

Evapotranspiration Estimation Incorporating FAO56 Methodology

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M.E. Jensen, D. Raes, M. Smith*





Discussion Points

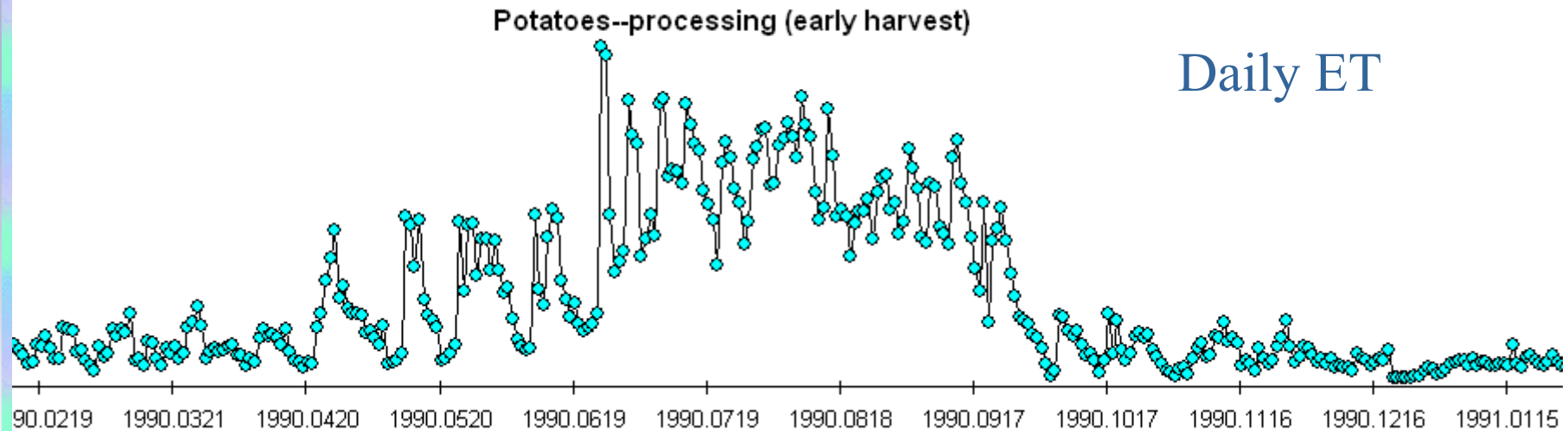
- **Brief Review of the Crop Coefficient
– Reference ET approach of FAO56**
- **Current Implementations**
- **Recent Applications**

Evapotranspiration (ET) varies widely with

- Time of Year
- From Day to Day

Therefore, rigorous Equations and Models are needed

Ashton, Idaho, USA 1990 calendar year -- Potatoes





Reference ET

9/4/2015

INOVAGRI, Fortaleza, Brazil, Aug. 31, 2015

FAO56 Reference ET: A Living Evaporation Index

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

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

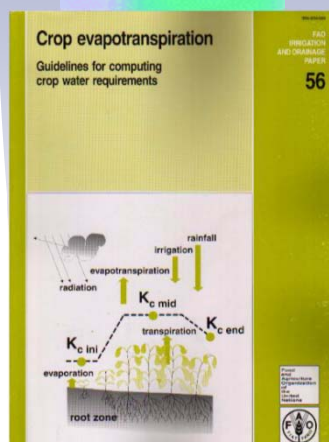
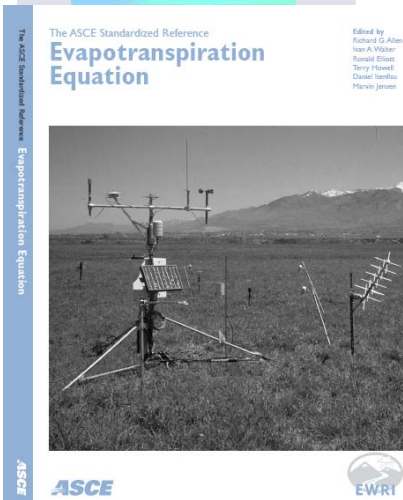
f (Solar Radiation)

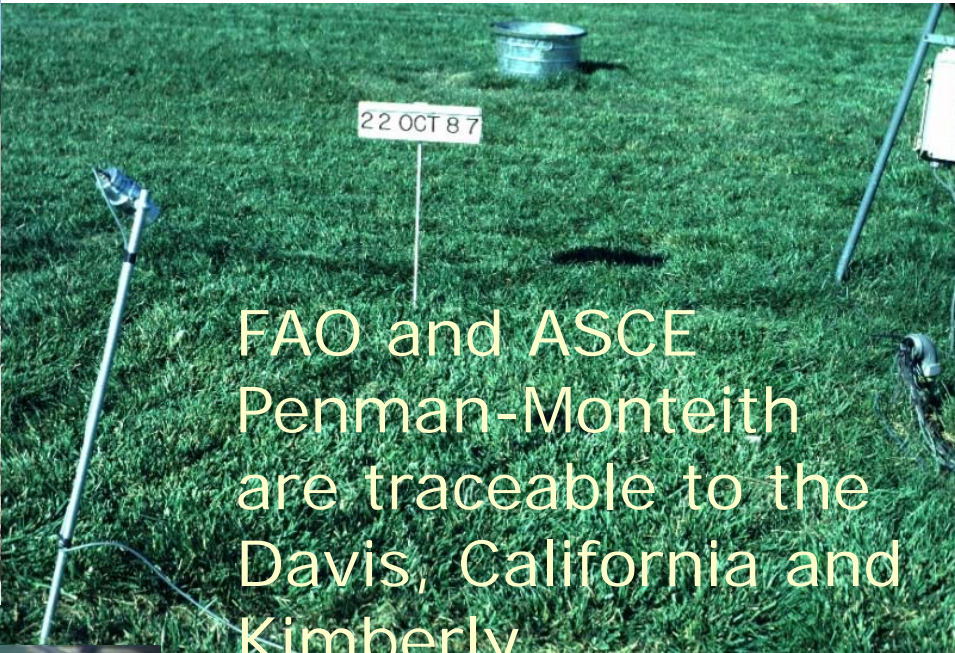
f (Temperature)

Wind Speed

f (Humidity)

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



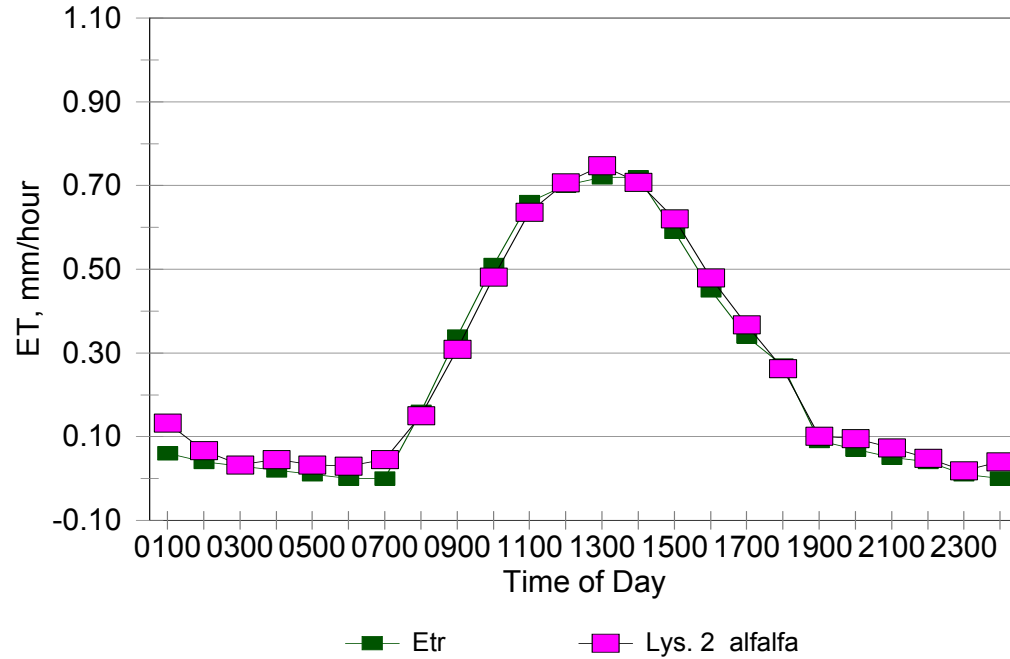


FAO and ASCE
Penman-Monteith
are traceable to the
Davis, California and
Kimberly,
Idaho (USDA)
Lysimeters

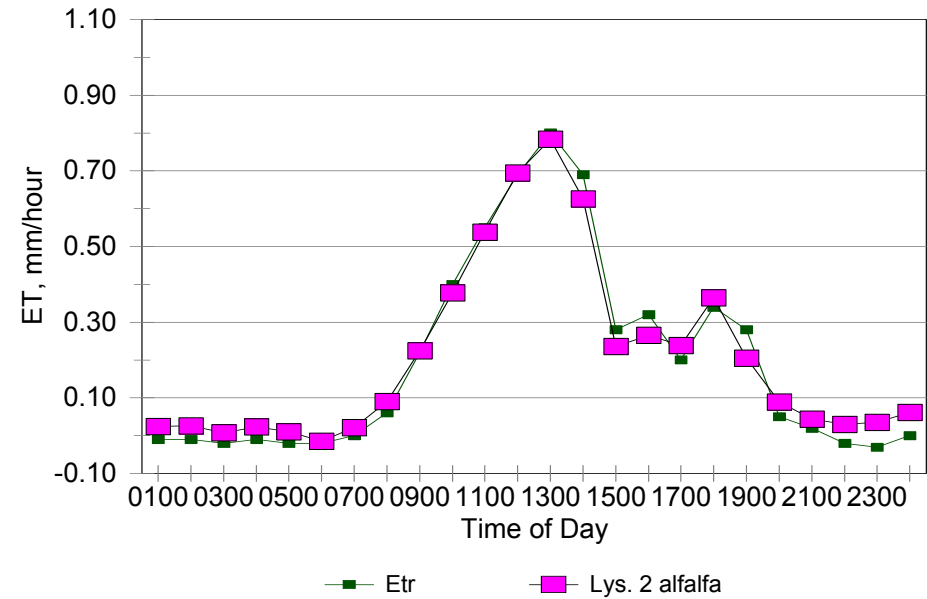


Kimberly Lysimeters - September 4, 1990

Data from Dr. J.L Wright

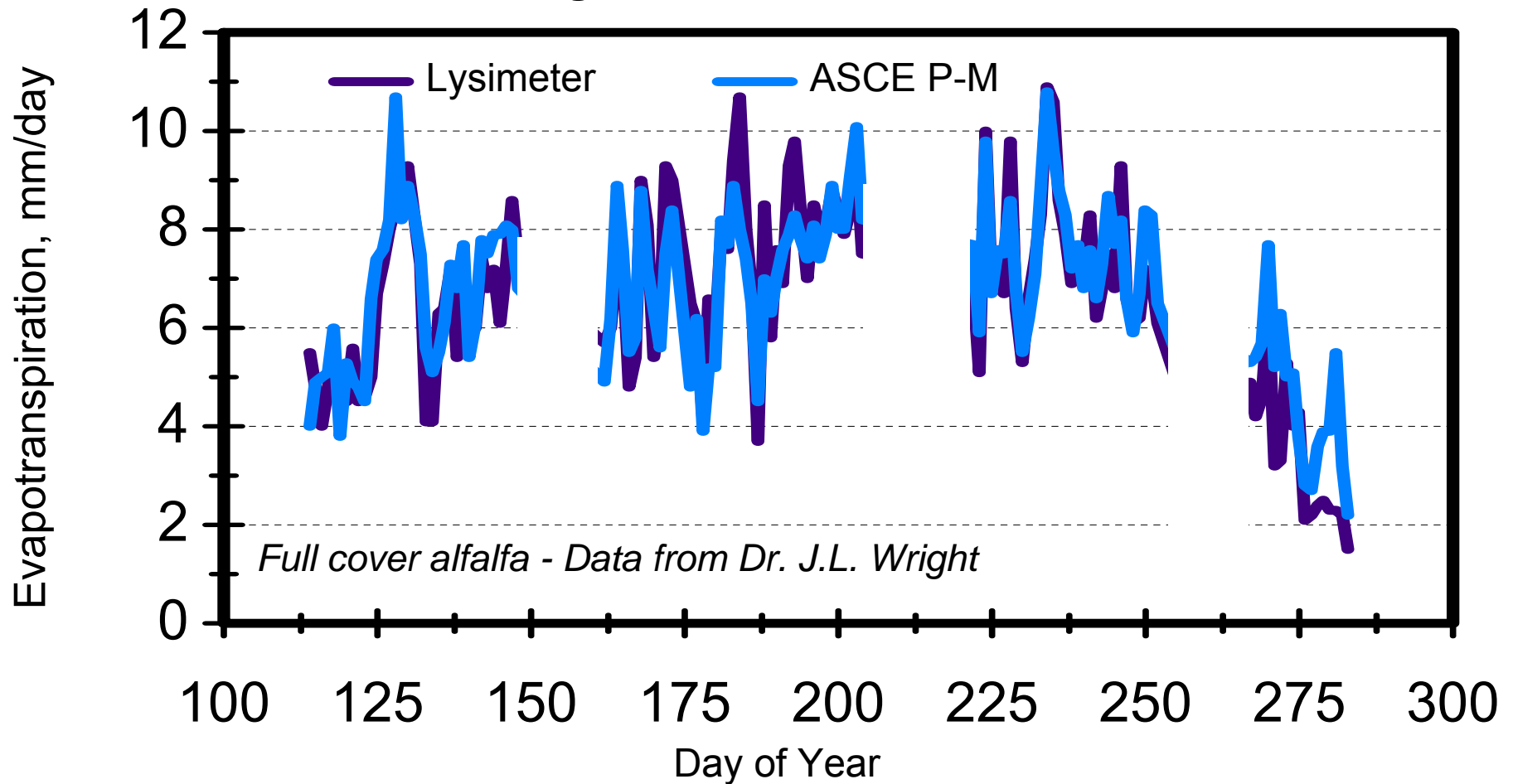


Kimberly Lysimeters -September 7, 1990



Good day-to-day correspondance with lysimeter

Kimberly, Idaho 1969



Daily Timestep

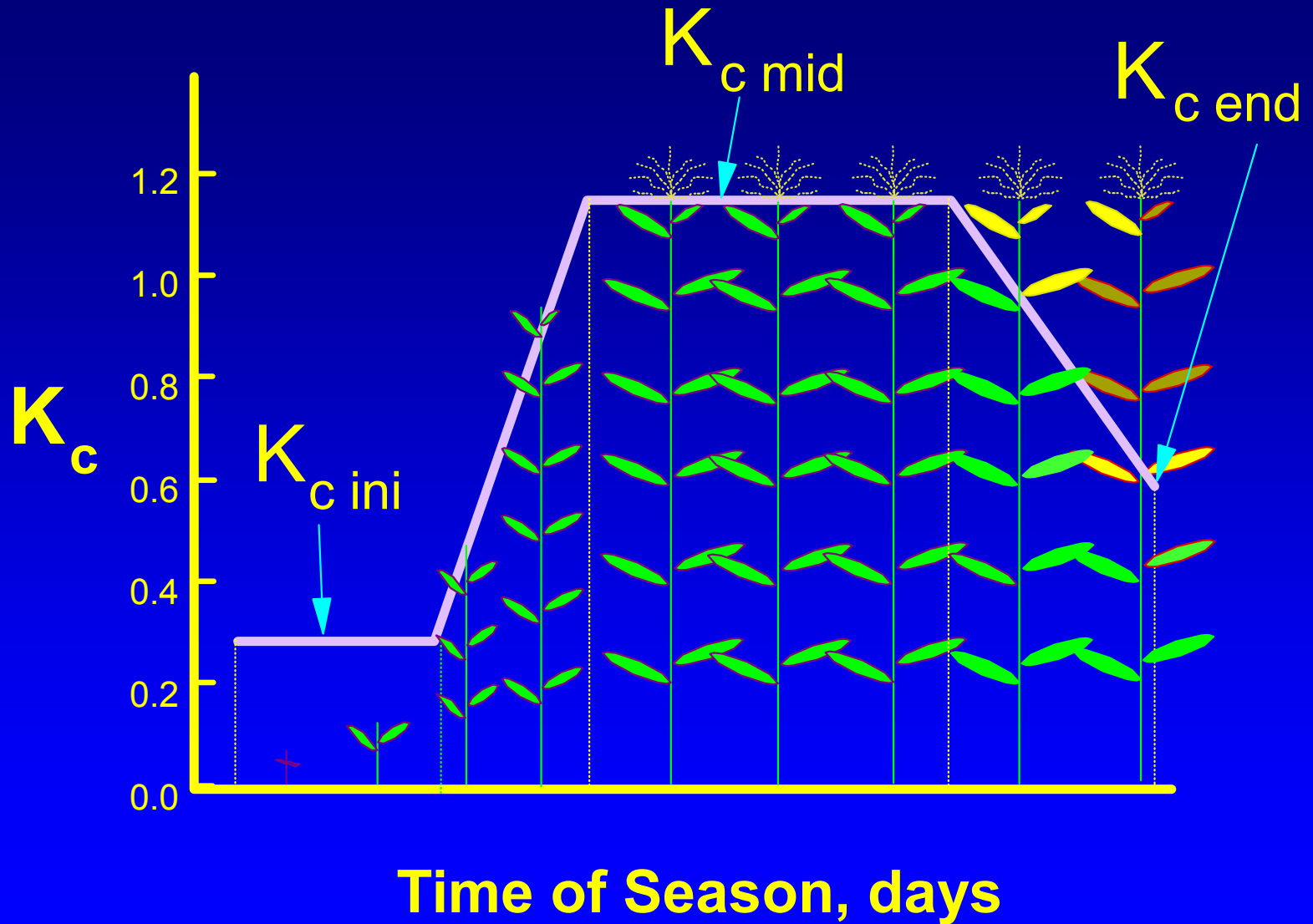


Crop Coefficients

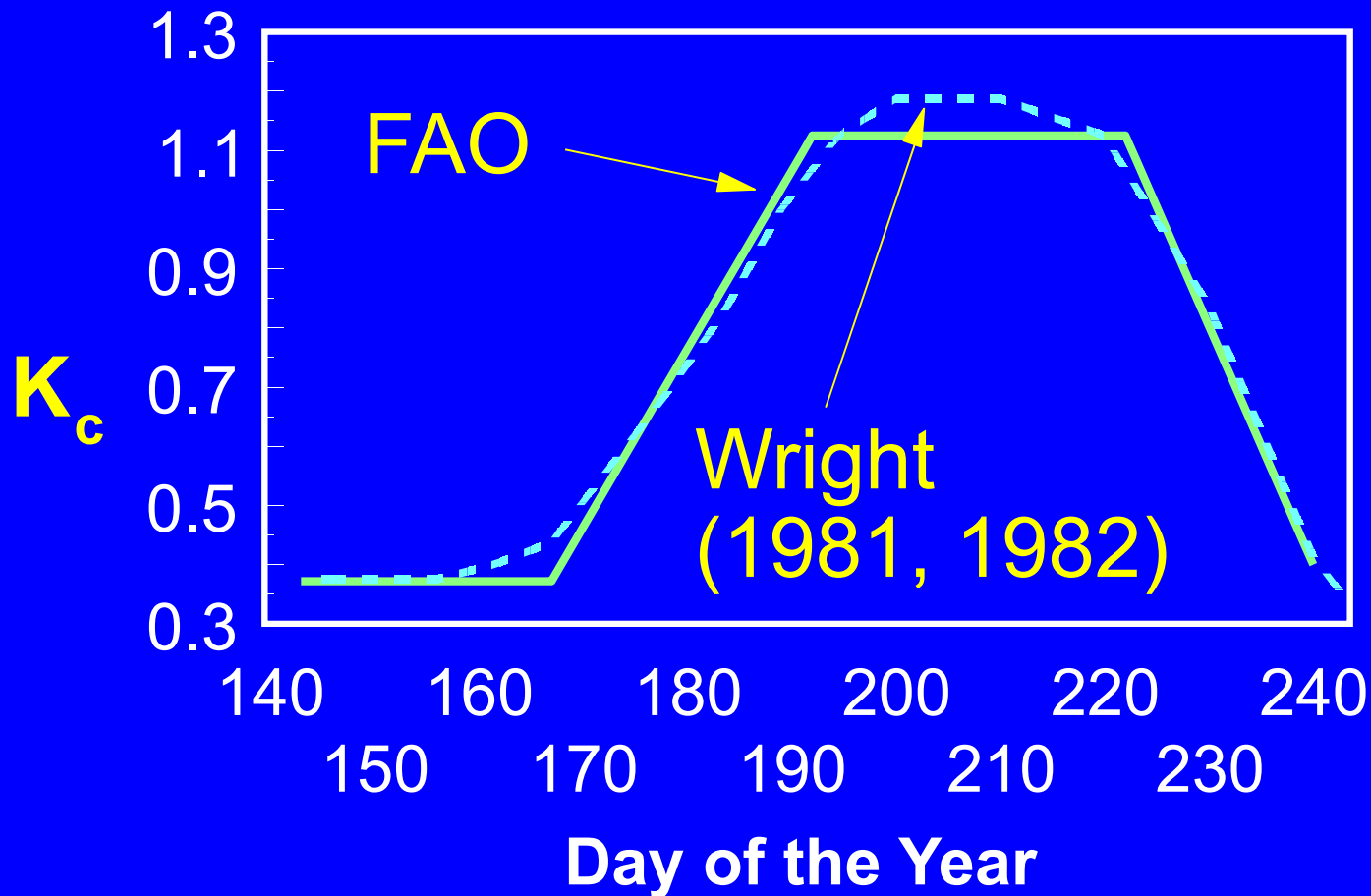
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INOVAGRI, Fortaleza, Brazil, Aug. 31, 2015

Crop Coefficient = ET/ET_{ref}



Crop Coefficient Curve Types





Single or Dual K_c ???

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INOVAGRI, Fortaleza, Brazil, Aug. 31, 2015

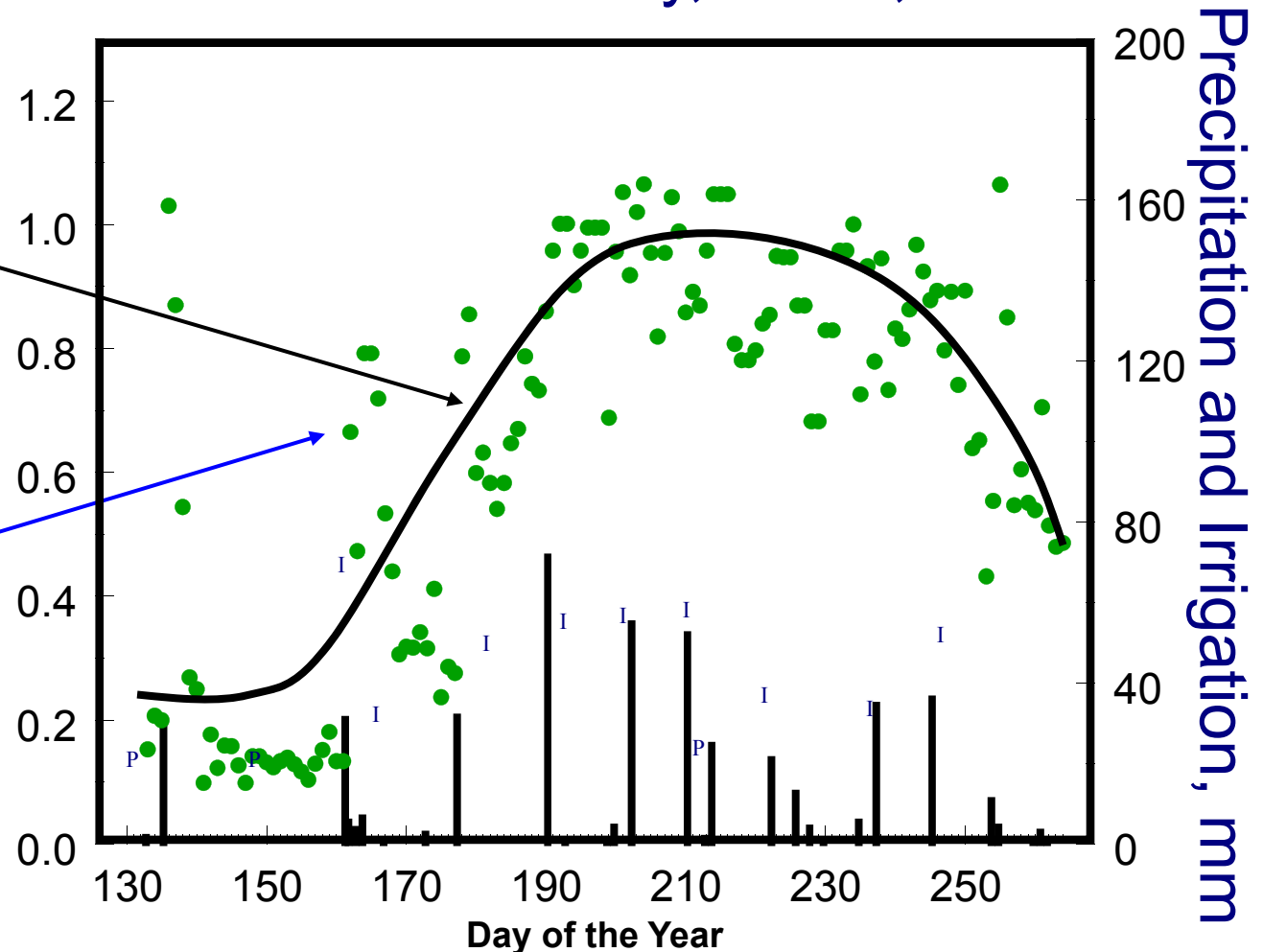
K_c measured by Lysimeter

each dot is one day

Sweet Corn-- Kimberly, Idaho, 1976

“Single”
Curve
averaging
evaporation
“Spikes” K_c

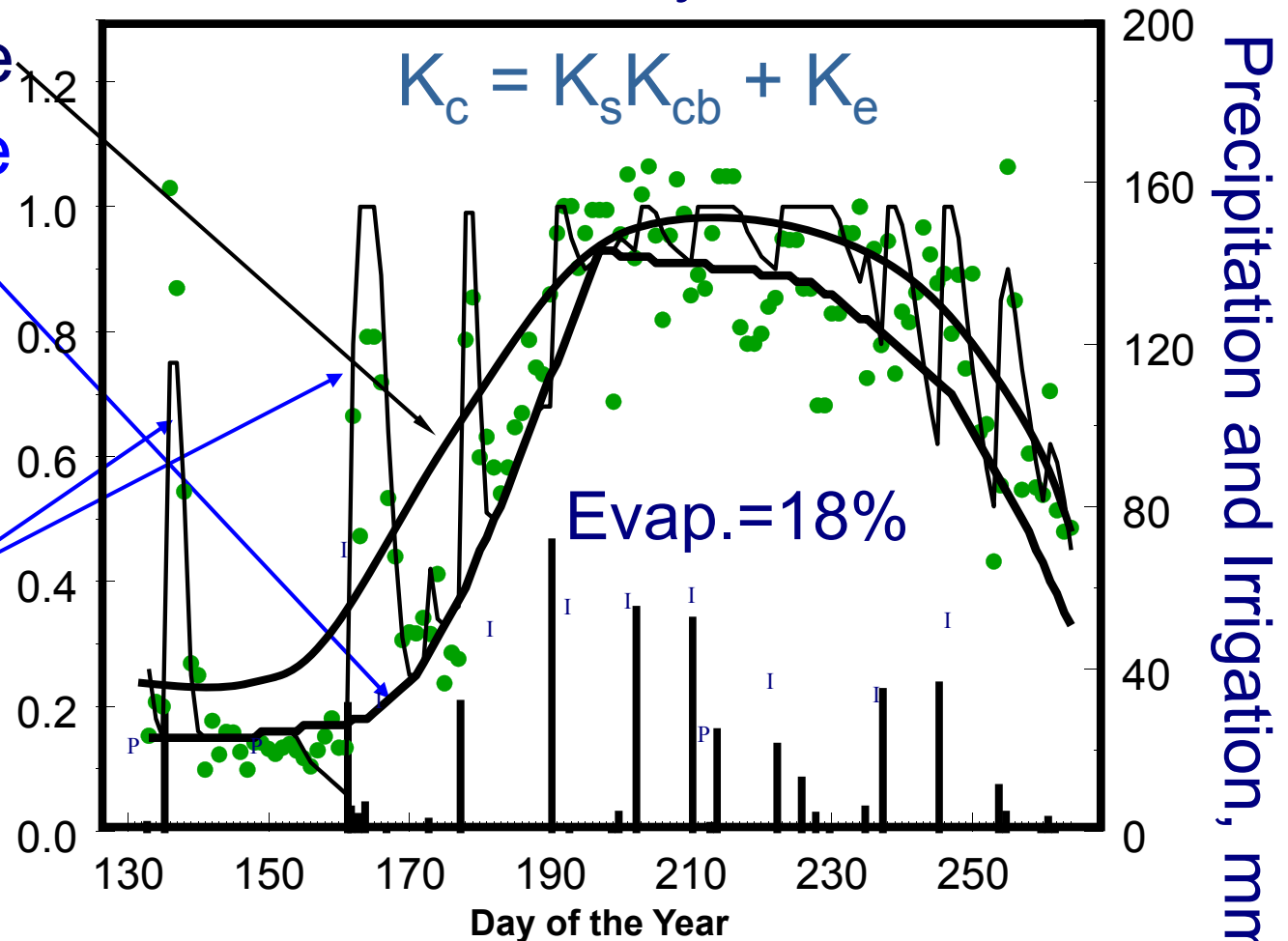
Wet Soil
Evaporation
“Spikes”
(K_e)



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)



CIGR, Bari, Italy, Sept. 10, 2013
 data courtesy of Dr. J.L. Wright, USDA-ARS

'Dual' K_c Procedure

$$\frac{ET}{ET_{ref}}$$

$$K_c = K_s K_{cb} + K_e$$

K_s = water stress (0 - 1)

K_{cb} = basal K_c (*dry surface*)

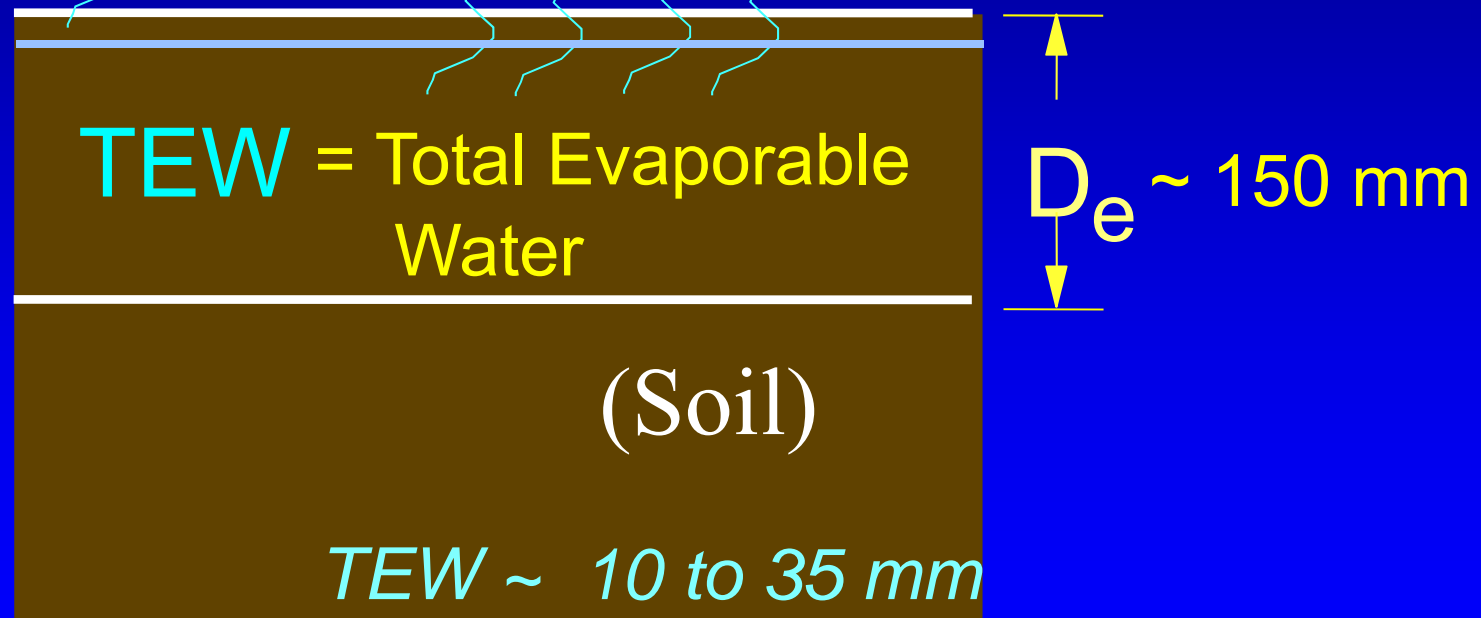
K_e = evaporation coefficient

Evaporation Coefficient - K_e

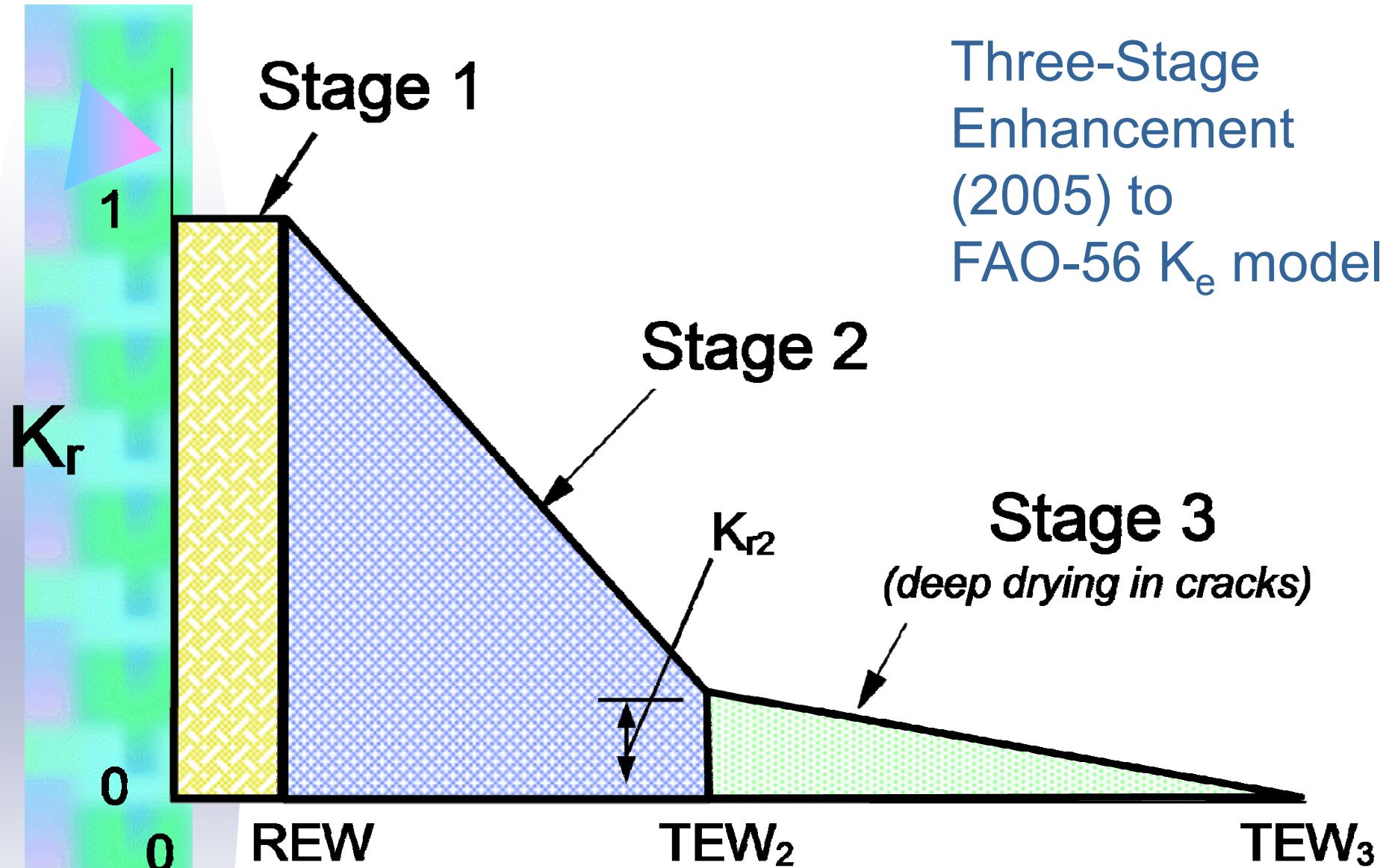
FAO-56 Simple Drying Function

$$E_s = K_e ET_{ref}$$

Skin Evaporation
(Allen, 2011)



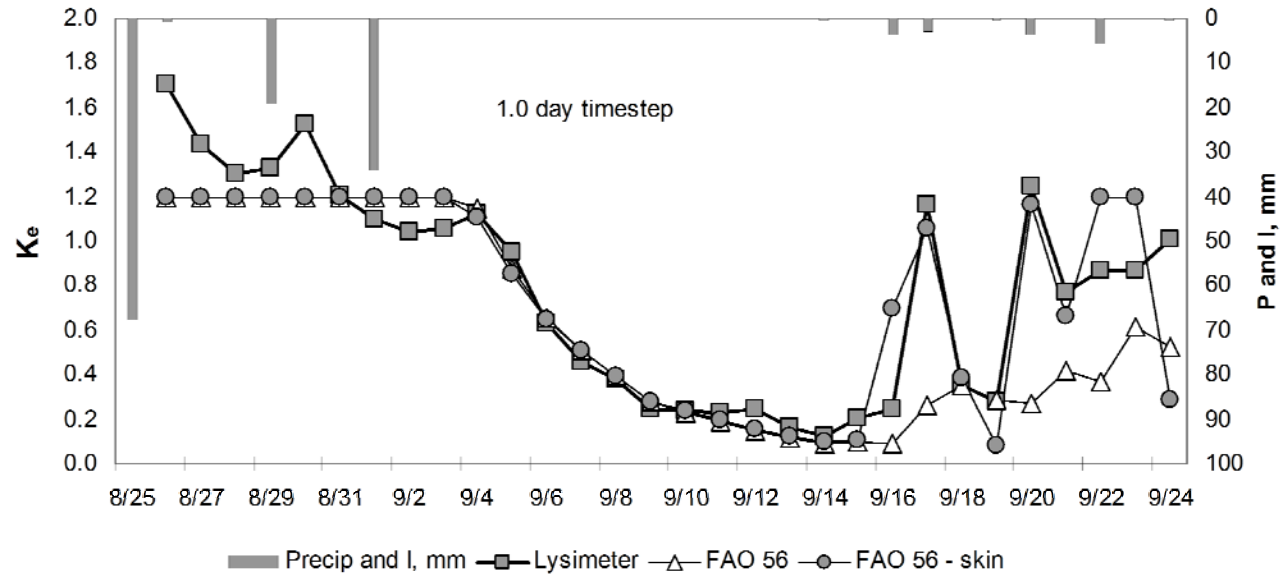
Three-Stage
Enhancement
(2005) to
FAO-56 K_e model



D_e cumulative depth of evaporation

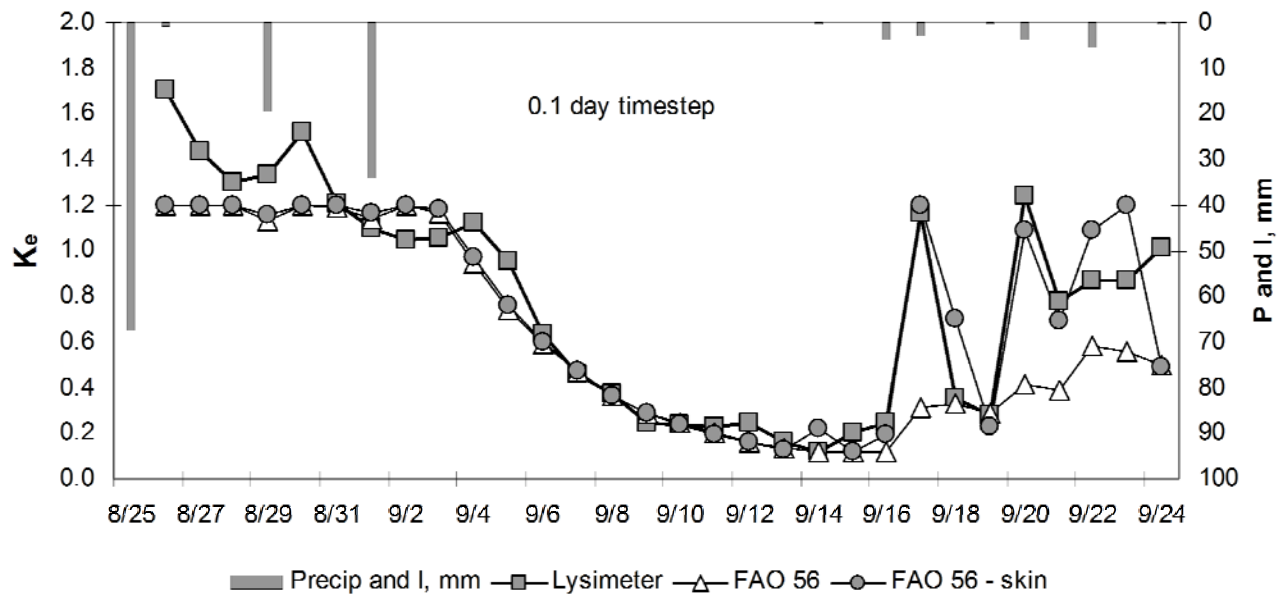
CIGR, Bari, Italy, Sept. 10, 2015

Skin Evaporation Enhancement (2011) to FAO-56 K_e model



FAO-56 K_e
model vs.
Kimberly
Lysimeter

– Bare Soil



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



Why Apply the Dual K_c method for estimating water depletion?

- Advantages

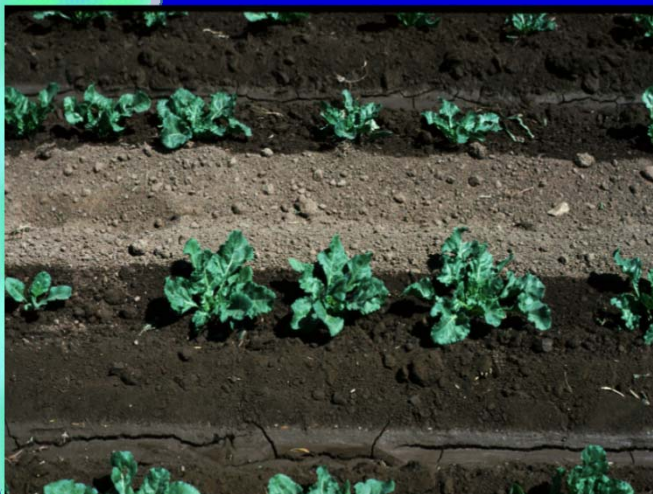
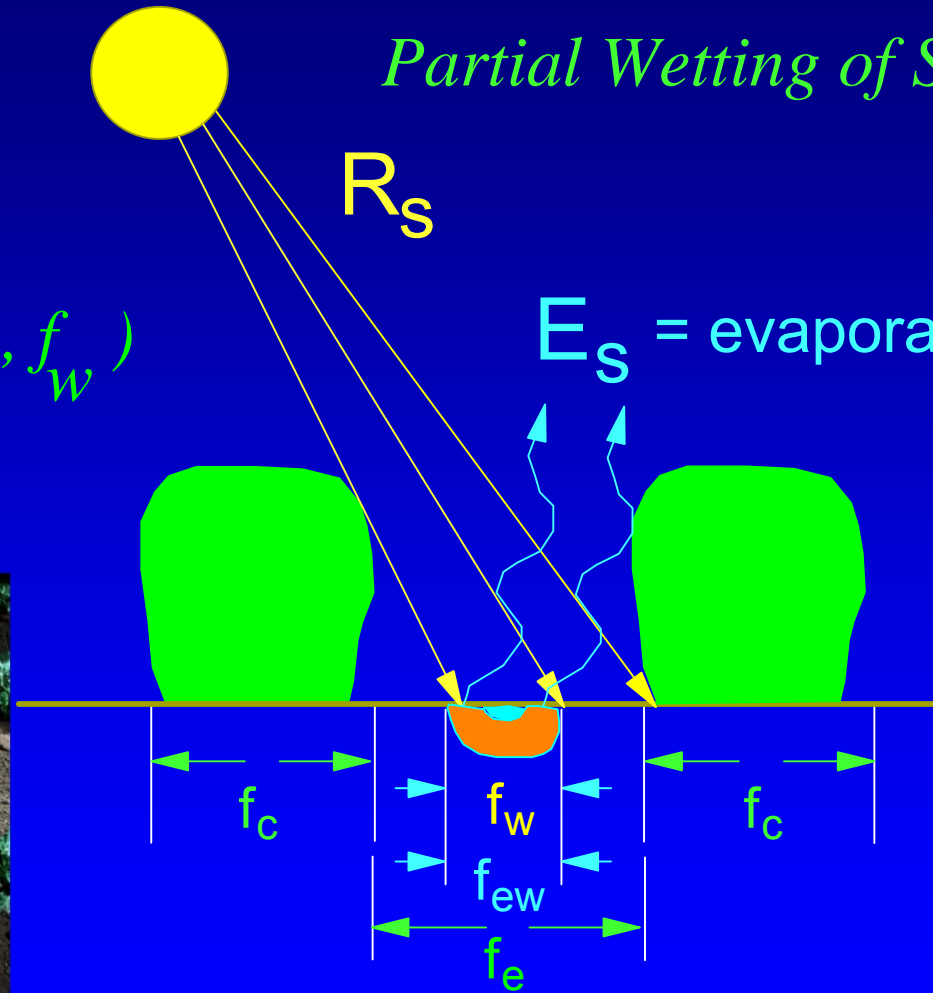
- K_c value varies with wetting frequency
- K_c estimates can be made during wintertime when process is only evaporation from soil

Partial Surface Wetting/Drying

Partial Wetting of Surface

$$f_{ew} = \min(1 - f_c, f_w)$$

E_s = evaporation

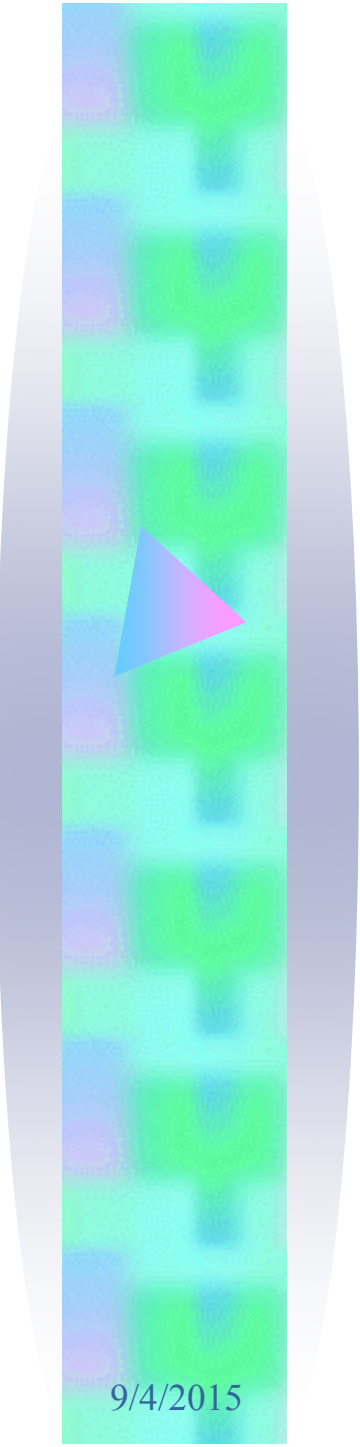




Some Example Applications of the FAO-56 Dual Kc Method in the United States

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INOVAGRI, Fortaleza, Brazil, Aug. 31, 2015



Comparison of Aggregated Estimates against ET from Irrigation Scheme-wide Water Balance

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Imperial Irrigation District:
Aggregated FAO-56 vs. ET by Water
Balance ~ 200,000 irrigated ha



9/4/2015



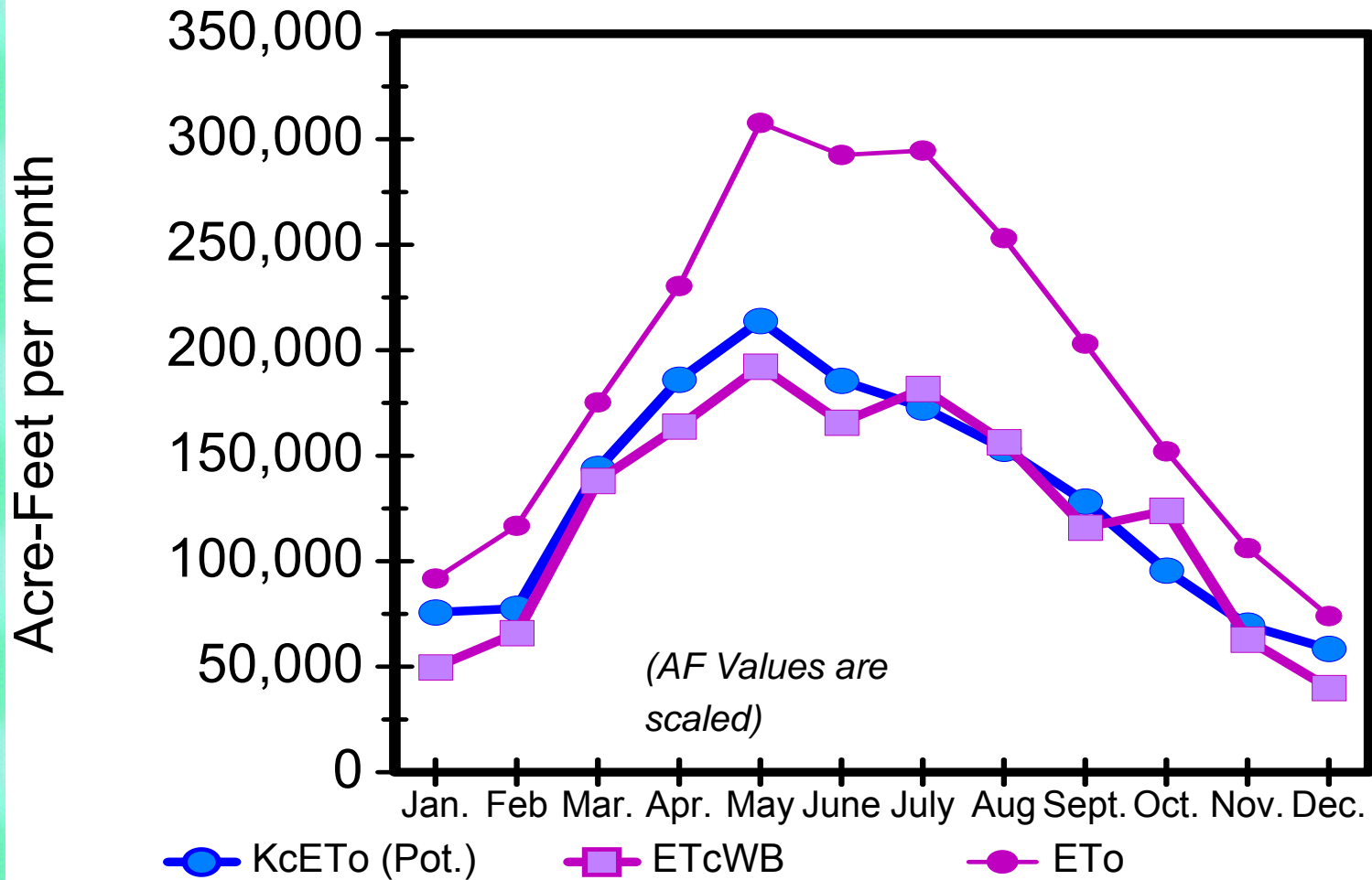
Water Balance of the Imperial Project

$$\text{ET} = \text{Inflow} - \text{Surface Outflow} \\ + \text{Precipitation} \\ - \Delta \text{Soil Water} \\ - \text{Deep Percolation}$$

- accuracy of annual ET from the Imperial Valley water balance is +/- 5% (95% C.I.)

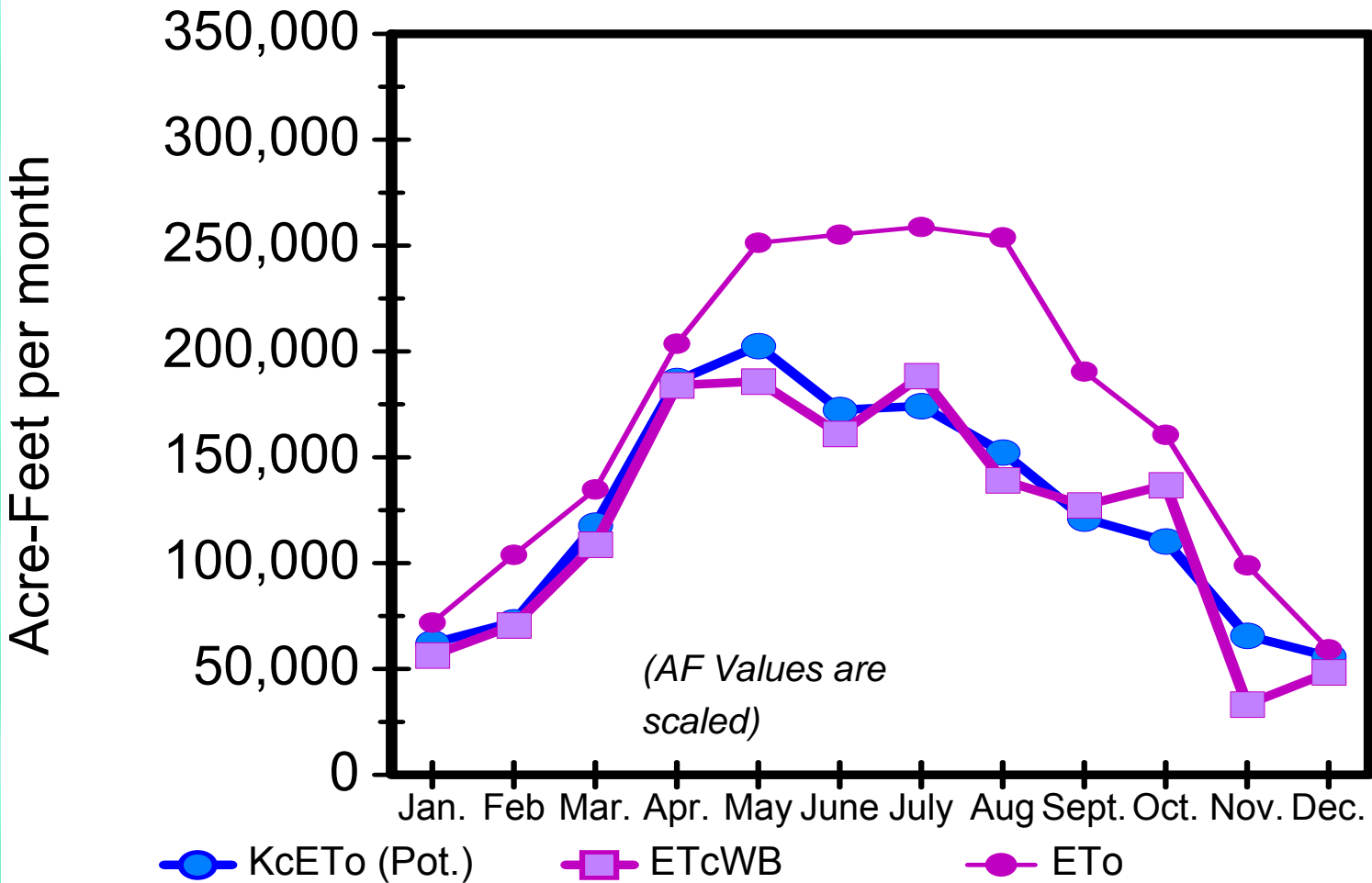
-- Used FAO-56 Grass Reference ETo and Linear $K_{cb} + K_e$

Total Project Evapotranspiration 1990



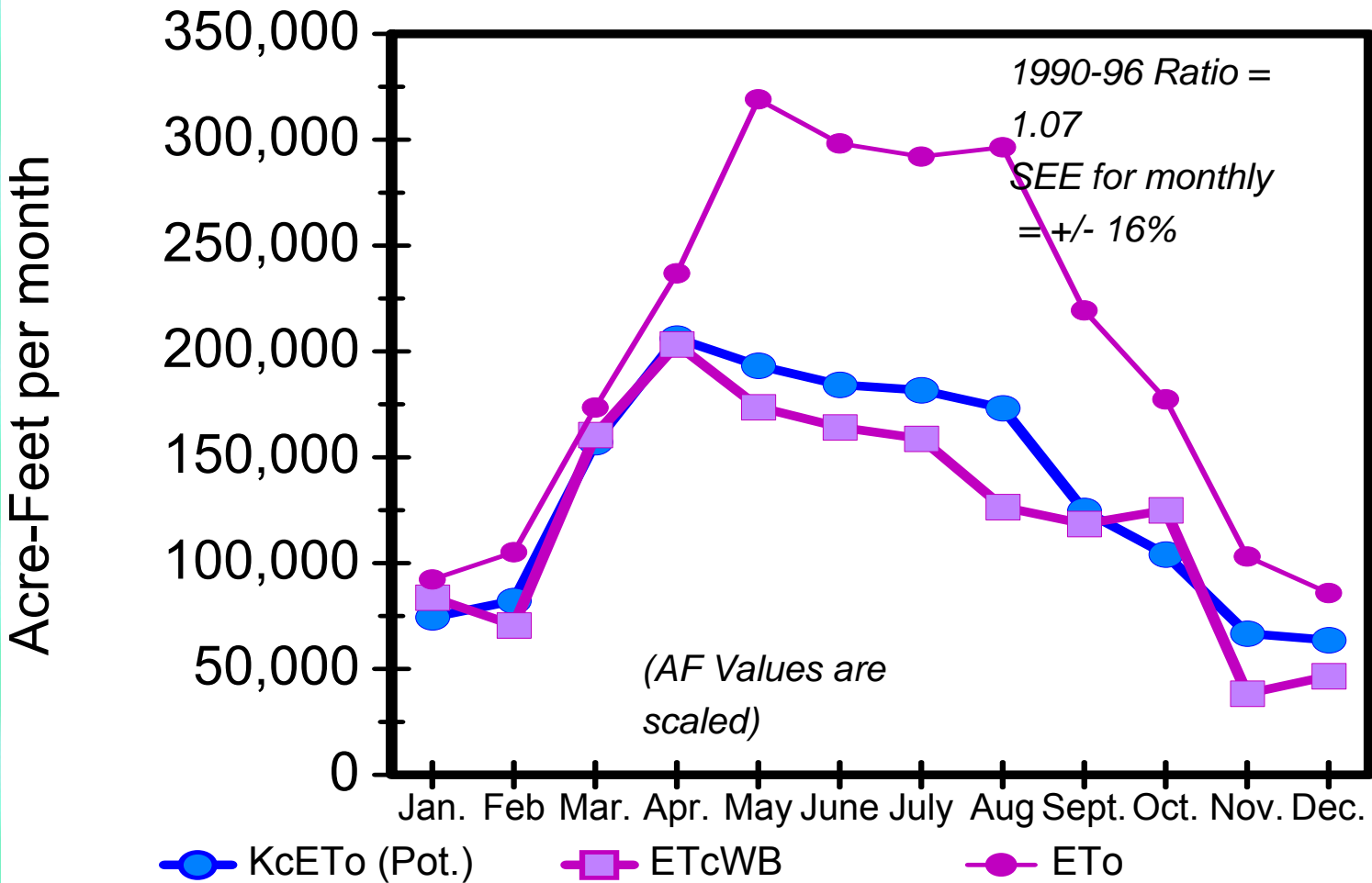


Total Project Evapotranspiration 1991





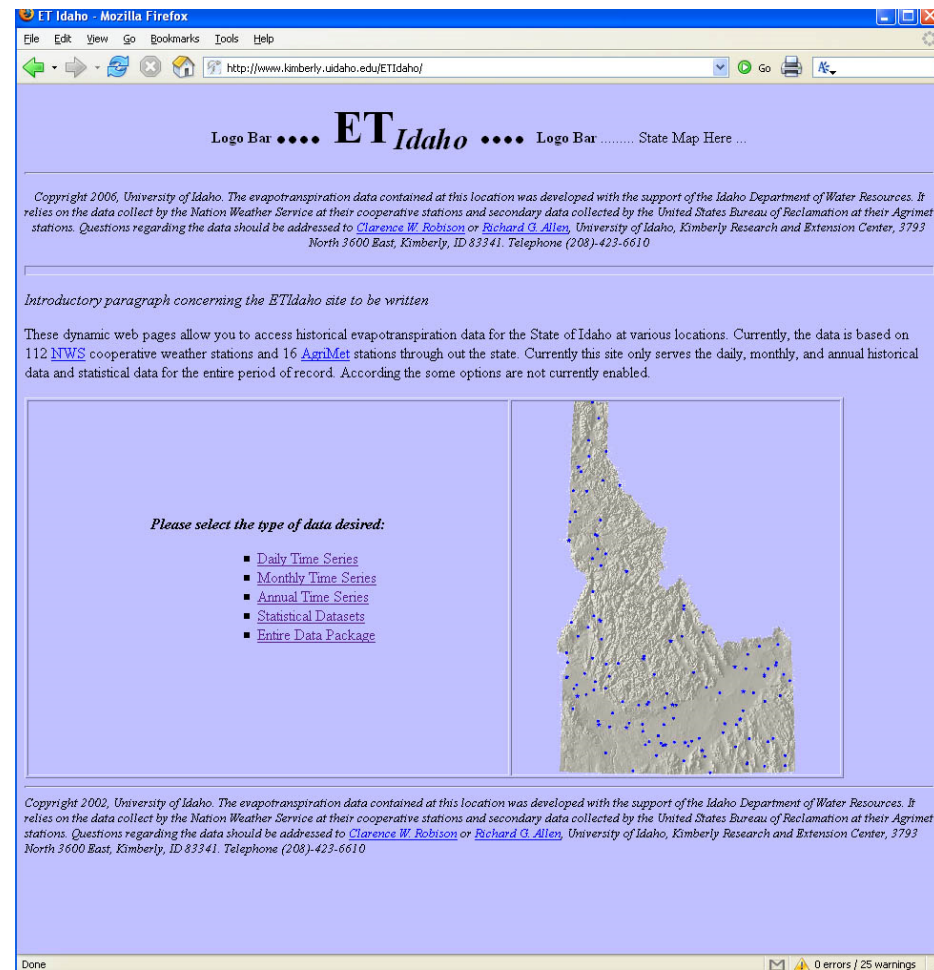
Total Project Evapotranspiration 1996



ET-Idaho – ET and Irrigation Water Requirements for the State of Idaho -- FAO-56 Dual K_c Basis

Operated
365
days/year

120
locations

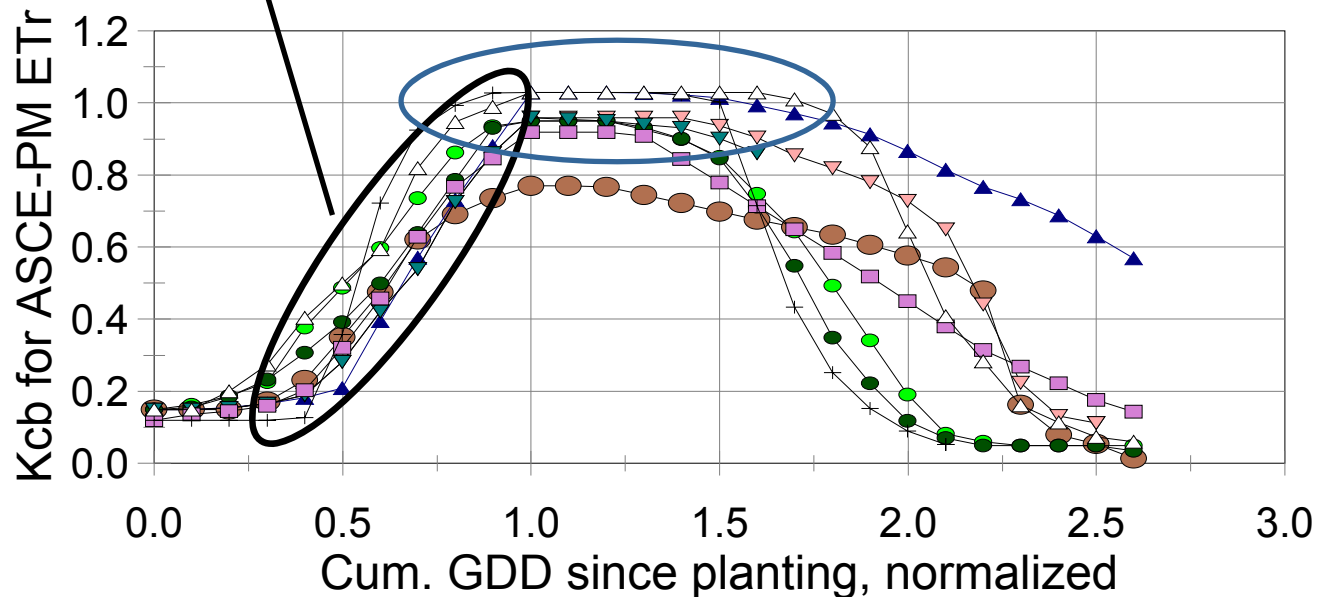


The screenshot shows a web browser window titled "ET Idaho - Mozilla Firefox" with the address bar displaying "http://www.kimberly.uidaho.edu/ETIdaho/". The website has a blue header with the "ET Idaho" logo and a "State Map Here ..." link. Below the header is a copyright notice for 2006, University of Idaho, and an introductory paragraph. A section titled "Please select the type of data desired:" contains a list of links: "Daily Time Series", "Monthly Time Series", "Annual Time Series", "Statistical Datasets", and "Entire Data Package". To the right of this list is a map of Idaho with numerous blue dots representing data collection locations. A second copyright notice is visible at the bottom of the page content.

Cumulative Growing Degree Days used to Estimate Kc Development. Using CGDD creates some similarity in the K_{cb} shape

Basal Kcb for the ASCE PM ETr Method

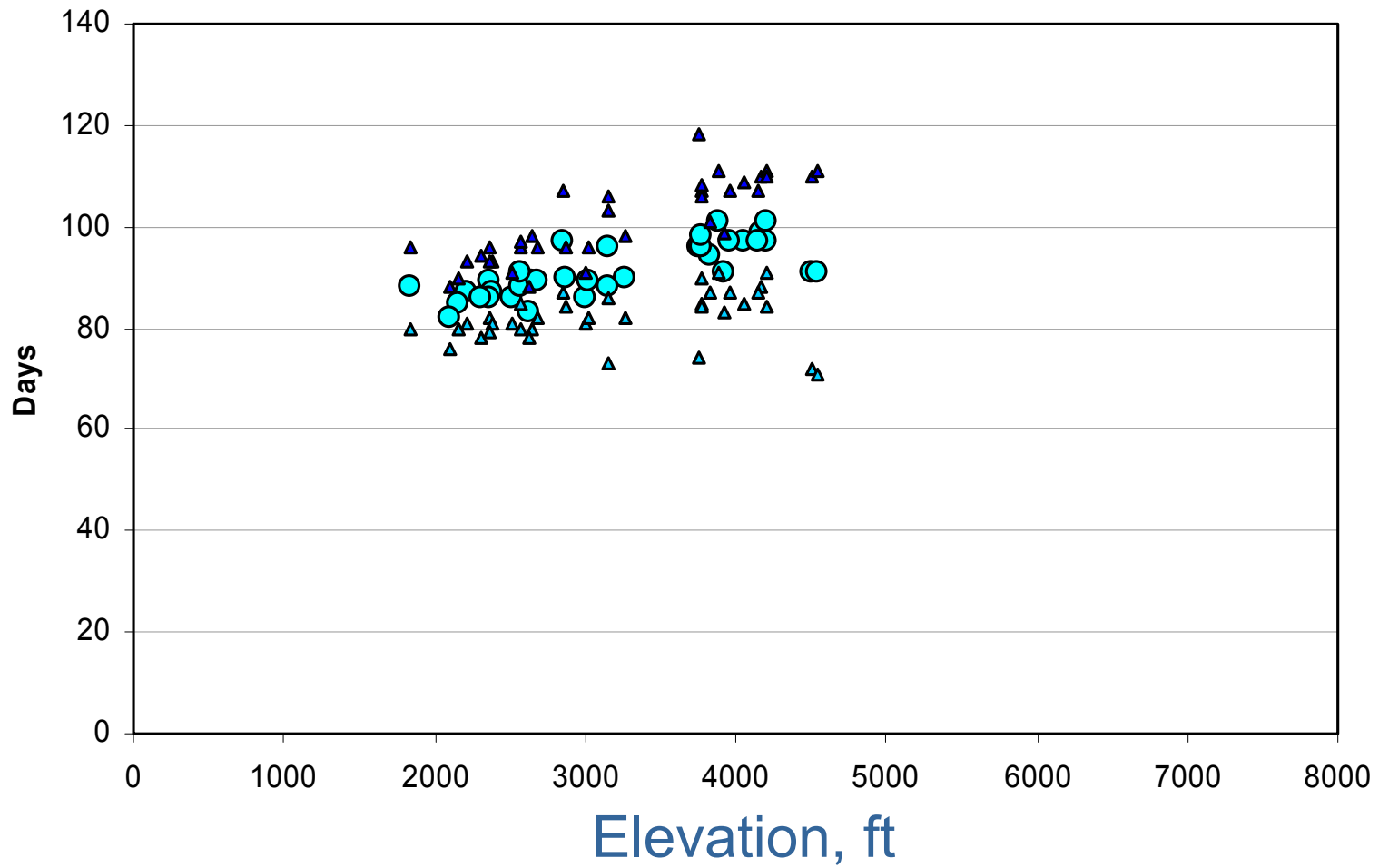
based on Kimberly Lys., Wright(1982)



- Potatoes 1972
 - Beans 1973
 - Beans 1974
 - ▲— Sugar Beets 1975
 - ▼— Field Corn 1976
 - ▼— Sweet Corn 1976
 - Peas
- Used Alfalfa Reference ET_r and Curvilinear $K_{cb} + K_e$

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

Season Length, Dry Beans - seed

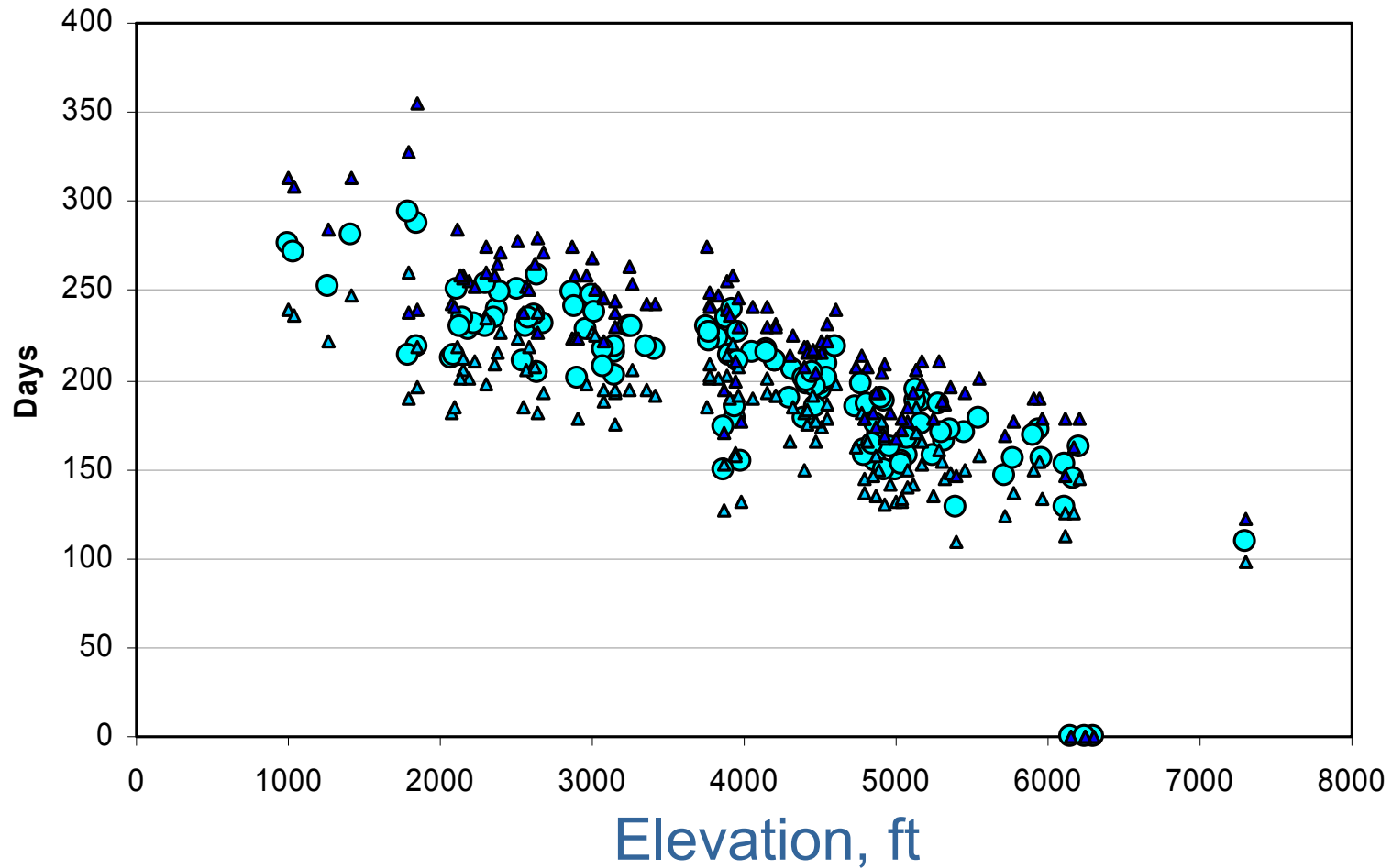


● Season mean ▲ mean - S.D. ▲ mean + S.D.

Alfalfa Season Lengths vs. Elevation across Idaho

Thermal-estimated Start and Frost Ended

Season Length, Alfalfa Hay

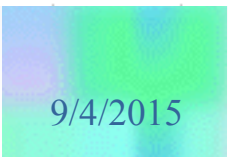
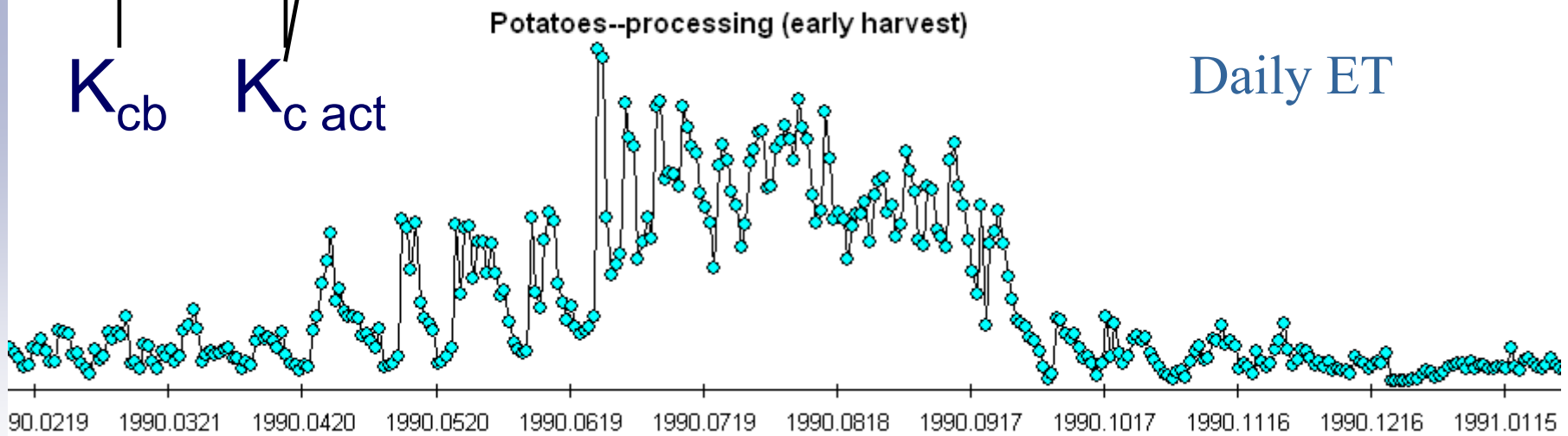
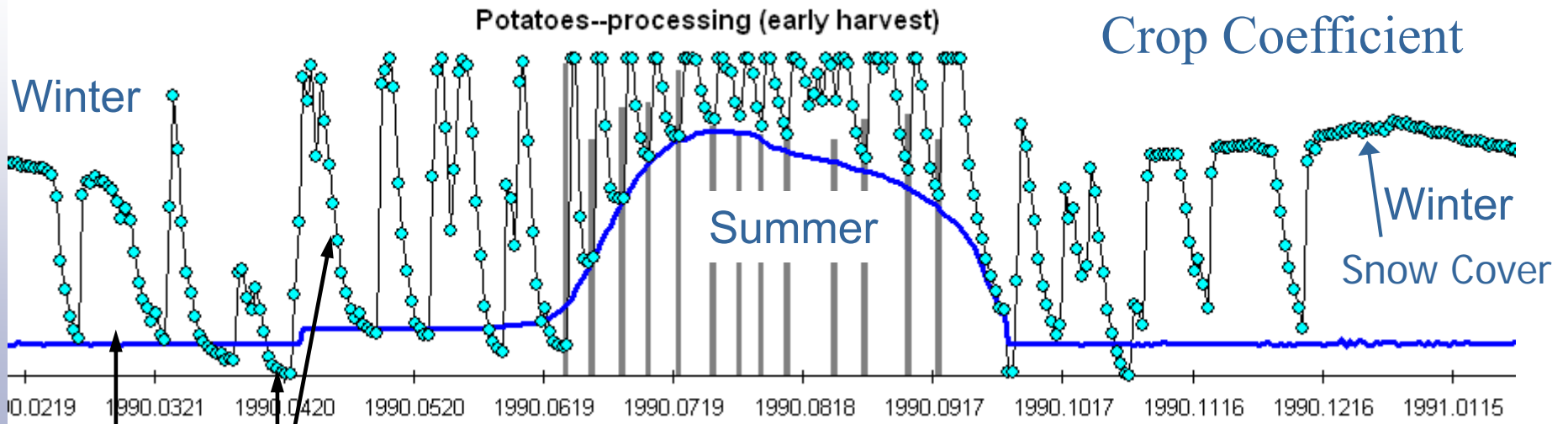


● Season mean ▲ mean - S.D. ▲ mean + S.D.



Operated 365 days/year

Ashton, 1990 calendar year -- Potatoes

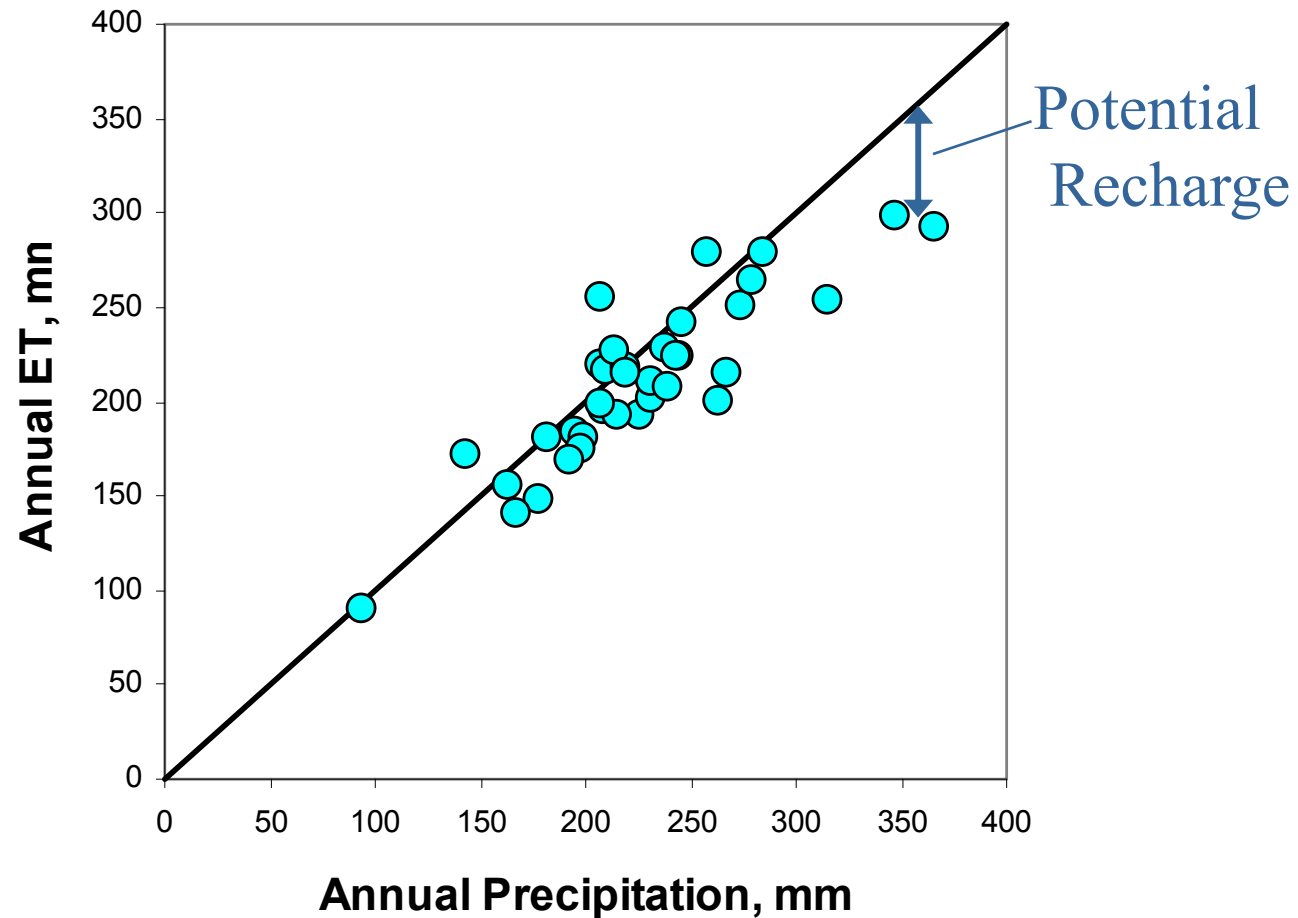


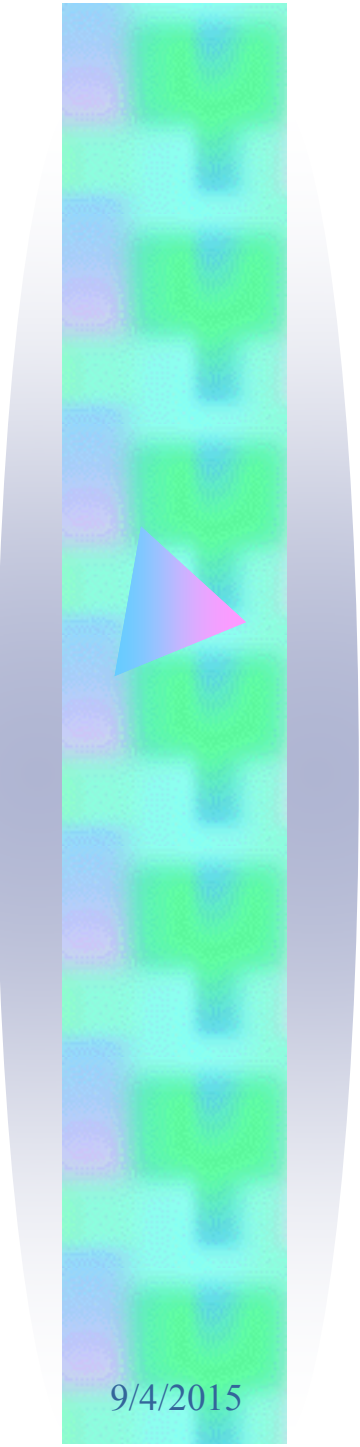
9/4/2015

$$K_{c act} = (K_s K_{cb} + K_e) \quad (\text{and } ET_{c act} = K_{c act} ET_r)$$

Annual ET vs. Precipitation - Desert

Salmon, Idaho 1930-1967 - Sagebrush





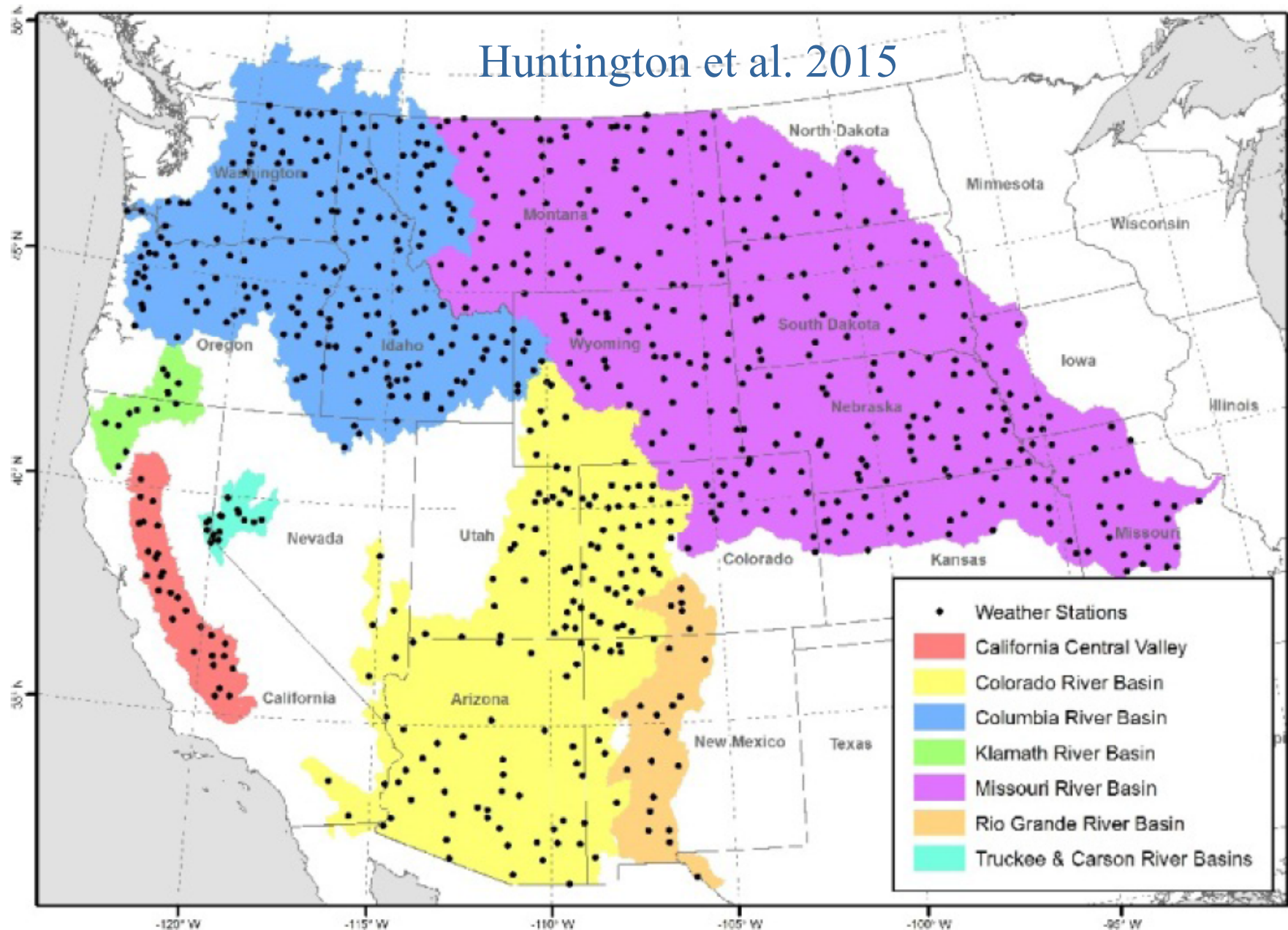
Projection of Impacts of Climate Change on ET and Net Irrigation Water Requirements

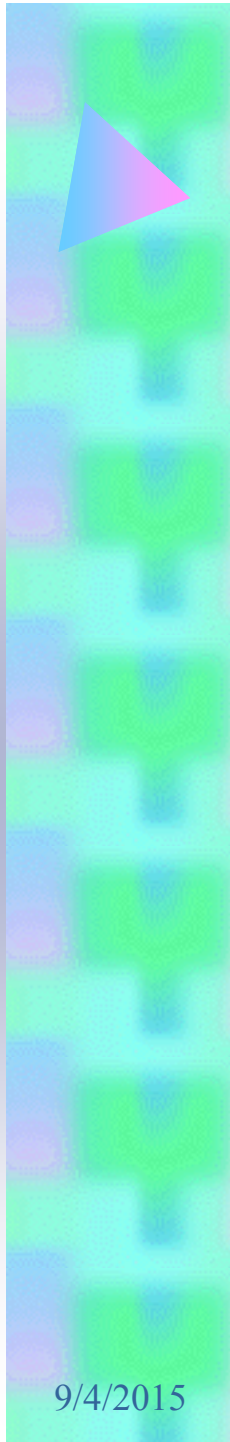
9/4/2015

INOVAGRI, Fortaleza, Brazil, Aug. 31, 2015

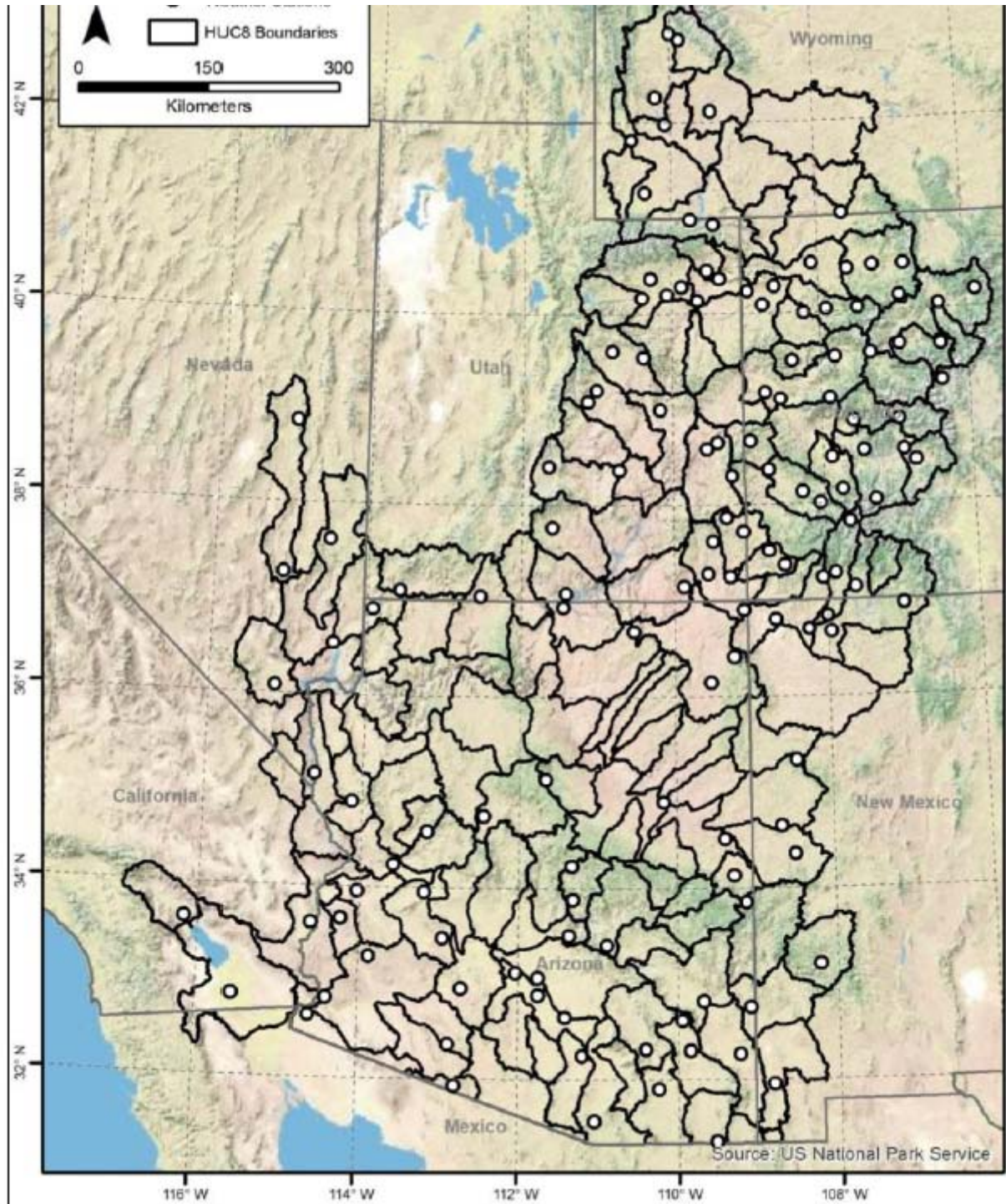
West-Wide Climate Risk Assessment – Seven Major River Basins – US Bureau of Reclamation, DRI, UI

Huntington et al. 2015





9/4/2015



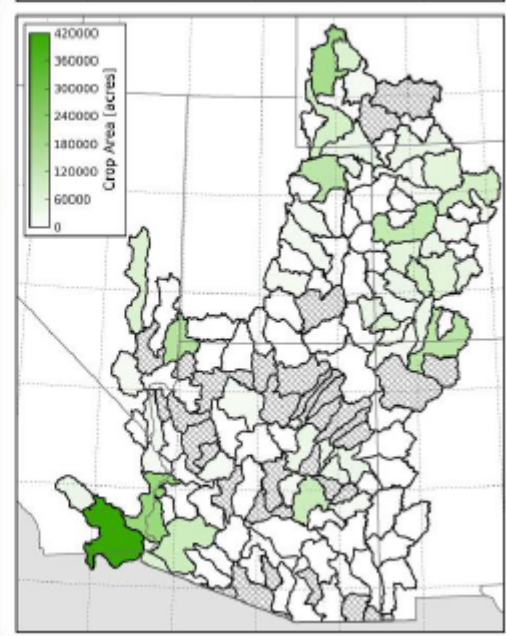
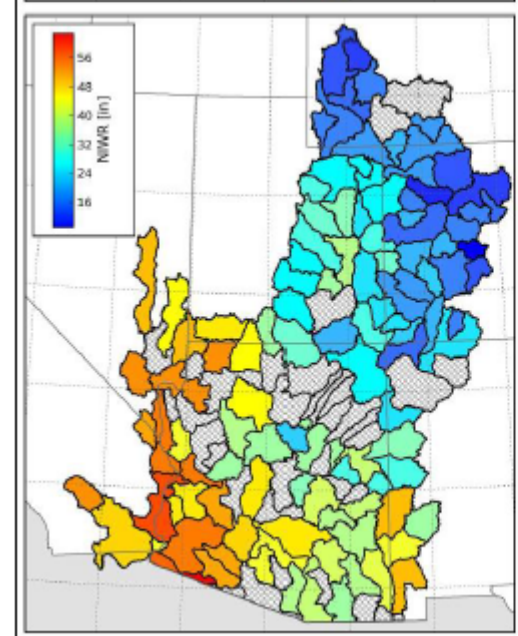
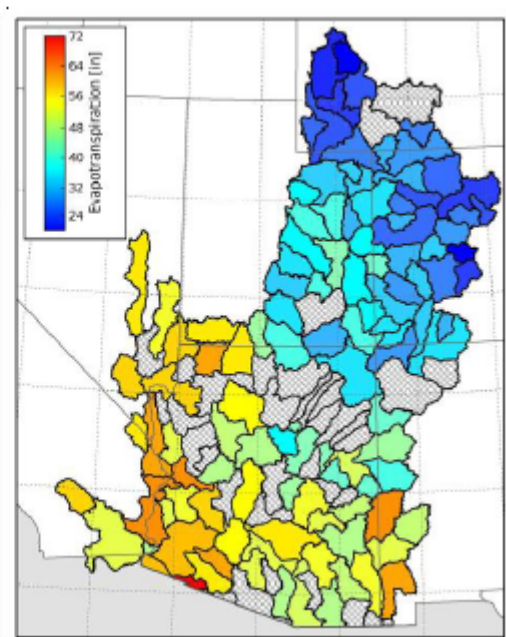
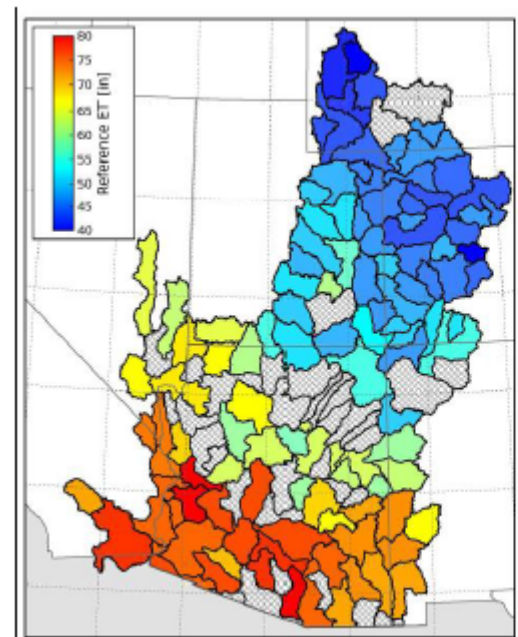
Colorado River Basin



ET_{ref}

Net Irrigation Water Requirement (NIWR)

9/4/2015



ET_{crop}

Baseline Values in the Basin

Distribution of Irrigation

CIGR, Bari, Italy, Sept. 10, 2013

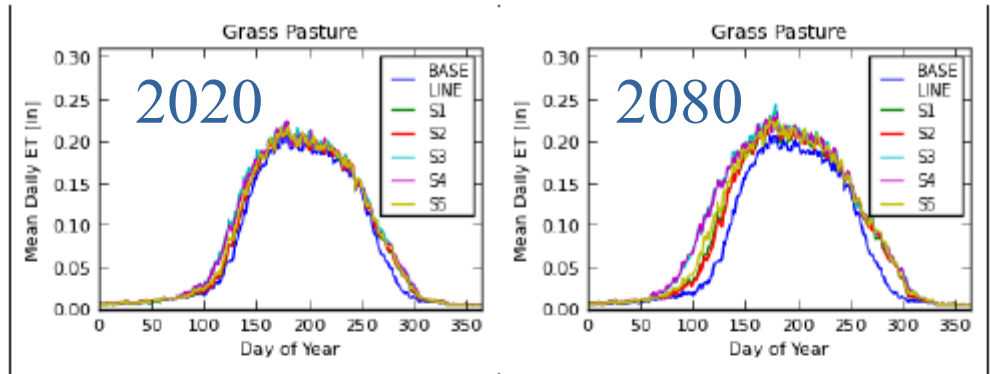


Figure 20.—Colorado River Basin – COOP station WY6555 (Mountain View, WY). Baseline and projected mean daily grass pasture evapotranspiration for all scenarios and for time periods 2020 (left) and 2080 (right).

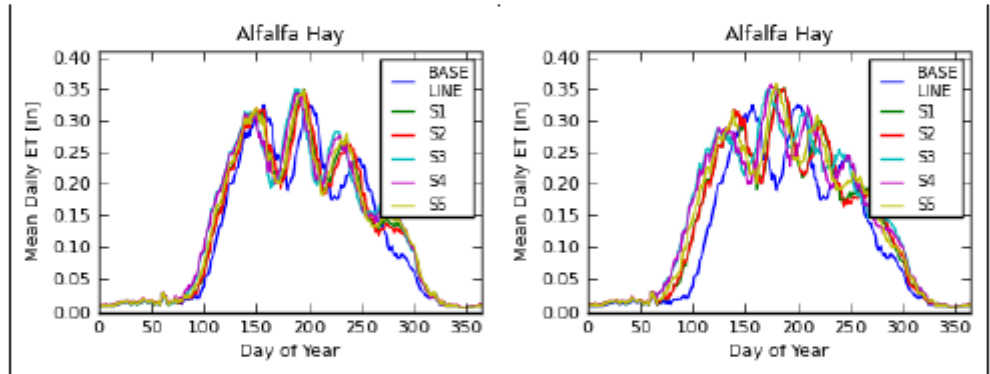
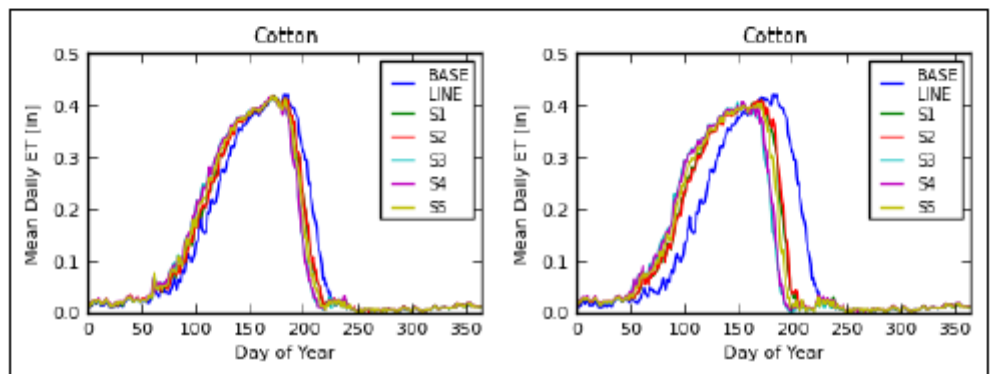


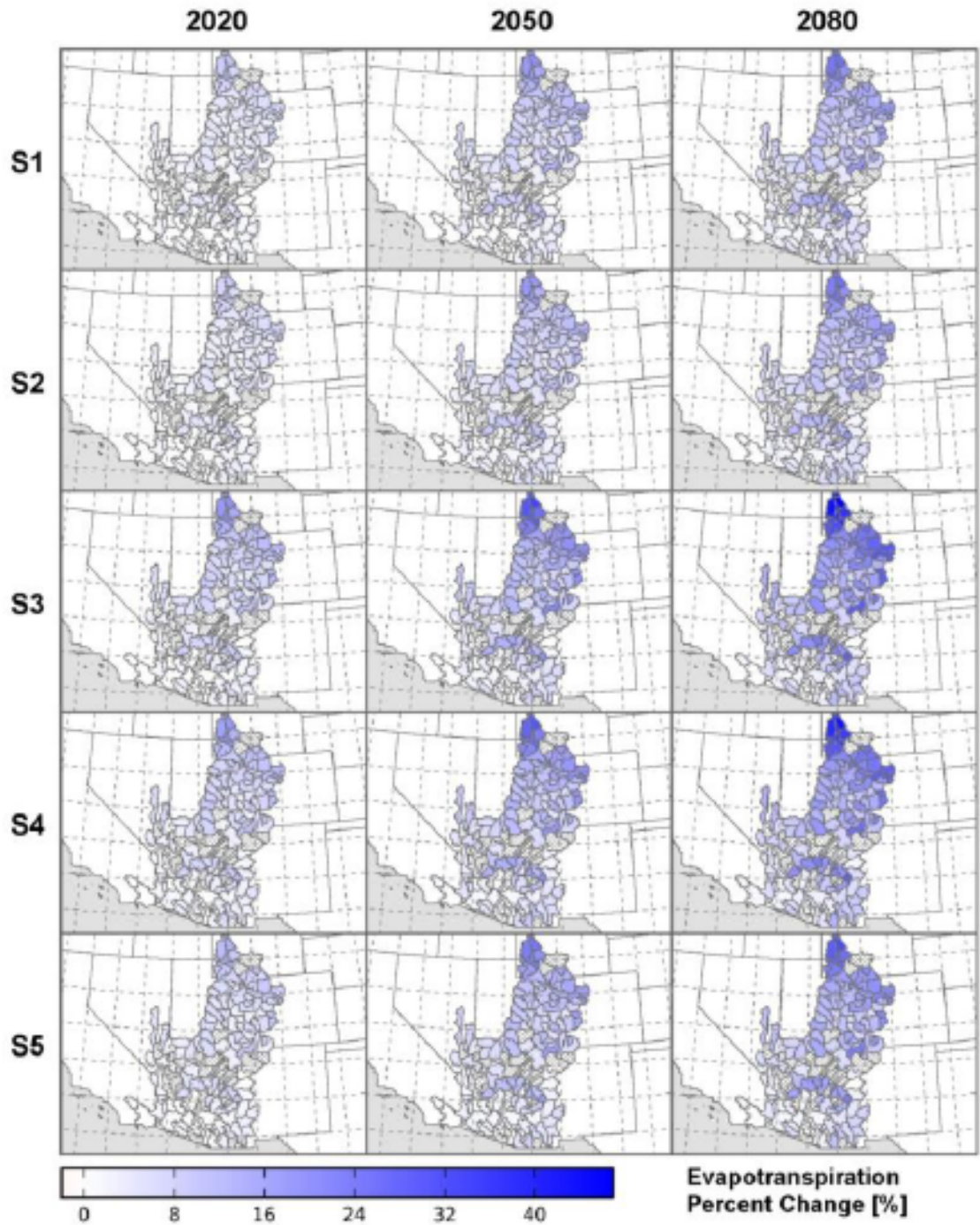
Figure 21.—Colorado River Basin – COOP station UT5969 (Myton, UT). Baseline and projected mean daily alfalfa evapotranspiration for all scenarios and for time periods 2020 (left) and 2080 (right).



Shifts in ET

-- Kc curves were a function of thermal units

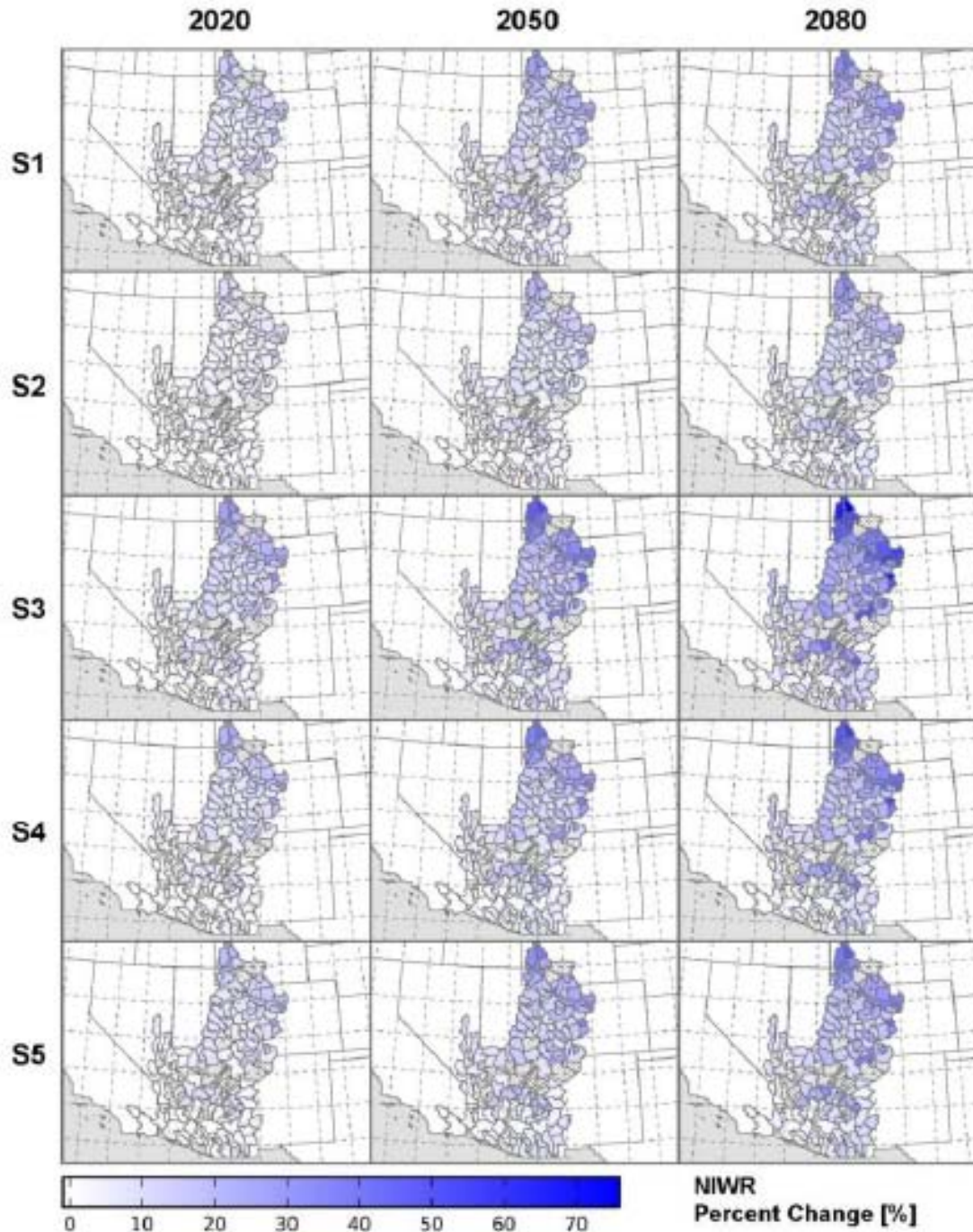
- S1 – warmer, drier
- S2 – warmer, wetter
- S3 – hotter, drier
- S4 – hotter, wetter
- S5 – central tendency



Percent Change
in **ET**

--- using FAO-56
Dual Kc Method

- S1 – warmer, drier
- S2 – warmer, wetter
- S3 – hotter, drier
- S4 – hotter, wetter
- S5 – central tendency



Percent Change
in **Net Irrigation
Water
Requirement**

--- using FAO-56
Dual Kc Method

- S1 – warmer, drier
- S2 – warmer, wetter
- S3 – hotter, drier
- S4 – hotter, wetter
- S5 – central tendency

, 2015

Mead, Nebraska –

Comparison with Eddy Covariance

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



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/>

Spreadsheet interface showing input parameters, calculations, and two graphs for a Mead Dryland Site, 2007, Kcb = 1.00.

Input Parameters:

- Root growth = 60 d, Root start = 165 DoY, MADini = 60, MAD = 60%
- Rootmin = 0.20 m, Rootmax = 2.0 m, AW = 170 mm/m
- Stress allow = 0 (no. 1) days
- Midseas. Av. RH = 85%
- Midseas. Av. Wind Speed = 1.00 m/s
- Initial D₀ = 5 mm
- Initial f_w = 1

Graphs:

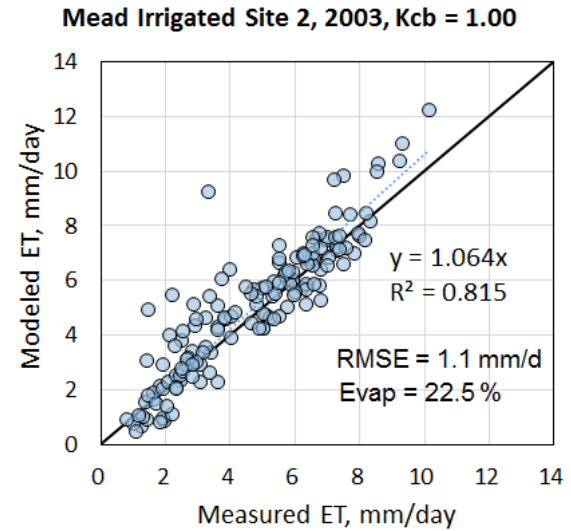
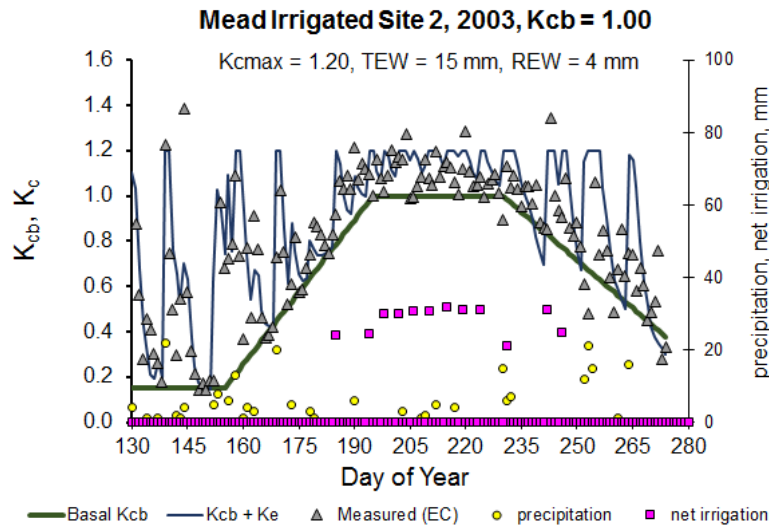
- Left Graph:** K_{cb}, K_c vs Day of Year. Shows Basal K_{cb}, K_{cb} + K_e, Measured (EC), and precipitation. Root growth is indicated by a shaded area.
- Right Graph:** Modeled ET, mm/day vs Measured ET, mm/day. Shows a scatter plot with a regression line $y = 1.007x$, $R^2 = 0.482$, and RMSE = 1.43 mm/d. Evap = 19.8%.

Table 1: Daily Data (Days 130-168)

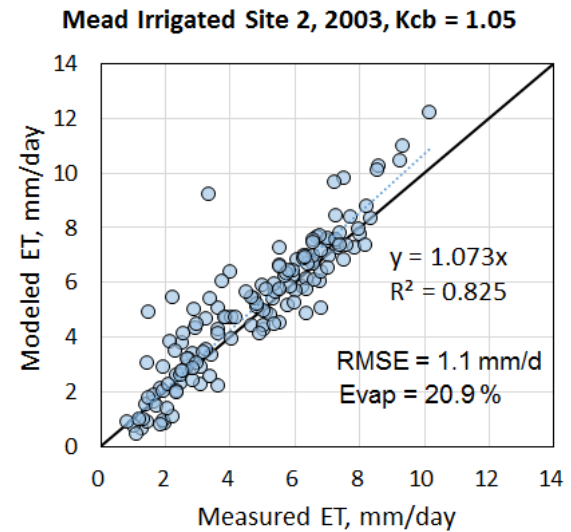
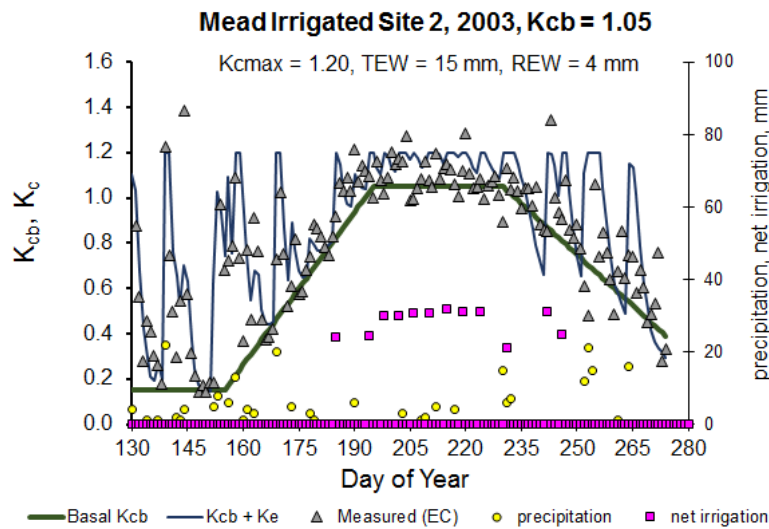
Day	Year	J	ET _r (mm/d)	P - PD (mm)	Height (m)	K _{cb}	K _c	f _w	f _{so}	f _{so}	K _e	K _c	ET _c (mm/d)	ET _{act} (mm/d)	Root Depth (m)	RAW (mm)	Ending Deplet. (mm)	Net Irrigation (mm)	Drainage (DP) (mm)	K _c	Adjusted K _c (K _{cadj})	Corrected Ending Depletion (mm)			
130	2005	130	6.07		0.15	0.30	1.00	0.01	1.00	0.99	5.0	0.83	0.79	4.81	5.72	0.20	20.4	10.7	0.94	1.00	0.94	10.7			
131	2005	131	7.8		0.15	0.30	1.10	0.01	1.00	0.99	9.9	0.02	0.02	0.18	10.04	0.17	1.95	1.95	0.20	20.4	12.1	1.00	0.17	12.1	
132	2005	132	8.51		0.15	0.30	1.10	0.01	1.00	0.99	10.0			10.04	0.15	1.28	1.28	0.20	20.4	13.3	1.00	0.15	13.3		
133	2005	133	11.7		0.15	0.30	1.10	0.01	1.00	0.99	10.0			10.04	0.15	1.76	1.76	0.20	20.4	15.1	1.00	0.15	15.1		
134	2005	134	11.4		0.15	0.30	1.10	0.01	1.00	0.99		1.00	0.95	10.83	10.94	1.10	12.54	12.54	0.20	20.4	17.5	1.00	1.10	17.5	
135	2005	135	4.64		0.15	0.30	1.10	0.01	1.00	0.99	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	
136	2005	136	5.57		0.15	0.30	1.10	0.01	1.00	0.99	9.1	0.16	0.15	0.83	9.30	0.30	1.66	1.66	0.20	20.4	17.9	1.00	0.30	17.9	
137	2005	137			0.15	0.30	1.10	0.01	1.00	0.99				10.01	0.17	1.16	1.16	0.20	20.4	19.1	1.00	0.17	19.1		
138	2005	138			0.15	0.30	1.10	0.01	1.00	0.99	0.15	1.46			10.01	0.15	1.44	1.44	0.20	20.4	20.5	0.99	0.15	20.5	
139	2005	139			0.15	0.30	1.10	0.01	1.00	0.99	0.15	1.27			10.01	0.15	1.27	1.27	0.20	20.4	21.8	0.90	0.13	21.7	
140	2005	140			0.15	0.30	1.10	0.01	1.00	0.99	0.15	1.27			10.01	0.15	1.27	1.27	0.20	20.4	22.9	0.81	0.12	22.7	
141	2005	141			0.15	0.30	1.10	0.01	1.00	0.99	0.15	1.49			10.01	0.15	1.49	1.49	0.20	20.4	24.2	0.72	0.11	23.8	
142	2005	142			0.15	0.30	1.10	0.01	1.00	0.99	1.15	1.08			9.99	0.19	1.15	1.08	0.20	20.4	24.7	0.69	0.14	24.4	
143	2005	143			0.15	0.30	1.10	0.01	1.00	0.99	3.71	1.10	4.26		4.26	0.20	20.4	4.26	0.20	20.4	18.2	1.00	1.10	18.2	
144	2005	144			0.15	0.30	1.10	0.01	1.00	0.99	4.56	1.10	5.23		5.23	0.20	20.4	-0.2	0.20	20.4	10.0	1.00	1.10	0.0	
145	2005	145			0.15	0.30	1.10	0.01	1.00	0.99	8.91	1.01	4.94		4.94	0.20	20.4	4.9		20.4	4.9	1.00	1.01	4.9	
146	2005	146			0.15	0.30	1.10	0.01	1.00	0.99	7.67	1.02	3.69		3.69	0.20	20.4	4.3		20.4	4.3	1.00	1.02	4.3	
147	2005	147			0.15	0.30	1.10	0.01	1.00	0.99	9.14	0.96	2.33		2.33	0.20	20.4	6.4		20.4	6.4	1.00	0.96	6.4	
148	2005	148			0.15	0.30	1.10	0.01	1.00	0.99	9.64	0.33	1.37		1.37	0.20	20.4	7.5		20.4	7.5	1.00	0.33	7.5	
149	2005	149			0.15	0.30	1.10	0.01	1.00	0.99	9.44	1.01	5.68		5.68	0.20	20.4	9.1		20.4	9.1	1.00	1.01	9.1	
150	2005	150			0.15	0.30	1.10	0.01	1.00	0.99	9.38	0.36	1.20		1.20	0.20	20.4	8.5		20.4	8.5	1.00	0.36	8.5	
151	2005	151			0.15	0.30	1.10	0.01	1.00	0.99	5.00	1.10	5.73		5.73	0.20	20.4	0.3		20.4	0.3	1.00	1.10	0.3	
152	2005	152			0.15	0.30	1.10	0.01	1.00	0.99	7.98	0.94	3.51		3.51	0.20	20.4	3.8		20.4	3.8	1.00	0.94	3.8	
153	2005	153			0.15	0.30	1.10	0.01	1.00	0.99	6.39	1.10	4.58		4.58	0.20	20.4	2.8		20.4	2.8	1.00	1.10	2.8	
154	2005	154			0.15	0.30	1.10	0.01	1.00	0.99	9.77	1.04	6.26		6.26	0.20	20.4	7.0		20.4	7.0	1.00	1.04	7.0	
155	2005	155			0.15	0.30	1.10	0.01	1.00	0.99	8.28	1.10	7.32		7.32	0.20	20.4	6.5		20.4	6.5	1.00	1.10	6.5	
156	2005	156			0.15	0.30	1.10	0.01	1.00	0.99	9.99	0.42	2.63		2.63	0.20	20.4	9.1		20.4	9.1	1.00	0.42	9.1	
157	2005	157			0.15	0.30	1.10	0.01	1.00	0.99	10.01	0.15	1.84		1.84	0.20	20.4	11.0		20.4	11.0	1.00	0.15	11.0	
158	2005	158			0.15	0.30	1.10	0.01	1.00	0.99	10.01	0.17	1.93		1.93	0.20	20.4	12.9		20.4	12.9	1.00	0.17	12.9	
159	2005	159			0.15	0.30	1.10	0.01	1.00	0.99	10.01	0.20	1.49		1.49	0.20	20.4	14.4		20.4	14.4	1.00	0.20	14.4	
160	2005	160			0.15	0.30	1.10	0.01	1.00	0.99	10.01	0.22	1.91		1.91	0.20	20.4	16.3		20.4	16.3	1.00	0.22	16.3	
161	2005	161			0.15	0.30	1.10	0.01	1.00	0.99	10.01	0.25	1.87		1.87	0.20	20.4	18.2		20.4	18.2	1.00	0.25	18.2	
162	2005	162			0.15	0.30	1.10	0.01	1.00	0.99	10.01	0.27	1.89		1.89	0.20	20.4	19.8		20.4	19.8	1.00	0.27	19.8	
163	2005	163			0.15	0.30	1.10	0.01	1.00	0.99	10.01	0.30	1.85		1.85	0.20	20.4	21.7		20.4	21.7	0.91	0.27	21.5	
164	2005	164			0.15	0.30	1.10	0.01	1.00	0.99	10.01	0.30	1.85		1.85	0.20	20.4	2.5		20.4	2.5	1.00	1.10	2.5	
165	2005	165			0.15	0.30	1.10	0.01	1.00	0.99	10.01	0.30	1.85		1.85	0.20	20.4	2.5		20.4	2.5	1.00	1.10	2.5	
166	2005	166			0.15	0.30	1.10	0.01	1.00	0.99	4.2	0.96	0.70	4.44	5.43	4.24	1.10	5.45	5.45	0.20	20.4	11	1.00	1.10	11
167	2005	167			0.15	0.30	1.10	0.01	1.00	0.99	9.36	1.07	6.76		6.76	0.23	23.5	7.8		20.4	107	1.00	1.07	107	
168	2005	168			0.15	0.30	1.10	0.01	1.00	0.99	9.97	0.47	3.24		3.24	0.26	26.5	11.1		20.4	111	1.00	0.47	111	
169	2005	169			0.15	0.30	1.10	0.01	1.00	0.99	10.00	0.42	3.13		3.13	0.29	29.6	14.2		20.4	142	1.00	0.42	142	

Modified here to use Alfalfa Reference

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

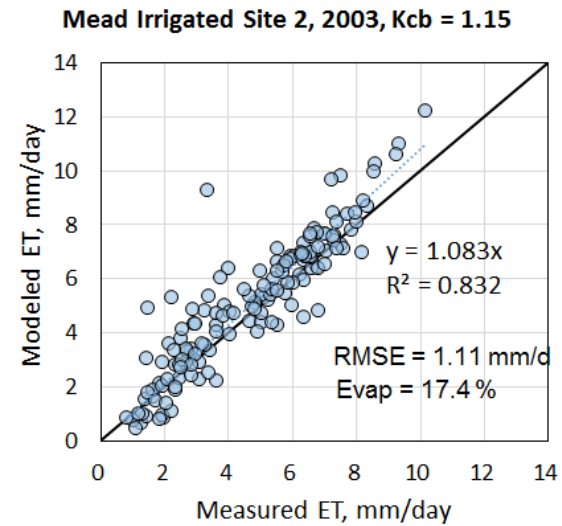
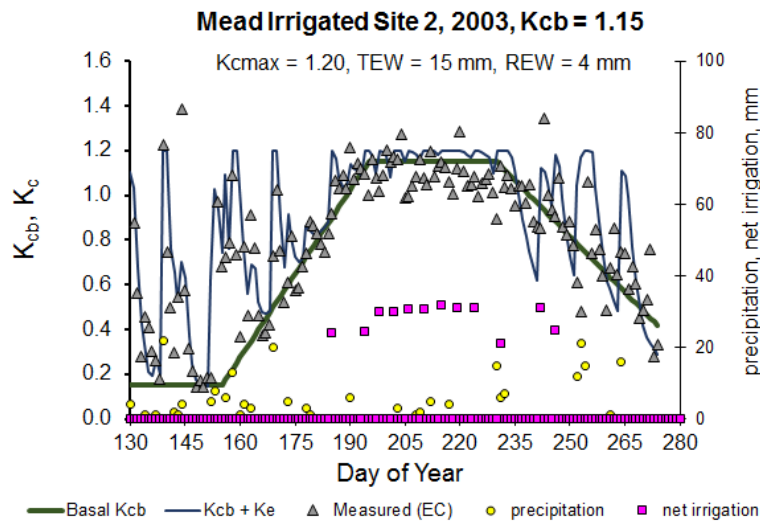


$K_{cb\ mid} = 1.00$

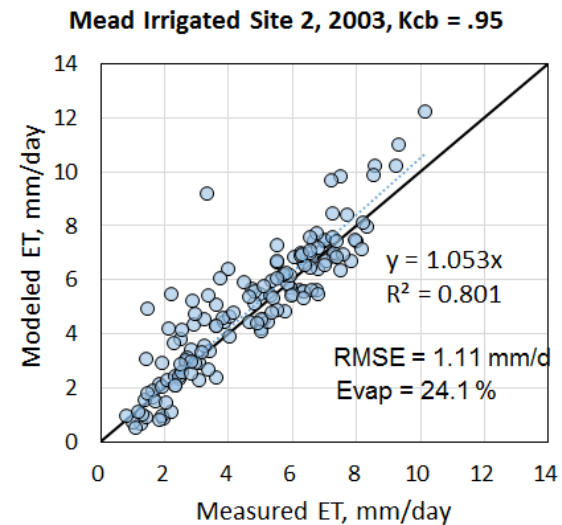
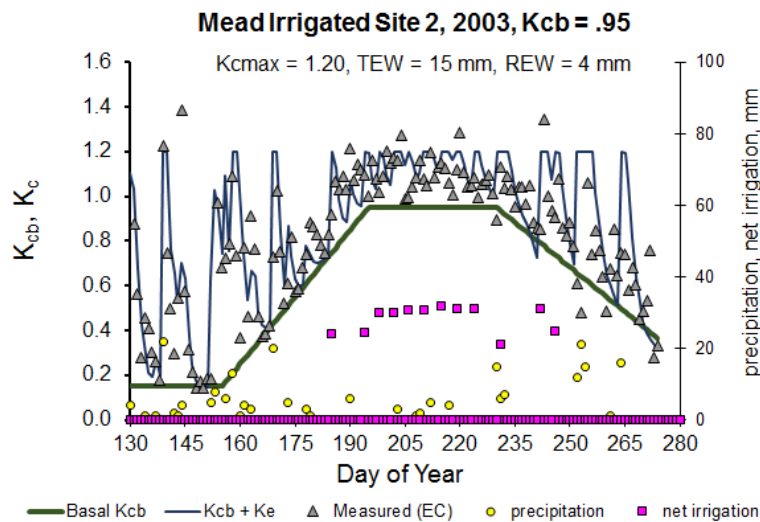


$K_{cb\ mid} = 1.05$

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



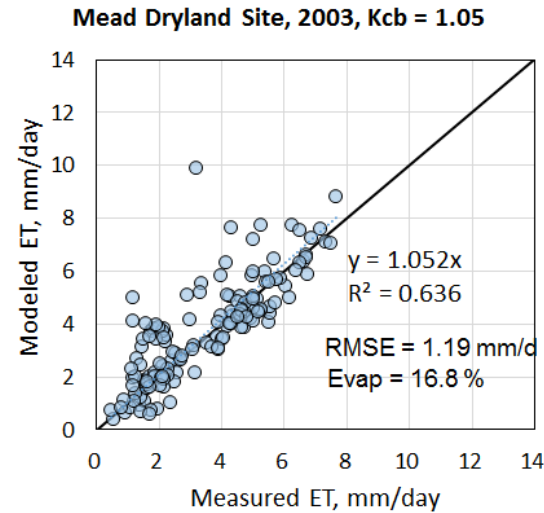
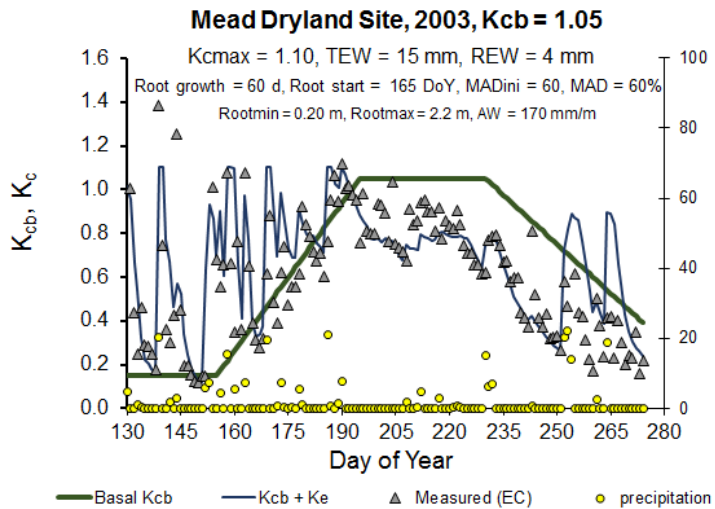
$K_{cb\ mid} = 1.15$



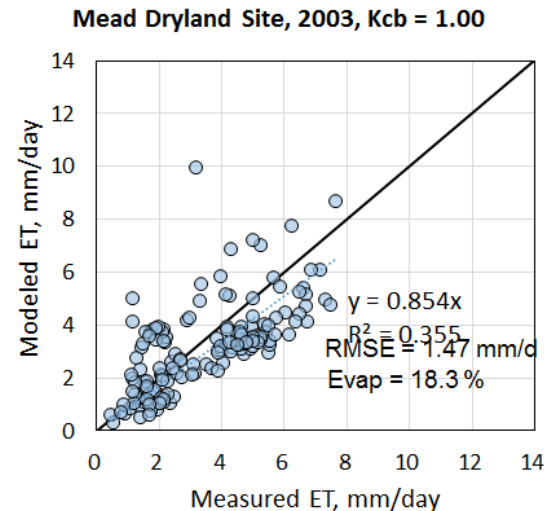
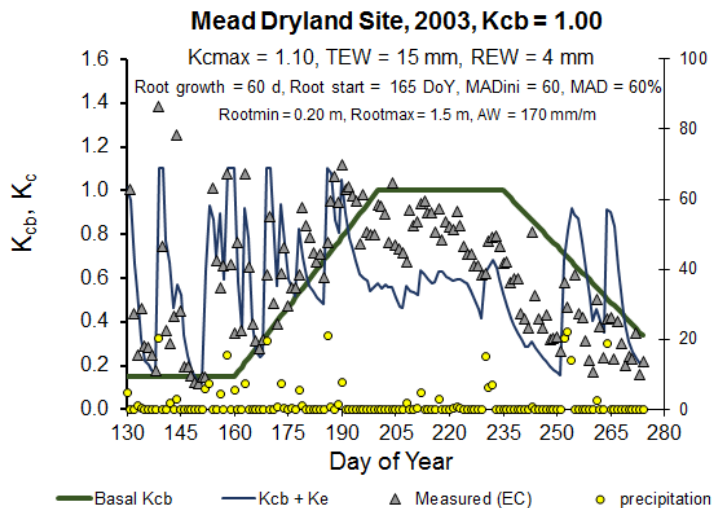
$K_{cb\ mid} = 0.95$

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

Rainfed Field – Impact of Rooting Depth



K_{cb mid} = 1.05
Z_{root} = 2.2 m

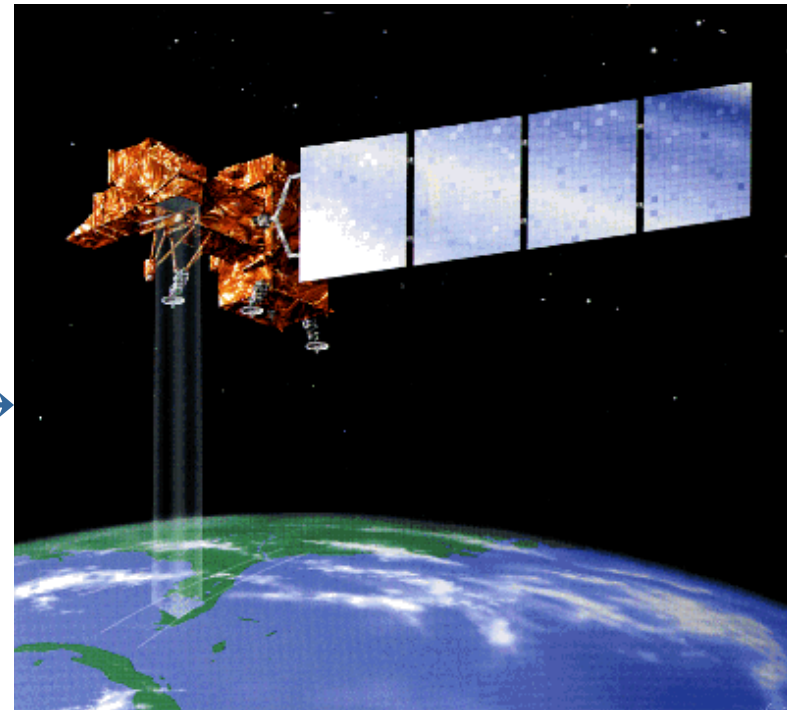


K_{cb mid} = 1.00
Z_{root} = 1.5 m



Landsat 5 1984 – 2012

8-days
apart

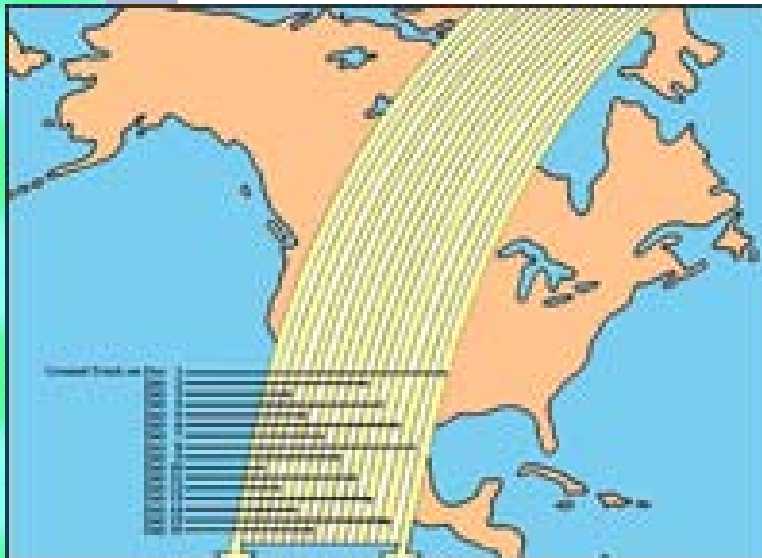
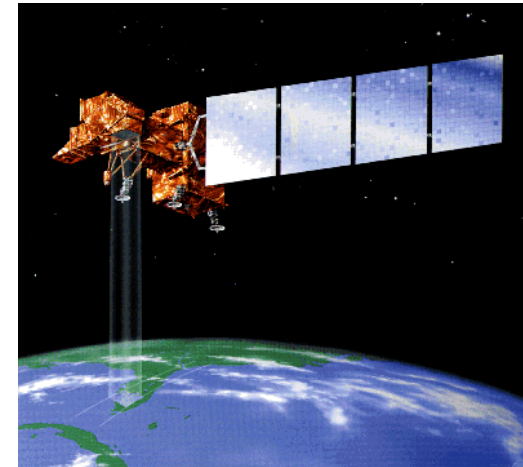
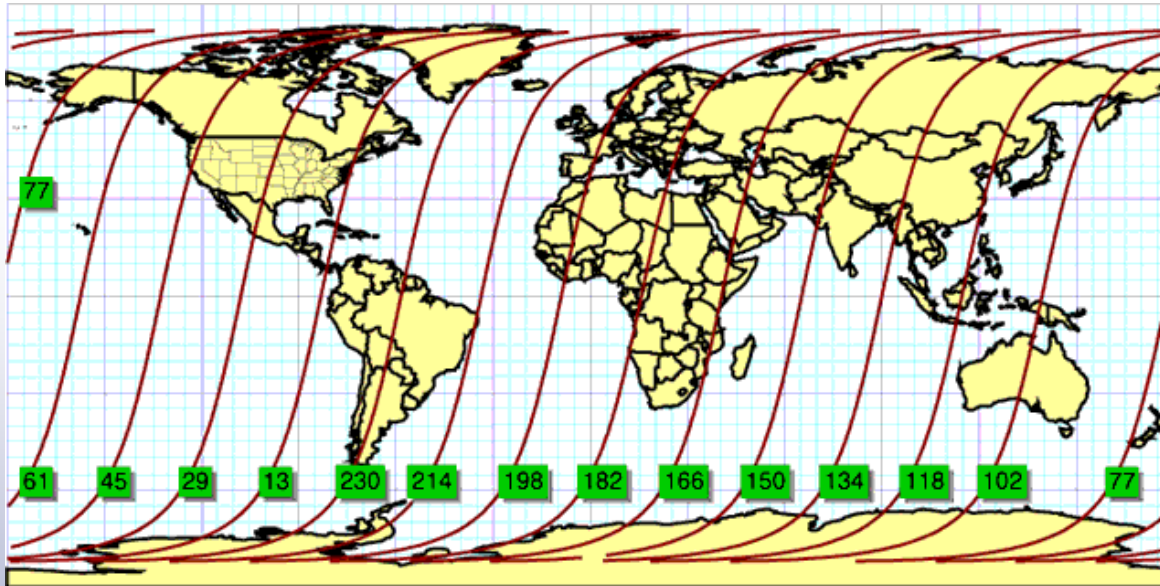


Landsat 7 1999 – 2017



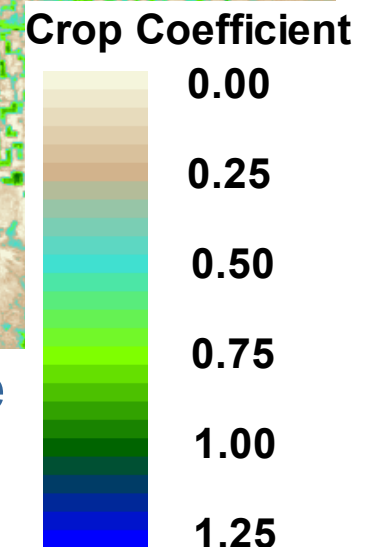
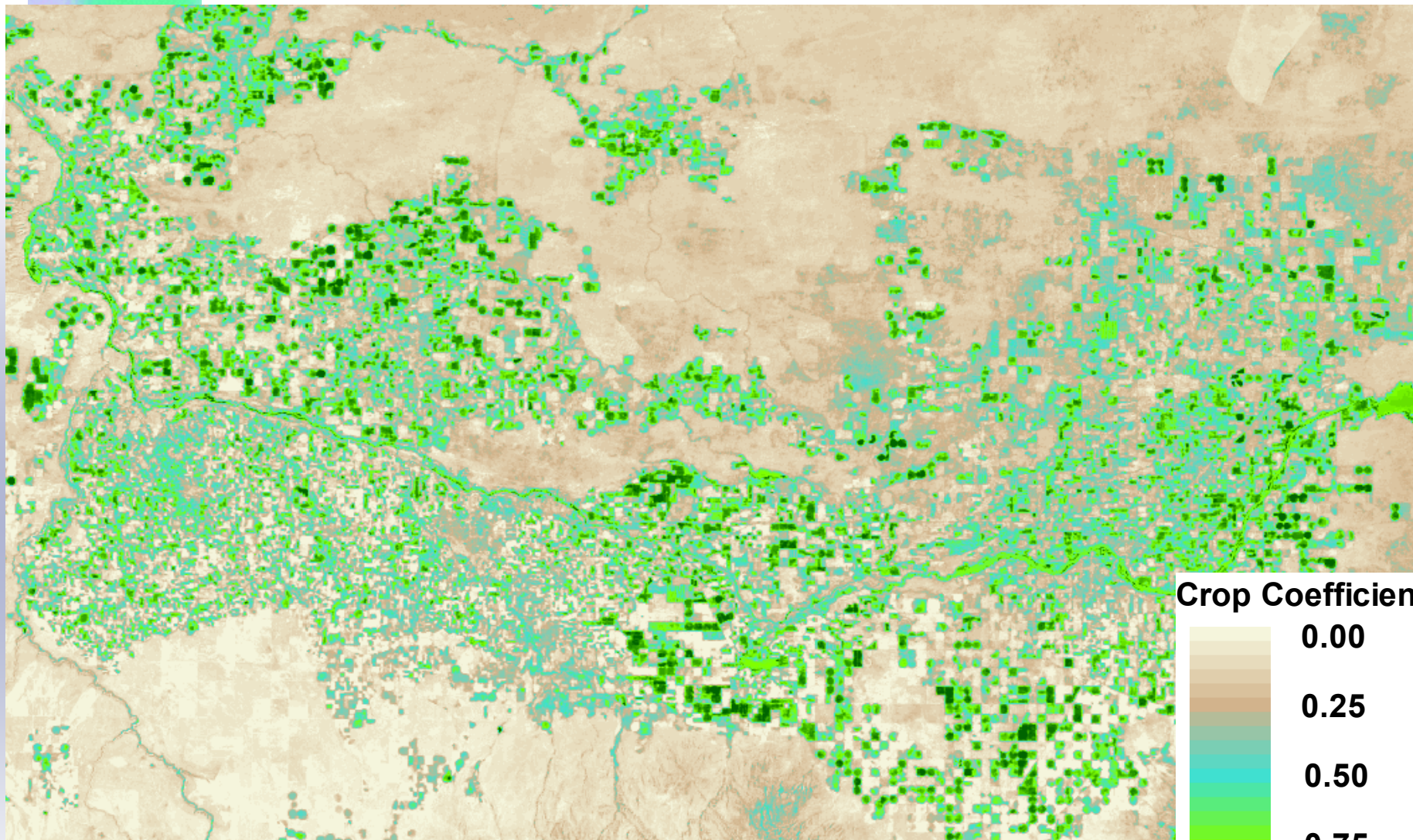
Landsat 8 (LDCM)
Feb. 2013 – 20xx
(replaced Landsat 5)

K_c 's from
Space



Landsat is a “polar orbiter”
 orbiting Earth each 90 minutes
 returning to the same location
 (path) each 16 days.

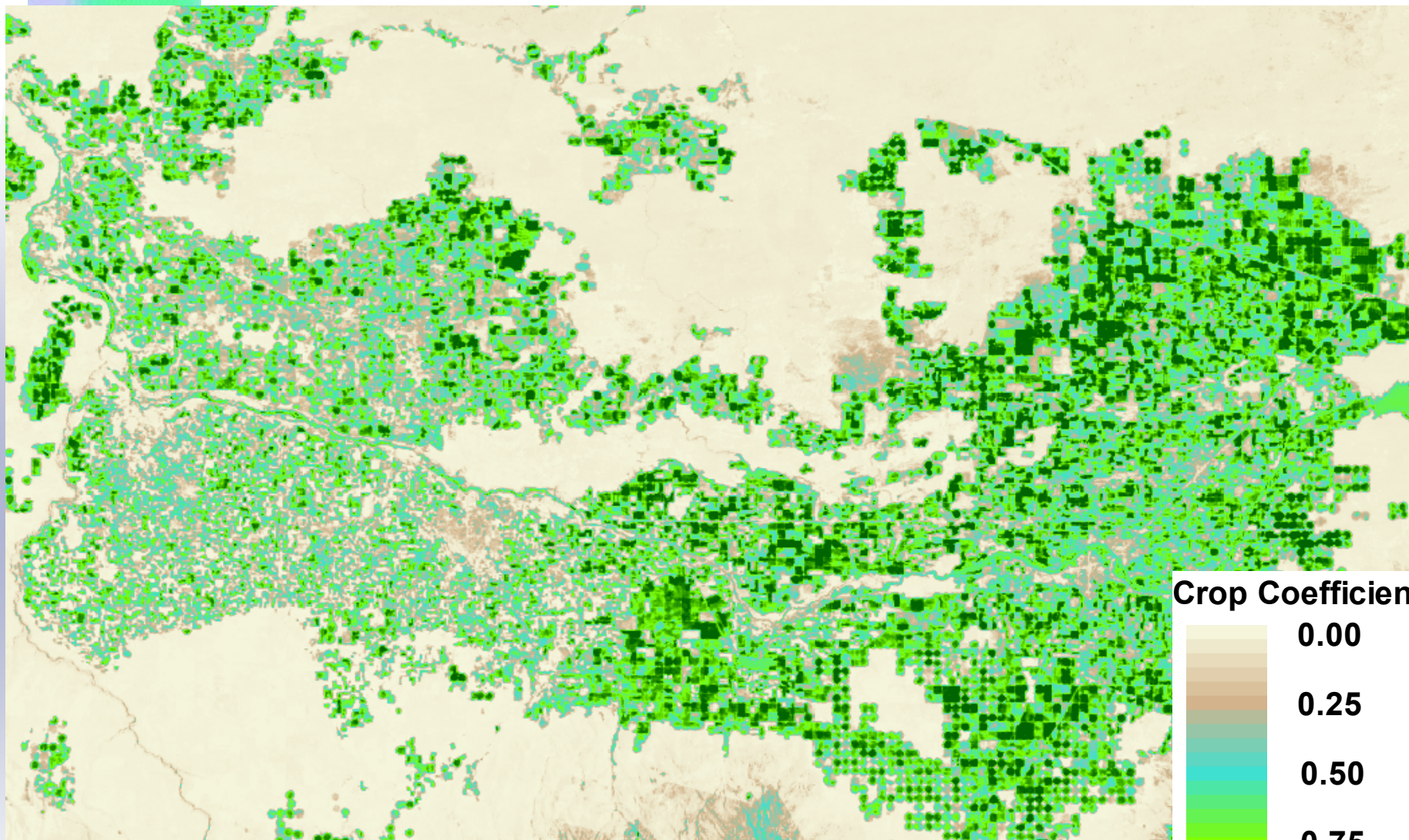
200,000 ha of Coverage – K_c produced by METRIC



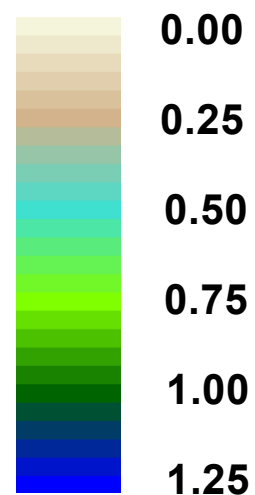
K_c via METRIC-Landsat Energy Balance
May/2/2000 – SouthCentral Idaho, USA

9/4/2015

INOVAGRI, Fortaleza, Brazil, Aug. 31, 2015



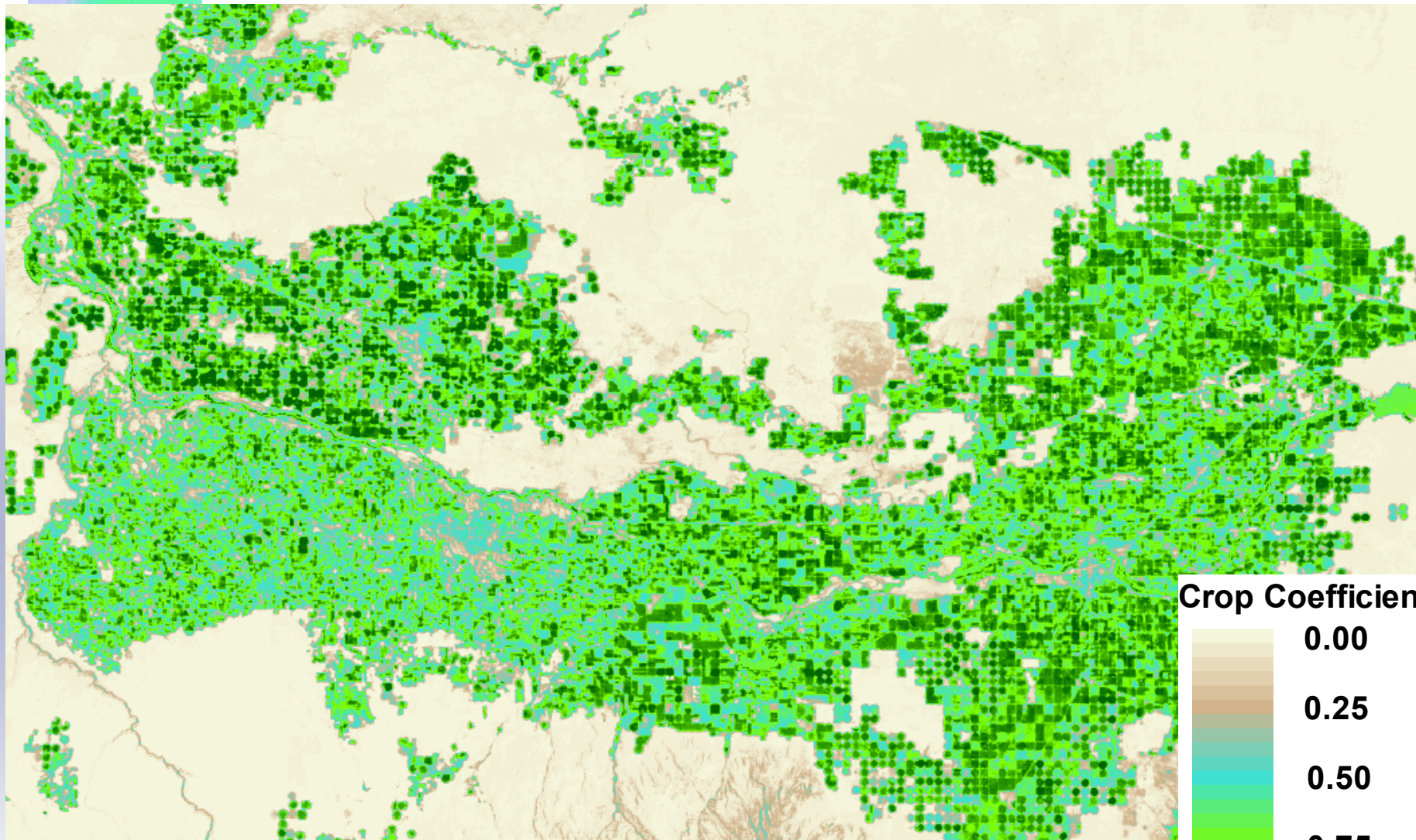
Crop Coefficient



June/19/2000

9/4/2015

INOVAGRI, Fortaleza, Brazil, Aug. 31, 2015



Crop Coefficient

0.00

0.25

0.50

0.75

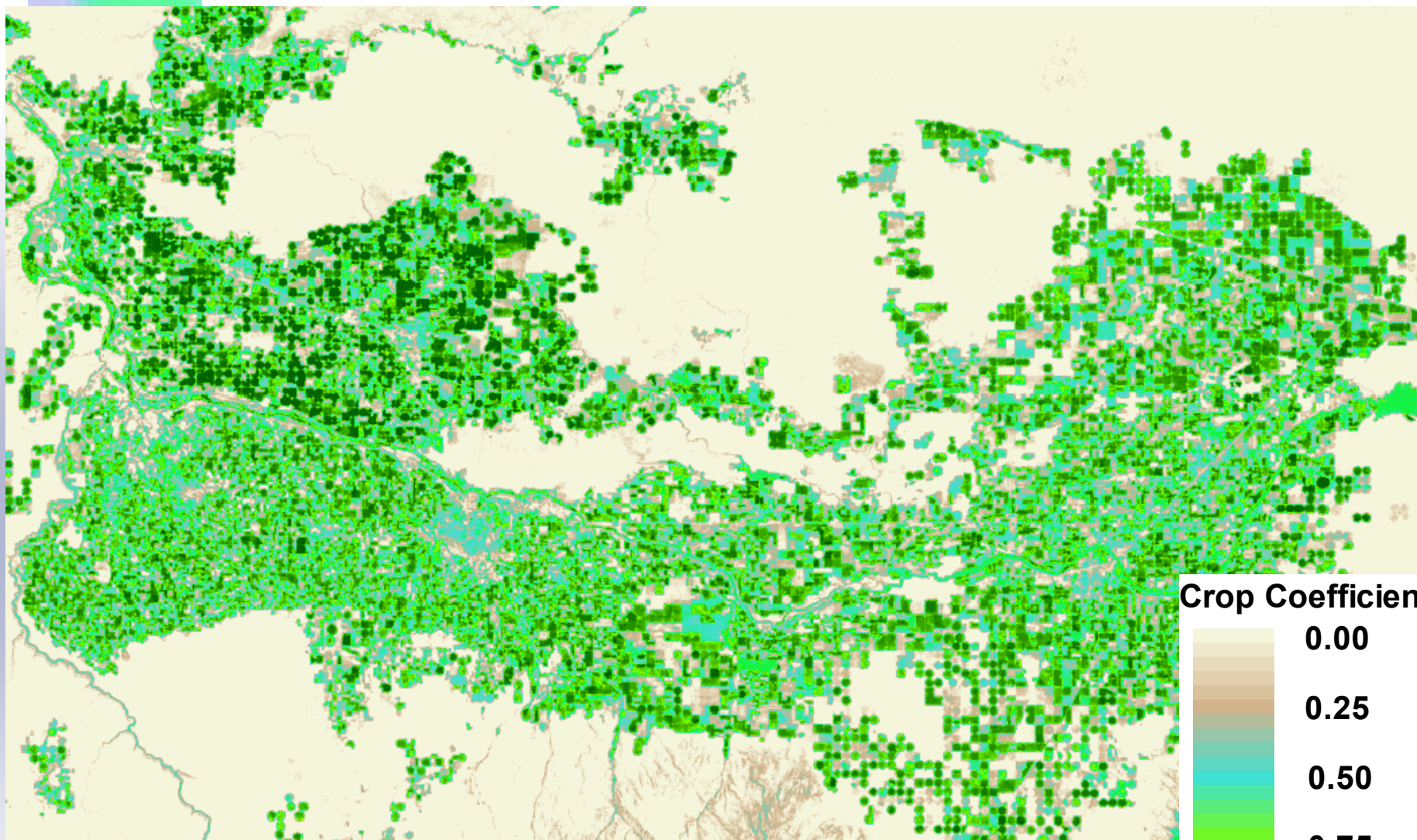
1.00

1.25

July/21/2000

9/4/2015

INOVAGRI, Fortaleza, Brazil, Aug. 31, 2015



Crop Coefficient

0.00

0.25

0.50

0.75

1.00

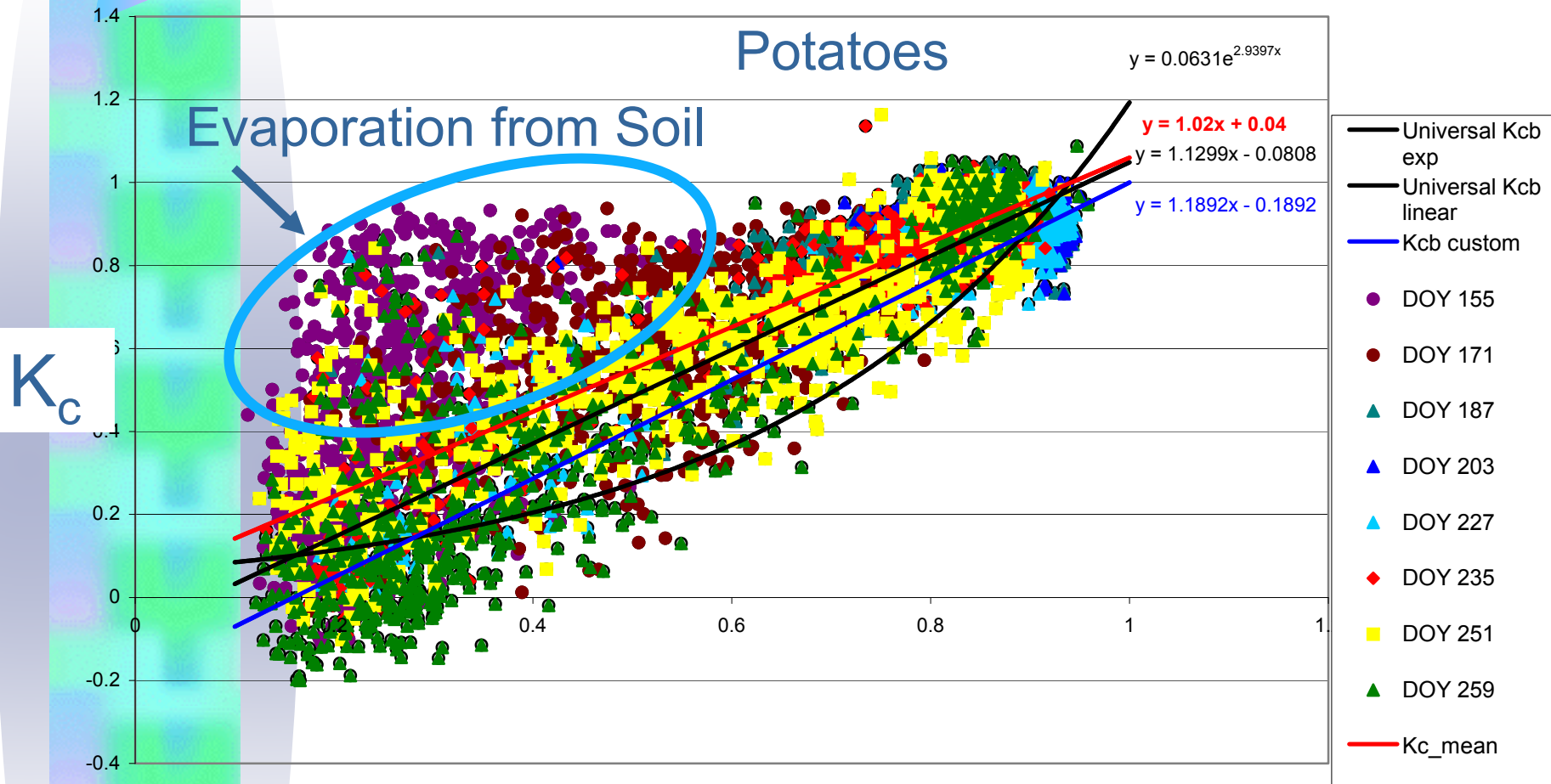
1.25

August/14/2000

9/4/2015

INOVAGRI, Fortaleza, Brazil, Aug. 31, 2015

We can also calibrate NDVI-based K_c via Energy Balance



K_c

NDVI

Each point is one agricultural field.
Each color is a Landsat date

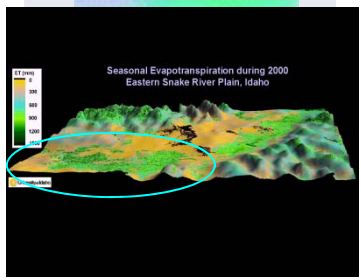
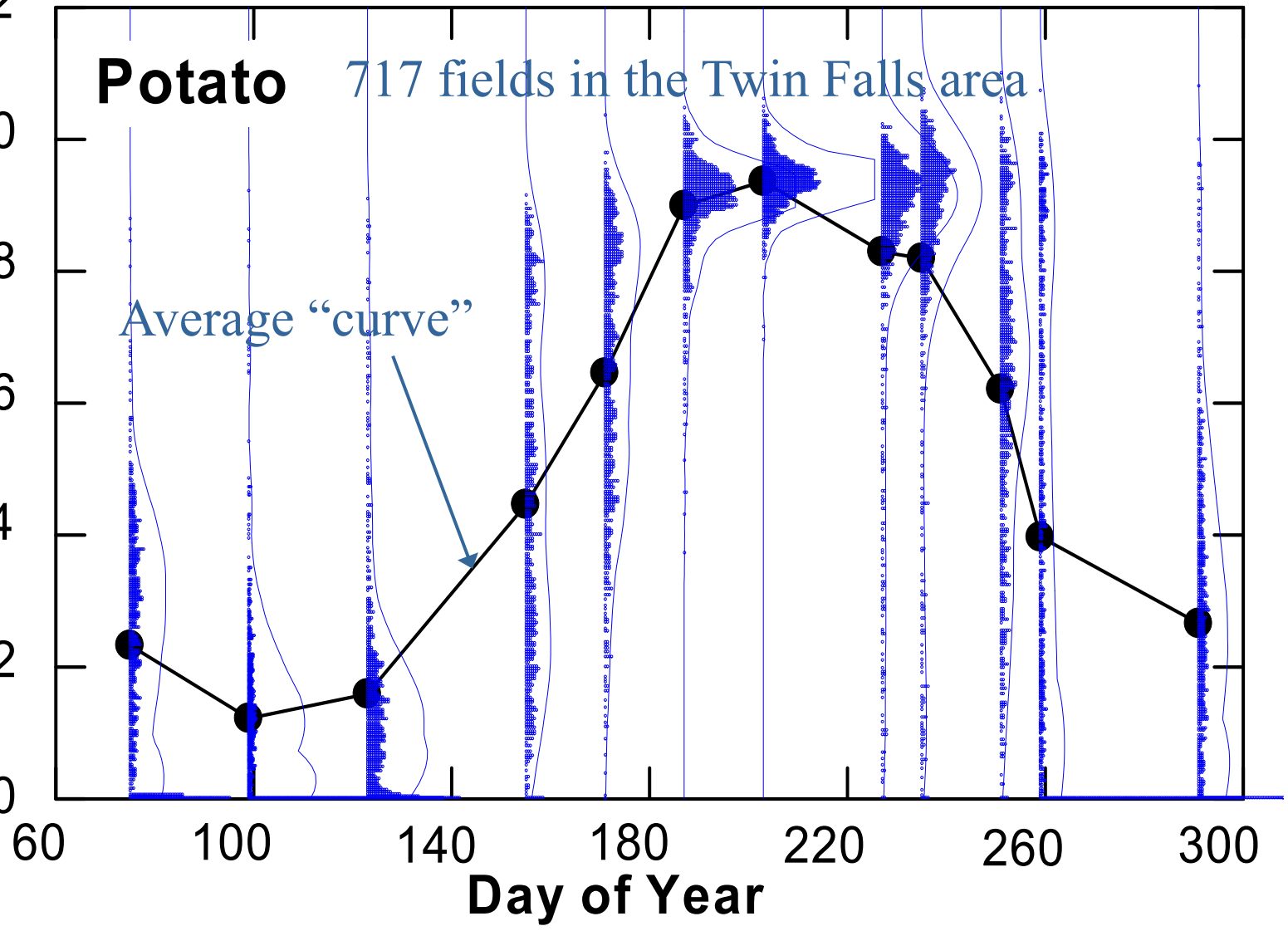
NDVI = Normalized
Difference
Vegetation Index

Use to Refine Local Information

Kc

Potato 717 fields in the Twin Falls area

Average "curve"



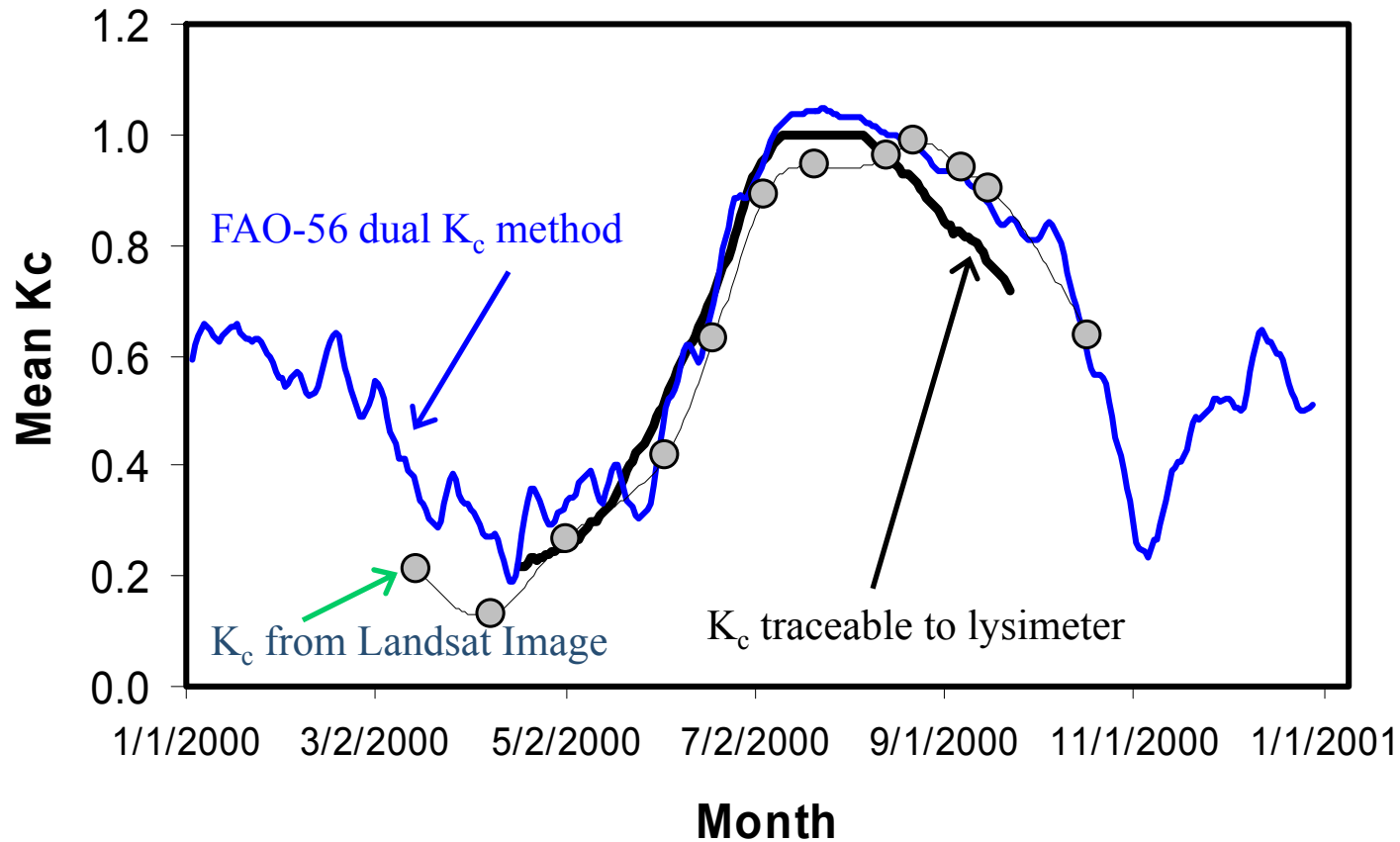
Comparing METRIC vs. traditional K_c ET_{ref} methods

$$(K_c = ET_{act} / ET_{ref})$$

alfalfa reference ET_r basis

Sugar Beets

Twin Falls, Idaho 2000



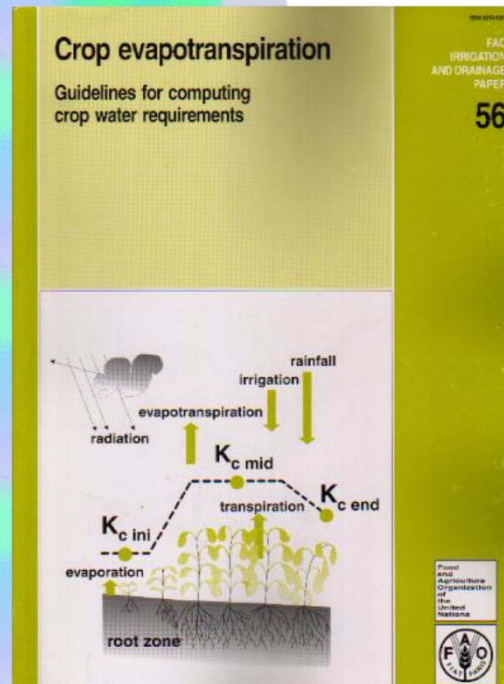
(relatively good agreement among very independent approaches, including during the 'shoulder' periods when ground has partial cover)

- Agrimet for 2000
 $K_{cmean} ET_{ref}$
- Allen-Robison - 14 yr ave.
 $(K_{cb} + K_e) ET_{ref}$
- METRIC for 2000
Energy Balance
-

A photograph of a cork oak grove. The trees are arranged in neat, parallel rows that recede into the distance, creating a sense of depth. The ground is covered in lush green grass. The trees have thick, dark trunks and dense, green foliage. The overall scene is bright and natural.

**Estimating Crop
Coefficients from Fraction
of Cover and Height**

Why does K_c change between two fields of the same crop?



(these are both grapes. Why isn't the K_c the same?)



INOVAGRI, Fortaleza, Brazil, Aug. 31, 2015

Allen and Pereira 2009, Irrigation Science, ASABE Mono.

--FAO-56 style approach

(assuming bare soil between vegetation)

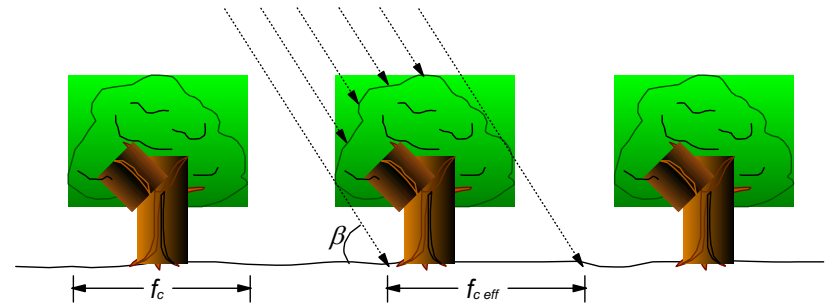
$$K_{cb} = K_{cmin} + K_d (K_{cb\ full} - K_{cmin})$$

K_{cmin} = minimum K_{cb} for bare soil
(~0.10-0.15)

K_d = density coefficient (0-1)

$K_{cb\ full}$ = K_{cb} for full ground covered by
vegetation

Density Coeff.



$$K_d = \min \left(1, f_{c\text{eff}}^{\left(\frac{1}{1+h}\right)}, M_L f_{c\text{eff}} \right)$$

K_d = density coefficient (0-1)

M_L = multiplier on $f_{c\text{eff}}$ (~1.5-2)

(to set upper flux limit per fraction of cover)

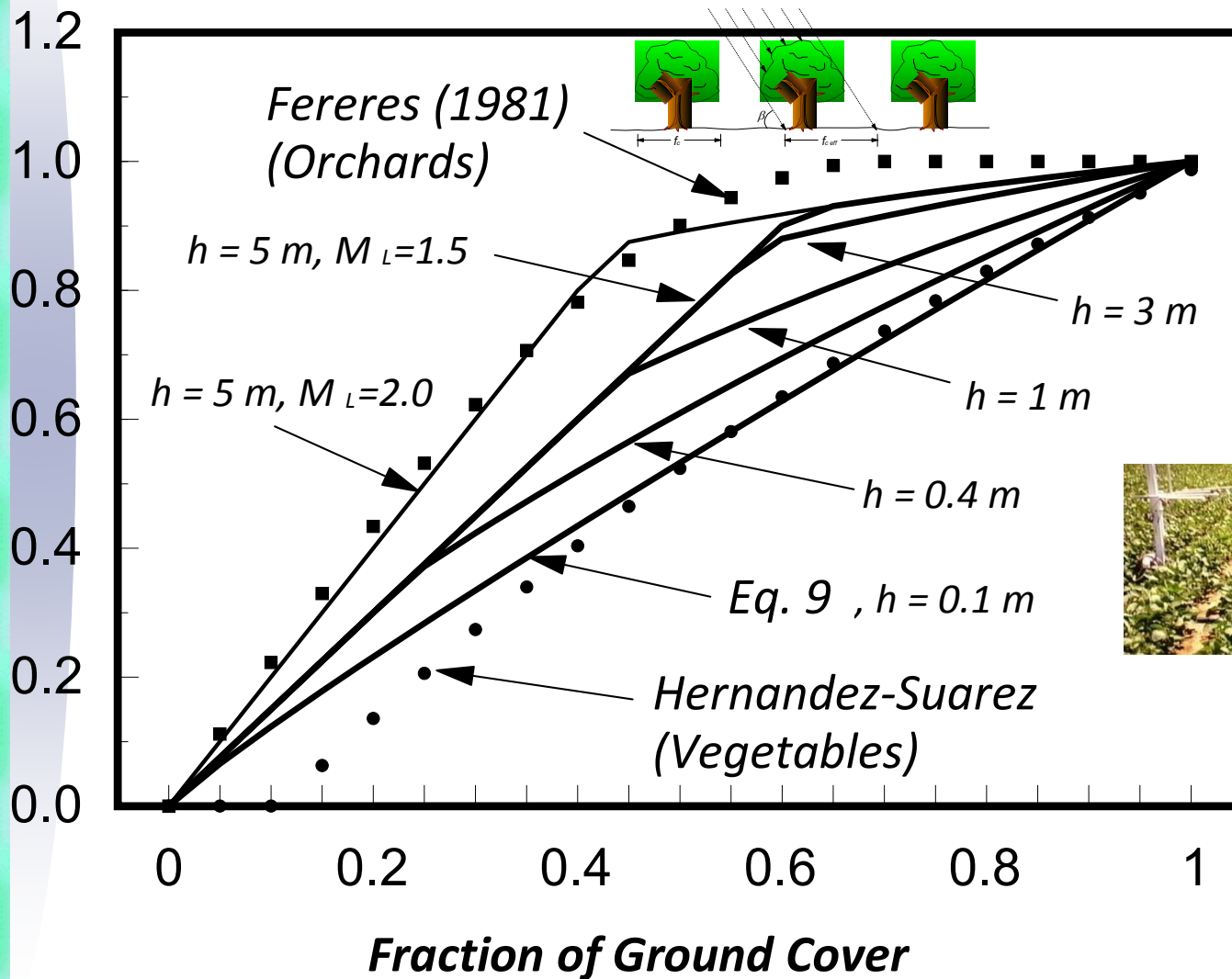
$f_{c\text{eff}}$ = effective fraction of ground covered
(shaded) by vegetation (0-1)

h = height, m *(for radiation + microadvection)*

Density Coeff.

$$K_d = \min \left(1, f_{ceff}^{\left(\frac{1}{1+h}\right)}, M_L f_{ceff} \right)$$

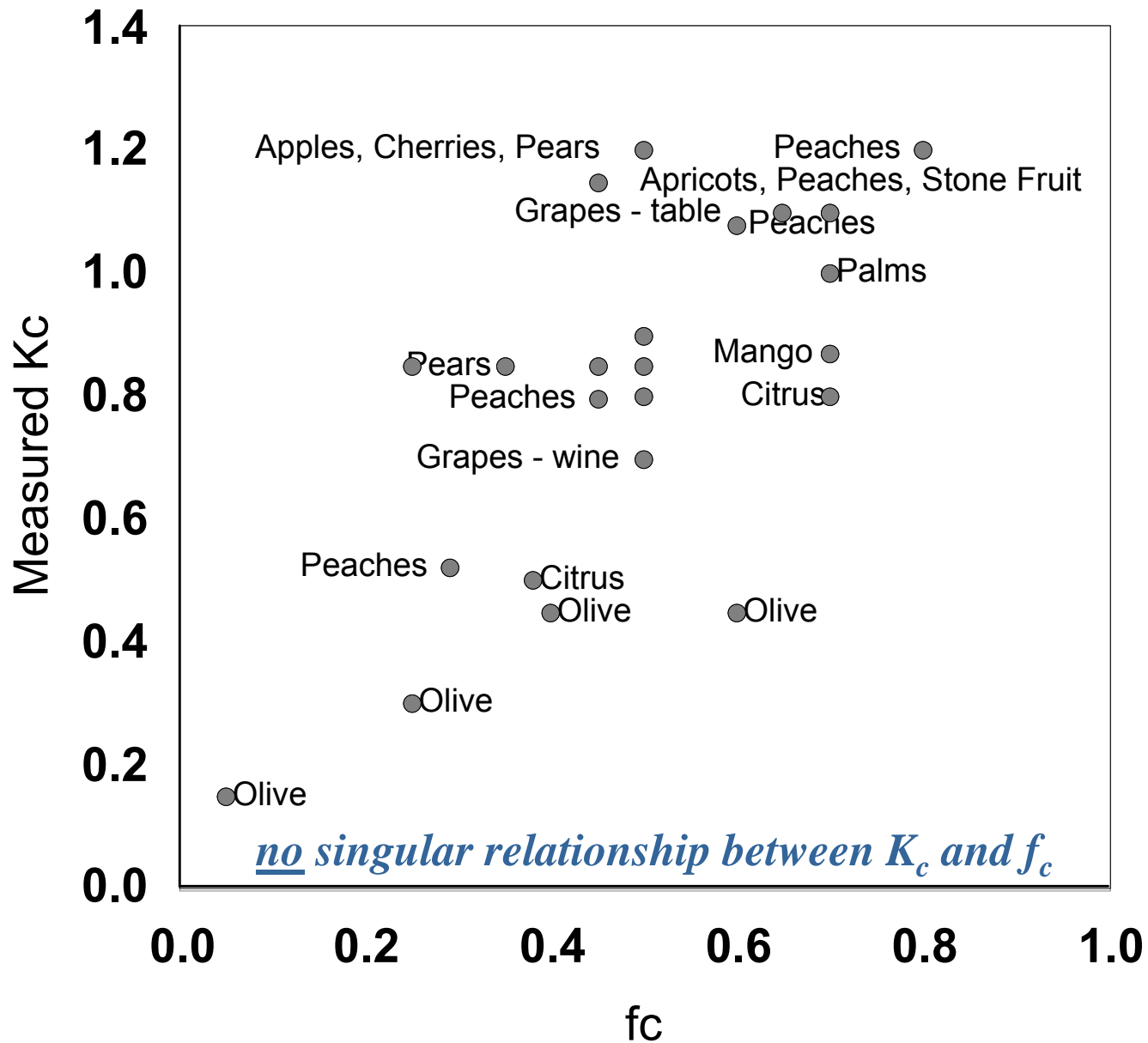
K_d



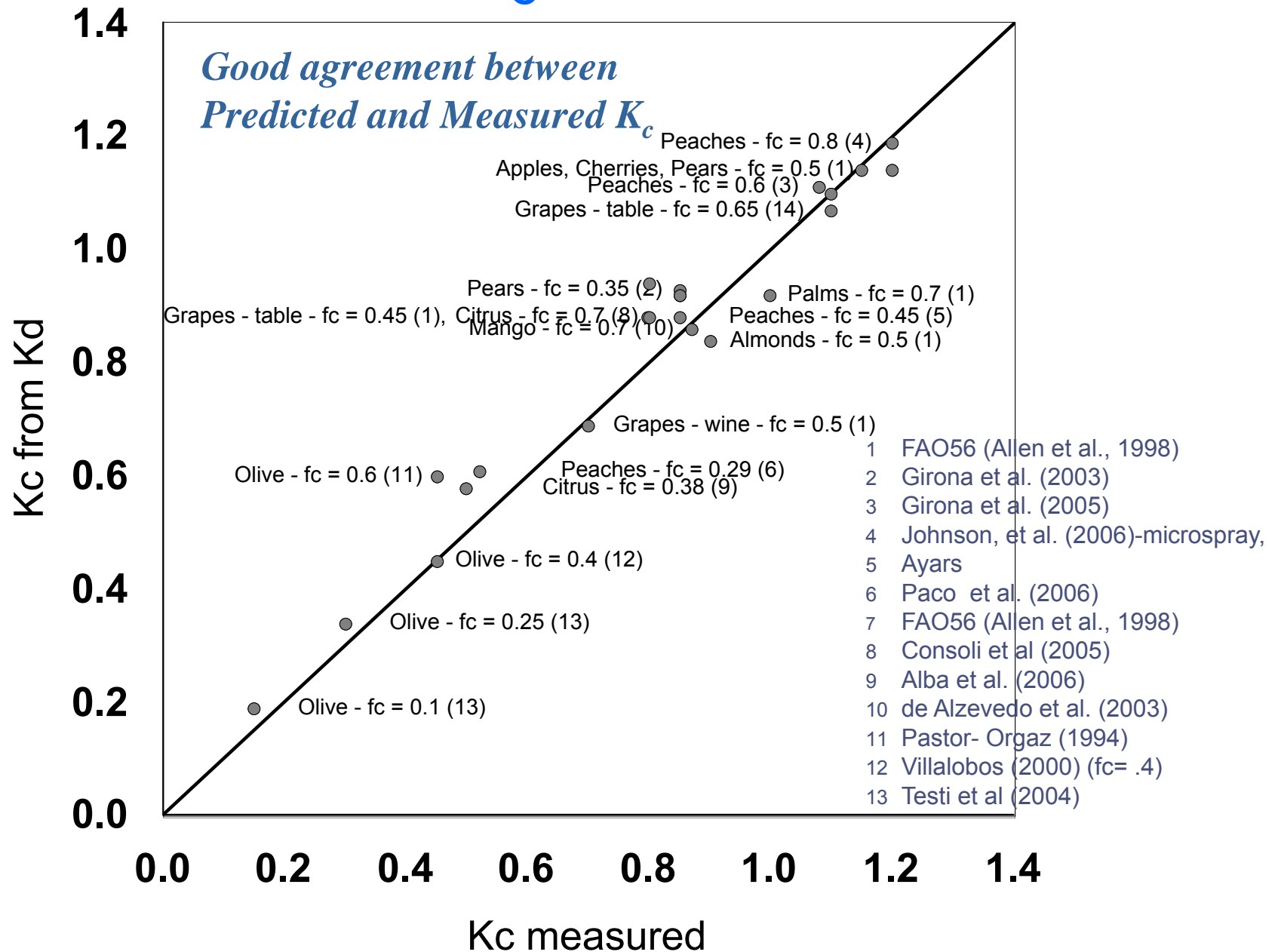
Expanded K_{co} tables for Orchards

Crop	$K_{c\ ini}$	$K_{c\ mid}$	$K_{c\ end}$	$K_{cb\ ini}$	$K_{cb\ mid}$	$K_{cb\ end}$
Fruit Trees						
Almonds						
- no ground cover - high density (f _{ceff} = 0.7)	0.40	1.00	0.70	0.20	0.95	0.65
- no ground cover - med. density (f _{ceff} = 0.5)	0.40	0.85	0.60	0.20	0.80	0.55
- no ground cover – low dens. / young (f _{ceff} = 0.25)	0.35	0.50	0.40	0.15	0.45	0.35
- active ground cover - high density (f _{ceff} = 0.7)	0.85	1.05	0.85	0.75	1.00	0.80
- active ground cover - med. density (f _{ceff} = 0.5)	0.85	1.00	0.85	0.75	0.95	0.80
- act. grnd cover – low dens. / young (f _{ceff} = 0.25)	0.85	0.95	0.85	0.75	0.90	0.80
Apples, Cherries, Pears						
- no ground cover - high density (f _{ceff} = 0.7)	0.50	1.15	0.80	0.30	1.10	0.75
- no ground cover - med. density (f _{ceff} = 0.5)	0.50	1.05	0.75	0.30	1.00⁴	0.70
- no ground cover - low dens./ young (f _{ceff} = 0.25)	0.40	0.70	0.55	0.25	0.65	0.50
- act. grnd cov., killing frost – h.dens. (f _{ceff} = 0.7)	0.50	1.20	0.85	0.40	1.15	0.80
- act. grnd cov., killing frost – m.dens. (f _{ceff} =0.5)	0.50	1.15	0.85	0.40	1.10	0.80
- act. grnd cov., killing frost – l.dens. (f _{ceff} = 0.25)	0.50	1.05	0.85	0.40	1.00	0.80
- act. grnd cov., no frosts – h. dens. (f _{ceff} = 0.7)	0.85	1.20	0.85	0.75	1.15	0.80
- act. grnd cov., no frosts – m. dens. (f _{ceff} = 0.5) ³	0.85	1.15	0.85	0.75	1.10	0.80
- act. grnd cov., no frosts – l. dens. (f _{ceff} = 0.25)	0.85	1.05	0.85	0.75	1.00	0.80

Orchard K_c 's from literature



Orchard K_c 's from literature





Conclusions on K_c

- The K_c ET_r method is robust and transferable
- The K_c incorporates a number of factors affecting ET
- K_c curves can be tailored based on
 - weather data
 - fraction of ground cover
- The dual K_c provides good estimation of impacts of evaporation from soil



Thank You

9/4/2015

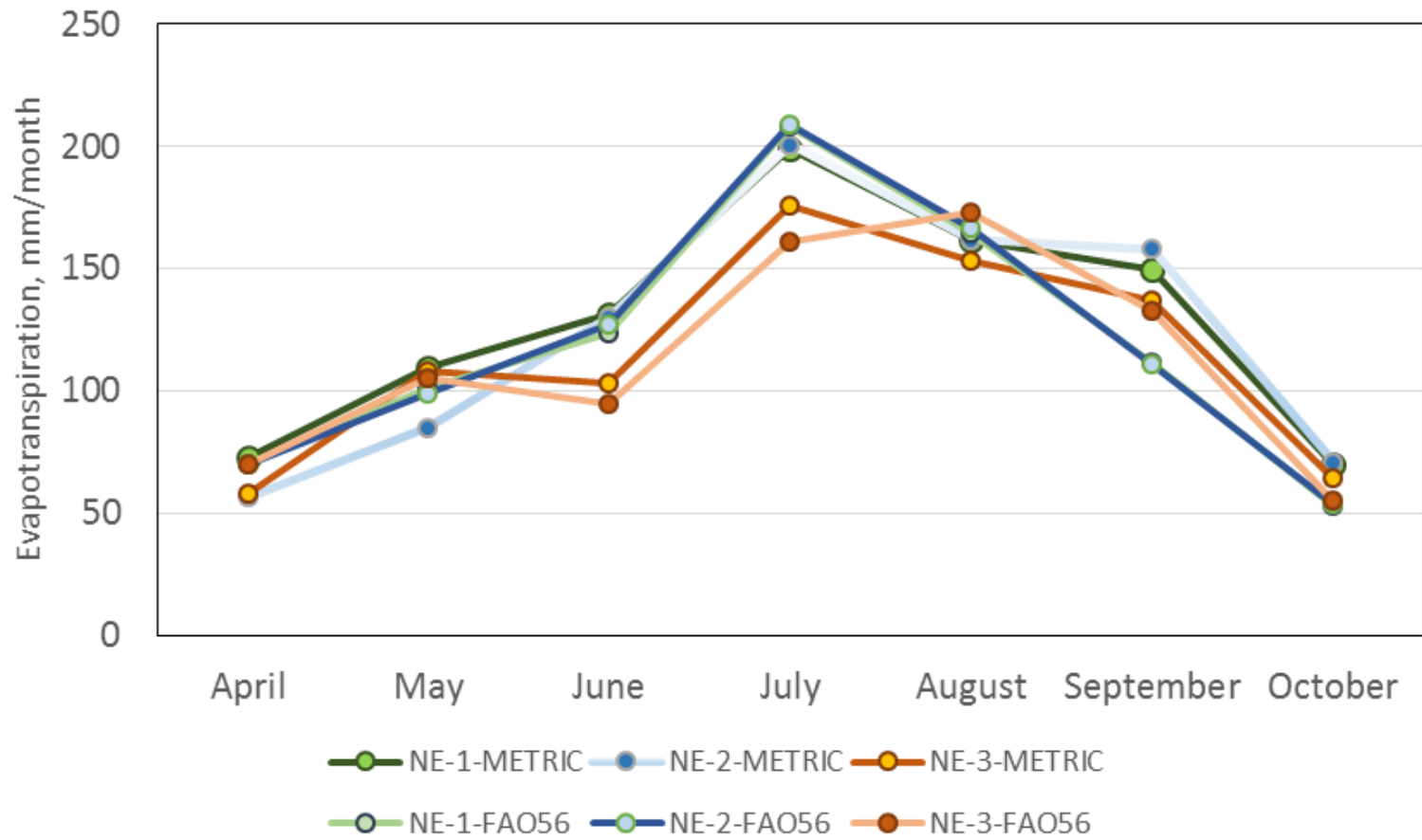
CIGR, Bari, Italy, Sept. 10, 2013

Spatial ET_{ref} from Gridded Weather Data Sets

- large gridded weather bases include:
 - the European Centre for Medium-Range Weather Forecasts (ECMWF) (deBruin et al. 2012 has ETo)
 - North American Land Data Assimilation System (NLDAS) and Global Land Data Assimilation System (GLDAS).
 - ECMWF and GLDAS data sets are produced for the whole globe at 1 degree spatial resolution (100 km) or finer, and for specific regions at 12 km resolution.
 - Time steps range from hourly to 24-h for calculation of reference ET.
 - The data may be “Arid” and needs “conditioning”
- We need good spatial Precipitation Data



METRIC and FAO-56 Comparison 2013 - Mead, NE



INOVAGRI, Fortaleza, Brazil, Aug. 31, 2015

9/4/2015