

Satellite-based Determination of Evapotranspiration to Improve On-Farm Water Management



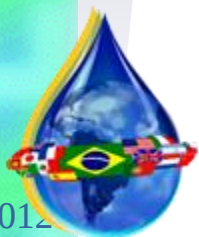
Richard G. Allen

Professor

Water Resources Engineering

Univ. Idaho – Kimberly, Idaho USA

acknowledgements – R.Trezza, M. Tasumi, I.Lorite-Torres, J.L. Wright

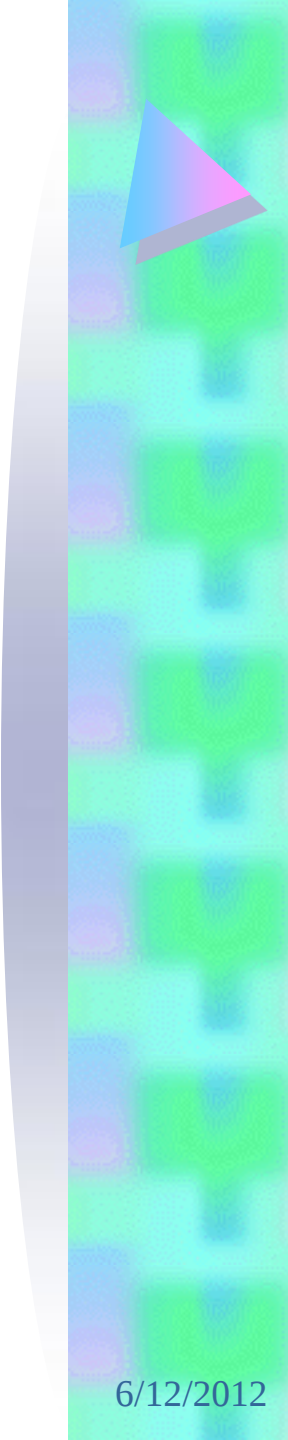


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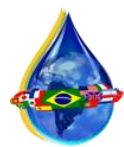


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Discussion Points

- **How can Satellite-based Energy Balance be used to estimate Crop Coefficients?**
- **How can monitoring of many fields via Satellite provide useful information on variation and behavior of Evapotranspiration by Crops?**



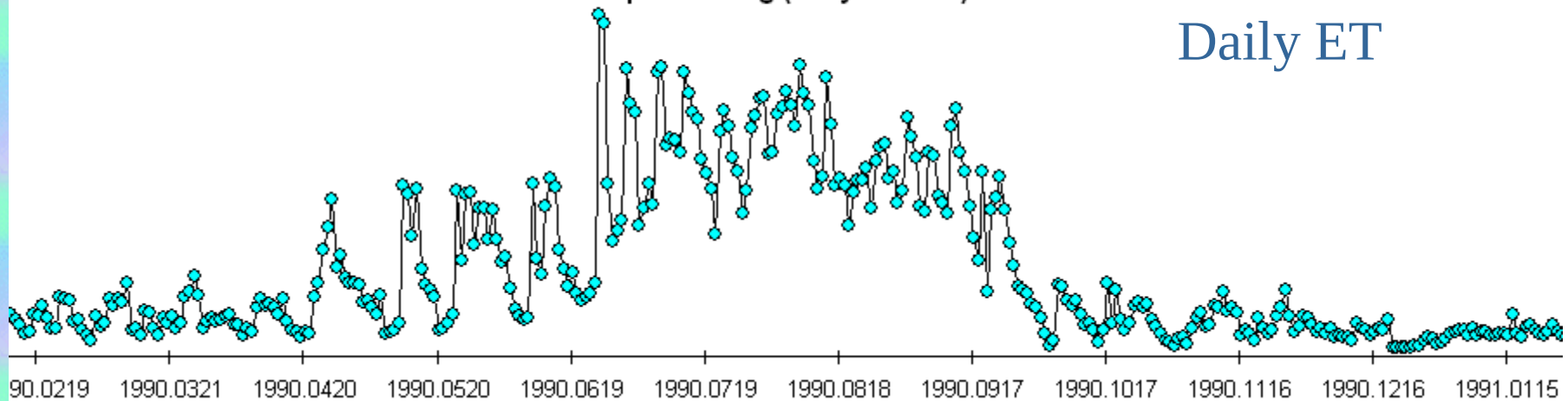
Evapotranspiration (ET) varies widely with

- Time of Year
- From Day to Day

Ashton, 1990 calendar year -- Potatoes

Potatoes--processing (early harvest)

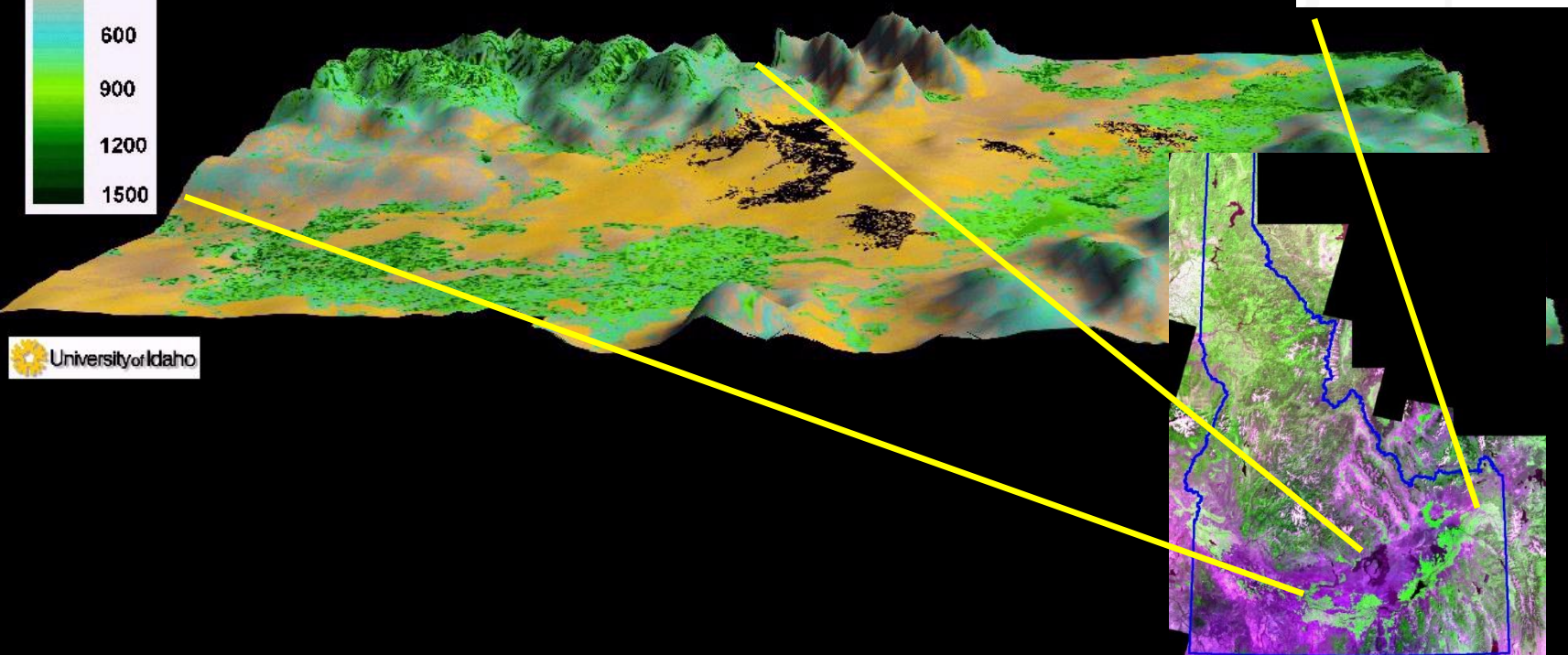
Daily ET





Evapotranspiration also varies in Space (150 km x 300 km area) (20,000 fields)

Seasonal Evapotranspiration during 2000
Eastern Snake River Plain, Idaho



University of Idaho

ET varies in space

*April – October, 2006 ET over SE Idaho
from METRIC-Landsat*

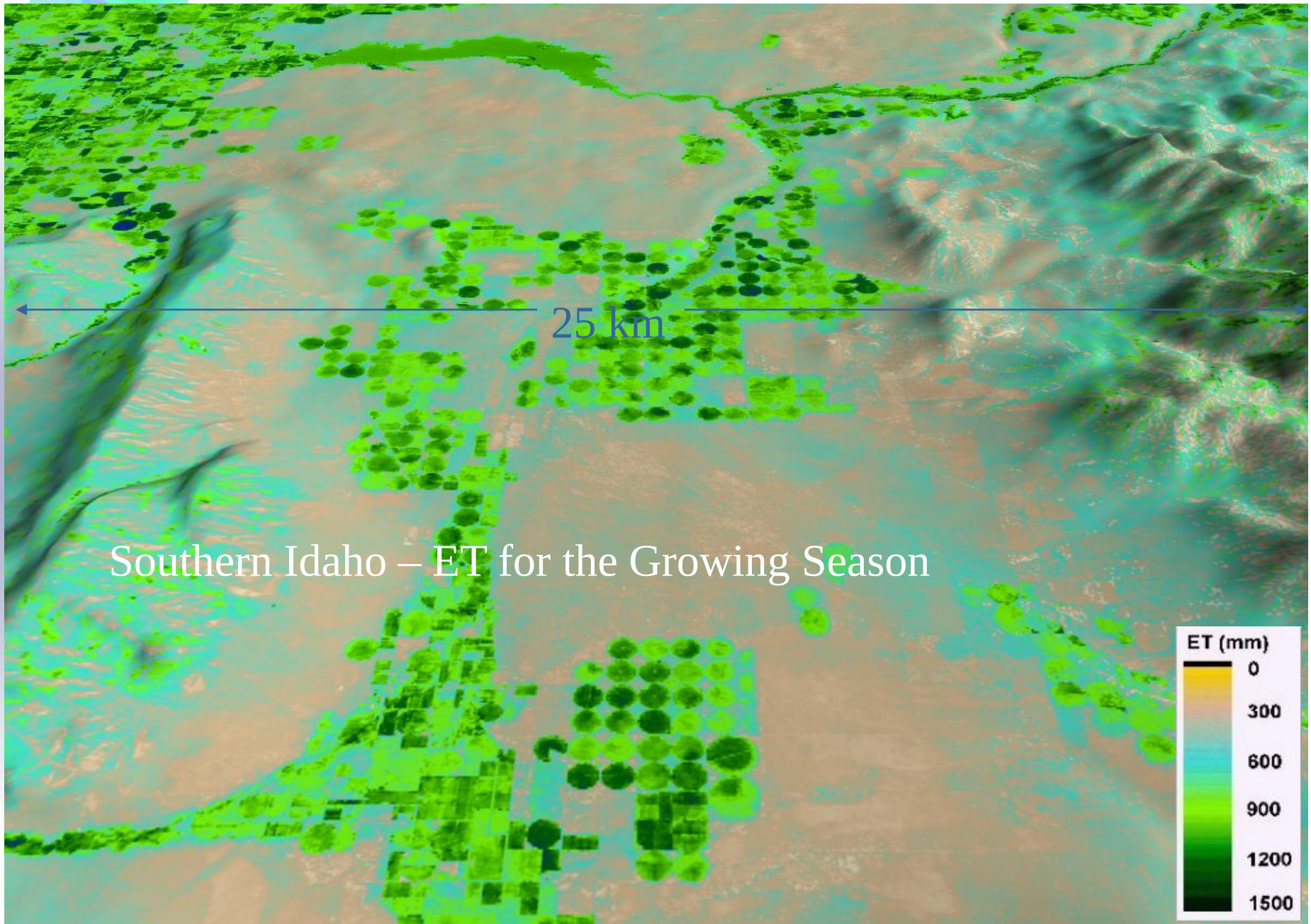
Southern Idaho – Growing Season ET

~160 km



ET varies in space

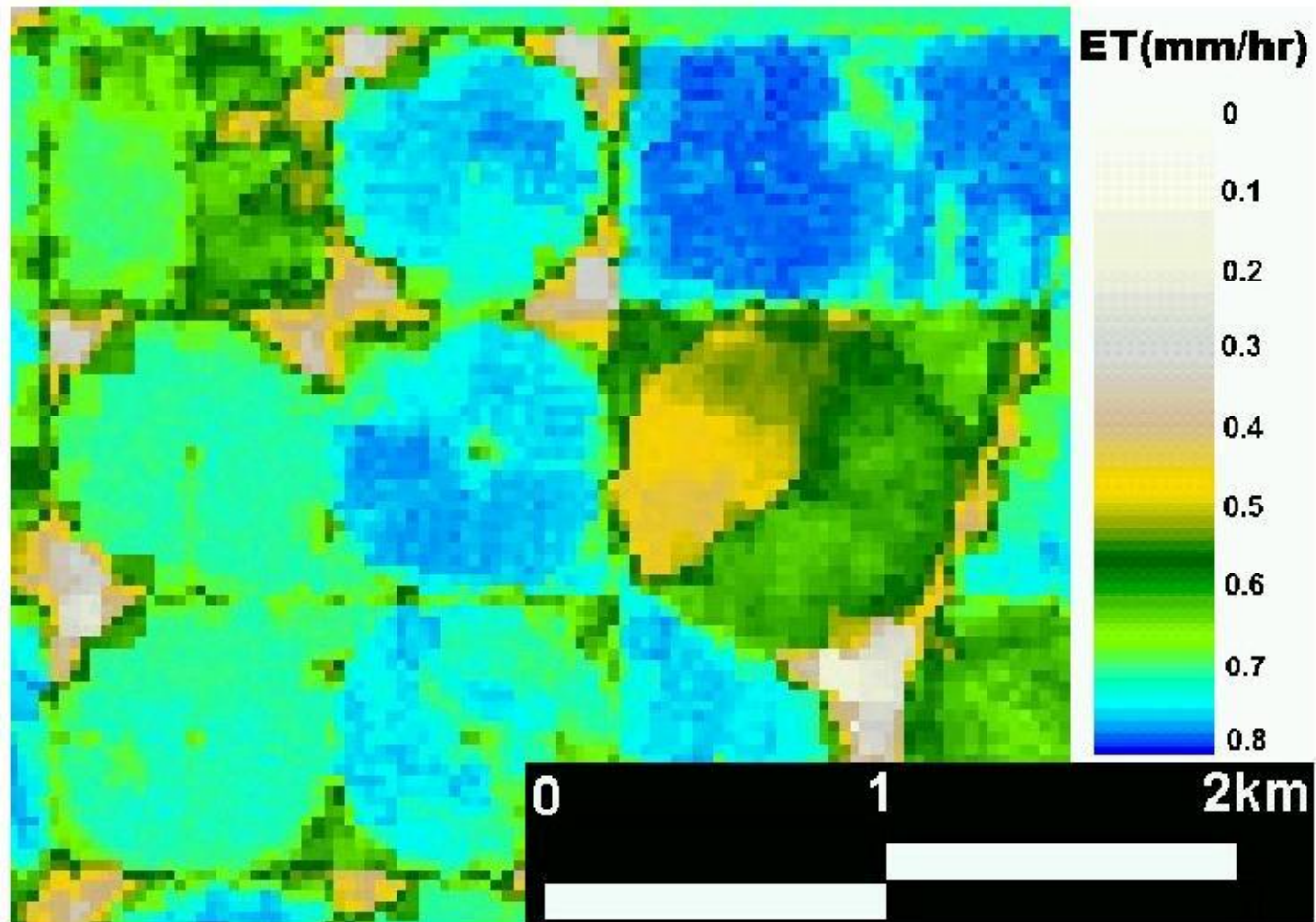
*April – October, 2006 ET in SE Idaho
from METRIC-Landsat*



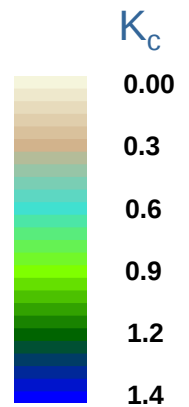
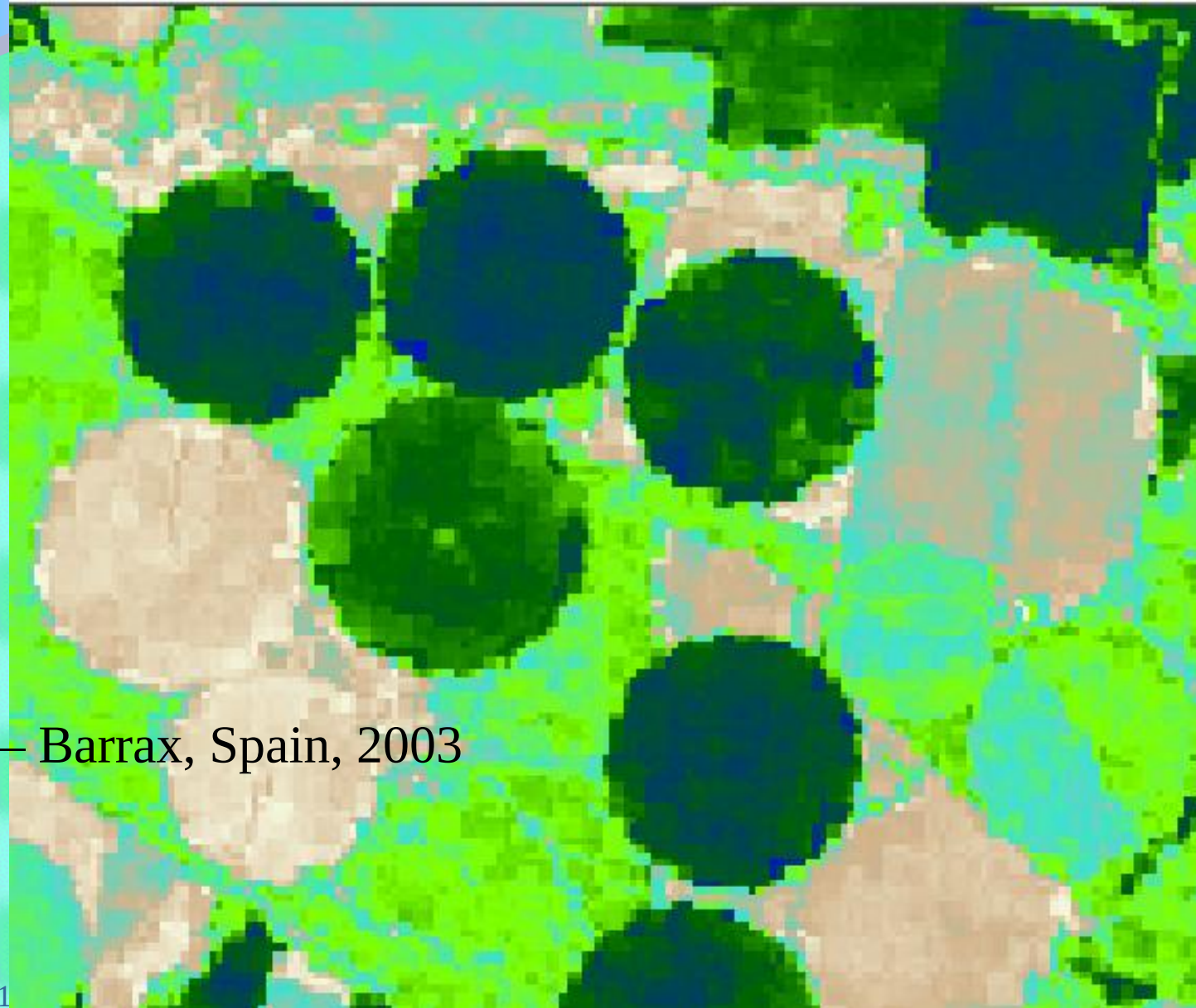
ET may vary within in a field (*irrig. uniformity, plant uniformity, soil uniformity – usually minor*)

Evapotranspiration at time of Landsat overpass

Oakley Fan, Idaho, July 7, 1989



Crop Coefficients = ET/ET_{ref} also vary spatially



(K_c based
on ET_o)

Reference ET: A Living Evaporation Index

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

Full Penman-Monteith

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

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

C_n and
 C_d are
constants

Standardized ASCE Penman-Monteith

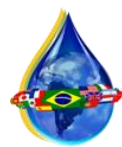
$$ET_{ref} = \frac{0.408 \Delta(R_n - G) + \gamma \frac{C_n}{T + 273} u_2 (e_s - e_a)}{\Delta + \gamma (1 + C_d u_2)}$$

f (Solar Radiation)

f (Temperature)

Wind Speed

f (Humidity)



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The ASCE Standardized Reference
Evapotranspiration Equation

Edited by
Richard L. Allen
Ivan A. Walter
Ronald E. Smith
Terry Howell
Daniel R. Rouse
Hector J. Giron



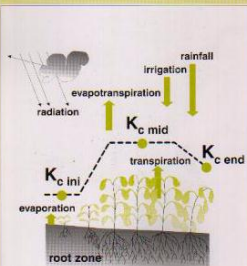
ASCE

EWRI

Crop evapotranspiration

Guidelines for computing
crop water requirements

56



07/12/2012

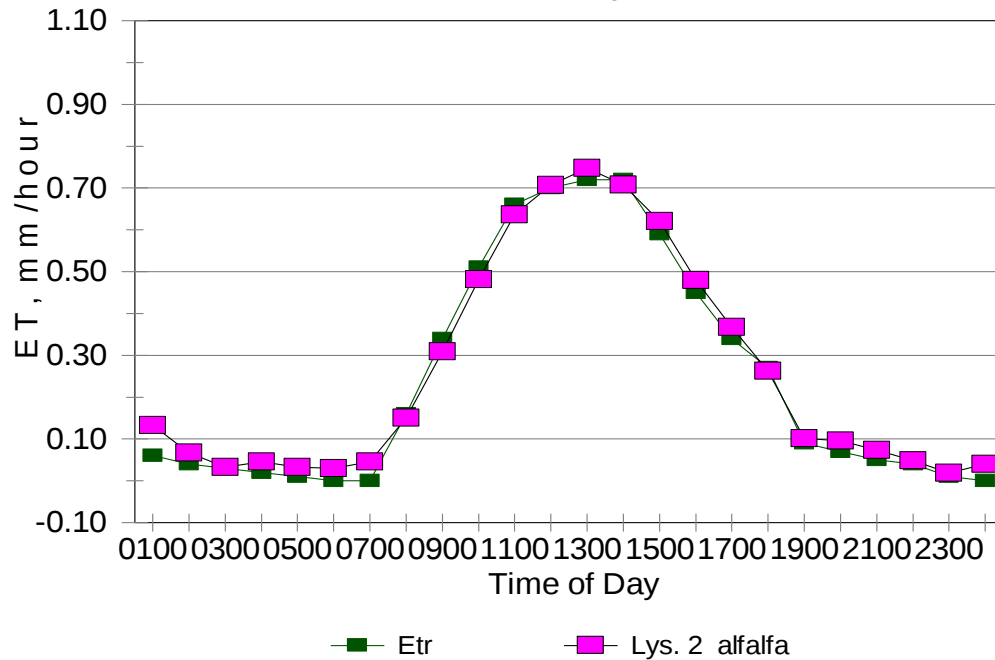


ASCE Penman-Monteith
is traceable to the
Kimberly, ID (USDA) and
Davis, CA Lysimeters



Kimberly Lysimeters - September 4, 1990

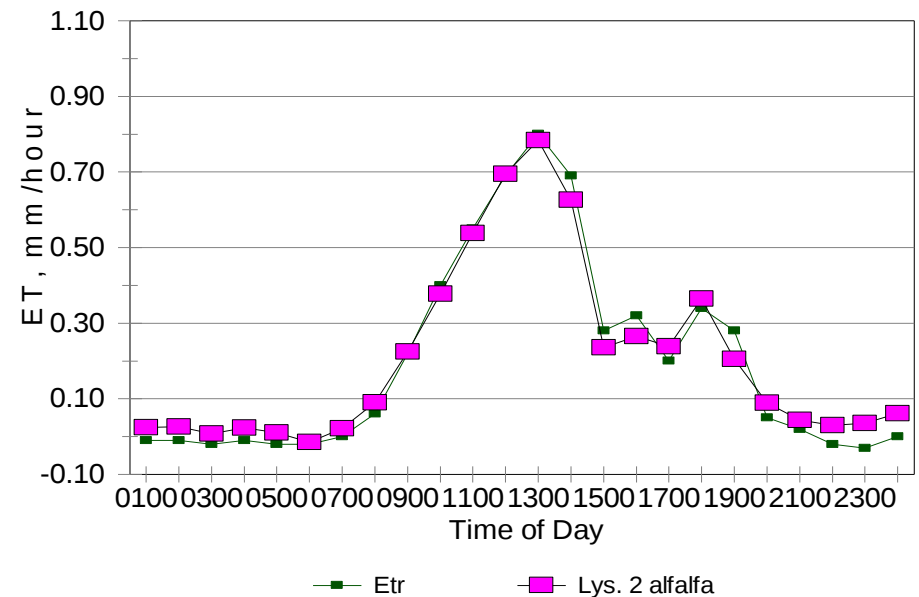
Data from Dr. J.L Wright

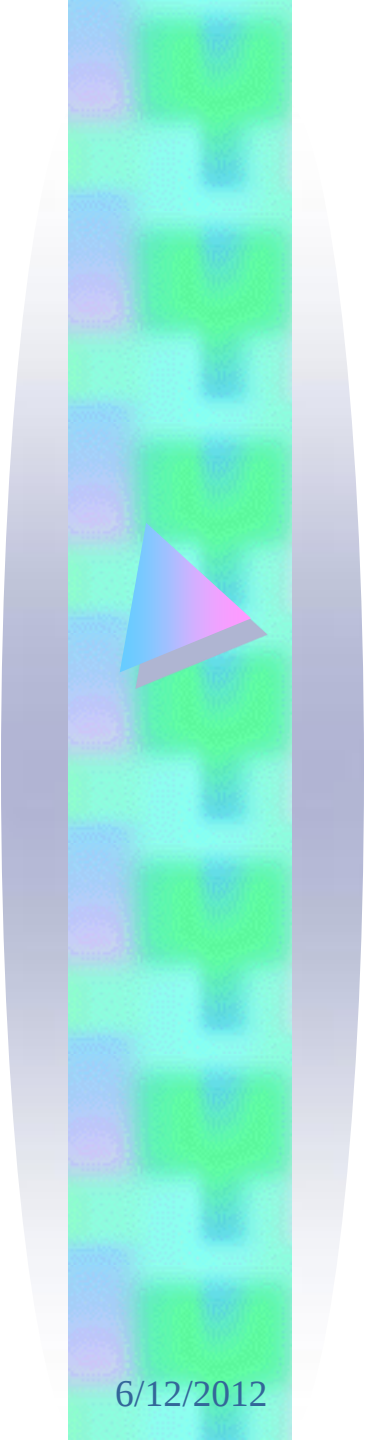


ASCE Standardized
Penman-Monteith
(alfalfa reference)
at Kimberly, Idaho

- hourly time step

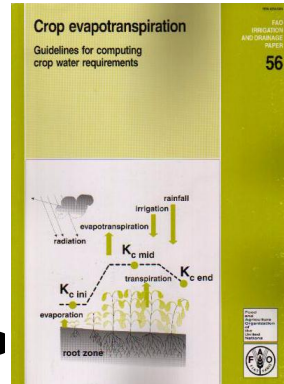
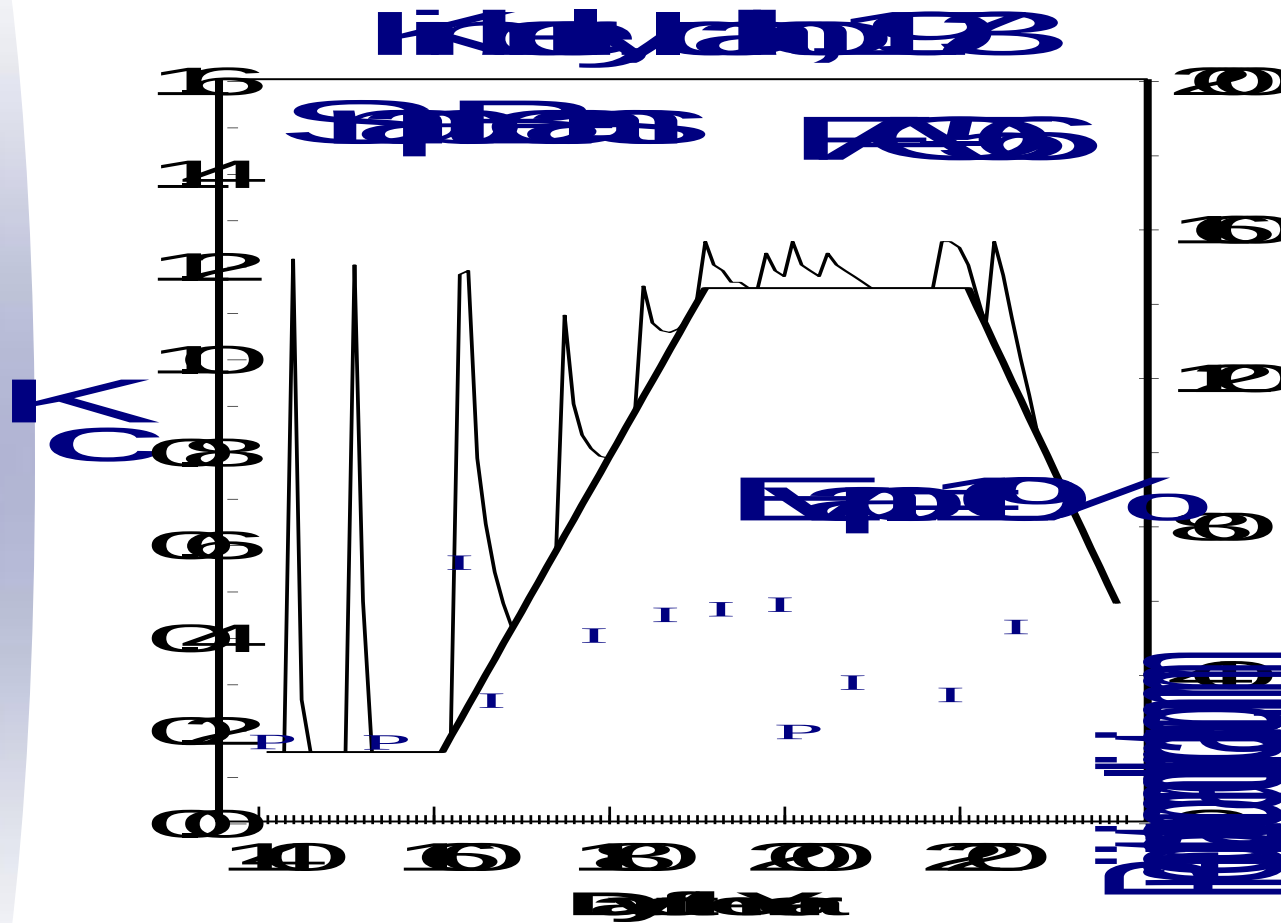
Kimberly Lysimeters -September 7, 1990



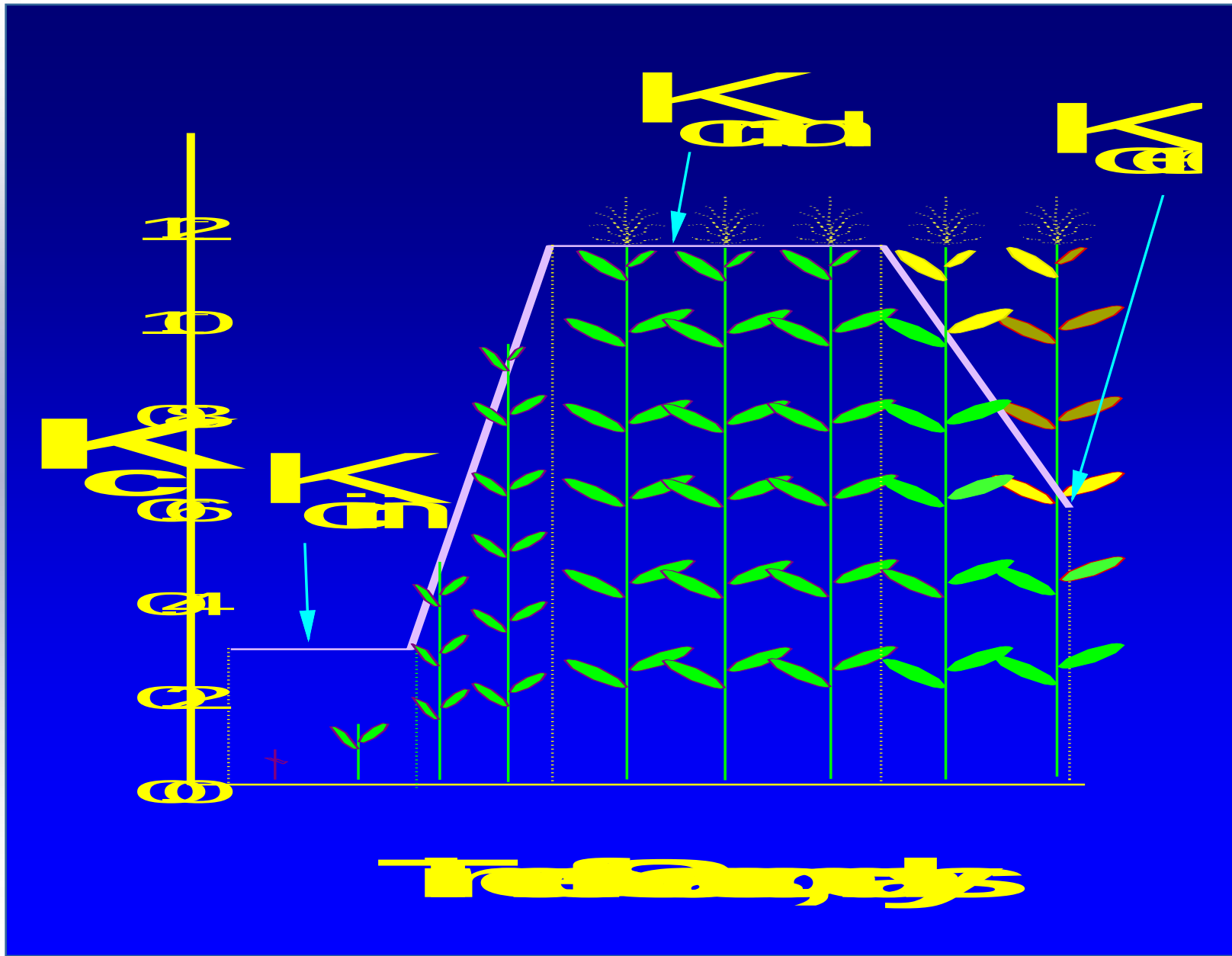


Crop Coefficients

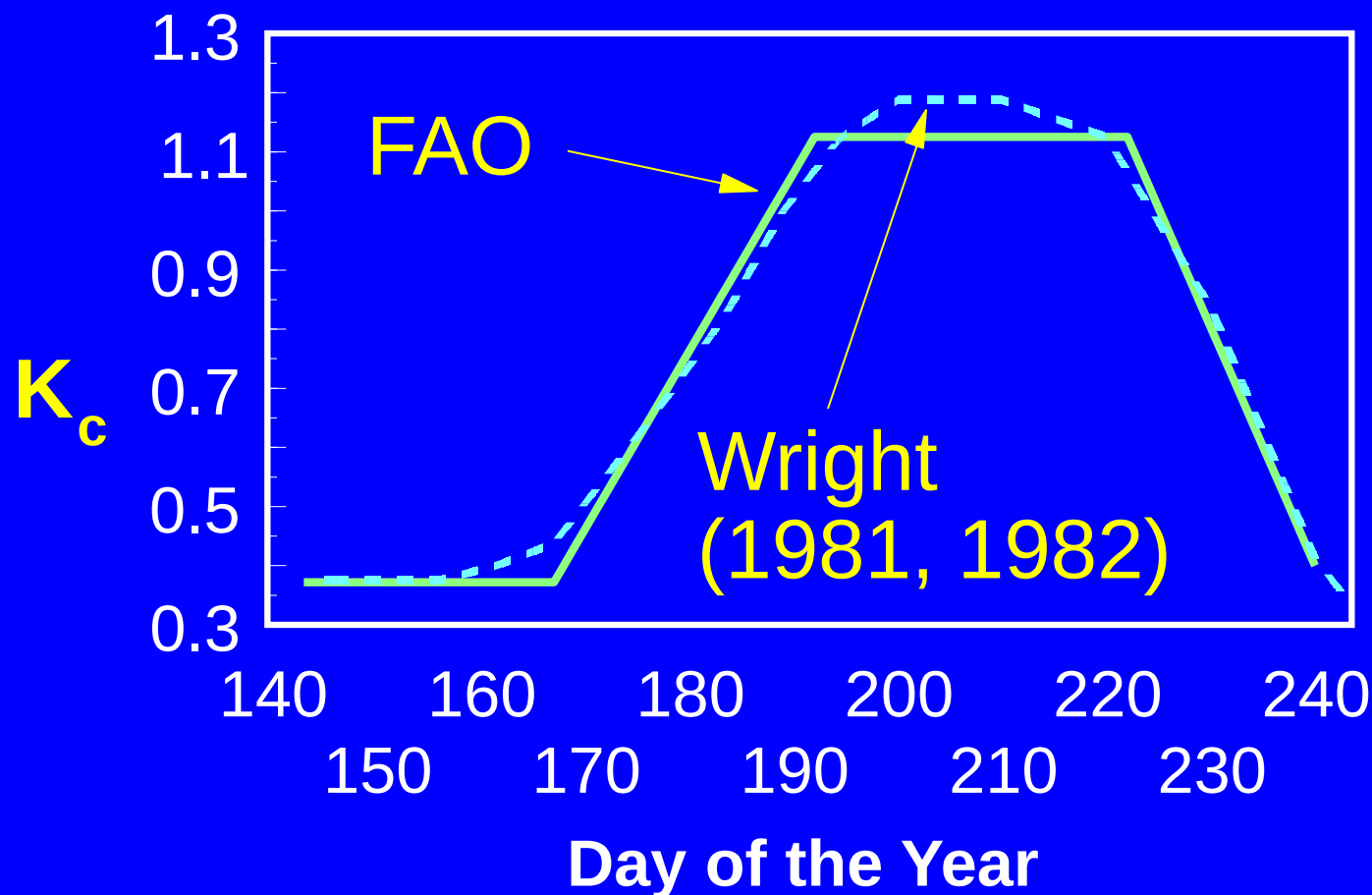
$$ET_c = K_c ET_{ref}$$

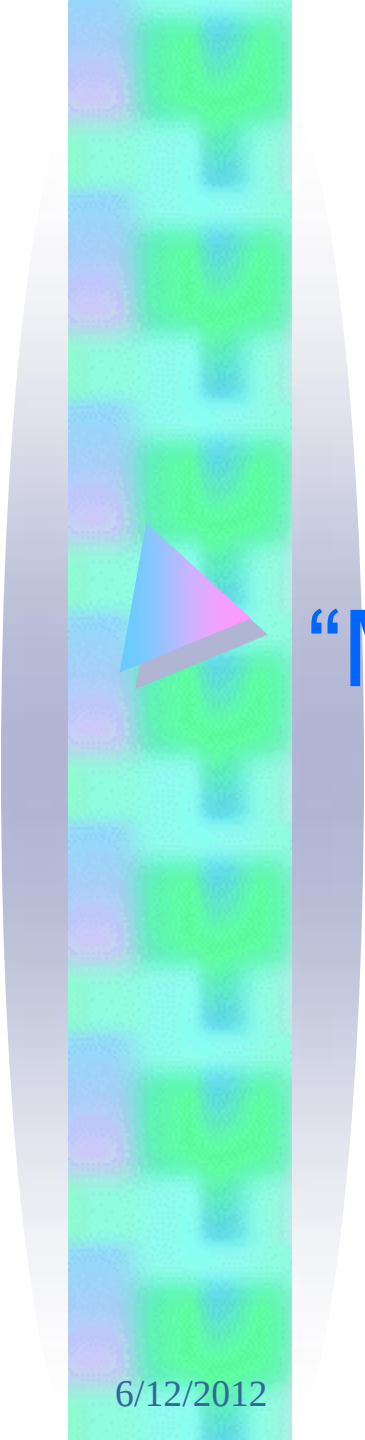


Crop Coefficient = ET/ET_{ref}



Crop Coefficient Curve Types





“Mean” vs. Dual K_c Approaches

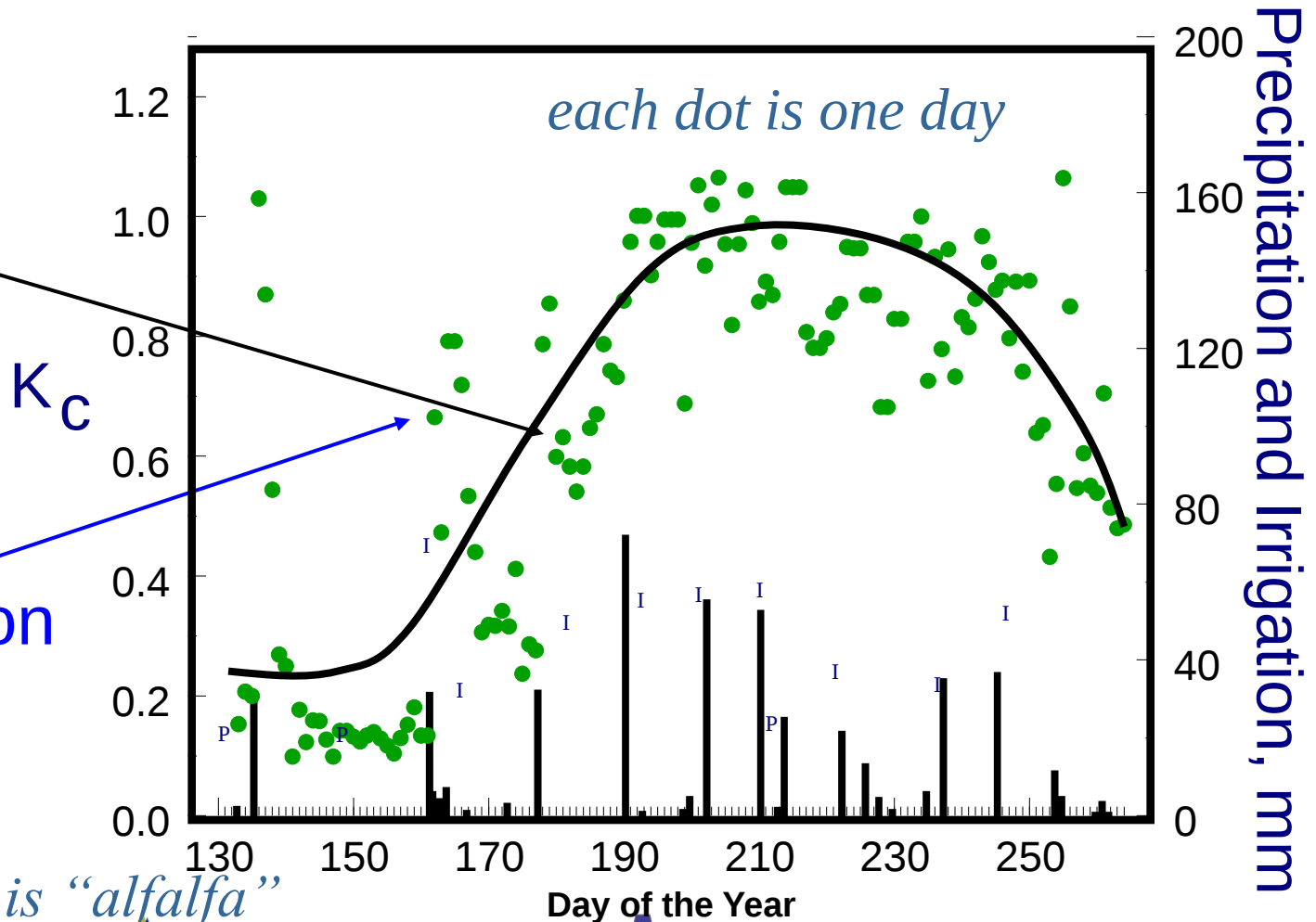
K_c from Lysimeter

Sweet Corn-- Kimberly, Idaho, 1976

“Mean”
Curve
averaging
“Spikes”

Wet Soil
Evaporation
“Spikes”
(K_e)

Reference type is “alfalfa”

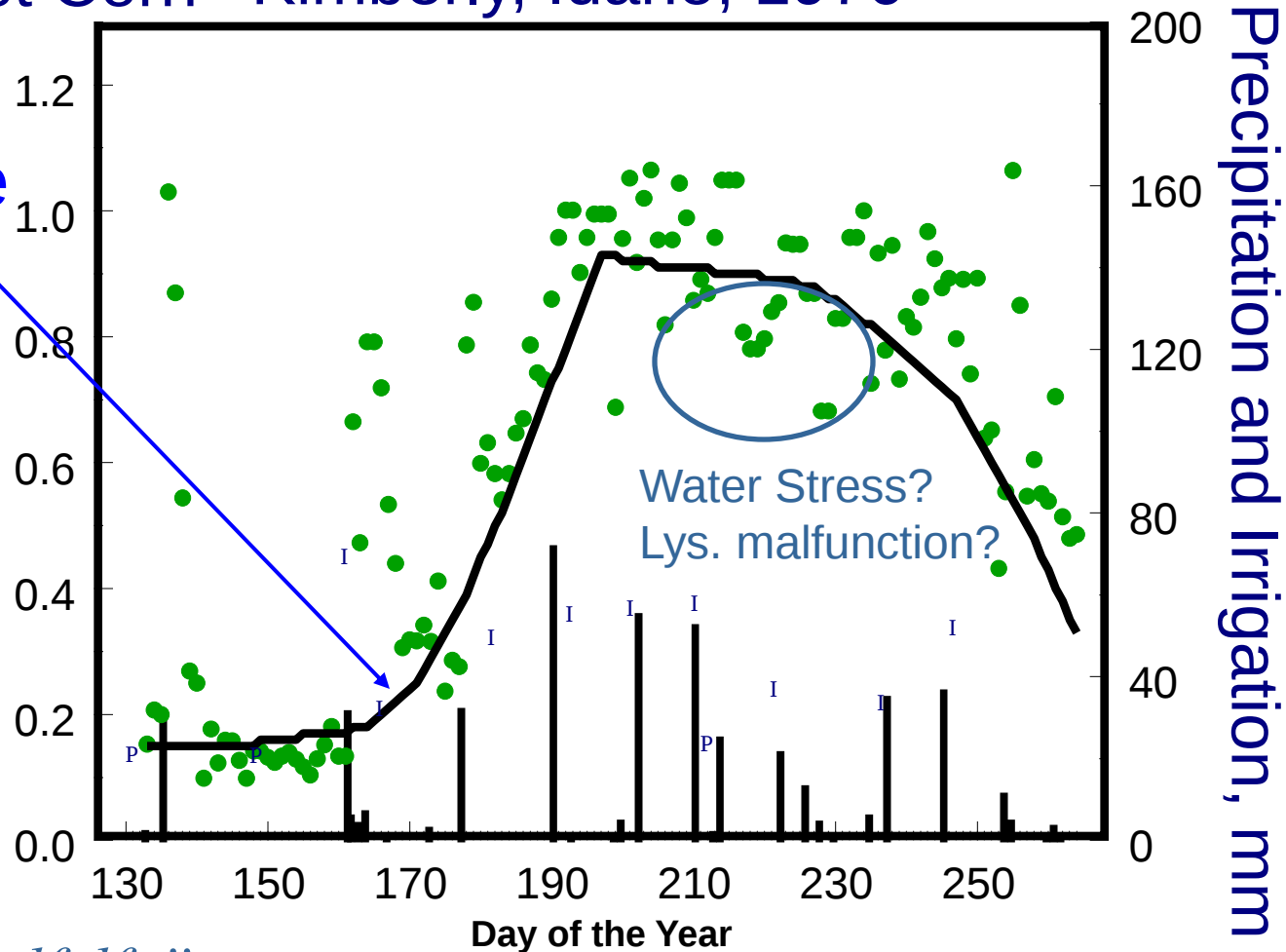


K_c from Lysimeter

Sweet Corn-- Kimberly, Idaho, 1976

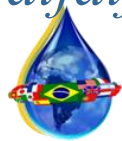
Basal K_c Curve
(K_{cb}) (drawn
by Wright)

K_c



Reference type is "alfalfa"

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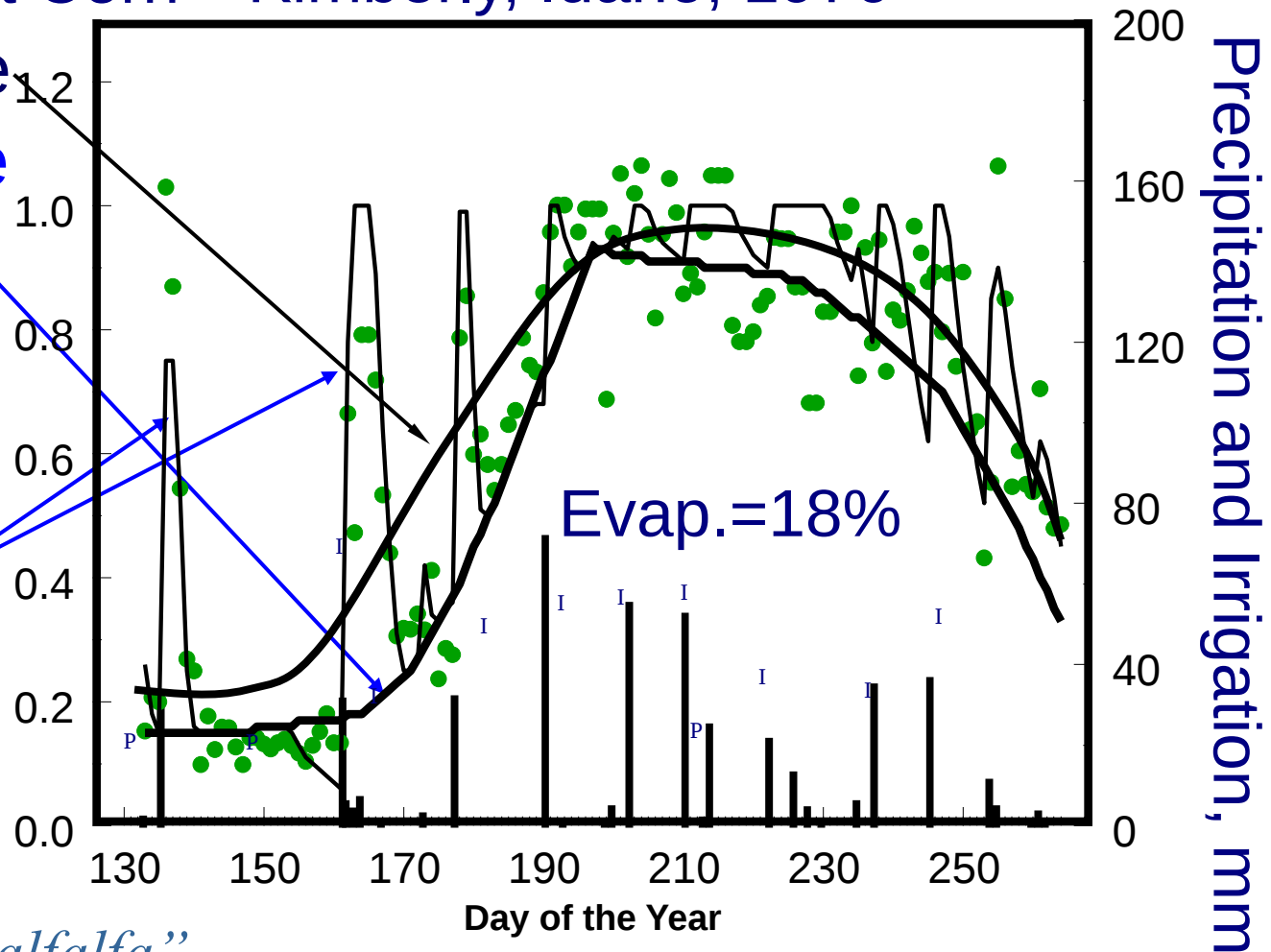
data courtesy of Dr. J.L. Wright, USDA-ARS

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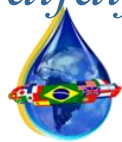
The “Dual K_c ” method Splits Soil Evaporation from Transpiration

Sweet Corn Kimberly, Idaho, 1976

“Mean” K_c Curve
Basal K_c Curve
(K_{cb})
 K_c
Wet Soil
Evaporation
“Spikes”
(K_e)



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

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‘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*)

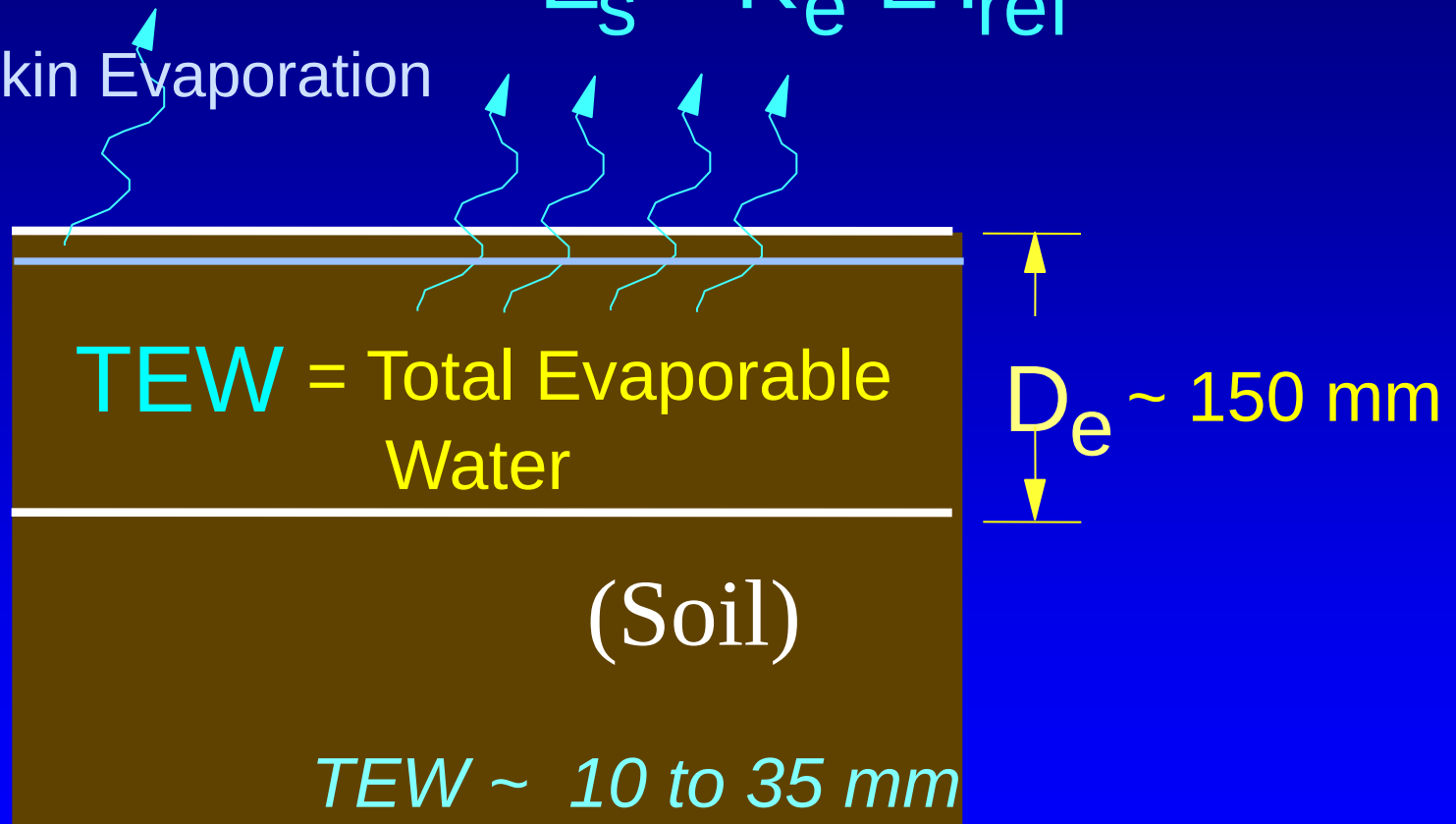
K_e = evaporation coefficient

Evaporation Coefficient - K_e

FAO-56 Simple Drying Function

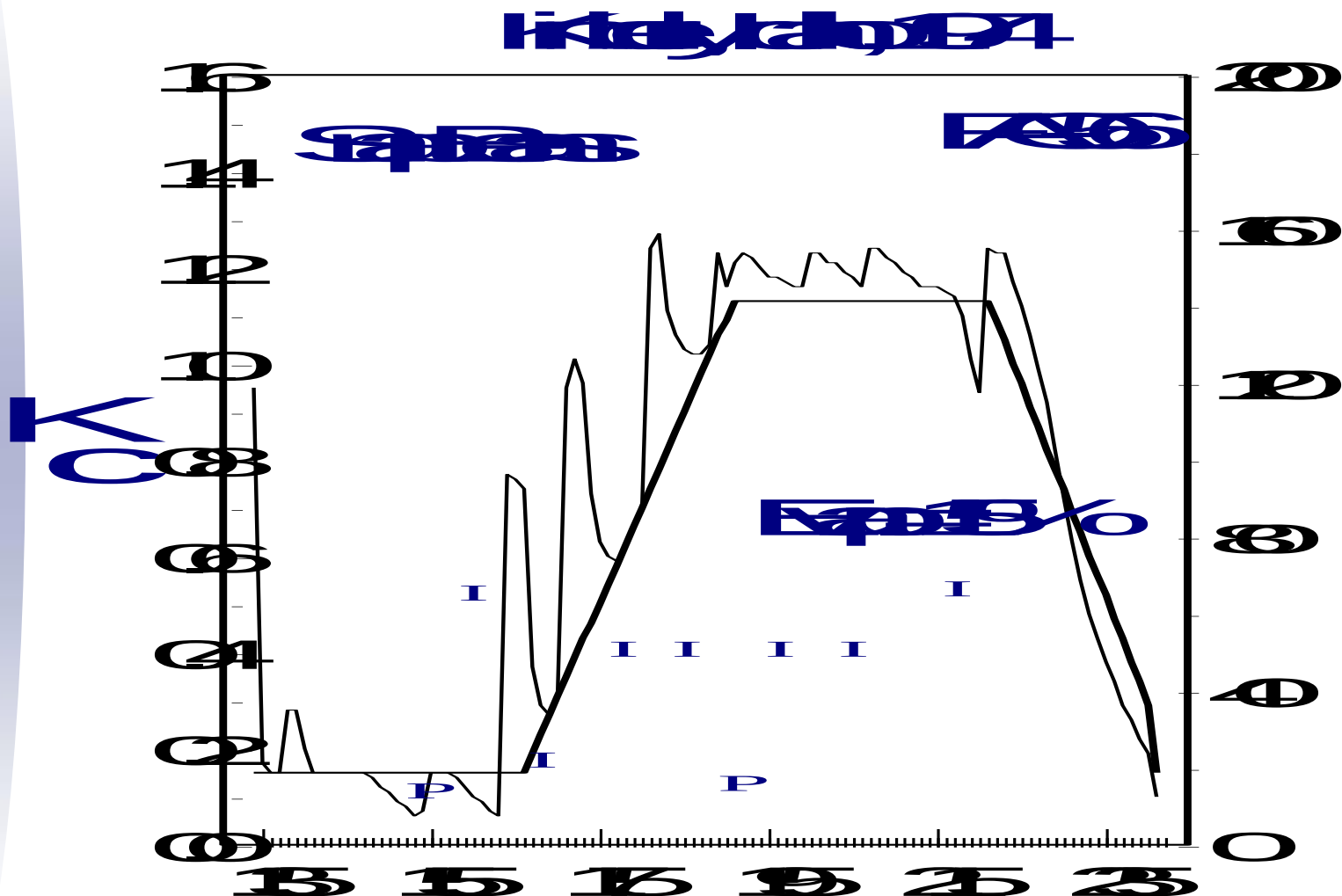
$$E_s = K_e ET_{ref}$$

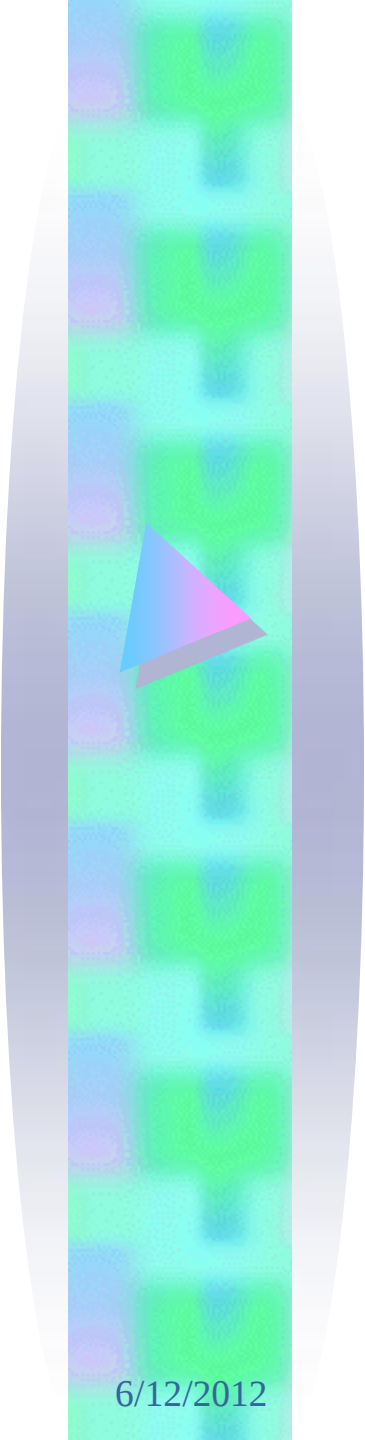
Skin Evaporation



FAO Style Crop Coefficient

Ratio = 0.99 SEE = 0.66 mm/day



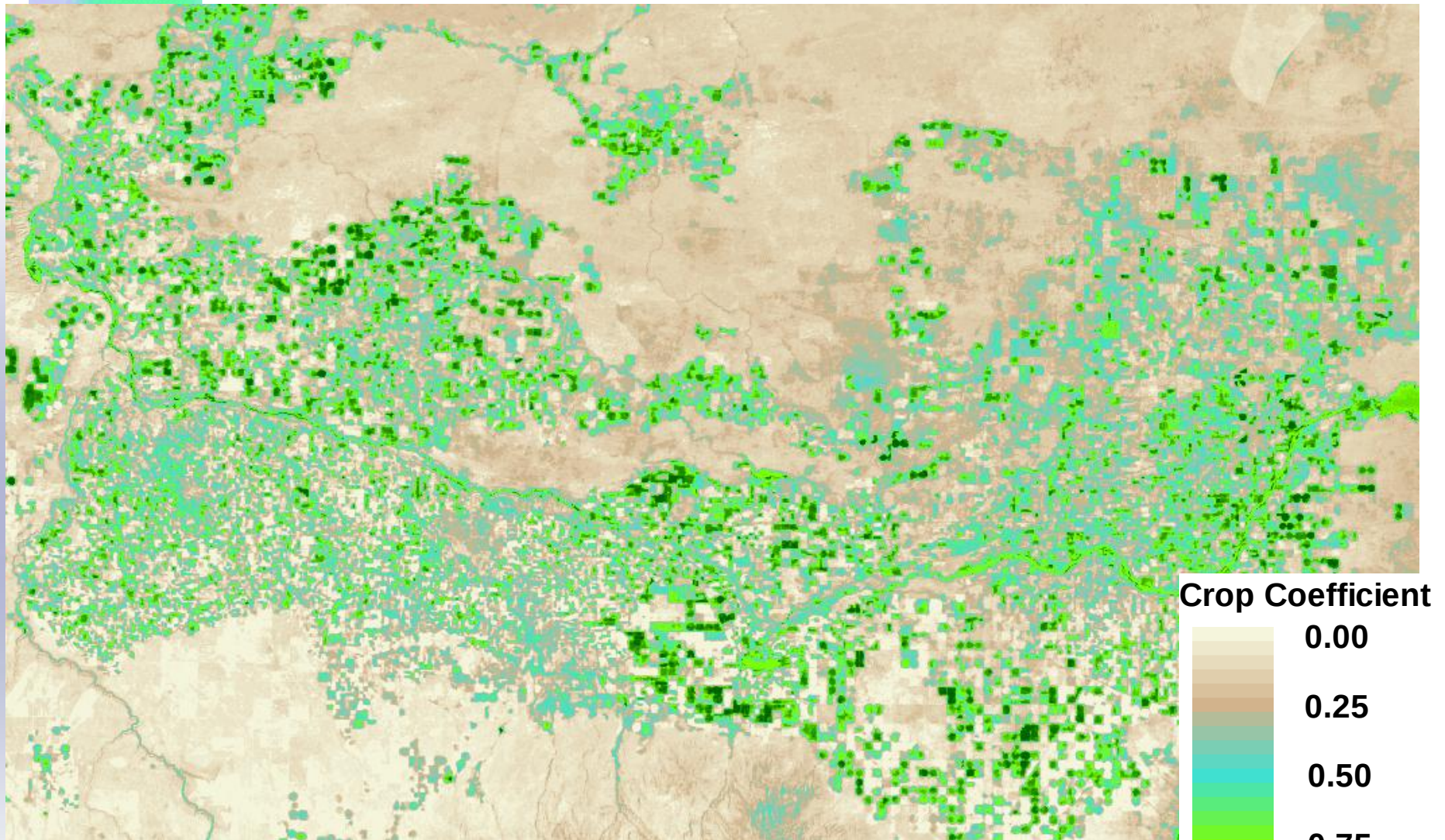


What about K_c Curves for all
the other fields ??

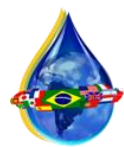
Vegetables - many types of culture



The “Population” of K_c varies among fields May 2, 2000



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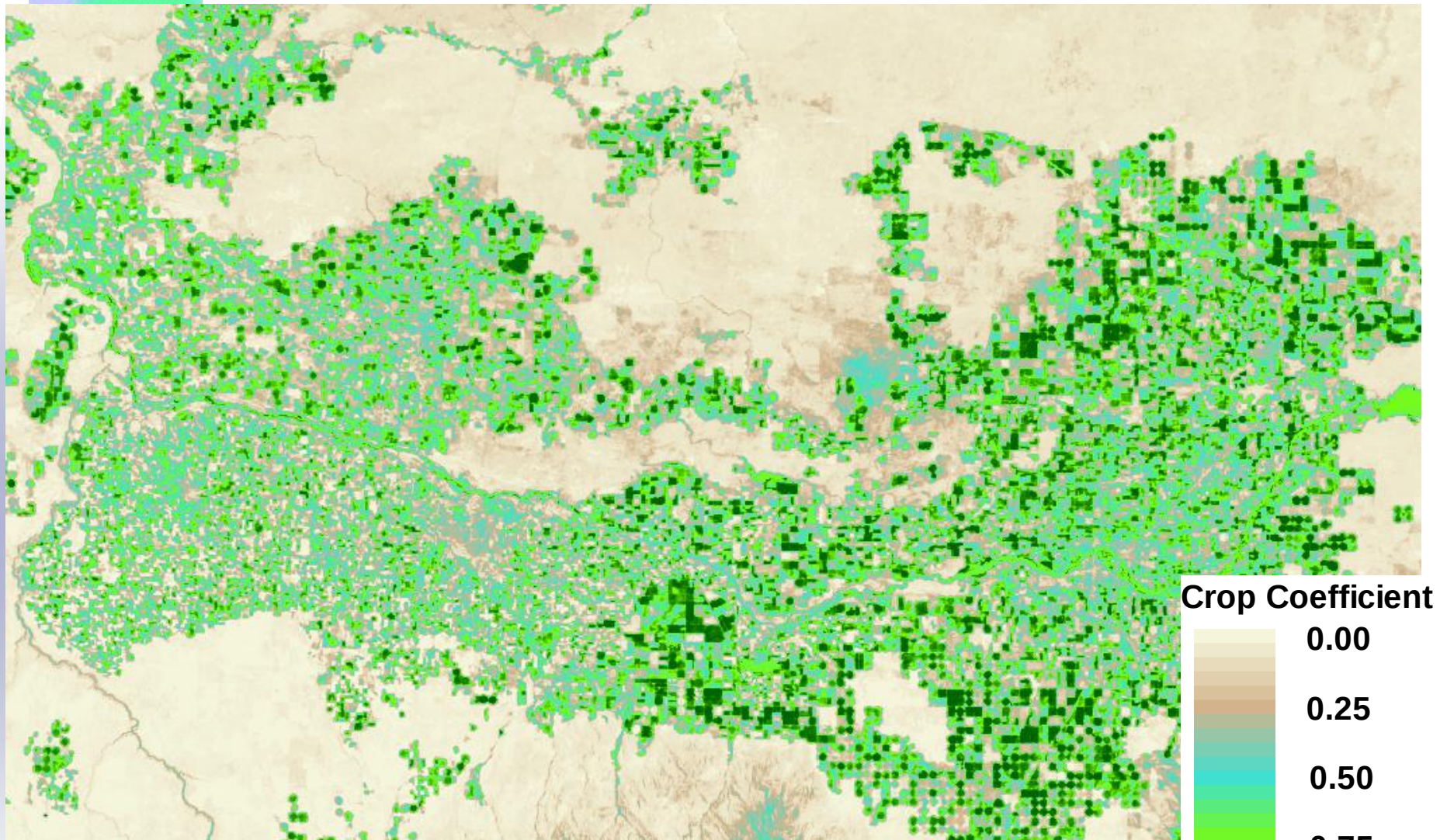
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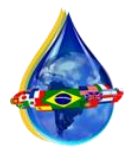


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June 3, 2000



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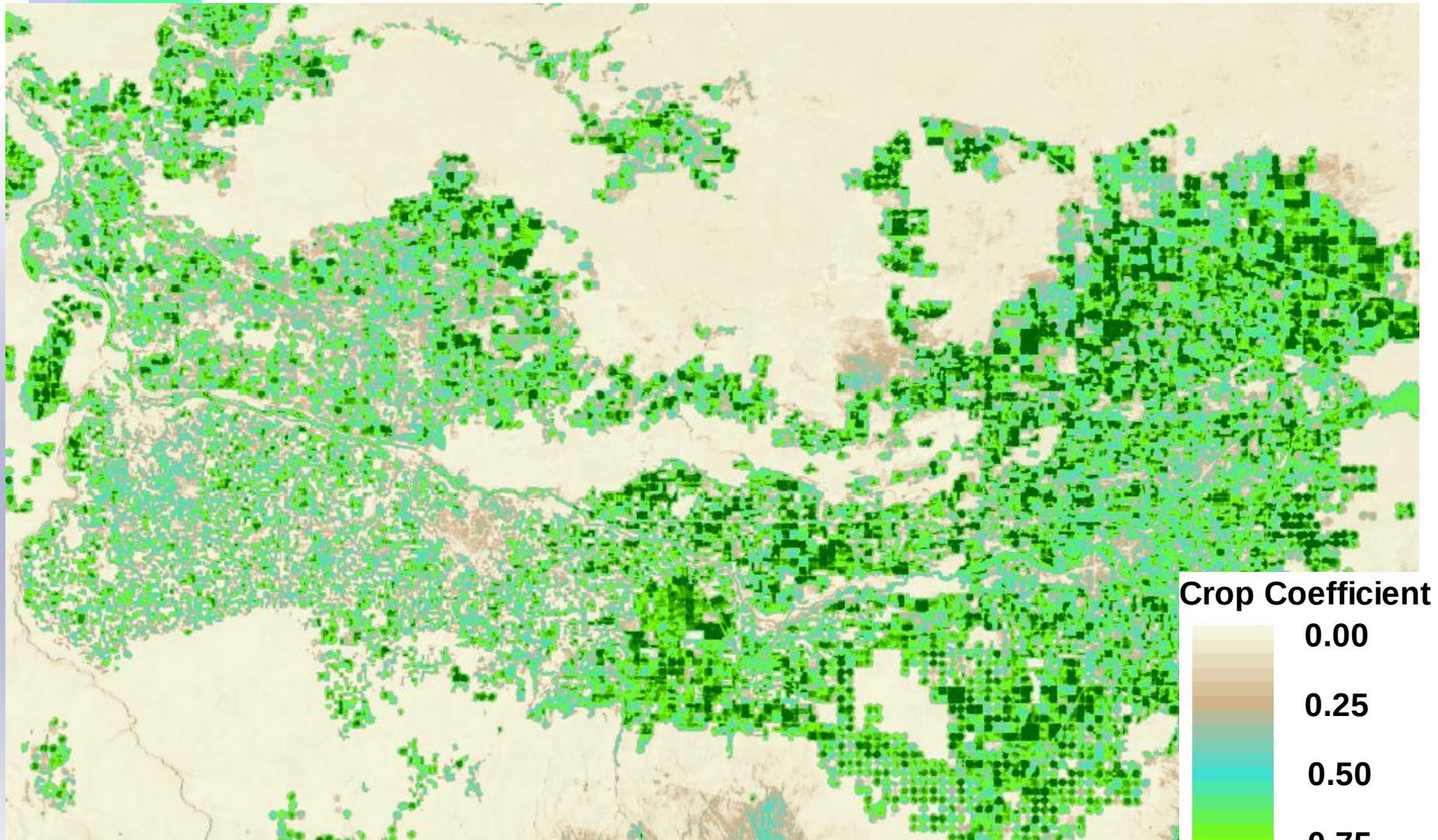
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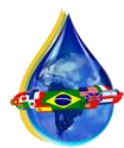


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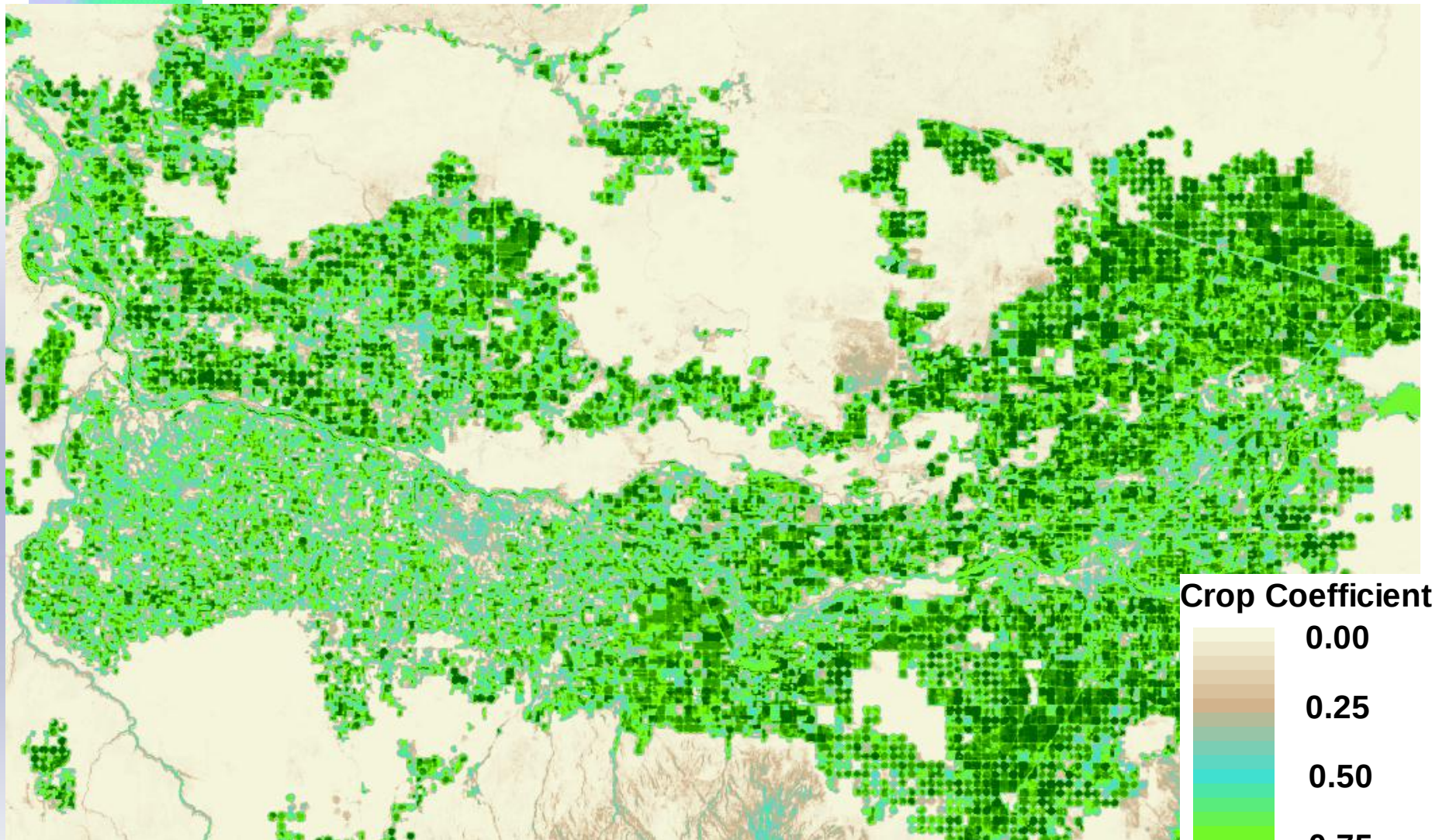
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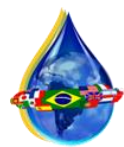


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July 5, 2000



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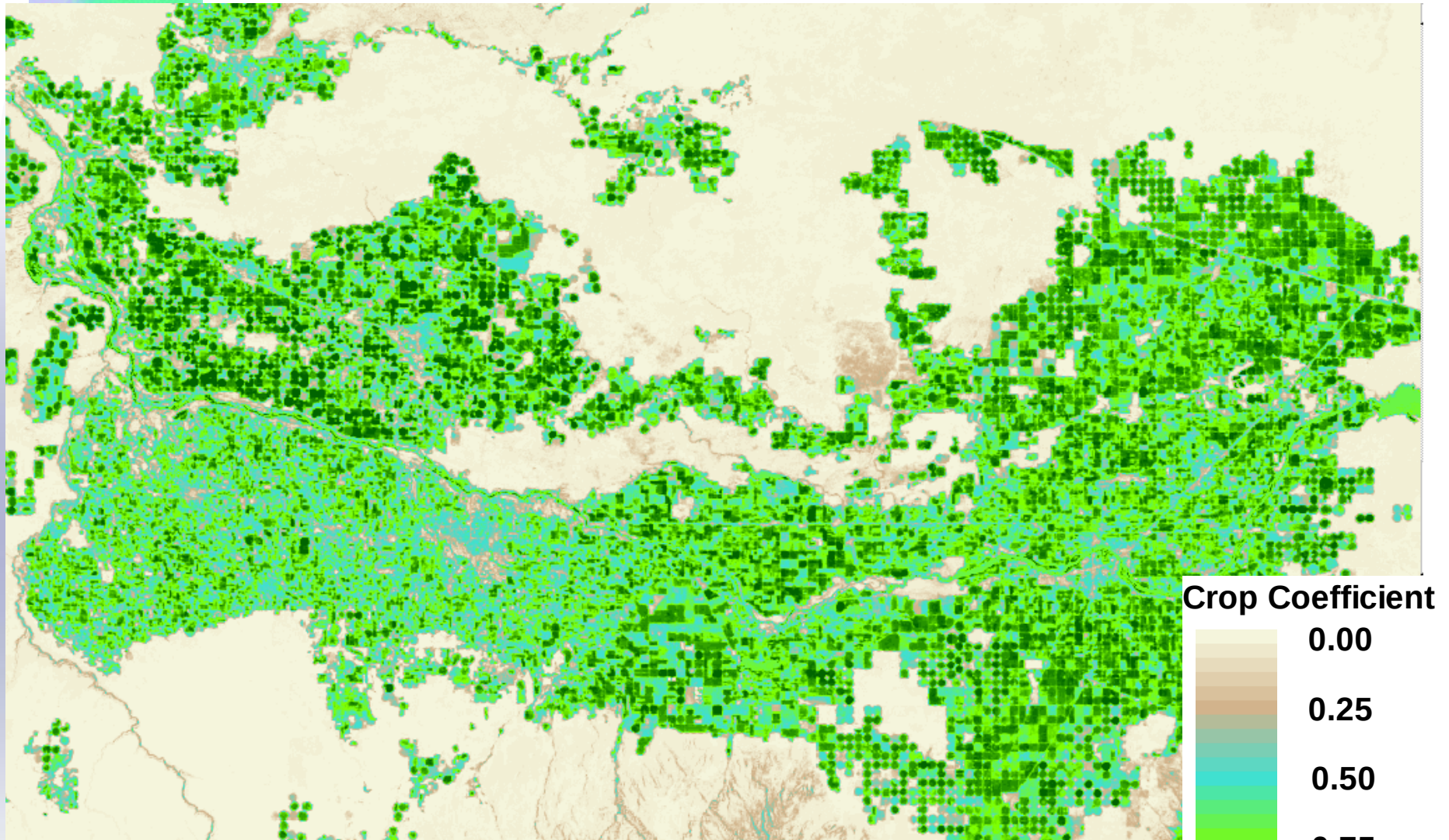
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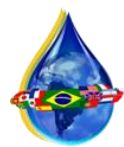


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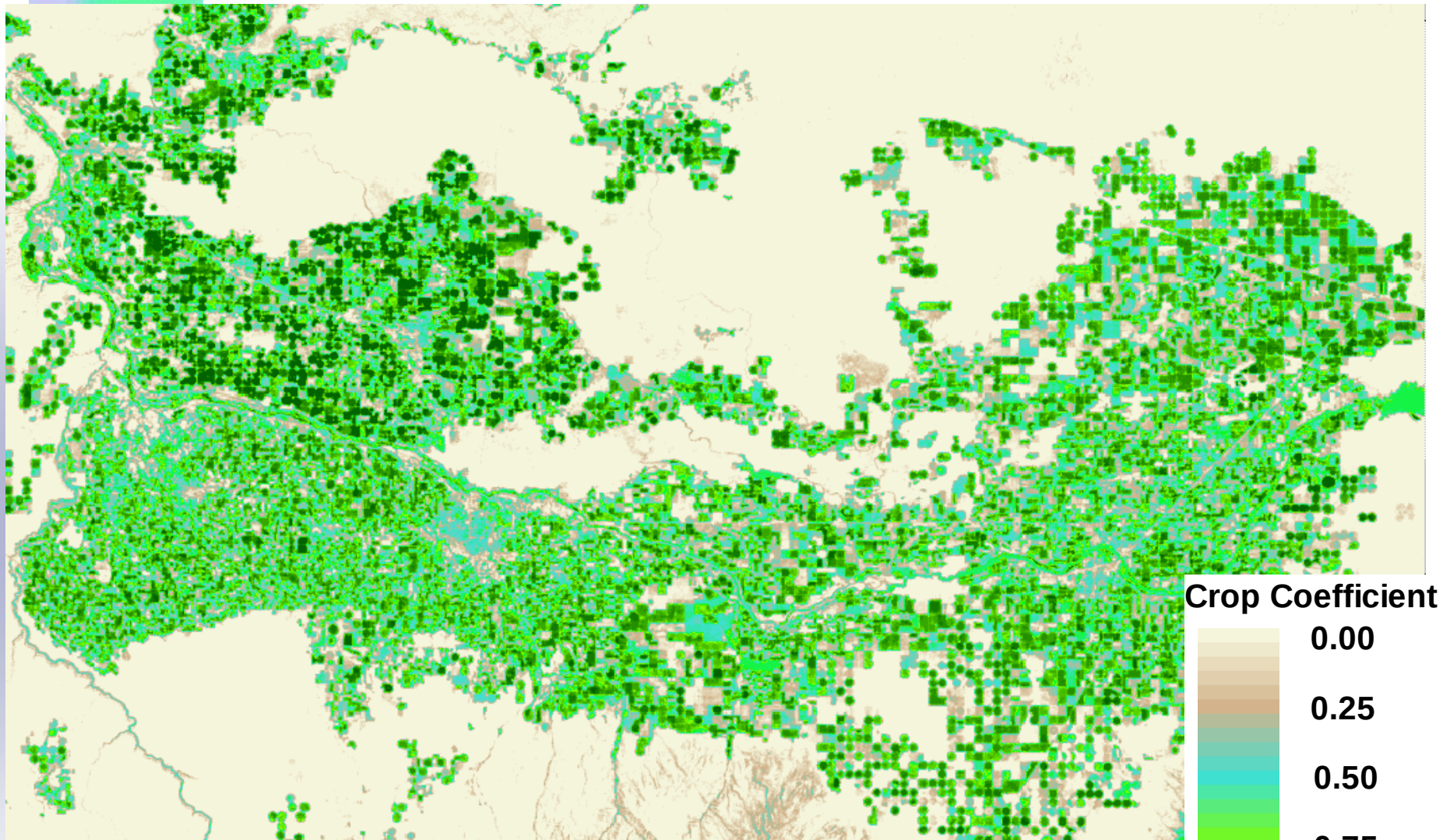
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Crop Coefficient

0.00

0.25

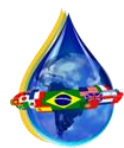
0.50

0.75

1.00

1.25

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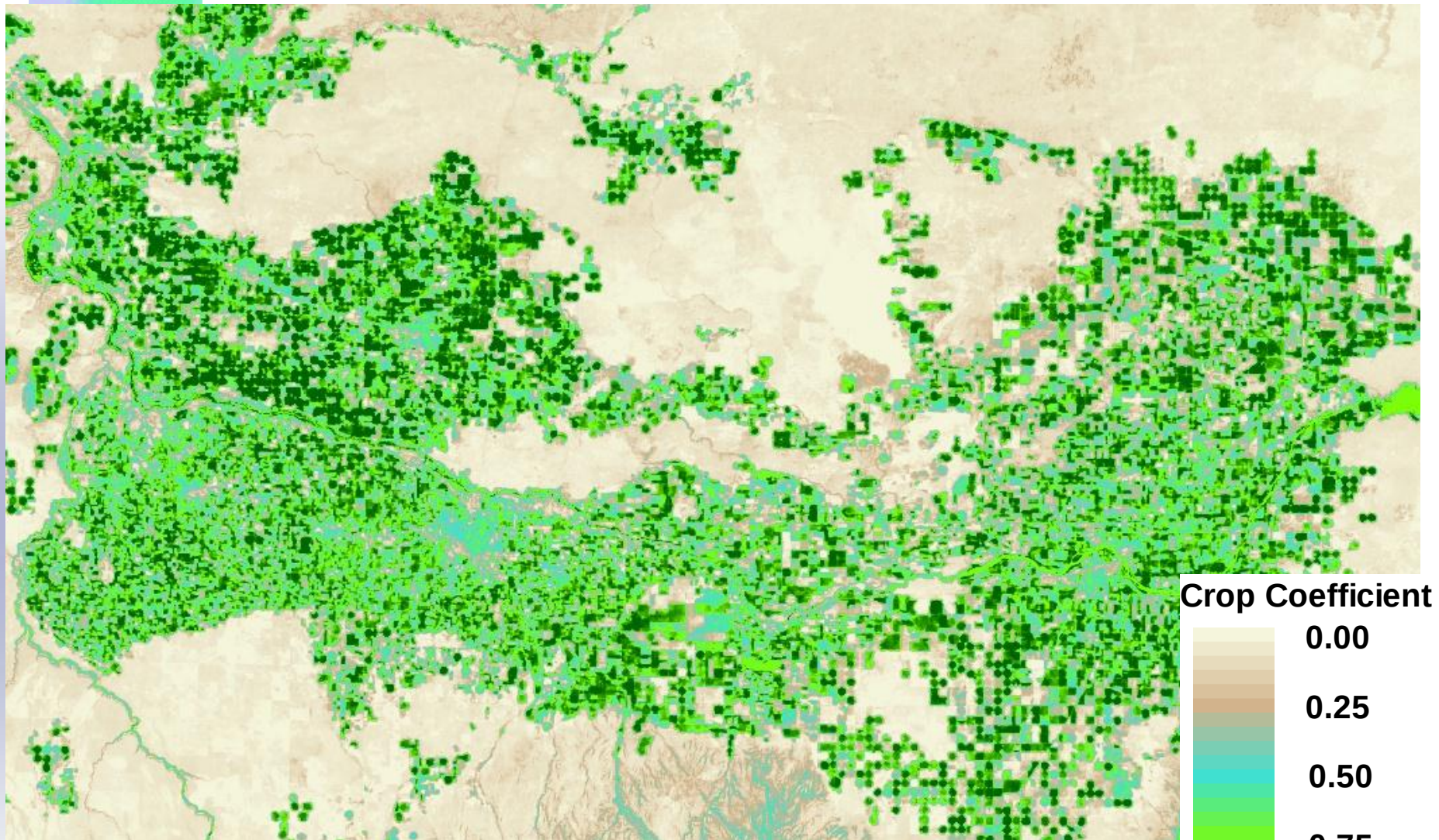
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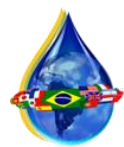


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Fact -- ET is constrained by Energy Availability

$$ET = R_n - G - H$$

R_n (radiation from sun and sky)

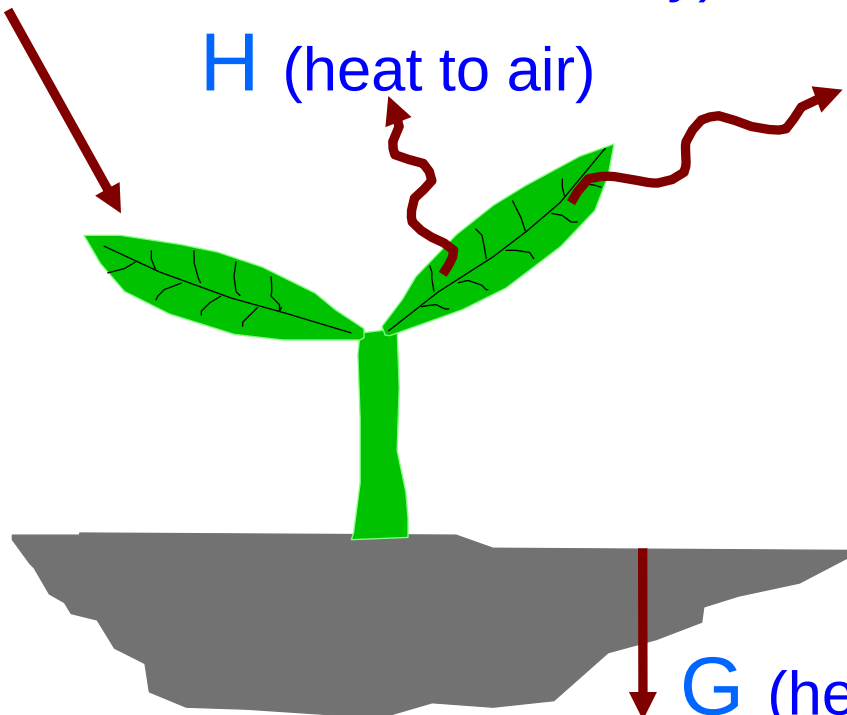
H (heat to air)

ET

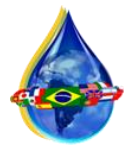
The energy balance includes all major sources (R_n) and consumers (ET , G , H) of energy

Basic Truth:

Evaporation
consumes
Energy



G (heat to ground)



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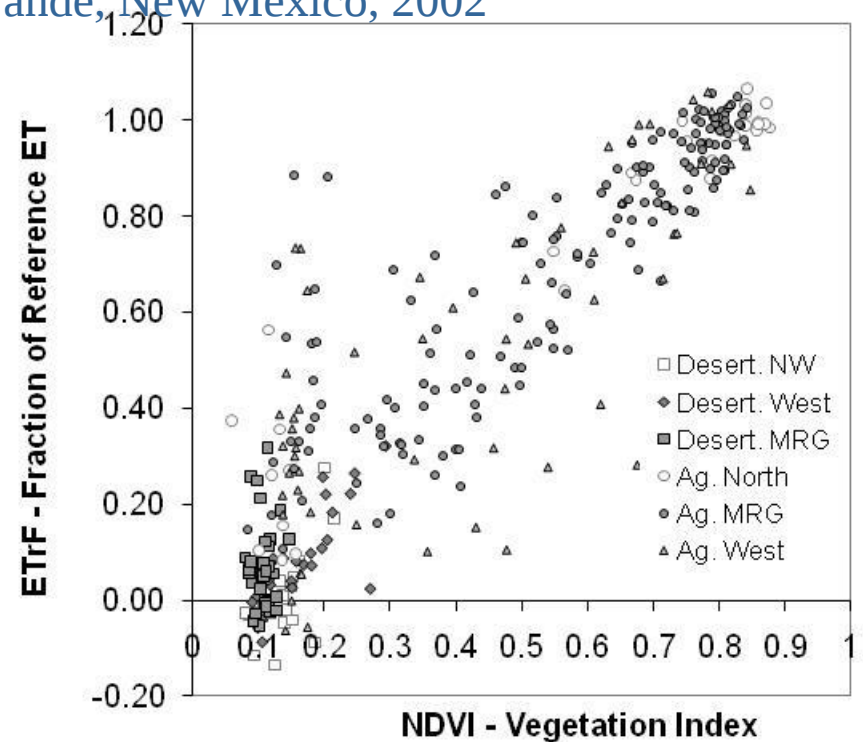
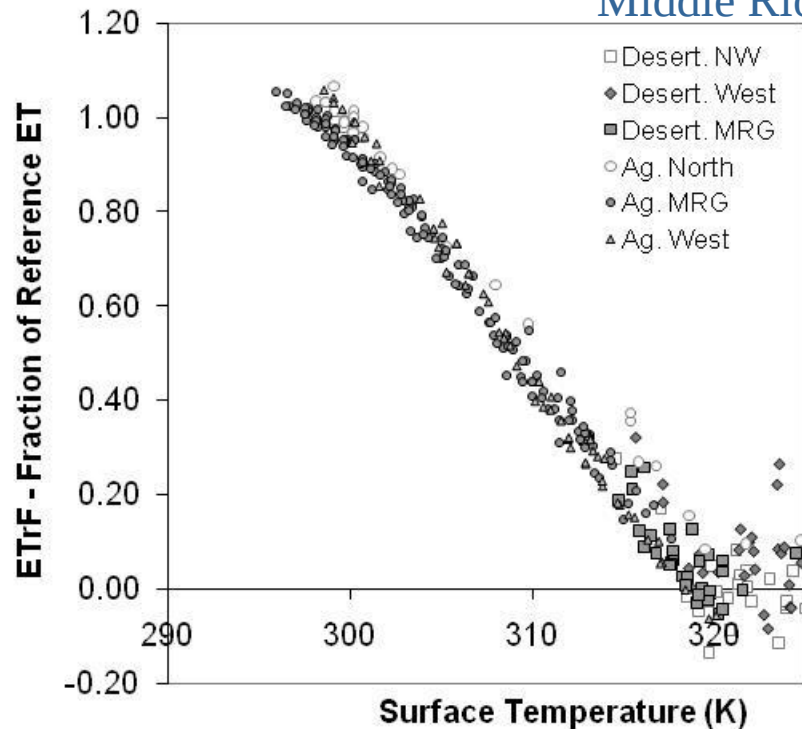


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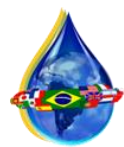
Why use Energy Balance (and “Surface Temperature”)?

-- ET is more influenced by Surface Temperature, rather than with Vegetation Amount

Middle Rio Grande, New Mexico, 2002



ET_rF = fraction of reference ET (ET_rF is same as crop coefficient)



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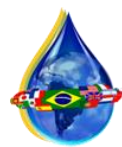
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Energy balance gives us “actual” ET

We can ‘see’ impacts on ET caused by:

- water shortage
- disease
- crop variety
- planting density
- cropping dates
- salinity
- management

• *(these effects can be converted into a crop coefficient)*



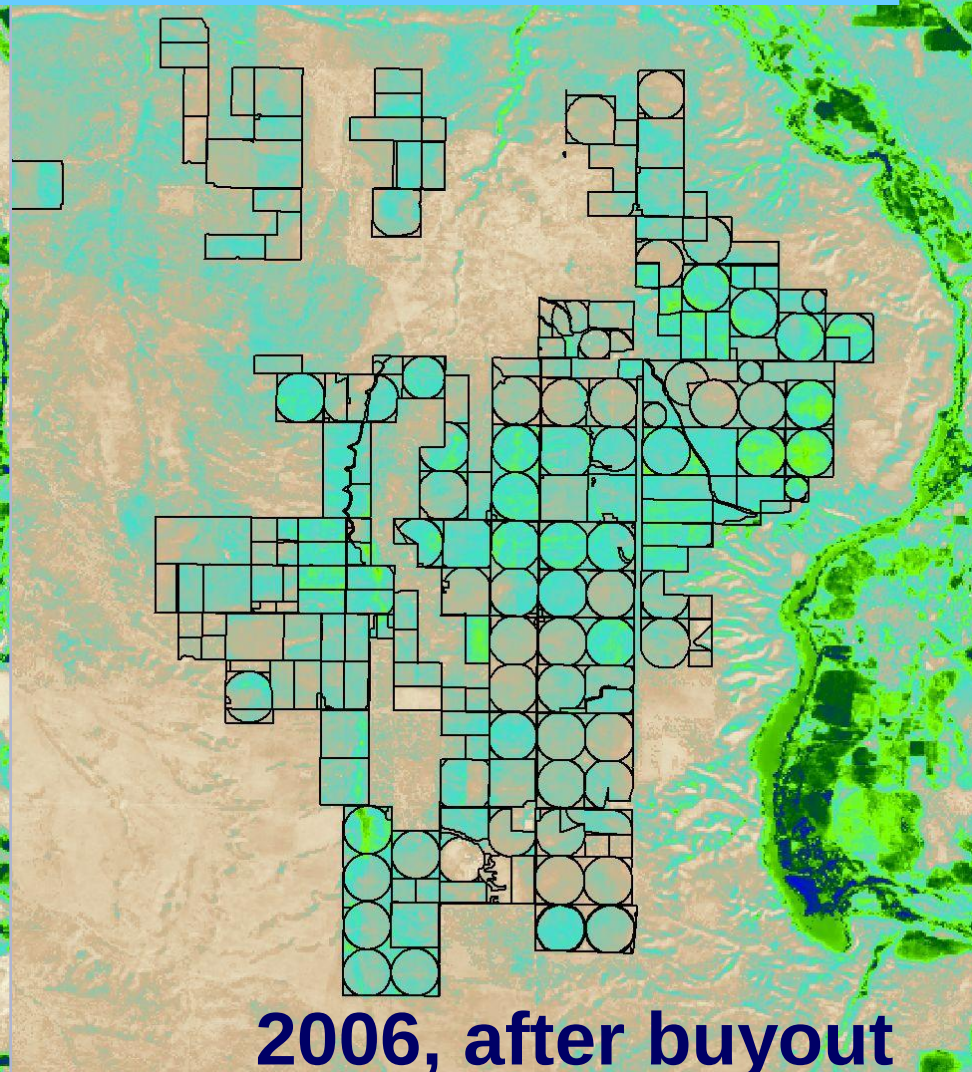
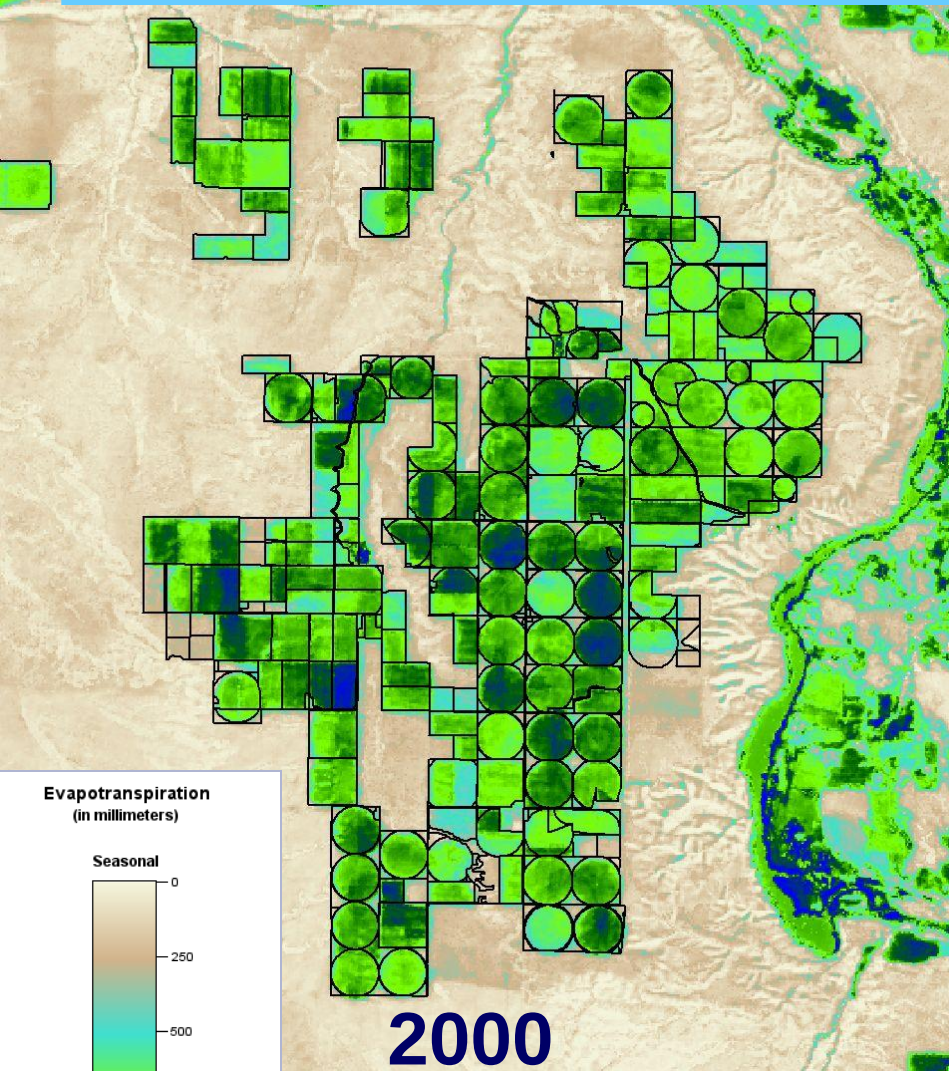
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Bell Rapids Irrigation Project, Idaho: Seasonal ET



- High lift pumps irrigated 12,000 ha
- State purchased water rights in 2005 for \$24 million
- Supports endangered salmon



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ET Investigations involving METRIC/Landsat -- Applications for Water Management

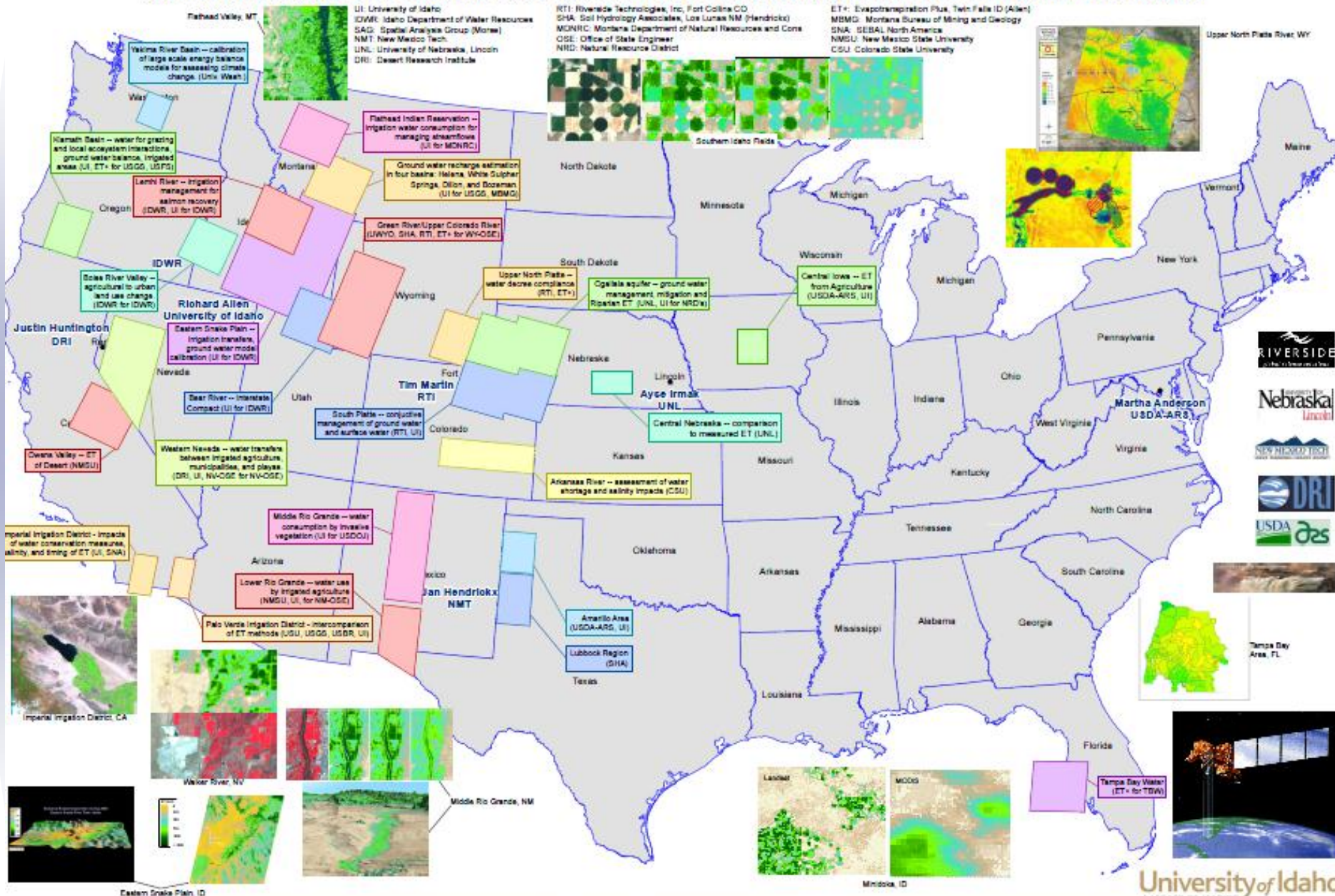
University of Idaho and Associates/Partners

Richard Allen (UI), Ricardo Trezza (UI), Bill Kramber (IDWR), Tony Morse (SAG), Jan Hendrickx (NMT), Ayse Irmak (UNL), Justin Huntington (DRI), Clarence Robison (UI), Carlos Kelly (UI), Jeppe Kjaersgaard (UI), Jeremy Greth (UI), Masahiro Tasumi (UI), Tim Martin (RTI)

UI: University of Idaho
IDWR: Idaho Department of Water Resources
SAG: Spatial Analysis Group (Morse)
NMT: New Mexico Tech
UNL: University of Nebraska, Lincoln
DRI: Desert Research Institute

RTI: Riverside Technologies, Inc., Fort Collins, CO
SHA: Soil Hydrology Associates, Los Lunas, NM (Hendrickx)
MONRC: Montana Department of Natural Resources and Conservation
OSE: Office of State Engineer
NRD: Natural Resource District

ET+: Evapotranspiration Plus, Twin Falls, ID (Allen)
MBMG: Montana Bureau of Mining and Geology
SNA: SEBAL, North America
NMSU: New Mexico State University
CSU: Colorado State University



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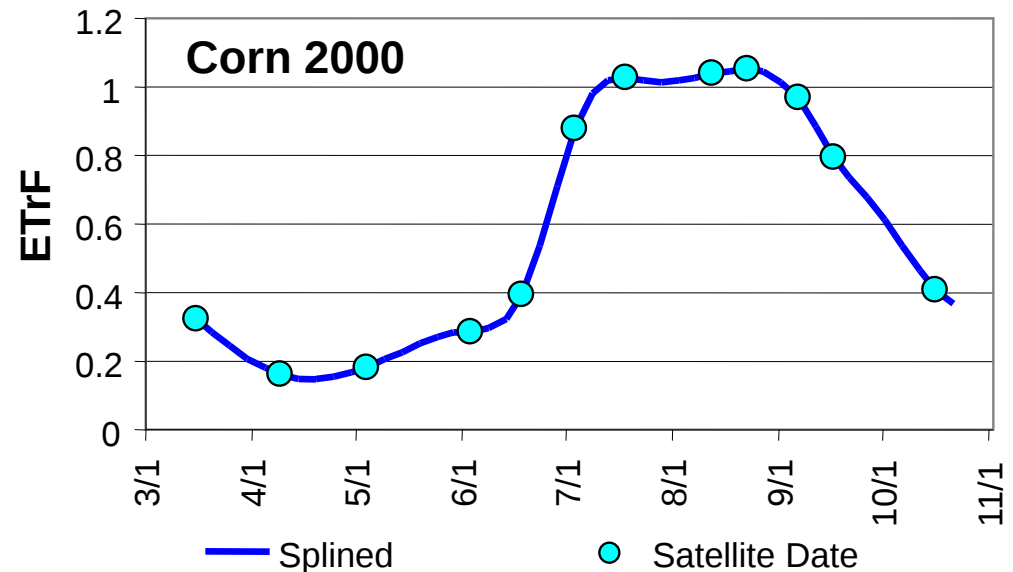
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March 21-22, 2008, Yamaguchi, Japan

How do we Interpolate/Integrate for Monthly or Seasonal ET from Satellite?

$ET_r F$ = fraction of reference
(potential) ET

(same as crop coefficient)



$$ET_{period} = \int ET_r F_t \times ET_{r24t} dt$$

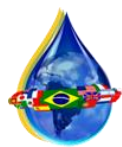
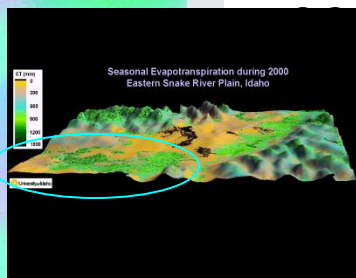
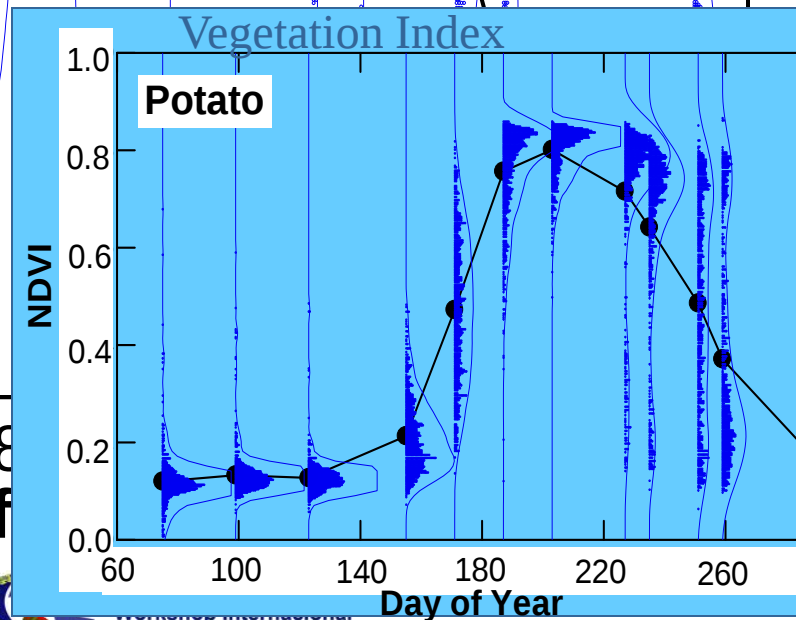
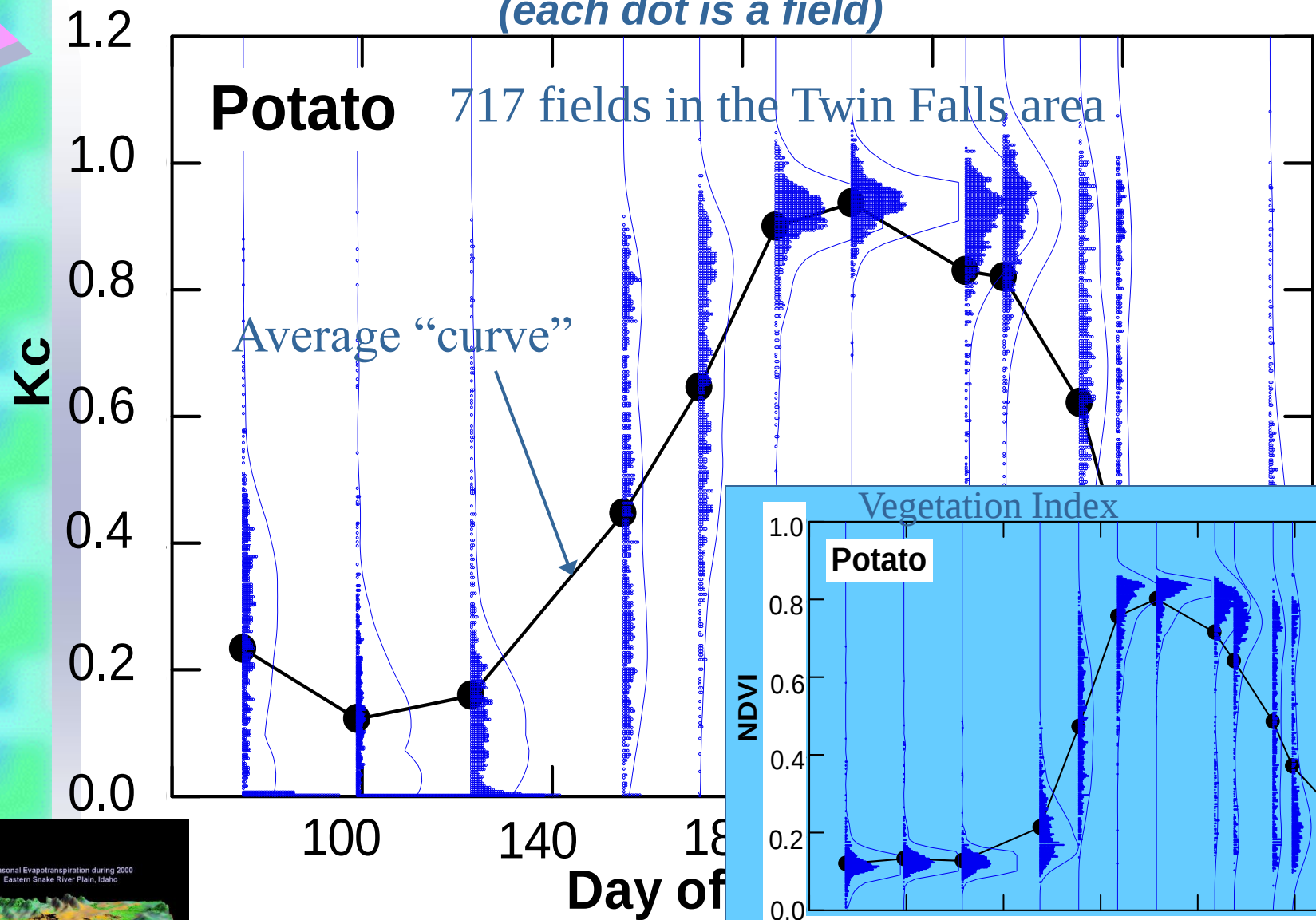
$$ET_r F_{period} = \frac{\int ET_r F_t \times ET_{r24t} dt}{\int ET_{r24t} dt}$$

ET_{r24} accounts for daily weather effects



Populations of K_c from Potato Fields

(each dot is a field)



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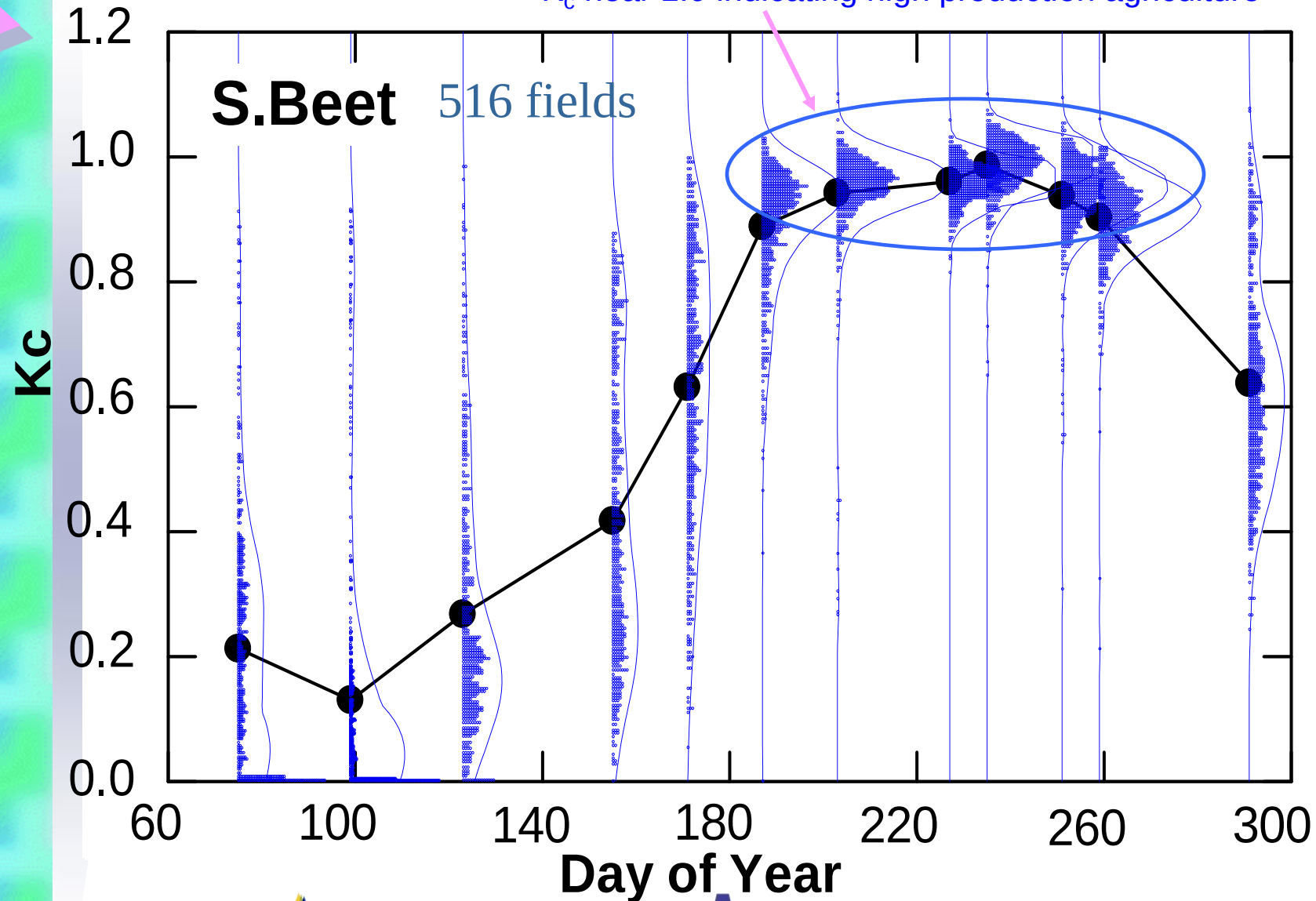
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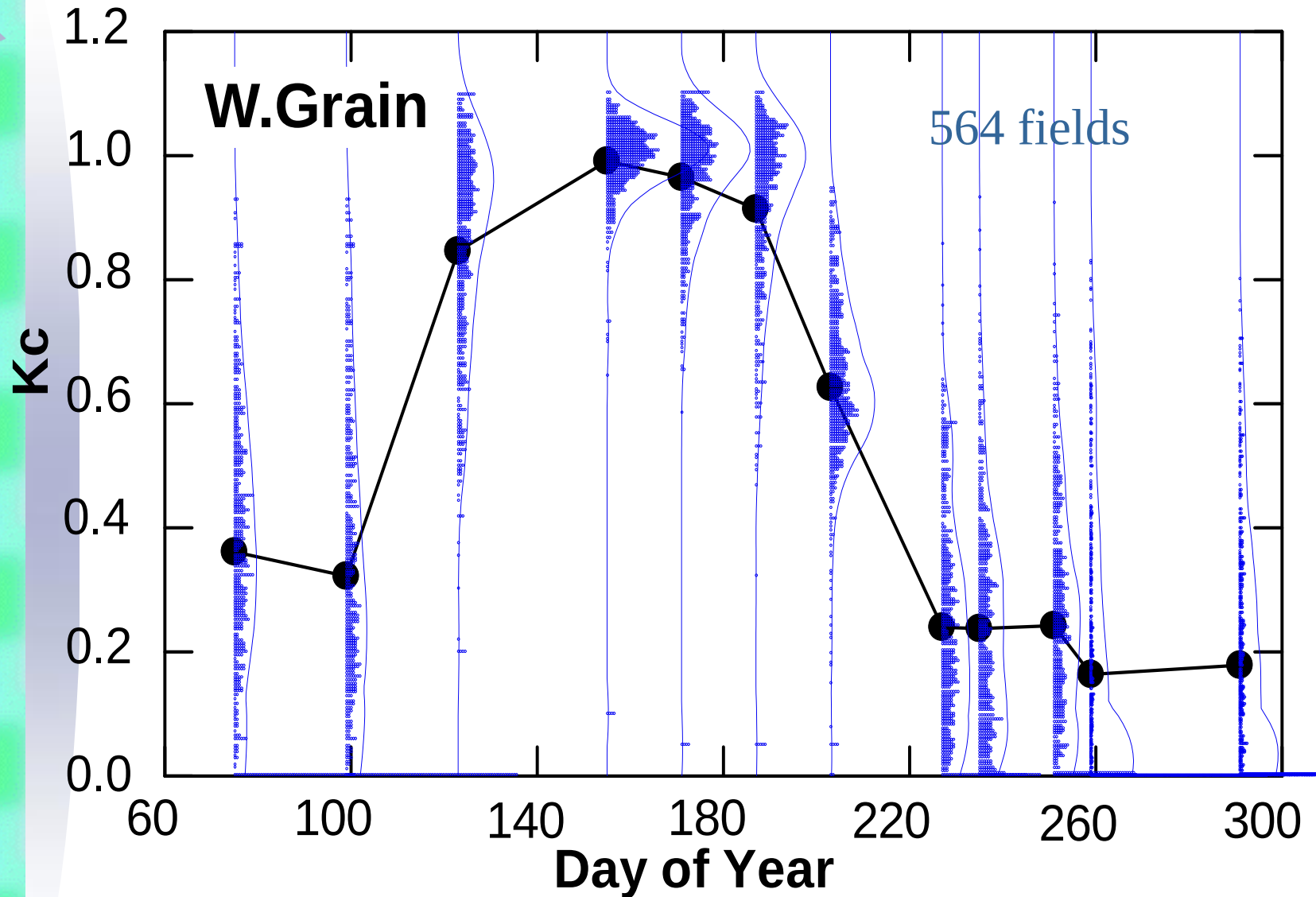
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Populations of K_c from Sugar Beet Fields

K_c near 1.0 indicating high production agriculture

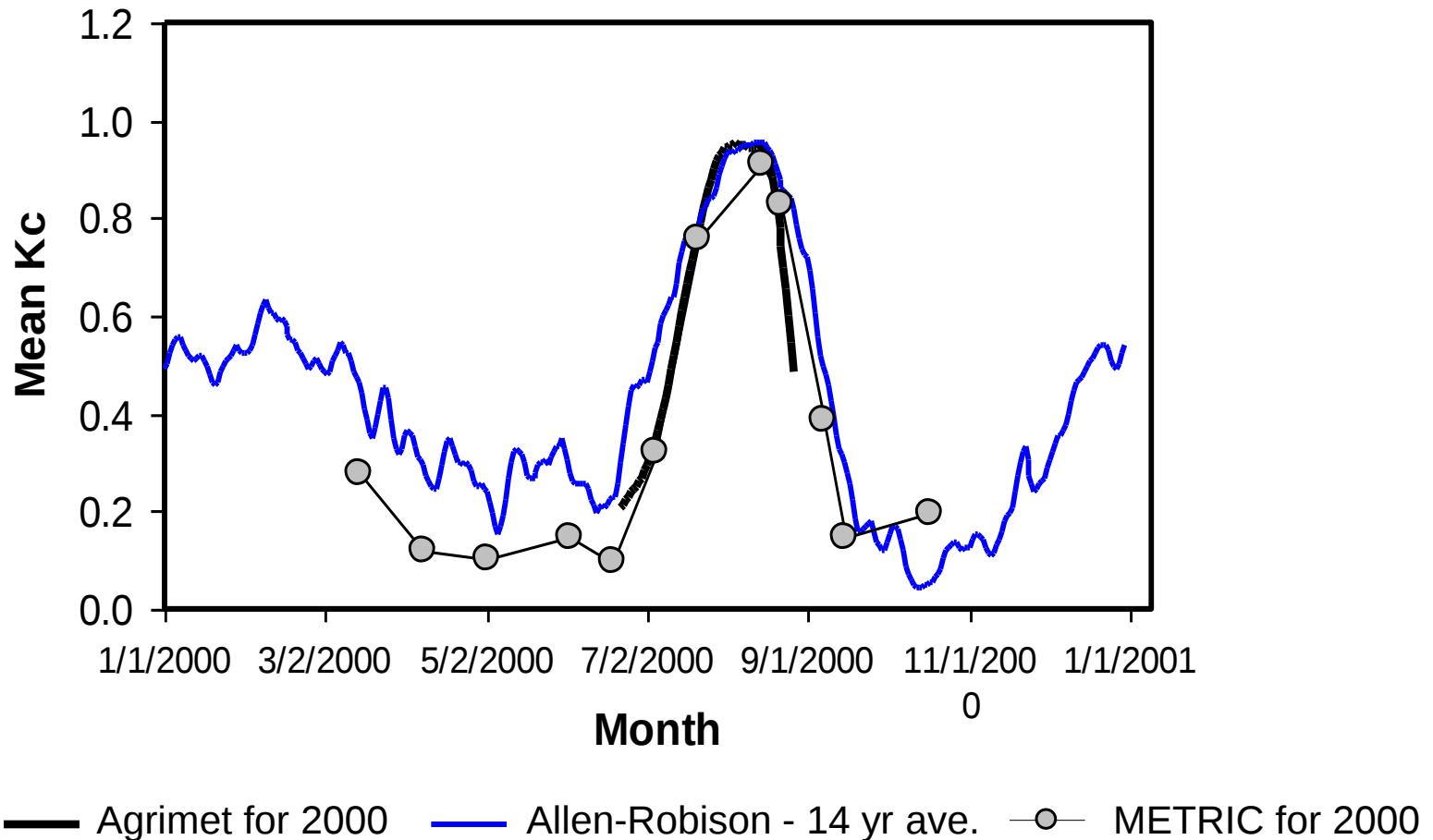


Populations of K_c from Winter Grain Fields



Use Satellite-based K_c from Satellite to compare with “Traditional” K_c Curves and Methods

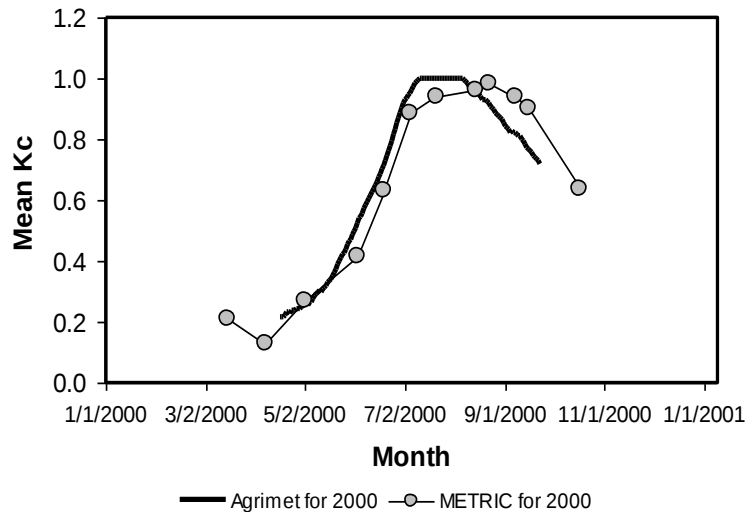
Dry Beans Twin Falls, ID 2000



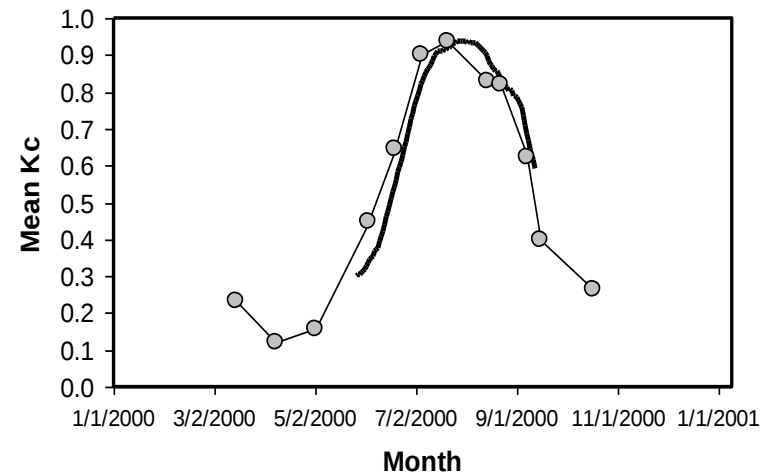
Comparison with Local K_c Curves

-- south-central Idaho

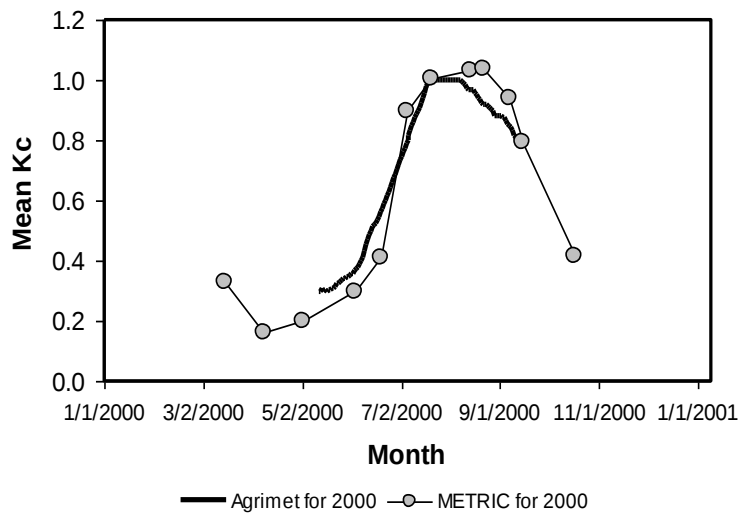
Sugar Beets
Twin Falls, ID 2000



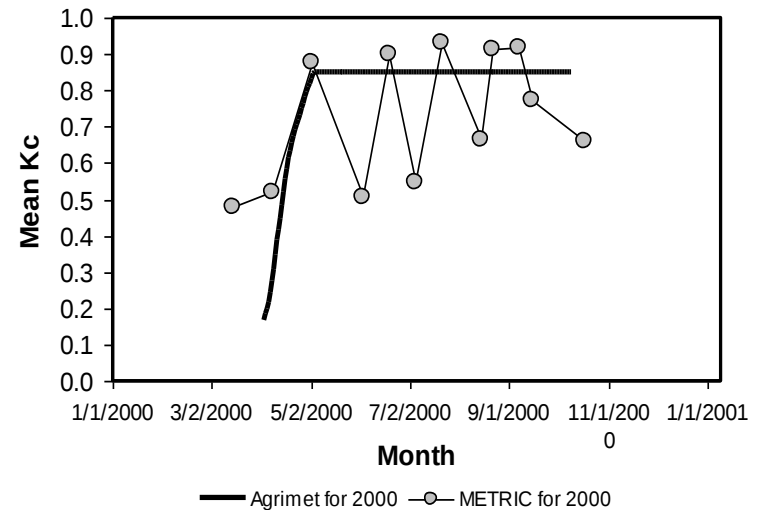
Potatoes
Twin Falls, ID 2000



Field Corn
Twin Falls, ID 2000

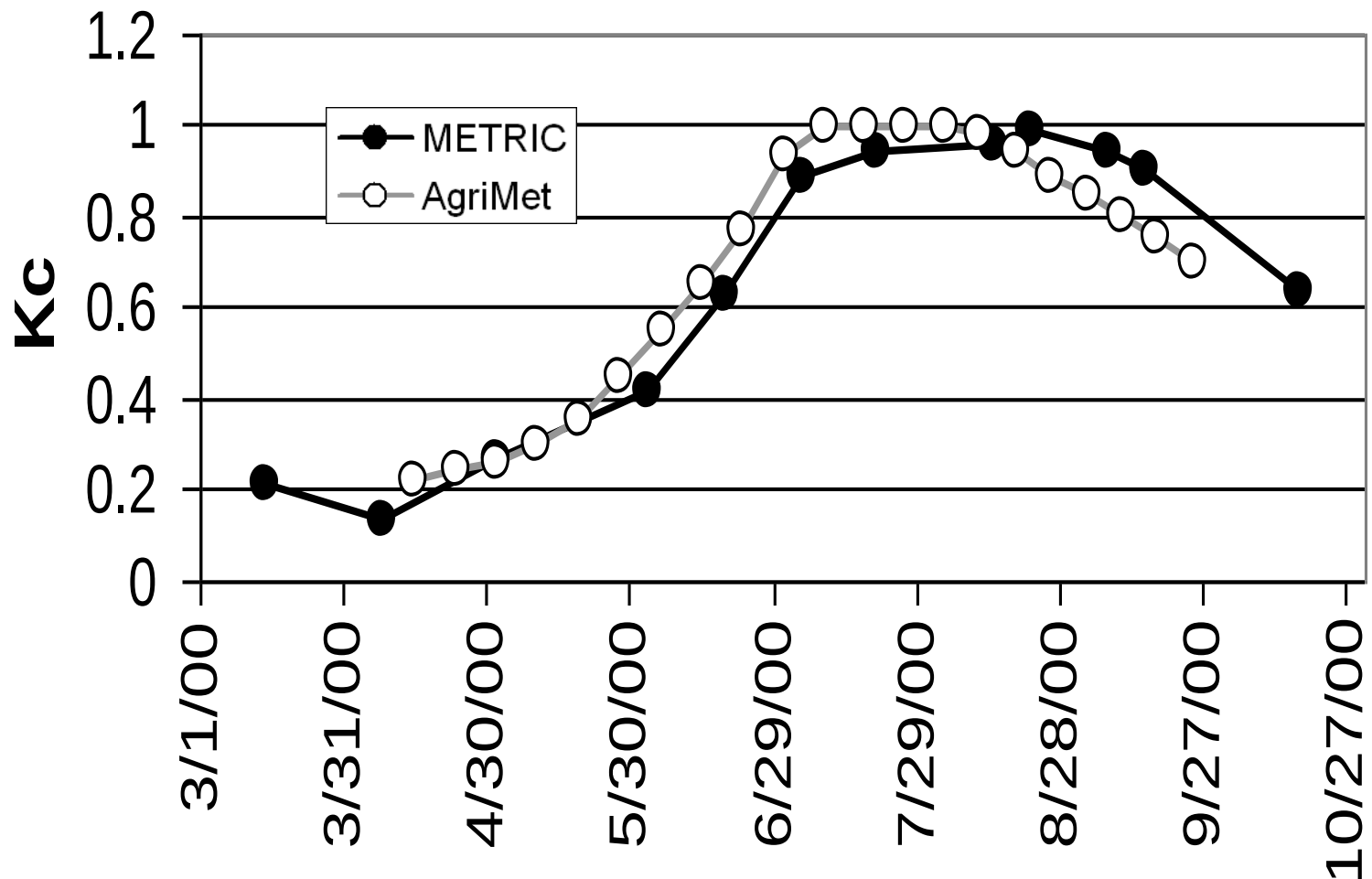


Alfalfa - Dairy hay
Twin Falls, ID 2000



Use to Refine Local K_c Curves

Sugar Beet



(Original K_c curve is in ASCE Manual 70)



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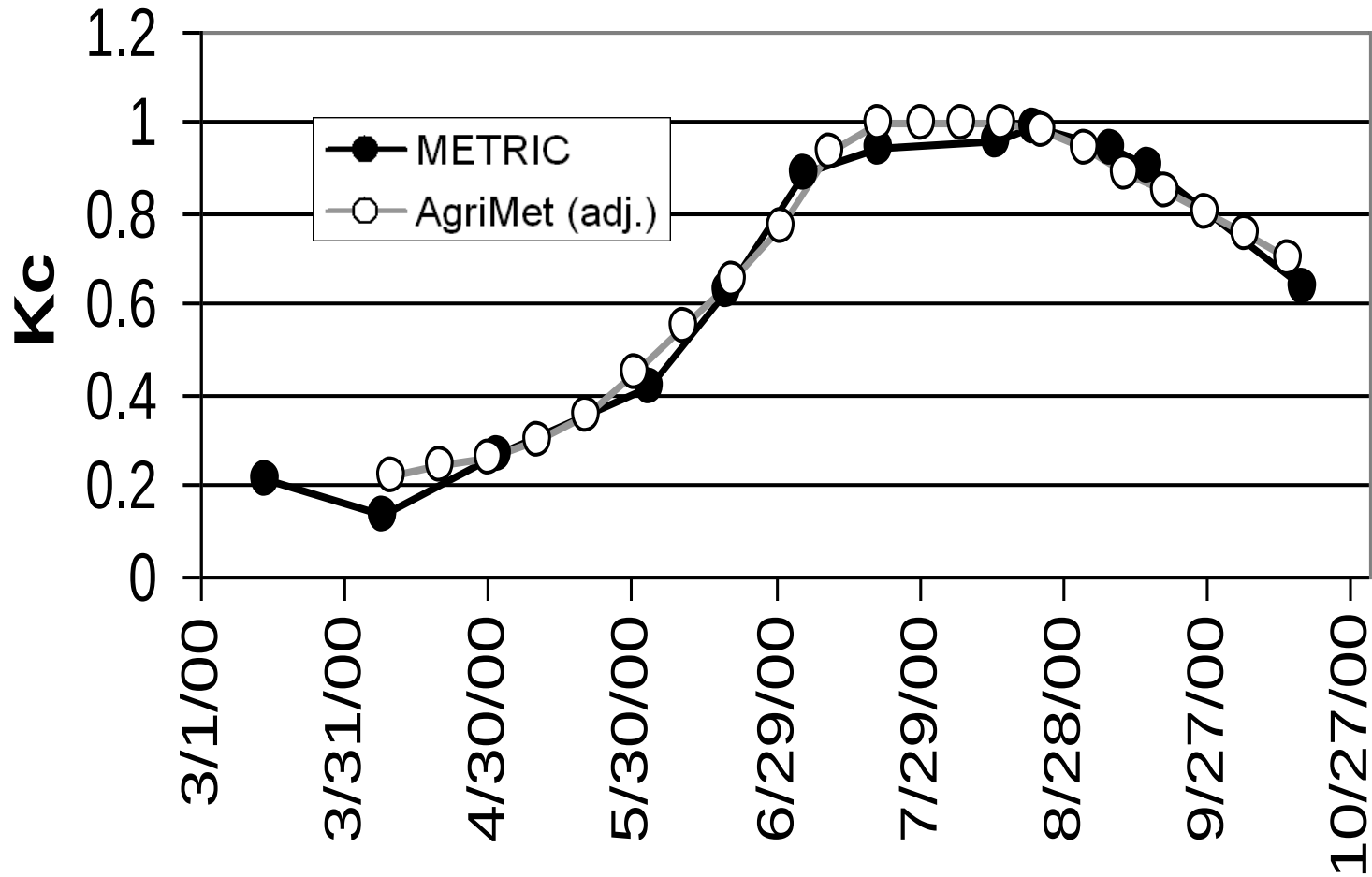


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Use to Refine Local K_c Curves

Sugar Beet

(we modify beginning, cover or harvest dates)



(Original K_c curve is in ASCE Manual 70)



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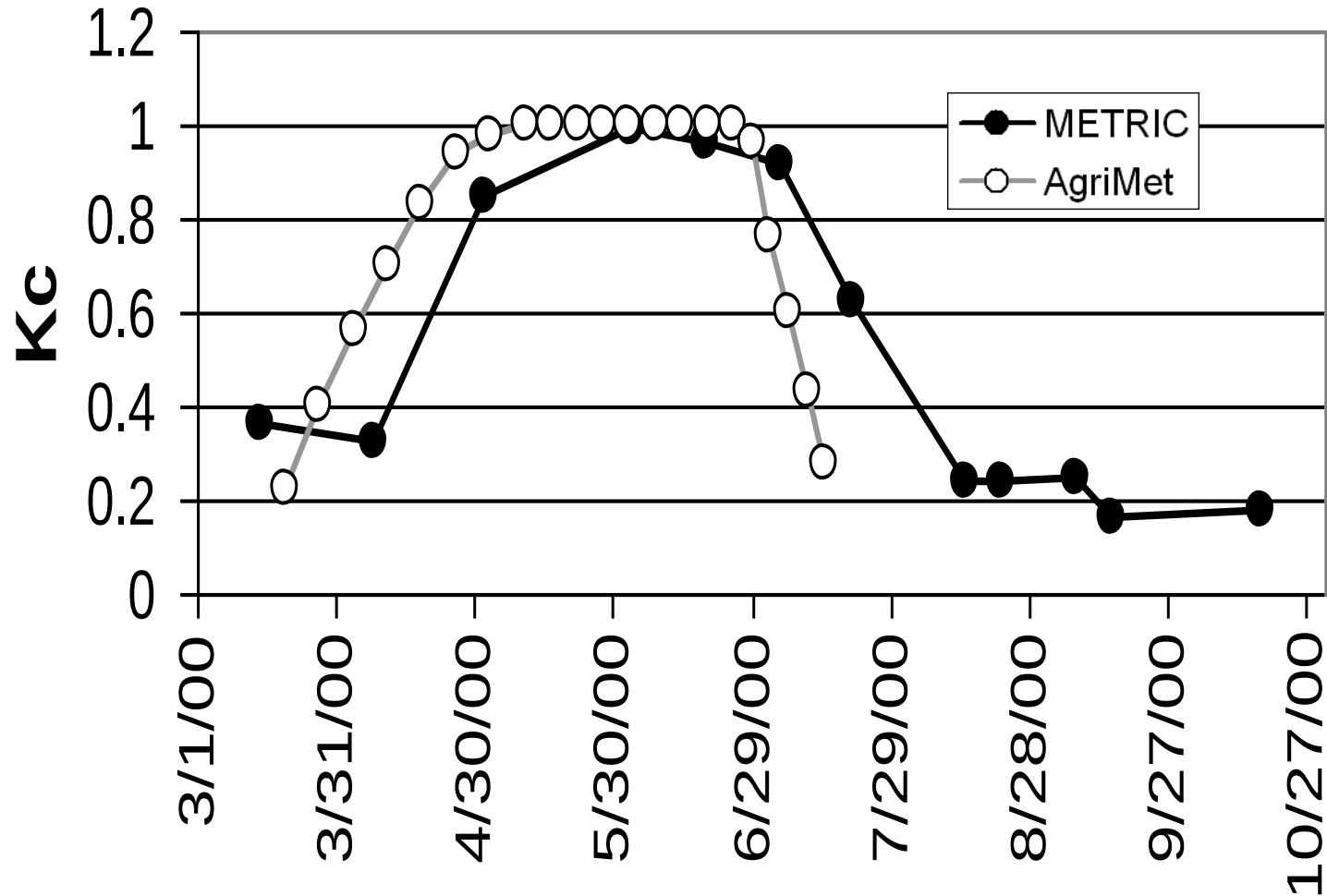
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Use to Refine Local K_c Curves

W.Grain



(Original K_c curve is in ASCE Manual 70)



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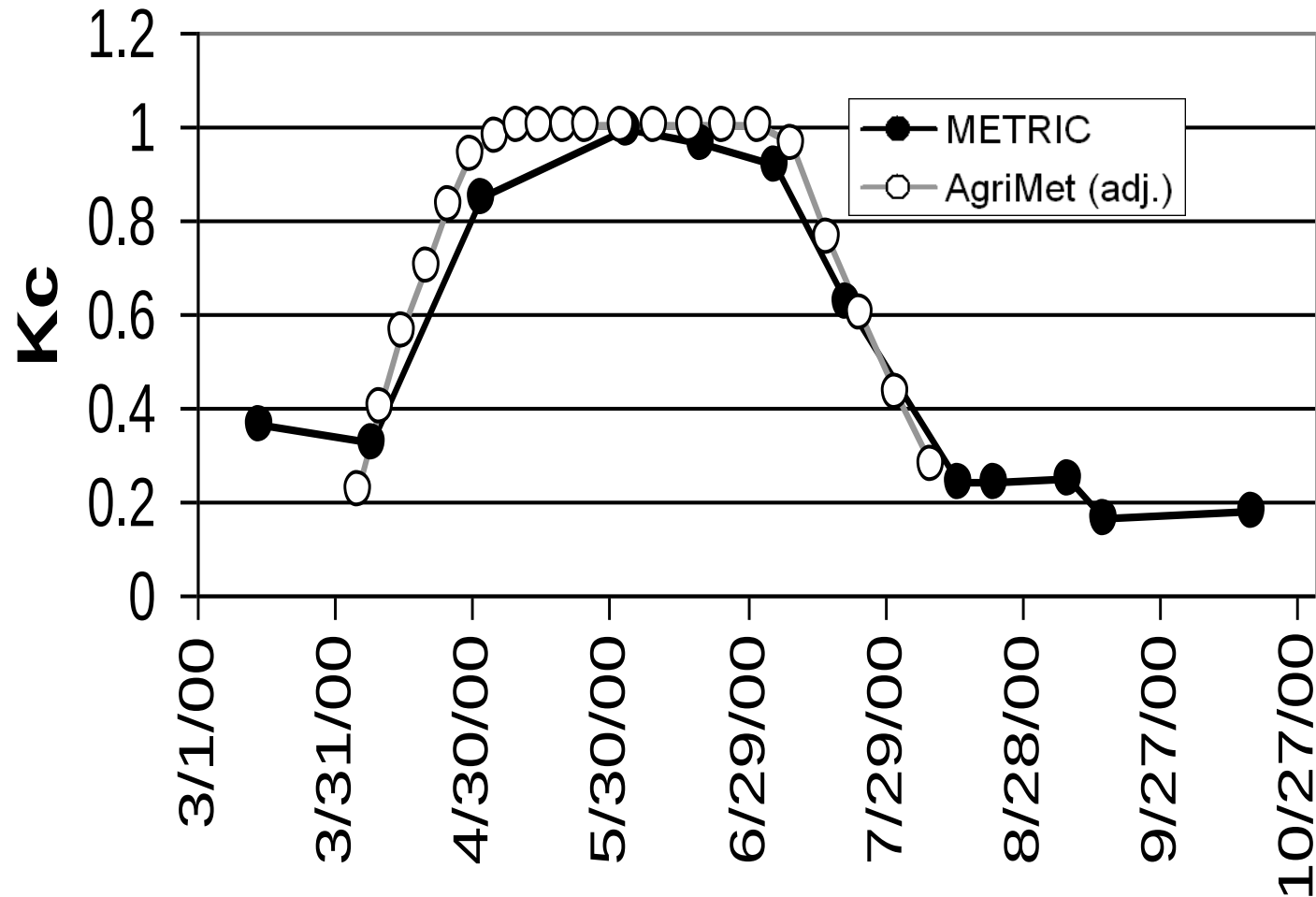


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Use to Refine Local K_c Curves

W.Grain

(we modify beginning, cover or harvest dates)



(Original K_c curve is in ASCE Manual 70)



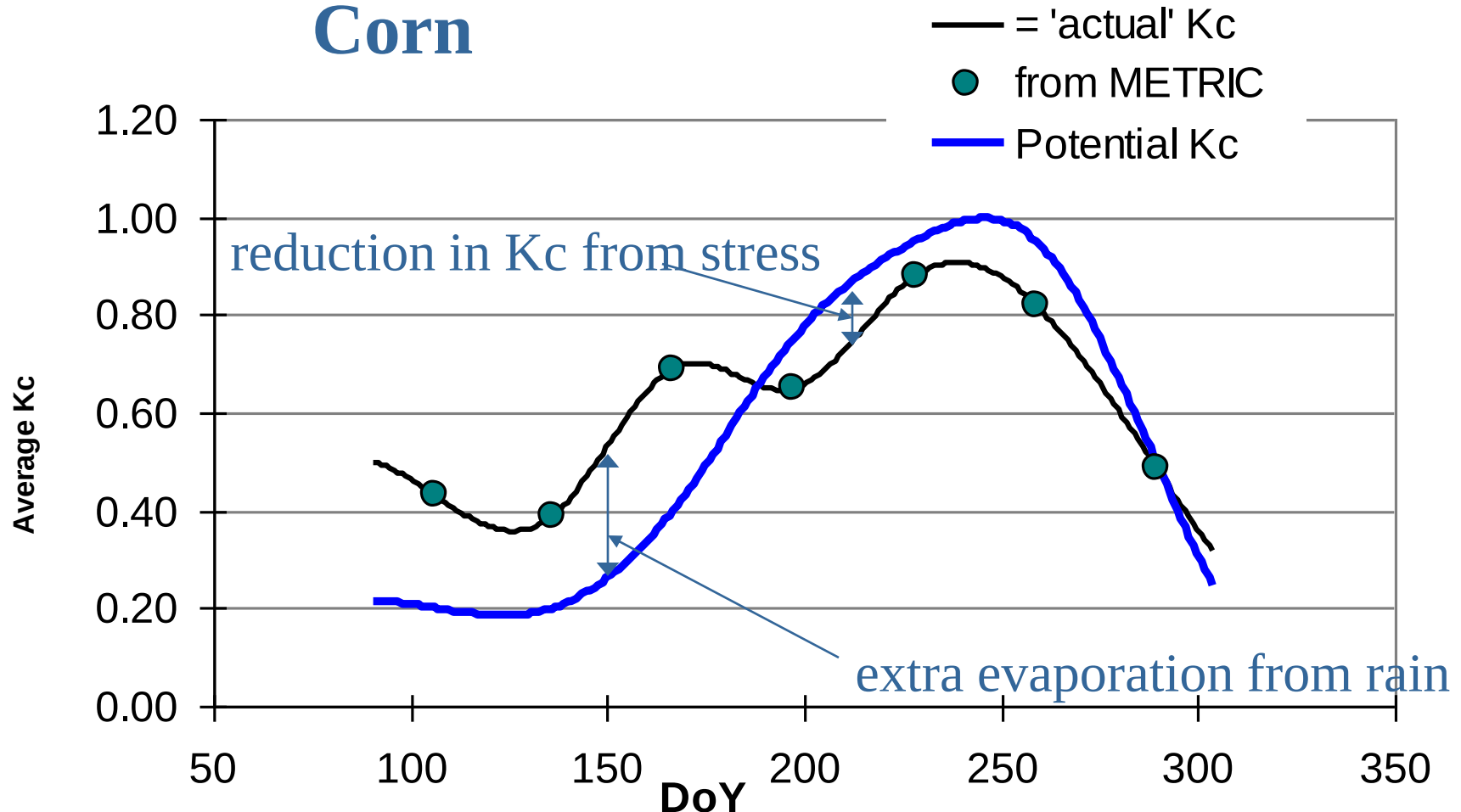
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Explanation of differences between Actual K_c from METRIC and Potential K_c where potential K_c is computed to represent K_c with all ET from irrigation only, in the absence of any rain.

Corn



$$K_{c \text{ actual}} = K_s K_{cb} + K_e \text{ total}$$



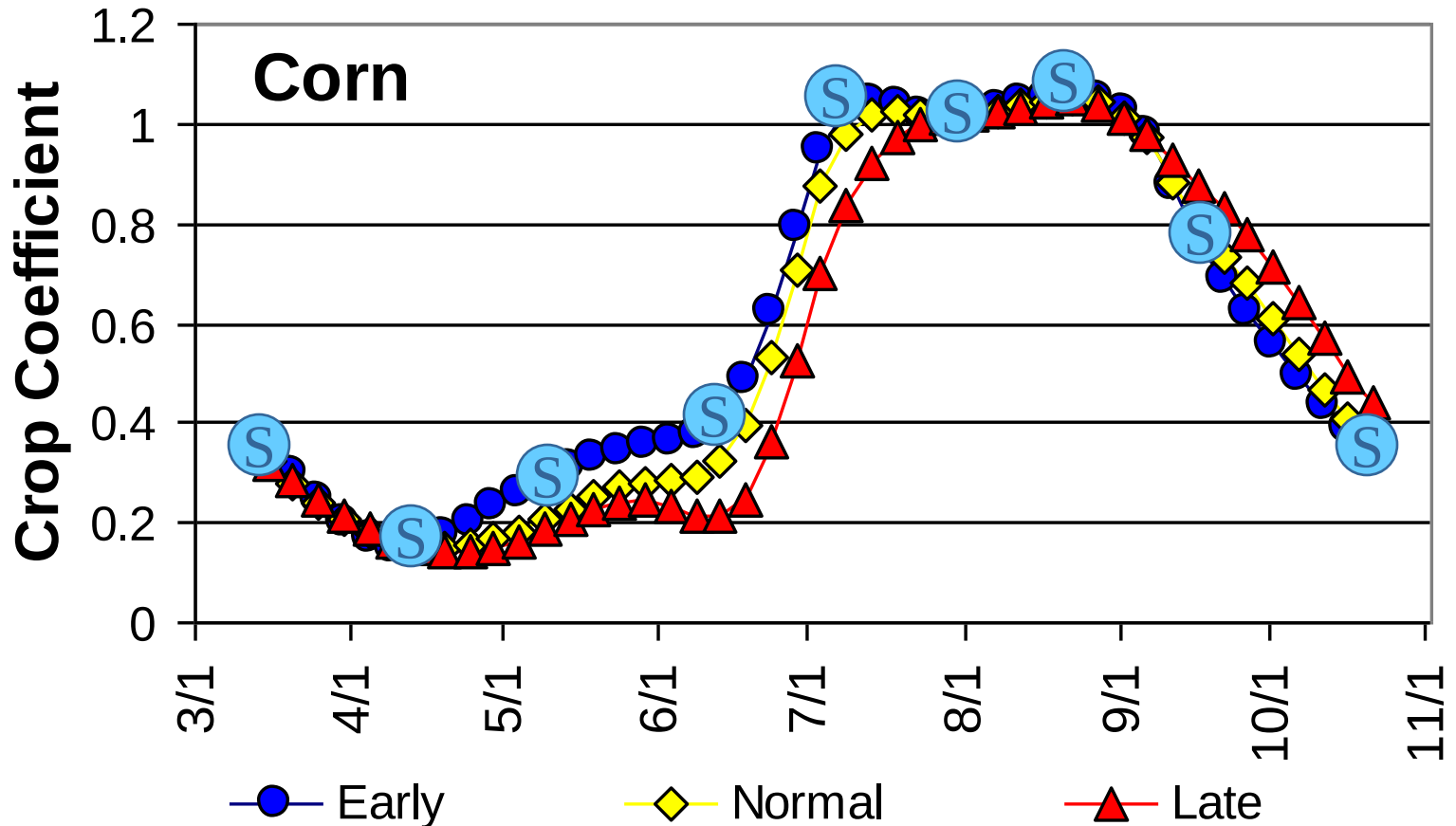
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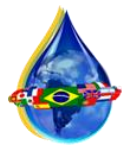
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(Note: all potential K_c curves shown on these slides are made up by Allen for illustration only. They do not represent any literature values. The METRIC derived curve is real and is from year 2005 near Scottsbluff Nebraska (from UNL (Aase, 1988 and Ian Ratcliffe)))

Integration of ETI (*aka* Crop Coefficient) for Seasonal ET



(S) = Satellite date

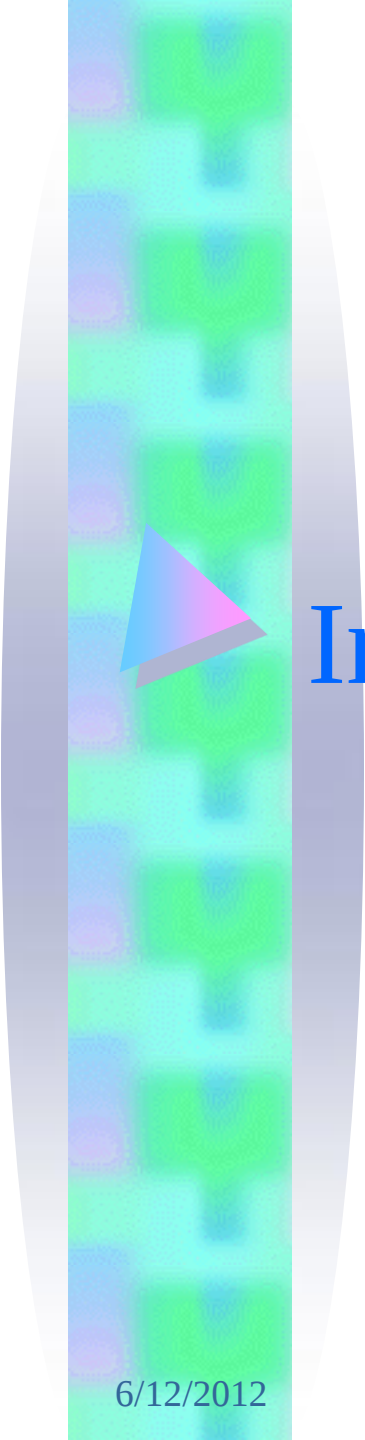


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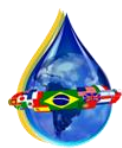
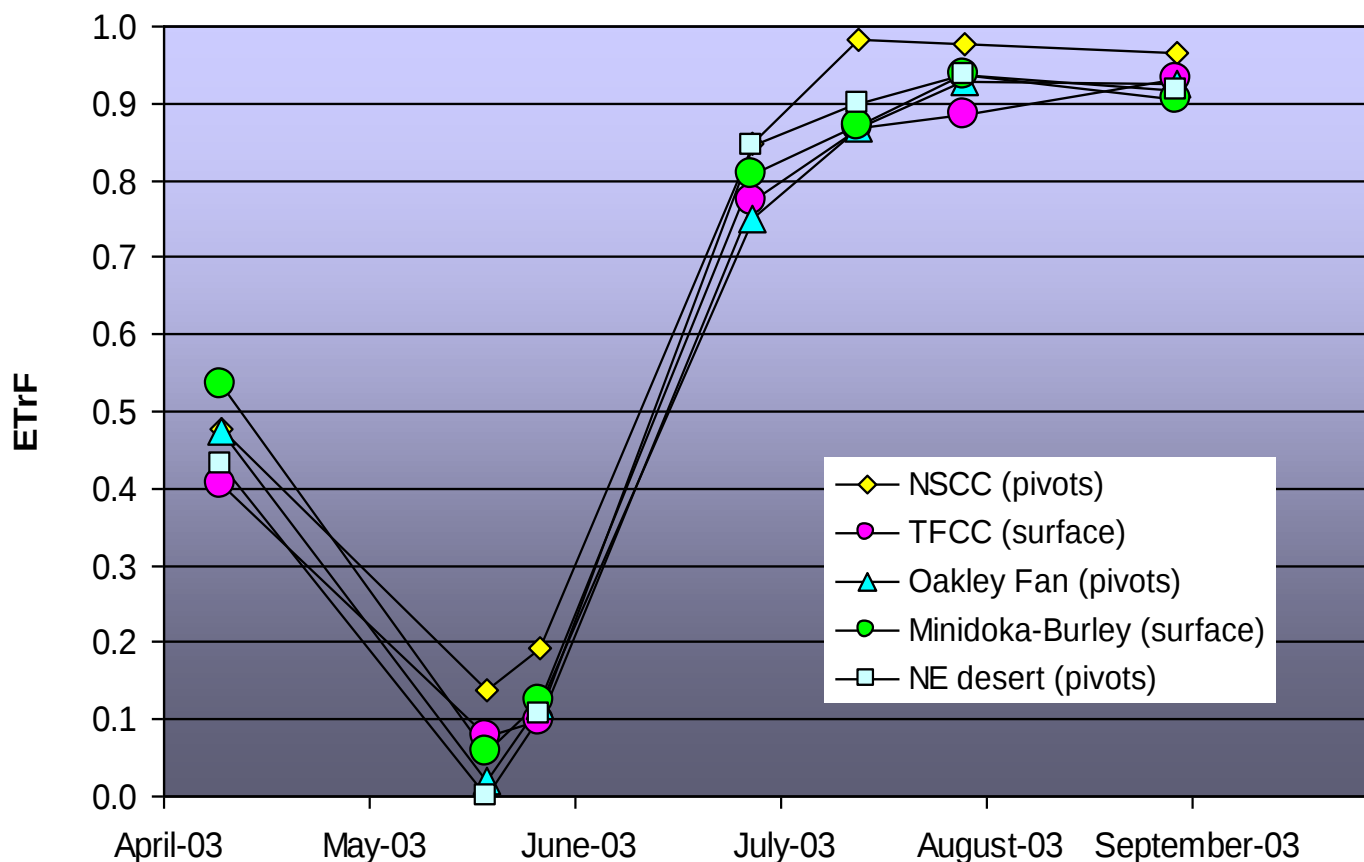
Impact of Irrigation Type

Impact of Irrigation System Type on ET

-- south-central Idaho -- 2003

METRIC Analyses by Lorite, Allen and Robison

Sugar Beets in Magic Valley during 2003



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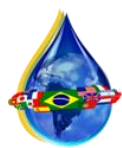
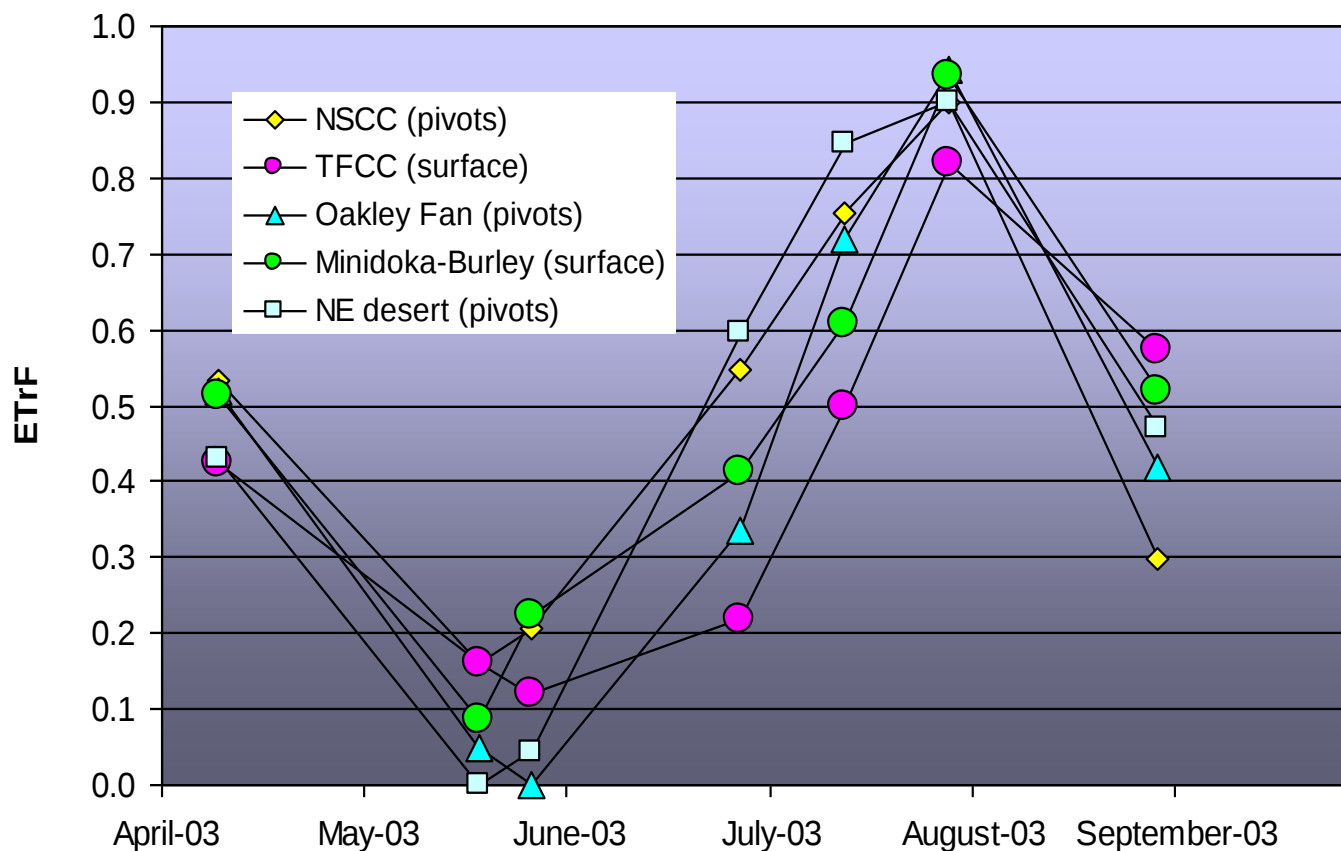
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Impact of Irrigation System Type on ET

-- south-central Idaho -- 2003

METRIC Analyses by Lorite, Allen and Robison

Beans in Magic Valley during 2003



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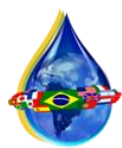
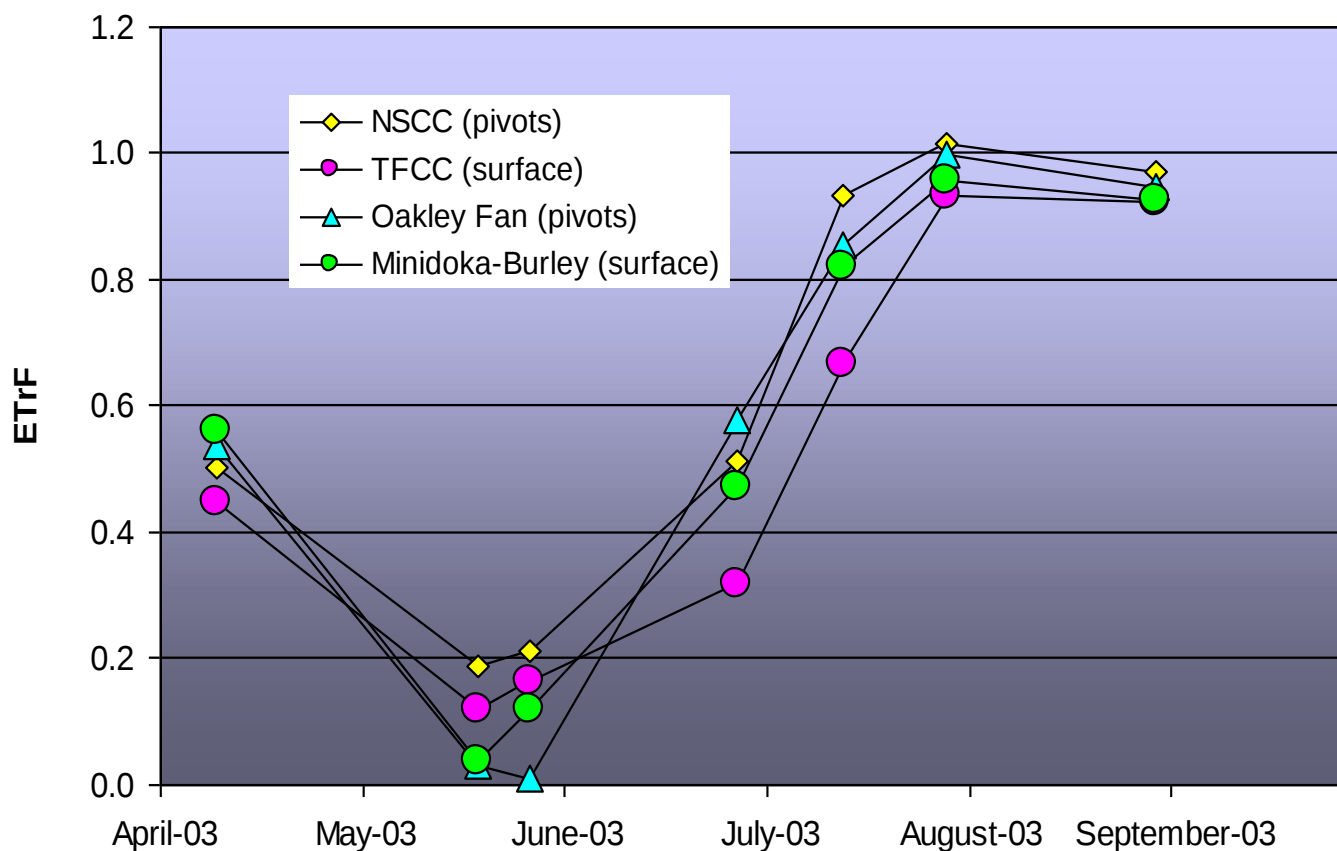
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Impact of Irrigation System Type on ET

-- south-central Idaho -- 2003

METRIC Analyses by Lorite, Allen and Robison

Corn in Magic Valley during 2003



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Impact of Irrigation System Type on ET

-- south-central Idaho -- 2003

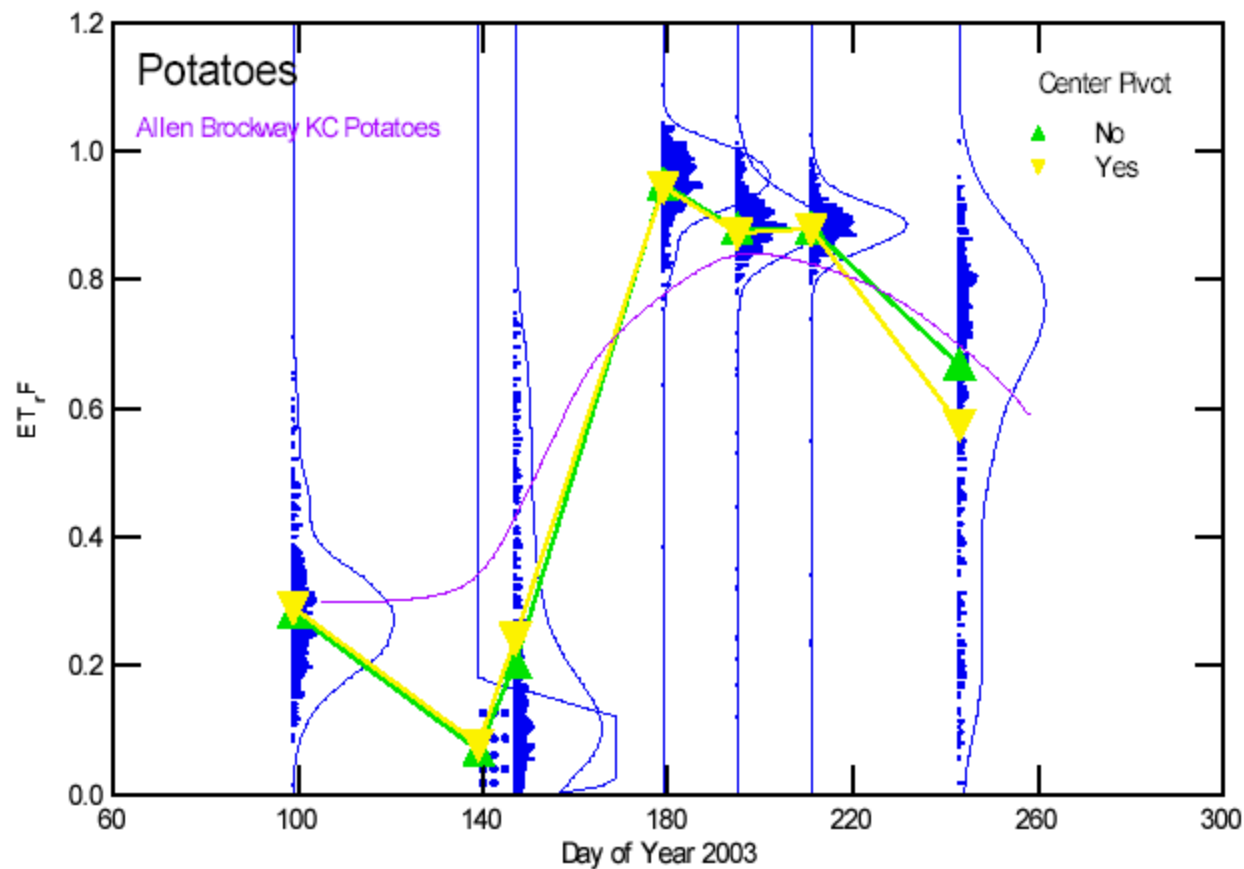
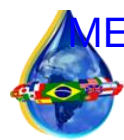
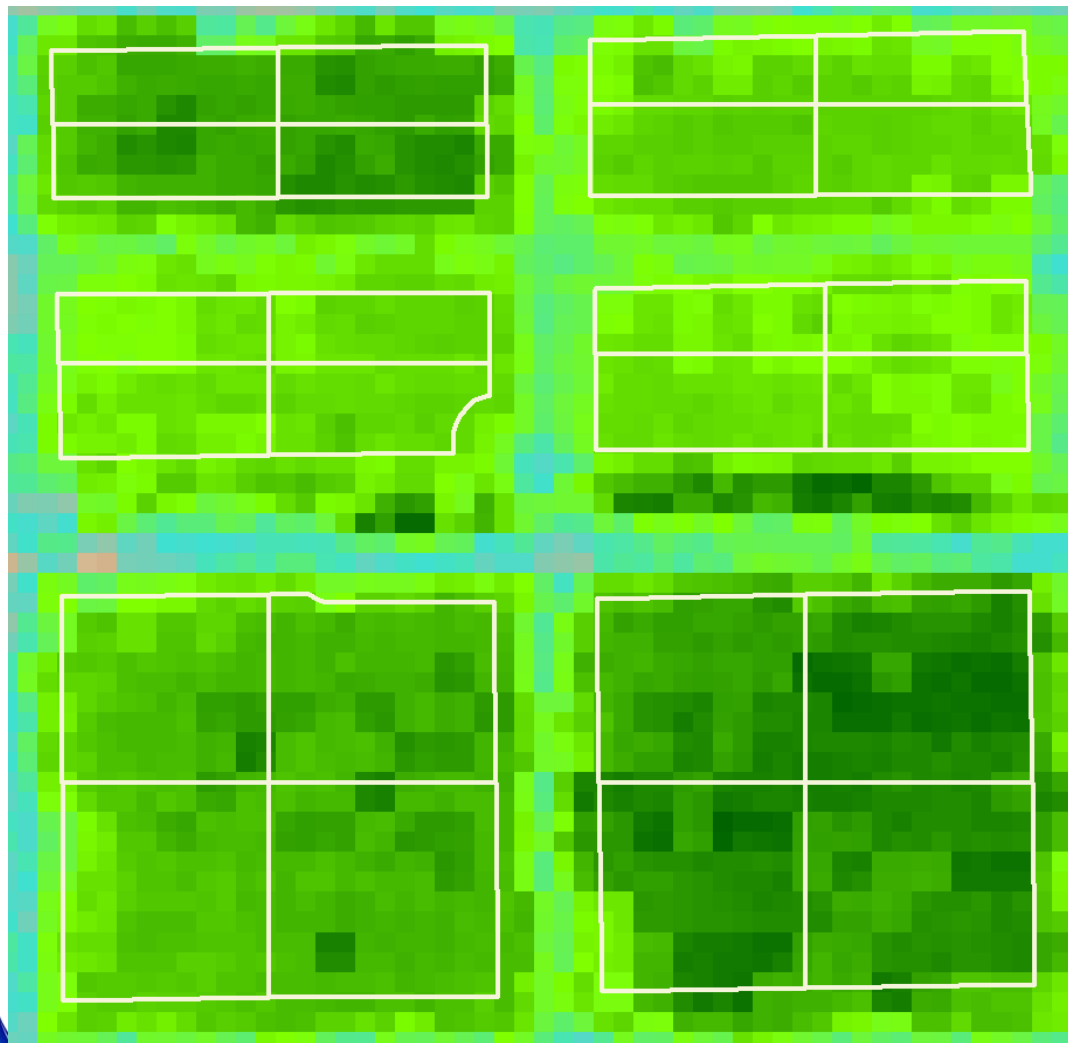


Illustration 4: Potato Field Averaged Pixels for Magic Valley



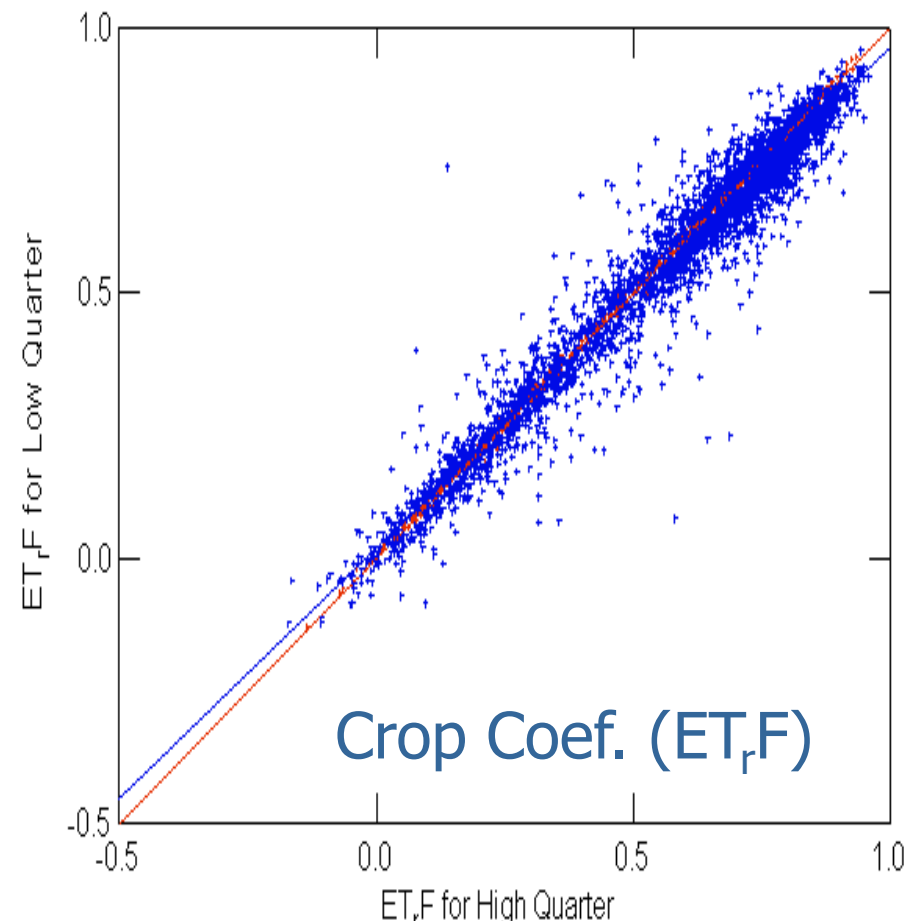
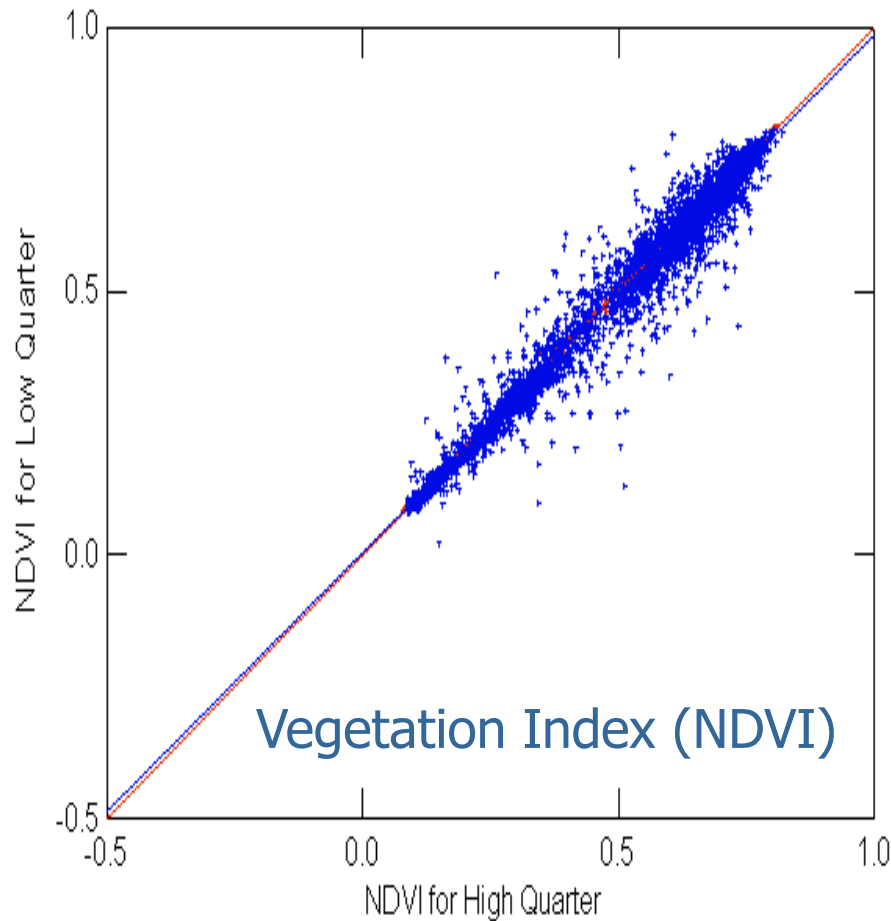
ET Variation within Fields

Quartered and buffered field polygons



ET Variation within 4200 Fields: year 2002

ET_rF is the "fraction" of reference $ET = K_c$



blue lines are regression lines red lines are regression through origin

Thanks

ET