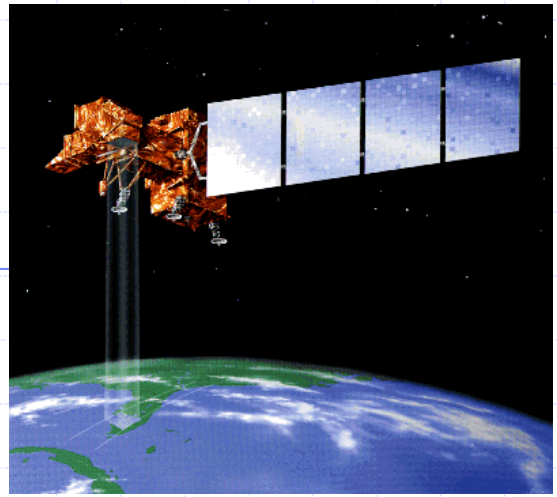


Operational Evapotranspiration Algorithms for LDCM

Rick Allen, University of Idaho

Collaborators: Tony Morse, Idaho Dept. Water Resources; Jan Hendrickx, New Mexico Tech; David Toll; NASA-GSFC; Graeme Aggett, Riverside Technology

LDCM Science Team Meeting, June 12, 2007

University of Idaho

USGS science for a changing world

NASA

Primary Objectives

- Continue development work in surface energy balance for ET mapping (METRIC) at Landsat scale resolution
- Interoperability of Landsat data and ET with other satellite system data and resolutions
- Use ET from energy balance to calibrate vegetation-based (reflectance-based) procedures

ET "mapping" with *METRIC*^{tm}

- Mapping EvapoTranspiration with high Resolution and Internalized Calibration

  Developed by Allen, Tasumi and Trezza
  University of Idaho, *Kimberly*

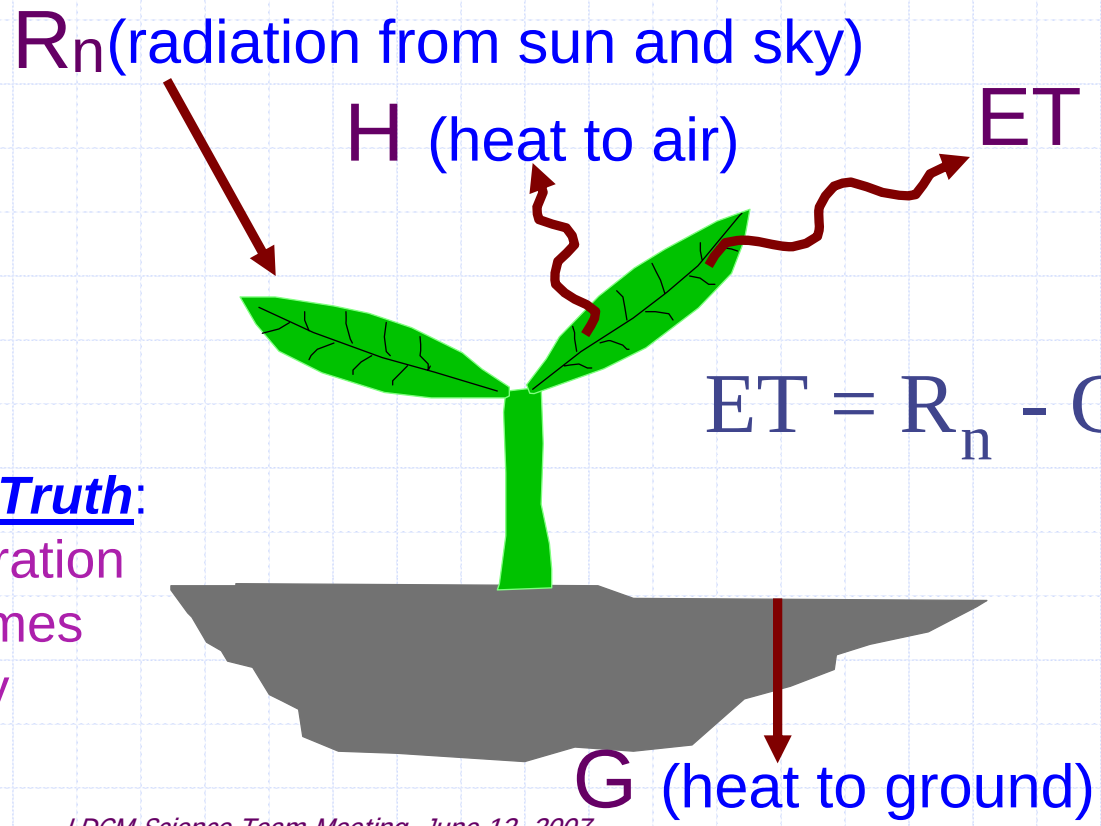
  – ***development began in 2000***
  – ***rooted in the Dutch SEBAL^{2000} algorithms by Bastiaanssen***

  Principle applications have been:

  Irrigated Agriculture
  Riparian Vegetation
  Desert Systems
  Wetlands

Why Energy balance?

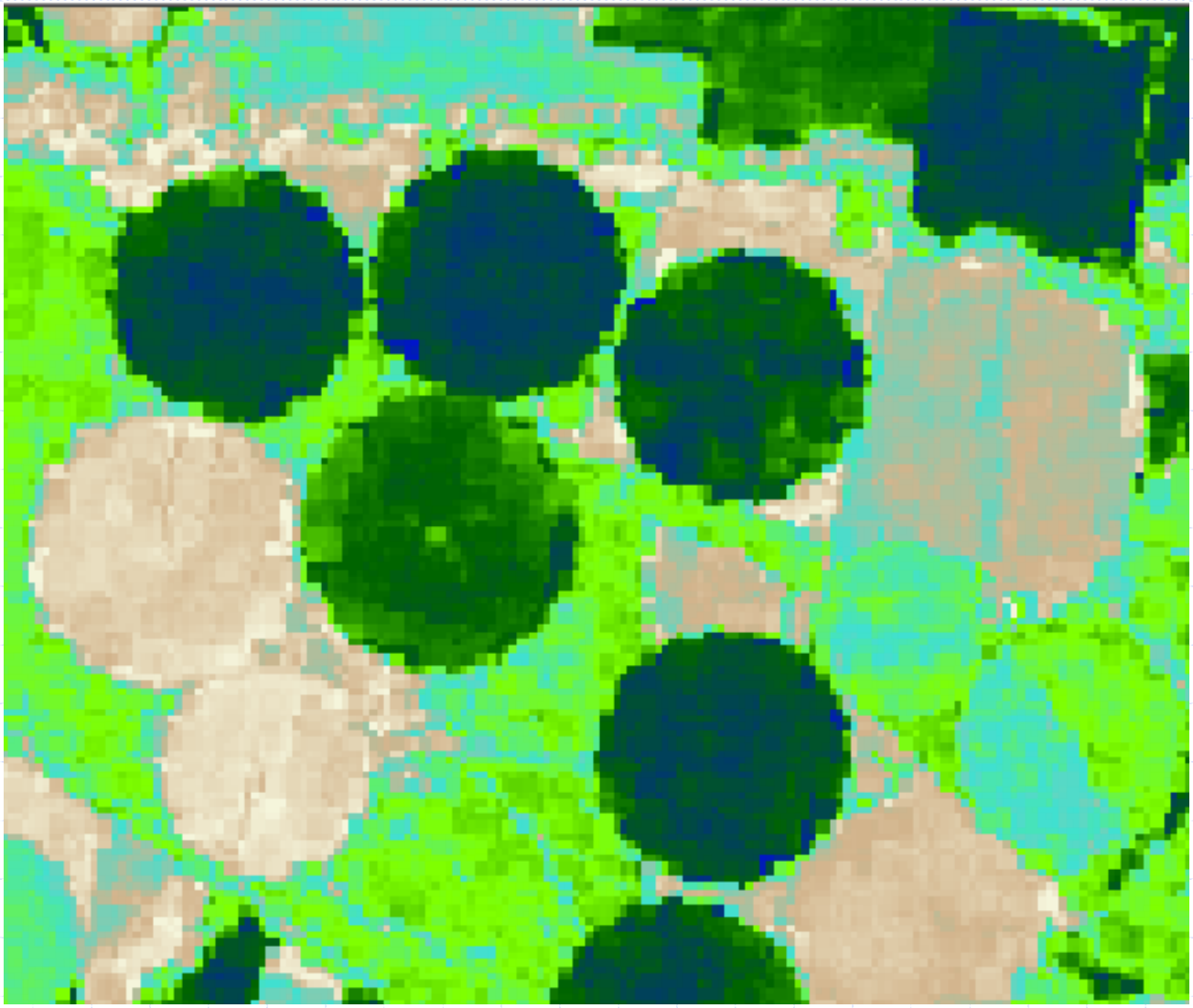
- ET is calculated as a "residual" of the energy balance



$$ET = R_n - G - H$$

Basic Truth:
Evaporation consumes Energy

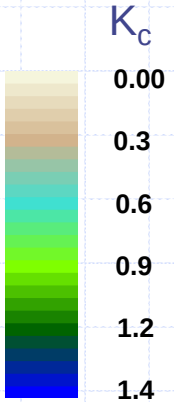
Why use High Resolution Imagery?



METRIC application in La Mancha, Spain, 2003

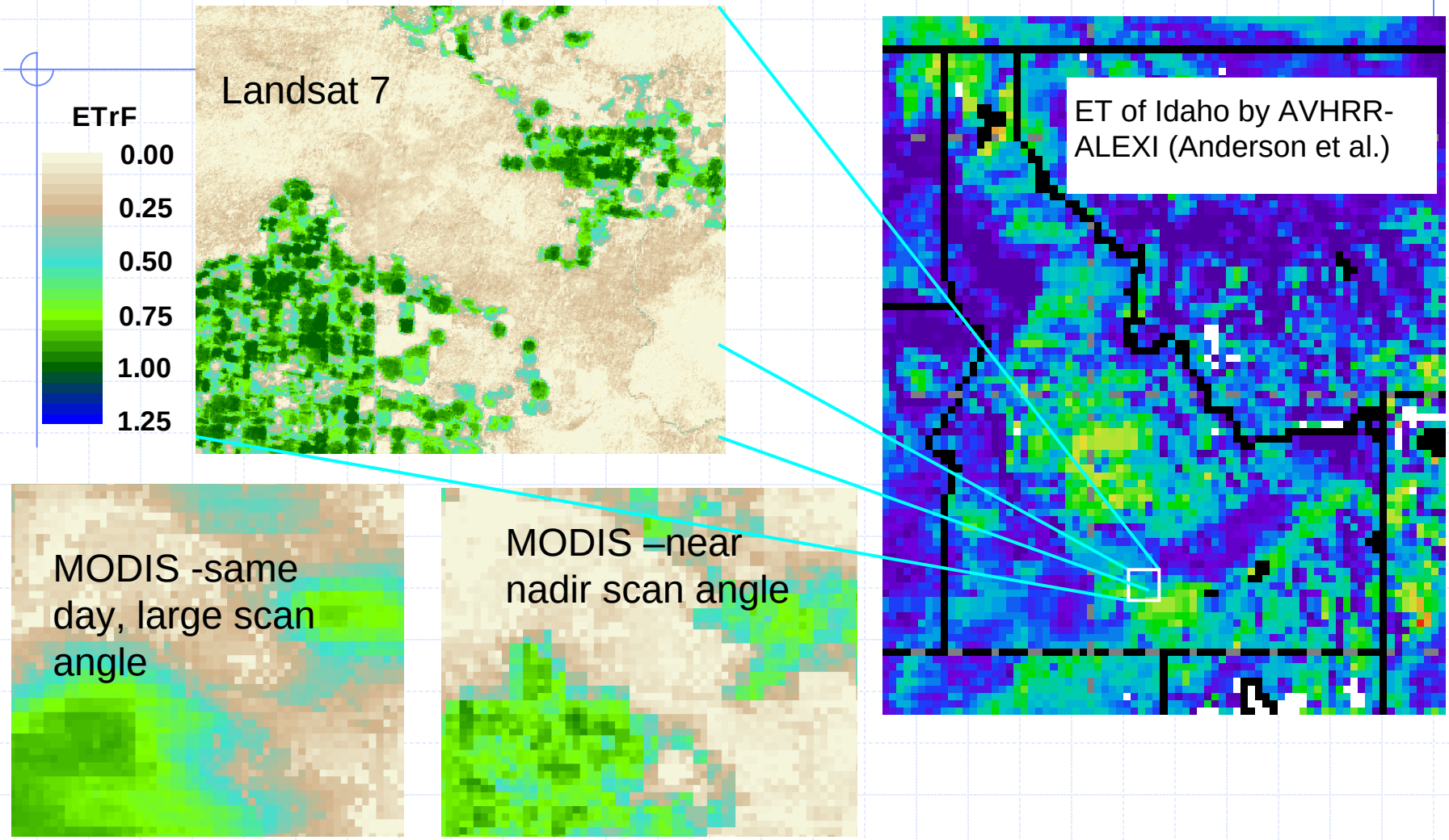
ET from *individual* Fields is *Critical* for:

- Water Rights,
- Water Transfers,
- Farm Water Management



(K_c based on ET_o)

Why use High Resolution Imagery?



Recent Activity

- Briefing session with NASA HQ (Dr. Michael Freilich, Director of Earth Science Programs)
  - Explain why TIR is needed on LDCM
  - How and why we are able to use it for Evapotranspiration (ea. 16 days→ continuous)
  - Jim Irons of Goddard also presented
- Letter by Senators Crapo (Idaho) and Salazaar (Colorado) + 5 other Senators to Senate Appropriations Committee (June 8 2007) for funding of TIR

United States Senate

WASHINGTON, DC 20510

June 8, 2007

Senator Robert C. Byrd
Chairman
Committee on Appropriations
Washington, DC 20510

Senator Thad Cochran
Ranking Member
Committee on Appropriations
Washington, DC 20510

Senator Barbara Mikulski
Chairwoman
Subcommittee on Commerce,
Justice, Science & Related Agencies

Senator Richard Shelby
Ranking Member
Subcommittee on Commerce,
Justice, Science & Related Agencies

Dear Chairman Byrd, Chairwoman Mikulski, Senator Cochran, and Senator Shelby:

Water is a precious and scarce natural resource. The prolonged drought over large portions of the United States, particularly the West has had a range of adverse effects: record wildfires, crop failure, threats to endangered wildlife and municipal water shortages.

Recognizing this, it is increasingly critical that we provide the resources necessary to gather the data required to make sound decisions related to our present and future water use. The economic costs of drought can be mitigated through improvements in forecasting accuracy to help detect drought farther in advance, enhance forecast accuracy, and more precisely indicate location, intensity, and duration.

One such invaluable data source that federal and state agencies have come to rely on is the Landsat Program, a series of satellite missions jointly managed by NASA and the U.S. Geological Survey. Since 1972, Landsat satellites have collected information about Earth from space, taking specialized digital photographs of the continents and surrounding coastal regions. This has enabled scientists to evaluate the dynamic changes caused by both natural processes and human practices, including drought.

The thermal infrared (TIR) data provided by Landsat 5 and Landsat 7 is used to calculate evapotranspiration and water use on a field-by-field basis, as well as to monitor related

Acknowlegements:
- Tony Willardson
  - Western States Water Council
- Tony Morse
  - Idaho Dept. Water Resources
- Martha Anderson
  - USDA-ARS
- David Tuthill
  - Idaho State Engineer

with capabilities similar to Landsat 5 and Landsat 7, is estimated at around $90 million dollars. We respectfully request that the Appropriations Committee add $35 million to the President's FY2008 LDCM request and direct NASA to immediately take the necessary steps to ensure a thermal sensor is included on Landsat 8 to continue providing this vital information for current and future natural resources management.

No other federal program can provide this information, nor is there any comparable public or private source, locally or internationally. If we fail to act now, we will lose this important tool for the long-term future. Even now, it is likely NASA may need to build the thermal data sensor "in-house," so as not to delay the scheduled 2011 launch.

Therefore, we urgently ask that you include $35 million in FY2008 under NASA's Landsat Data Continuity Mission for the addition of a thermal sensor on Landsat 8. We cannot afford to lose this tool and the critical information it provides for water resource and infrastructure planning.

Sincerely,

Ken Salazar
United States Senator

Jeff Bingaman
United States Senator

Max Baucus
United States Senator

Tim Johnson
United States Senator

Mike Crapo
United States Senator

John Thune
United States Senator

Ron Wyden
United States Senator

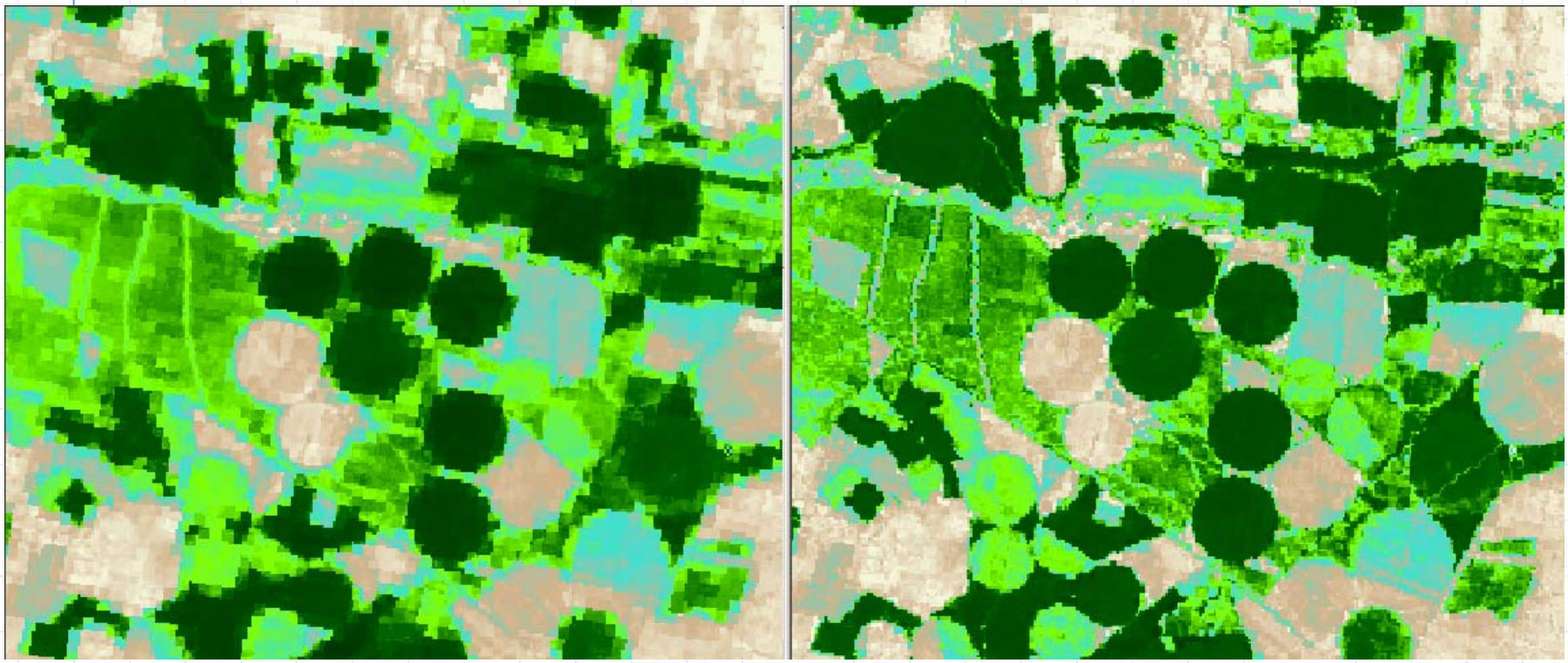
University of Idal

Sharpening of Thermal Band of Landsat 5 from 120 m to 30 m using NDVI

Landsat 5 -- Albacete, Spain, 07/15/2003

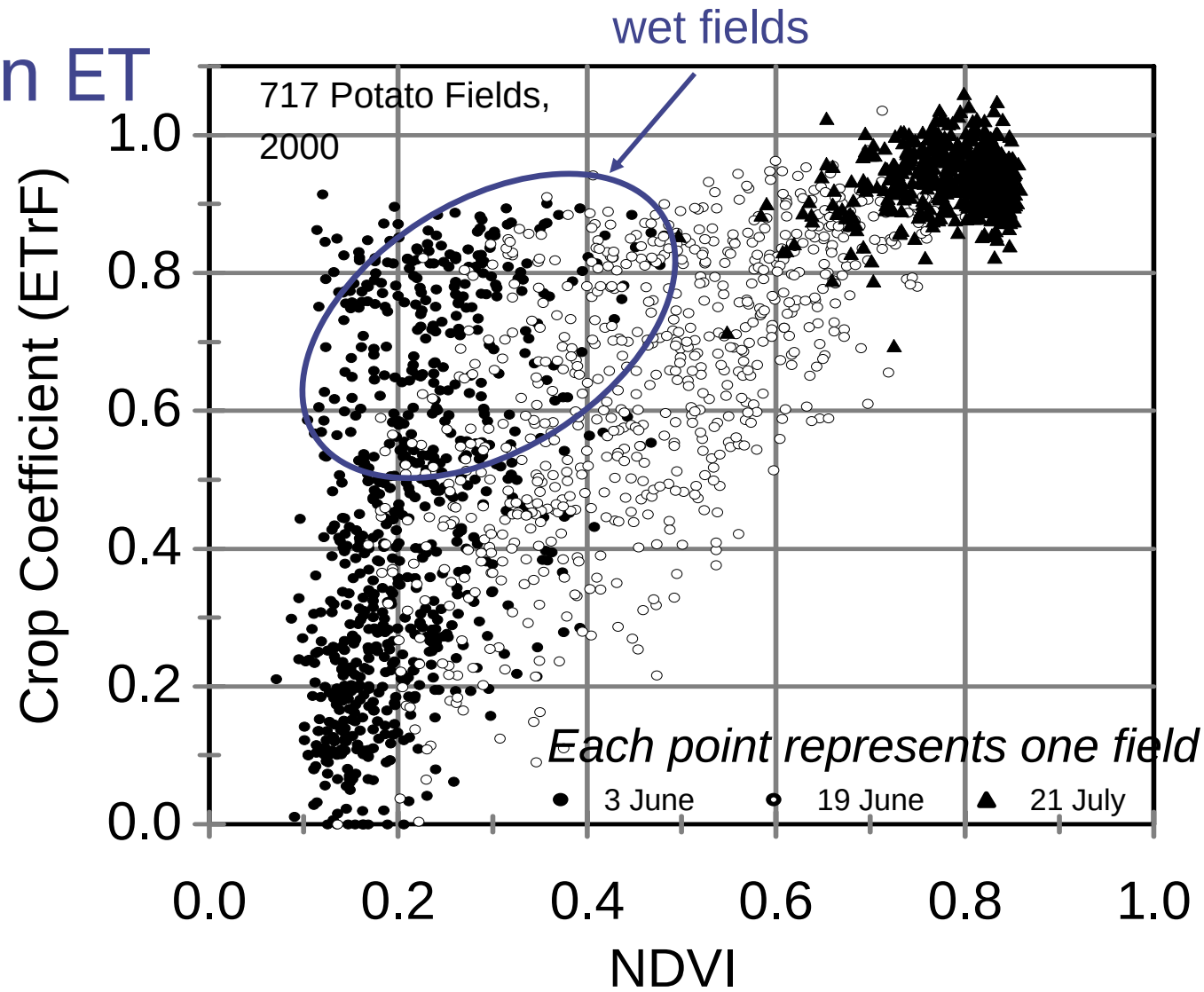
ET ratio before sharpening

ET ratio after sharpening



Variation in ET

The biggest downside to using a Vegetation Index for calculating ET is that it can not "see" soil evaporation nor stress due to water shortage or over watering



ET_rF = Fraction of Reference ET = $\frac{ET}{ET_r}$ ← from weather data

NDVI = Normalized Difference Vegetation Index

Basing a 'basal' ETrF on Vegetation Indices

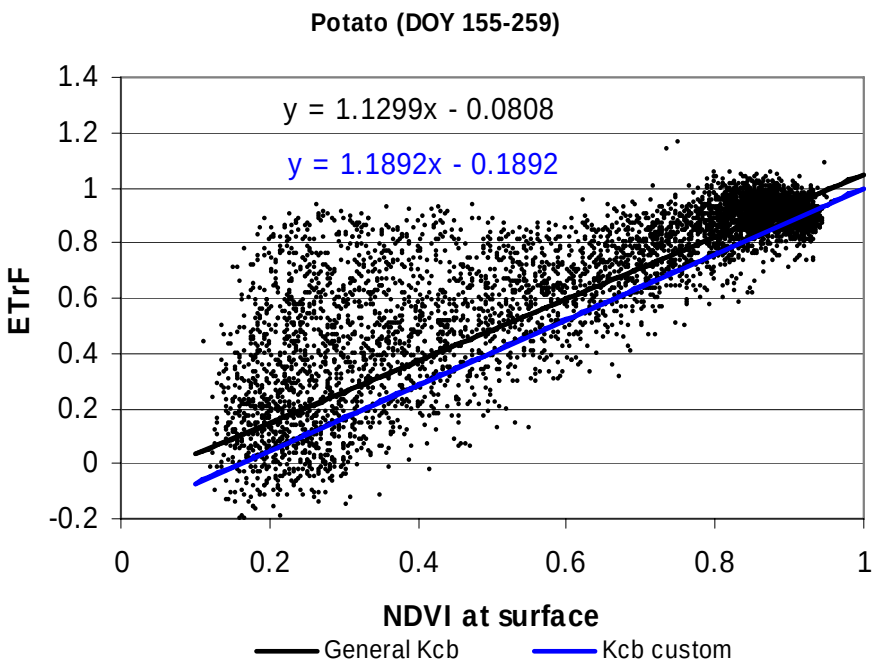
$ETrF = ET_{act} / ET_{ref}$

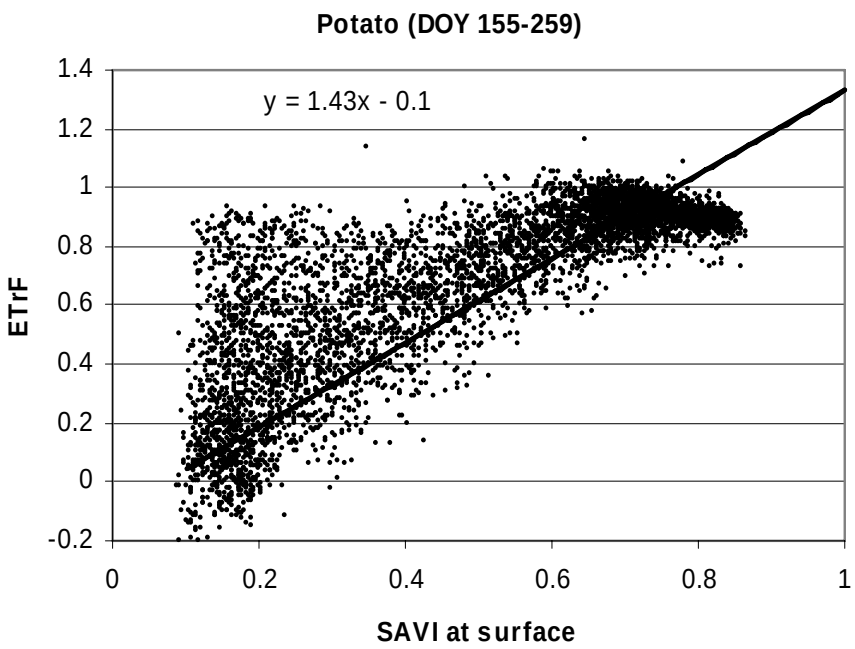
'basal' ETrF (for transpiration only) ~ a + b (VI)

$$NDVI = \frac{\rho_{nir} - \rho_{red}}{\rho_{nir} + \rho_{red}}$$

5,736 potato fields

$$SAVI = \frac{(1+L)(\rho_{nir} - \rho_{red})}{L + \rho_{nir} + \rho_{red}}$$

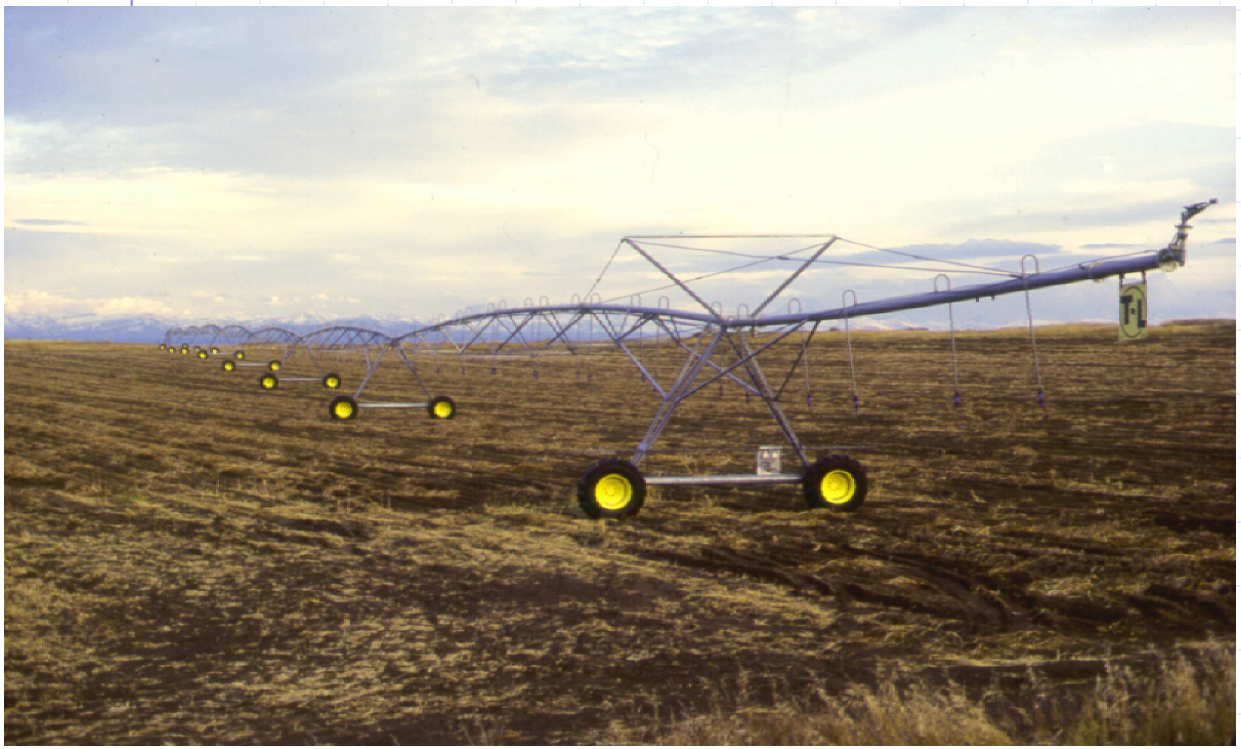




Estimating evaporation from soil separately

- We break the ETrF into two components
  - Basal ETrF = Kcb representing transpiration (from VI)
  - Ke representing evaporation from bare soil

$$ET = (Kcb + Ke) * ETr$$

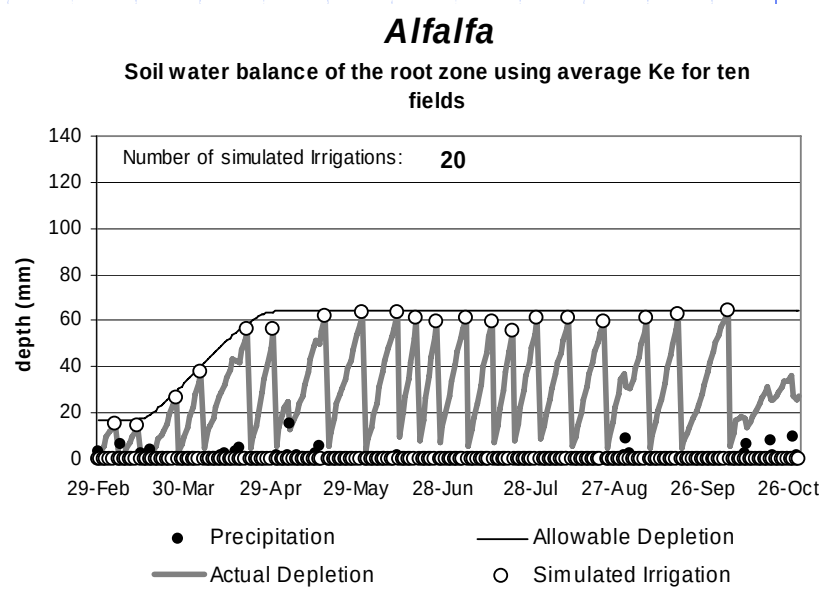


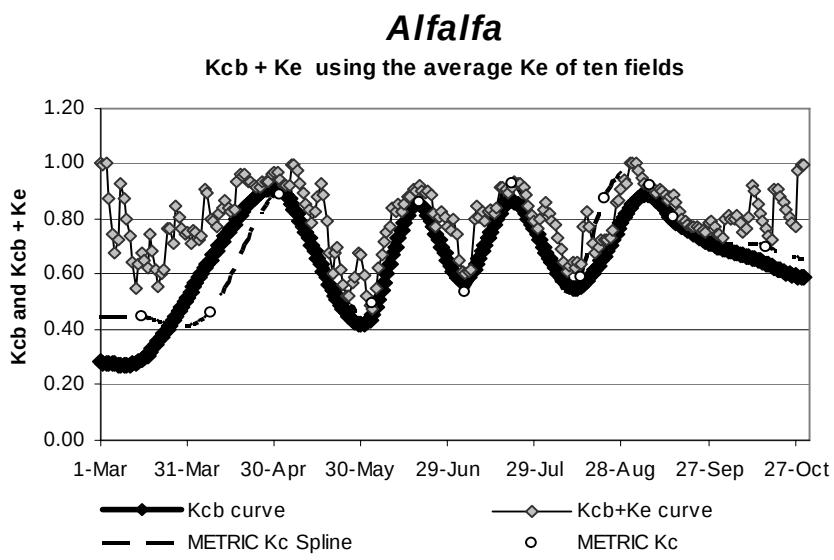
Ke obtained from water balance of the root zone (following FAO 56) with simulated irrigations

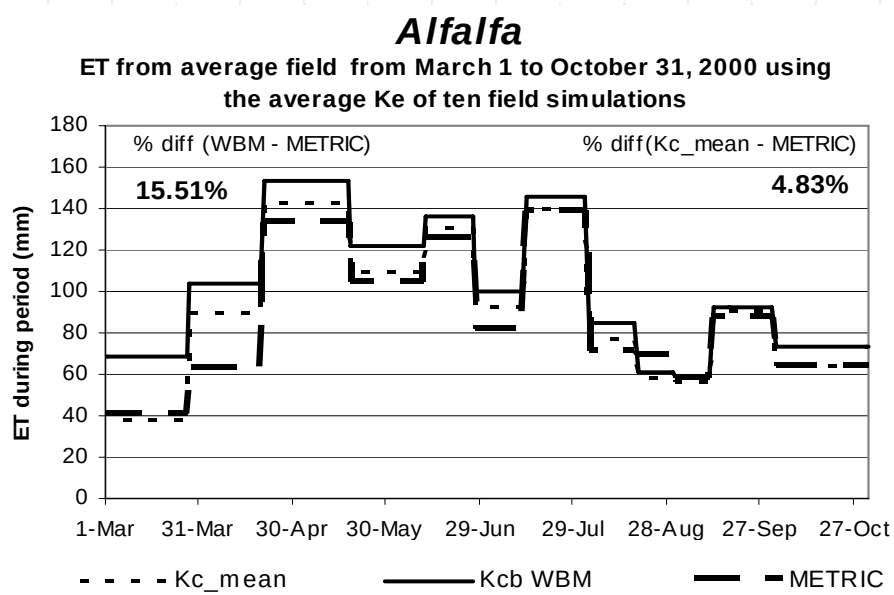
Alfalfa

(~ center pivot type of scheduling)

General Characteristics	Height (m)	Root depth (m)	Kc
Max	0.6	1	1
Min		0.25	0.1
fw (irrig.):	1		
REW: (mm)	8		
TEW: (mm)	23		
initial De: (mm)	0		
Initial fw:	1		
Avail.Water (mm/m)	160		
Ze (m) :	0.1		
FC-.5WP (m/m)	0.23		
MAD during Initial Stage %	70		
MAD after Initial Stage %	40		
Irrigation based on Kcb			
Kcb threshold	0.25		



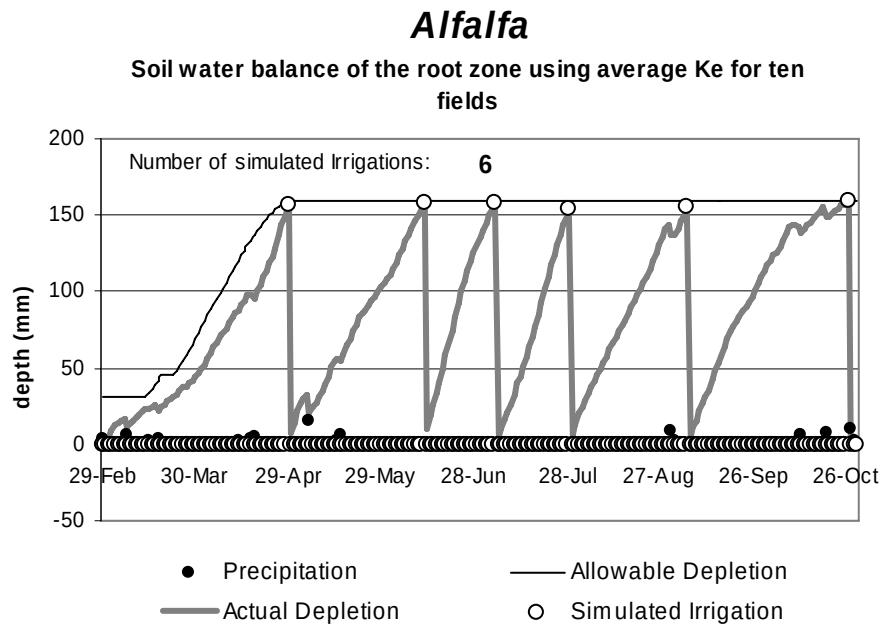


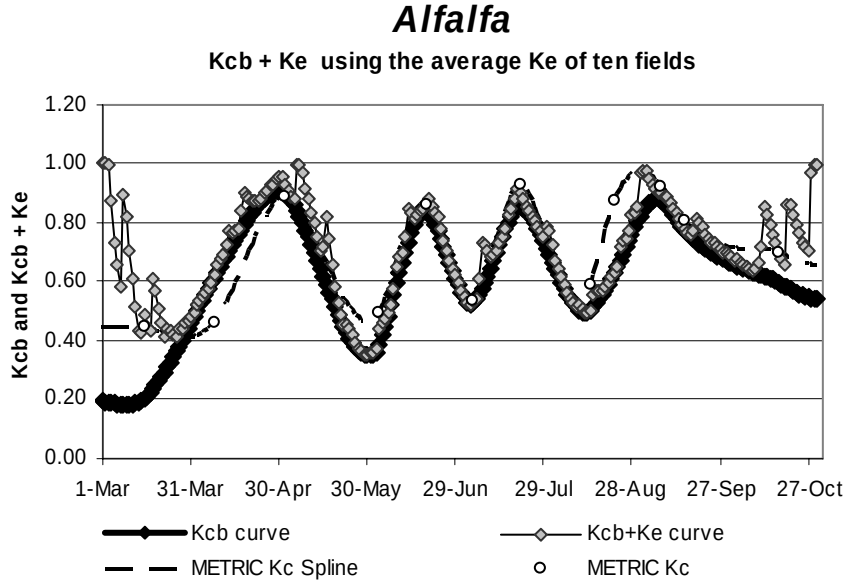


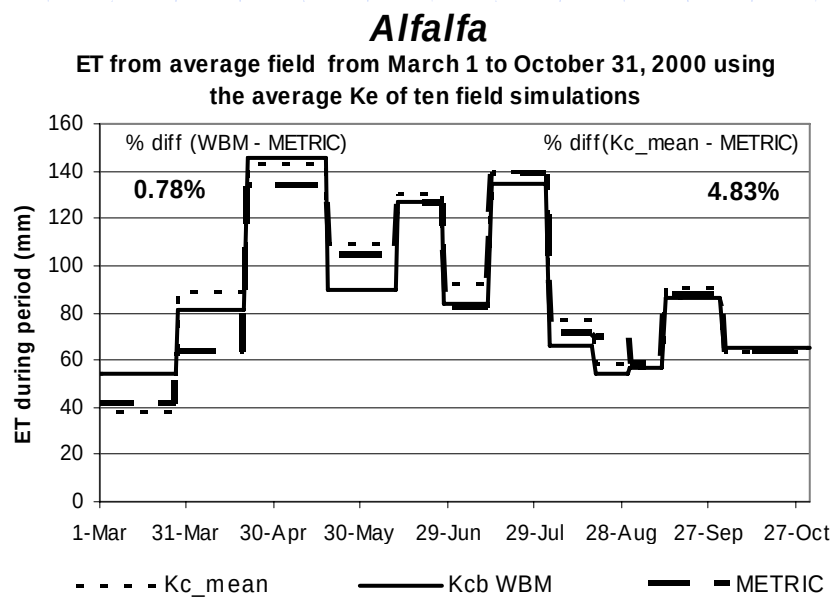
Alfalfa

(less frequent irrigation scheduling)

Alfalfa Characteristics	Height (m)	Root depth (m)	Kc
Max	0.7	2	1
Min		0.25	0.1
fw (irrig.):	1		
REW: (mm)	8		
TEW: (mm)	23		
initial De: (mm)	0		
Initial fw:	1		
Avail.Water (mm/m)	160		
Ze (m) :	0.1		
FC-.5WP (m/m)	0.23		
MAD during Initial Stage %	70		
MAD after Initial Stage %	50		
Irrigation based on Kcb			
Kcb threshold	0.25		



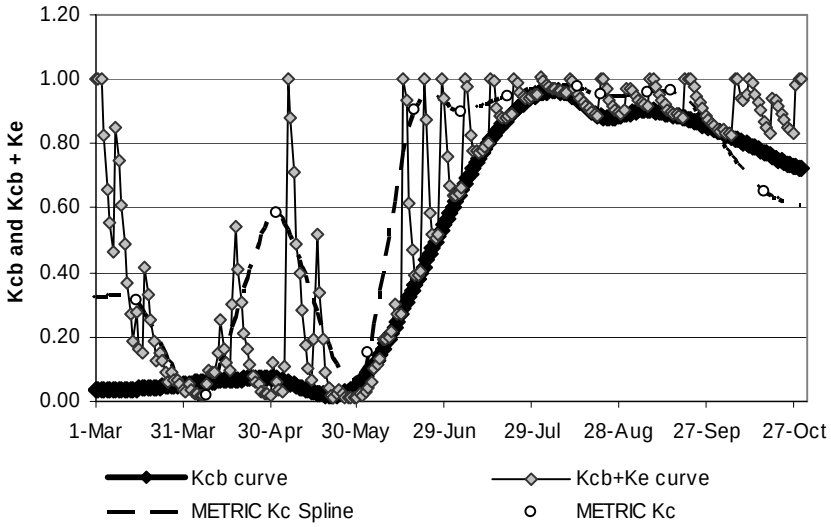




Other Crops within the Magic Valley

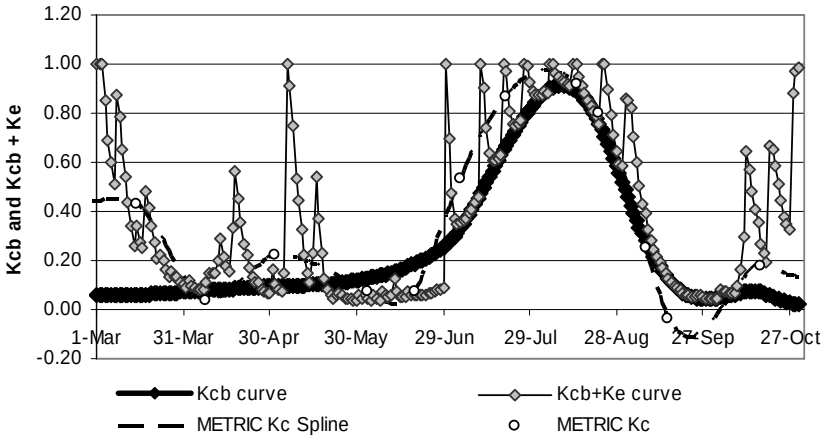
Sugar Beets

Kcb + Ke for field #4



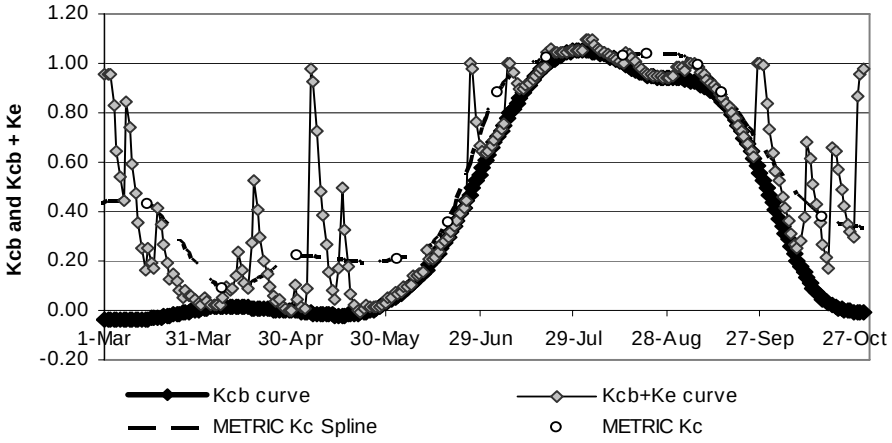
Beans

Kcb + Ke using the average NDVI_ats of ten fields



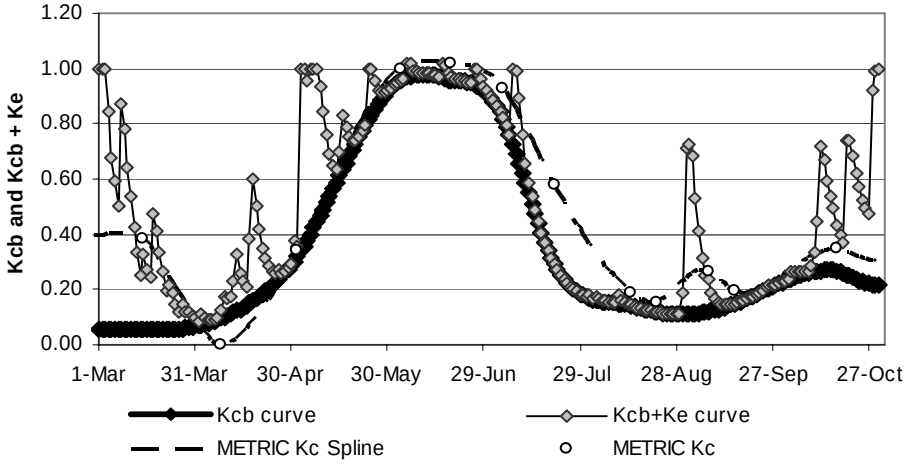
Corn

Kcb + Ke using the average NDVI_ats of ten fields



Spring Grain

Kcb + Ke using the average NDVI_ats of ten fields

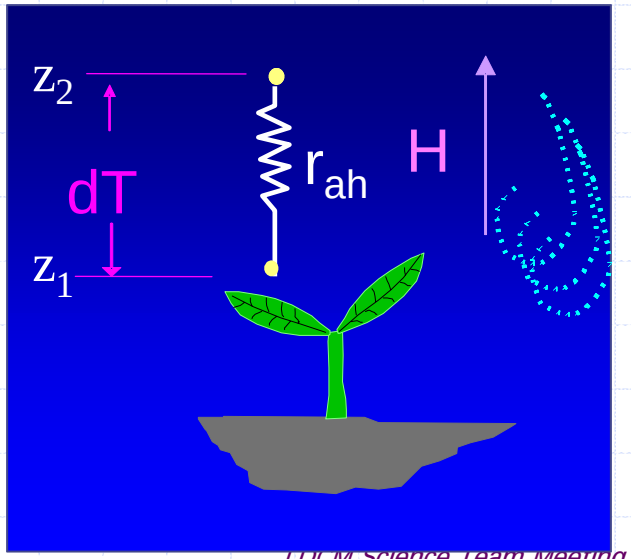


Automated Calibration inside METRIC ("anchor pixel" selection)

- Automatic selection of the cold and hot anchor pixels used in the calibration of METRIC.

$$dT = a + b\,T_s$$

$$a = \frac{dT_{hot} - dT_{cold}}{T_{s\,hot} - T_{s\,cold}} \qquad b = dT_{hot} - a\,T_{s\ hot}$$



Purpose:

- **Automate the application over wide areas**
- **Ease of Operation (reduction in anxiety)**
- **Increase in accuracy and consistency**

Statistics to Guide Auto-Selection of Pixels

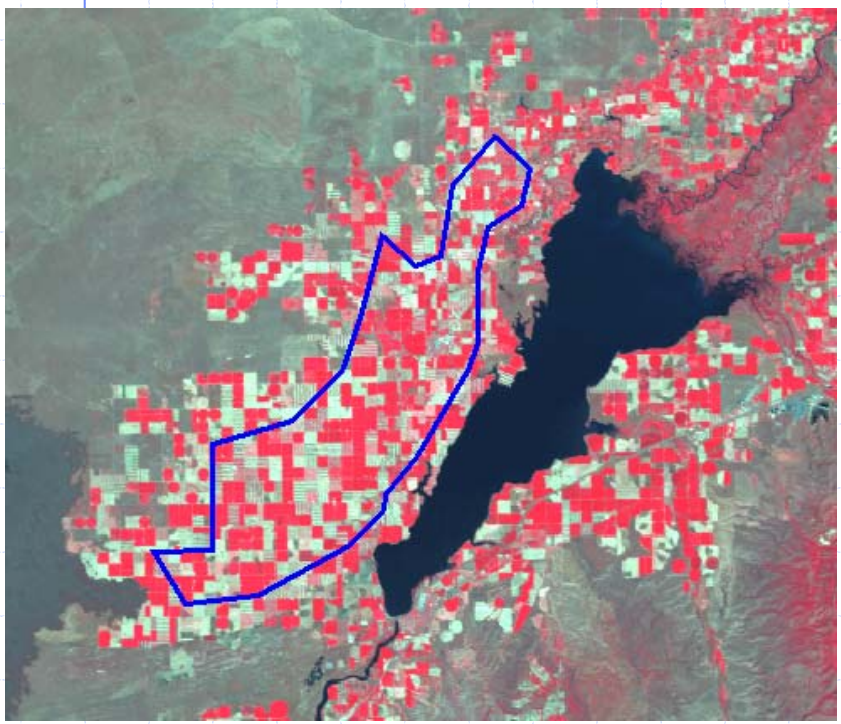
Cold Pixel

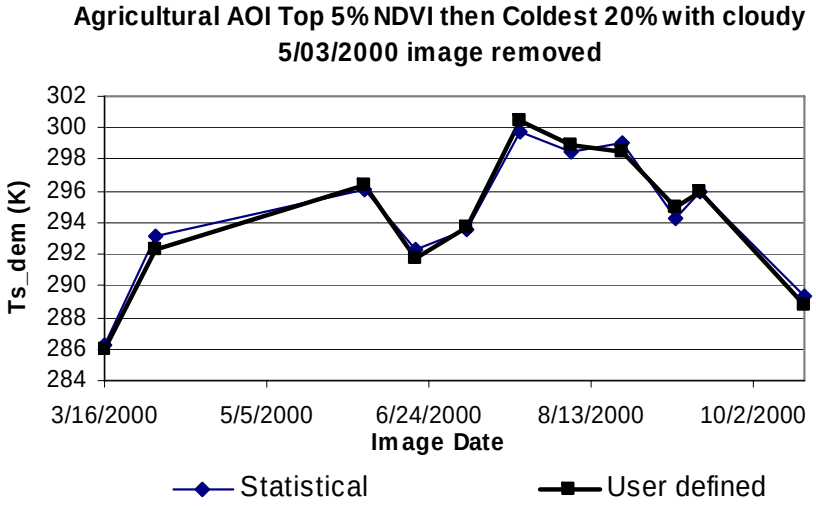
- Select top 5% highest NDVI
- Then select coldest 20% of Ts
- Take average Ts of the remaining sample as the Ts for the cold Pixel

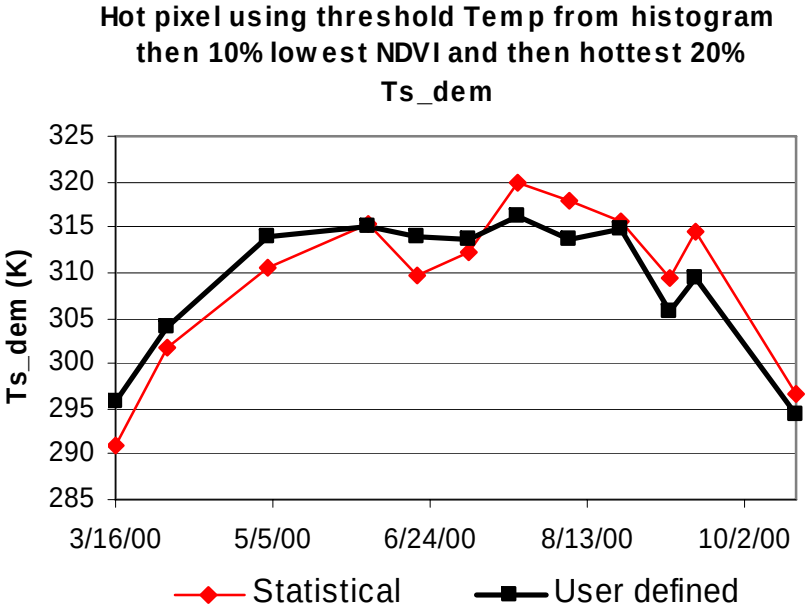
Hot Pixel

- Select the lowest 10% of NDVI
- Then select the hottest 20% of Ts
- Take average Ts of the remaining sample as the Ts for the hot pixel

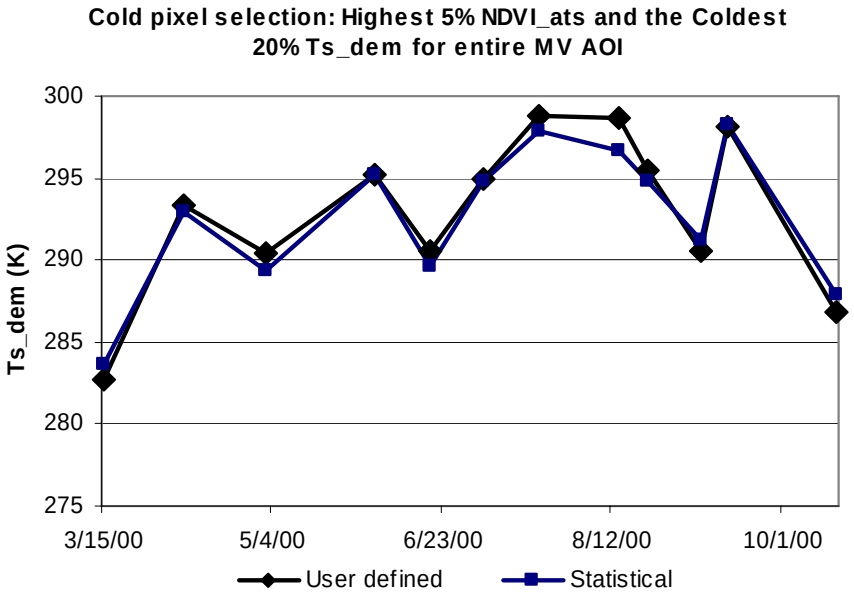
Path 39 (Aberdeen area near American Falls)

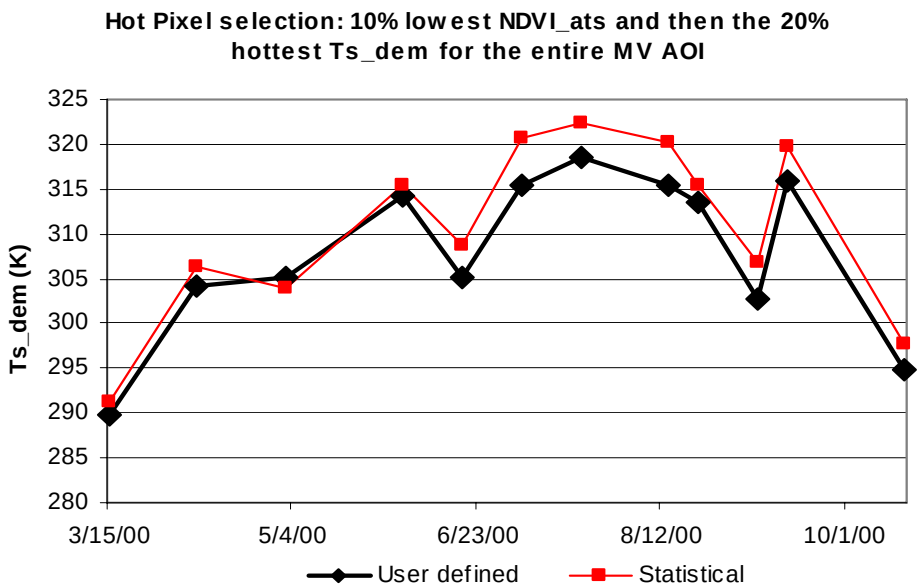


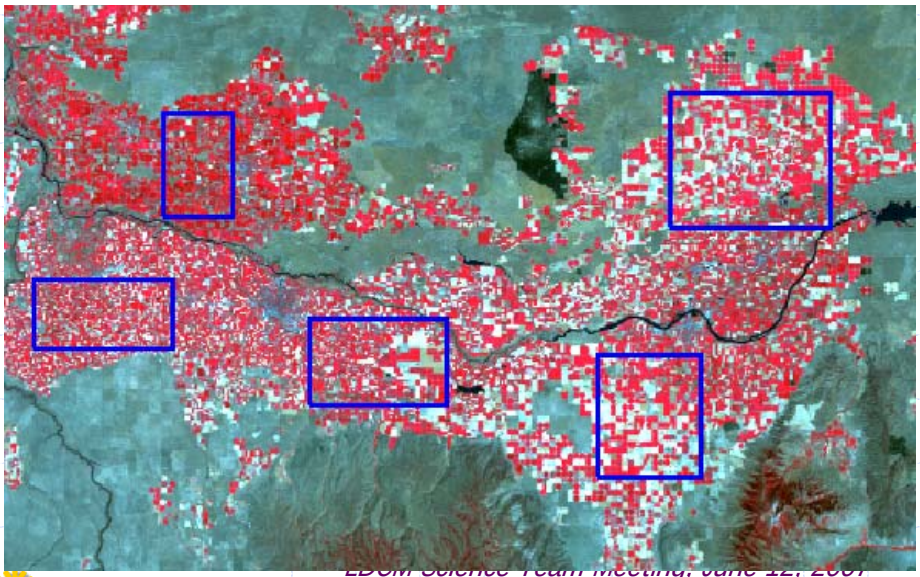


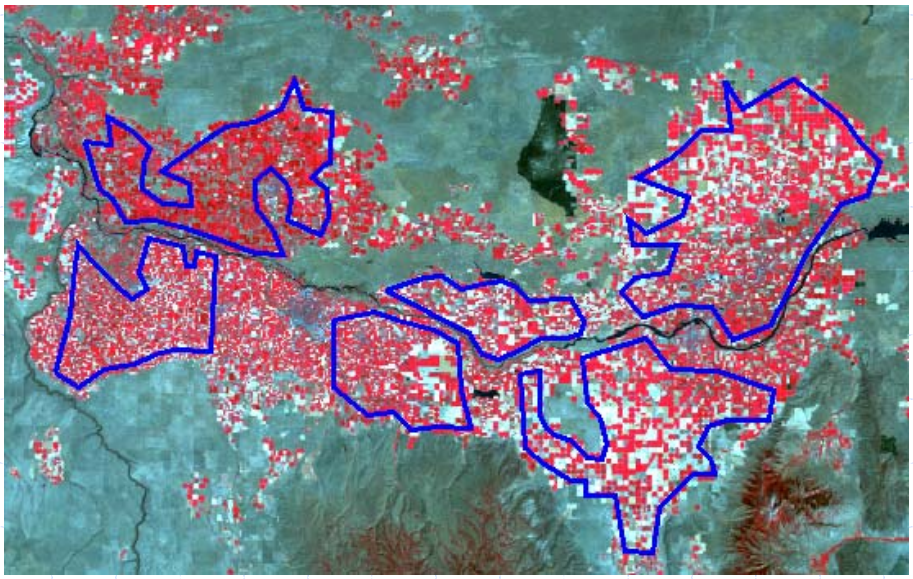


Path 40 Statistical analysis

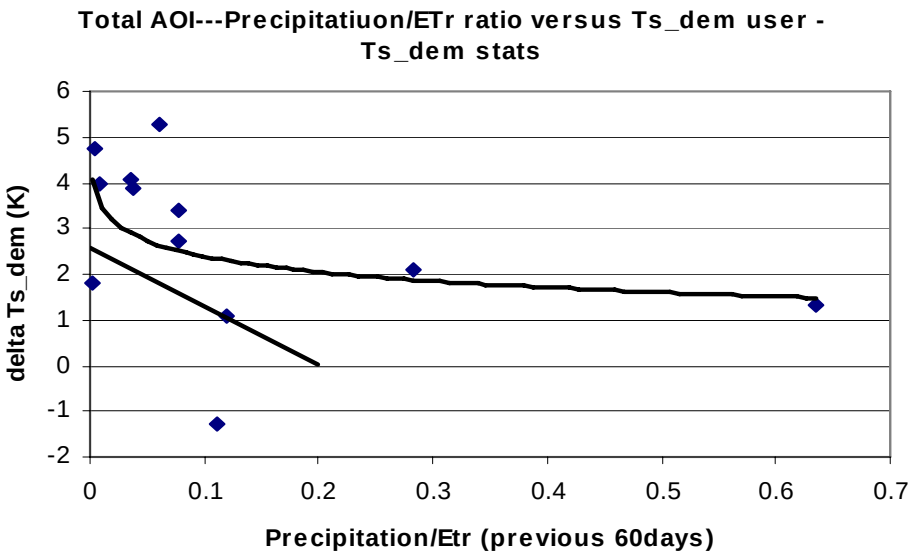


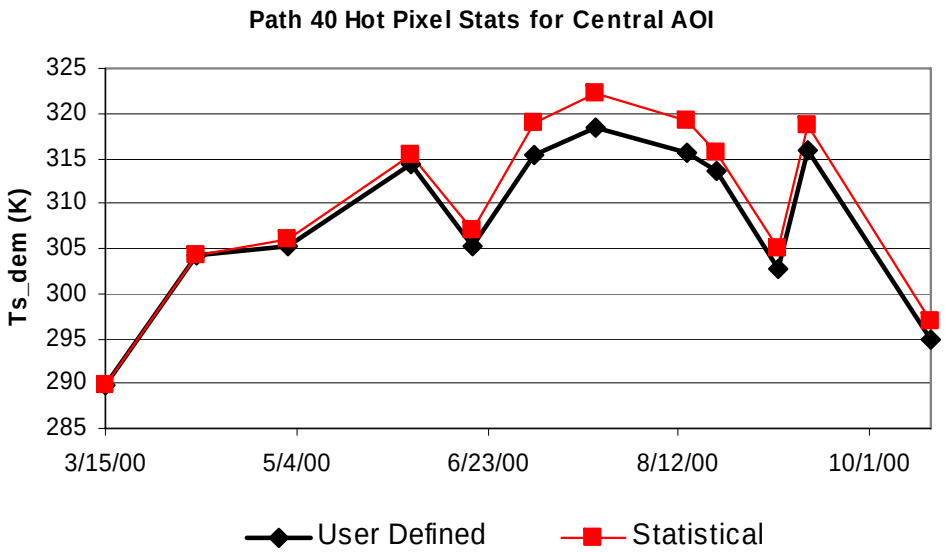


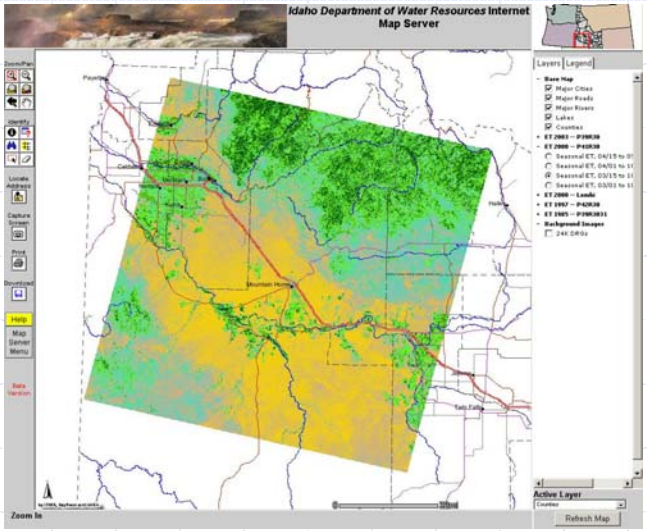




Use Relative Antecedent Wetness (Precip./ET_{ref} to modify selection)





More information at:

- www.kimberly.uidaho.edu/water/ (METRIC^{tm})
- http://www.idwr.idaho.gov/gisdata/et.htm
- http://maps.idwr.idaho.gov/et/