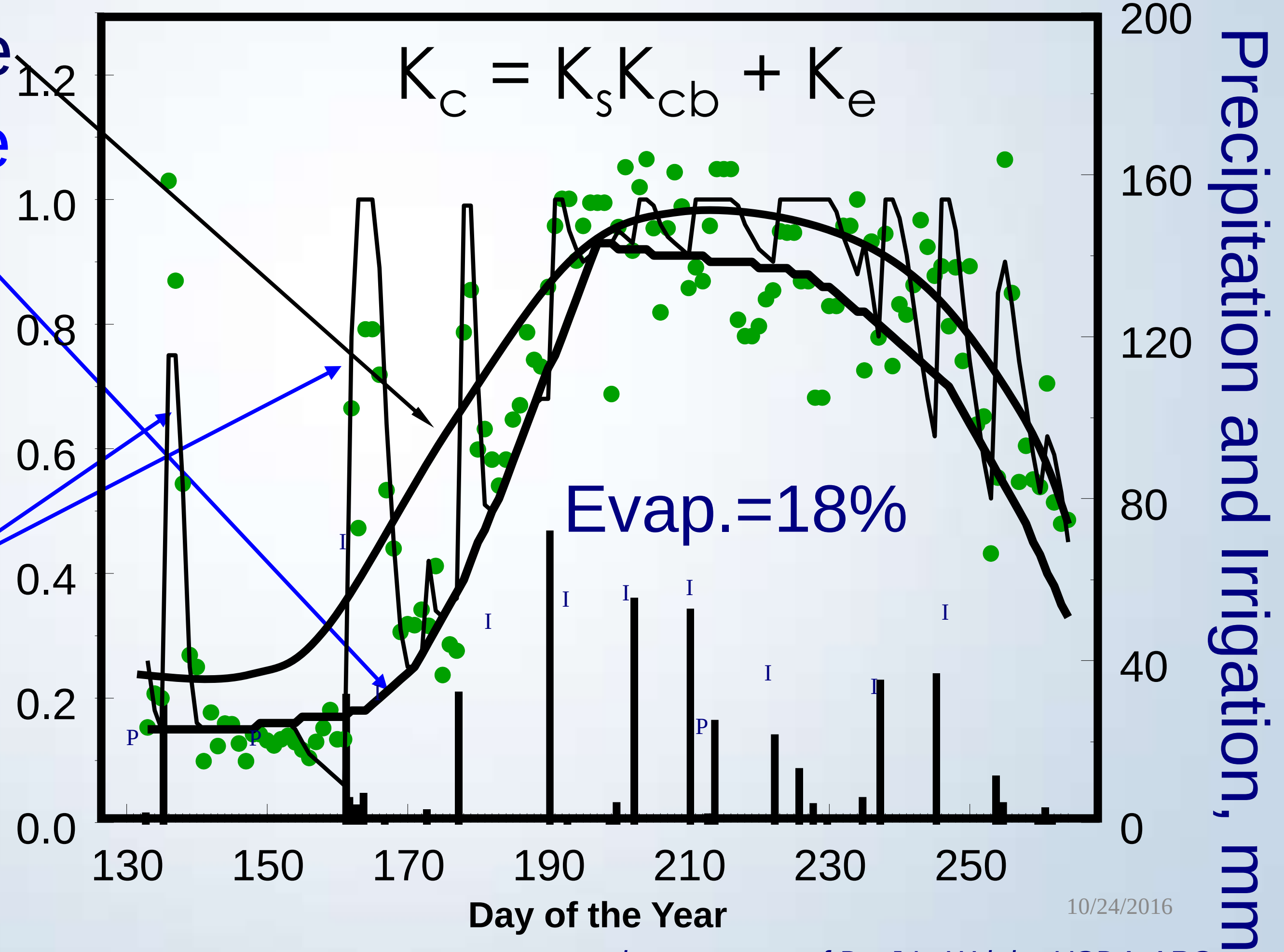
Sweet Corn Kimberly, Idaho, 1976

"Mean" K_c Curve

Basal K_c Curve (K_{cb})

K_c

Wet Soil Evaporation "Spikes" (K_e)

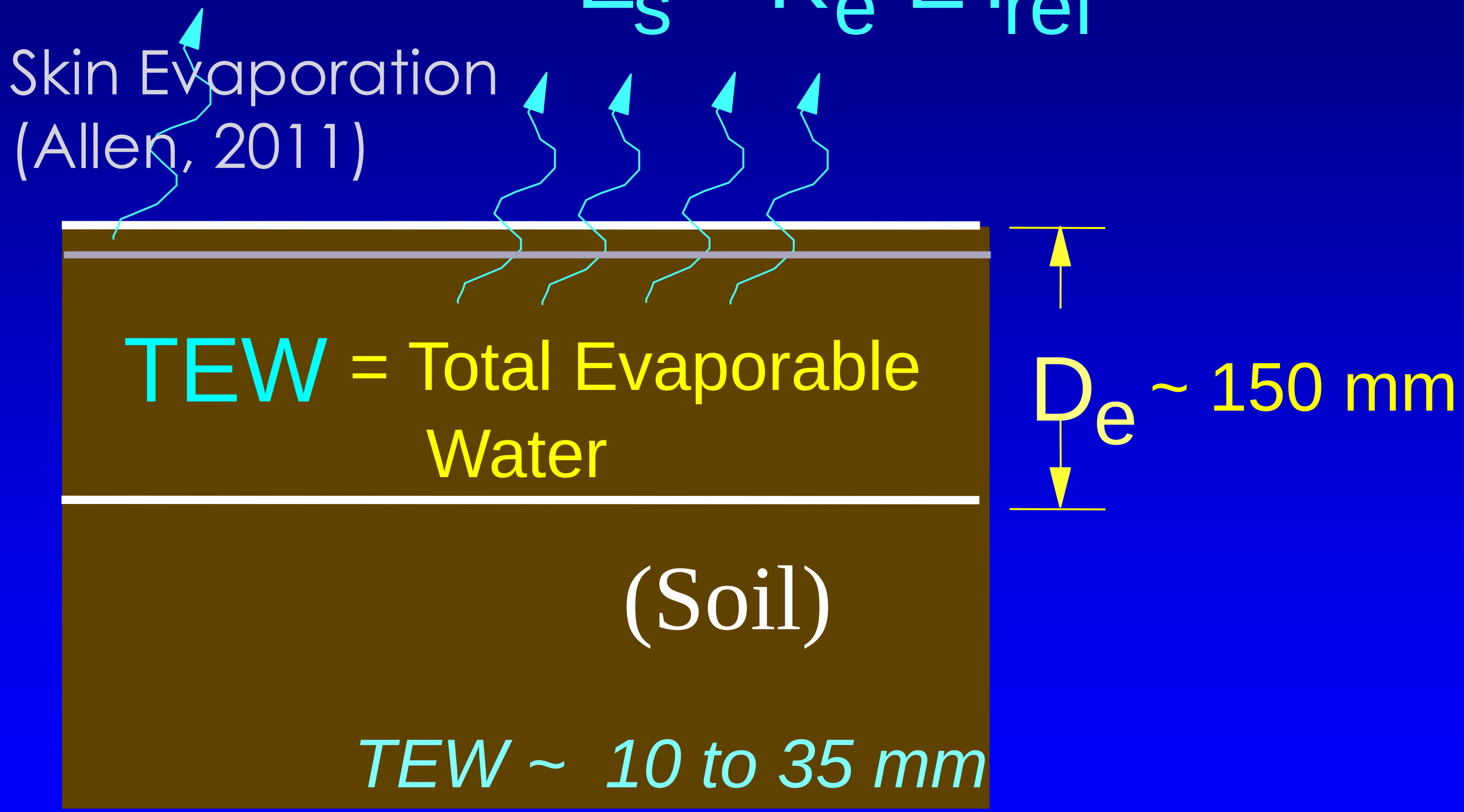


data courtesy of Dr. J.L. Wright, USDA-ARS

Evaporation Coefficient - K_e

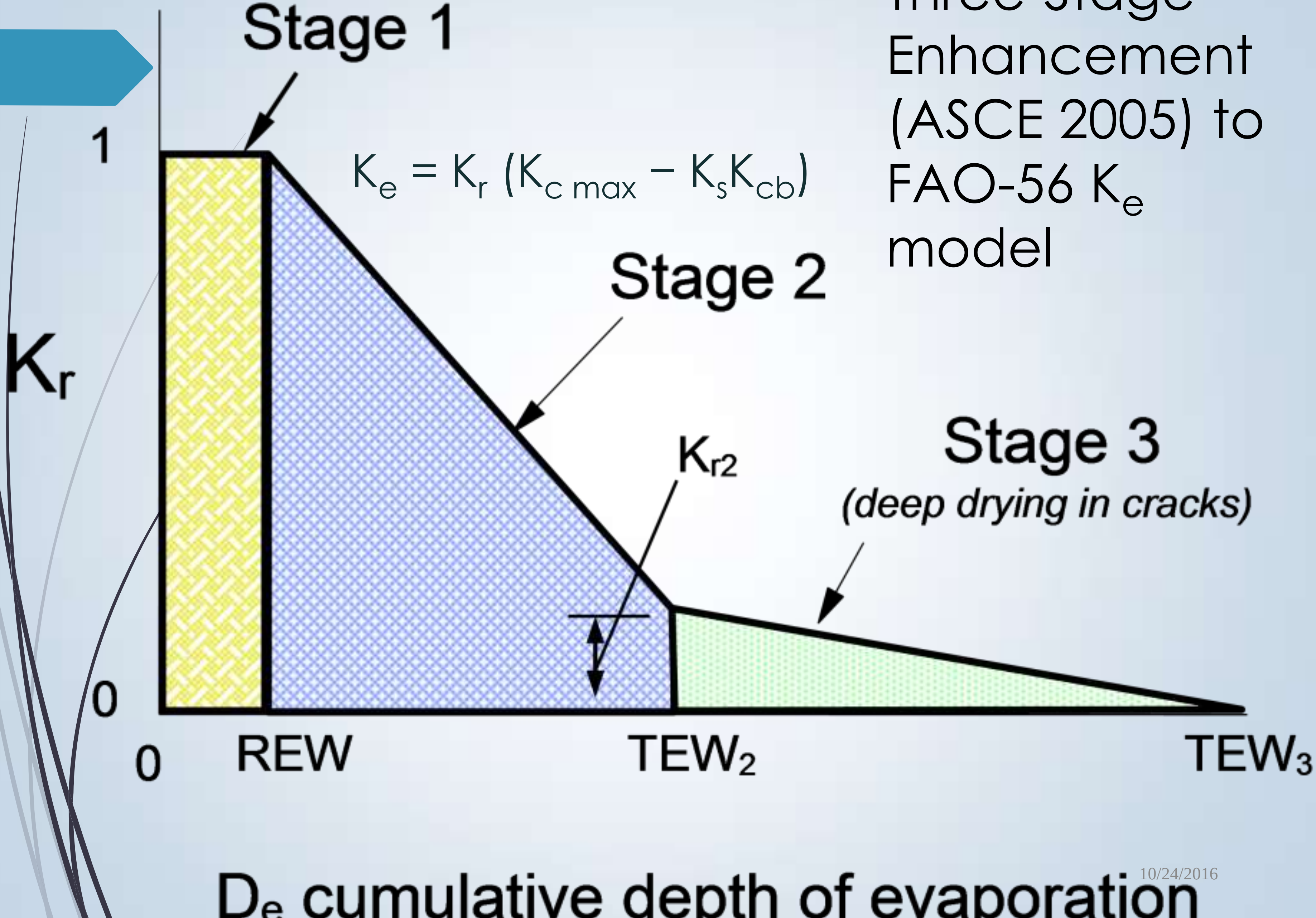
FAO-56 Simple Drying Function

$$E_s = K_e \, ET_{ref}$$

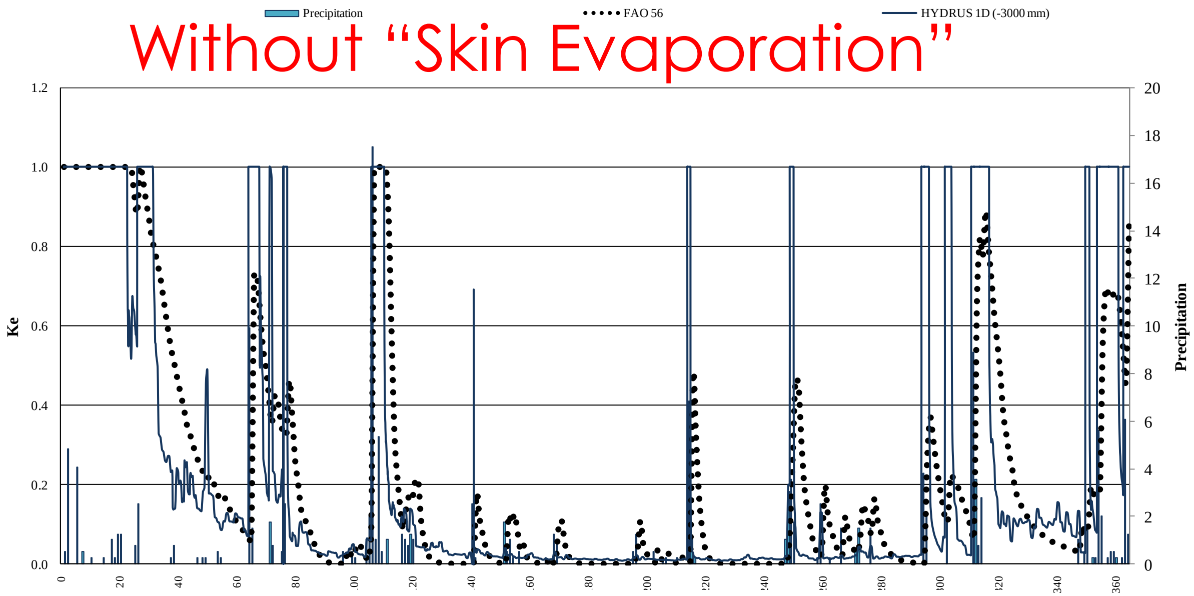


Three-Stage Enhancement (ASCE 2005) to FAO-56 K_e model

$$K_e = K_r\,(K_{c\,max} - K_s K_{cb})$$



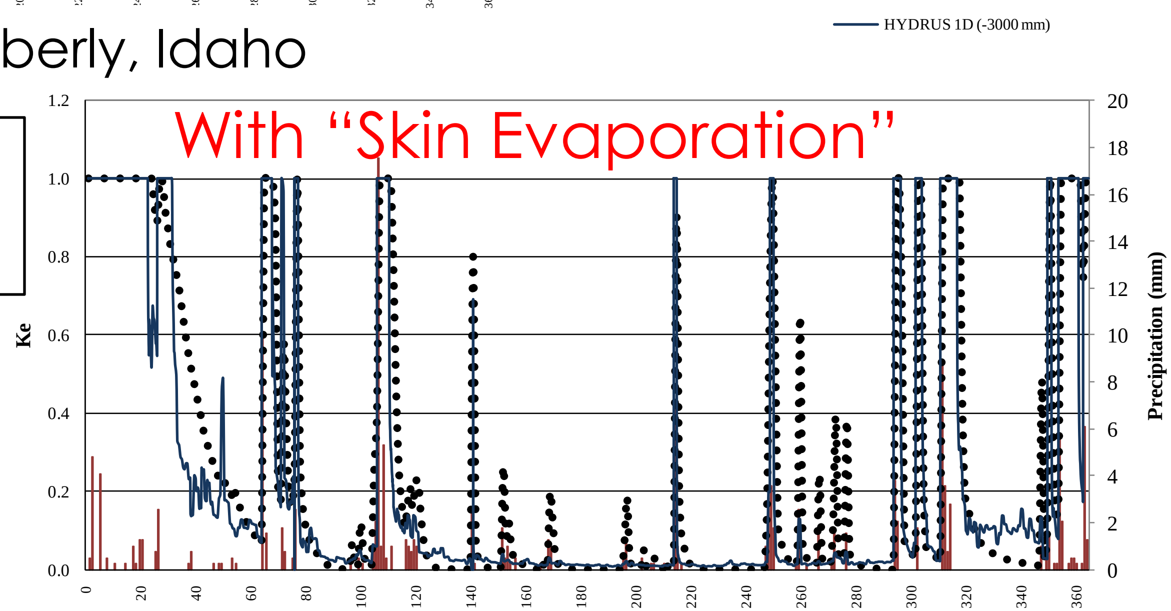
Comparison of FAO-56 K_e model with Skin Evaporation Enhancement with Hydrus 1-D



Day of Year – Kimberly, Idaho

— Hydrus

...... FAO-56 K_e

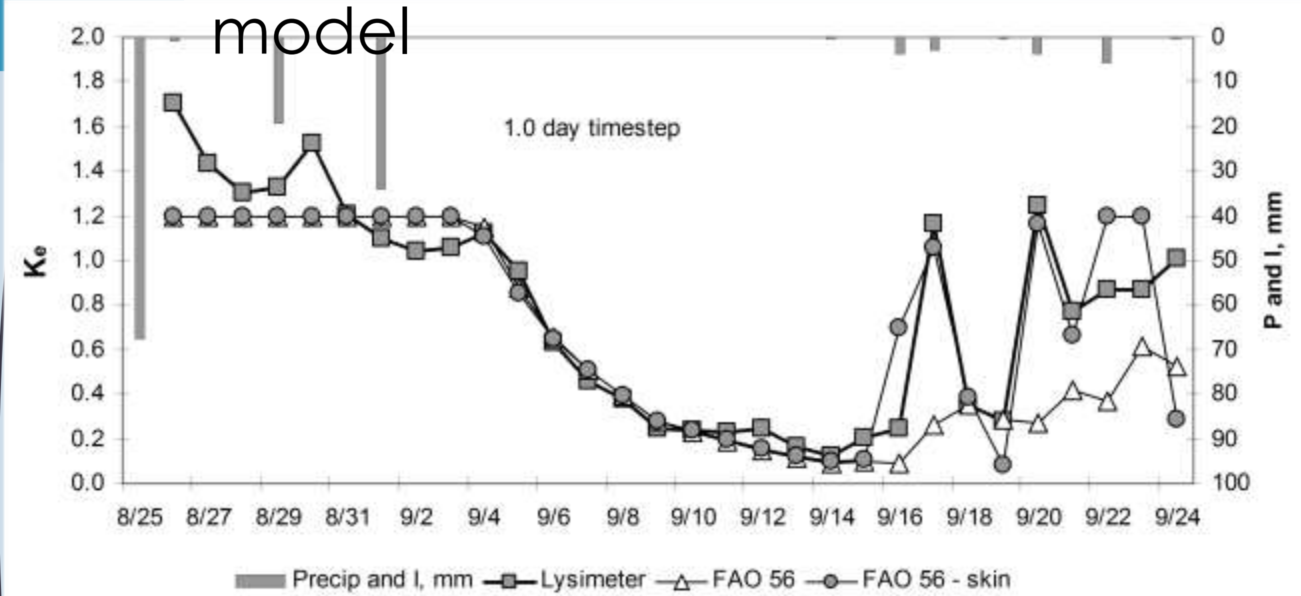


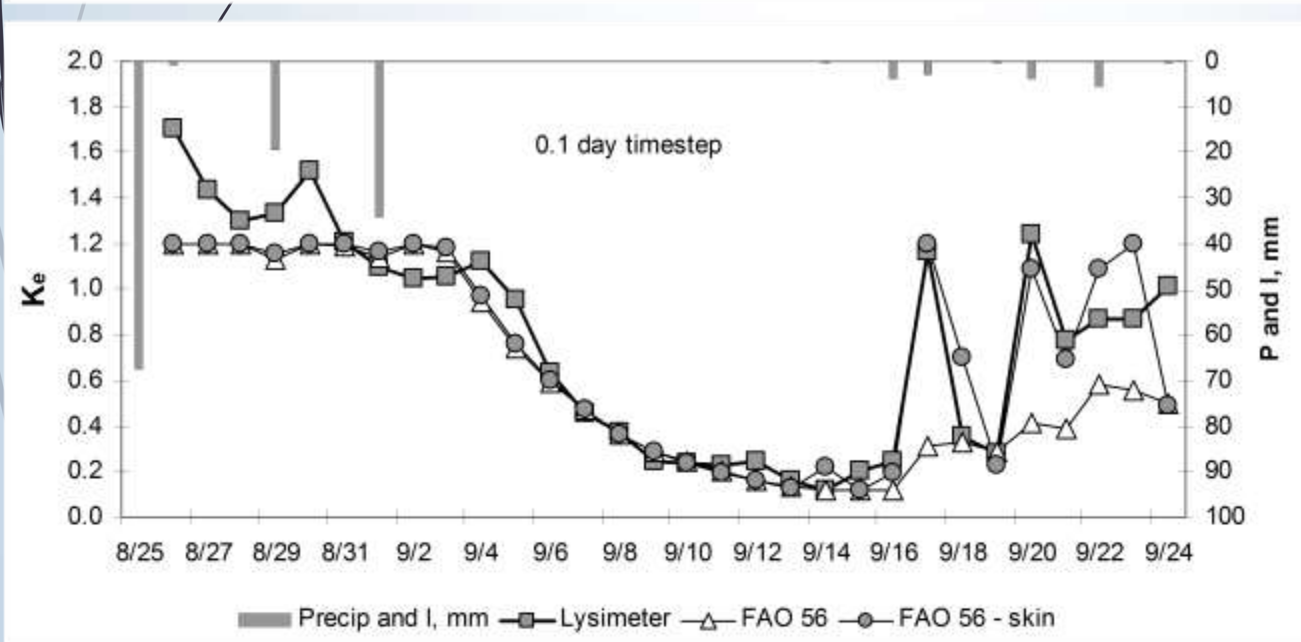
Day of Year – Kimberly, Idaho

Conclusion: Skin Enhancement causes FAO-56 K_e model to behave similar to Hydrus

Allen 2011 Ag.Wat.Man

Impact of TimeStep length and Behavior of the Skin Evaporation Enhancement (2011) with FAO-56 K_e model



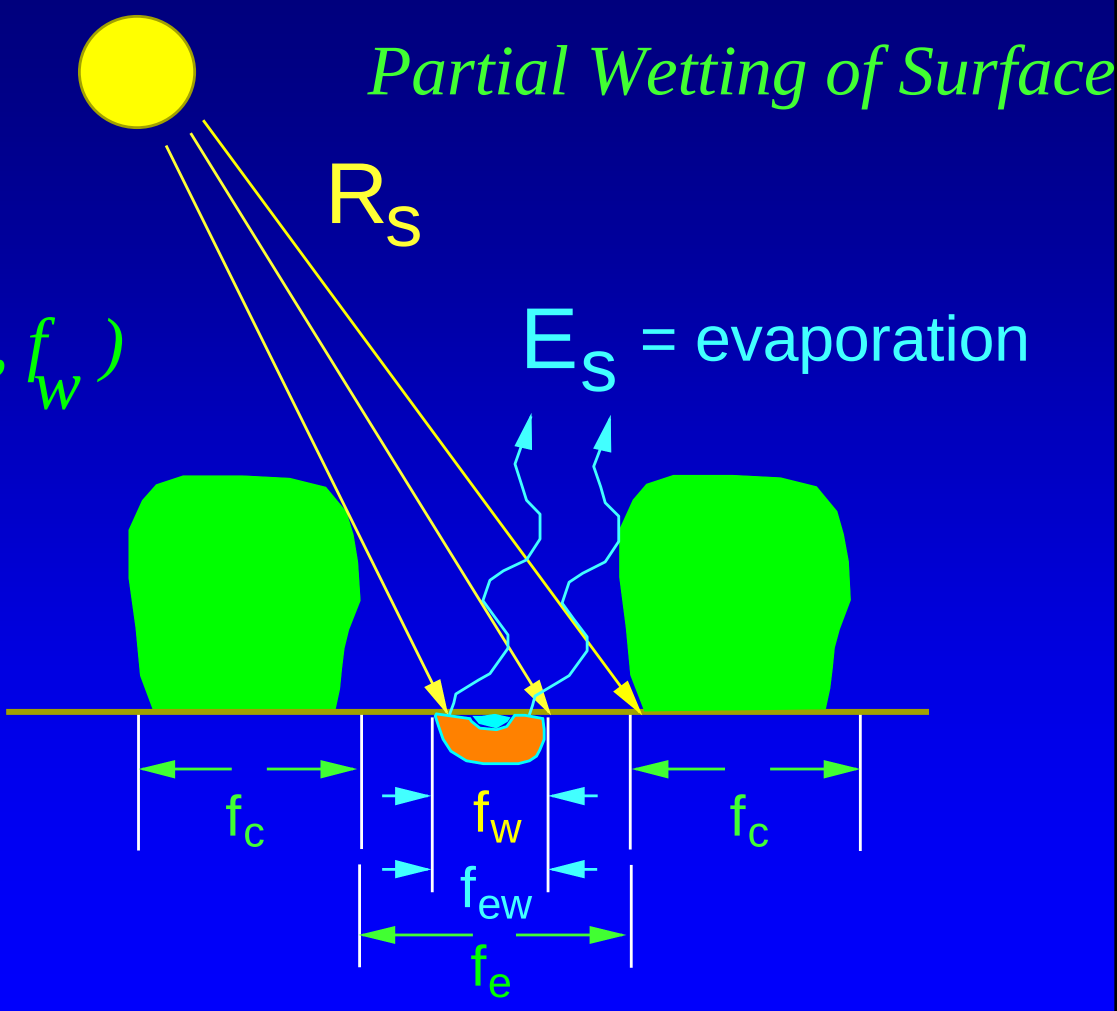


FAO-56 K_e model vs. Kimberly Lysimeter

– *Bare Soil Conditions*

Conclusion: Skin Enhancement is Important for Precip. Events < 10 mm. Model can be applied on daily or hourly timestep

Partial Surface Wetting/Drying in FAO-56 Dual K_c model



Why Apply the Dual K_c method for estimating water depletion?

- Advantages
  - Capture variation in daily K_c value according to wetting frequency from rainfall and irrigation
  - K_c estimates can be made during wintertime to estimate water lost as evaporation from soil

Mead, Nebraska –

Comparison with Eddy Covariance

—Illustrate Low Sensitivity to $K_{cb\ mid}$

Mead, NE Ameriflux Site

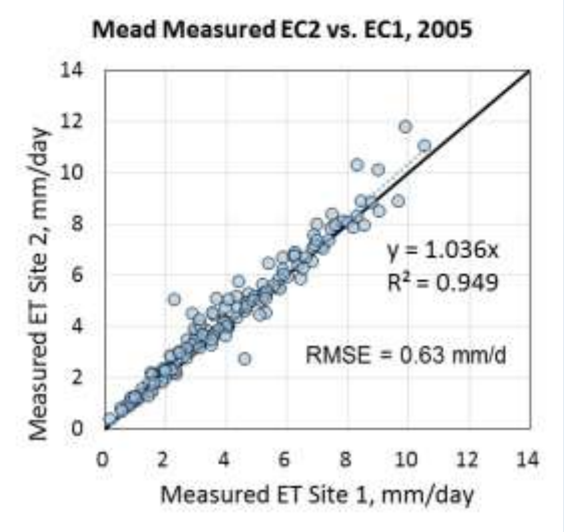
Eddy Covariance data by Andy Suyker and S. Verma, UNL, et al.

Mead Eddy Covariance Closure

- 2003 - Corn
  - Rainfed = 91%
  - Irrigation 1 = 88%
  - Irrigation 2 = 84%
- 2005 - Corn
  - Rainfed = 89%
  - Irrigation 1 = 85%
  - Irrigation 2 = 85%

$ET_{cor.}$ =
$ET \times (R_n\text{-}G)/(H+\lambda E)$

-- preserves the Bowen Ratio = $H/\lambda E$



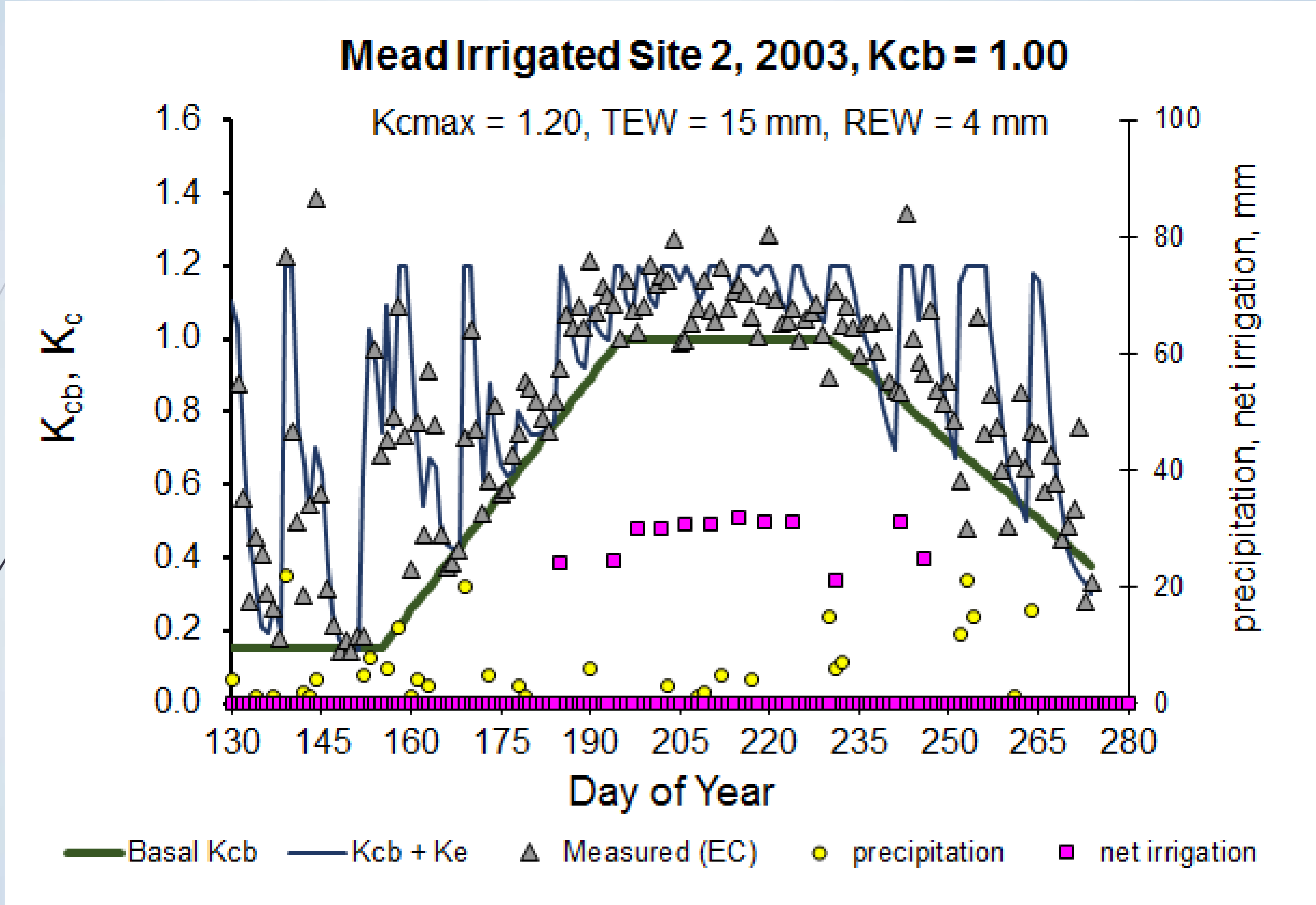
The Dual K_c Approach

- $K_c = K_s K_{cb} + K_e$
- $K_e = K_r (K_{c\ max\ r} - K_s K_{cb})$
- $K_{c\ max\ r} = \max[K_{c\ max\ bare}, (K_{cb} + 0.05)]$

subscript 'r' for alfalfa reference so that $K_{c\ max\ bare}$ ~ 1.0 to 1.2

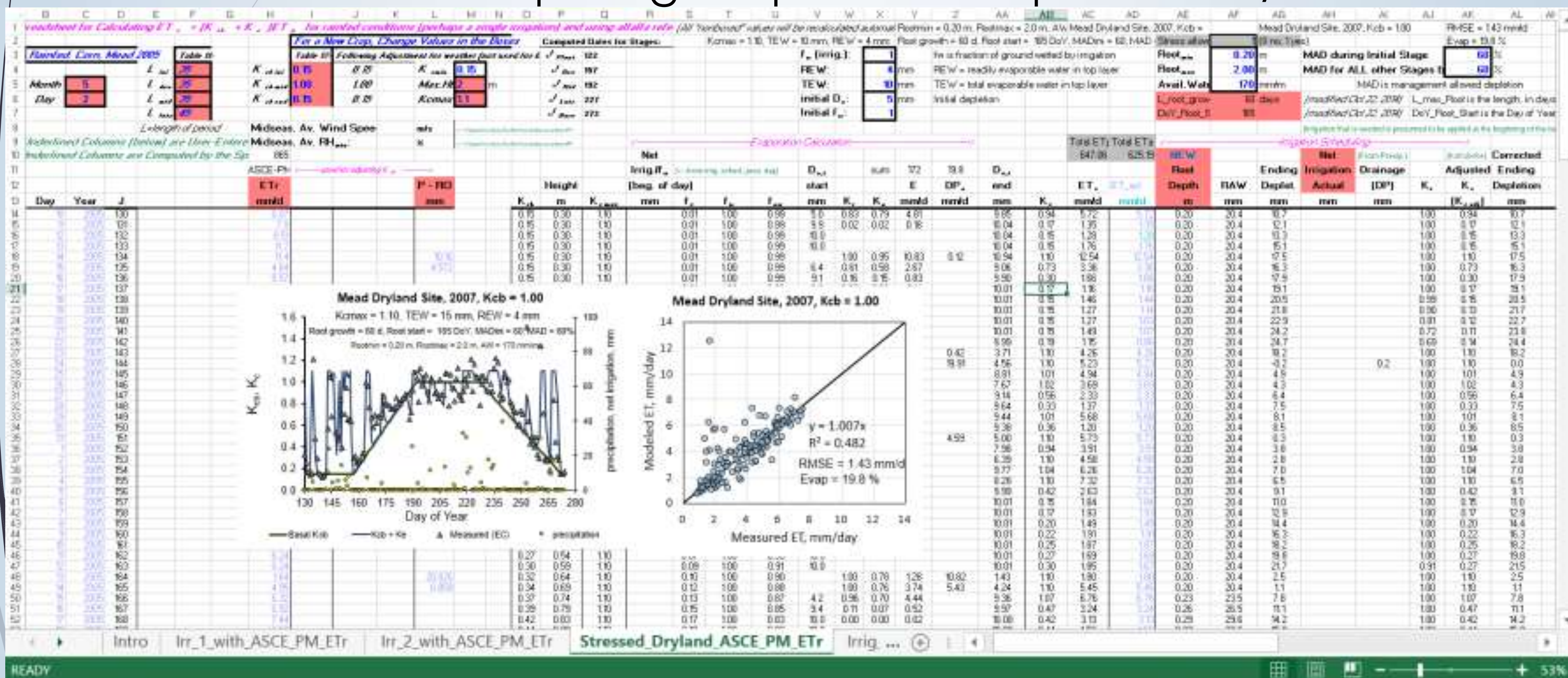
K_e can take up the "slack" or remaining 'energy' represented by the difference between $K_{c\ max\ r}$ and K_{cb}

Irrigated Field – Dual K_c Calculation



FAO-56 Dual Kc Example Spreadsheet -- Annex 8 of FAO-56 -- available at:

http://extension.uidaho.edu/kimberly/2013/04/guidelines-for-computing-crop-water-requirements/



Modified here to use Alfalfa Reference

FAO-56 Dual Kc Spreadsheet

	B	C	D	E	F	G	H	I	J	K	L	M	N
	readsheet for Calculating $ET_c = (K_{cb} + K_e)ET_o$ for rainfed conditions (perhaps a singl												
								For a New Crop, Change Values in the Bo					
	Rainfed Corn, Mead 2005				Table 11:			Table 17:	Following Adjustment for weather (not u				
				L_{ini}	35		$K_{cb\,ini}$	0.15	0.15		K_{cmin}	0.15	
	Month	5		L_{dev}	35		$K_{cb\,mid}$	1.00	1.00		Max.Ht	2	m
	Day	2		L_{mid}	35		$K_{cb\,end}$	0.15	0.15		Kcmax	1.1	
				L_{late}	45								
				L=length of period			Midseas. Av. Wind Spee			m/s			
	Underlined Columns (below) are User-Entere						Midseas. Av. RH_{min}:			%			
	Underlined Columns are Computed by the Sp						865						
							ASCE-PM	‹---------used for adjusting K_{cb} ----------›					
							ETr				P - RO		
	Day	Year	J				mm/d				mm		
	10	2005	130				6.07						
	11	2005	131				7.8						
	12	2005	132				8.51						
	13	2005	133				11.7						
	14	2005	134				11.4				10.16		

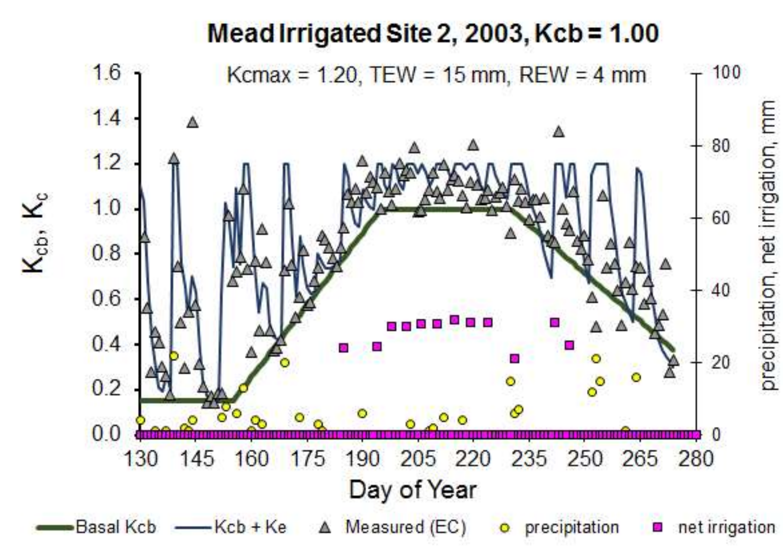
Modified here to use Alfalfa Reference

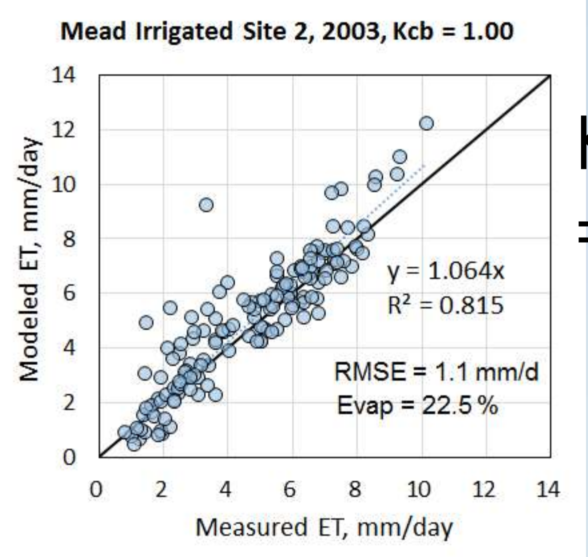
V	W	X	Y	Z	AA	AB	AC	AD	AE	AF	AG	AH	AI	AJ	AK	AL
l be recalculated automat		Rootmin = 0.20 m, Rootmax = 2.0 m, AW					Mead Dryland Site, 2007, Kcb =				Mead Dryland Site, 2007, Kcb = 1.00				RMSE = 1.43 mm/d	
' = 10 mm, REW = 4 mm		Root growth = 60 d, Root start = 165 DoY, MADini = 60, MAD							Stress allow	1	(0 no, 1 yes)				Evap = 19.8 %	
f_w (irrig.):		1		fw is fraction of ground wetted by irrigation					$Root_{min}$	0.20	m	MAD during Initial Stage			60	%
REW:		4	mm	REW = readily evaporable water in top layer					$Root_{max}$	2.00	m	MAD for ALL other Stages b			60	%
TEW:		10	mm	TEW = total evaporable water in top layer					Avail.Wate	170	mm/m		MAD is management allowed depletion			
initial D_e:		5	mm	Initial depletion					L_root_grow	60	days	(modified Oct 22, 2014)	L_max_Root is the length, in days			
Initial f_w:		1							DoY_Root_S	165		(modified Oct 22, 2014)	DoY_Root_Start is the Day of Year			
												(Irrigation that is needed is presumed to be applied at the beginning of the ne				
ion Calculation-----------------------------------›							Total ETp	Total ETa	‹--------------------------------Irrigation Scheduling-------------------------------›							
							647.06	625.19	NEW			Net	(From Precip.)		(KsKcb+Ke)	Corrected
$D_{e,i}$		sum	172	19.8	$D_{e,i}$				Root		Ending	Irrigation	Drainage		Adjusted	Ending
start			E	DP_e	end		ET_c	ET_act	Depth	RAW	Deplet.	Actual	(DP)	K_s	K_c	Depletion
mm	K_r	K_e	mm/d	mm/d	mm	K_c	mm/d	mm/d	m	mm	mm	mm	mm		($K_{c\,adj}$)	mm
5.0	0.83	0.79	4.81		9.85	0.94	5.72	5.72	0.20	20.4	10.7			1.00	0.94	10.7
9.9	0.02	0.02	0.18		10.04	0.17	1.35	1.35	0.20	20.4	12.1			1.00	0.17	12.1
10.0					10.04	0.15	1.28	1.28	0.20	20.4	13.3			1.00	0.15	13.3
10.0					10.04	0.15	1.76	1.76	0.20	20.4	15.1			1.00	0.15	15.1
	1.00	0.95	10.83	0.12	10.94	1.10	12.54	12.54	0.20	20.4	17.5			1.00	1.10	17.5
6.4	0.61	0.58	2.67		9.06	0.73	3.36	3.36	0.20	20.4	16.3			1.00	0.73	16.3

Sensitivity

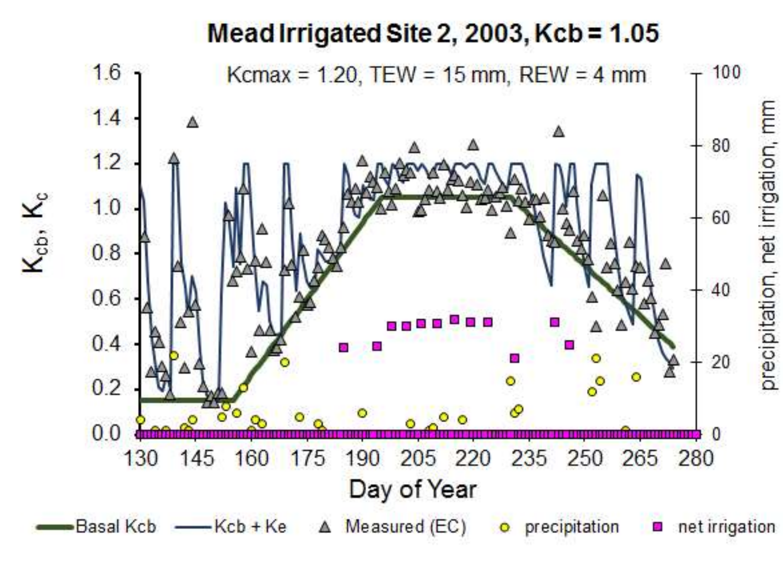
- Impact of $K_{cb\ mid}$
- Finding: With Dual K_c method, estimated ET is relatively insensitive to $K_{cb\ mid}$ and more sensitive to $K_{c\ max}$

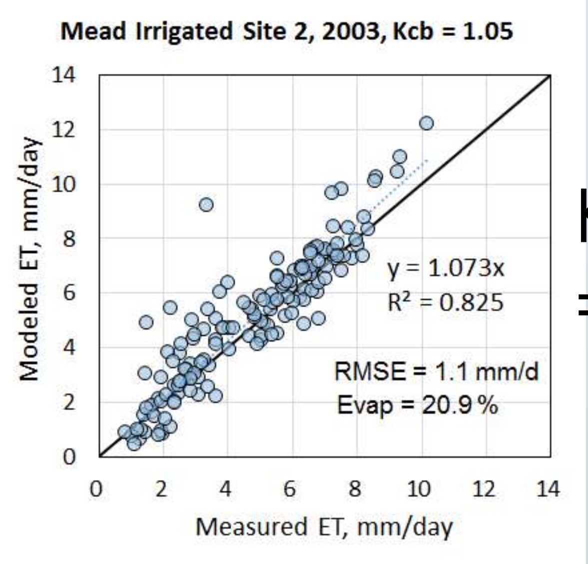
Irrigated Field – Impact of $K_{c\ mid}$





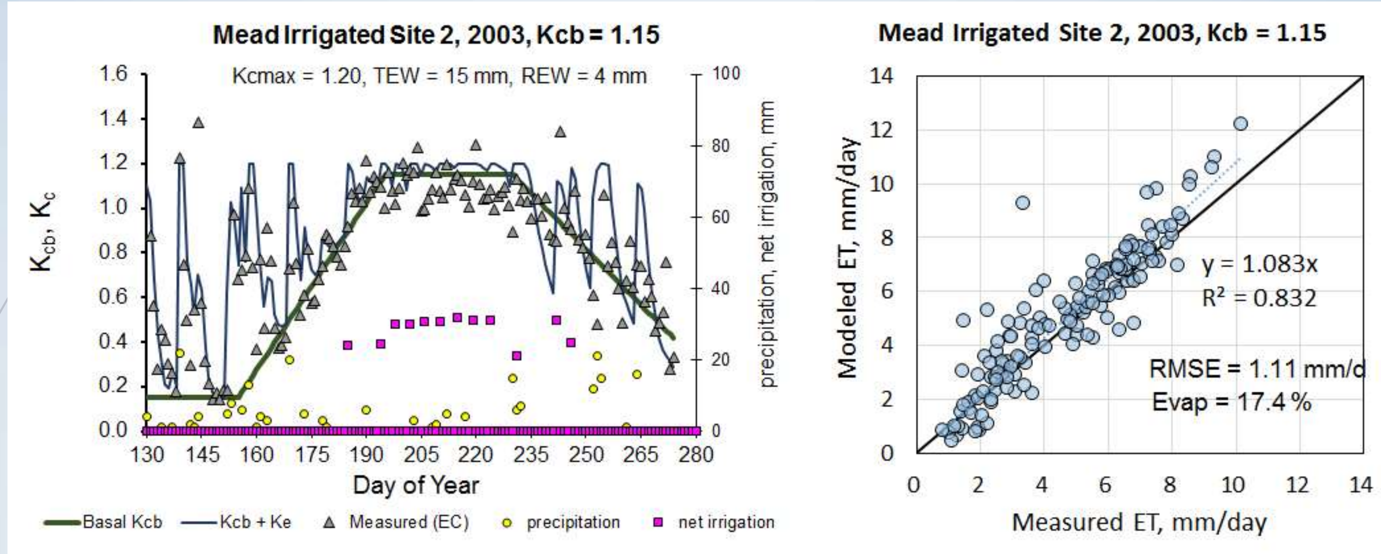
$K_{cb\ mid}$ = 1.00



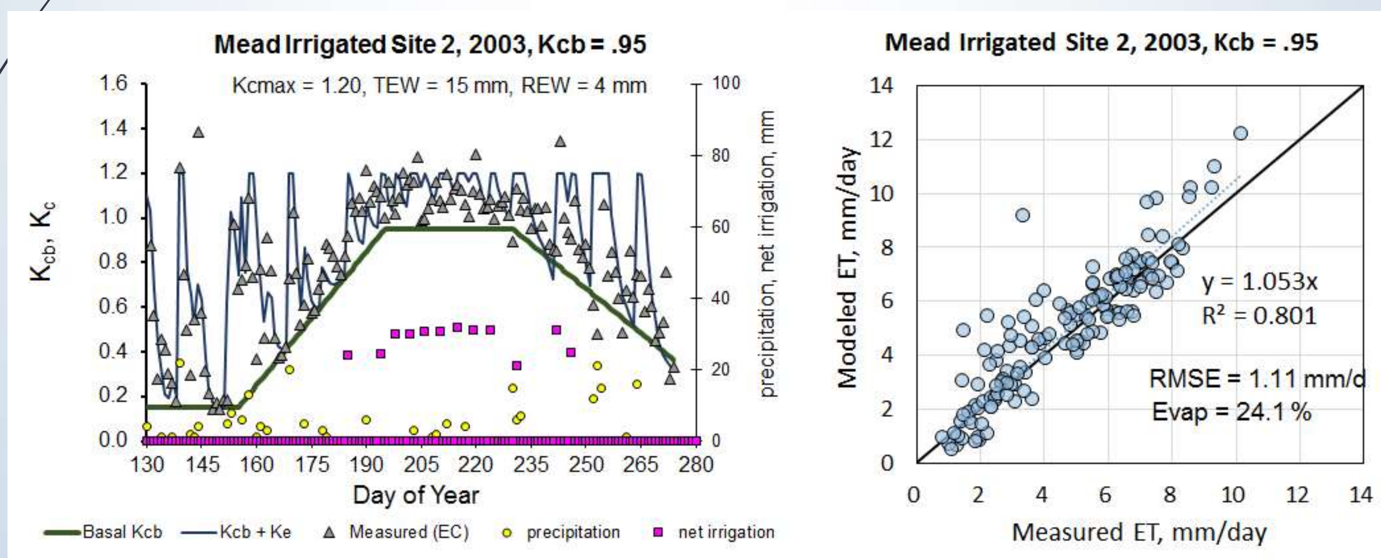


$K_{cb\ mid}$ = 1.05

Irrigated Field – Impact of $K_{c\ mid}$



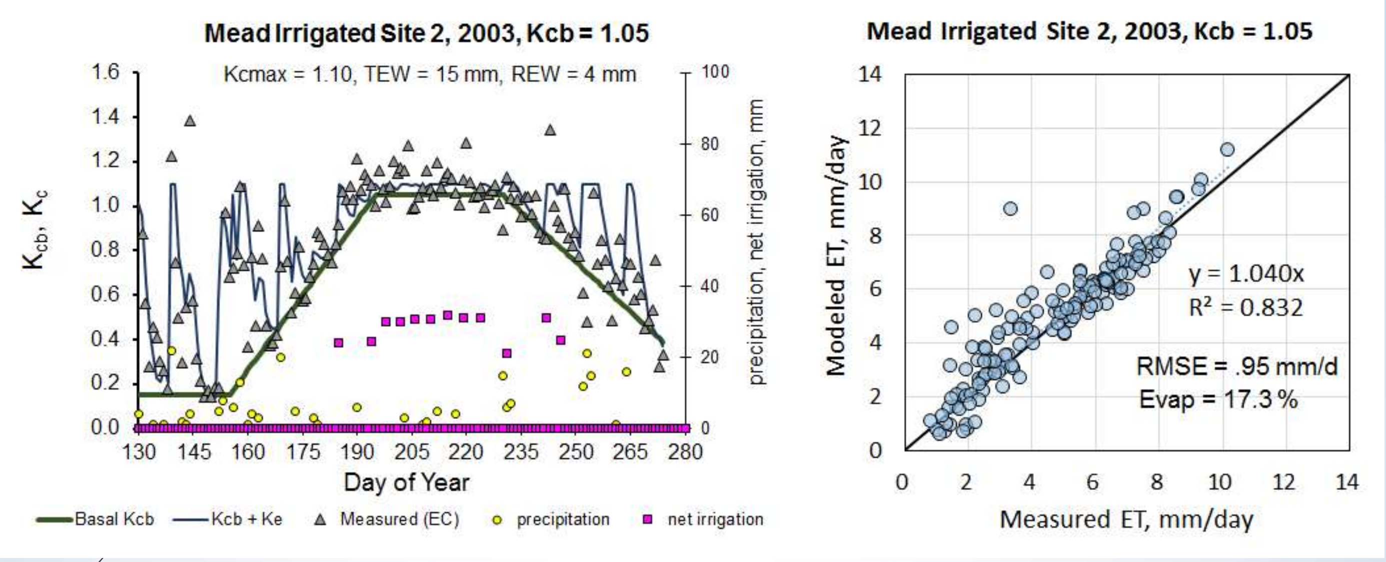
$K_{cb\ mid}$ = 1.15



$K_{cb\ mid}$ = 0.95

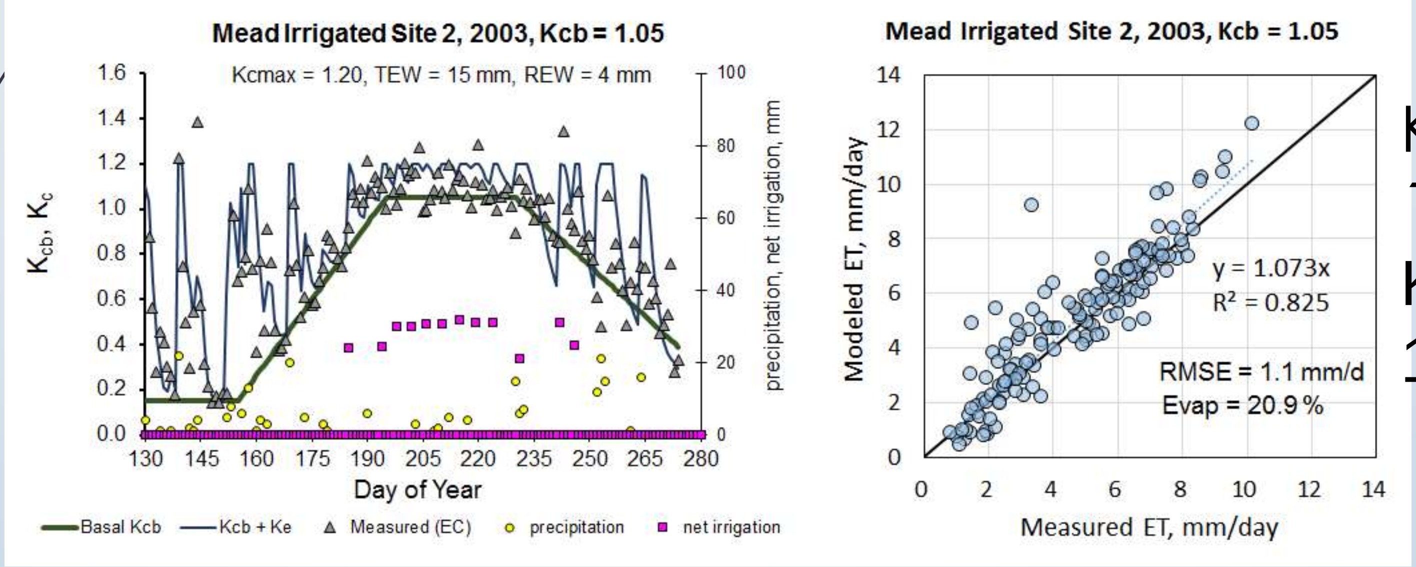
Conclusion: It is difficult to determine correct separation in T and E and correct $K_{c\ mid}$ using measured ET only

Irrigated Field – Impact of $K_{c\ max}$



$K_{c\ max}$ = 1.10

$K_{cb\ mid}$ = 1.05

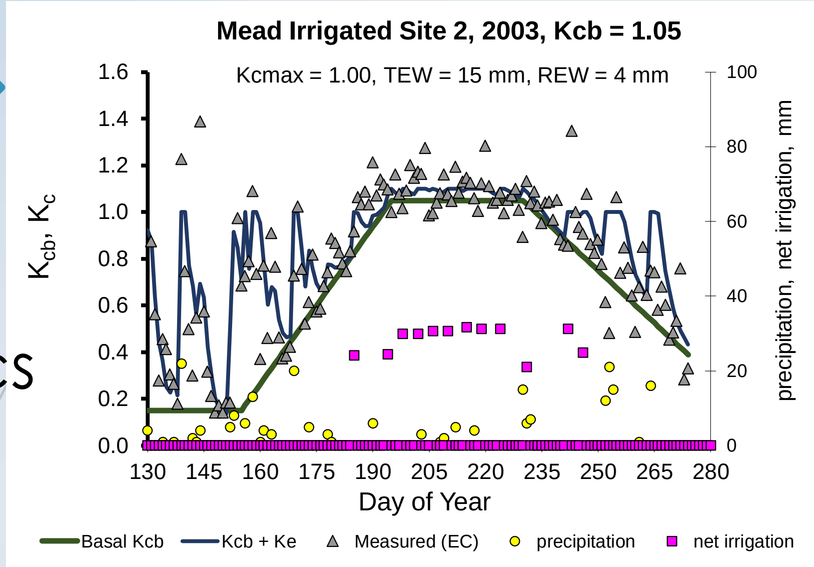


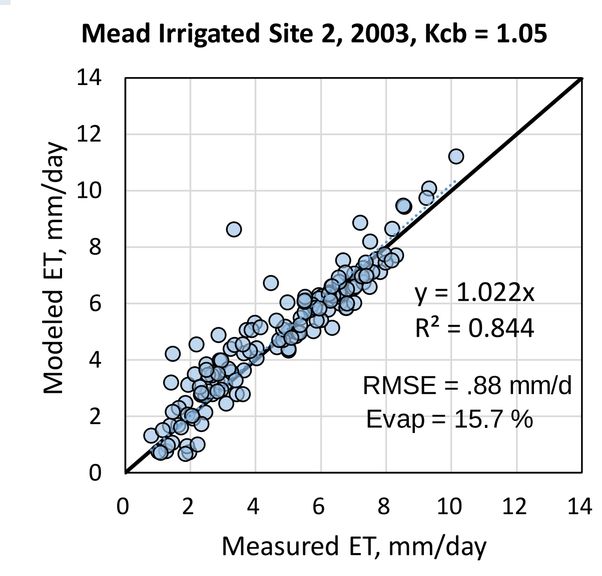
$K_{c\ max}$ = 1.20

$K_{cb\ mid}$ = 1.05

Irrigated Field – Impact of $K_{c\ max}$

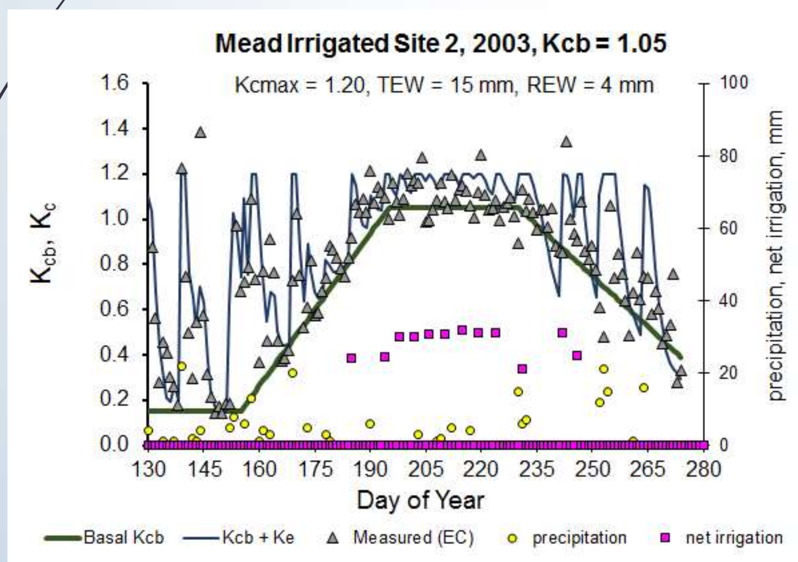
Best overall Statistics

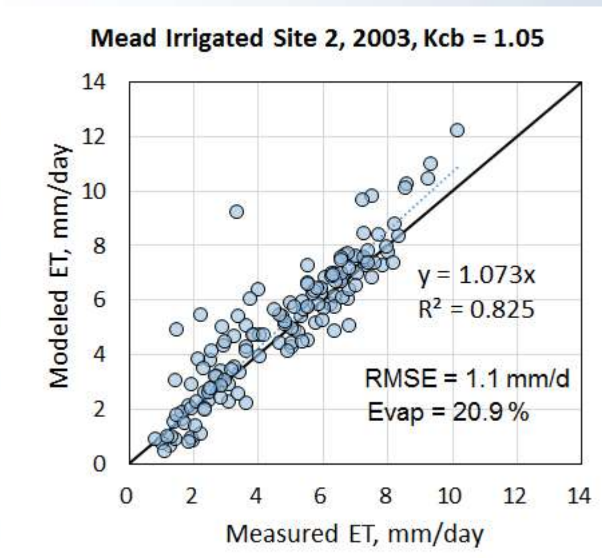




$K_{c\ max}$ = 1.00

$K_{cb\ mid}$ = 1.05





$K_{c\ max}$ = 1.20

$K_{cb\ mid}$ = 1.05

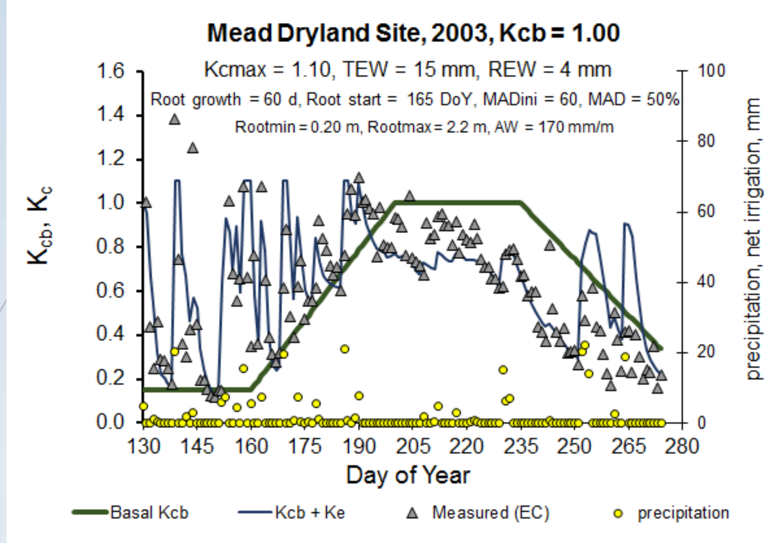
Sensitivity - Conclusion

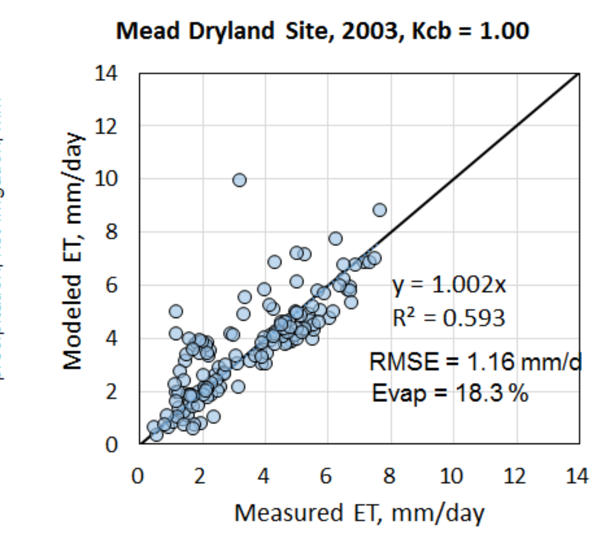
- With dual K_c method, worry less about $K_{cb\ mid}$ and more about $K_{c\ max}$.
- With alfalfa reference, $K_{c\ max\ r}$ is expected to be ~ 1.0 to 1.1
- With grass reference, $K_{c\ max\ o}$ is ~ 1.2 to 1.4, depending on wind speed and Relative Humidity.

Sensitivity to Rooting Depth

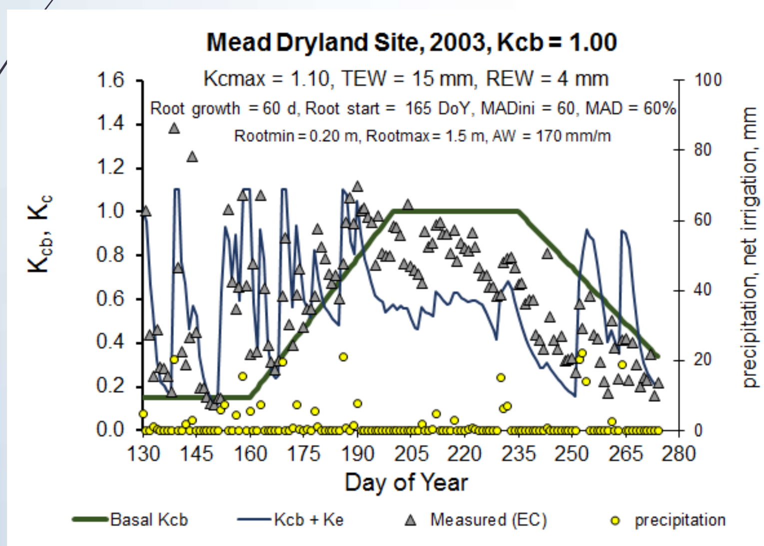
- Impact of Rooting depth under Stressed Conditions
- Finding: Estimation of ET under stress conditions is quite sensitive to the estimate for Total Available Water (TAW) where TAW = MAD x WHC x R_z.
- Therefore, ET is sensitive to MAD and R_z estimates.

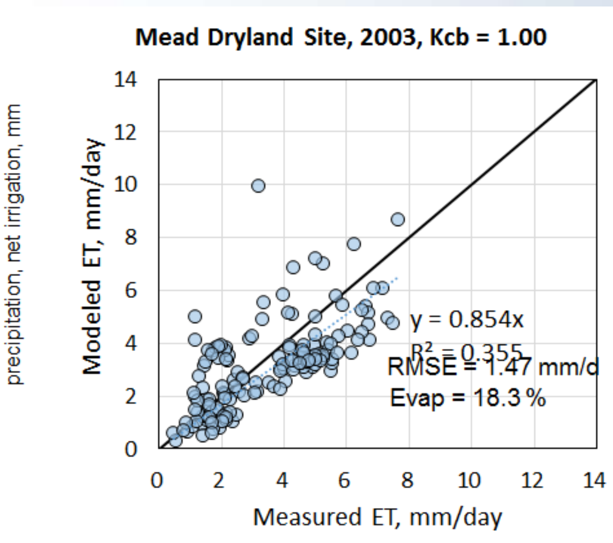
Rainfed Field – Impact of Rooting Depth





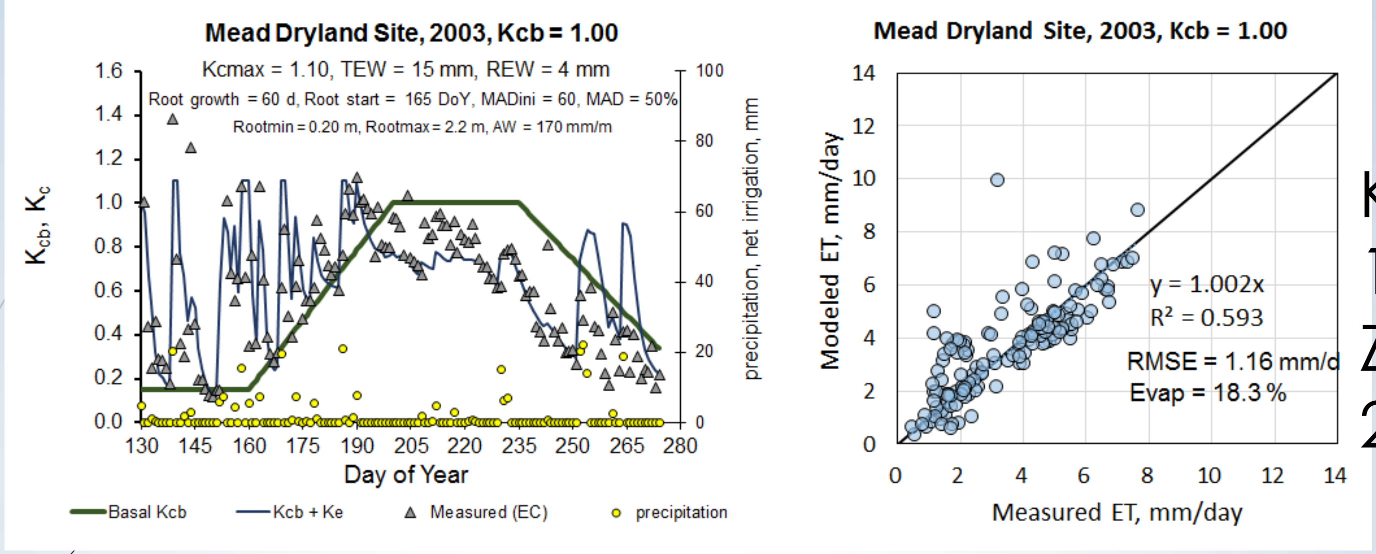
$K_{cb\ mid}$ = 1.00
Z_{root} = 2.2 m





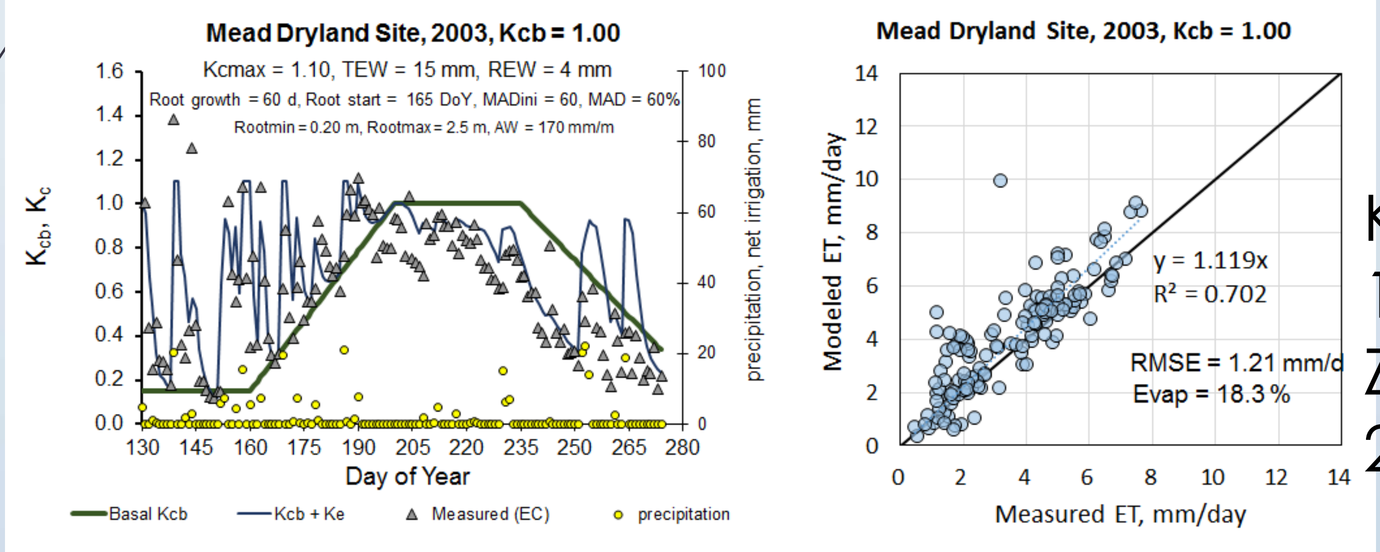
$K_{cb\ mid}$ = 1.00
Z_{root} = 1.5 m

Rainfed Field – Impact of Rooting Depth



$K_{cb\ mid}$ = 1.00

Z_{root} = 2.2 m



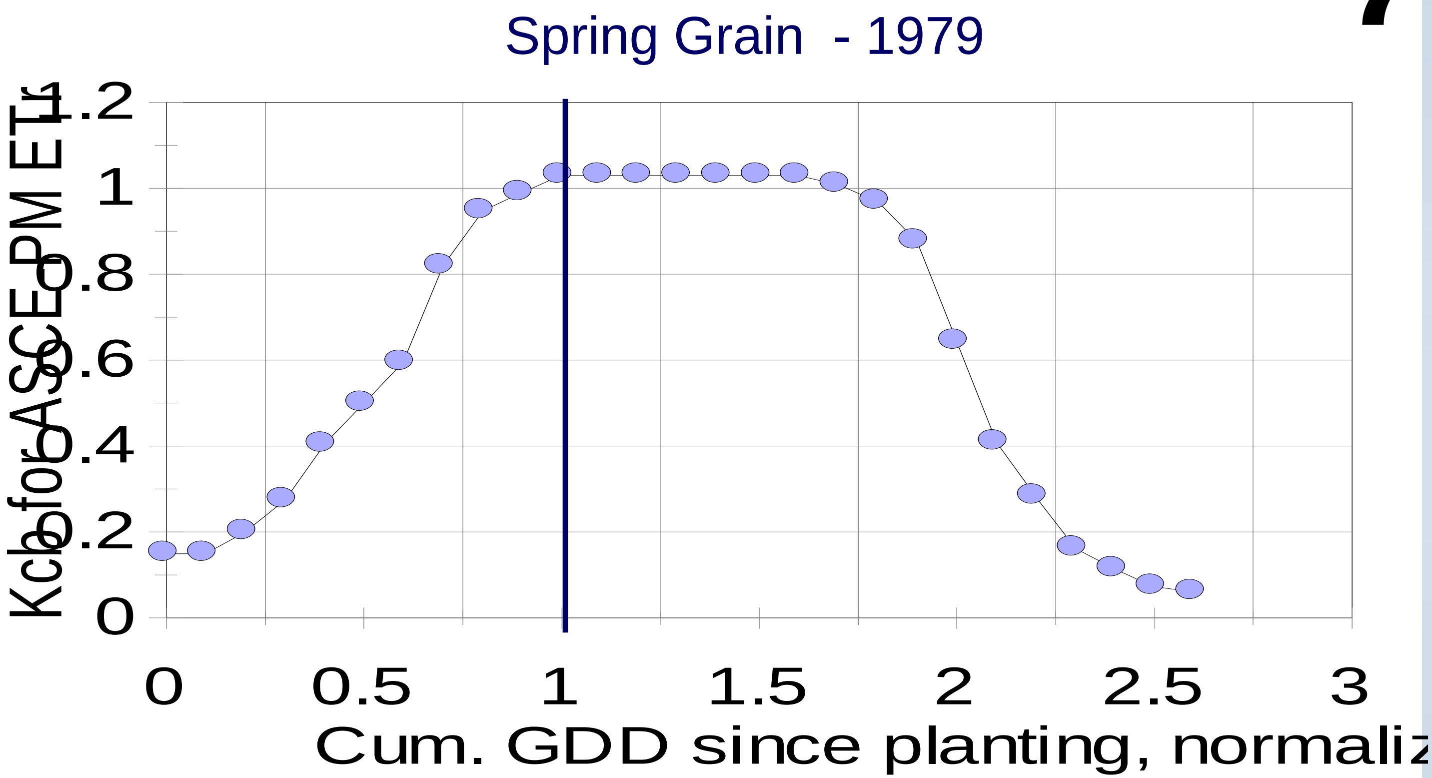
$K_{cb\ mid}$ = 1.00

Z_{root} = 2.5 m

Improving the Estimation of the Time Basis of K_c

Normalized (ratio of) **Cumulative Growing Degree Days** (GDD) from Planting to Effective Full Cover (Wright, 1998; Allen and Wright, 2003)

7



$$GDD = max\left(\frac{T_{max} + T_{min}}{2} - T_{base}, 0\right)$$

nt (198

T_{base} is 0°C for many crops, 5°C for others

Cumulative GDD for Wright (1982) K_{cb}'s as used in Idaho – Allen and Robison (2007)

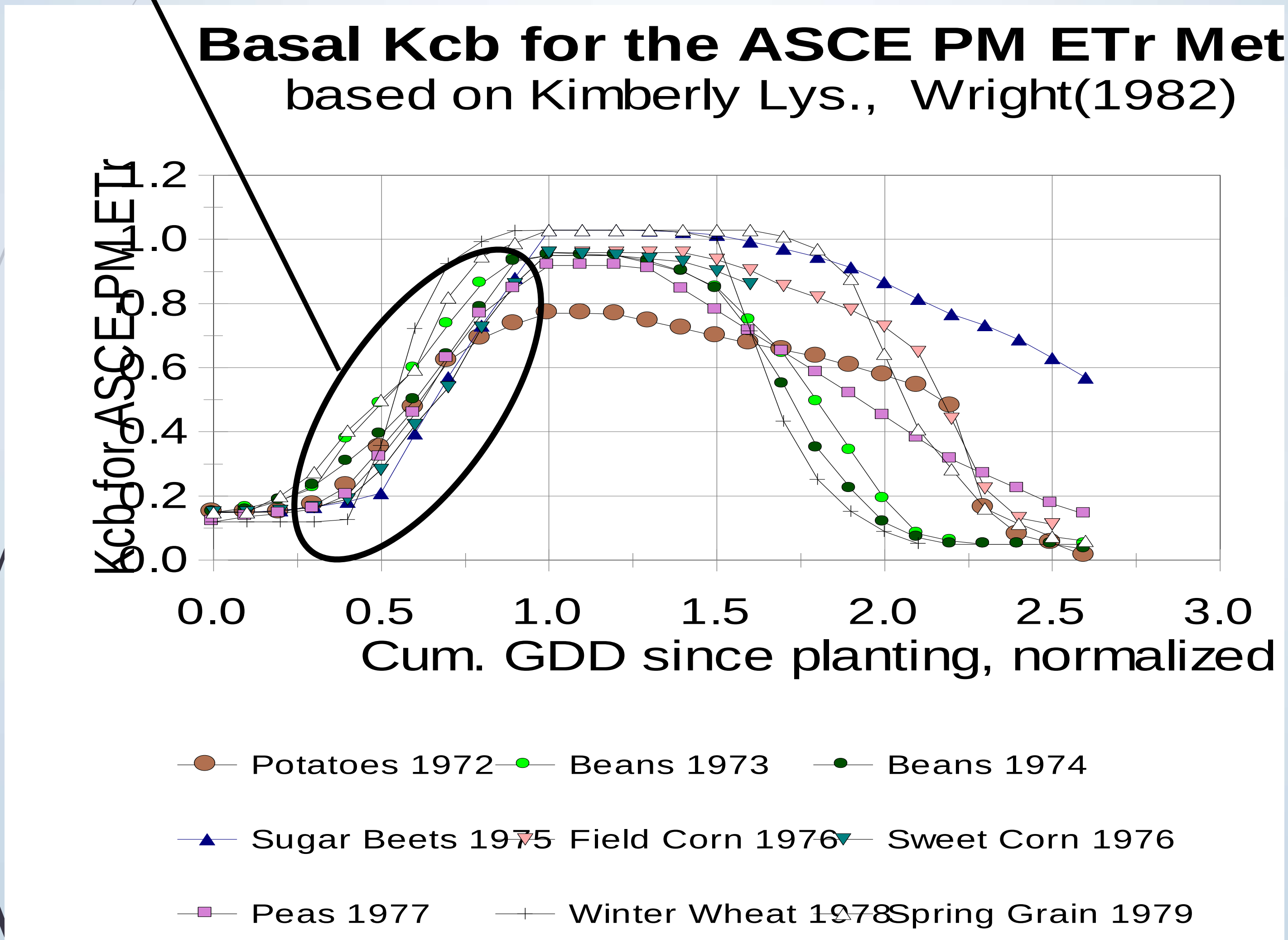
	Spr. Wht	Wint Wht	Peas seed	Peas frsh	Sug. Beet	Pota to bake	Pota to proc ess.	Bea ns	Field Corn
GDD Base, ºC	0	0	0	0	5	5	5	5	10-corn
CGDD Planting to EFC	840	1080	635	635	970	740	700	670	540
CGDD Planting to Terminate	2160	2600	1620	1000	2600	1780	1500	950	1400

(winter wheat is planted Oct. 15 and accumulates all winter)

http://www.kimberly.uidaho.edu/ETIdaho/

CGDD creates some similarity in the K_{cb} shape

similar shapes during development vs. CGDD

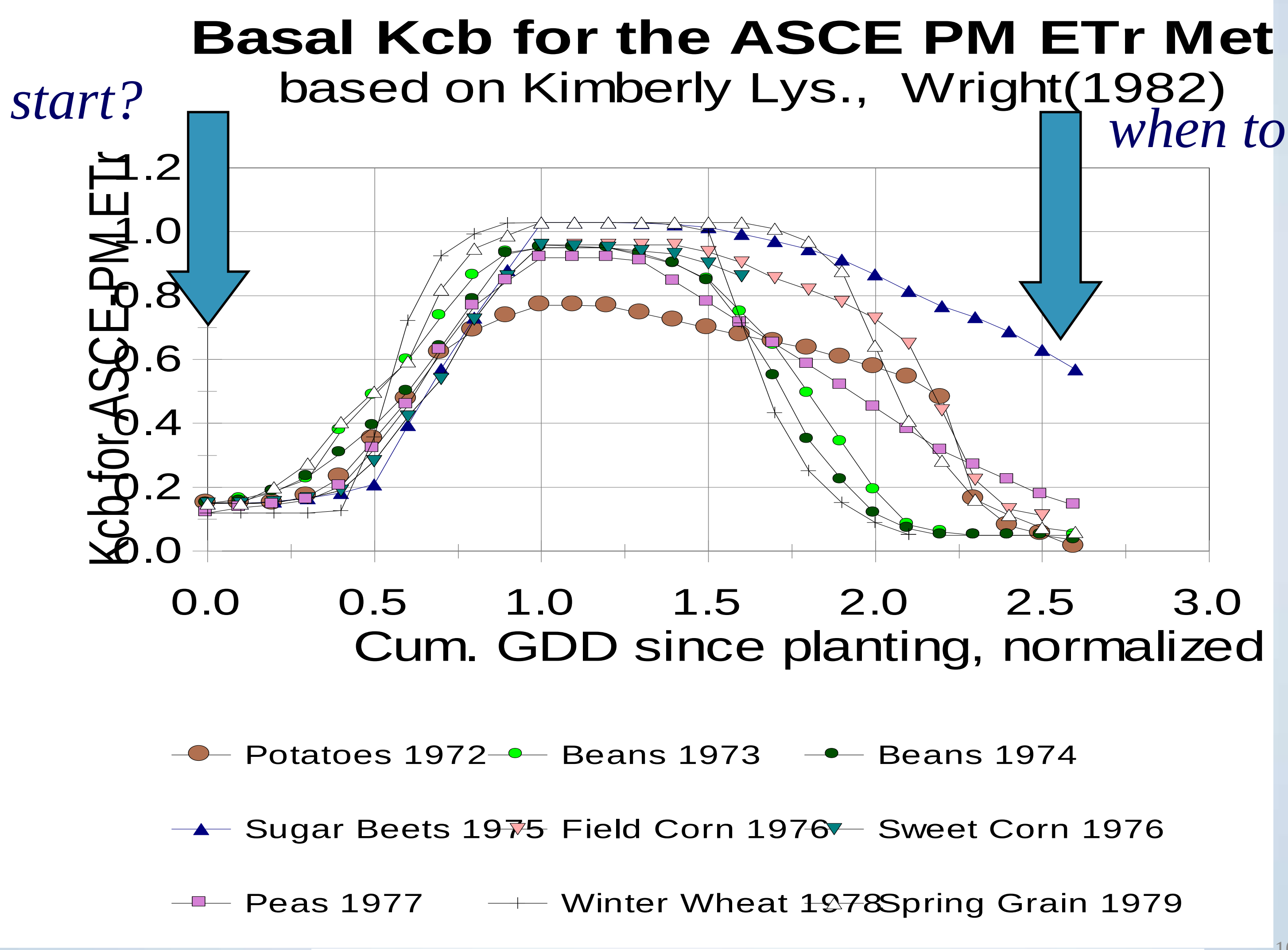


http://www.kimberly.uidaho.edu/water/asceewri/Conversion_of_Wright_Kcs_2c.pdf

Starting and Ending the K_{cb}

when to start?

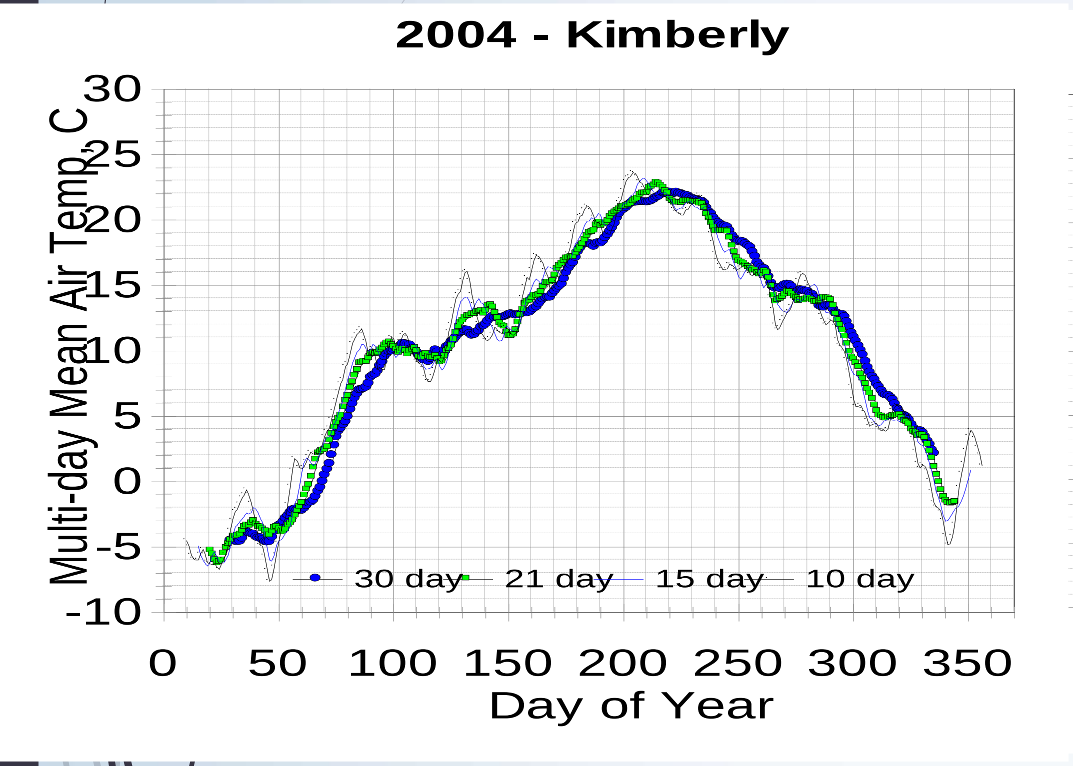
when to end?

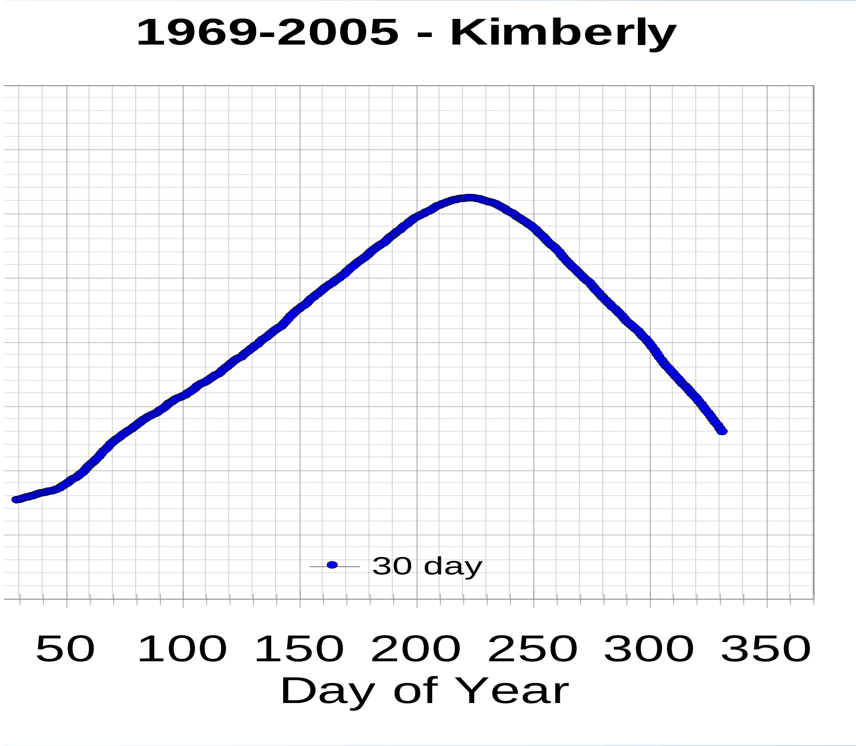


http://www.kimberly.uidaho.edu/water/asceewri/Conversion_of_Wright_Kcs_2c.pdf

How to Start Planting or Greenup:

Use 30 day (running average) mean daily air temperature





--similar to SCS method, except it is better to use T30 that <u>ENDS</u> on the predicted planting/greenup date

T_{30} for Idaho Crops – Allen and Robison (2007)

	Spr. Wht	Peas seed	Sug. Beet	Potato bake	Field Corn	Beans
Year of Wright	1979	1977	1975	1972	1976	1973
Plant Date of Wright	Apr 1	Apr 10	Apr 15	Apr 25	May 5	May 22
T30 used in ETIdaho, °C	4	5	8	6 to 7	10	14

http://www.kimberly.uidaho.edu/ETIdaho/

When to End: Killing Frosts

Killing Frosts as used in Idaho – Allen and Robison (2007) (^oC)

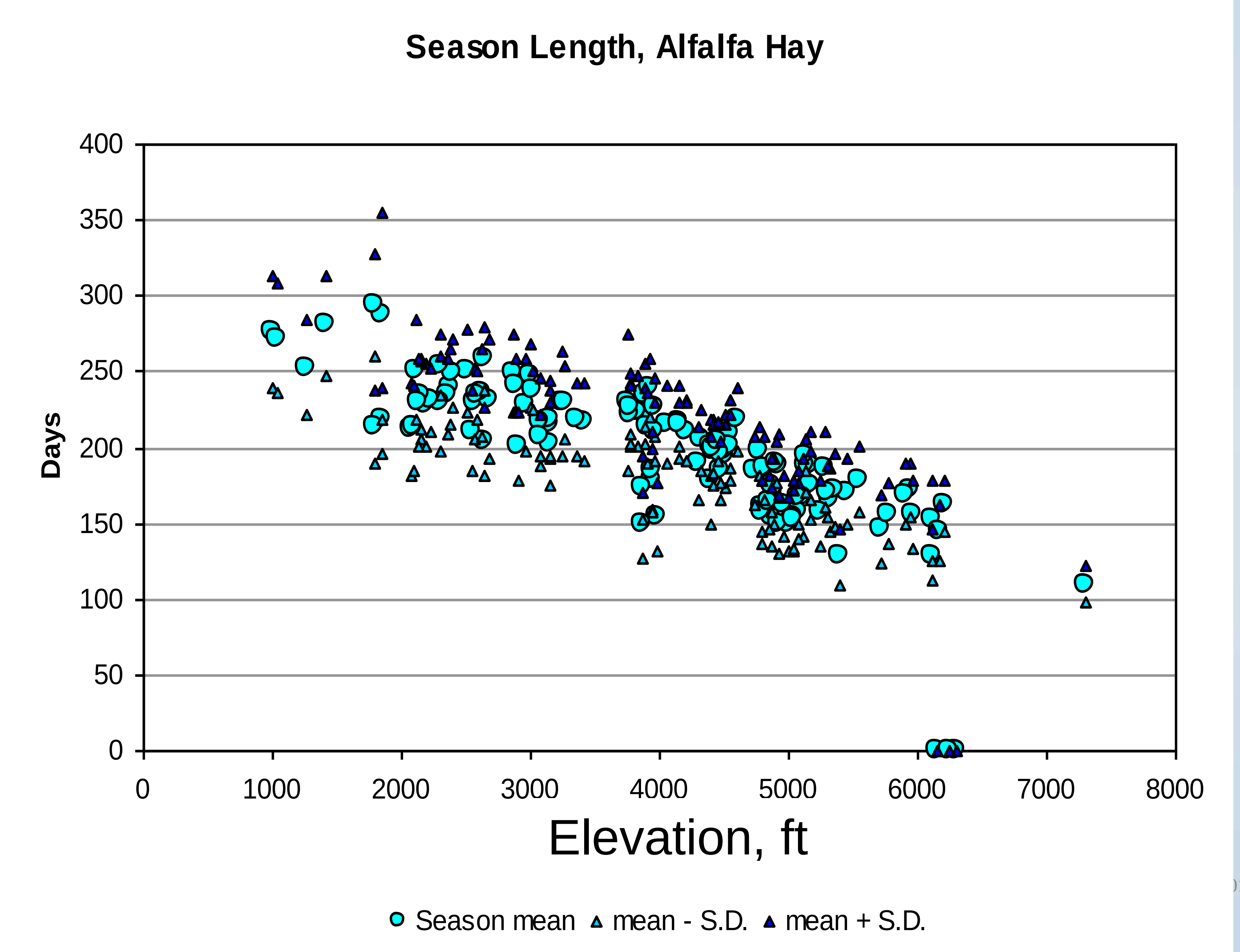
Spr. Wht	Peas seed	Sug. Beet	Pot. bake	Field Corn	Bean	Alf alfa	Past.	Hops
---	-4	-4	-2	-4 to -5	-2	-7	-5	-2

Cattails	Poplar	Cottonwood	Willows	Sun flowr
-2	-5	-4	-6	-4

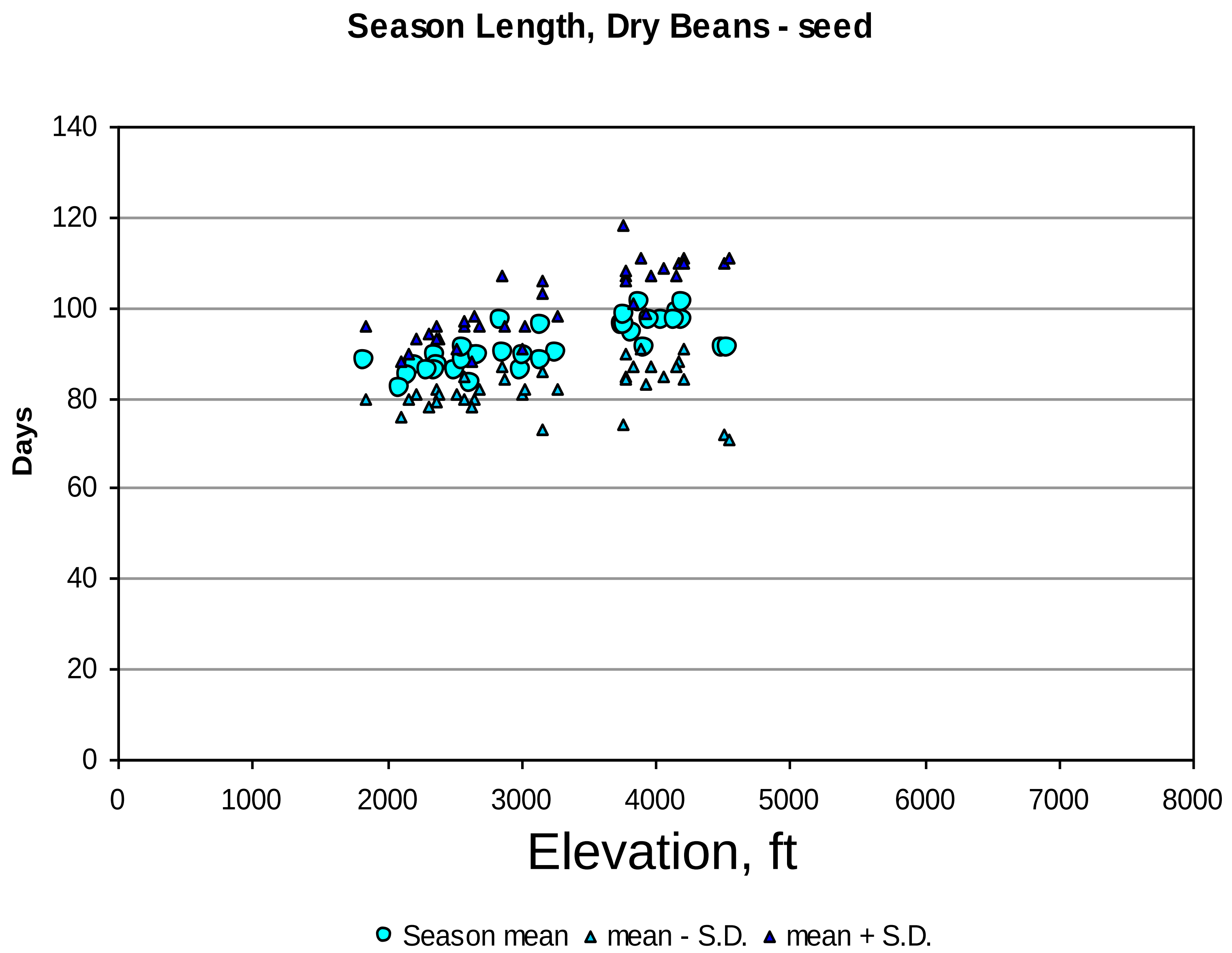
--Note: These are temperatures inside a Weather Shelter *(not on the ground)*

http://www.kimberly.uidaho.edu/ETIdaho/

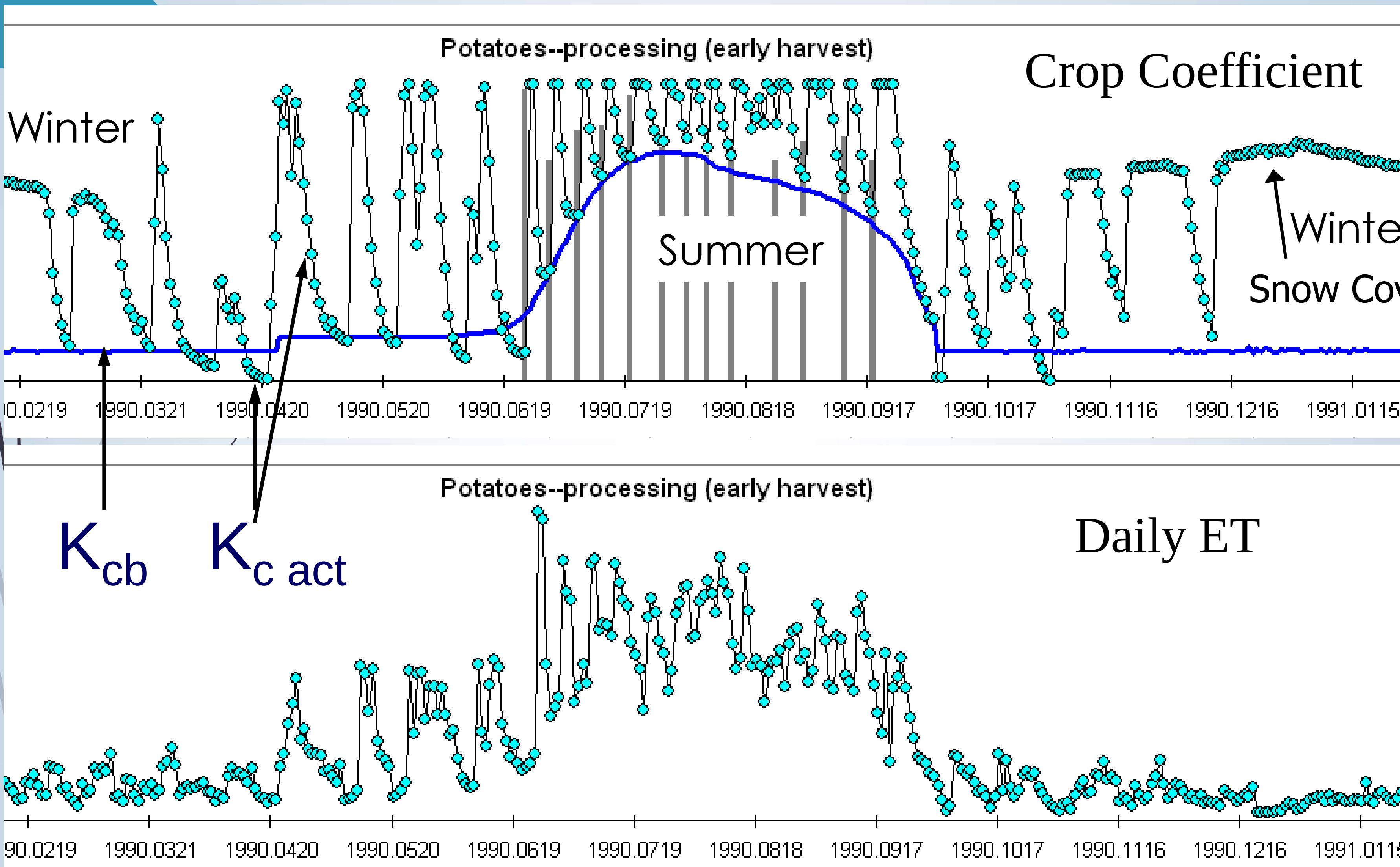
Alfalfa Season Lengths vs. Elevation across Idaho
Thermal-estimated Start and Frost Ended



Defined **Dry Bean** Season Lengths vs. Elevation Thermal-estimated Start and Thermal-estimated End

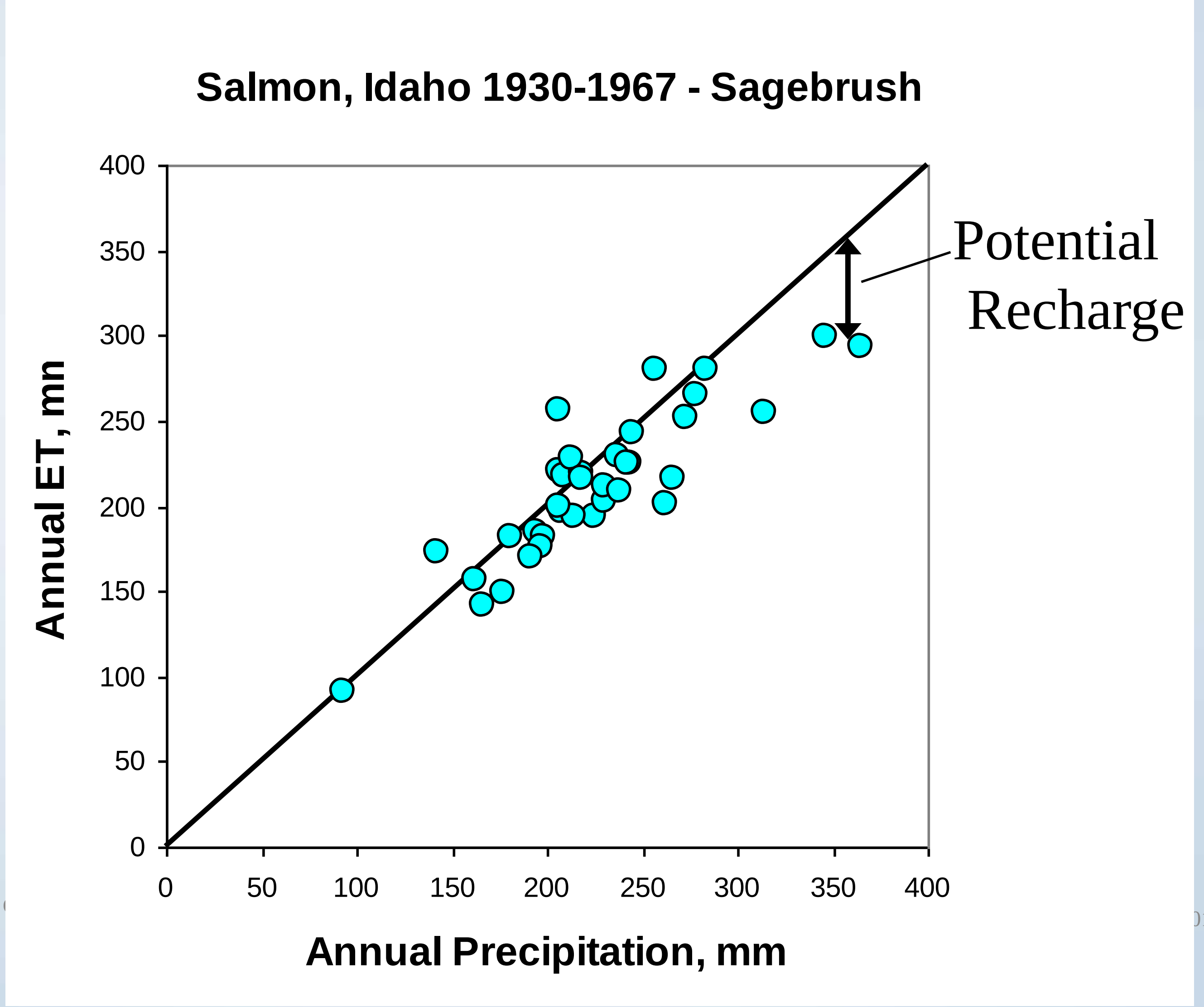


Ashton, 1990 calendar year -- Potatoes



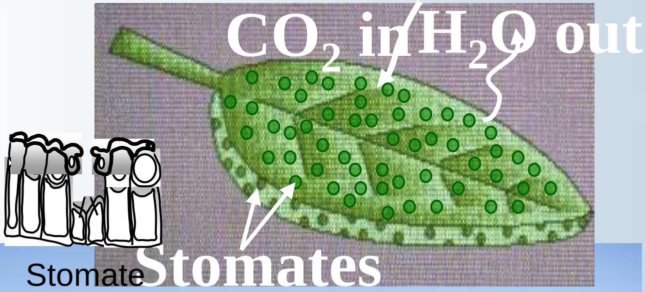
$$K_{c\ act} = \left(K_s\, K_{cb} + K_e\right)\ \left(and\ \ ET_{c\ act} = K_{c\ act}\ ET_r\right)$$

Annual ET estimates vs. Precipitation - Desert Sage Brush



Why K_{cb} should transfer among regions and climates

- Full-cover Alfalfa Reference (ET_r)
  - Dense stand with no cutting effects
  - 30 to 70 cm height
  - Extensive cover (~ 50 m or more)
- Field crop
  - Variable ground cover and leaf area
- If crop 'stomates' are 'programmed' to maximize photosynthesis and biomass production then
  - Relationship between ET_r and ET_c should be constant with climate and location
    - Both systems behave like passive resistors
    - Both systems use solar radiation capture, aerodynamic roughness and near surface boundary layer characteristics to drive ET



Overall Conclusions

- With dual K_c method, worry less about $K_{cb\ mid}$ and more about $K_{c\ max}$.
- Alfalfa reference provides more certainty than a grass reference since $K_{c\ max\ r}$ is ~ 1.0
- Under stressed conditions, accurate estimation of rooting depth (or MAD) and rooting growth rate is important.
- Starting and Stopping the Crop Growing Period and the Evolution of K_{cb} over time can be important for localized accuracy

Thank you