Landsat-based (Field-Scale) Evapotranspiration Estimates - METRIC Overview and Applications

Landsat 8 - launched Feb. 2013

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Who Cares about ET?

- Departments of Water Resources
- US Bureau of Reclamation
- US Geological Survey
- Environment
- Irrigators
- Courts

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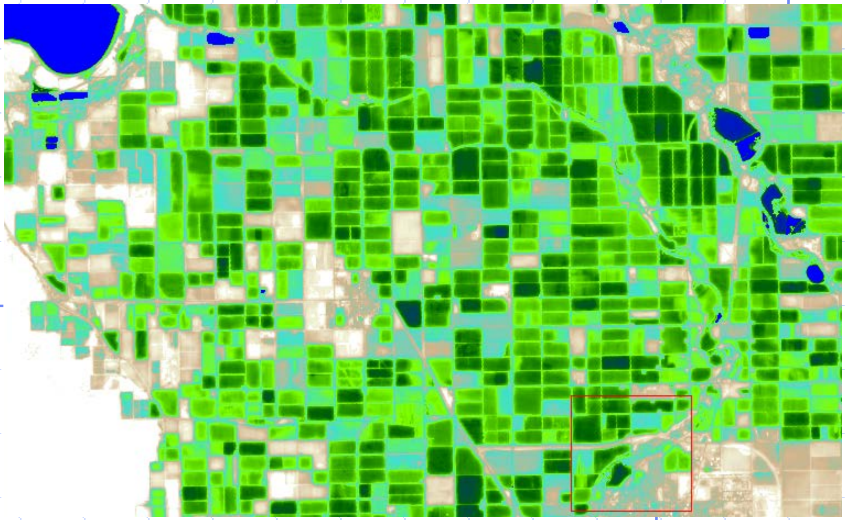
Applications in the West



Water Planning

Aquifer Depletions

Hydrologic Modeling

Endangered Species

Agricultural Water Use

Legal Finding-of-Fact

Water Rights Buy-Back

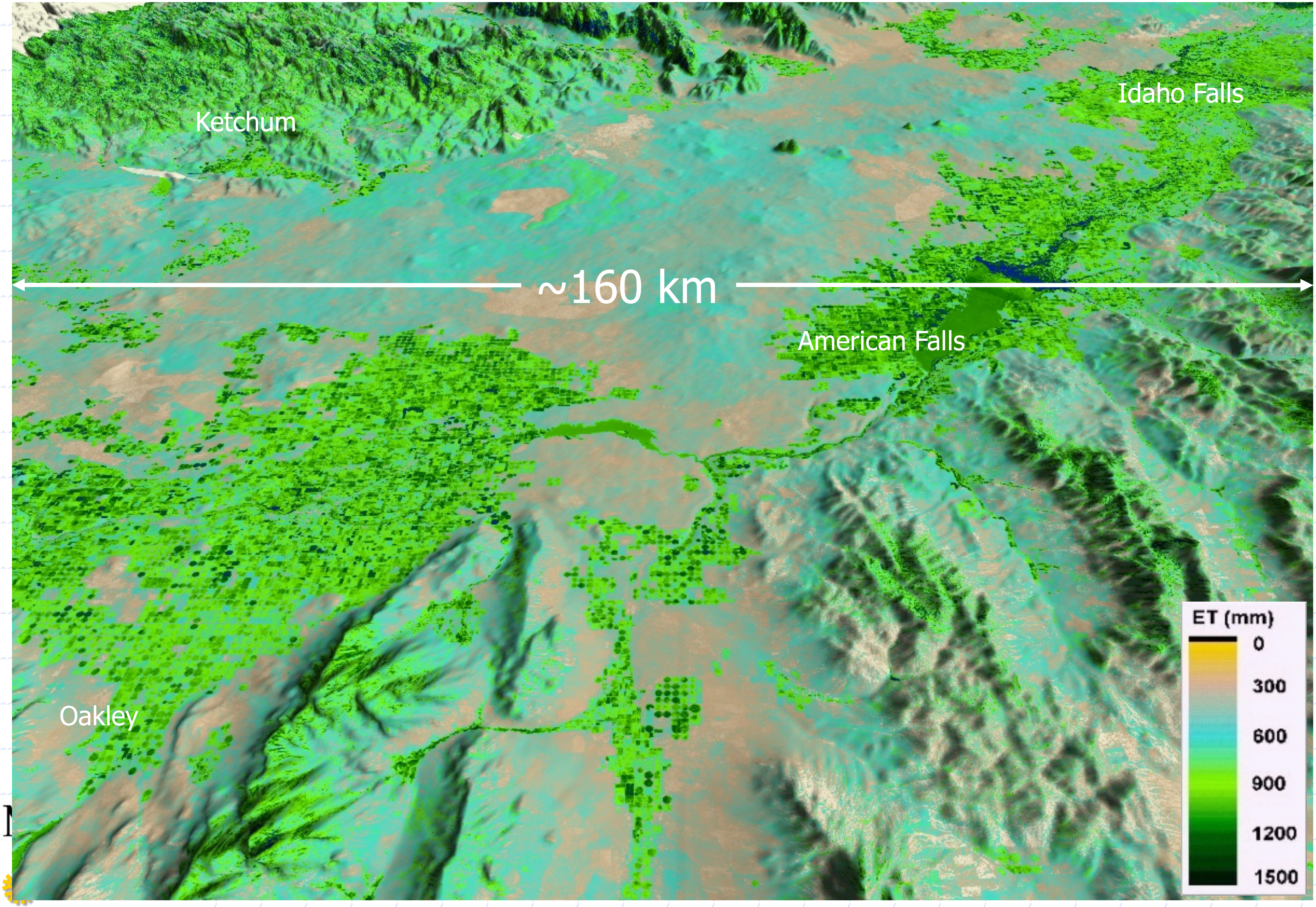
Water Rights Compliance

In-Season Water Demand

Tribal Water Rights Negotiations

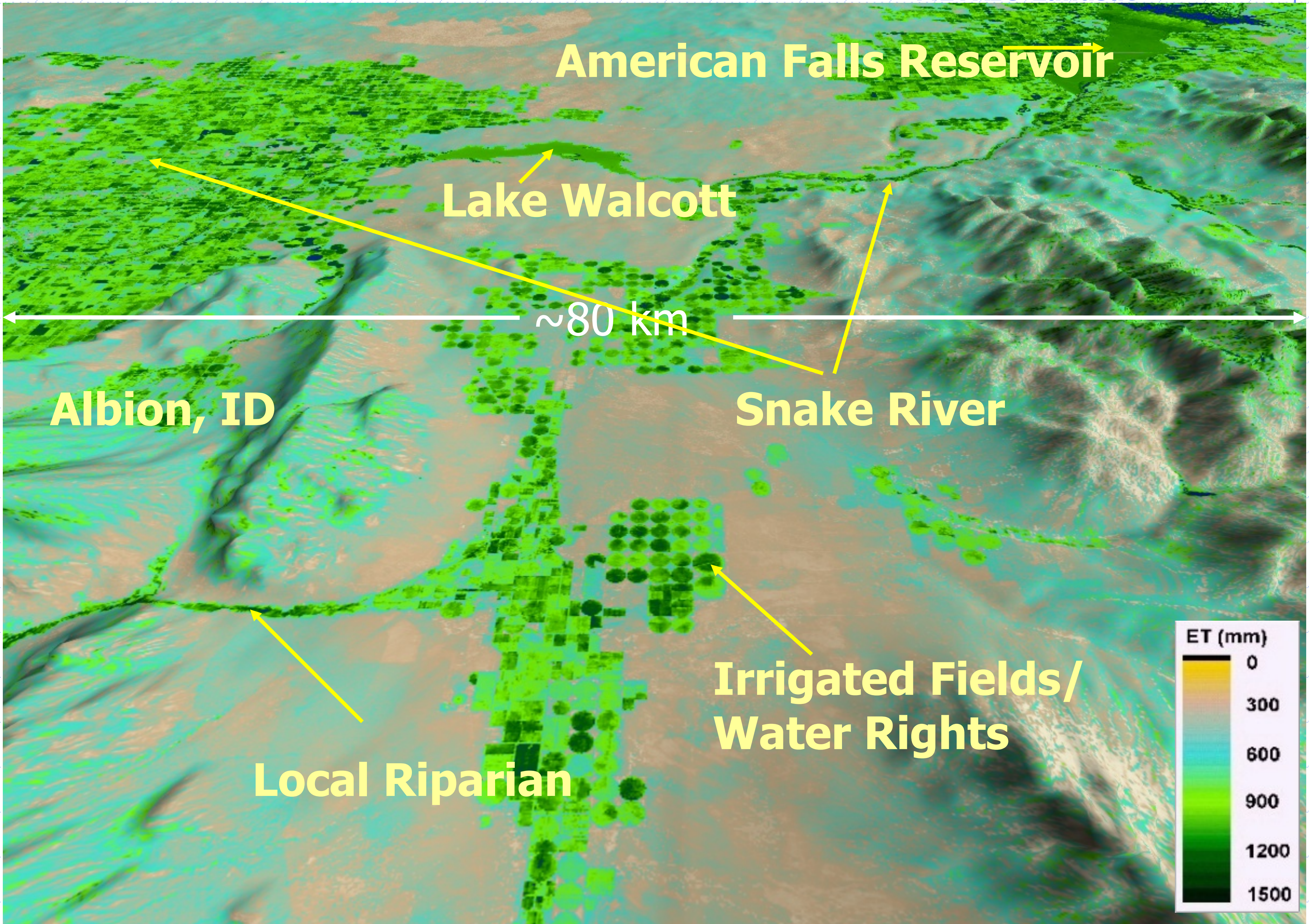
Does ET vary in Space? (Yes!) -- Monthly and Seasonal ET at 30 m resolution for the Eastern Snake Plain of Idaho

April – October, 2006 ET



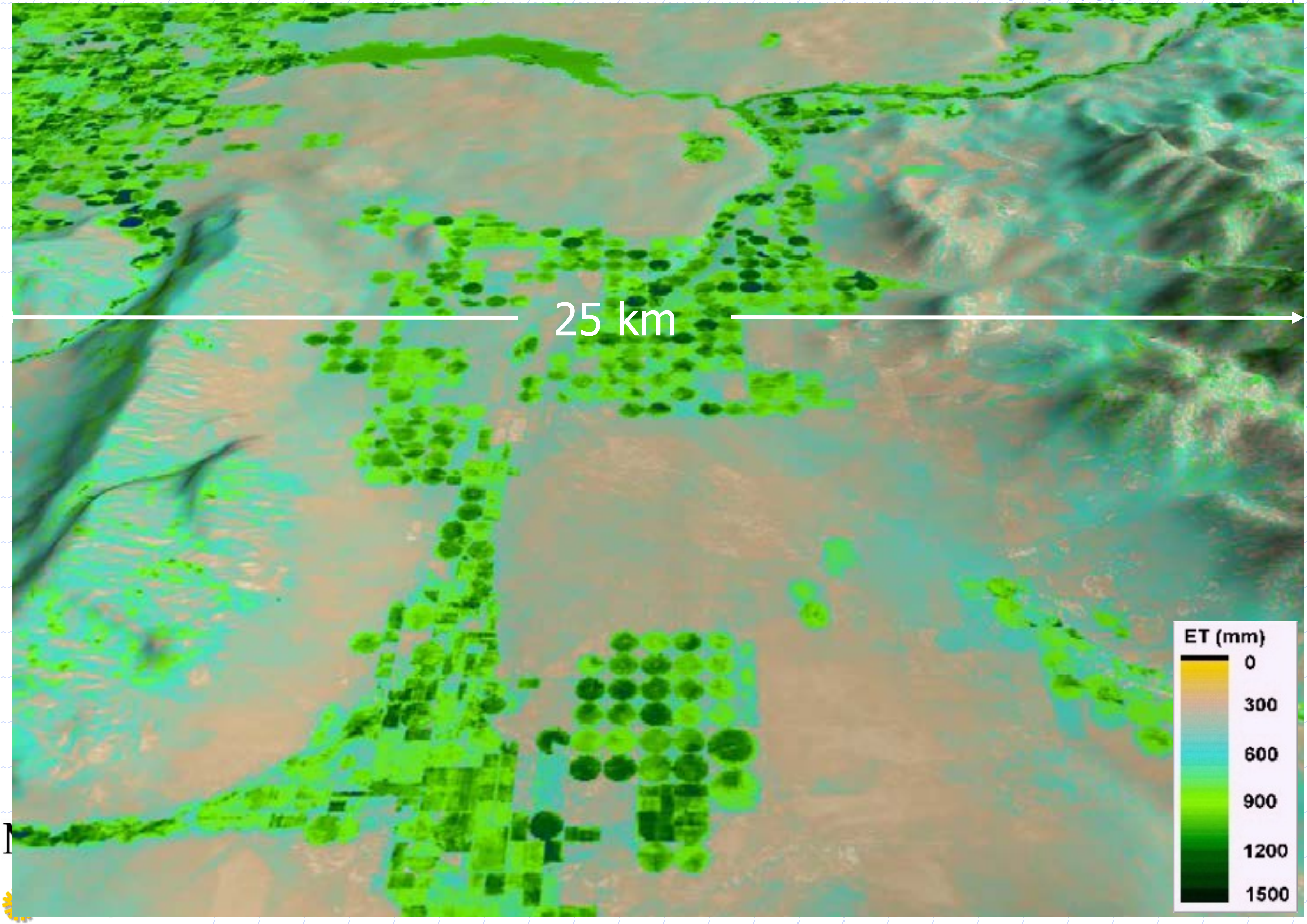
ET features at 30 m resolution

April – October, 2006 ET from METRIC-Landsat



ET features at 30 m resolution

April – October, 2006 ET from METRIC-Landsat

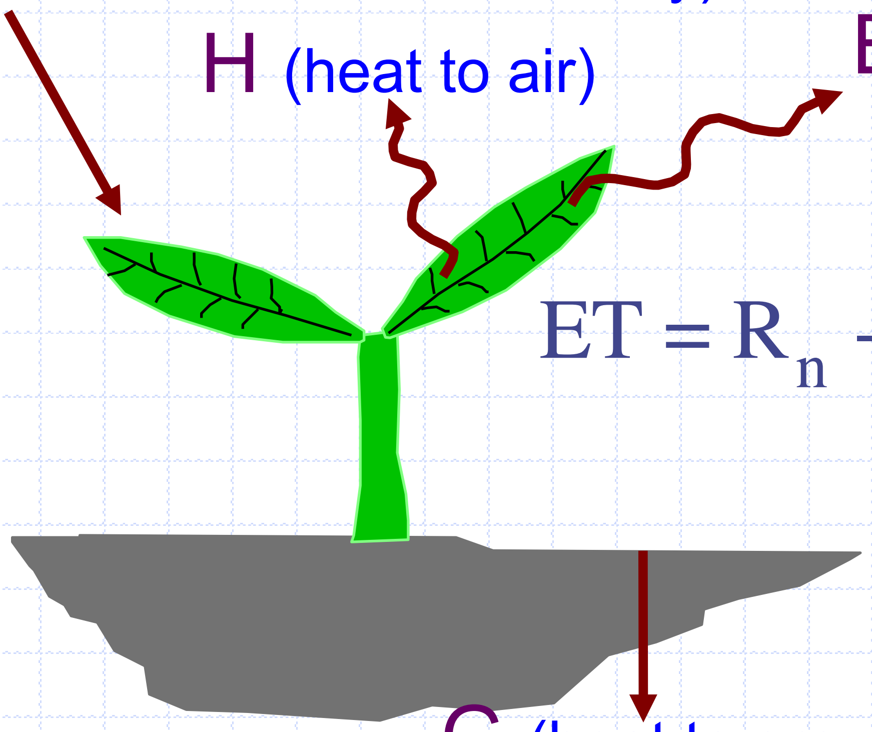


When Energy Balance Matters

- Energy Balance
  - Remember: ET is the water that changes from liquid to water vapor
  - Liquid to vapor conversion requires energy
  - We ‘look’ for the energy used to produce the evaporation
  - **EB components can be derived from the temperature of the surface**

Why use an "Energy balance"?

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



$$ET = R_n - G - H$$

Basic Truth: Evaporation consumes Energy

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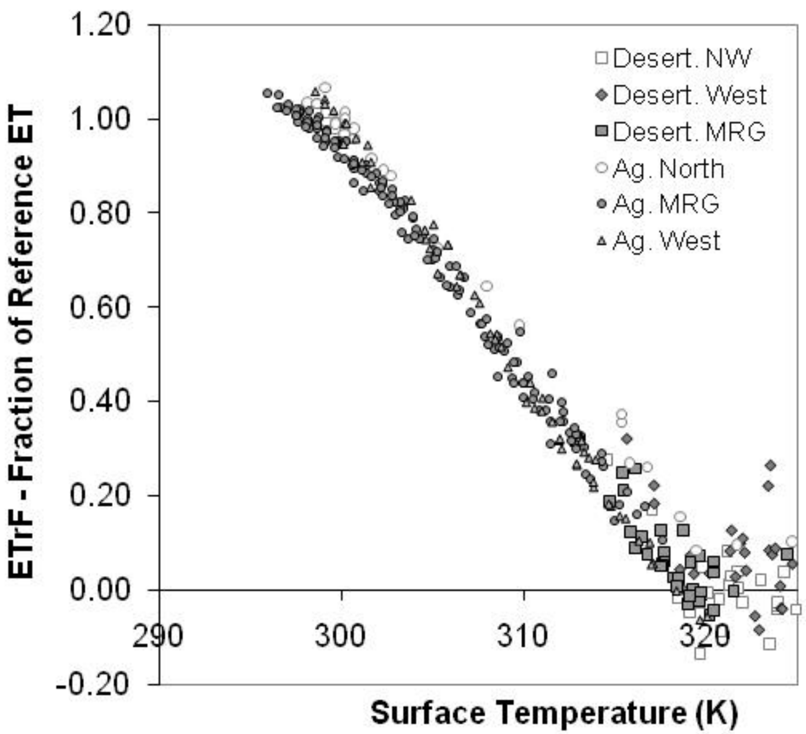
Energy balance gives us "actual" ET

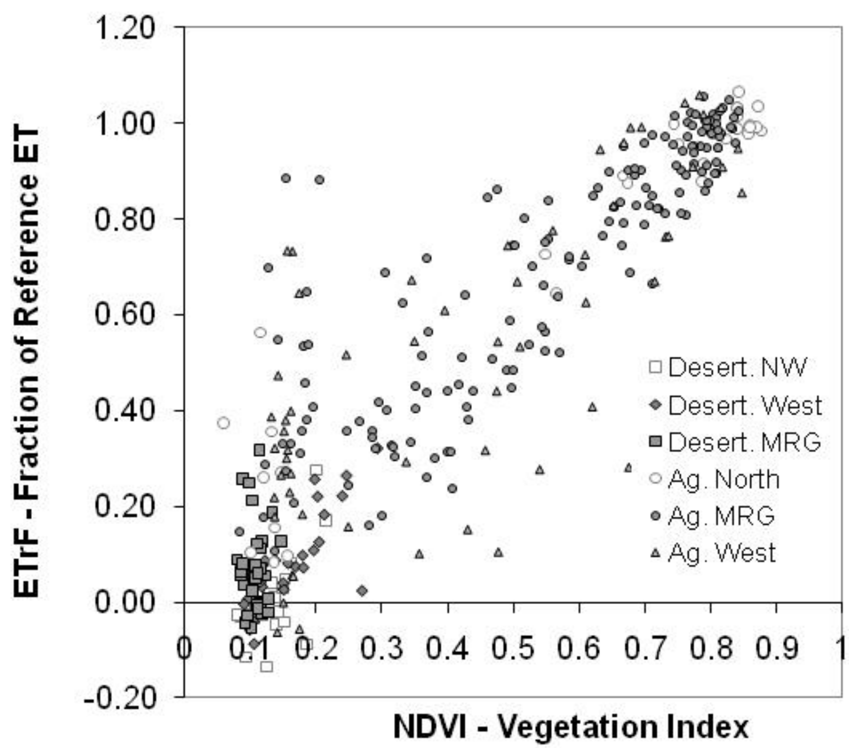
Energy Balance can 'see' impacts on ET caused by:

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

- *(these effects can cause the ratio ET / amount of vegetation to vary widely, thus the need to compute ET as a residual of the energy balance)*

ET is influenced more by (and correlated with) Surface Temperature, rather than with Vegetation Amount





Middle Rio Grande, New Mexico, 2002

ET_rF = fraction of Reference ET. $ET_rF = ET_{actual}/ET_{ref}$

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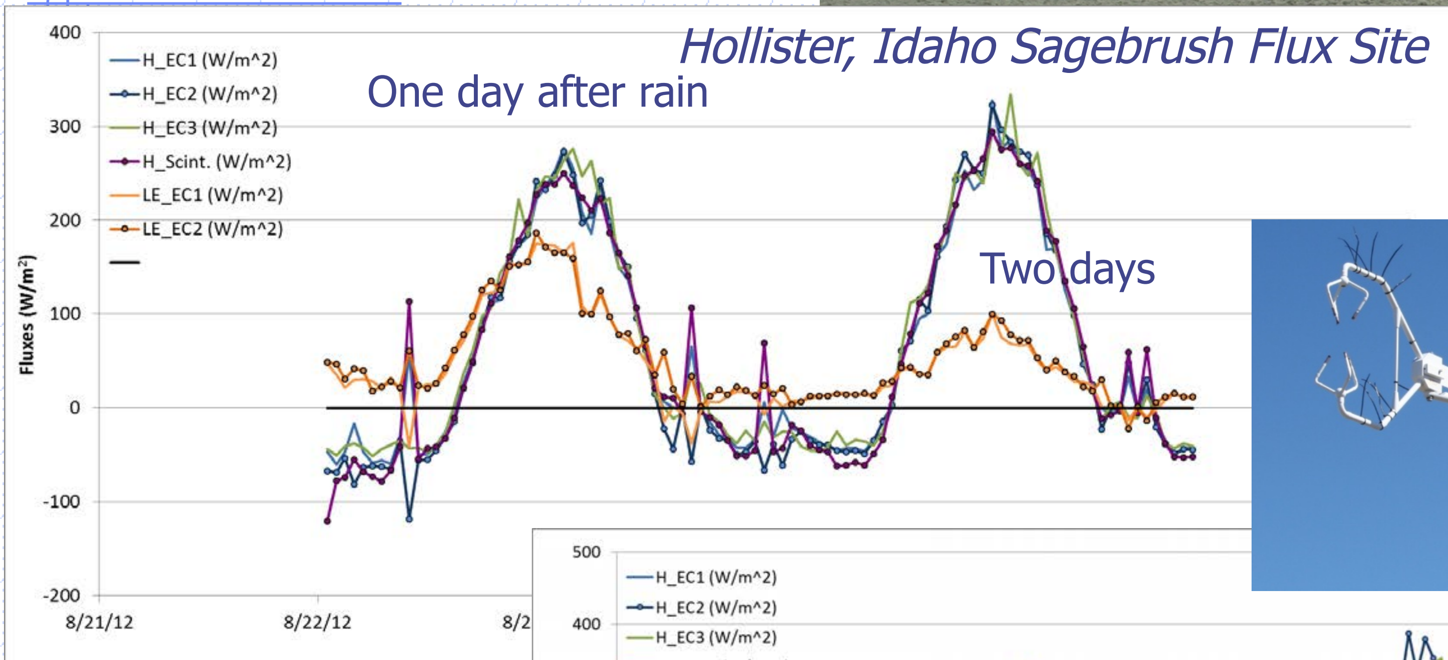
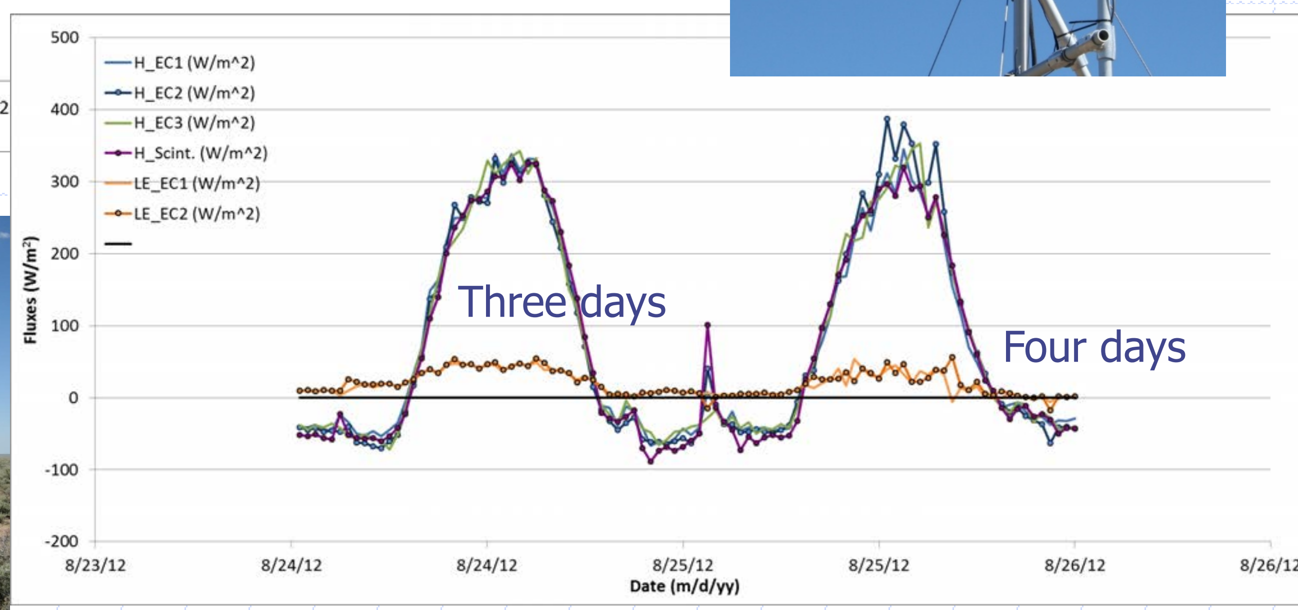
Low levels of ET require high quality surface energy balance (EB)





General EB Components in METRIC

(Mapping ET at high Resolution using Inverse Calibration)

- Net Radiation (R_n)
  - Reflected shortwave from satellite
  - Incoming shortwave from theory
  - Emitted longwave from satellite
  - Incoming longwave from emitted and atmospheric transmissivity
- Sensible Heat Flux (H)
  - Near surface vertical air temperature gradient (dT) keyed from surface temperature (T_s) – calibrated to each image date ($dT = a + b\ T_s$)
  - Aerodynamic resistance from
    - Wind speed at blending height (from gridded or local weather)
    - Aerodynamic roughness from vegetation indices and land use type
    - Buoyancy effects from iterative solutions
- Soil Heat Flux (G)
  - Function of H for nearly bare soil and function of R_n for vegetation
- $\lambda E = R_n - G - H$

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Sensible Heat Flux (H) – METRIC model

Advantage:
r_{ah} 'floats' above the surface and is 'free' of z_{oh} and some limitations of a single source approach

$$H = (\rho \times c_p \times dT) / r_{ah}$$

Advantage:
dT is inverse calibrated (simulated) (free of T_{rad} vs. T_{aero} vs. T_{air})

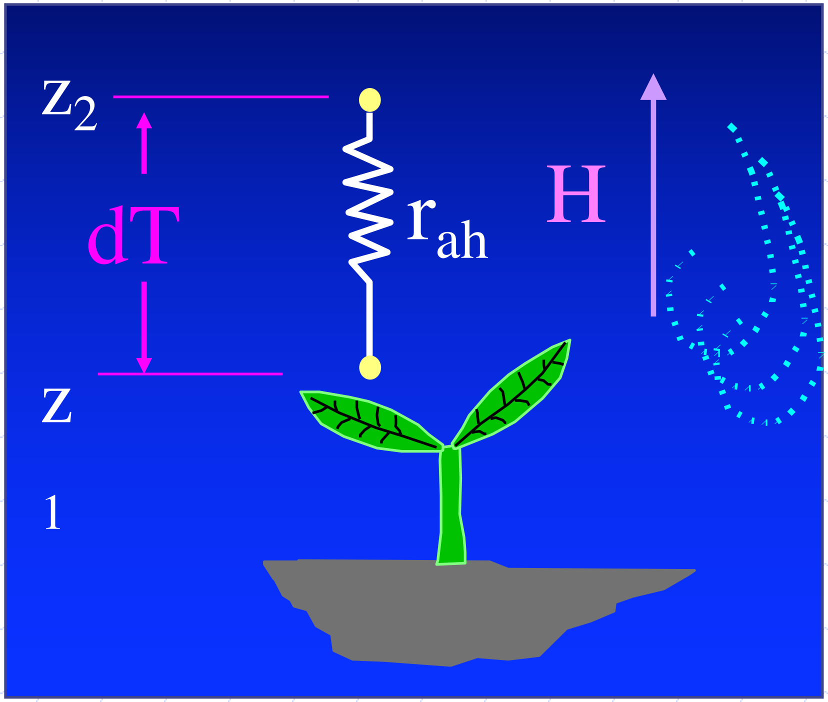
dT = "floating" near surface temperature difference (K)

r_{ah} = the aerodynamic resistance from z_1 to z_2

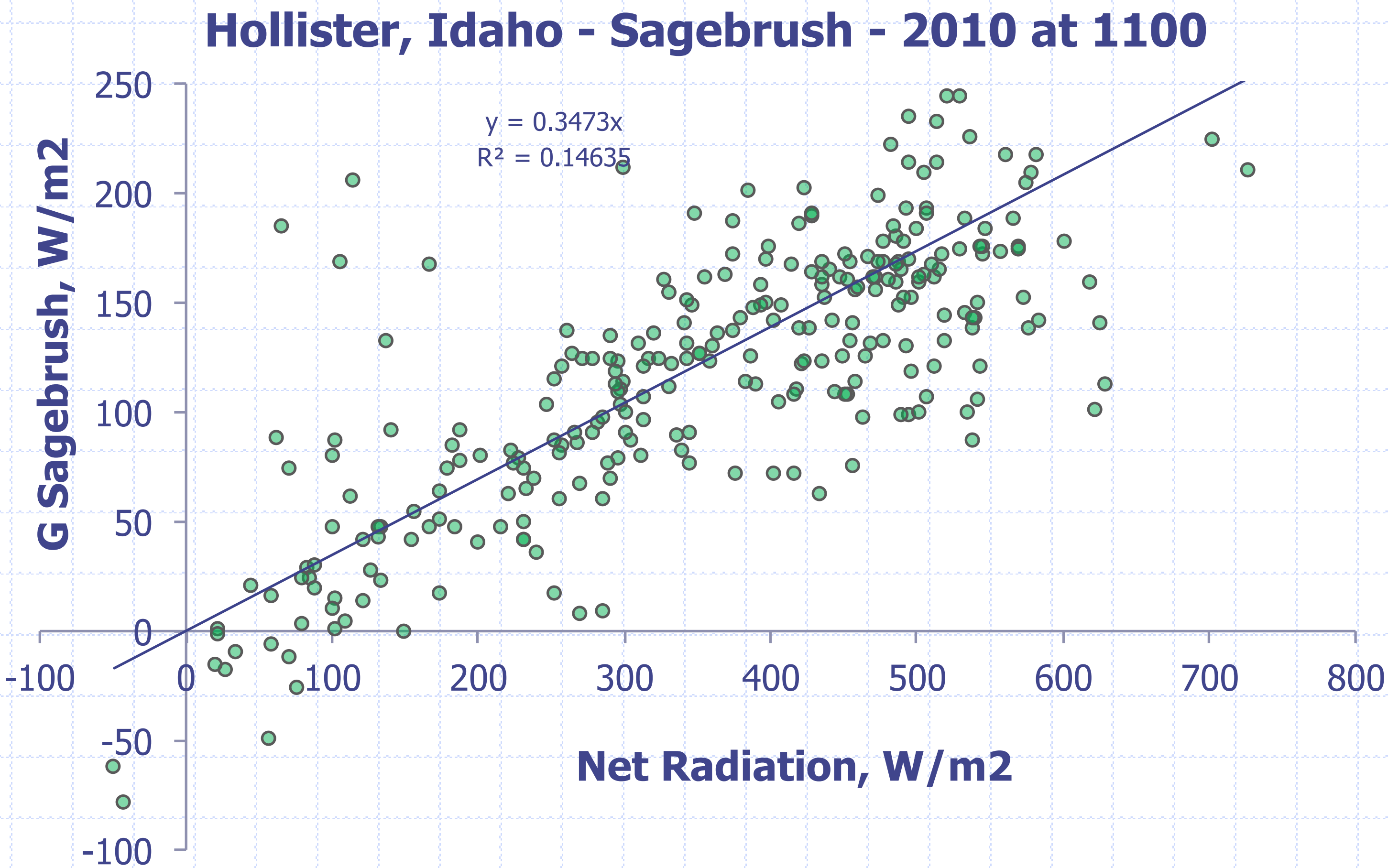
$$r_{ah} = \frac{\ln\left(\frac{z_2}{z_1}\right) - \Psi_{h(z_2)} + \Psi_{h(z_1)}}{u_* \times k}$$

u_* = friction velocity

k = von karmon constant (0.41)



G for water stressed systems can be large and needs to be accounted for



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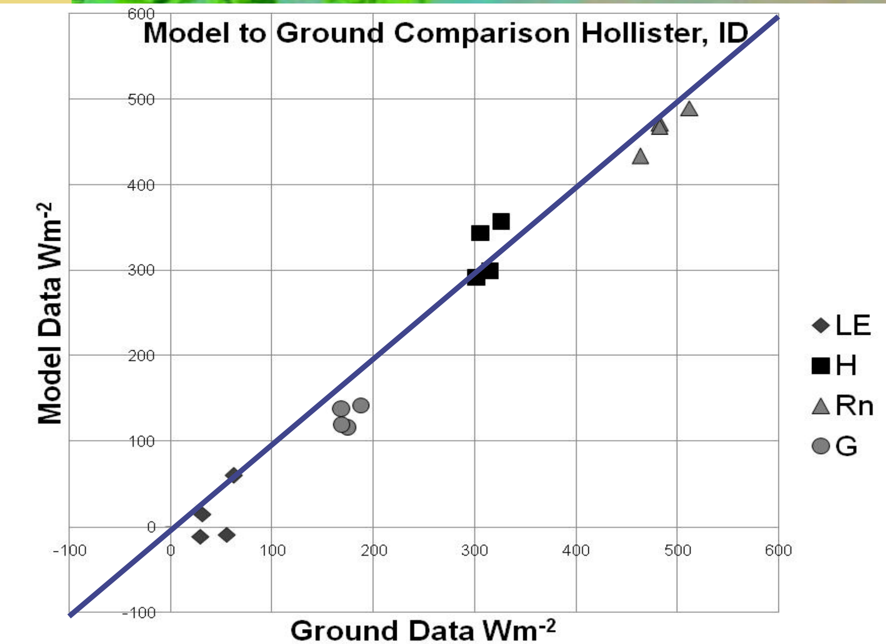
Idaho NSF EPSCoR Flux Sites – Desert Systems



Four Landsat Dates during 2010 – Sagebrush

April – September ET from METRIC

- Comparison of satellite-based surface energy balance (METRIC) with Eddy Covariance for very low ET signal

Calibration of METRIC/SEBAL:

$bias_{Rn\text{-}G} \rightarrow bias_{H\text{-}cal} \rightarrow bias_{dT} \rightarrow bias_{H\text{-}pixel} \not\rightarrow LE$

unbiased

The Sensible Heat (H) Function *calibrates around Biases in many of the Energy balance components:*

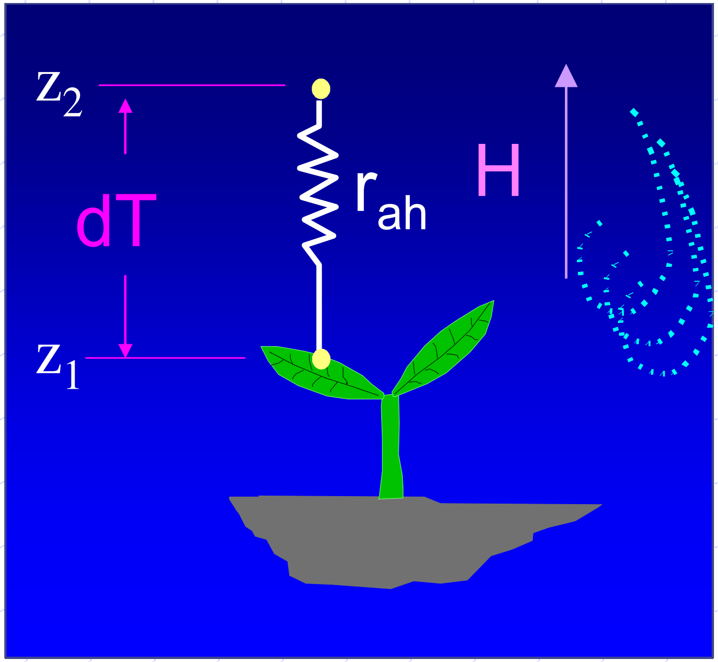
(Biases exist in: net radiation, soil heat flux, aerodynamic stability, aerodynamic roughness, absolute surface temperature, atmospheric correction)

any biases

$H = R_n - G - LE$ *(for calibration)*

$LE = R_n - G - H$ *(during application)*

Biases cancel out



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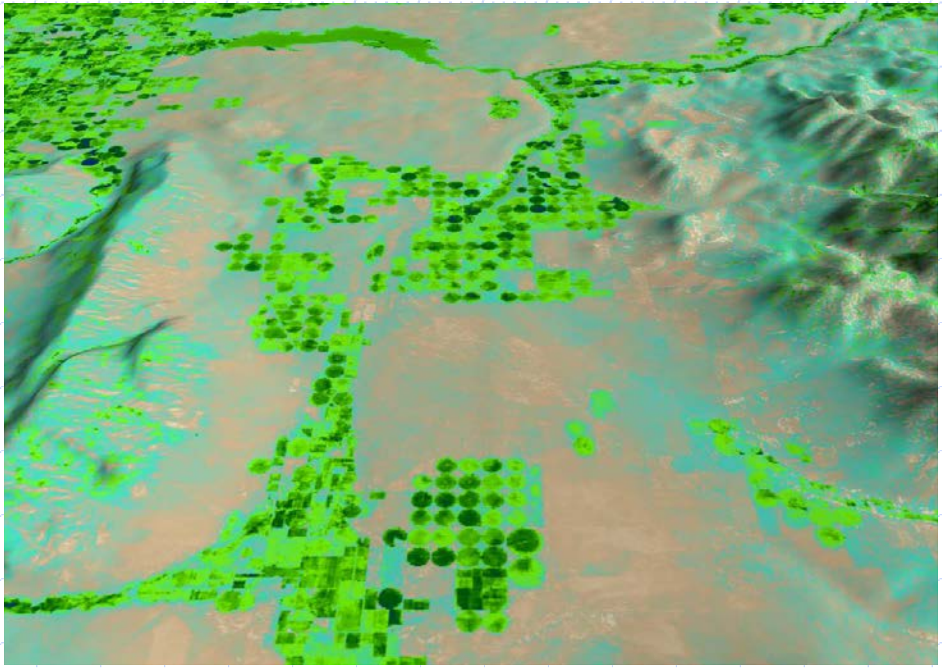
METRIC is an 'engineering' model aimed at field-scale ET with local (~200 km x 200 km) focus

A formula for quantifying spatially and time-variable processes:

Accuracy =
physics x human effort
+ human review and intervention

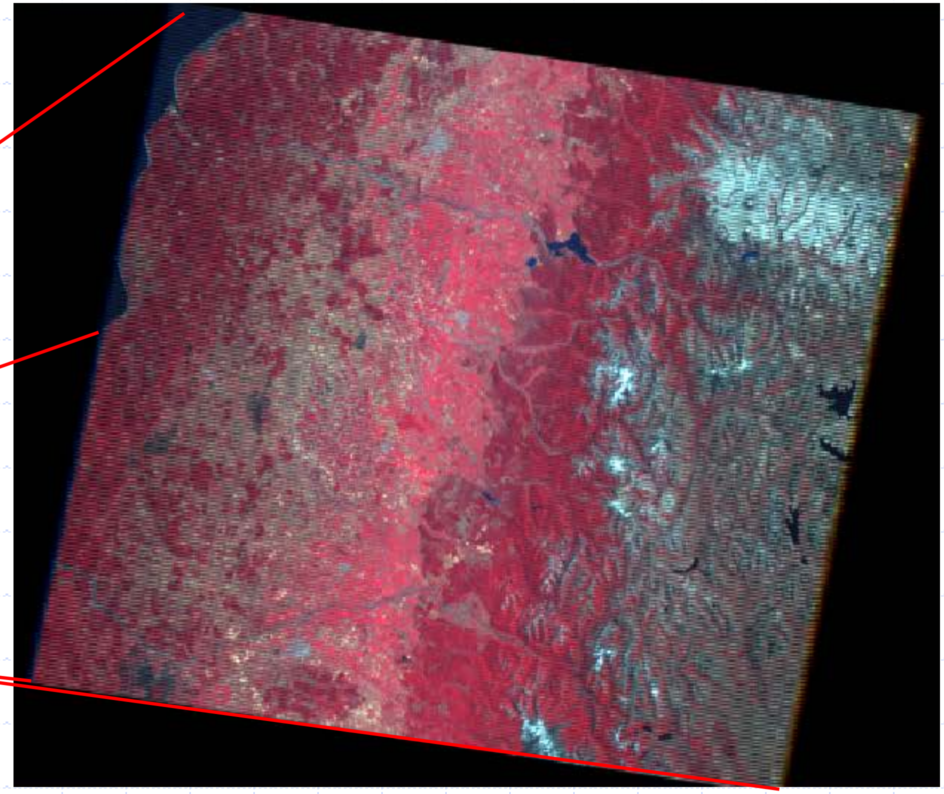


Fine-tuning adjustments in METRIC

- Soil heat flux of freezing soils
- Soil heat flux under organic mulch
- Soil heat flux optimization using EB inversion
- Excess aerodynamic resistance in sparse brush
- Nadir-based albedo adjustment for deep canopies
- Aerodynamic-based estimation of evaporation from water
- Radiation and Aerodynamic Algorithms in METRIC Level 3 for Complex Terrain (Mountains)

Olives in Chile

Chile



Study area is in the center of Chile

Path 233, Row 85, Landsat 7 processing (2011 & 2012)

Data by Dr. Samuel Ortega, Univ. Talca, Chile, collaboration with Dr. A. Kilic, Univ. Nebraska

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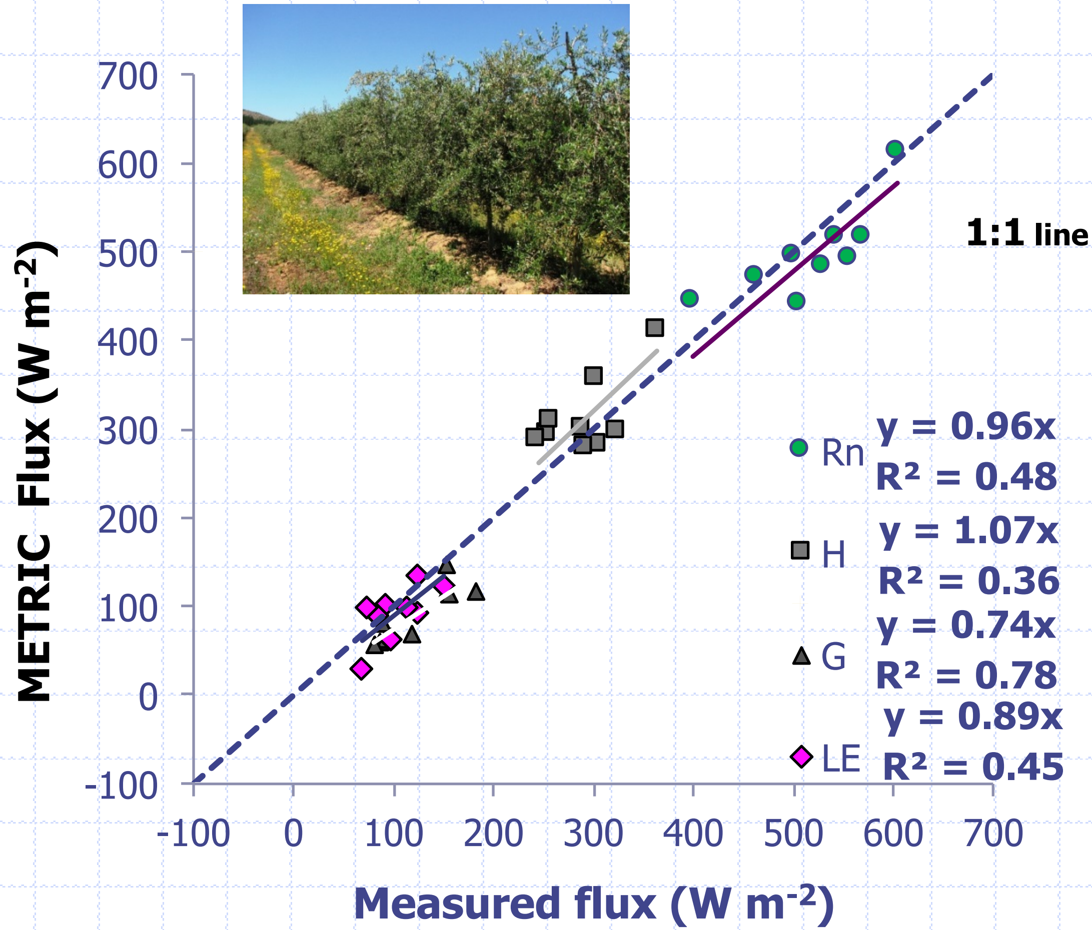
METRIC vs. Ground Measurements – Olive Orchard near Talca, Chile



New olive production in central Chile with relatively dense tree spacing.

ET fluxes measured using an eddy covariance system mounted above the crop.

Analyses by Samuel Orlando Ortega Salazar, with with A. Kilic, Univ. Nebraska

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Computing ET for Long (Monthly) Periods

- Utilize Relative ET from Landsat Snapshots
- Use "Fraction of Reference ET" (ET_rF) concept to extend Snapshots over time
- Use "Reference ET" (ET_r) as the daily Scaler that incorporates day-to-day weather impacts on ET

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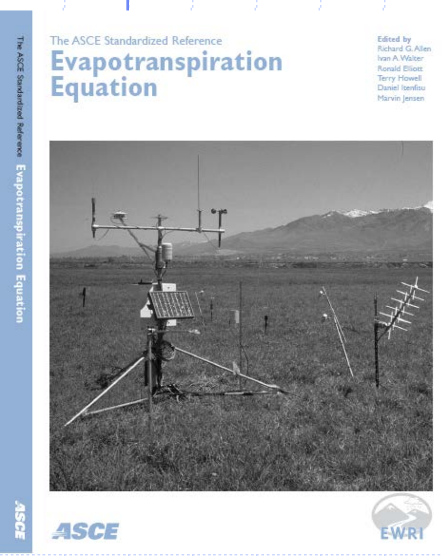
Reference ET:
A Living Evaporation Index

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

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



ASCE Penman-Monteith

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

Standardized ASCE Penman-Monteith

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

C_n and C_d are constants

f (Solar Radiation)

f (Temperature)

Wind Speed

f (Humidity)

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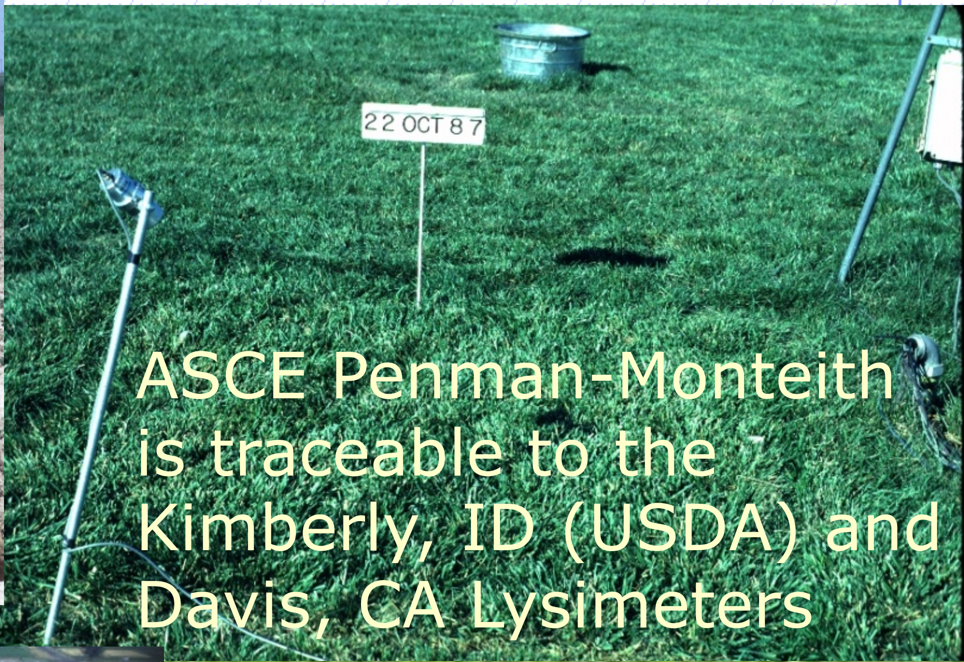
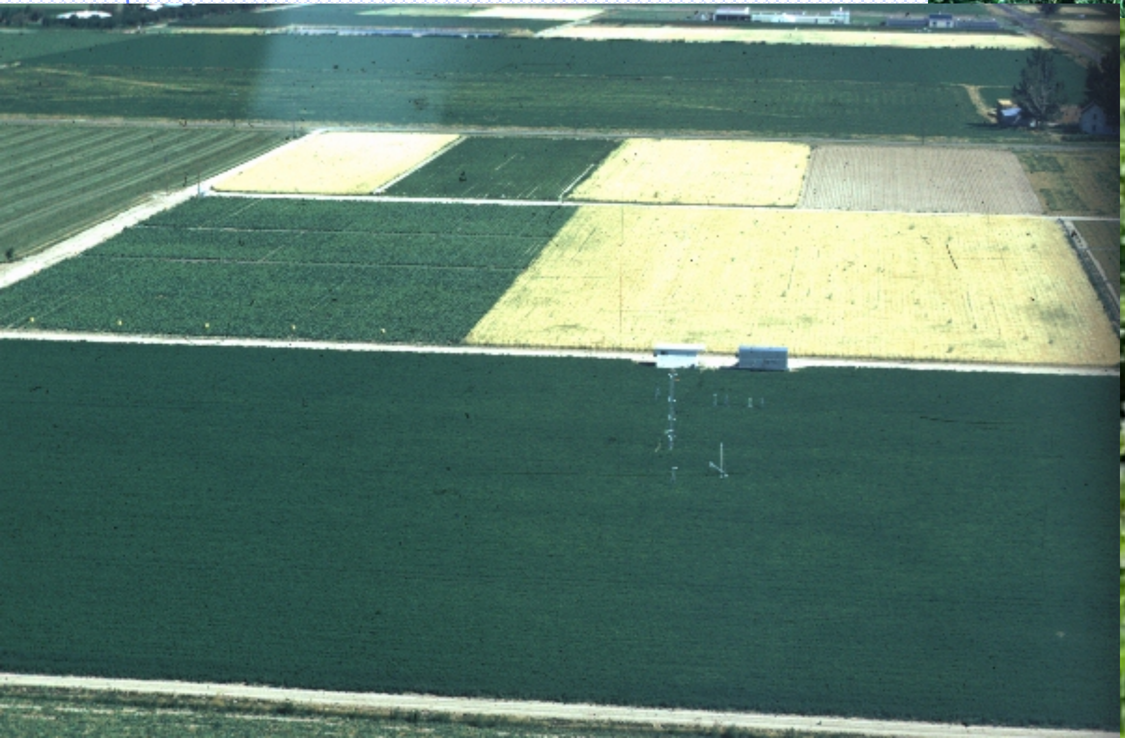
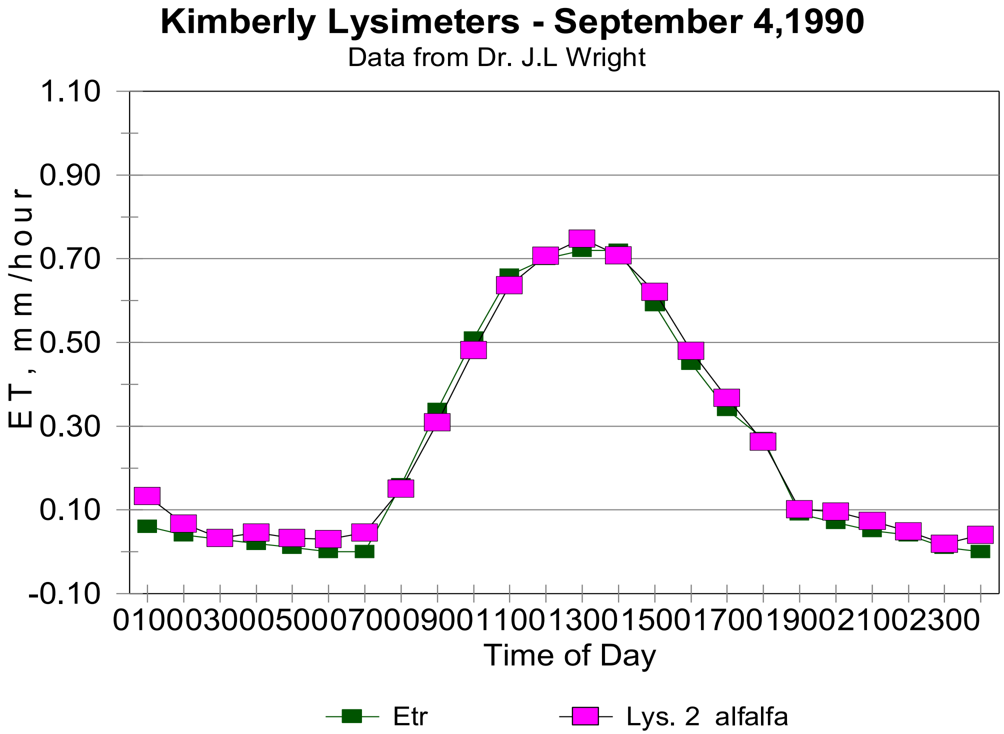
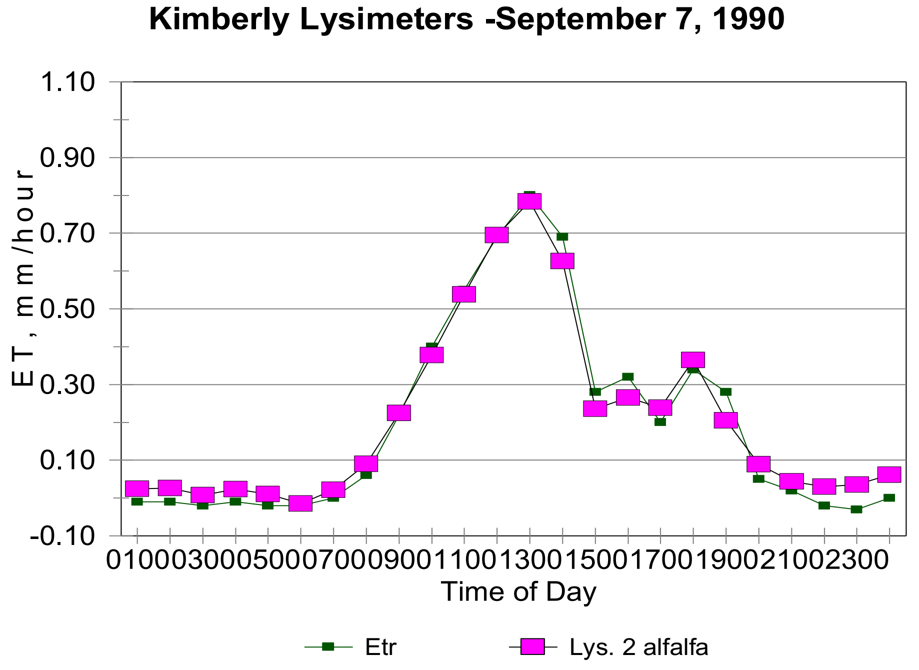


ASCE Penman-Monteith is traceable to the Kimberly, ID (USDA) and Davis, CA Lysimeters

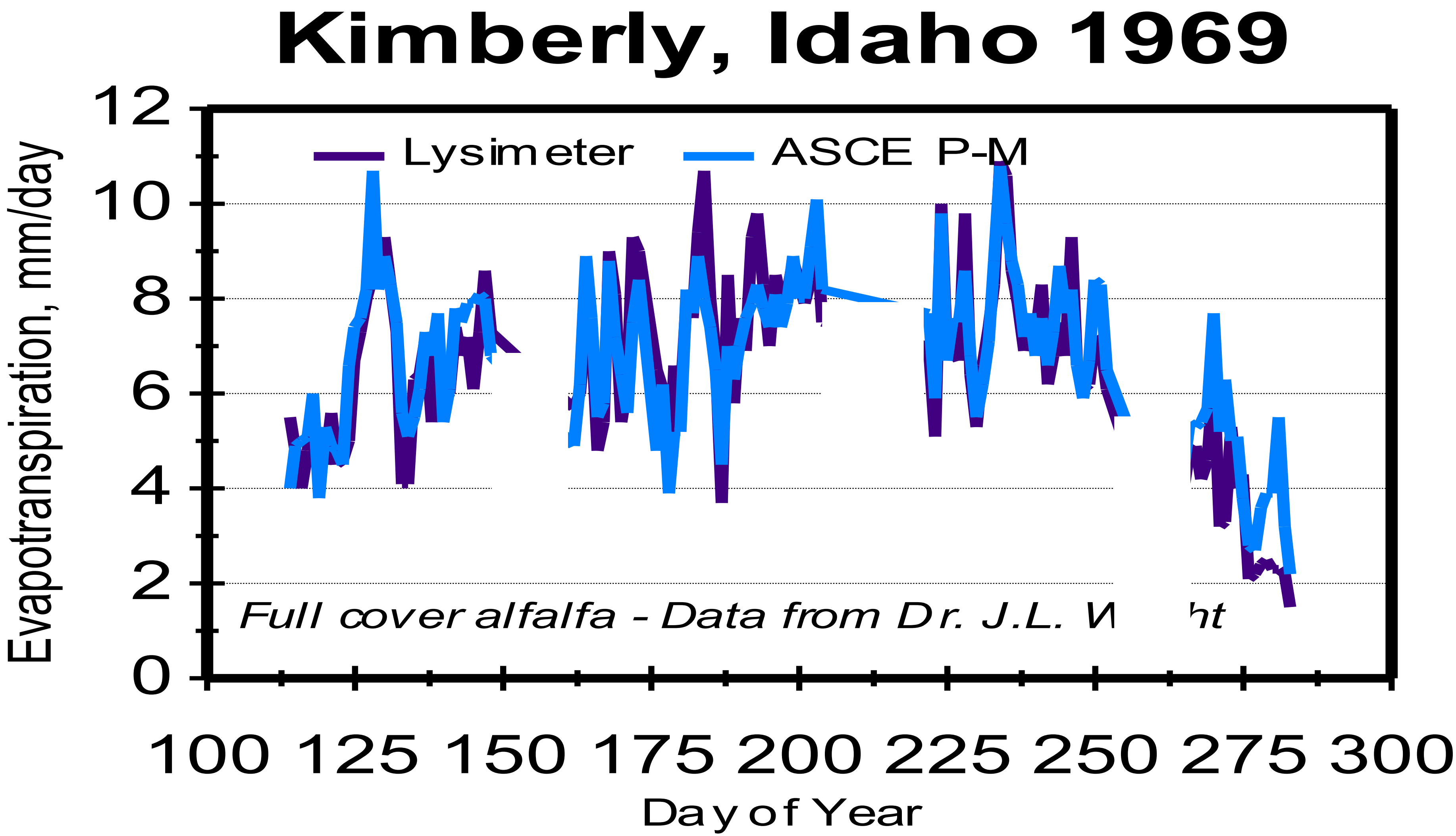



Kimberly Lysimeters - September 4,1990
Data from Dr. J.L Wright
ET, mm/hour
1.10
0.90
0.70
0.50
0.30
0.10
-0.10
0100 0300 0500 0700 0900 1100 1300 1500 1700 1900 2100 2300
Time of Day
Etr
Lys. 2 alfalfa


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


Kimberly Lysimeters -September 7, 1990
ET, mm/hour
1.10
0.90
0.70
0.50
0.30
0.10
-0.10
0100 0300 0500 0700 0900 1100 1300 1500 1700 1900 2100 2300
Time of Day
Etr
Lys. 2 alfalfa

Good day to day correspondance with lysimeter



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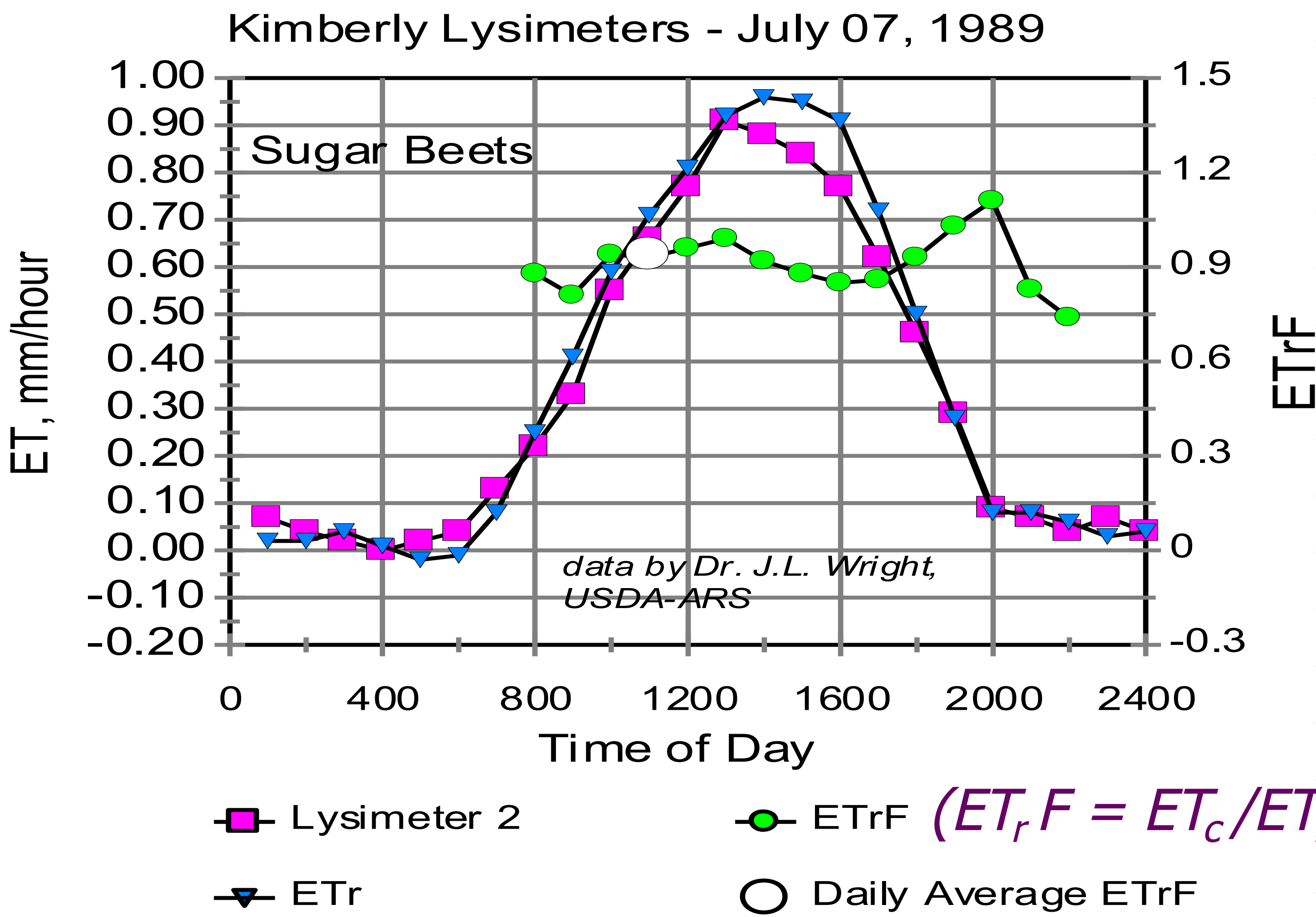
ET_rF = Fraction of ET_r = K_c
ET_rF is consistent through the day

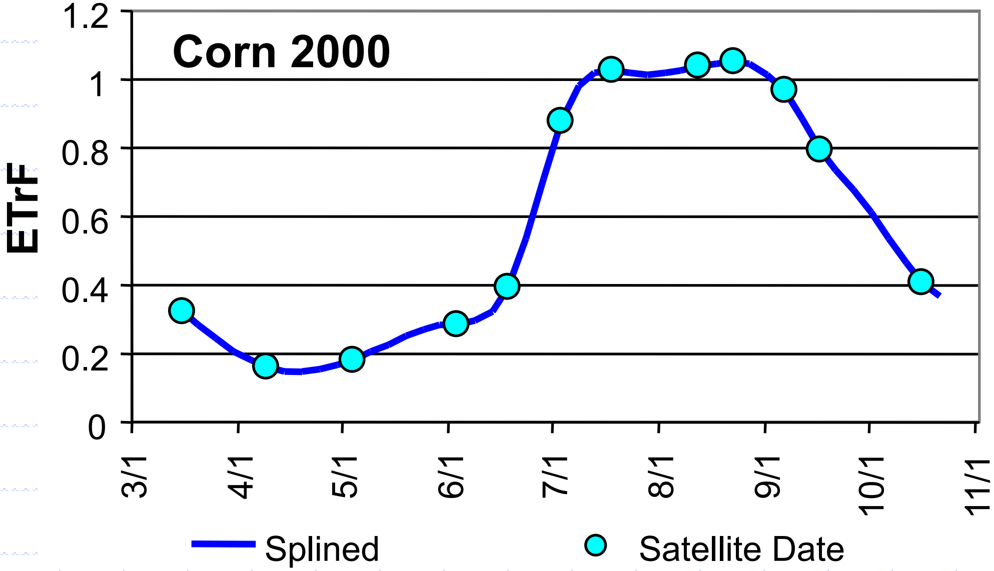


$(ET_rF = ET_c/ET_r)$

Interpolation/Integration for Monthly or Seasonal ET

ET_rF = fraction of reference (potential) ET

-- interpolated day-to-day using a cubic spline



$$ET_{period} = \int ET_rF_t \, x \, ET_{r24t} \, dt$$

Use ET_r to account for daily weather effects

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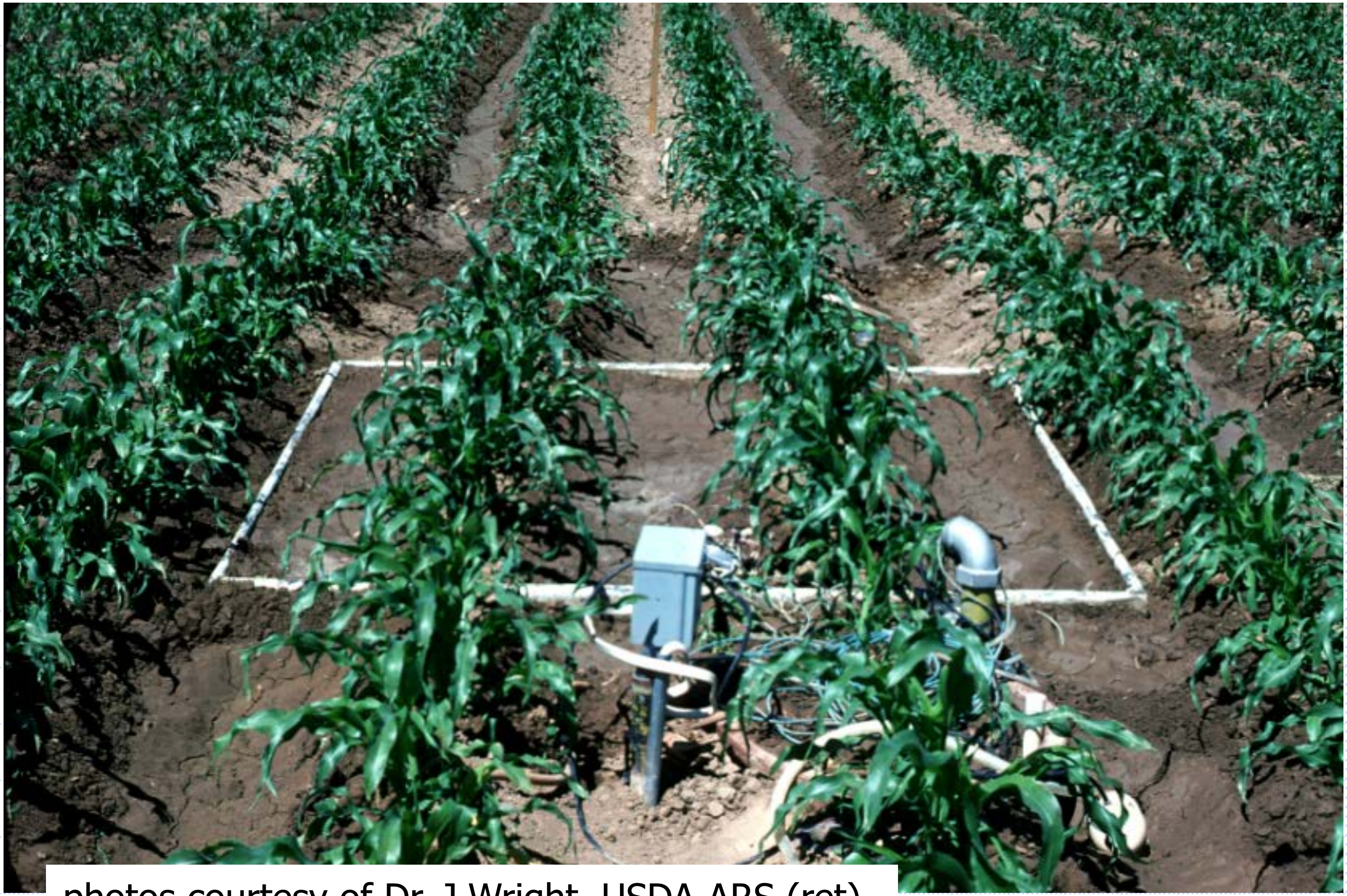
Weighing Lysimeter System at Kimberly, Idaho

Dr. James L. Wright, USDA-ARS



photos courtesy of Dr. J.Wright, USDA-ARS (ret)

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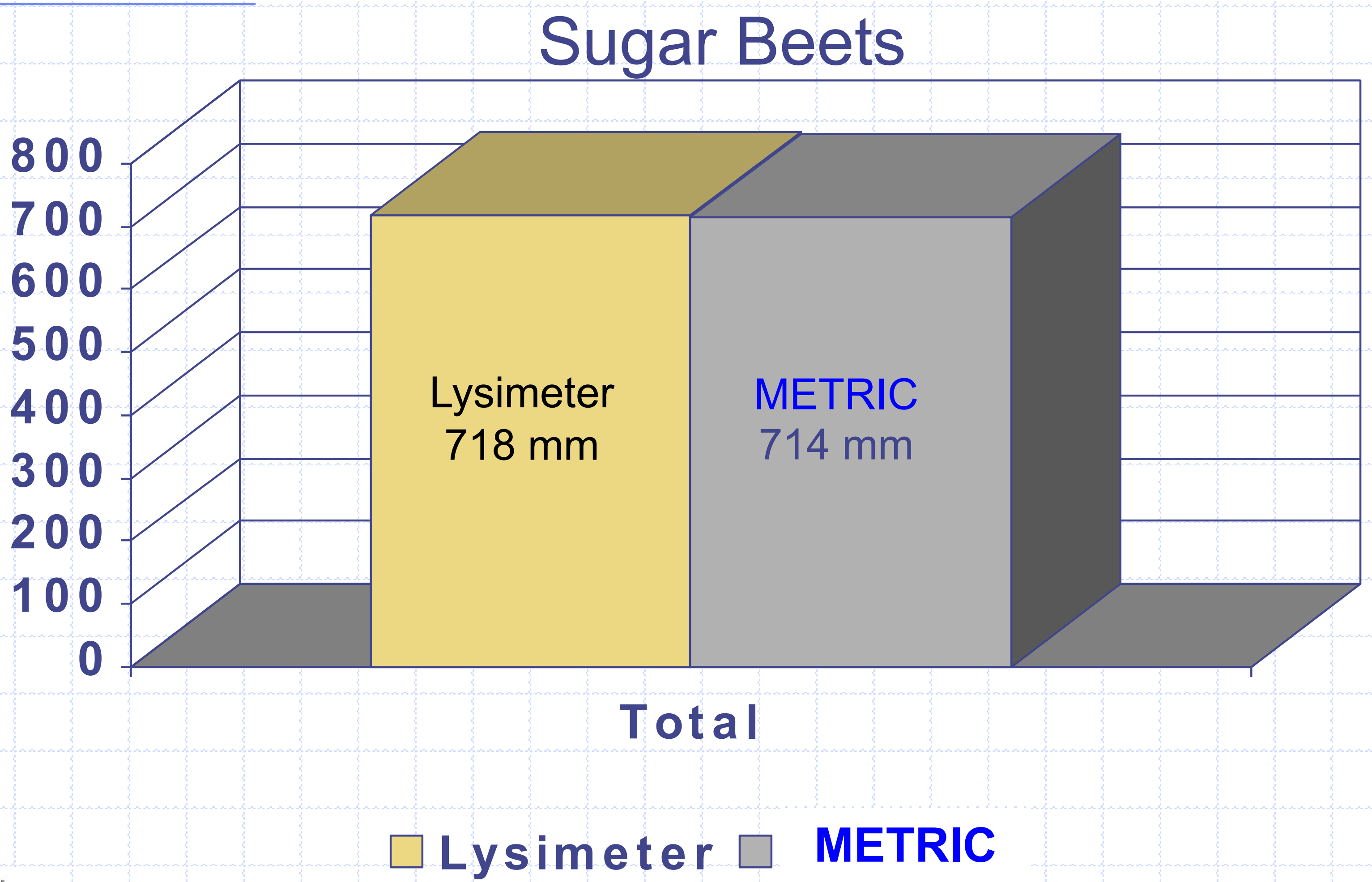
Comparison of Seasonal ET by METRIC^{tm} with Lysimeter

ET (mm) - April-Sept., *Kimberly, 1989*



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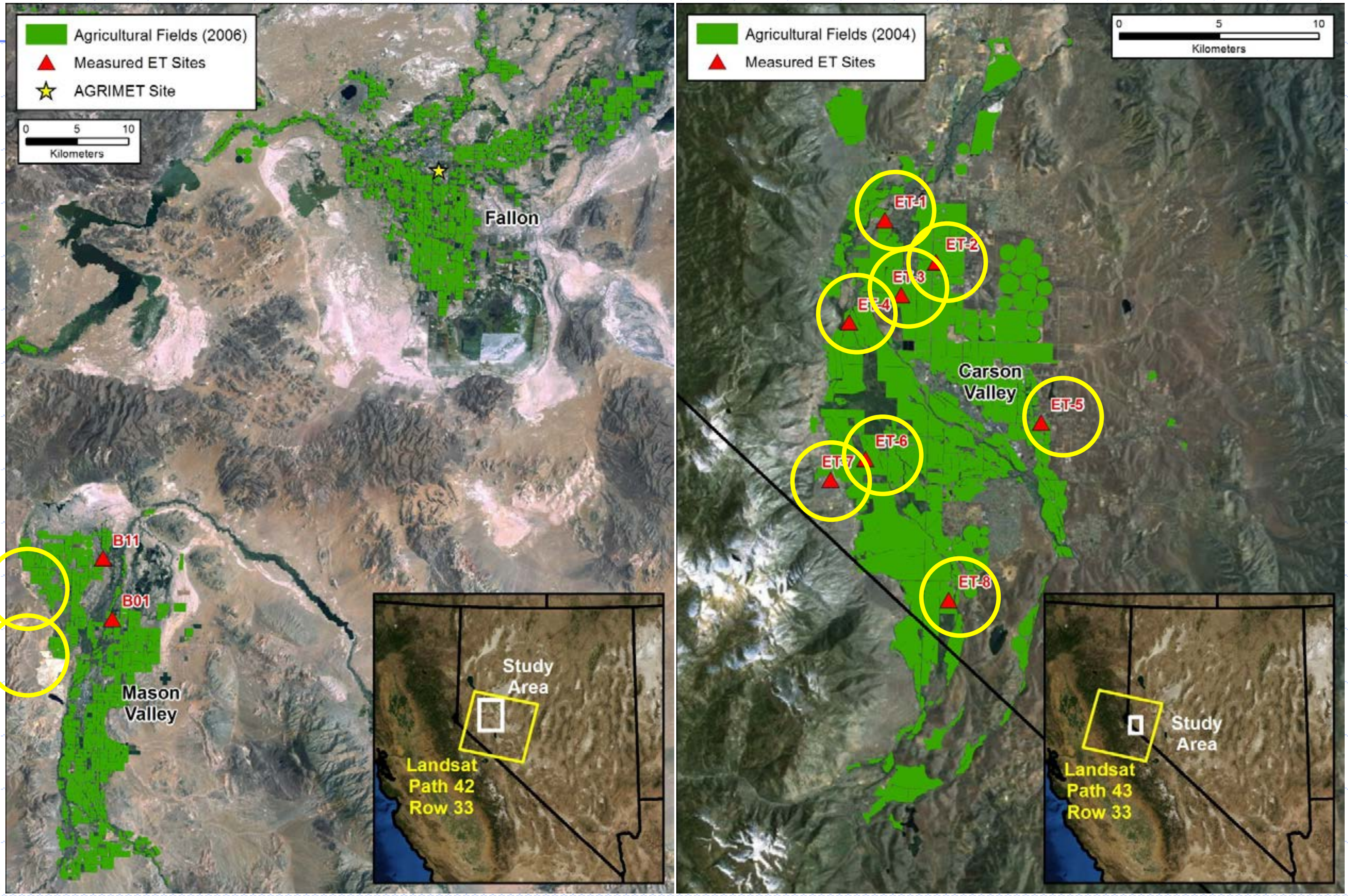
Nevada

compiled by Dr. Justin Huntington, DRI

Blind Comparison of METRIC Seasonal ET to Measured ET – Desert Research Institute



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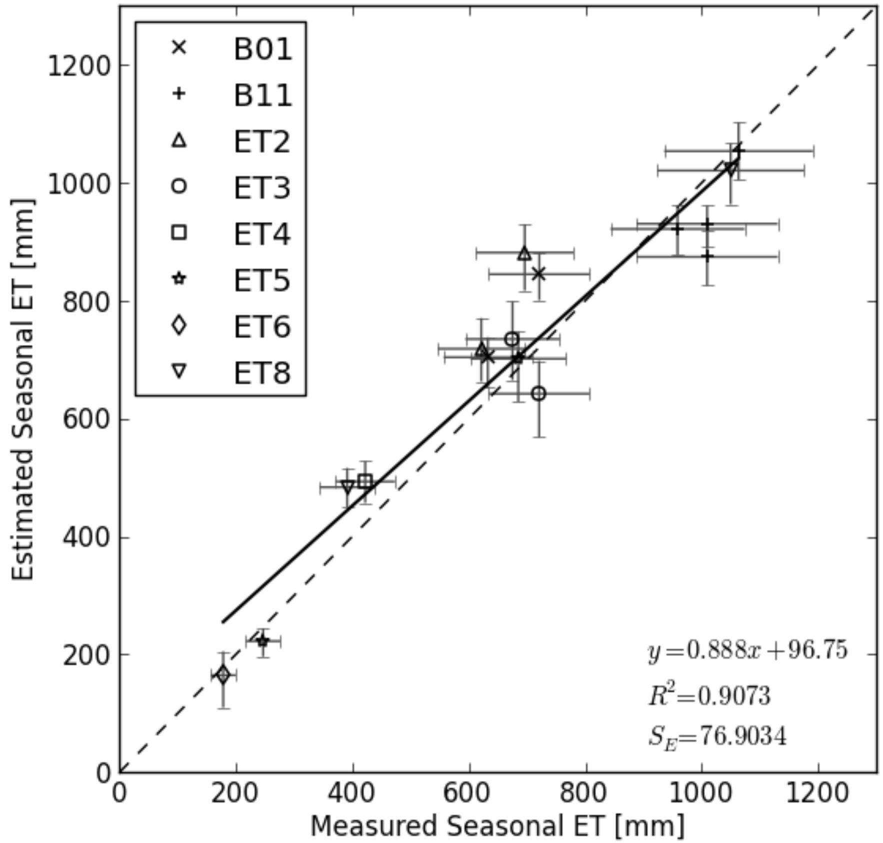
Ground measurement data by USGS

Nevada

Blind Comparison of METRIC Seasonal ET to Measured ET



Ground data by USGS

- Whiskers on X = +/- 12% USGS estimated uncertainty in measured Bowen ratio/eddy ET
- Whiskers on Y = +/- 95% confidence interval of 100 Monte Carlo METRIC ET estimates

Dr. Justin Huntington, DRI

University of Nebraska Lincoln

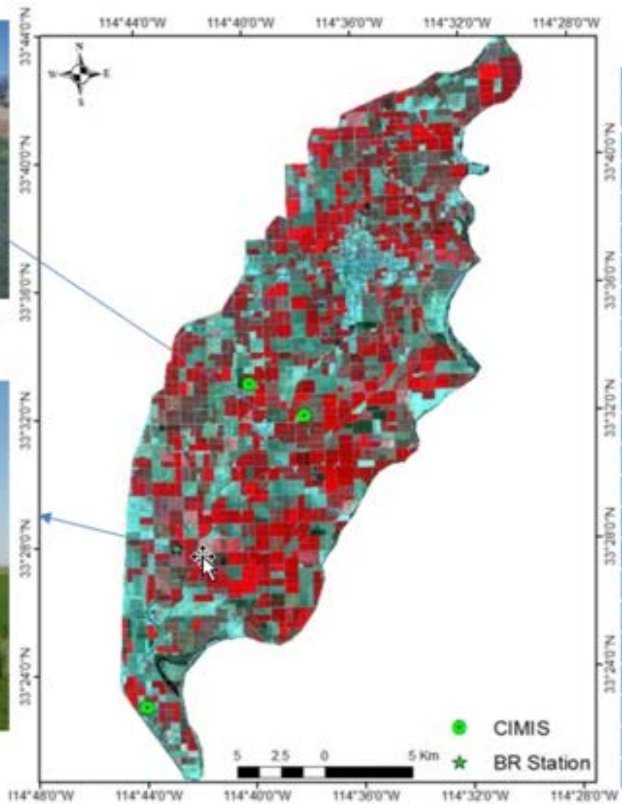
University of Idaho

"Blind" Intercomparison of Leading ET models – 2014 – SE California

Site 1: Palo Verde Irrigation District (PVID)

CIMIS Weather Station , Blythe NE # 135

Full surface energy balance flux measurements based on Bowen Ratio Station



False color RGB , NIR-Red-Green Landsat 5 image during DOY 131, May 10, 2008

List of Landsat 5 scenes used

No.	Date (2008)	DOY (2008)	Path	Raw
1	19-Jan	19	38	37
2	11-Feb	42	39	37
3	27-Feb	58	39	37
4	07-Mar	67	38	37
5	23-Mar	83	38	37
6	08-Apr	99	38	37
7	24-Apr	115	38	37
8	10-May	131	38	37
9	17-May	138	39	37
10	26-May	147	38	37
11	11-Jun	163	38	37
12	18-Jun	170	39	37
13	13-Jul	195	38	37
14	29-Jul	211	38	37
15	05-Aug	218	39	37
16	21-Aug	234	39	37
17	15-Sep	259	38	37
18	01-Oct	275	38	37
19	17-Oct	291	38	37
20	09-Nov	314	39	37
21	18-Nov	323	38	37

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USGS science for a changing world

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“Blind” Intercomparison of Leading ET models – 2014 – SE California

Summary of

Individual O
– vs. Ground Fl

	RMSE	BIAS	BIAS (%)
Measured			
	1.5	-0.2	-7.2%
	2.7	-2.5	-42.0%
METRIC	0.9	-0.1	1.6%
	1.3	-0.8	-9.8%
	2.1	-1.7	-22.9%

Seasonal Water Balance

Water balance Component	Depth (mm/year)			METRIC			
Precipitation	71	71	71	71	71	71	71
Inflow Main Canal	2479	2479	2479	2479	2479	2479	2479
Total Inflow	2550	2550	2550	2550	2550	2550	2550
Canal Spills	284	284	284	284	284	284	284
Drainage	998	998	998	998	998	998	998
ET	**(1000)**		**956**	**1223**	**952**	**X**	
Total Outflow	(2282)		2238	2505	2234	X	
Inflow- Outflow	(268)		312 (-12.2%)	34 (-1.8%)	316 (-12.4%)	X	

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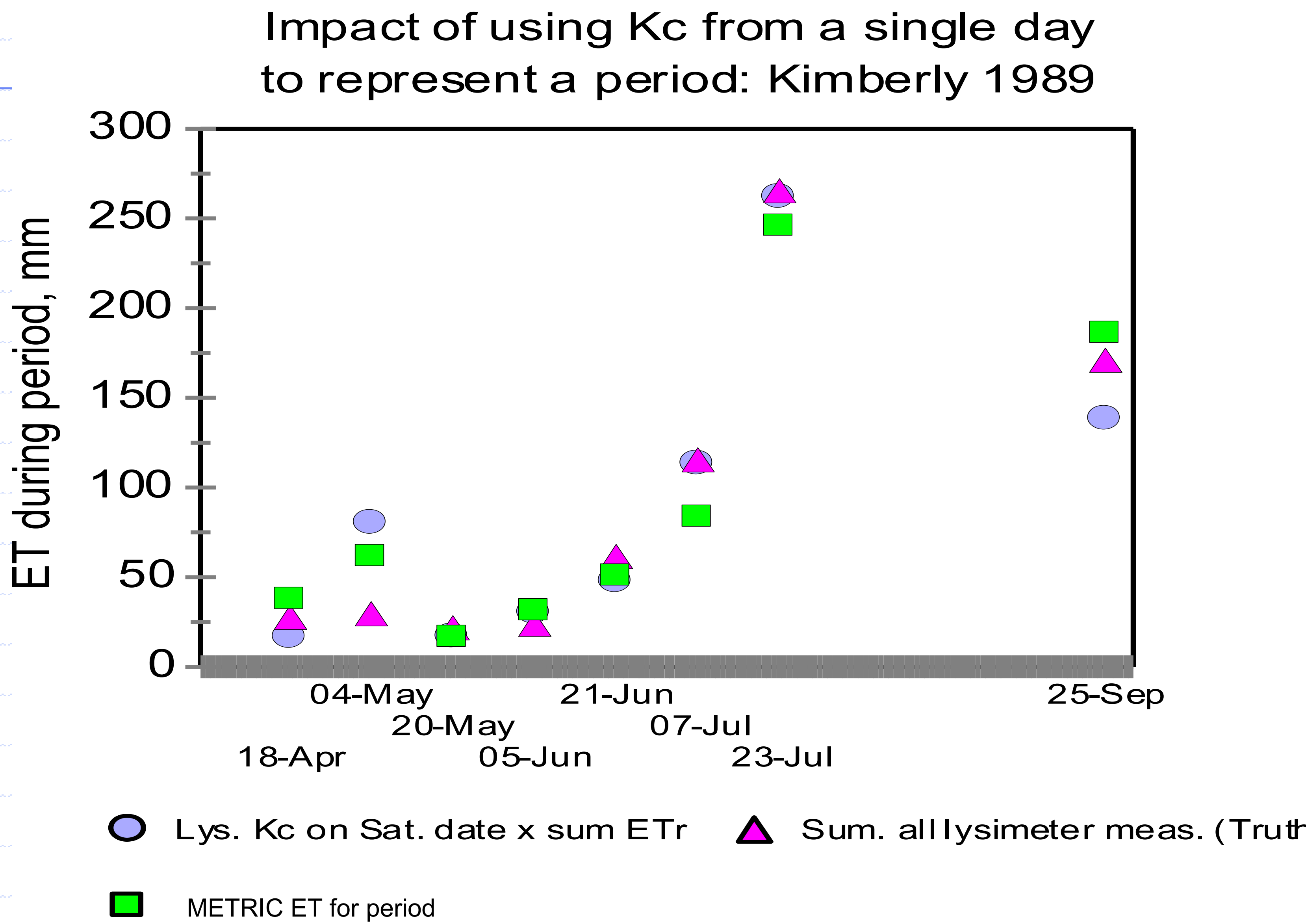
Estimates by METRIC were < 2% for both individual field and entire district

Comparison with Lysimeter Measurements:

1968-1991

Kimberly, Idaho – Periods between Satellites



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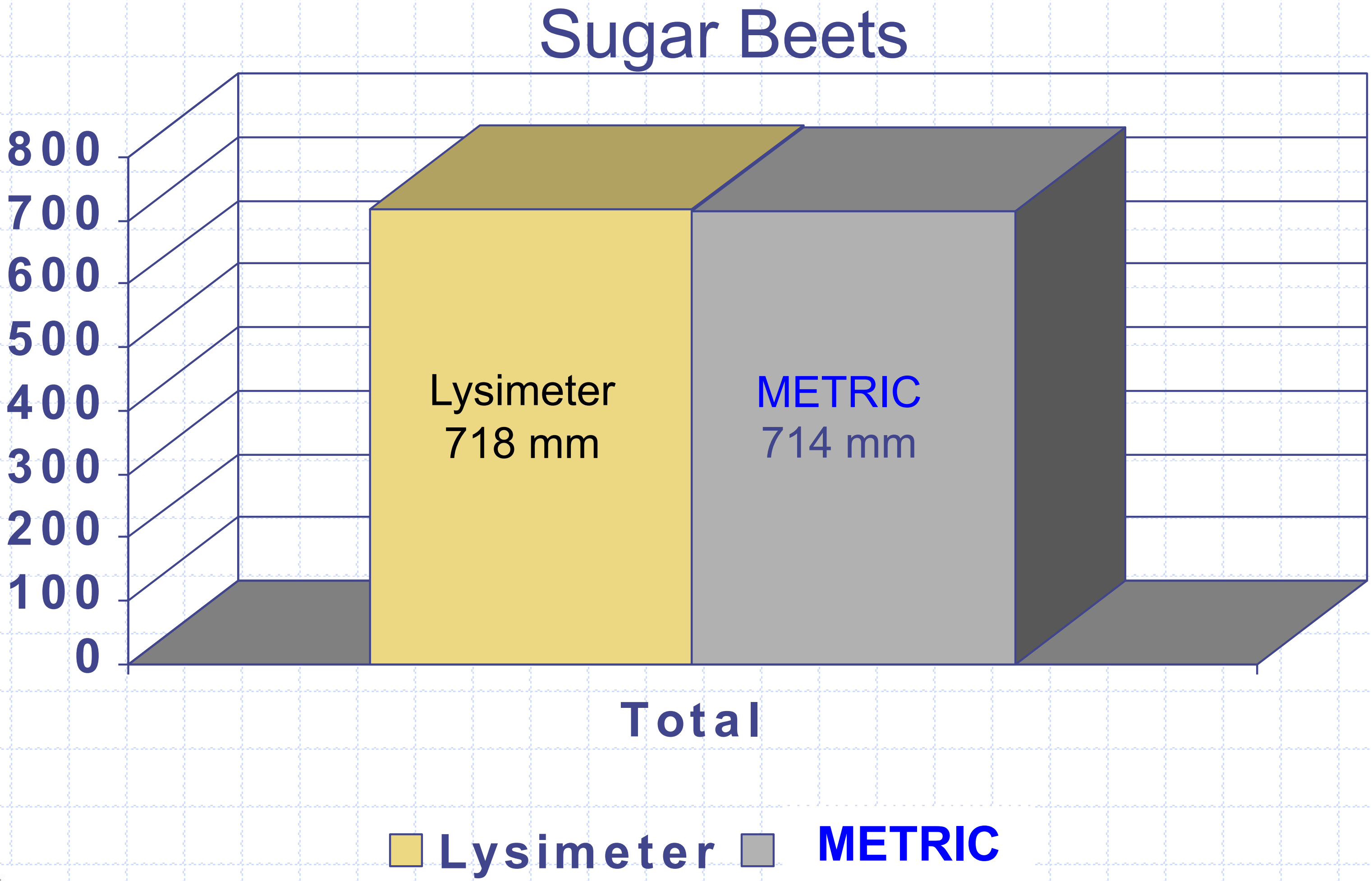
ET (mm) - April-Sept., *Kimberly, 1989*



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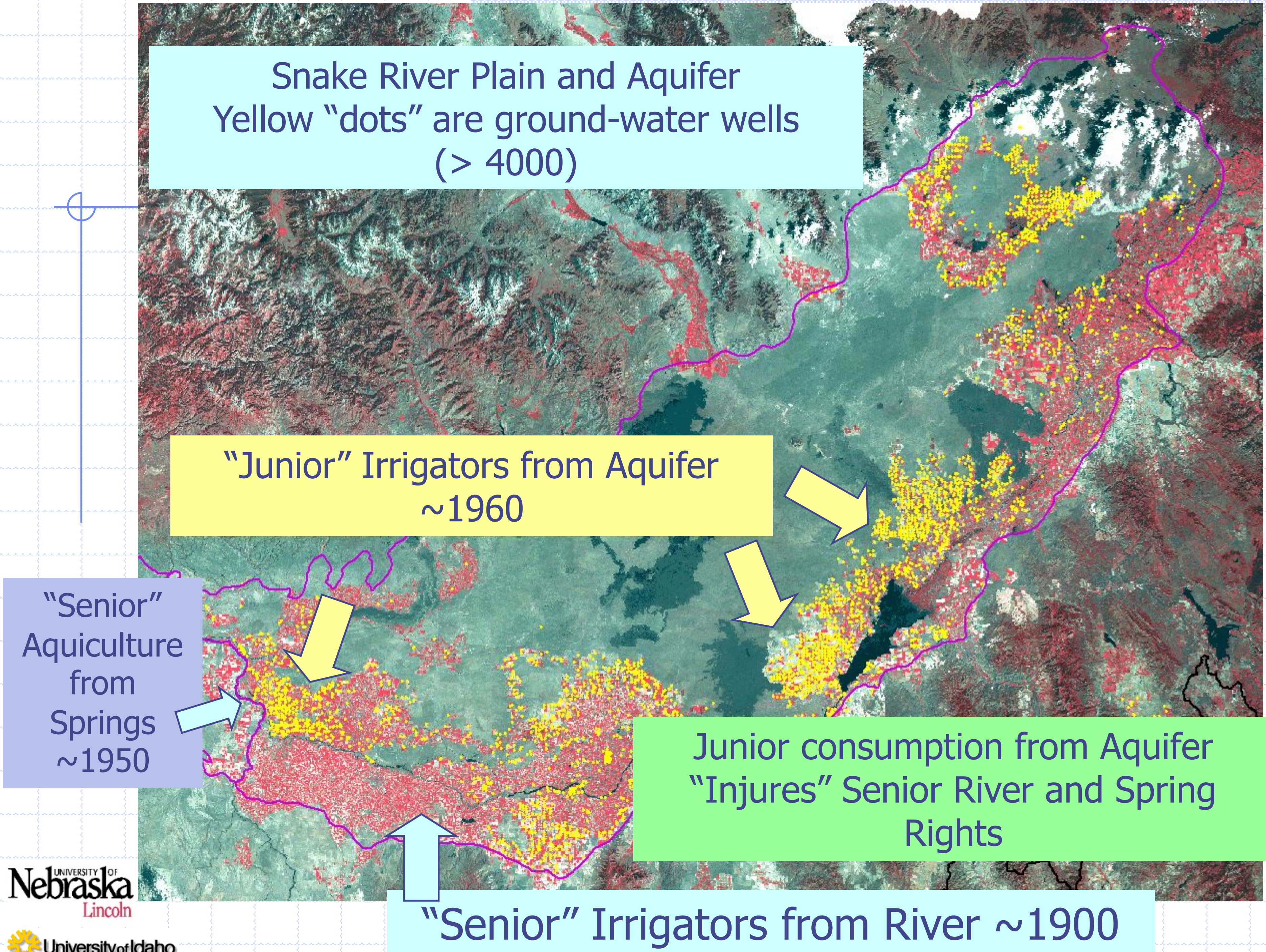
Applications where effort and accuracy matters



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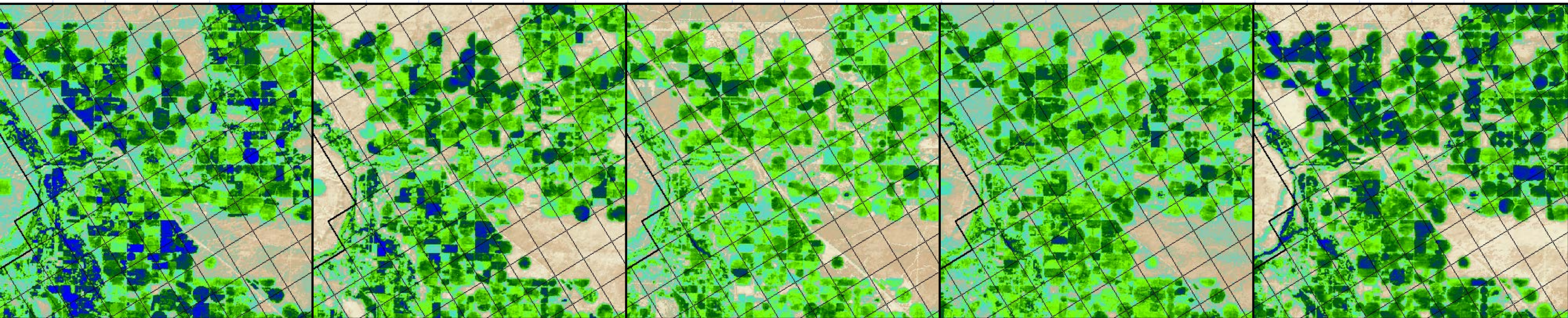
Idaho

Eastern Snake Plain Aquifer Model

METRIC ET data:

- Have provided more accurate calibration of the groundwater model
- Improved accuracy of depletions and recharge estimates
- Shows long term trends and annual variation in ET

1996 2000 2002 2006 2008



Idaho Clear Springs Foods Water Call

Idaho Business News

Water curtailment ordered in Magic Valley

POSTED: 11:13 MDT Thursday, July 23, 2009

by **IBR Staff**

Idaho Department of Water Resources Interim Director Gary Spackman on July 22 issued a **curtailment order** to about 250 holders of 315 junior water rights in south central Idaho's Magic Valley. The curtailment order is part of a continuing response to a water delivery call made in 2005 by senior water right holder Clear Springs Foods.

State goes ahead with first large-scale well closure of more than 300 water rights in M.V.

Water districts have limited options, could file a stay

7/31/2009

By Nate Poppino

Times-News writer

The Idaho Department of Water Resources will go forward this morning with a plan to shut off more than 300 water rights irrigating just less than 9,000 acres of Magic Valley farmland, the first wide-scale well curtailment to actually be carried out by the state.

Water watch begins

8/1/2009

Unprecedented well shut-off goes into effect in valley

By Nate Poppino and Jared Hopkins

WENDELL - Employees of Idaho's state water agency quietly fanned out across the Magic Valley Friday morning, to see if nearly 250 water-right holders have complied with an order to stop using some groundwater rights.

It was the first time that the Idaho Department of Water Resources actually enforced widespread well closures to provide water to another entity.

Talks fail to find well shutoff solutions

State continues curtailment enforement

By Nate Poppino

Times-News writer

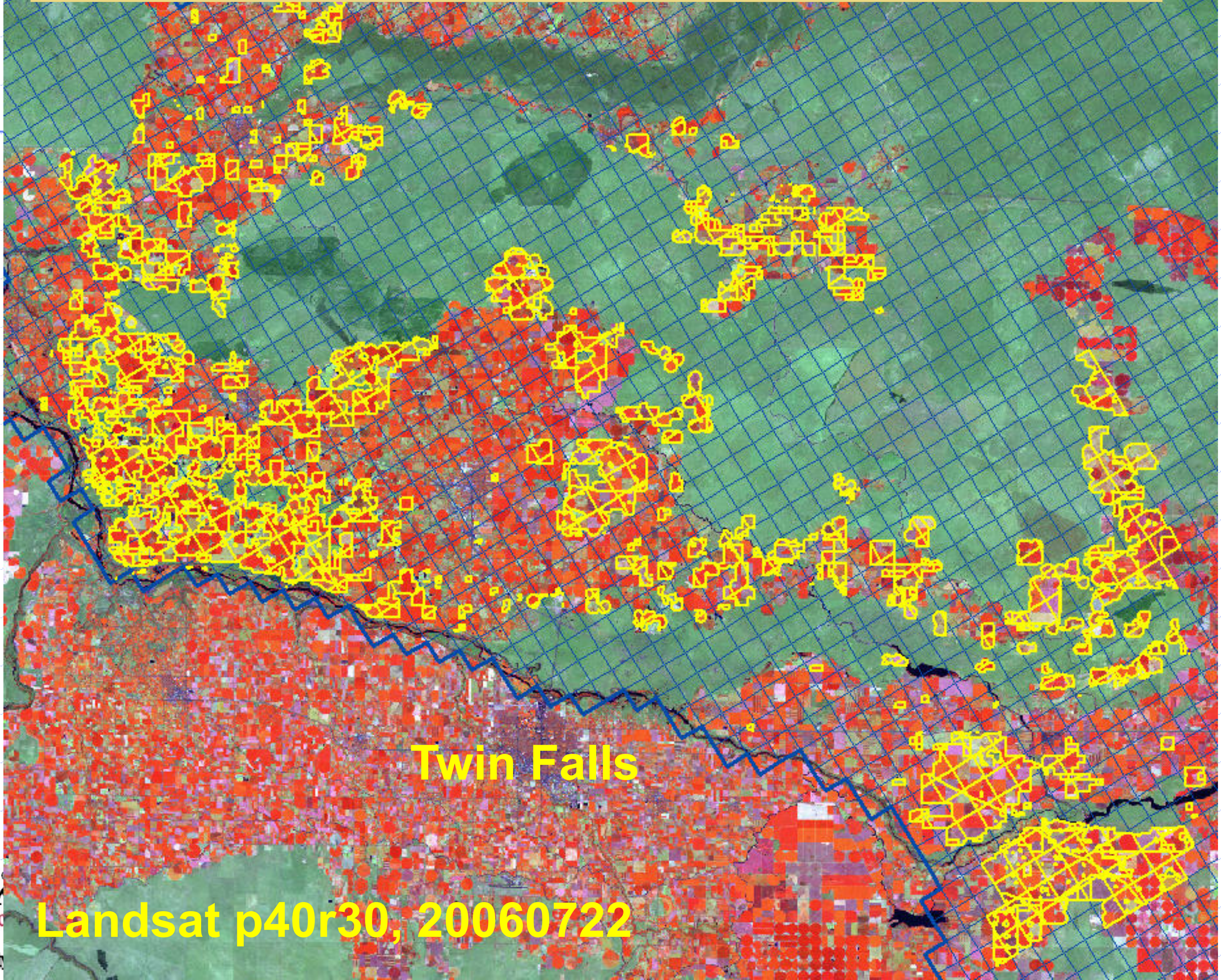
8/11/2009

Officials with two Magic Valley groundwater districts have not been able to reach an arrangement with a Buhl-area fish company, a setback in efforts to lift wide-scale well closures in the region.

Representatives of the North Snake and Magic Valley groundwater districts were attempting to reach an agreement to end curtailment of about 150 water rights affecting businesses, towns and about 4,150 acres of irrigated land. But Lynn Carlquist, chairman of the North Snake Ground Water District, said Monday afternoon that the districts will not be able to agree to requirements Clear Springs Foods listed as necessary for the company to consider a plan submitted last week acceptable.

The water rights were ordered shut down on July 31 by Idaho Department of Water Resources Interim Director Gary Spackman after he concluded the districts were not following through on a portion of an agreement aimed at providing more water for the springs Clear Springs relies on. Spackman's predecessor, Dave Tuthill, ruled last year that groundwater pumpers were depriving the company of part of its water.

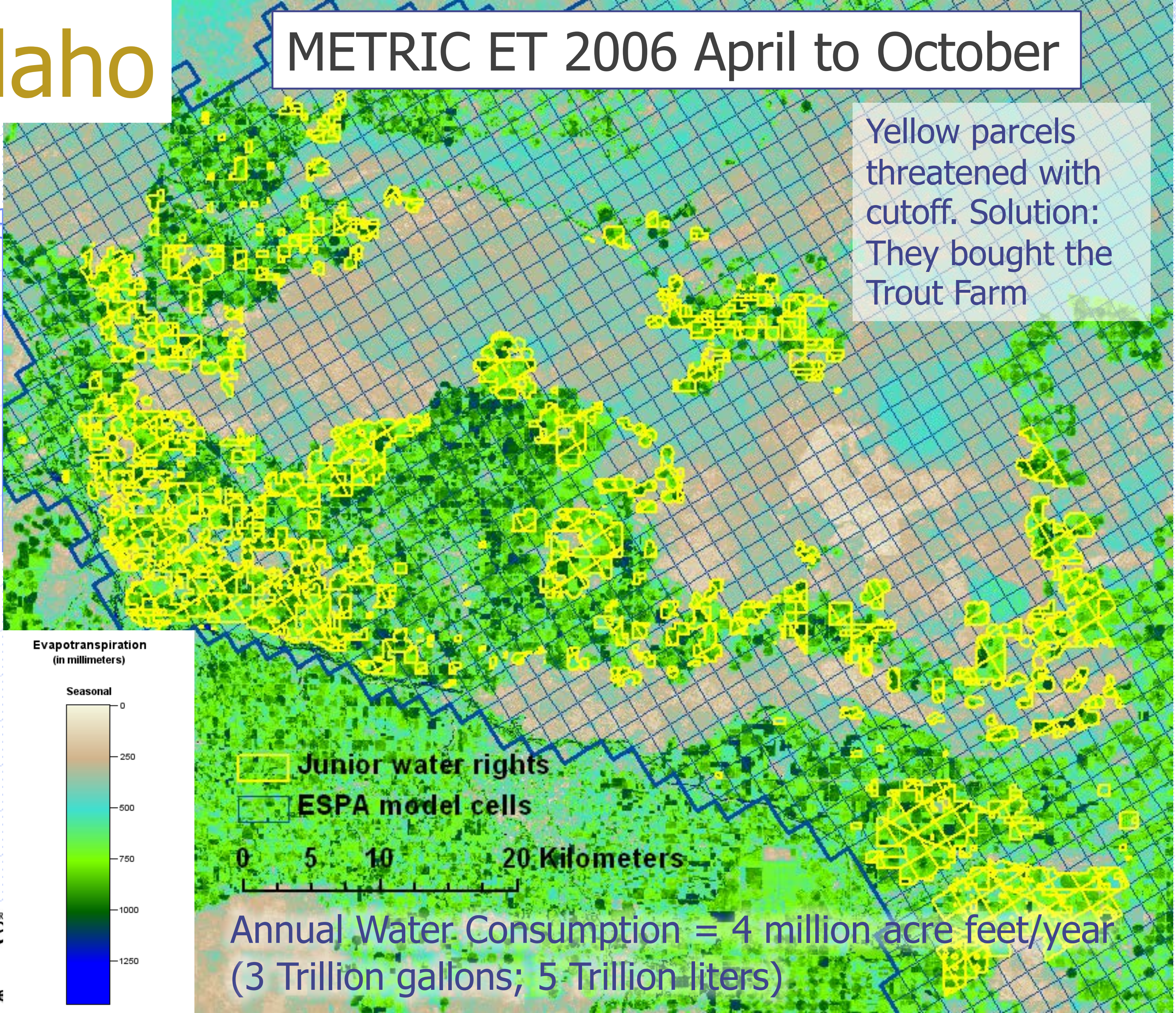
GW Model Cells and Junior Water Rights



Idaho

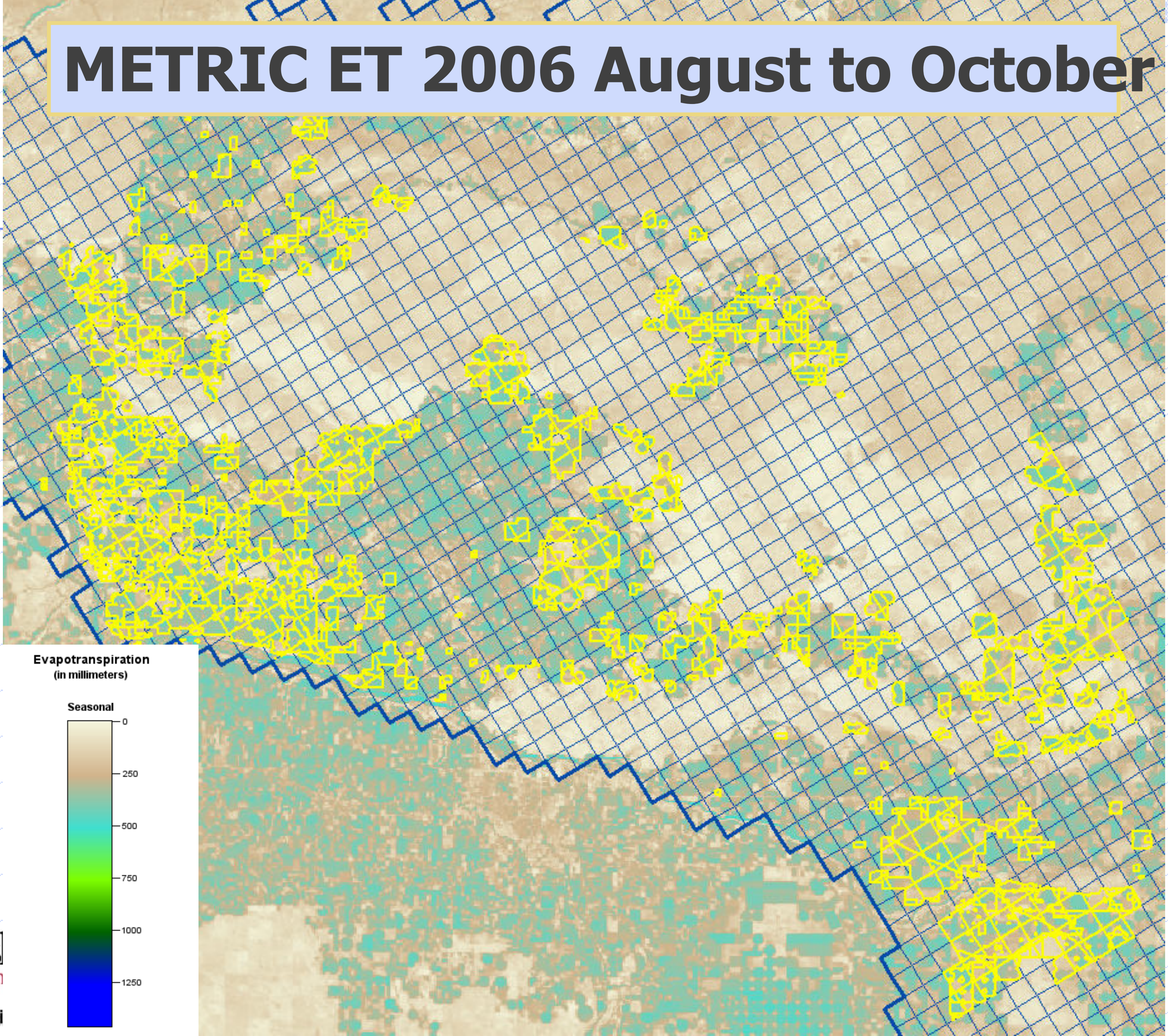
METRIC ET 2006 April to October

Yellow parcels threatened with cutoff. Solution: They bought the Trout Farm



Annual Water Consumption = 4 million acre feet/year (3 Trillion gallons; 5 Trillion liters)

METRIC ET 2006 August to October

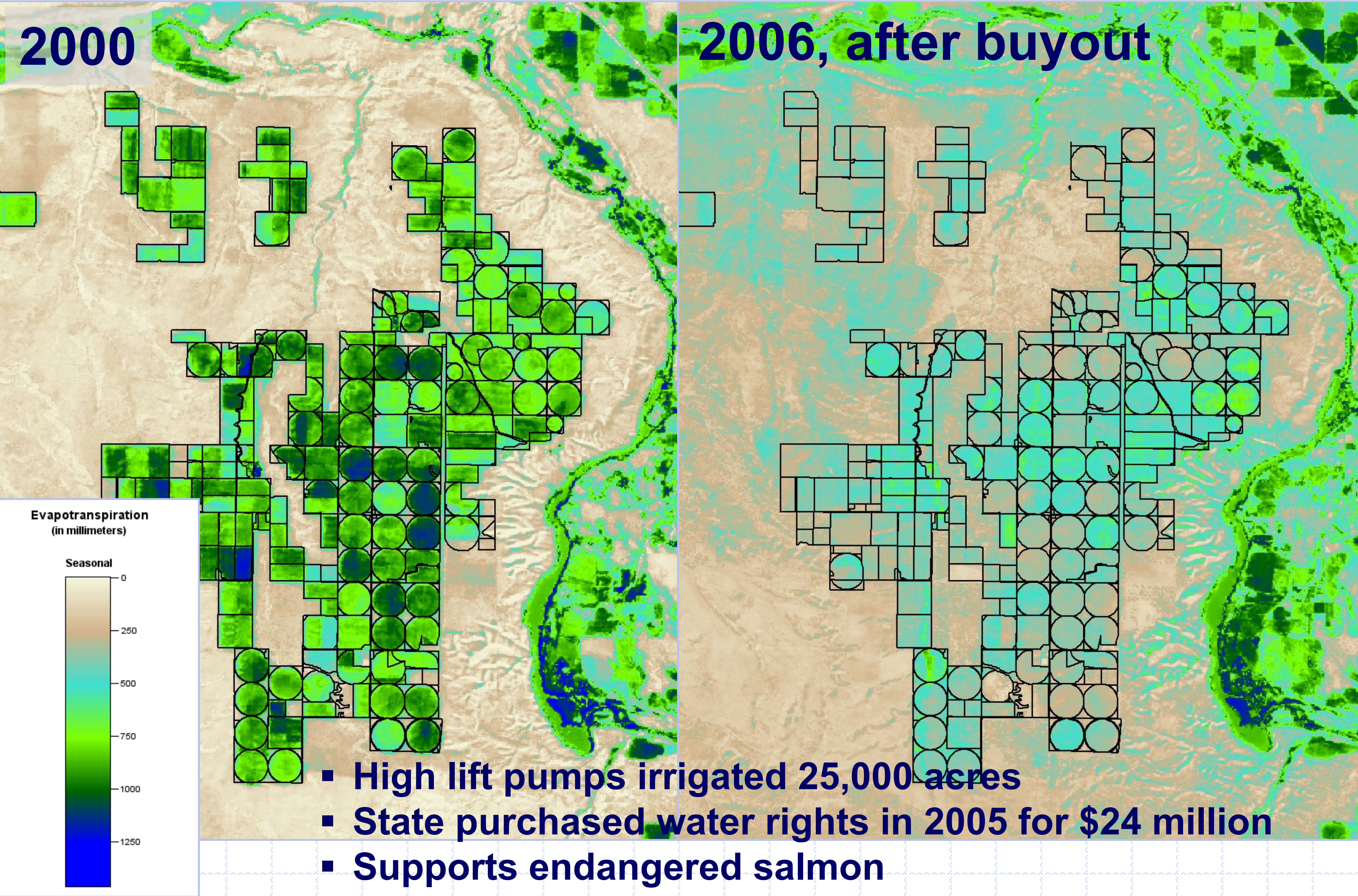


Example 2: Water Rights Buy-Back

- Issue:
  - Maintain minimum Snake River Flows
    - Endangered species
    - Hydro power rights
- Method: Buy out marginal water rights
- Negotiation
- Farmer's position: buy full water right
- IDWR's position: buy wet water

Idaho

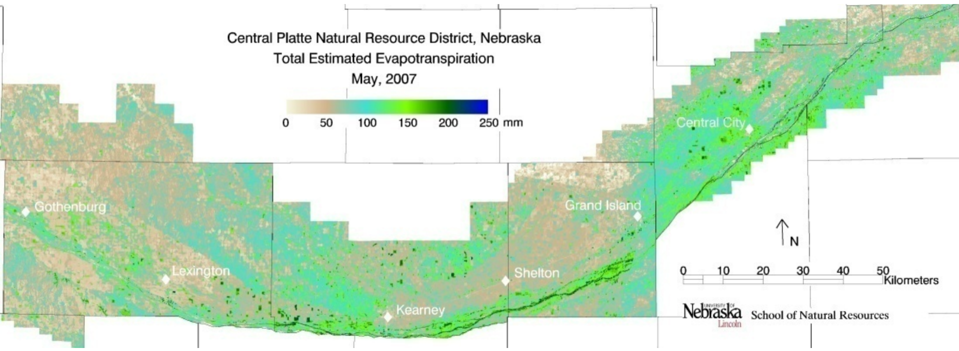
Bell Rapids Irrigation Project, Idaho: Seasonal ET

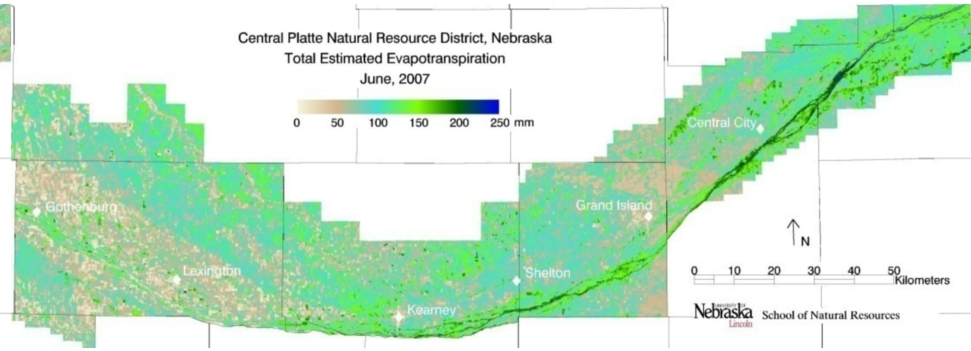


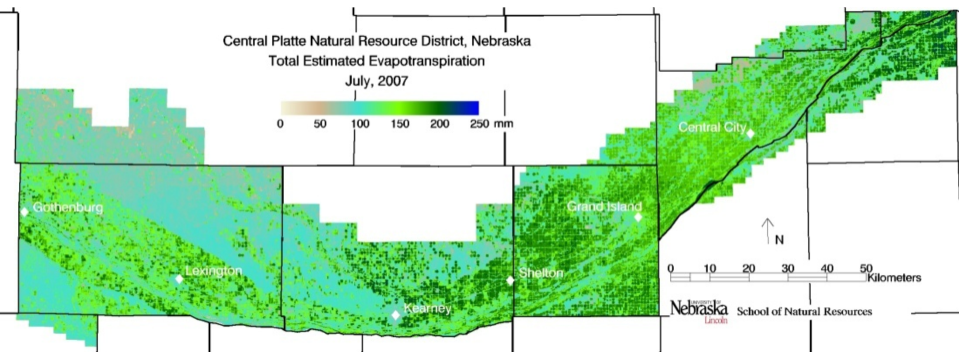
- High lift pumps irrigated 25,000 acres
- State purchased water rights in 2005 for $24 million
- Supports endangered salmon

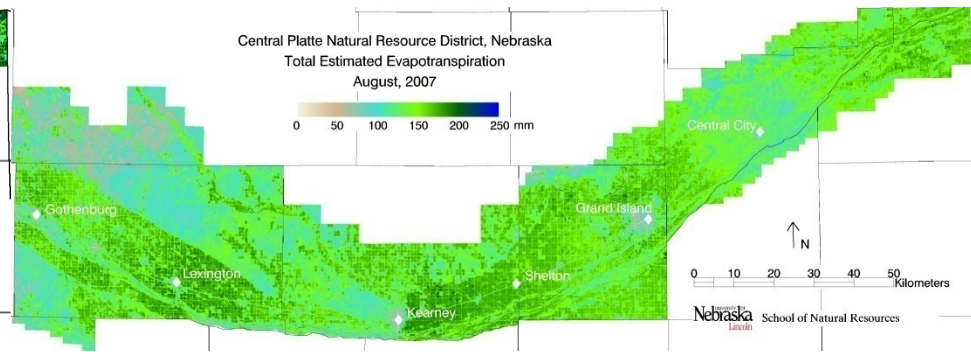
Nebraska

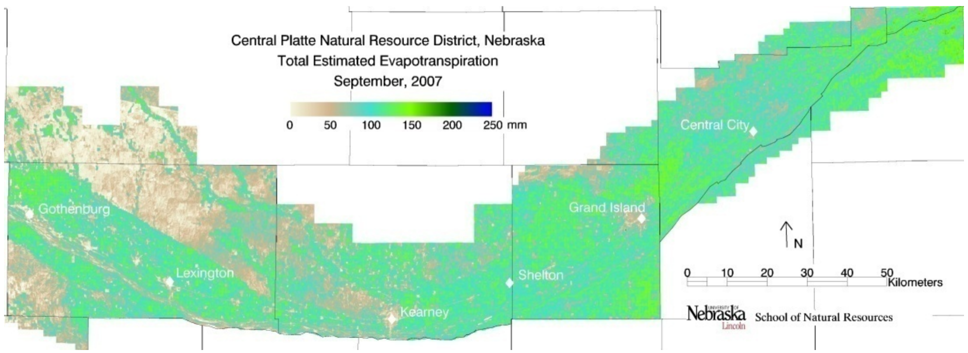
Central Platte Natural Resource District
--- Management of the Ogallala Aquifer











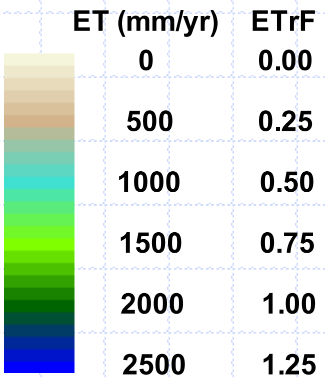
Monthly ET

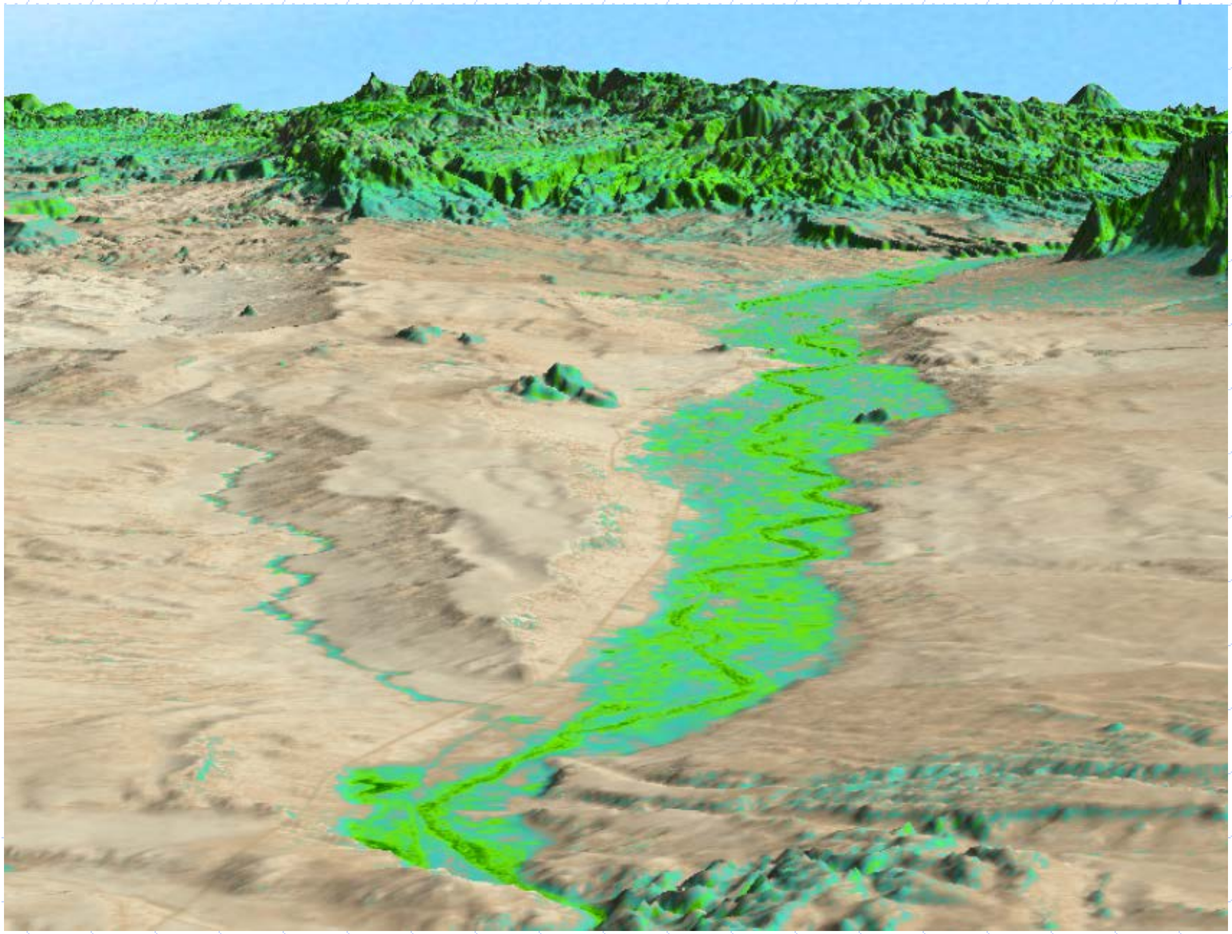
Dr. Ayse Kilic, UNL

New Mexico

Rio Grande of New Mexico

- Pueblo *(native American)* water rights dating to Coronado in 1500's
- Invasion of salt cedar
- Does increased pecan production increase ET from irrigated agriculture?

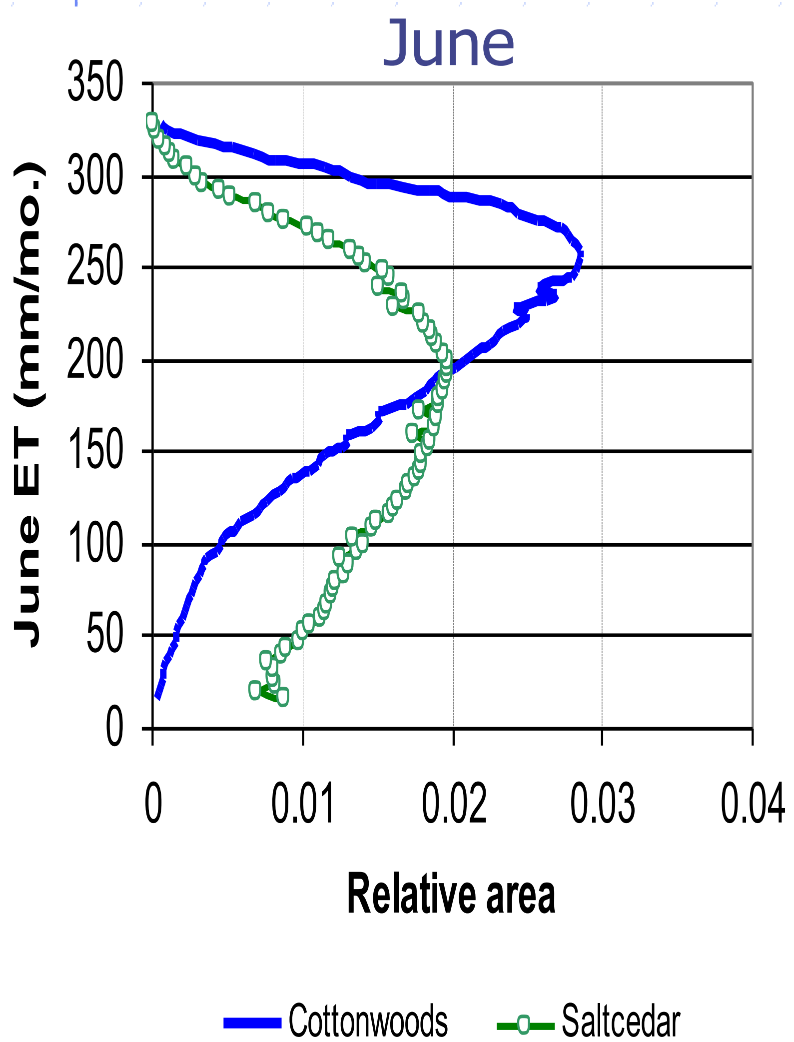


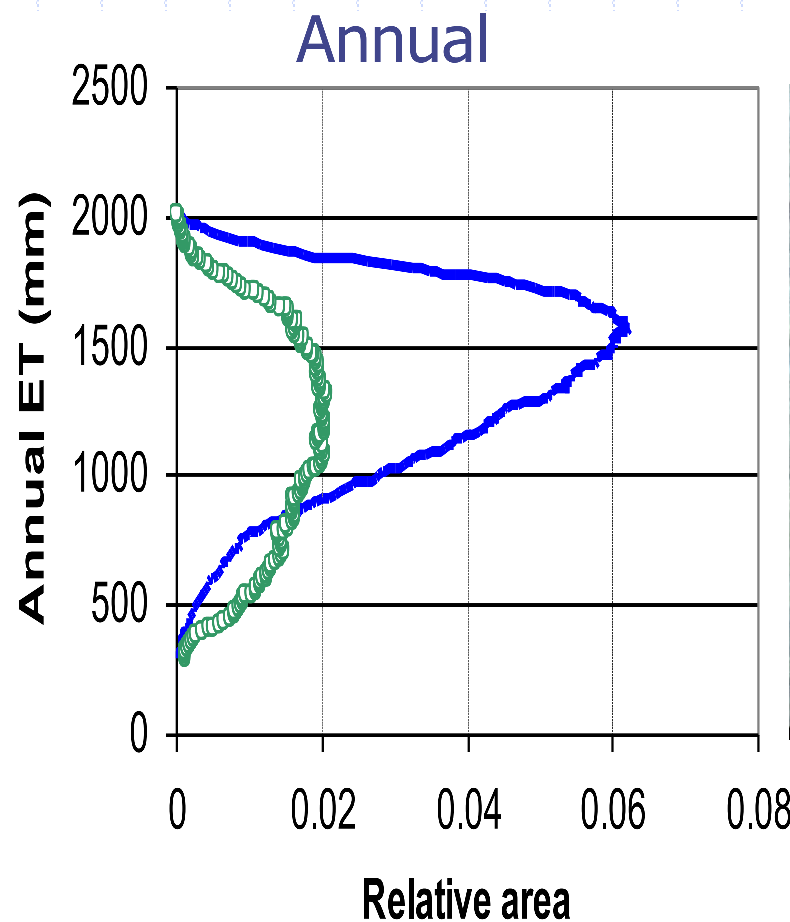


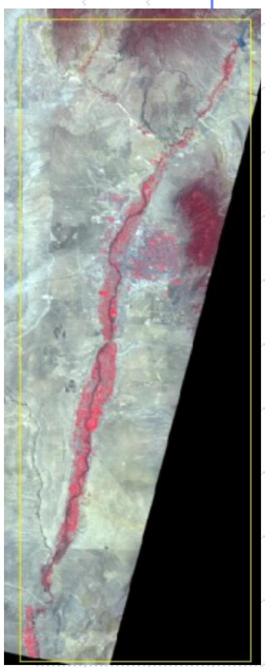
New Mexico

Frequency Distribution of ET

15,000 acres of cottonwood and salt cedar



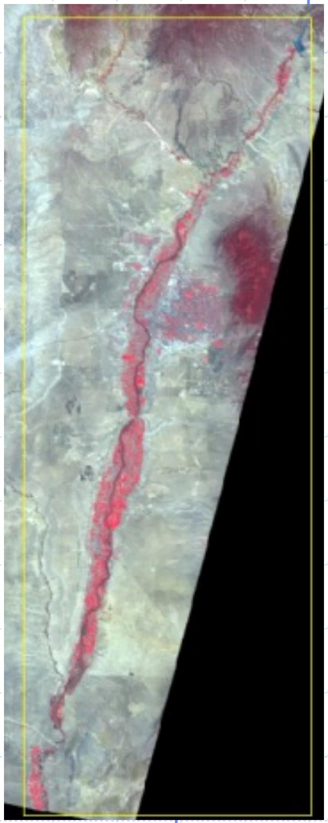




Tasumi and Allen, 2006

*Estimated water consumption by class of riparian vegetation within the riparian area between San Acacia and Cochiti, NM during 2002**

	Total area (acres)	Annual ET_rF (K_c)	Annual ET (mm)	Annual Water Consumption (AF)
Cottonwood	10,800	.67	1380	49,000
Salt Cedar	4,550	.54	1110	17,000
Willow	630	.71	1440	3000
R. Olive	90	.63	1280	400

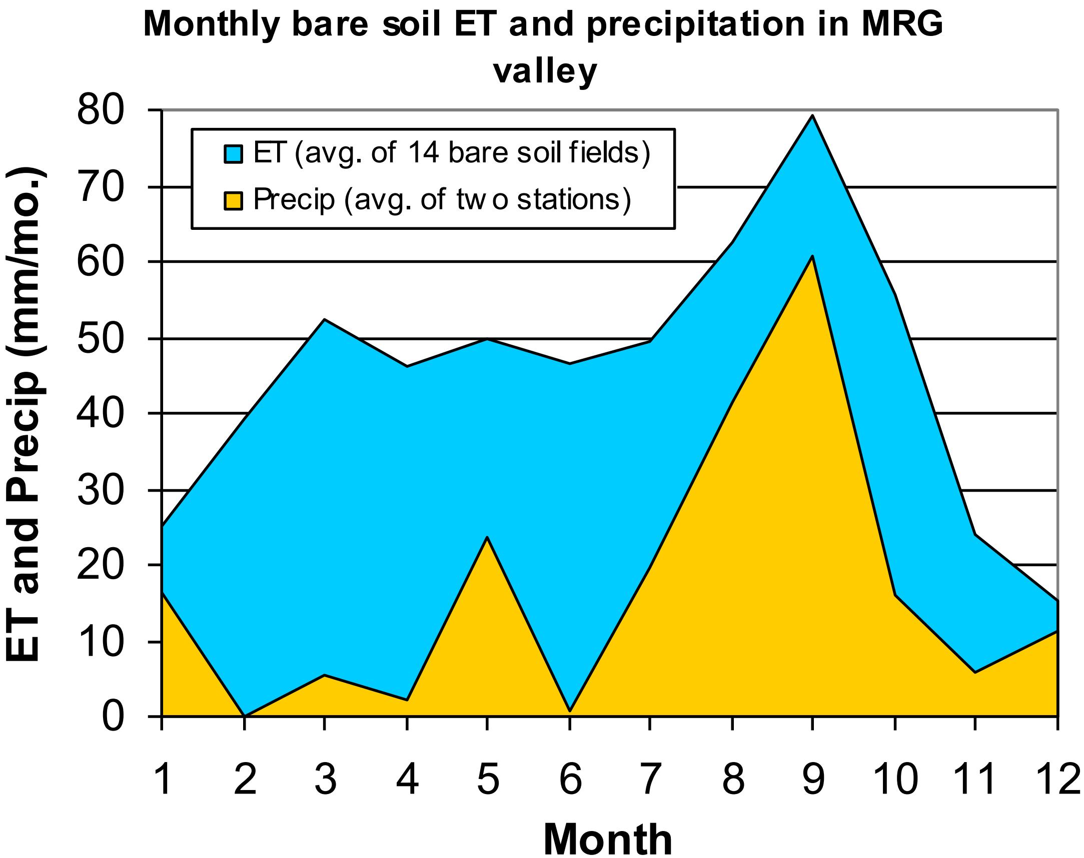


*Assumes constant ETrF (i.e., ET/ETr) during the day

From report by University of Idaho (Allen et al., 2004) to Keller-Bliesner Engineering, Logan, UT for U.S. Department of Justice

High Resolution Classification courtesy of Dr. Christopher Neale Utah State University

With Thermal Imaging, we can see important evaporation from wet soil – for example from high water tables

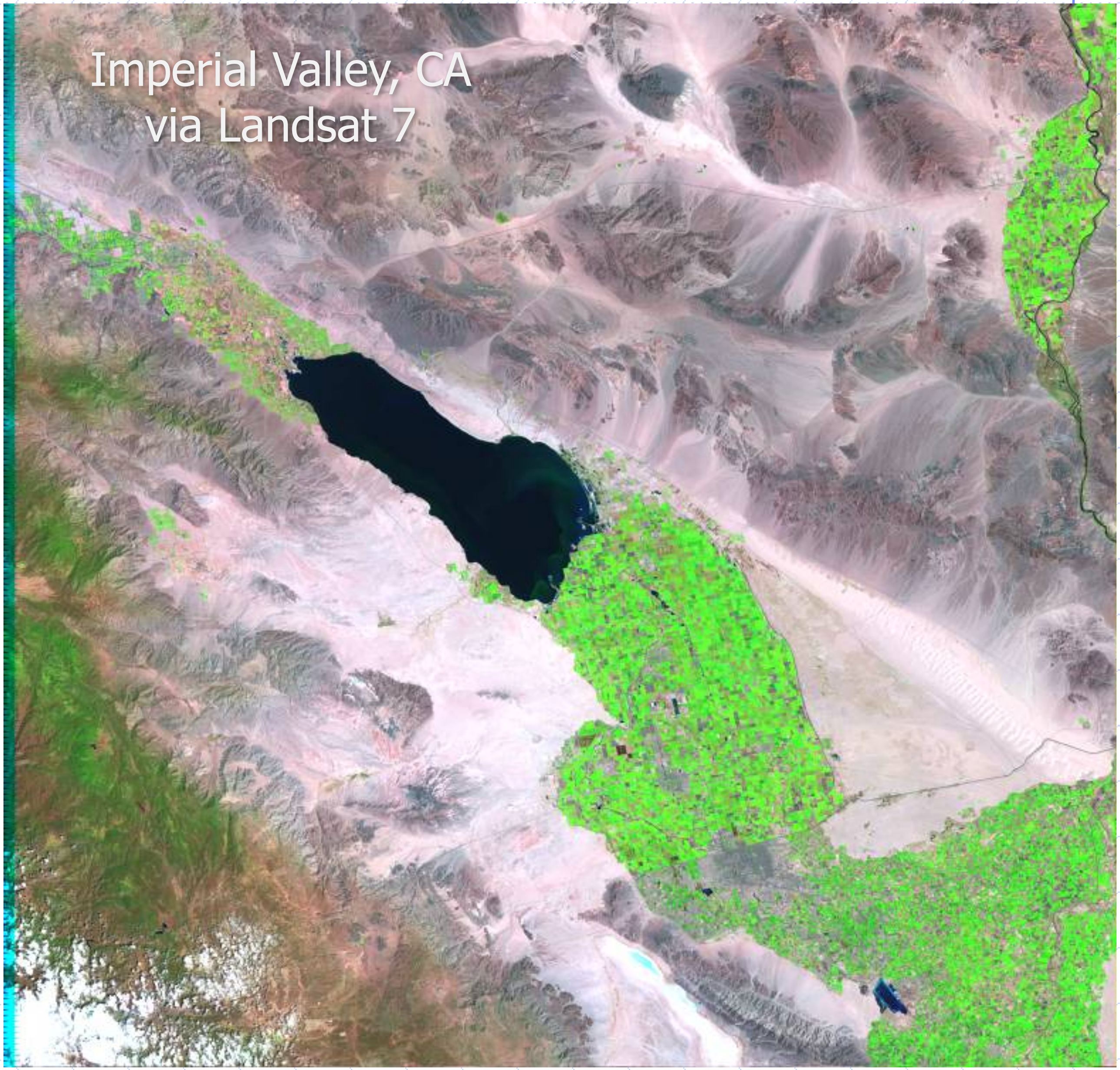


Evaporation during 2002 from continuously bare areas along the ***Middle Rio Grande*** *of NM contrasted with precipitation*

California

Imperial Valley

- ~15% of traditional water supply to agriculture will now flow to San Diego/ Los Angeles
- What is the impact on agriculture, water consumption and on the Salton Sea?



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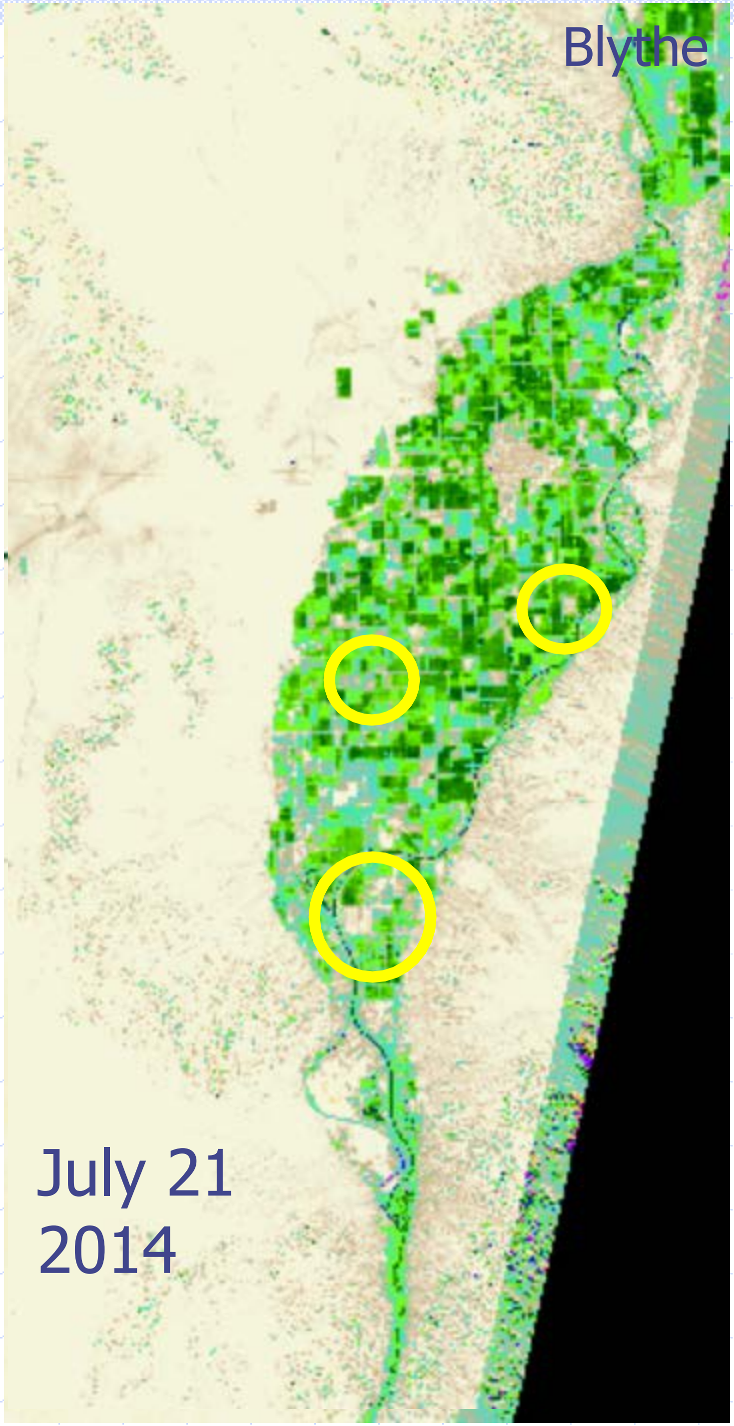
Fallowed Fields in 2014

- Reduction of ET 'should' reduce to nearly zero (if little rainfall)
- Transition of alfalfa fields is notable
- Cities are able to document reduction of agricultural ET and compliance with Colorado River Compact



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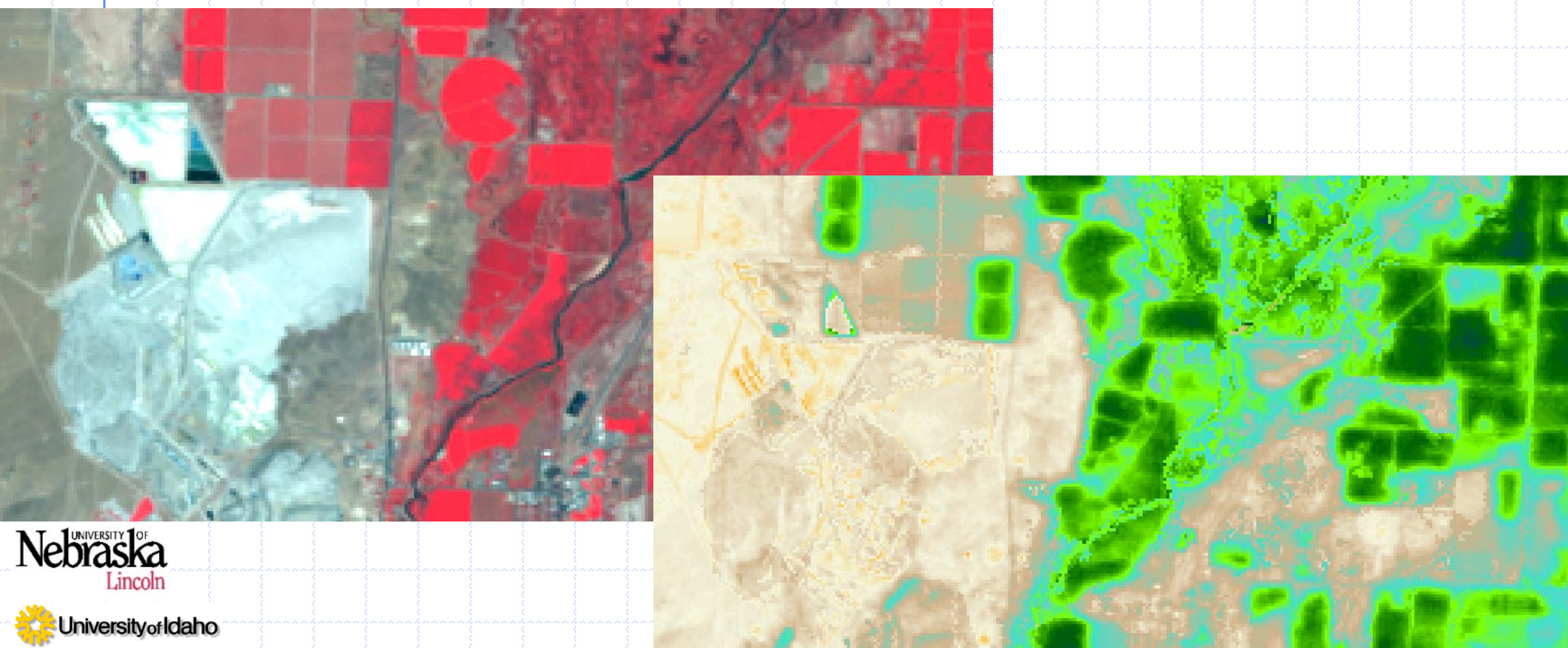
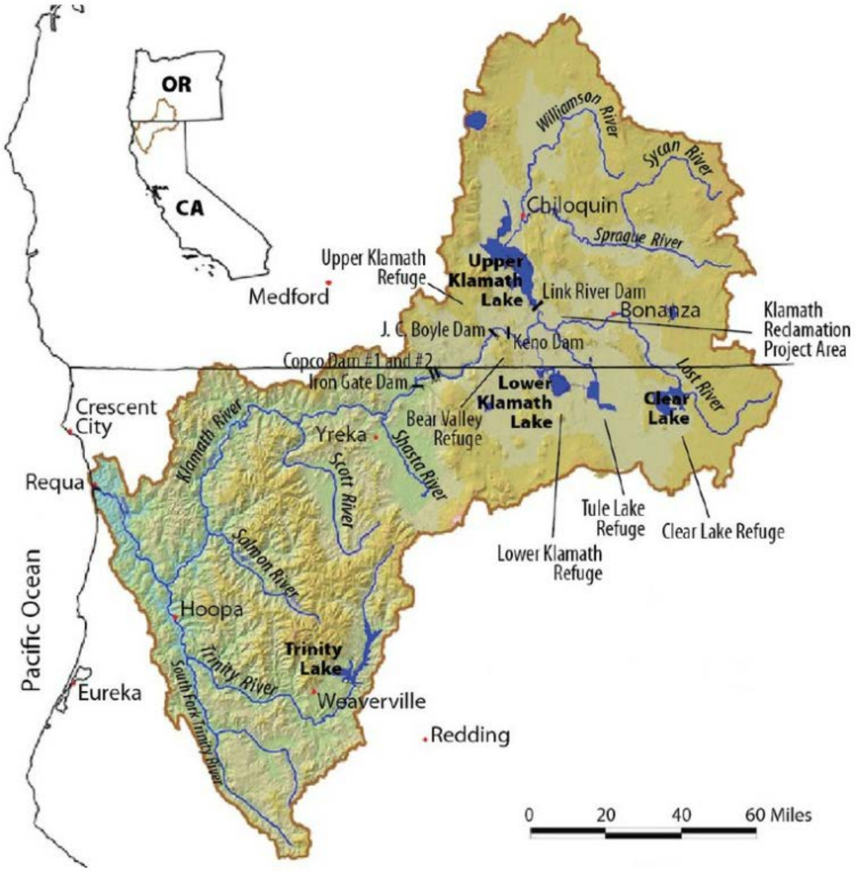
Nevada

- Desert Research Institute / Nevada Office State Engr.
  - Water transfers from Irrigated Ag. to Reno/Las Vegas
  - Water transfers from phreatophytes and playa to Las Vegas
  - *Need High Resolution thermal for narrow irrigation corridors and sometimes narrow phreatophytic systems*



The Klamath River Basin

- Home to many diverse species of wildlife
- Economically and culturally diverse rural communities
- The Karuk, Yurok, and Klamath Tribes harvest salmon and c'wam from the river for cultural and subsistence purposes
- Coastal commercial fishing families depend on Klamath salmon for their living
- Family farmers and ranchers use the river for irrigation of diverse crops
- Bitter conflicts have emerged between Tribal, agricultural, and commercial fishin communities
- Klamath Tribes were granted senior wate rights (may 2013) for large portions of the Upper Basin
- **This led to large scale water retirement for some irrigated areas - Requires Monitoring and Confirmation of Reduction in ET following Water Retirement**



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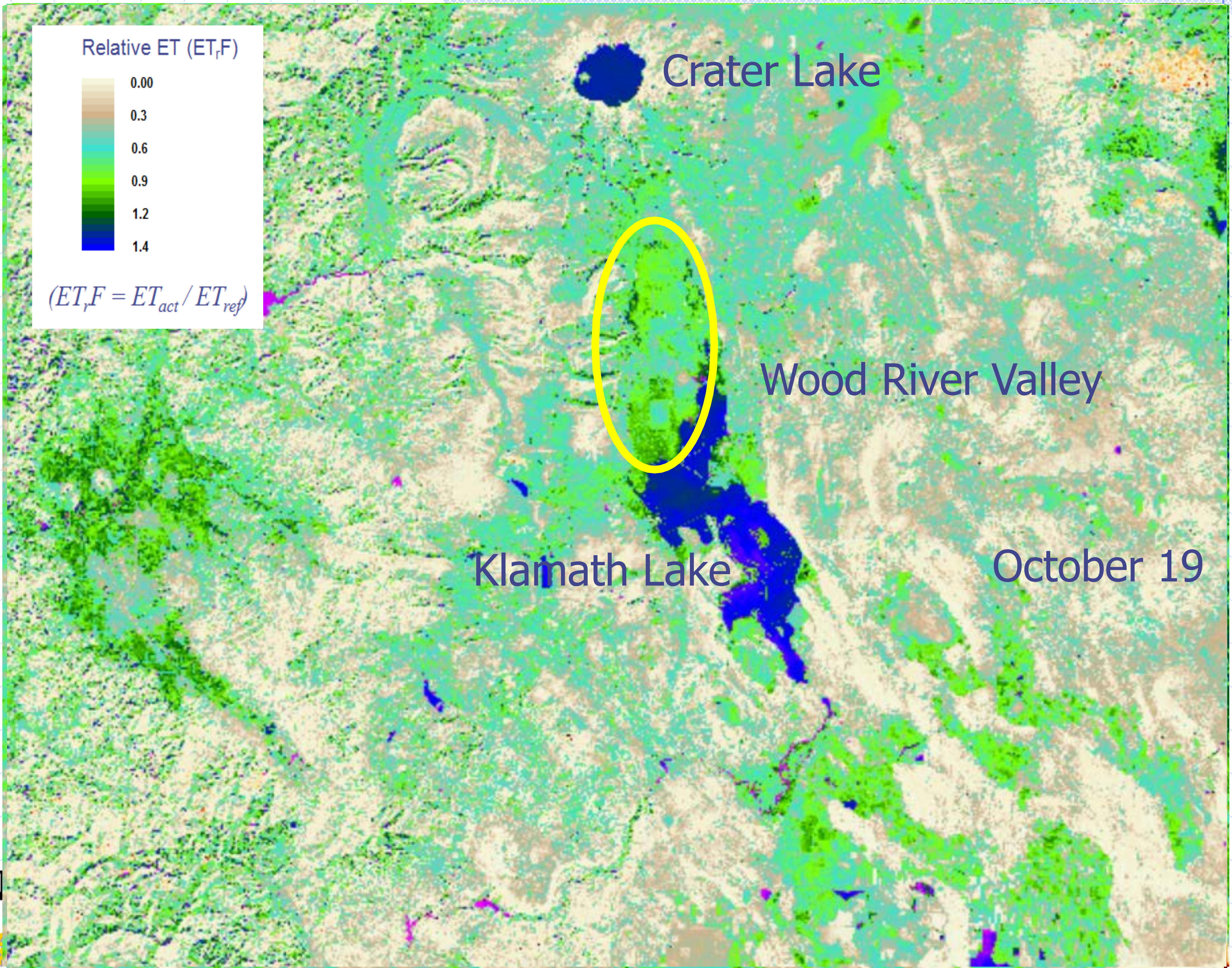
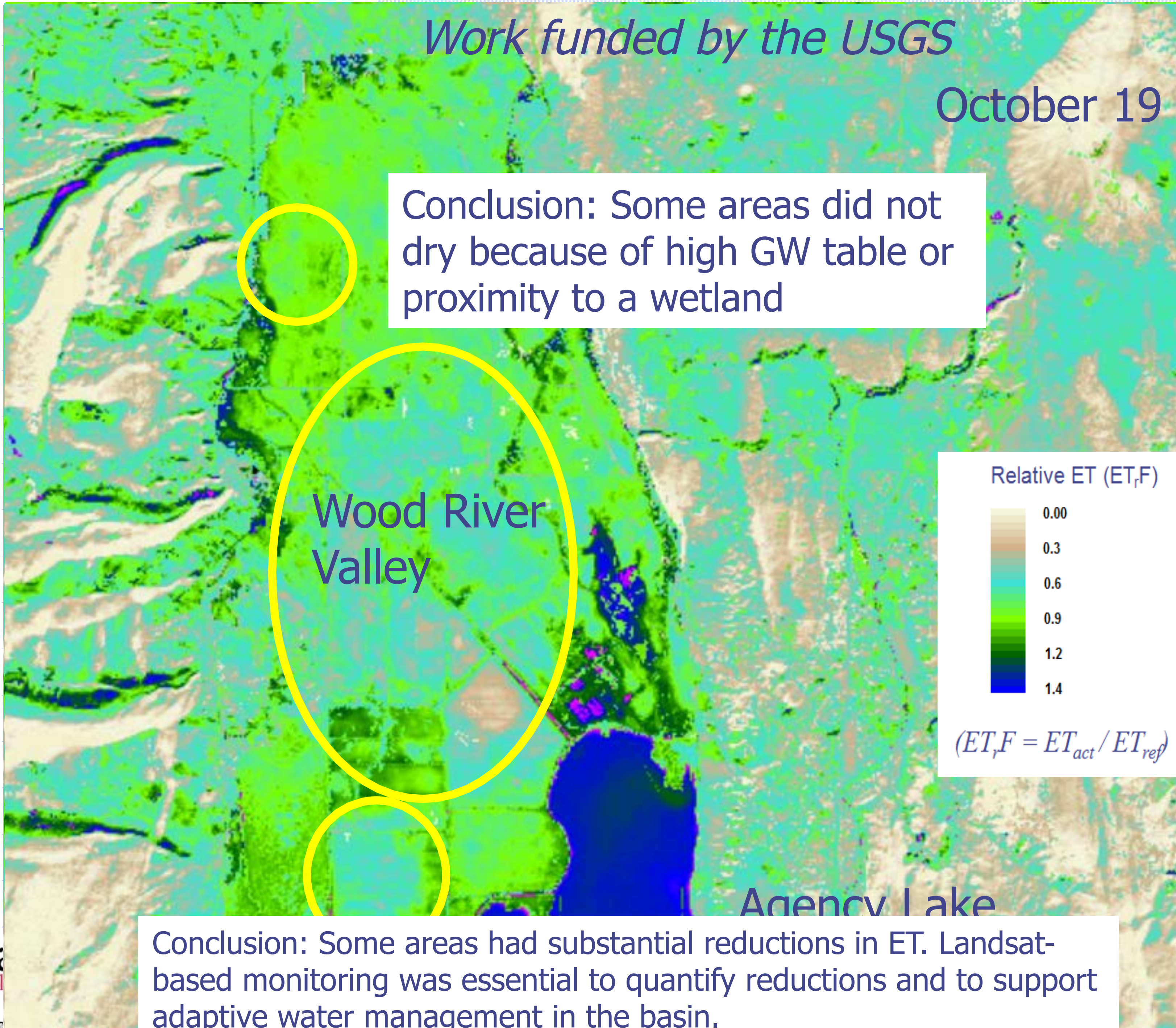


Relative ET (ET_rF)
0.00
0.3
0.6
0.9
1.2
1.4
$(ET_rF = ET_{act} / ET_{ref})$
Crater Lake
Wood River Valley
Klamath Lake
October 19



Conclusion: Some areas did not dry because of high GW table or proximity to a wetland

Conclusion: Some areas had substantial reductions in ET. Landsat-based monitoring was essential to quantify reductions and to support adaptive water management in the basin.

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US Supreme Court Introduction

- Montana vs. Wyoming on Tongue River
  - US Supreme Court case
  - Upstream vs. downstream water rights and Depletion by upstream state
  - Interstate Compact
  - High resolution ET used to aggregate water use across irrigated fields surrounded by desert
  - METRIC ET used to investigate expansion of irrigated acreage in Wyoming
  - Change in ET between dry and wet years
  - Testimony by Allen

Challenges in using High Resolution 'Snapshot' Satellite Images to Quantify Seasonal Water Consumption

- Landsat passes over each 16 days
- Parts of the image area are often cloudy
- Landsat 'snapshot' may miss the evaporation from rain events in between satellite dates

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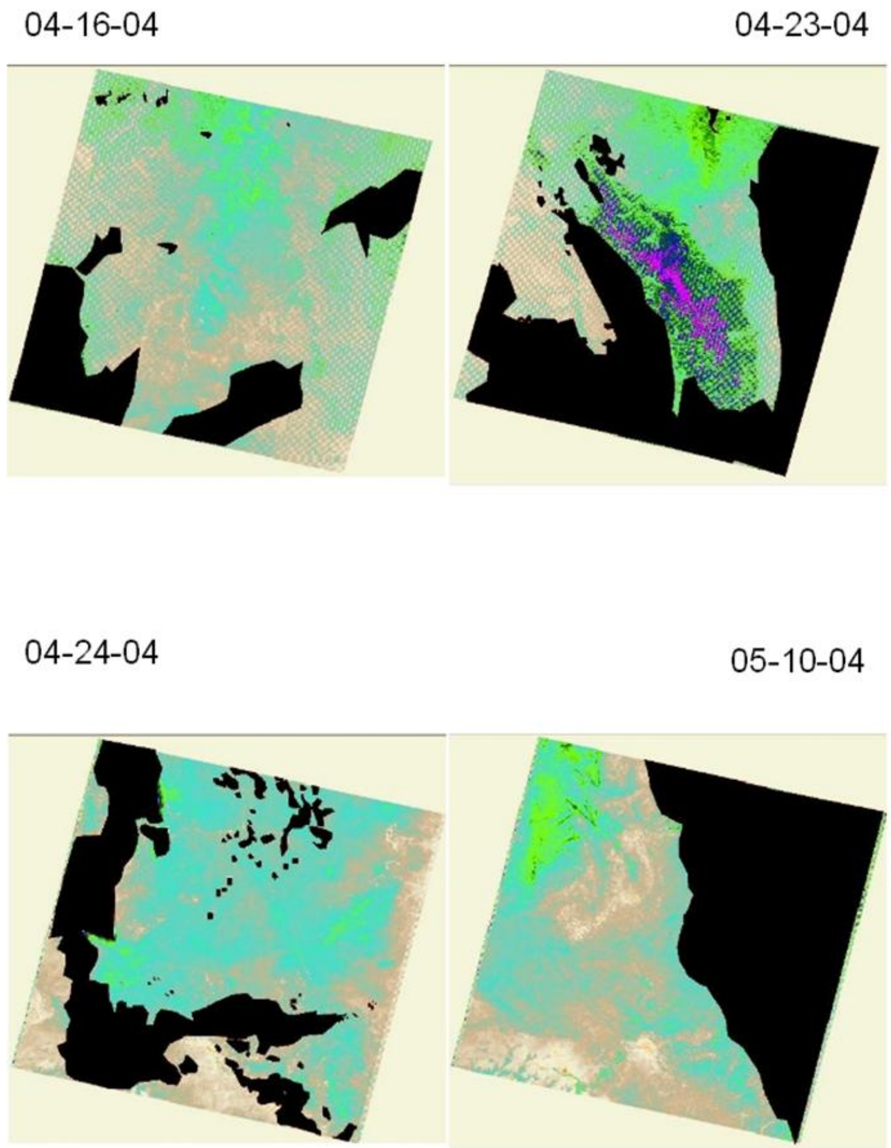
Images can be plagued with Clouds



north-central Wyoming

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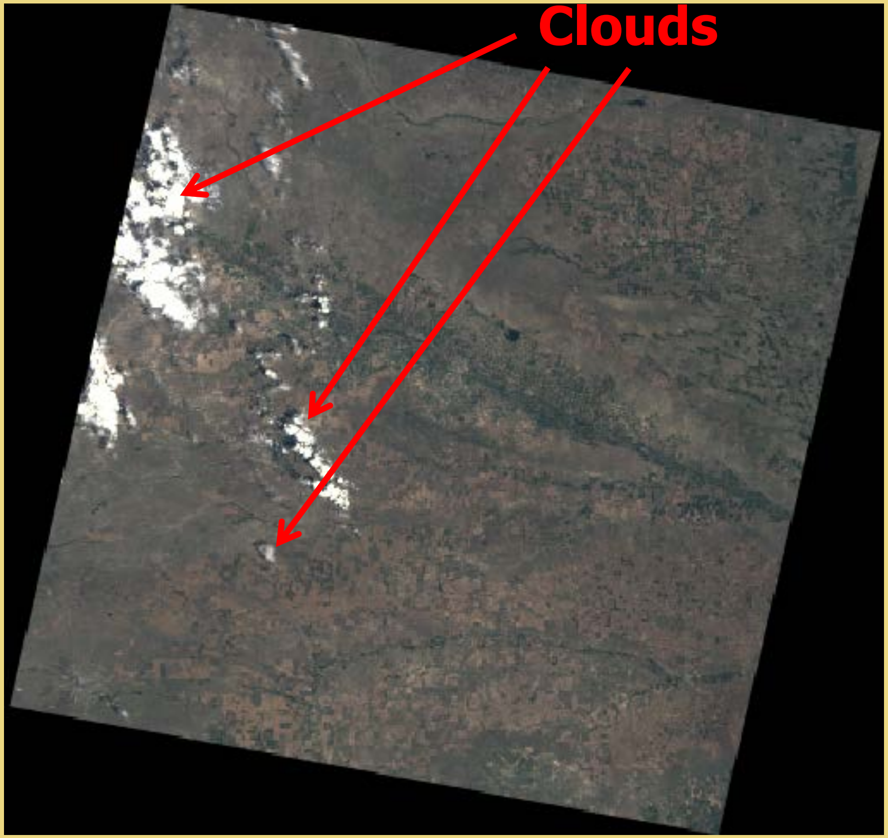
Cloud Mitigation

ET can not be estimated for areas covered by clouds.

Areas with cloud cover must be 'masked' out

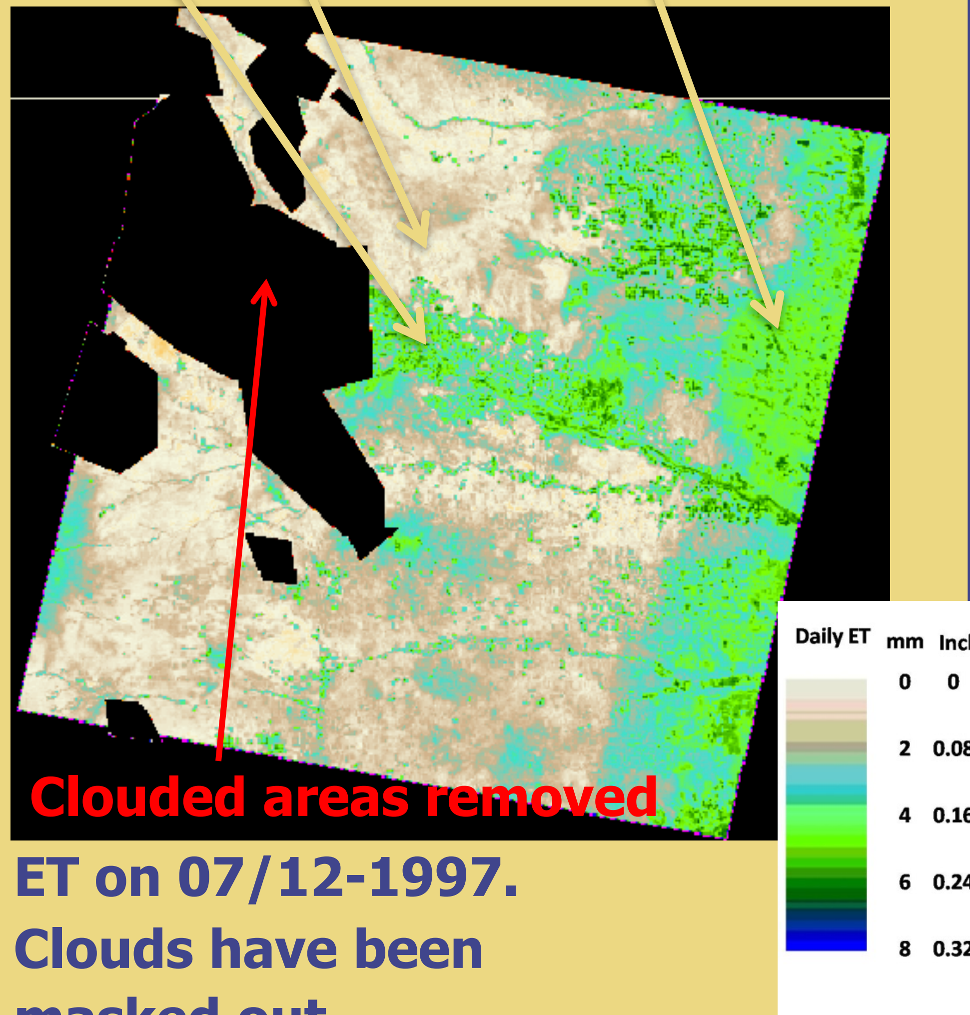


Landsat image 07/12-1997

Dry soil (low ET)

Irrig. Ag.

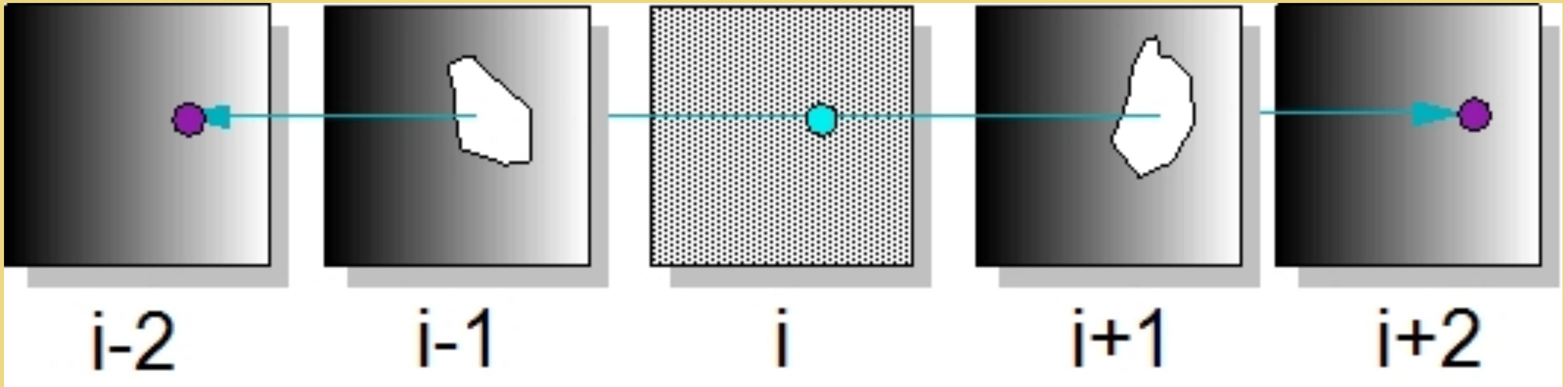
Recent rain in this area increases ET



ET on 07/12-1997. Clouds have been masked out.

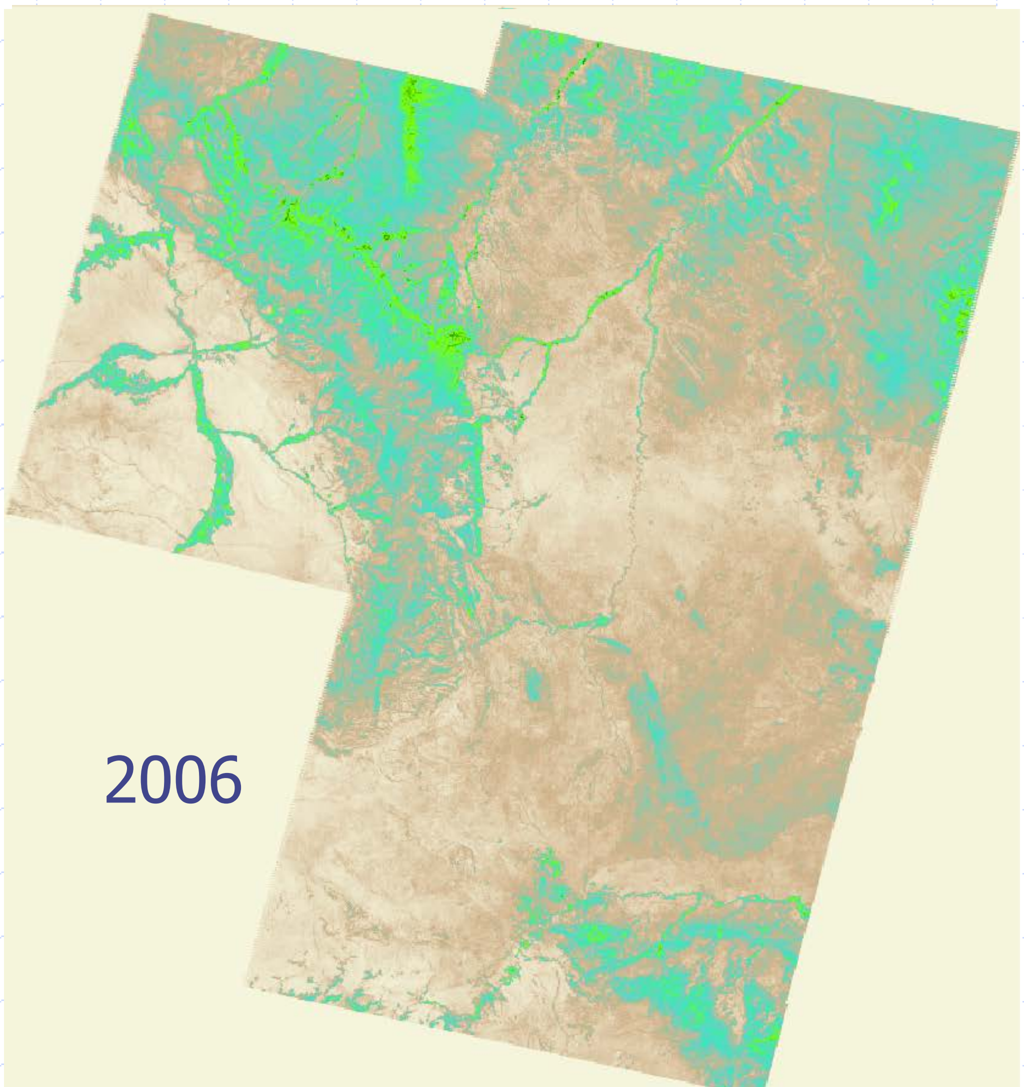
Nebraska Panhandle - 1997

Procedure for cloud gap filling

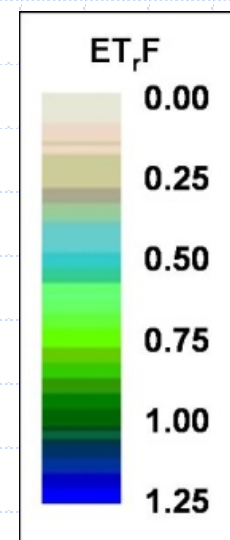


Borrow 'relative ET' information from adjacent images (in time)

ET from the north Wyoming Region for Years 2004 and 2006 following Time Integration between Landsat images and Mitigation for Clouds



Accurate seasonal ET does not come easy due to the lack of Landsats



Kelly and Allen, 2009

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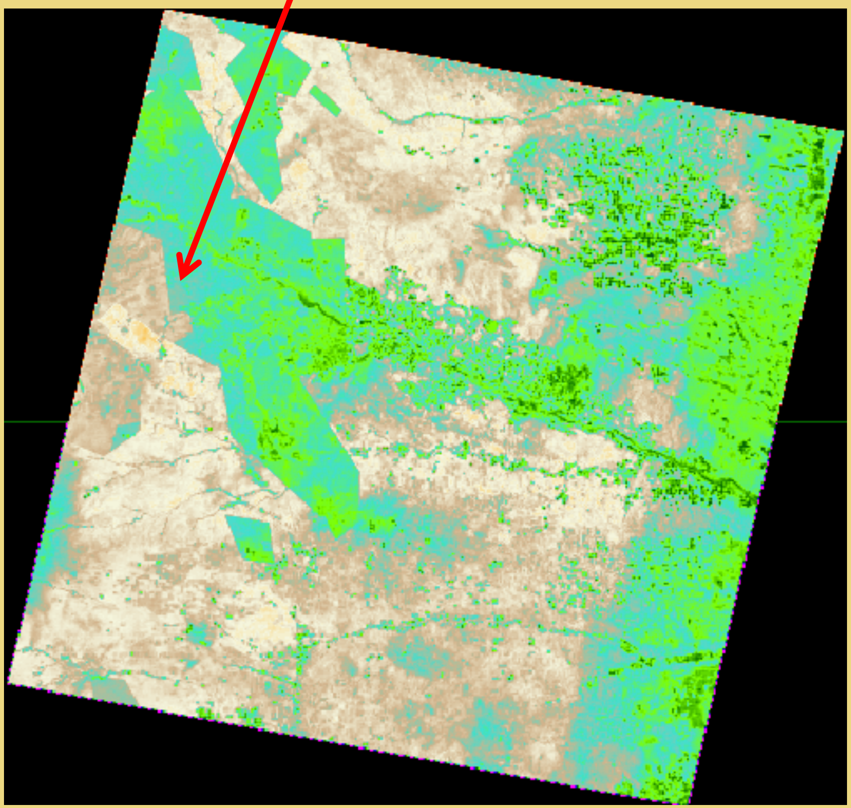
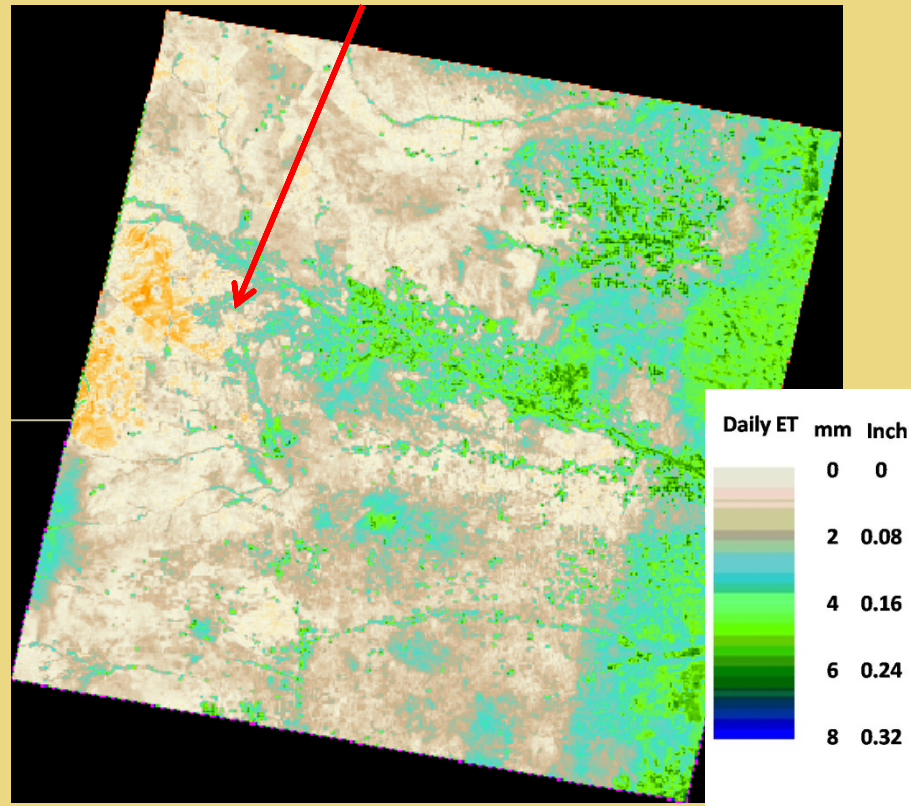
Step 2: Adjust for changes in Evaporation due to Rainfall

Filled areas are too high for bare soil

Better matching



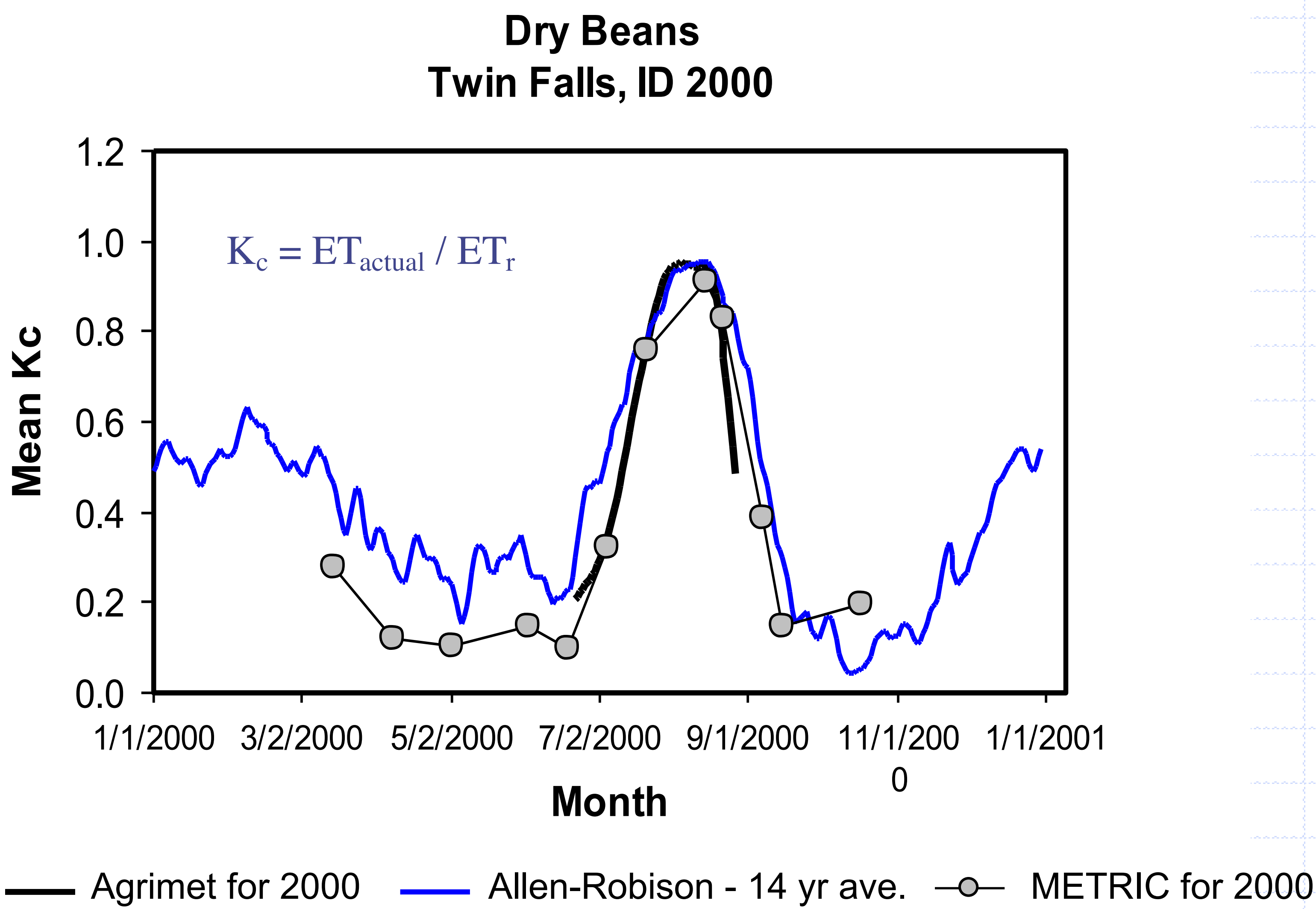
Filled with no adj.



Filled with adj. for Evap.

07/12-1997

Congruency of K_c from METRIC and K_c based Methods



Recent or Current users of METRIC

Public

- Idaho Dept. Water Resources --see previous slides
- USGS – Klamath River Basin, Montana GW modeling
- Metropolitan Water District – fallowing in Palo Verde
- New Mexico Office of the State Engineer (OSE)
- Wyoming Office of the State Engineer – Green River Basin – part of Colorado Compact
- Nevada Office of the State Engineer – water transfers from agriculture or from phreatophytic areas to cities
- California Water Resources Control Board – water consumption in the California Bay-Delta (just starting); - monitoring and intervention in Ground-water Sustainability Requirements throughout California (will use Satellite-based ET)

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Recent or Current users of METRIC

Public

- Central Platte Natural Resources District, Nebraska – Conjunctive management of GW and SW
- Univ. Texas – State wide explorations in ET mapping and intercomparisons of models
- North Dakota State Univ. – rainfed agriculture, wetlands
- Oregon Water Resources Dept. – ET from irrigation (Univ. Idaho); Impacts of Climate Change (ET+/HH)
- Montana Department of Natural Resources – ET depletions from irrigation, ET from tribal lands
- Department of Justice – Middle Rio Grande ET depletions

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Recent or Current users of METRIC

Commercial

- Soil Hydrology Associates, Las Lunas, NM – ET in hydrological models – CA, TX, NM, AZ
- Davids Engineering – multiple uses
- Riverside Technology Inc. – North Platte River (compact), South Platte River (Univ. Idaho), Morocco
- ET+ -- Klamath Basin, Palo Verde area
- Gallo, Inc. – management of ET and soil water to improve wine quality
- Intera, Inc. – ET of surface water and ground water in Pecos River Basin
- CalPoly / DRI – ET in the Central Valley of California
- State of Nevada / DRI – ET of water transfers from agriculture or playas to cities

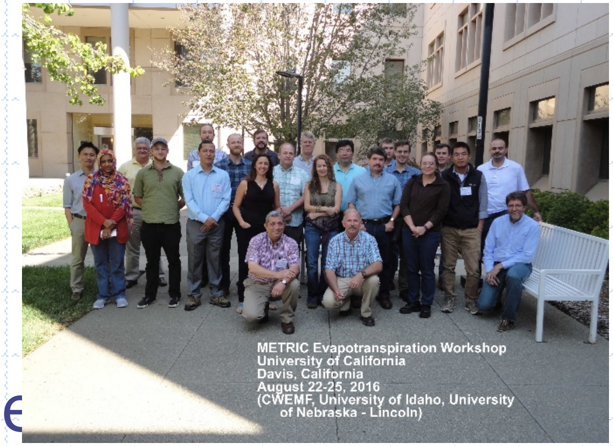
Recent or Current users of METRIC

International

- Andalusia State of Spain – ET from irrigated vs. rainfed olives
- Univ. Talca, Chile – ET from irrigated olives, wine grapes, orchards, including UAV-based systems
- Ciera, Brasil – ET for hydrologic models and irrigation depletions
- Morocco – Riverside Technology, Inc. – equity in water allocation

Access to METRIC

- Annual Training Courses on METRIC
  - Access to Level 1/2 METRIC Code
  - Access to METRIC Applications Manual
  - Four-day Training



- METRIC is coded into:
  - ERDAS Imagine with scripted mode
  - ArcGIS – ArcPy
  - Some segments in Python-GDAL

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CURRENT VENTURE:

EVAPOTRANSPIRATION MODELING TOOL AT LANDSAT RESOLUTION ON GOOGLE EARTH ENGINE --- EEFLUX

EEFlux Development Team

Ayse Kilic – University of Nebraska -- Professor and Developer Presenter, *Member of Landsat Science Team*

Justin Huntington – Desert Research Institute – Professor, *Member Landsat Science Team*

Rick Allen -- University of Idaho – Professor, *Member of Landsat Science Team*

Doruk Ozturk, Samuel Ortega, Babu Kamble, Ian Ratcliffe – University of Nebraska – Developers

Charles Morton – Desert Research Institute –

Clarence Robison – Univ. Idaho – GIS technician

Ricardo Trezza – University of Idaho – Professor

David Thau, Google, Inc. – Earth Engine Advocate

Tyler Erickson, Google, Inc. – Earth Engine Advocate

Rebecca Moore, Google, Inc. – Manager, Earth Engine / *Visionary*

Why an Evapotranspiration Tool on Google Earth Engine?

- Earth Engine (EE) has enormous computing and storage power
- EE has essentially free access
- EE holds the entire Landsat archive and NLDAS/CFSV2 gridded weather
- EE has strong developer support
- ET information is needed across the Global spectrum
- Google supports and encourages developers to 'change the world' regarding access to spatial information on the environment, natural resources, conservation and climate change

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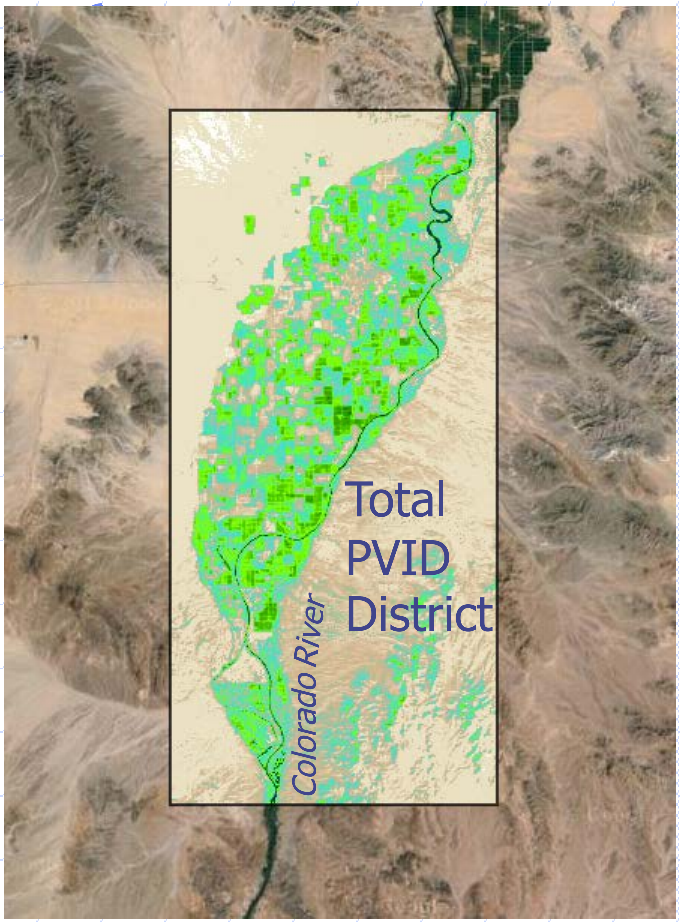
Google Earth Engine App --- EEFlux

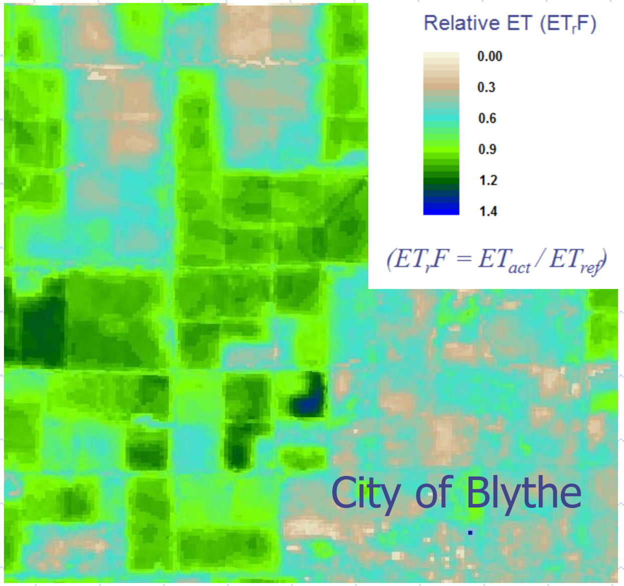


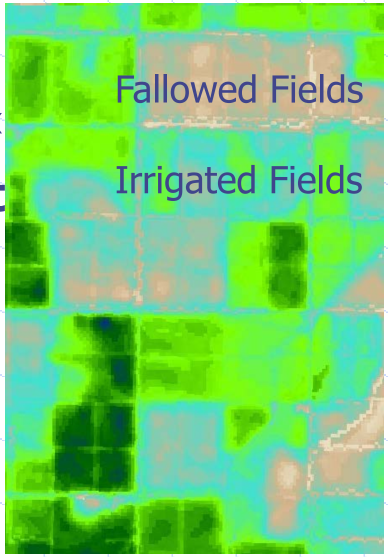
Earth Engine Evapotranspiration Flux

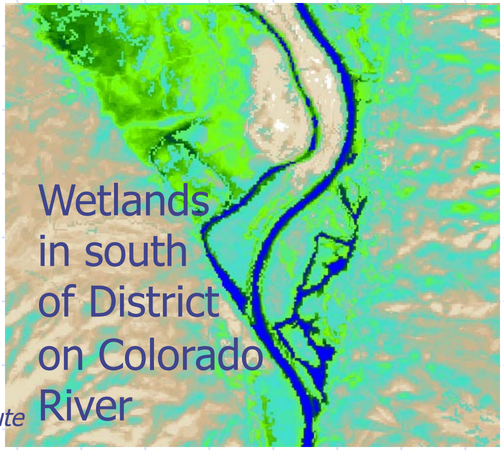
Palo Verde Irrigation District

Blythe, California – Jan. – Dec. 2008

-- Landsat 5 imagery Dec.







Univ. Nebraska-Lincoln, Univ. Idaho, Desert Research Institute

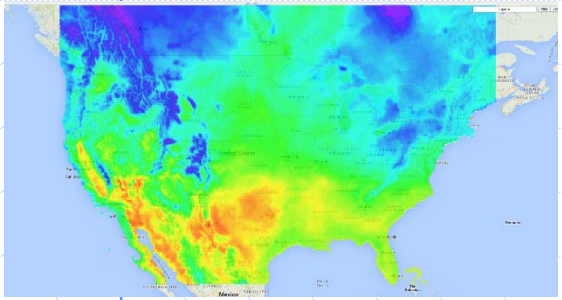
Computations are based on a complete surface energy balance ***(METRIC)***

University of Nebraska Lincoln

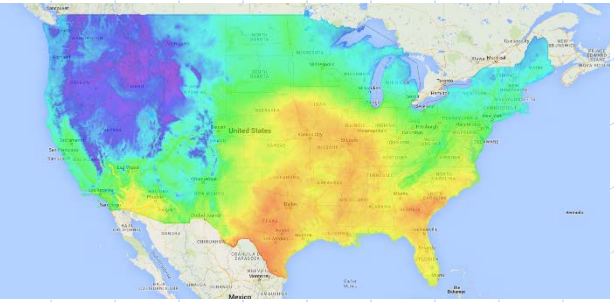
University of Idaho

Data Resources Used by EEFlux

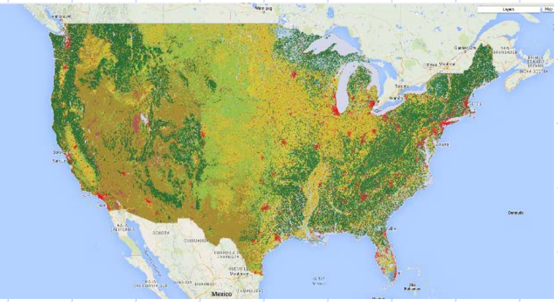
NLDAS-Jan 1, 1979 - Current



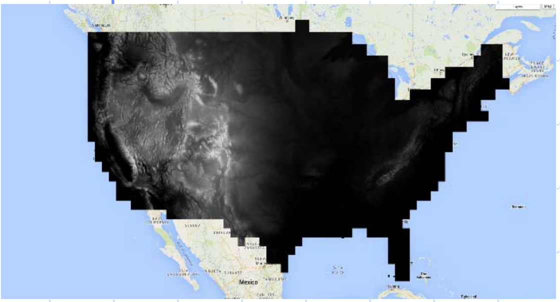
GRIDMET-Jan 1, 1979 - Current



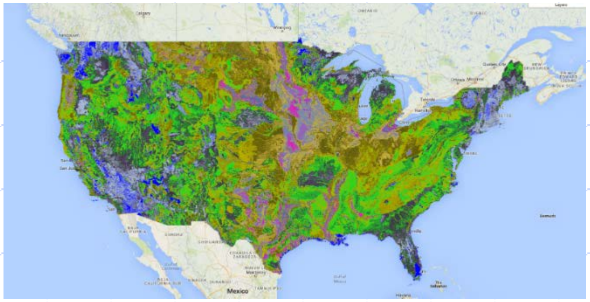
NLCD Landuse



DEM



Soil Data Layers



- Landsat 5/7/8 and MODIS
- Weather Data
  - Hourly Weather Data (NLDAS)--CONUS
  - Daily Weather Data (GRIDMET)--CONUS
  - Climate Forecast System Version 2, 6-hourly Products (CFSV2)--nonCONUS
- Landuse and Digital Elevation Maps
- Soil Data Layers (STATSGO--CONUS and FAO)

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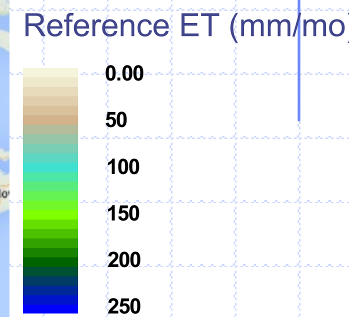
Reference ET on the Google Earth Engine EEFlux App.



Reference ET calculated using the ASCE Standardized Penman-Monteith Equation for the Tall Reference (Alfalfa) --computed from the GridMET data set of Abatzoglou (2012)

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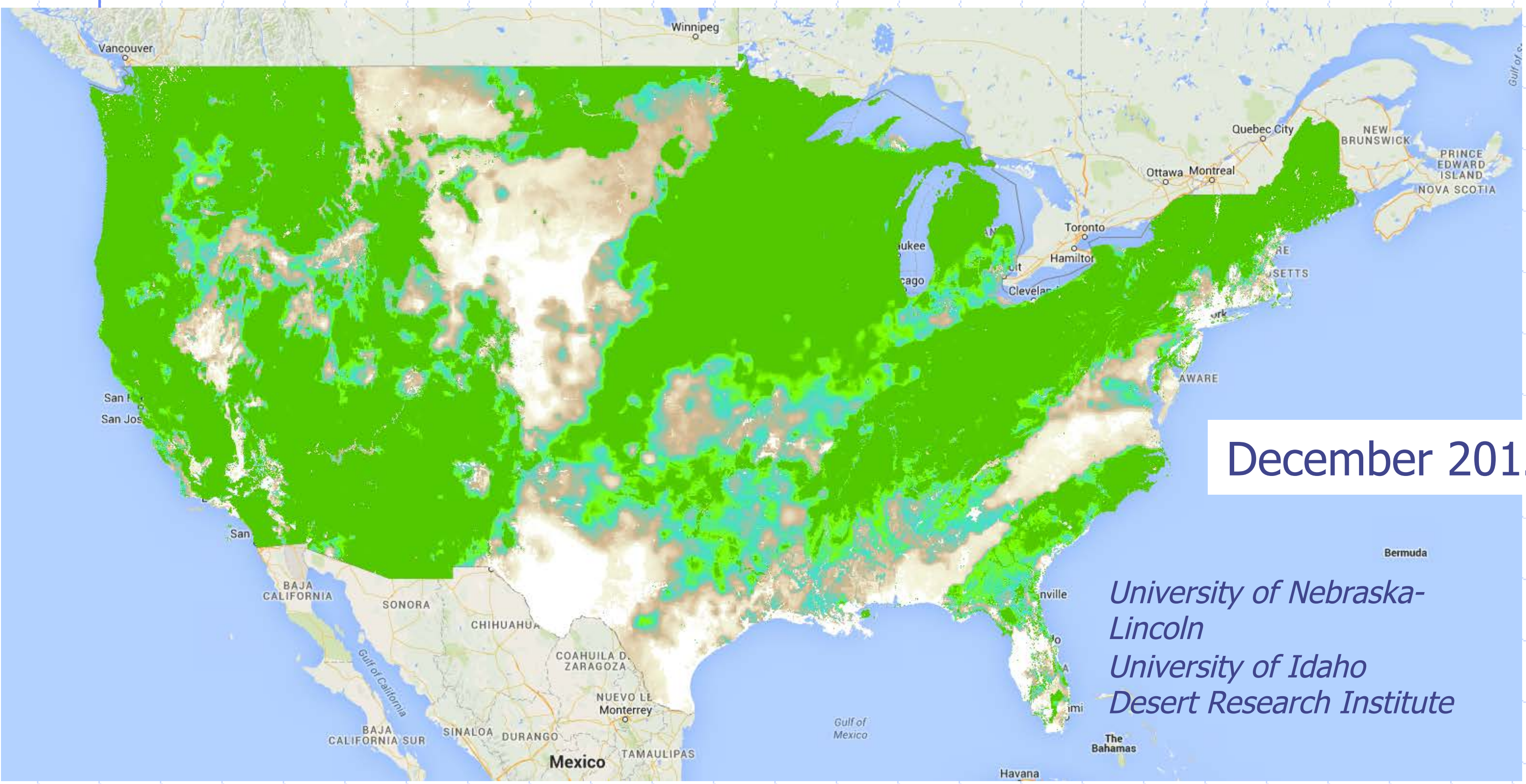
The Soil Surface Evaporation Component of the Google Earth Engine EEFlux App.

--- **Evaporation from Bare Soil** --- used to calibrate the EEFlux Evapotranspiration Surface Energy Balance to account for Precipitation Effects on ET



Evap. Coef. (K_e)

0.00
0.3
0.6
0.8
1.0

$(K_e = E_{act} / ET_{ref})$

--computed from the GridMET weather data set of Abatzoglou (2012)

-- GridMET is traceable to NLDAS and PRISM data sets

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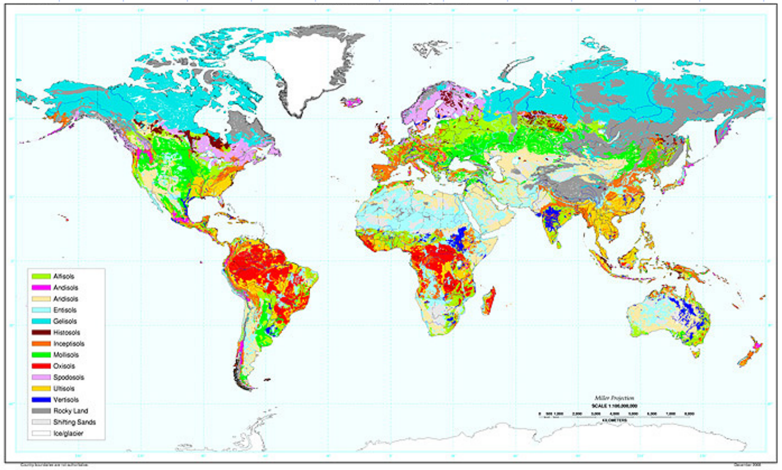
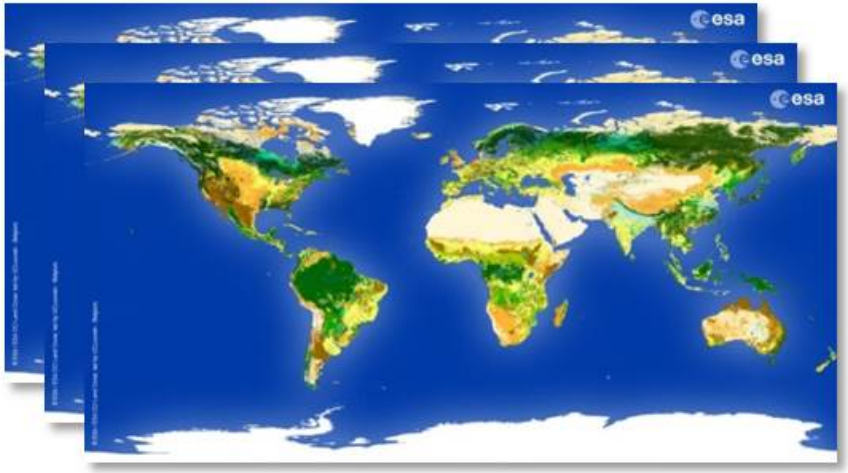
EEFlux -- IT IS RUNNING GLOBALLY

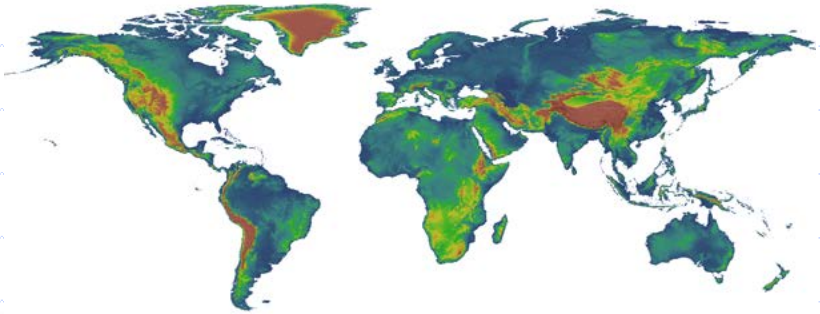
GLOBAL SOIL



LANDUSE-ESA

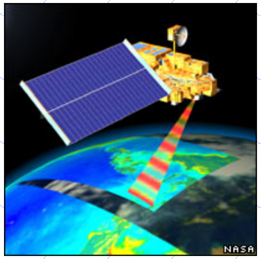


DIGITAL ELEVATION DATABASE-SRTM



LANDSAT 5/7/8

MODIS



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These data products are loaded and are functional on Earth Engine

Development Steps

Development of Web Access http://2.eeflux-level2-single-hotcold.appspot.com/

Development of a User Console

- to save project information *(coming)*
- free access to EEFlux API's (level 1)
- level 2 means to permit some degree of tuning

National and Global application (Seamless)

Automation of:

- Cloud detection and mitigation *(coming)*
- Calibration of EEFlux energy balance for highest accuracy
- Time integration to produce monthly and annual ET volumes *(coming)*
- Mosaicking paths *(coming)*

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University of Idaho

Demo of EEFlux

http://eeflux-level1.appspot.com/

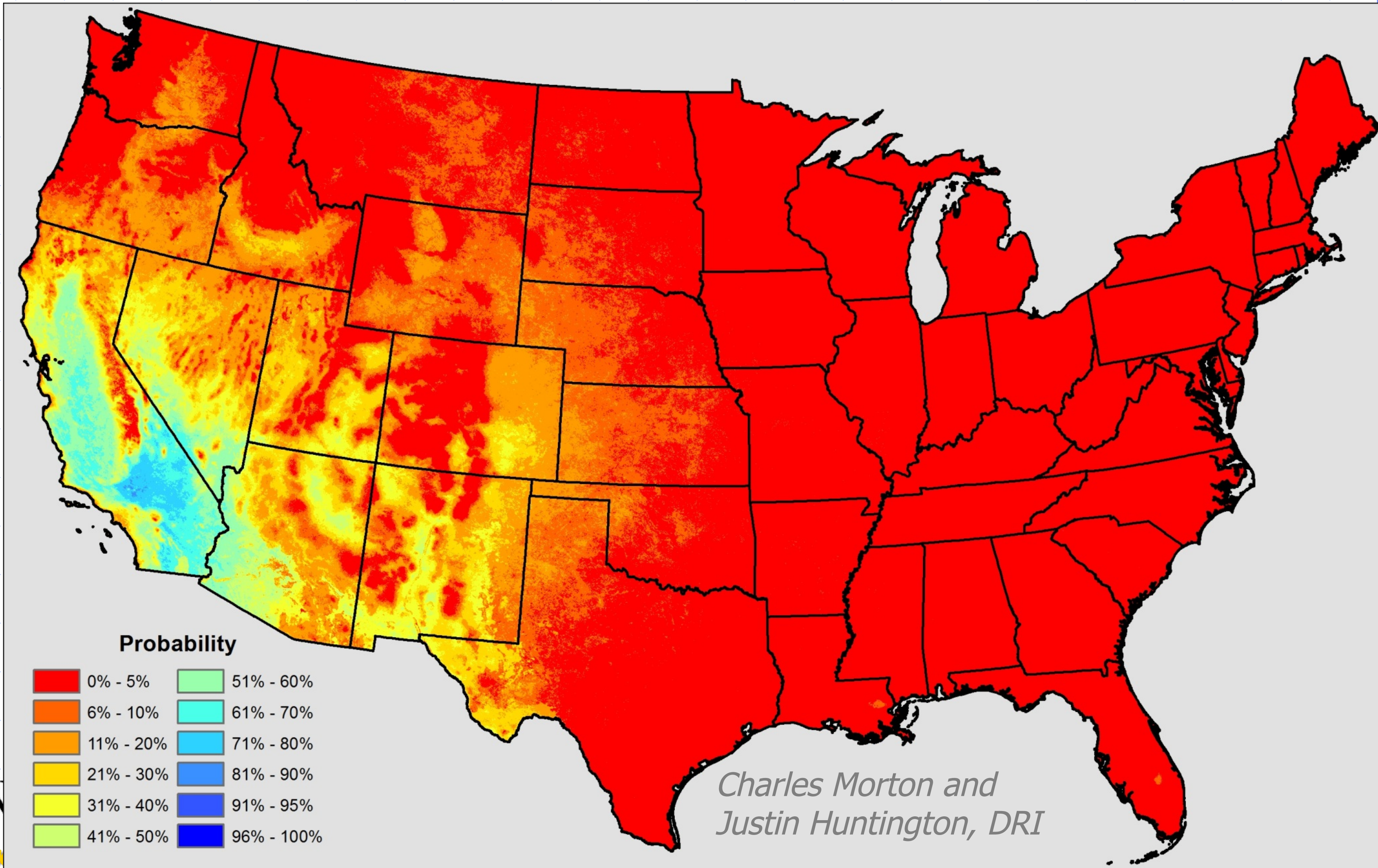
http://2.eeflux-level2-single-hotcold.appspot.com/

Need for Shorter Revisit Time for Landsat-type Satellites (with Thermal Imaging)

to Mitigate for Clouds

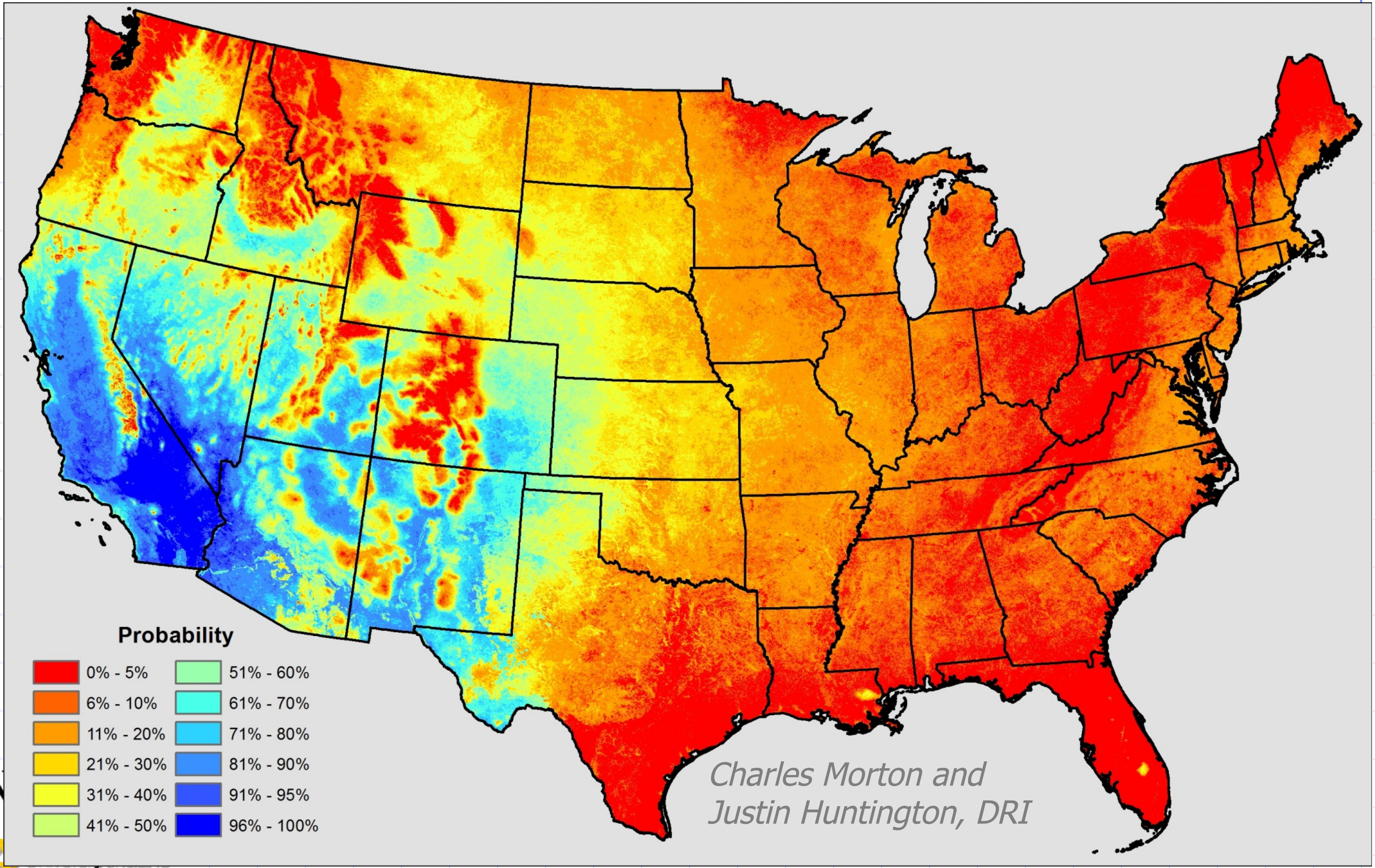
1 Satellite (image each 16 days)

Probability of producing a good estimate of Water Consumption over any given year (having a Cloud-free Image at least every 32 days during the growing season)



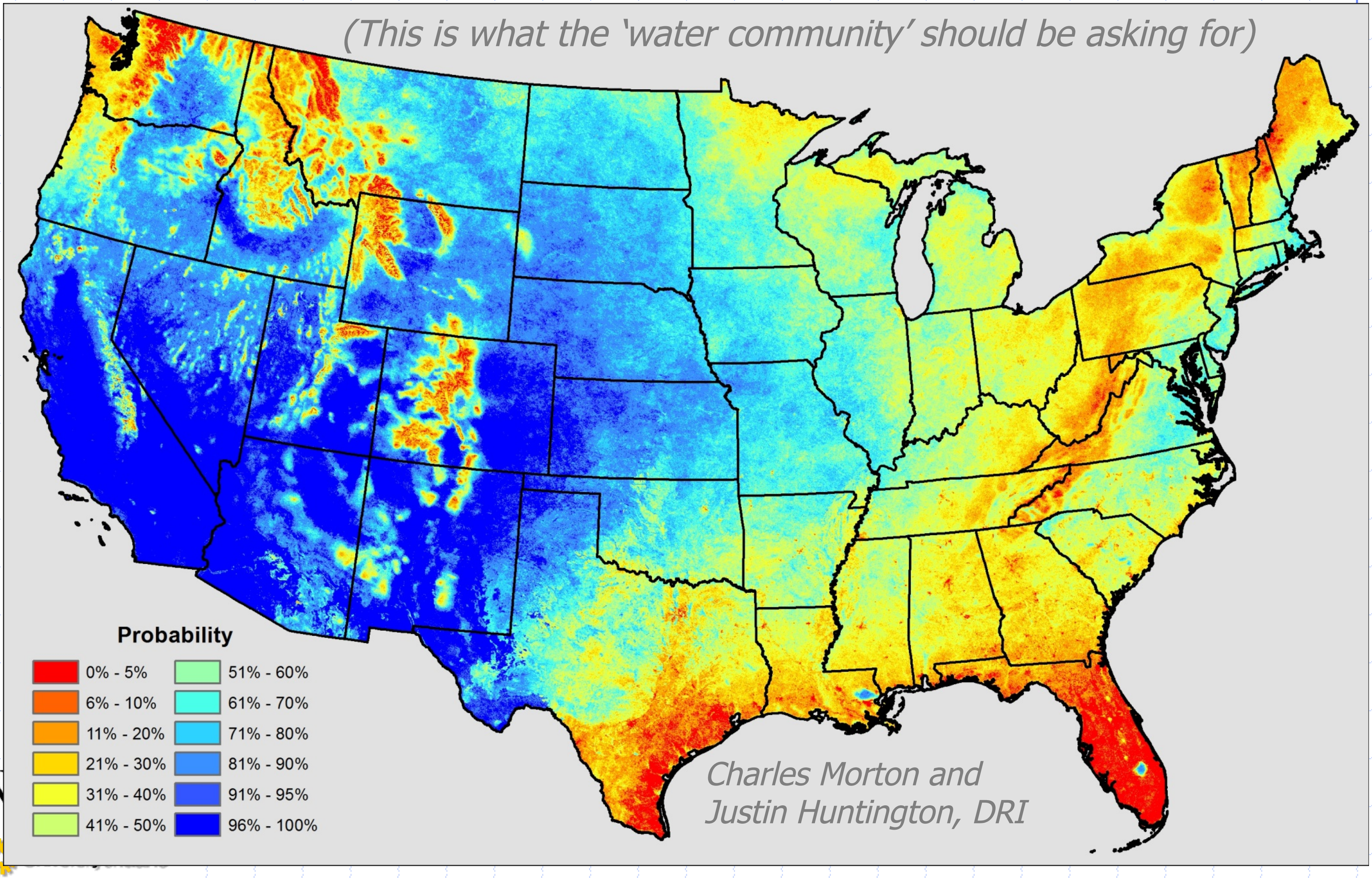
2 Satellites (image each 8 days)

Probability of producing a good estimate of Water Consumption over any given year (having a Cloud-free Image at least every 32 days during the growing season)



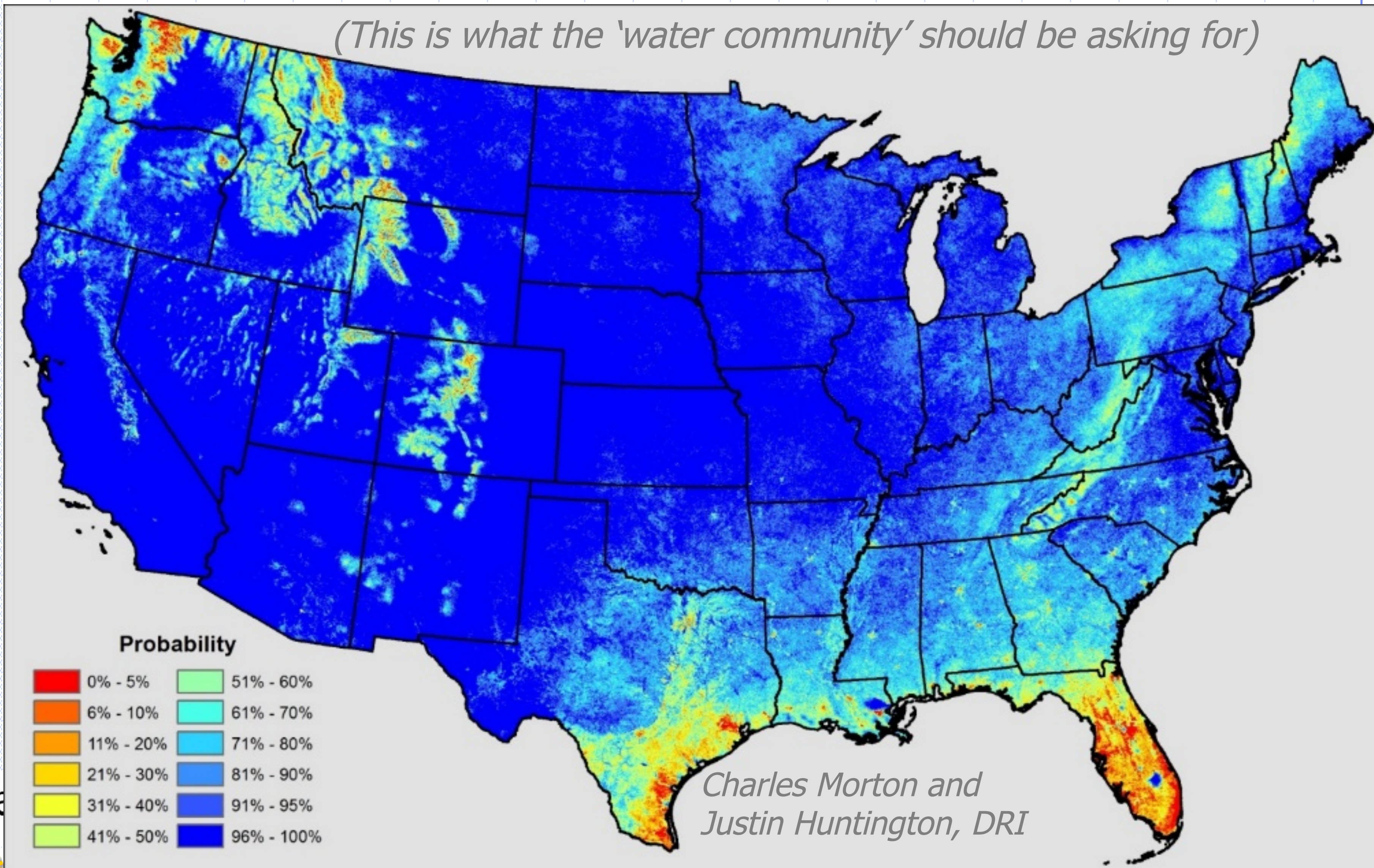
4 Satellites (image each 4 days)

Probability of producing a good estimate of Water Consumption over any given year (having a Cloud-free Image at least every 32 days during the growing season)



8 Satellites (image each 2 days)

Probability of producing a good estimate of Water Consumption over any given year (having a Cloud-free Image at least every 32 days during the growing season)



A Landsat-based "Earth-Selfie" concept

- Cost: Less than 3 coffee-latte's per American per year
- Support SIXTEEN Landsats in orbit
- *DAILY* Earth-Selfie's
- Consider:
  - *99% of all Americans spend at least $10 per week on superfluous things: cafe-lattes; bottled water; movies; gasoline to motor three blocks to the market-place or across town to look for designer jeans.*
  - *However, we don't want to spend the <$0.50 PER YEAR per American needed to launch and operate Landsats or similar that take field-scale 'selfies' of our Nation.*
  - *Less than $6 per American PER YEAR would place SIXTEEN Landsats into orbit, giving us DAILY Selfies of the entire Nation.*

$800 million/LS
÷8 years
x 16 LS
÷ 300 million Americans
= $5.30 per American per year

Can you imagine what that would be like? A Landsat 'Selfie' EVERY DAY???

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University of Idaho

Thank You

http://2.eeflux-level2-single-hotcold.appspot.com/

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Extra/Supplementary Material

Sensible Heat Flux (H) – METRIC model

$$H = (\rho \times c_p \times dT) / r_{ah}$$

Advantage:
r_{ah} 'floats' above the surface and is 'free' of z_{oh} and some limitations of a single source approach

Advantage:
dT is inverse calibrated (simulated) (free of T_{rad} vs. T_{aero} vs. T_{air})

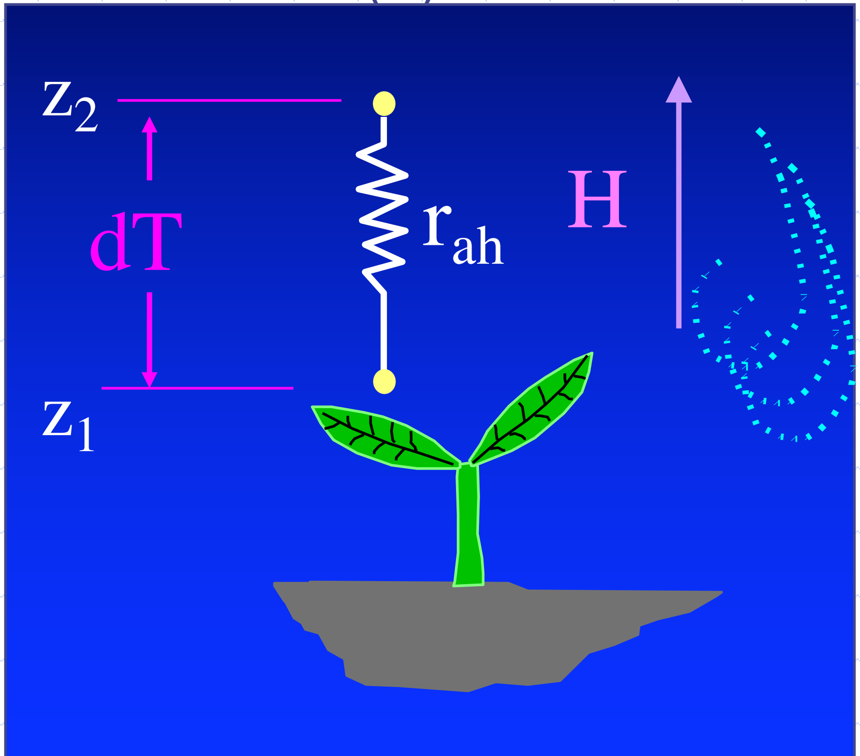
dT = "floating" near surface temperature difference (K)

r_{ah} = the aerodynamic resistance from z_1 to z_2

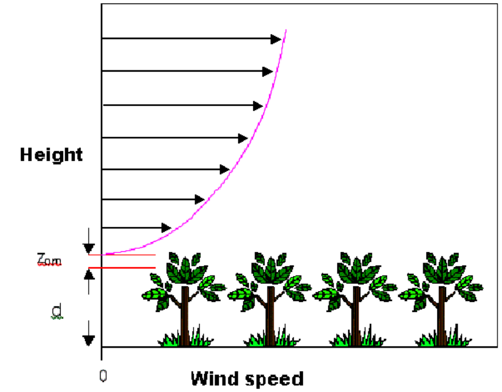
$$r_{ah} = \frac{\ln\left(\frac{z_2}{z_1}\right) - \Psi_{h(z_2)} + \Psi_{h(z_1)}}{u_* \times k}$$

u_* = friction velocity

k = von karmon constant (0.41)



Sensible Heat Flux (H) – “Traditional Approach”



$$H = \rho \ c_p \ (T_{aero} - T_{air}) / r_{ah}$$

Challenge (BIAS):
Up to 2 K different from T_{rad} (satellite)

Challenge (BIAS):
Unknown Spatial Distrib. of T_{air} (feedback between H, T_{rad}, T_{air})

T_{aero} = aerodynamic temperature

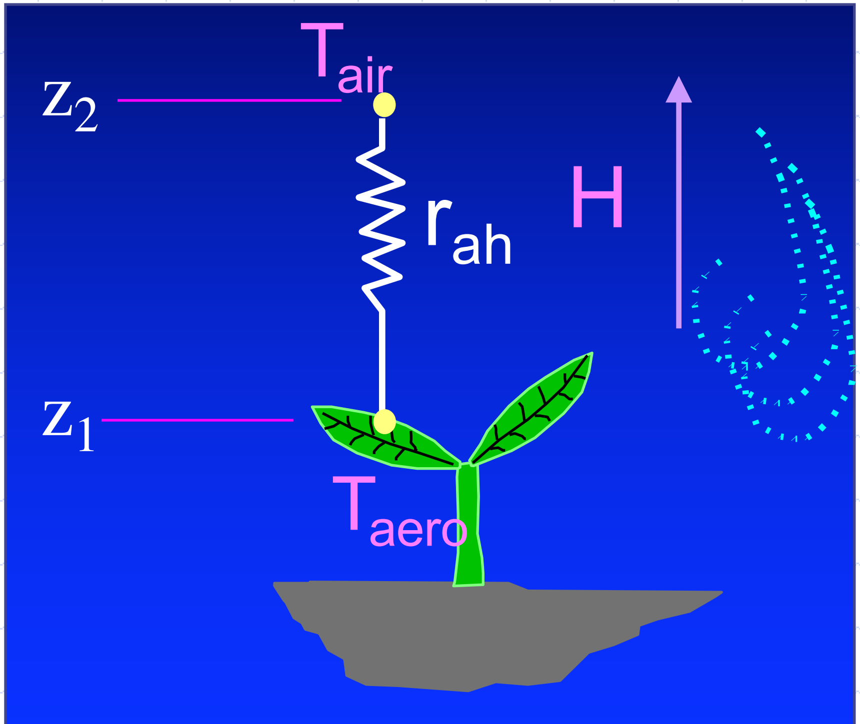
r_{ah} = the aerodynamic resistance

$$r_{ah} = \frac{\ln\left(\frac{z_2 - d}{z_{oh}}\right) - \Psi_{h(z_2)} + \Psi_{h(z_1)}}{u_* \ k}$$

u_* = friction velocity

k = von karmon constant (0.41)

ψ_h = buoyancy-instability correction = f(*H*)



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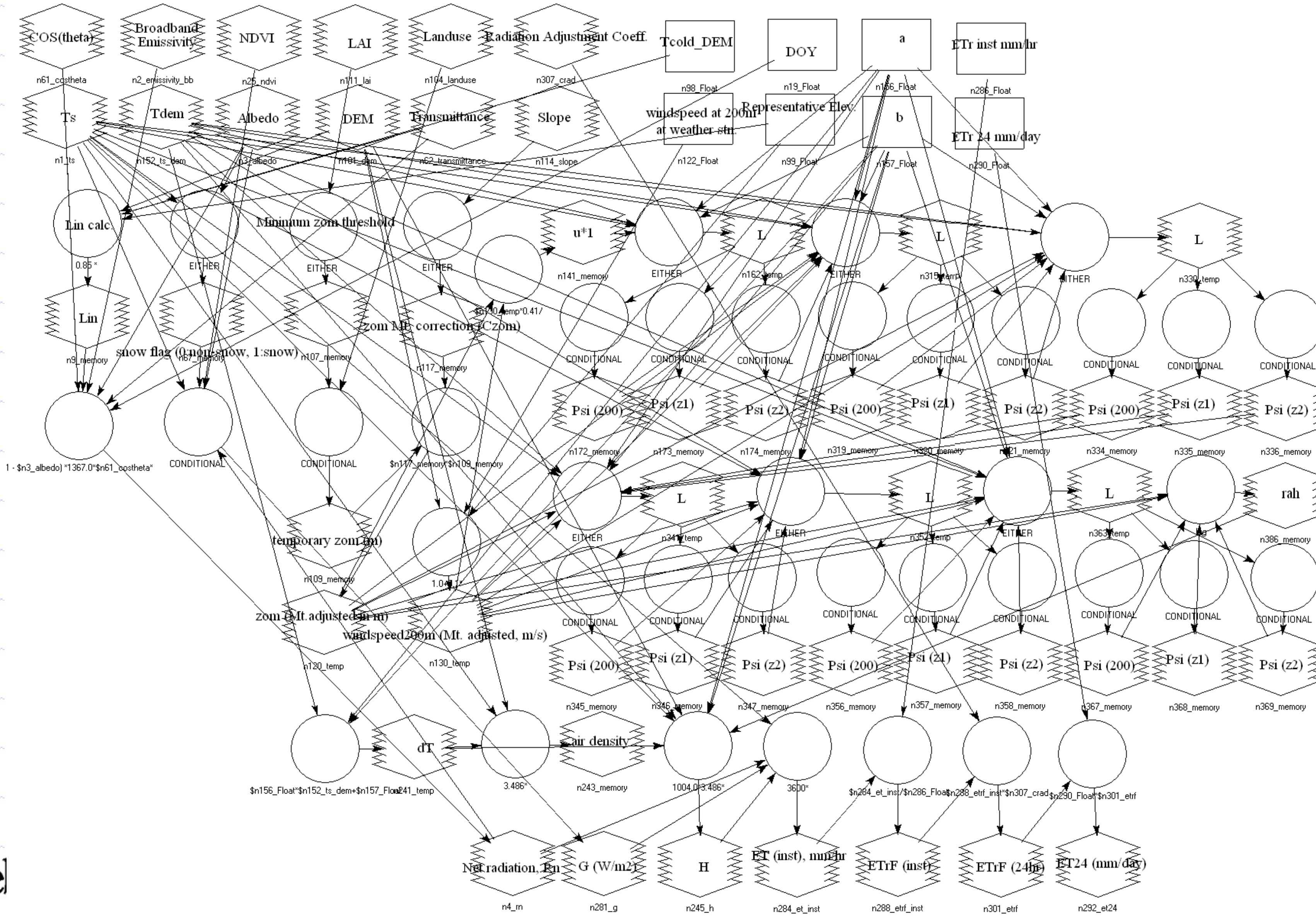
METRIC^{tm}-ERDAS submodel for sensible heat and ETrF

M02, Main energy balance model for SEBAL-ID: Sensible heat flux, Net radiation, Ground heat flux, Reference ET fraction and ET



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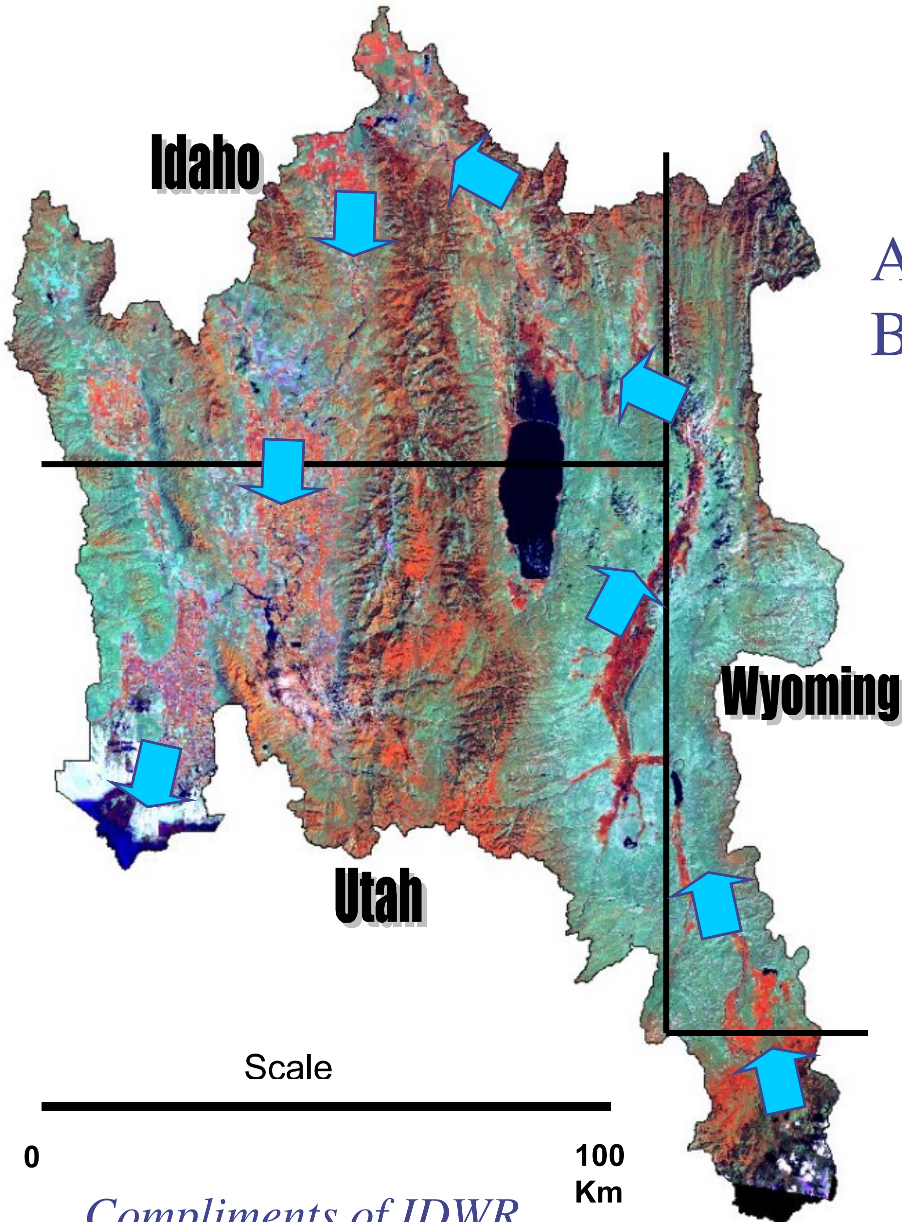
Application to the Bear River Basin



Compliments of IDWR

Bear River Compact

Three USA States

Need ET maps for:

- Total “depletion” by each state
- Total hectares of development
- Monitoring

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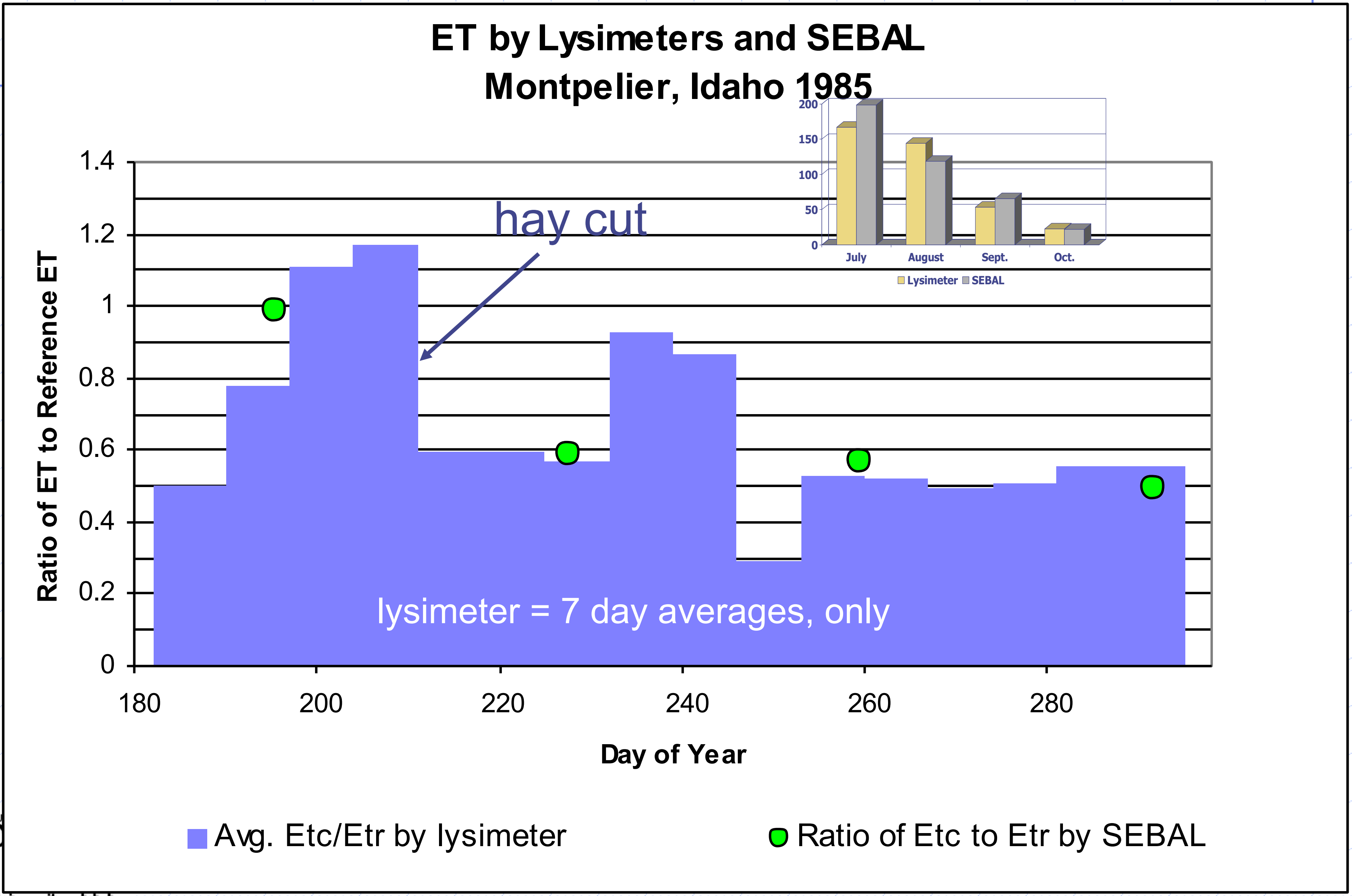
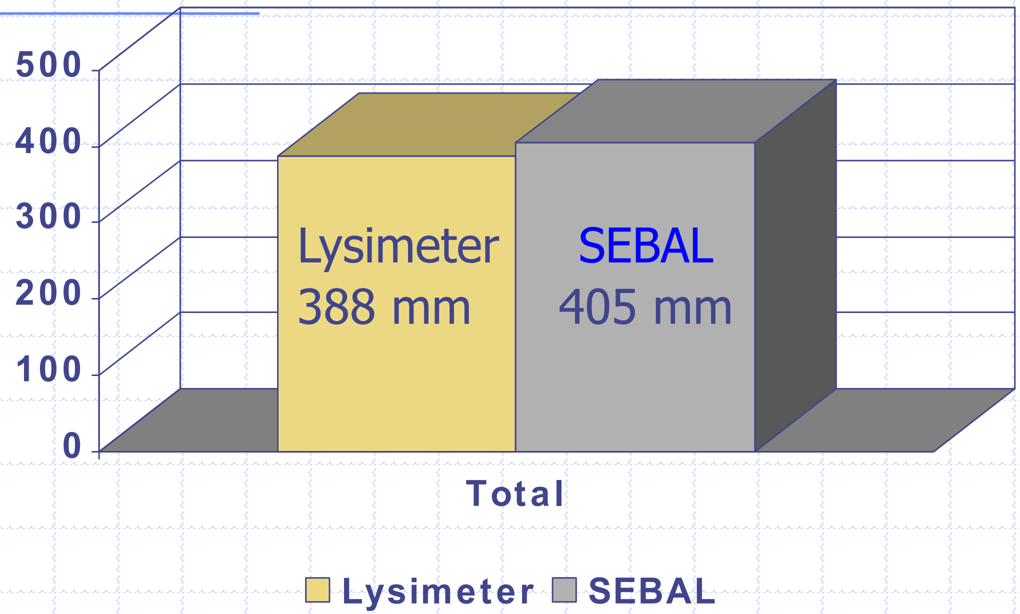
Validation in the Bear River Basin



Comparison of Seasonal ET by $SEBAL_{2000}$ with Lysimeter

ET (mm) - July-Oct., *Montpelier, ID 1985*



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Example 2: Legal Finding of Fact

- Water 'Call' 12/2007 by A&B Irrigation District (surface + senior ground-water)
- Water Call
  - Claim of injury due to water shortage in 2006
    - caused by lowering of aquifer by junior pumpers
  - Demand for curtailment order to junior GW irrigators
- A Curtailment Order
  - Issued by IDWR
  - Has the force of law
  - Built on Finding of Fact
- At stake: >1,000 farmers' livelihoods.

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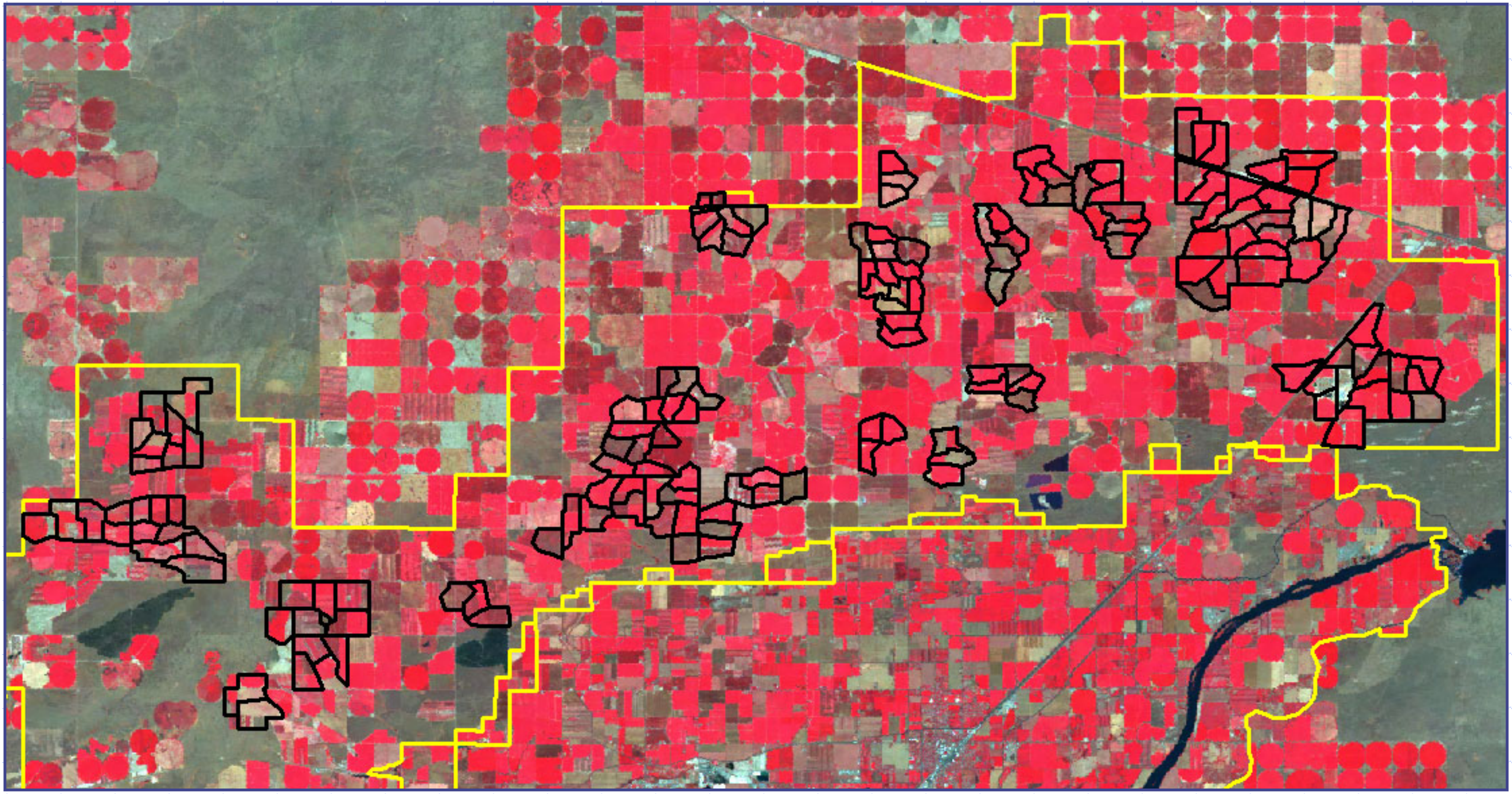
Legal Finding of Fact



Polygons of fields claimed to be water-short in 2006.

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The Crux of the Issue

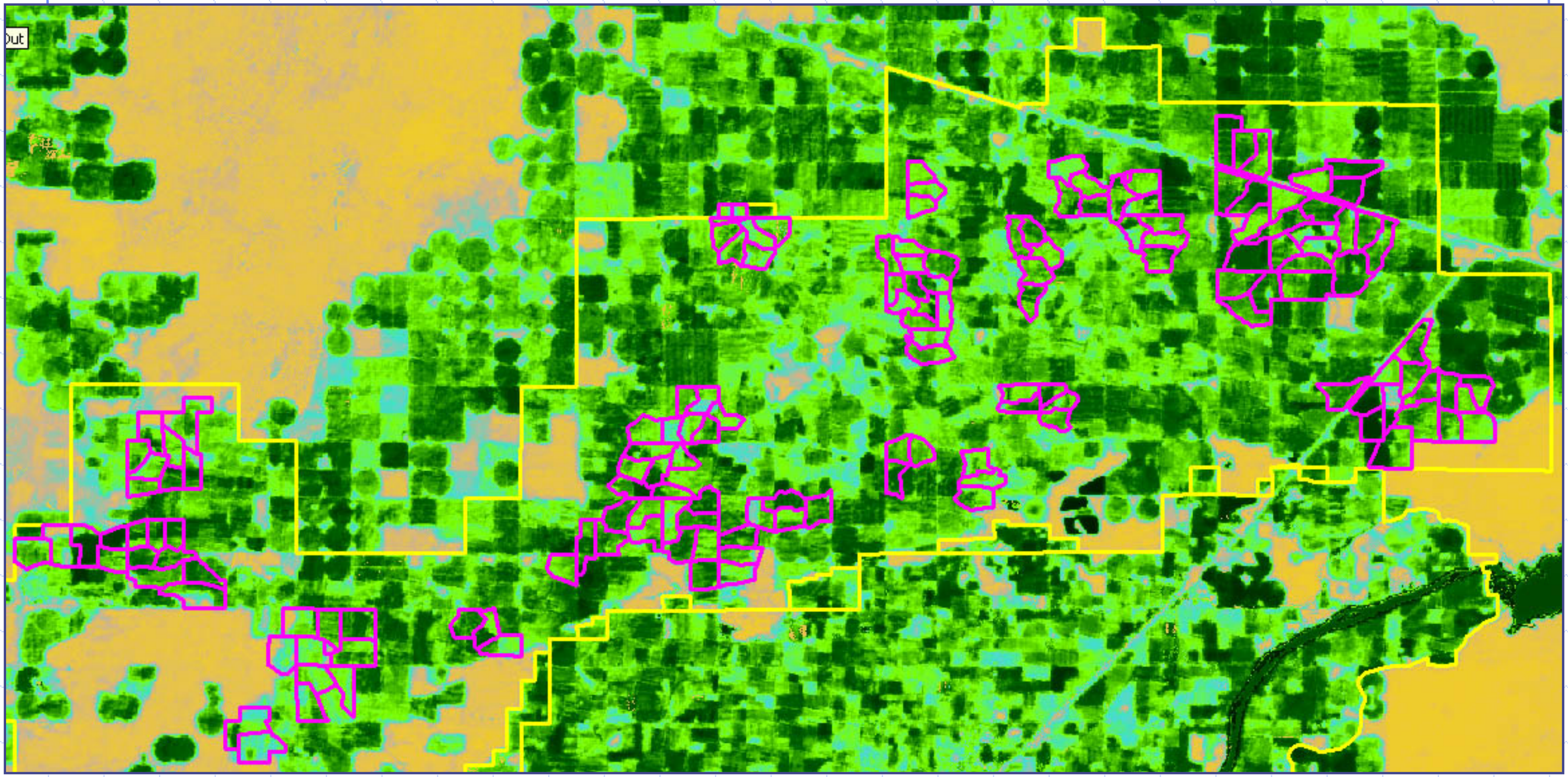
Was there enough water in 2006?

How do you assess that 2 years later?

How do you evaluate individual fields?

The Answer

- Use Landsat to map 2006 evapotranspiration



Purple polygons are fields claimed to be water-short in 2006

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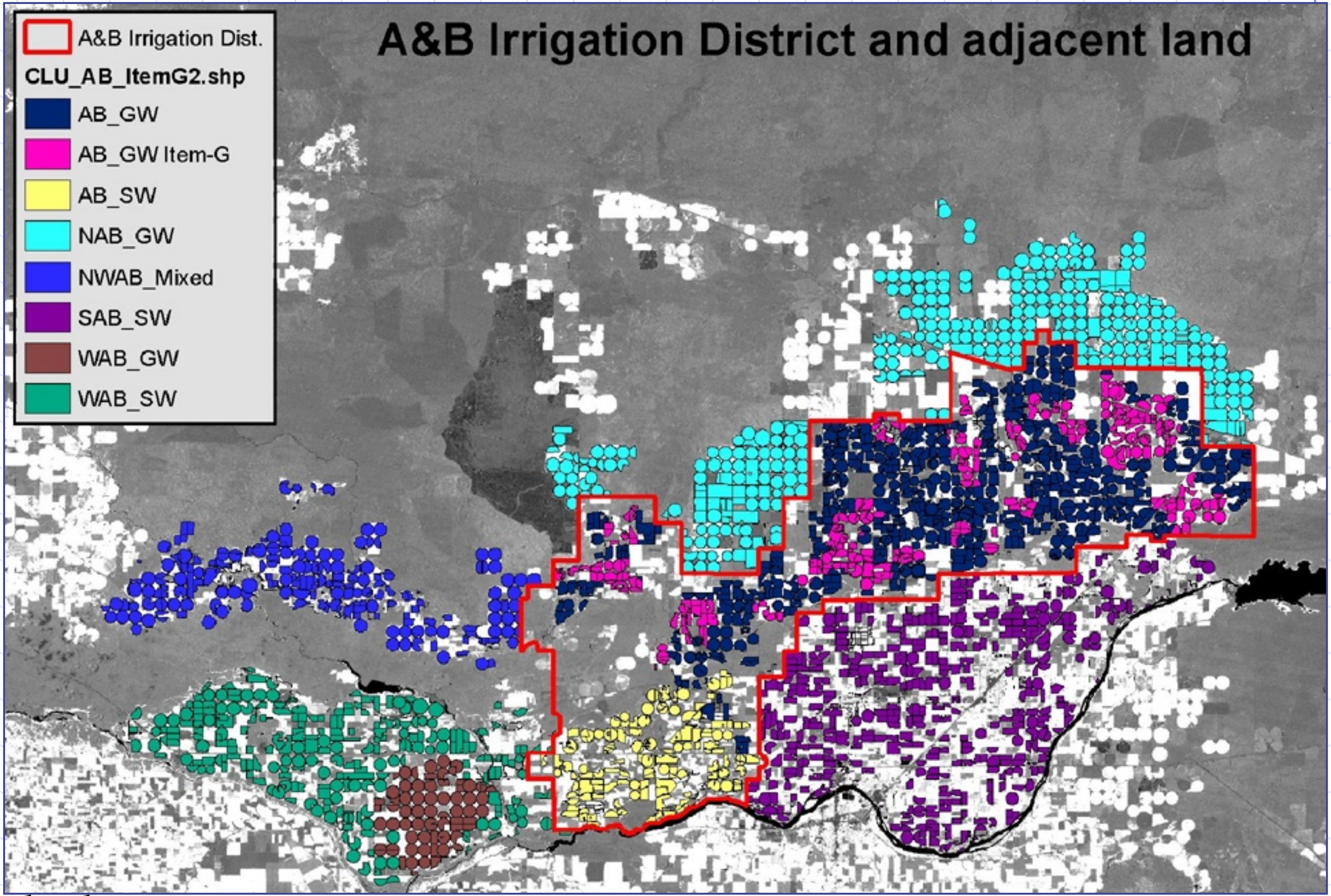
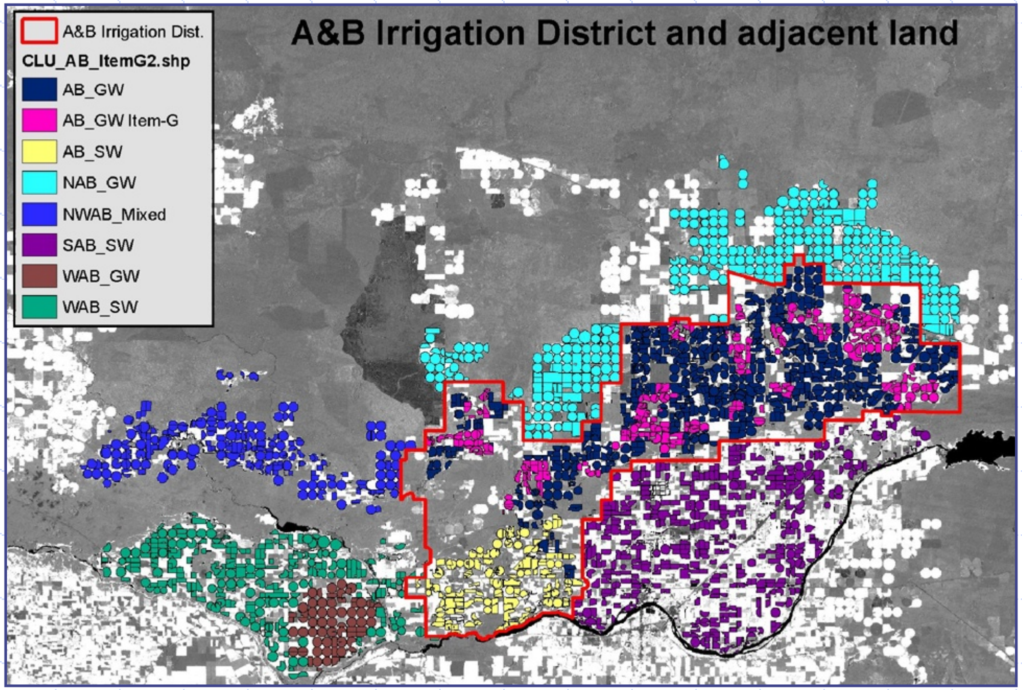


Water-short polygons and 'other' irrigation entities to be compared against

The Analysis

- METRIC ET Images for 6/20, 7/22, 8/7
  - Compared mean 24-hour ET
  - Compared mean Vegetation indices (NDVI)
  - Compared mean ratio ET / NDVI.



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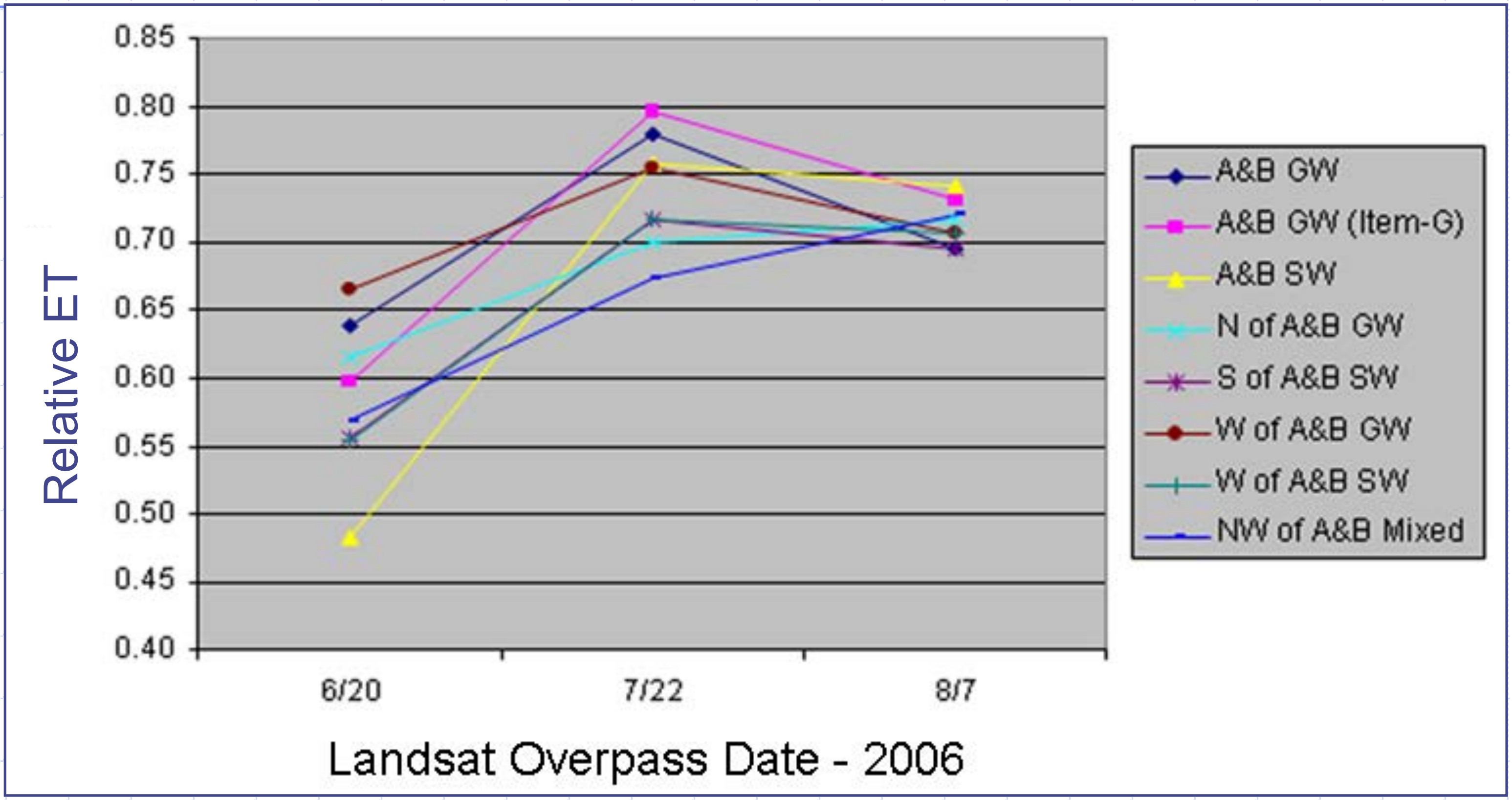
Relative ET



How much evapotranspiration? *(A&B did not appear to suffer)*

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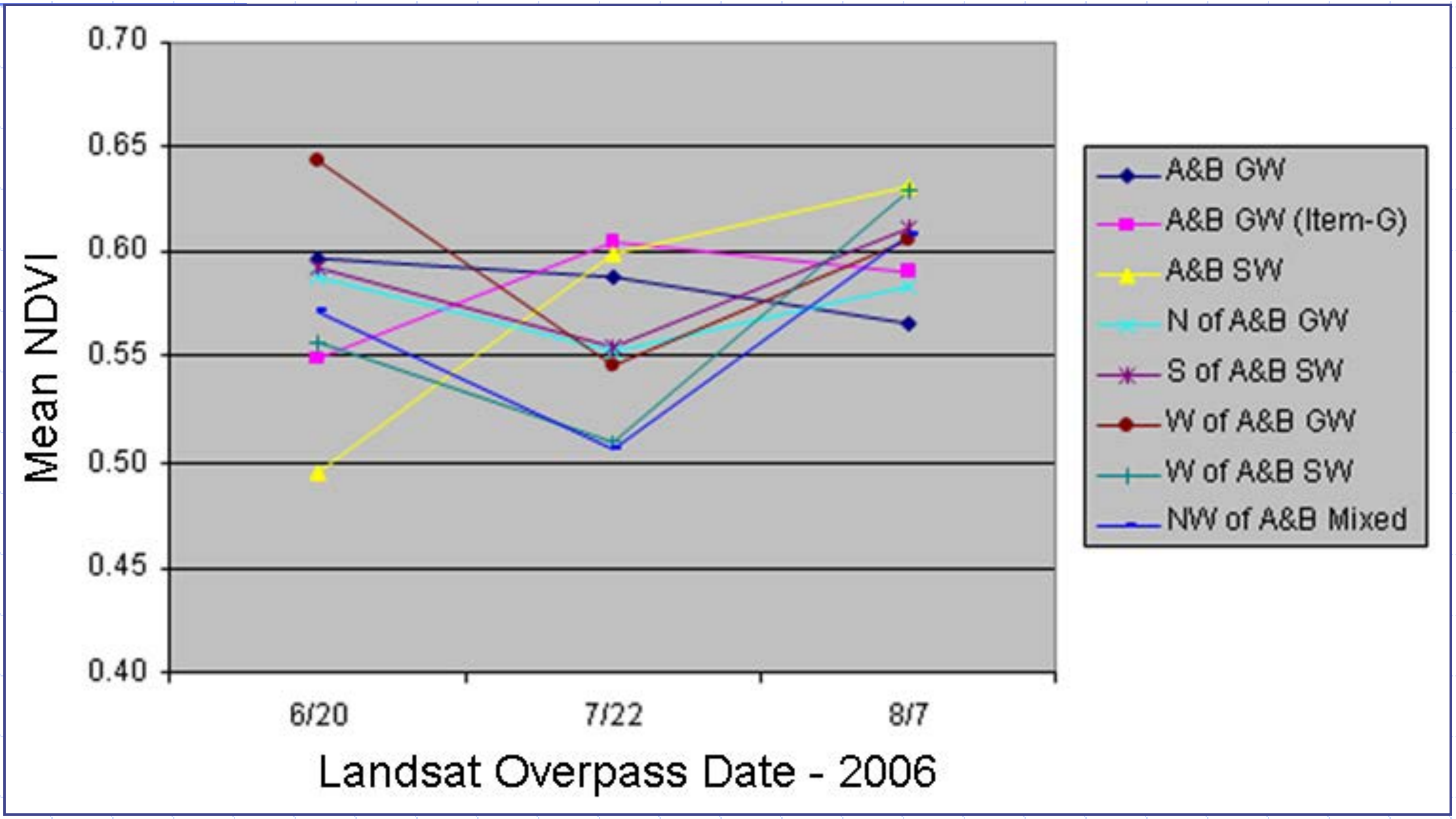
Mean NDVI



How much vegetation? *(A&B did not appear to have lower VI)*

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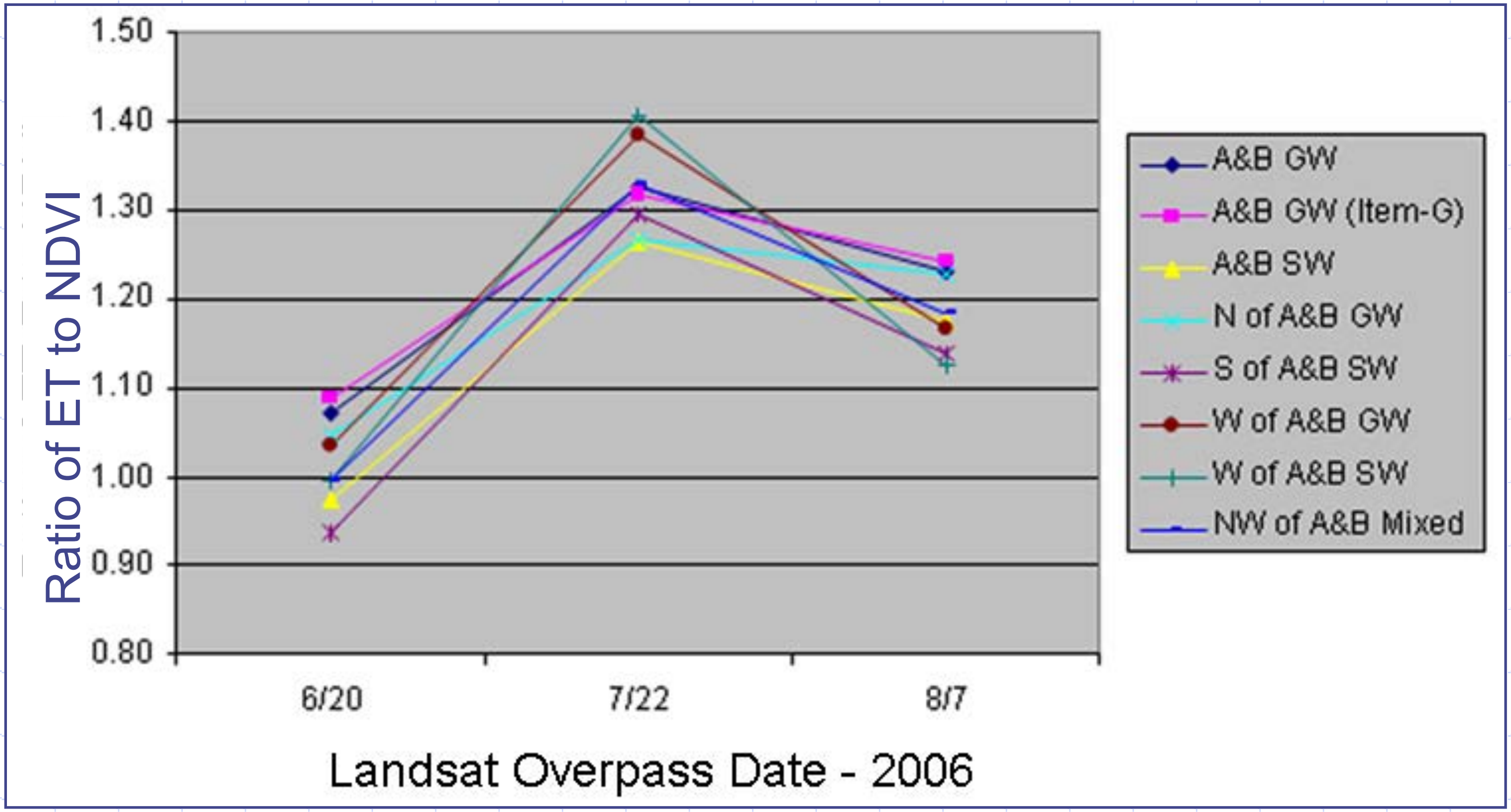
ET / NDVI



How much evapotranspiration per amount of vegetation?

(A&B did not appear to suffer)

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Result

IDWR denied the call

A&B appealed (and lost)

Analysis based on

- Unbiased data sets
- Single data source
- Field-level data
- Archive data

Landsat resolution (30 m) enabled the analysis

BEFORE THE DEPARTMENT OF WATER RESOURCES

OF THE STATE OF IDAHO

IN THE MATTER OF THE PETITION FOR DELIVERY CALL OF A&B IRRIGATION DISTRICT FOR THE DELIVERY OF GROUND WATER AND FOR THE CREATION OF A GROUND WATER MANAGEMENT AREA	ORDER

This matter originally came before the Director of the Department of Water Resources ("Director" or "Department") on July 26, 1994 when the A&B Irrigation District ("A&B" or "District") filed a petition for delivery call, which sought administration of junior priority ground water rights diverting from the Eastern Snake Plain Aquifer ("ESPA"), as well as the designation of the ESPA as a ground water management area.

On May 1, 1995, A&B, the Department, and other participants entered into an agreement that stayed the petition for delivery call until such time as a motion to proceed was filed with the Director. On March 16, 2007, A&B filed a motion to proceed seeking the administration of junior priority ground water rights, as well as the designation of the ESPA as a ground water management area.

Based upon the Director's consideration of the available information and documents filed herein, the Director enters the following Findings of Fact, Conclusions of Law, and Order.

FINDINGS OF FACT

Procedural History

1. On July 26, 1994, A&B filed a Petition for Delivery Call ("Petition") with the Department. The boundary of the A&B Irrigation District is depicted in Attachment A. According to the Petition, A&B "is the beneficial owner of Water License No. 20736, now known as A-36-02080, which entitles the Irrigation District to divert eleven hundred (1100) cfs from one hundred seventy-seven (177) wells for the irrigation of sixty-two thousand six hundred four and three tenths (62,604.3) acres within the irrigation district, with a priority of September 9, 1948." *Petition* at 1, ¶ 2. "That said water right is held in trust by the United States, for the benefit of the owners of said 62,604.3 acres, all of whom are landowners within and are included within A&B Irrigation District." *Id.* at 1, ¶ 3. Additionally, the Petition stated that due to diversions from the ESPA by junior priority ground water users, A&B "is suffering material injury as a result of the lowering of the ground water pumping level within the E[SPA] by an

Order of January 29, 2008 – Page 1

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Example 3: Water Planning for Endangered Species

- Landsat-based ET estimates
- overlay irrigated areas to calculate volumes of water used for irrigation of specific water rights
- Consumptive portion compared to diversions to help producers reduce diversions and sustain streamflows during summer for Salmon

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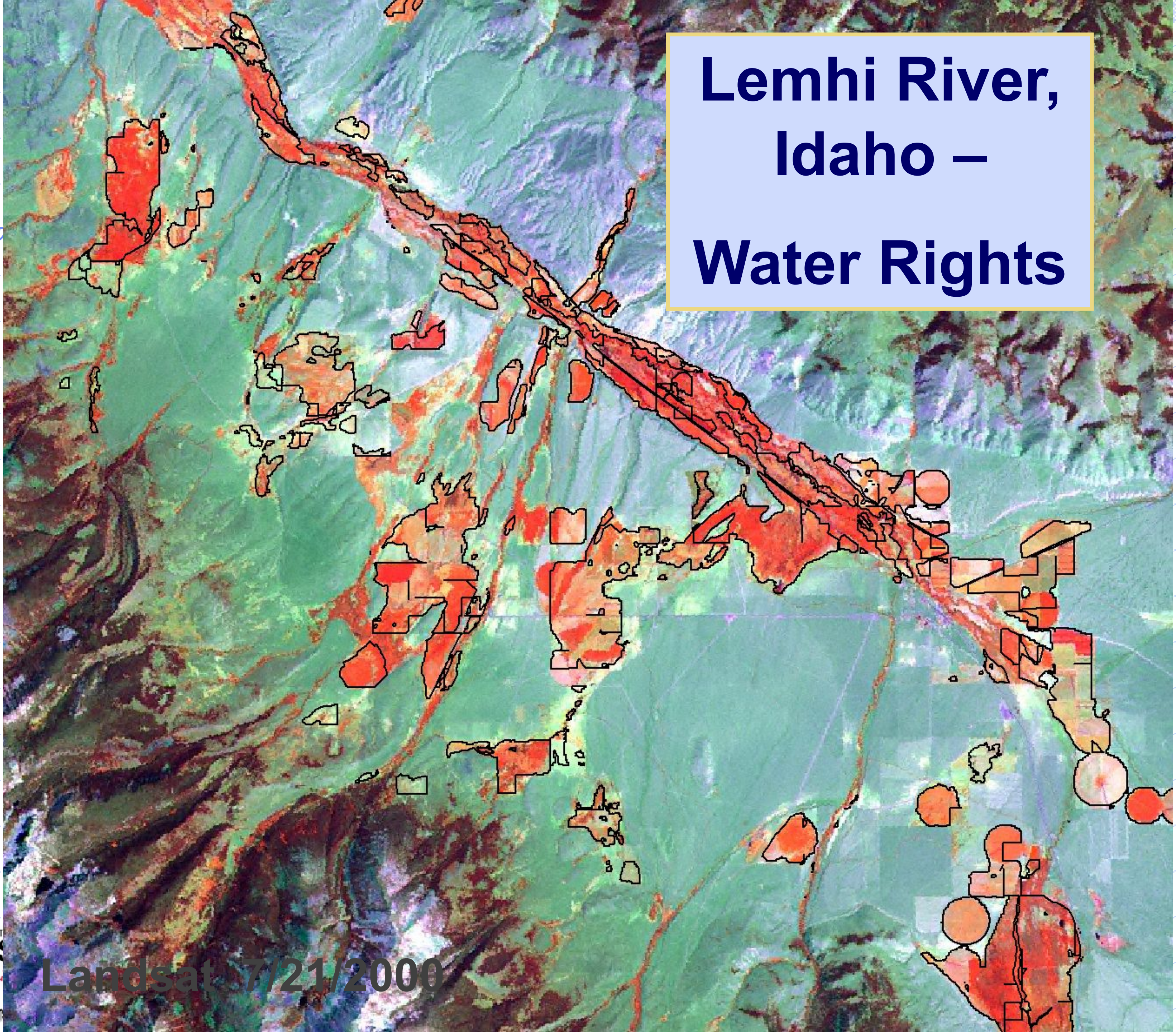
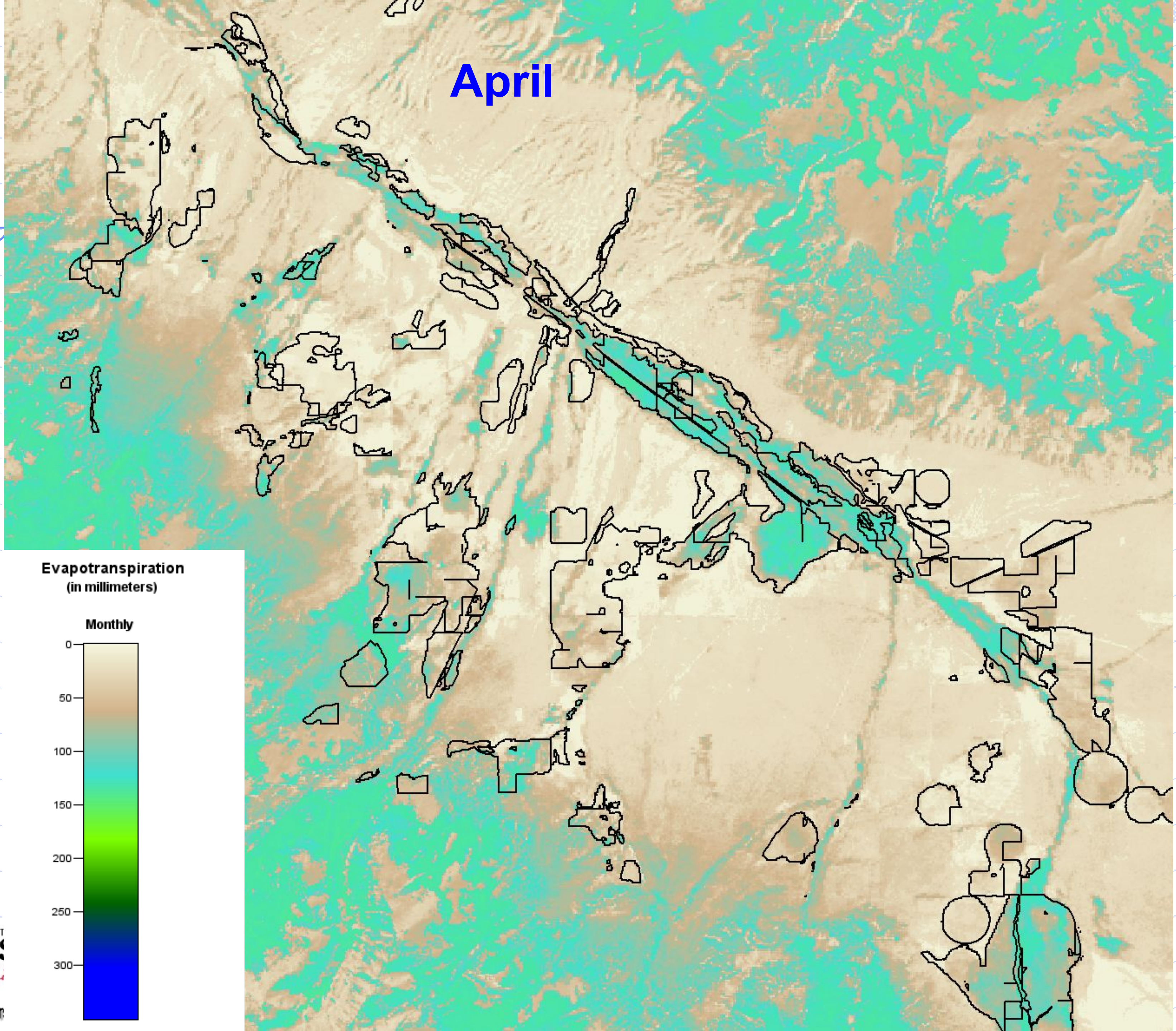
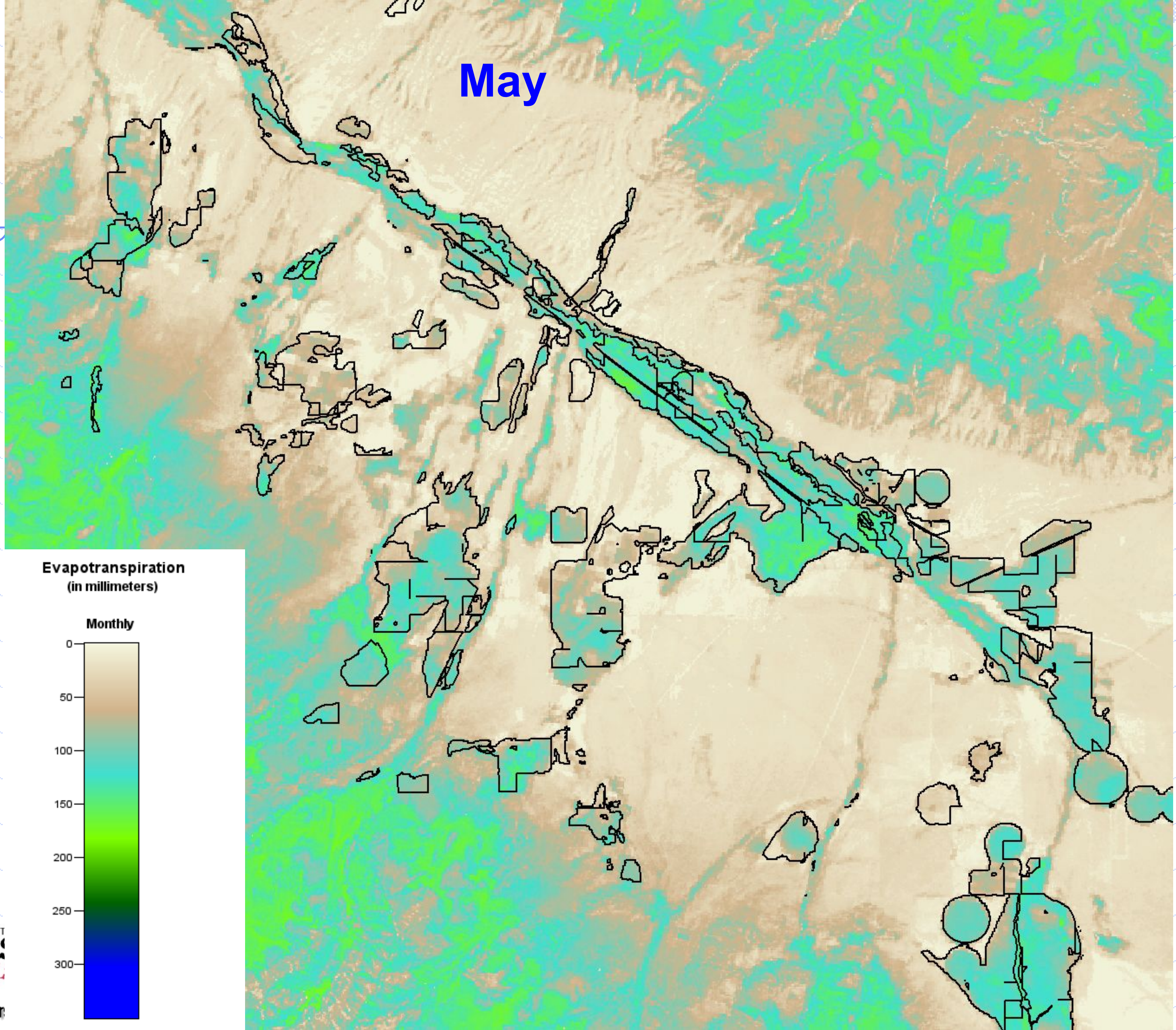
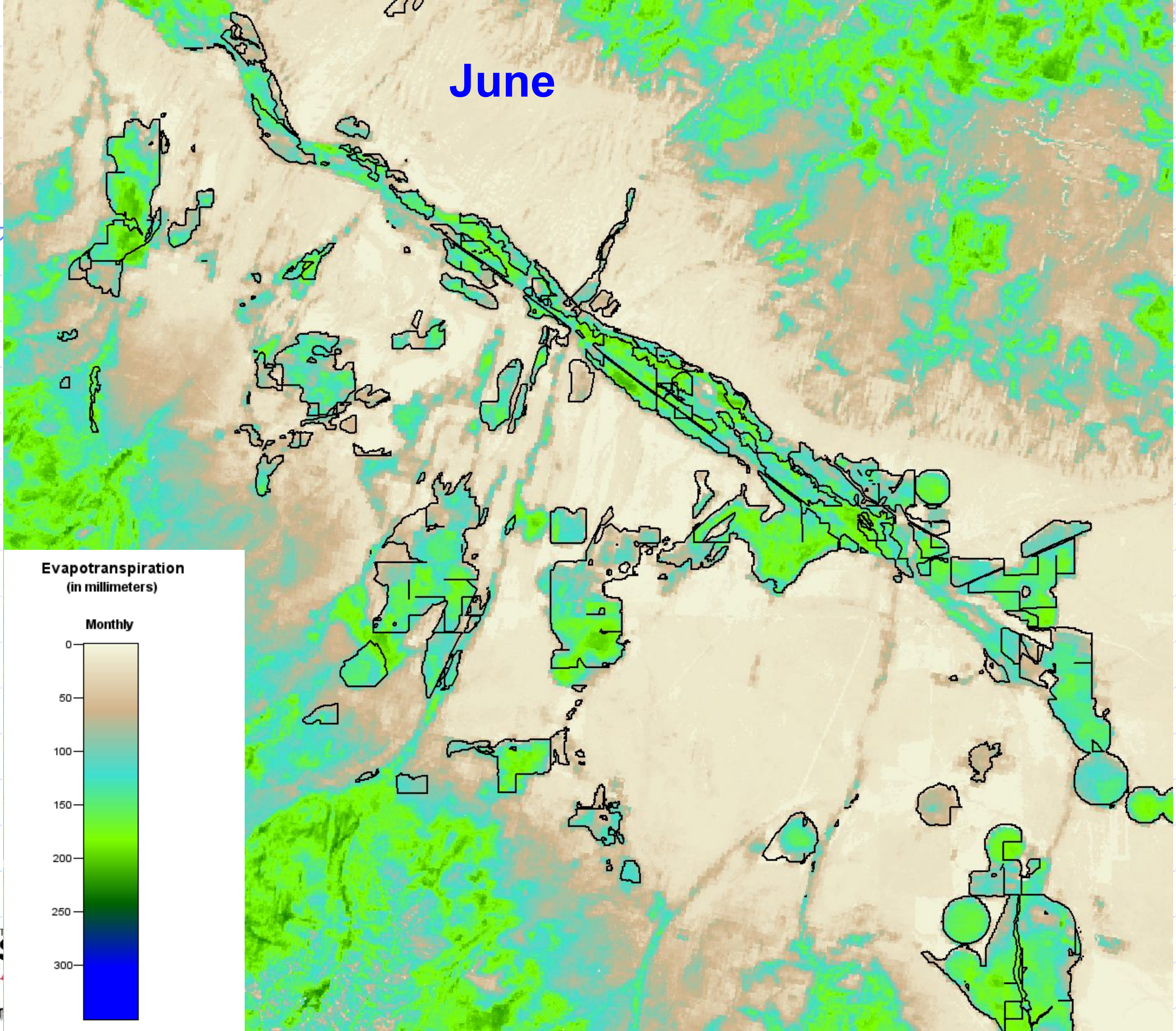
Lemhi River, Idaho – Water Rights




April
Evapotranspiration
(in millimeters)
Monthly
0
50
100
150
200
250
300


May
Evapotranspiration
(in millimeters)
Monthly
0
50
100
150
200
250
300



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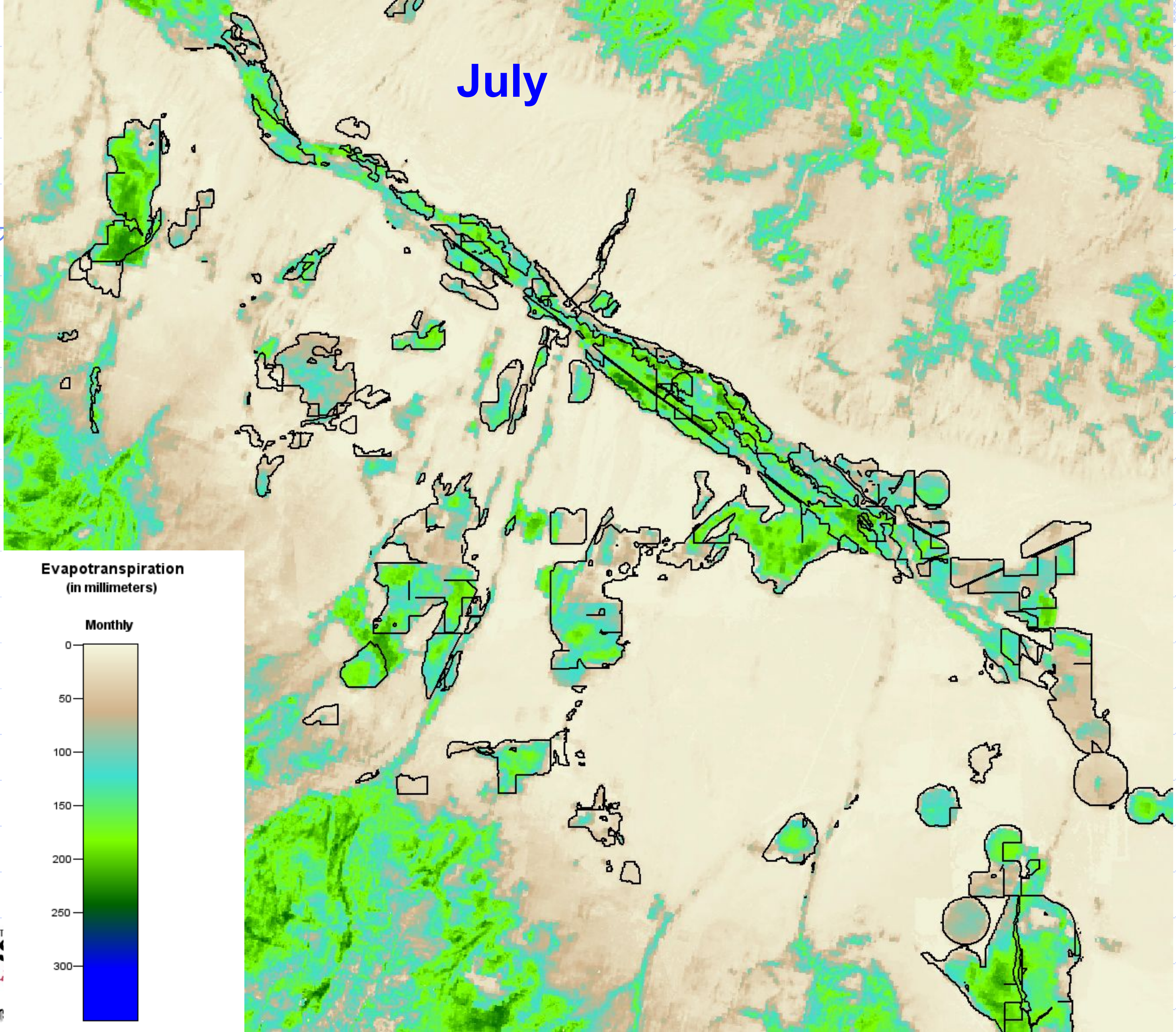
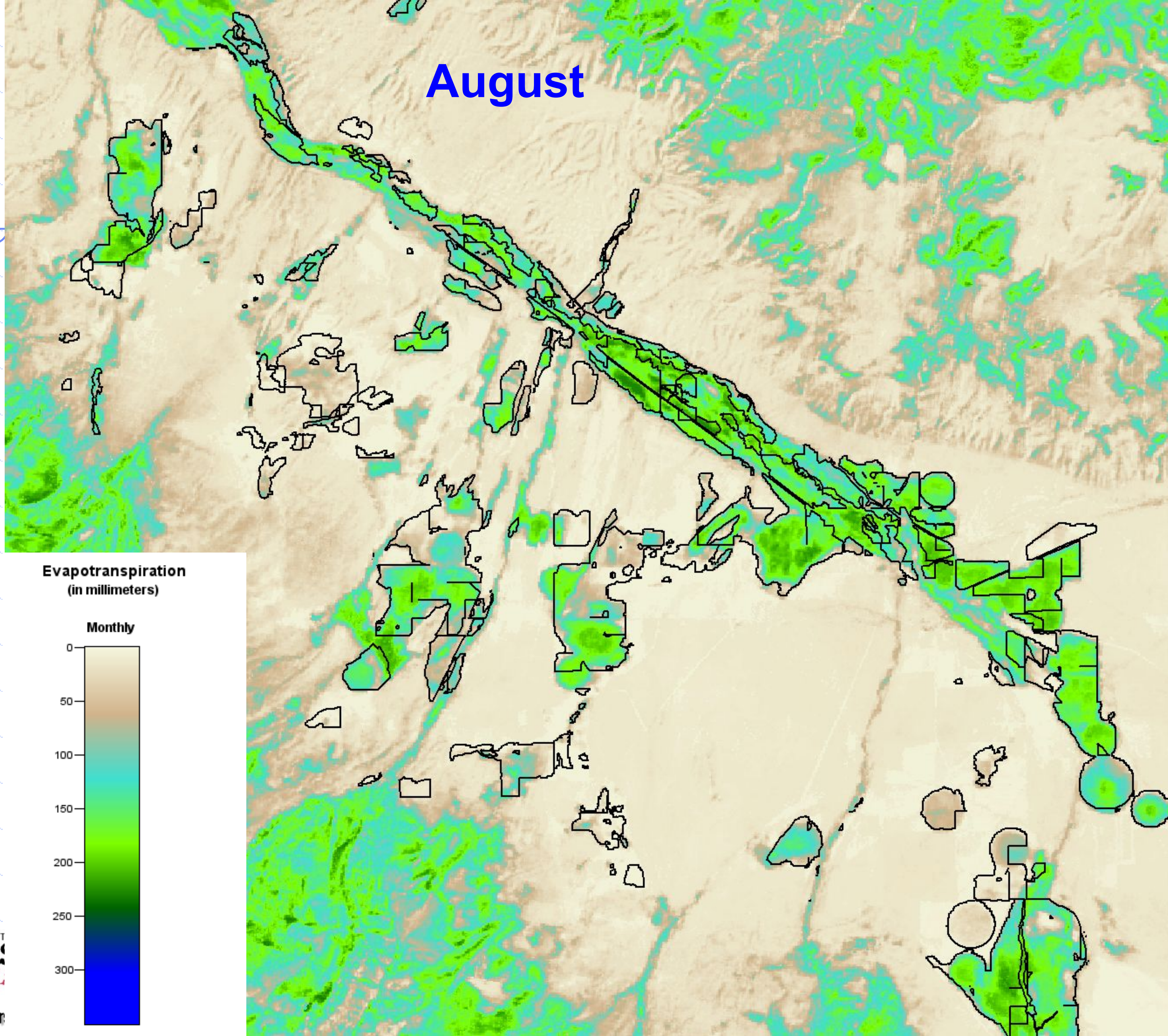
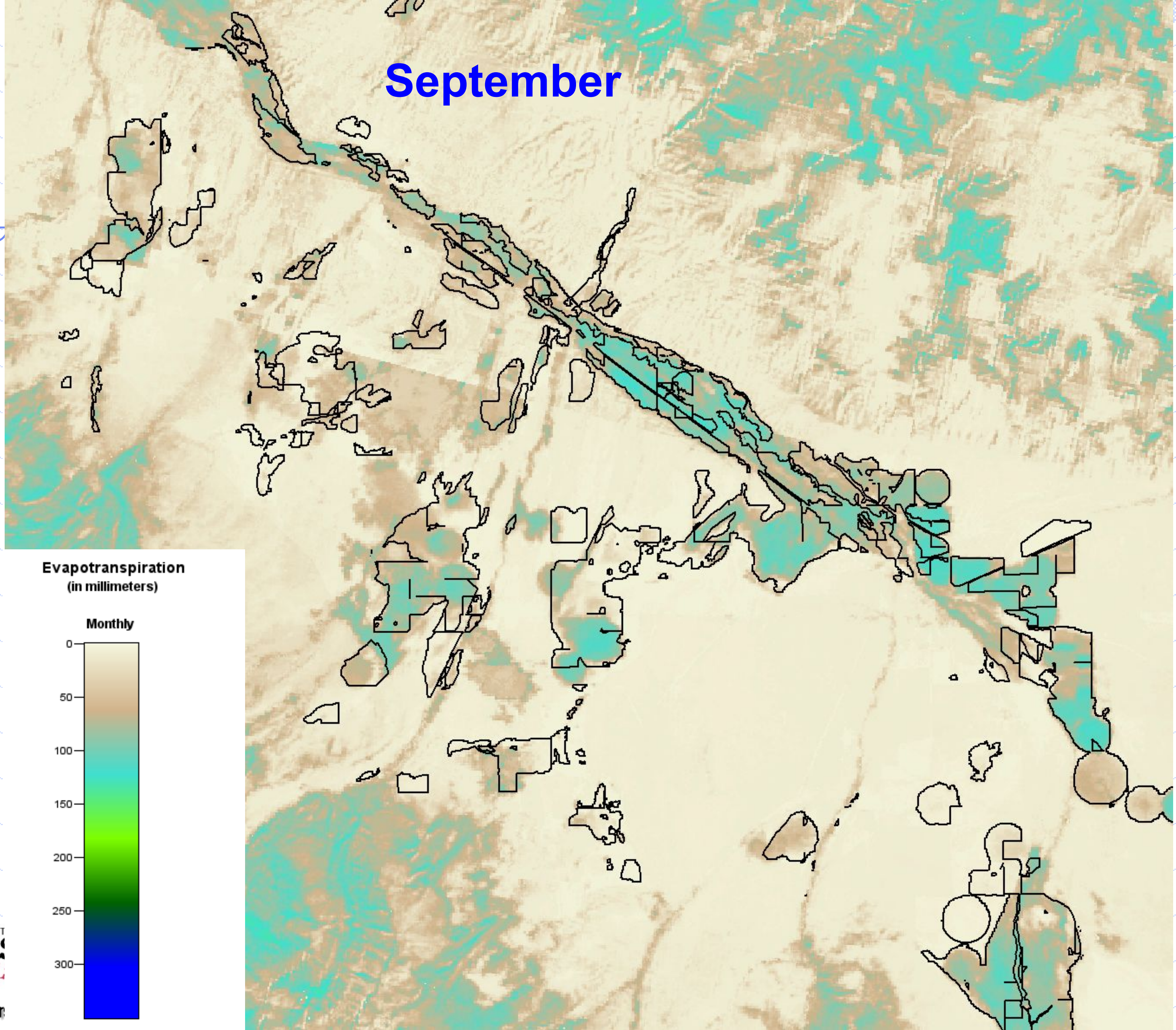

July
Evapotranspiration
(in millimeters)
Monthly
0
50
100
150
200
250
300

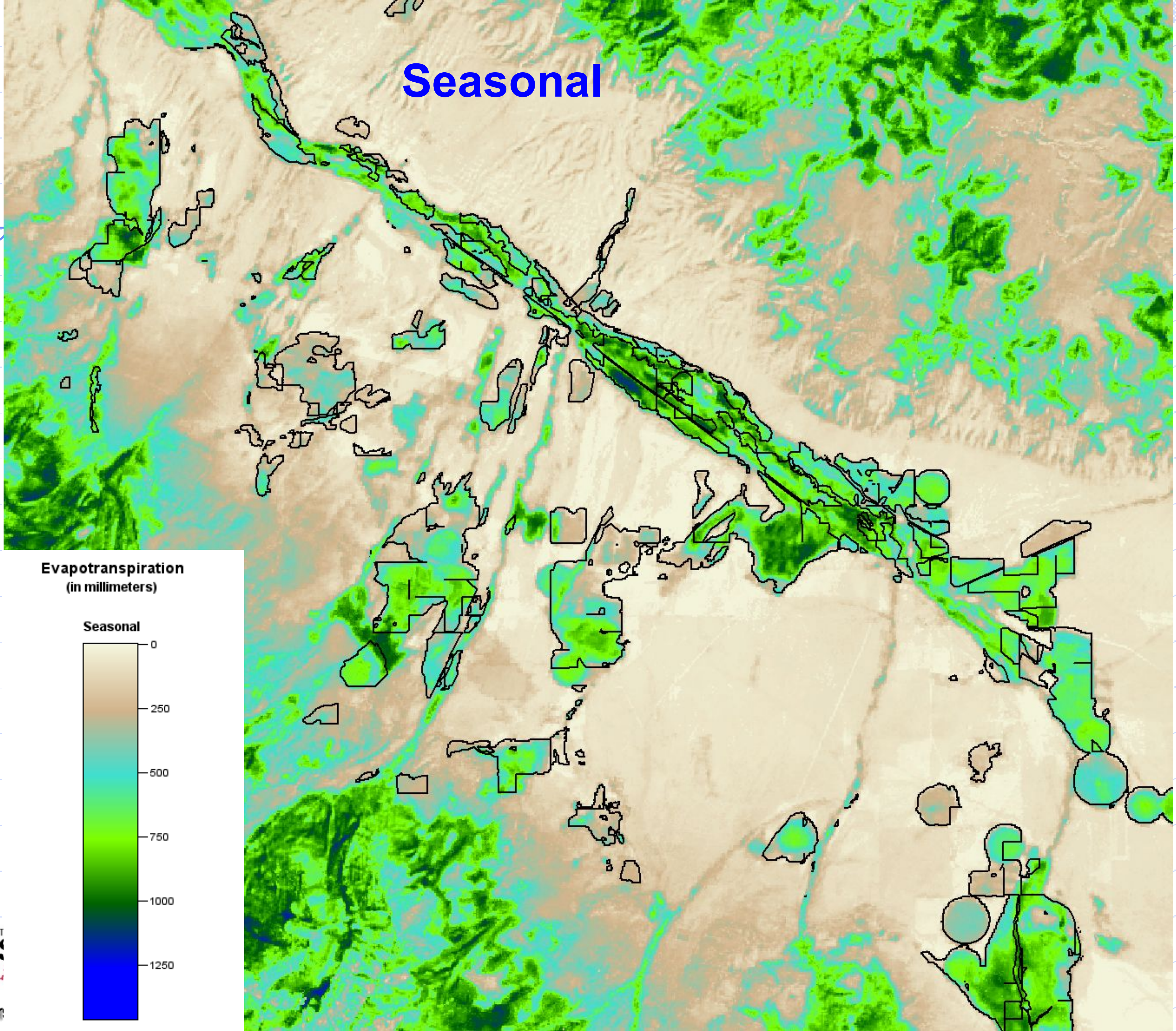
August



Evapotranspiration
(in millimeters)
Monthly
0
50
100
150
200
250
300

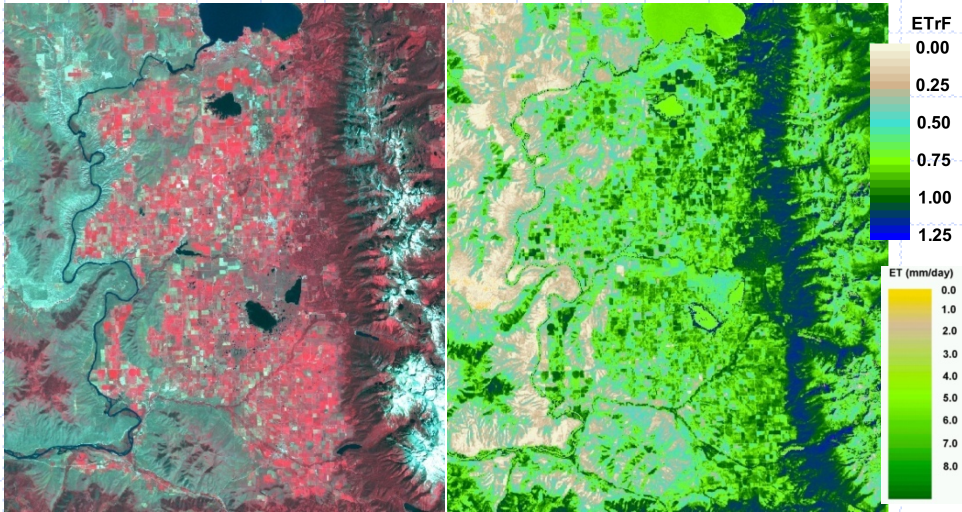

September
Evapotranspiration
(in millimeters)
Monthly
0
50
100
150
200
250
300

Seasonal


Evapotranspiration
(in millimeters)
Seasonal
0
250
500
750
1000
1250

Other METRIC Applications in Western Water Management

- Colorado
  - Conjunctive management of ground-water and surface water by State Engineer along the South Platte (Riverside Technology-UI*)*
  - Assessment of water shortage and salinity impacts along the Arkansas River (an independent application by CSU)
- Montana
  - Flathead Indian Reservation
    - Balancing Irrigation Depletions with instream flow needs



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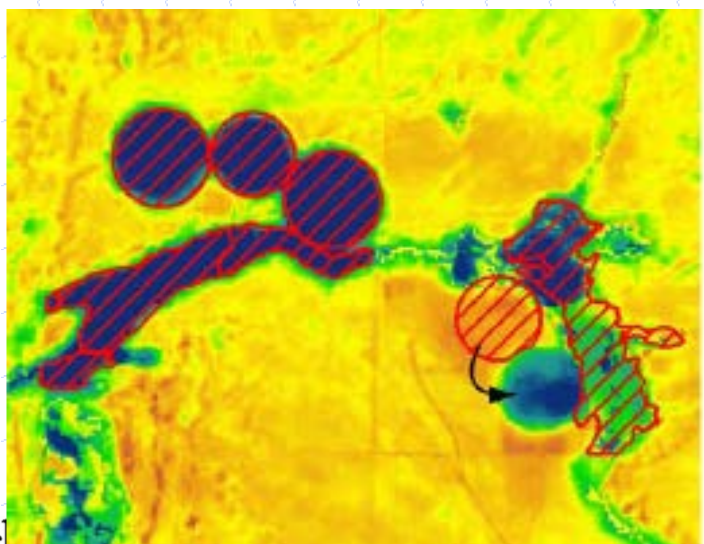
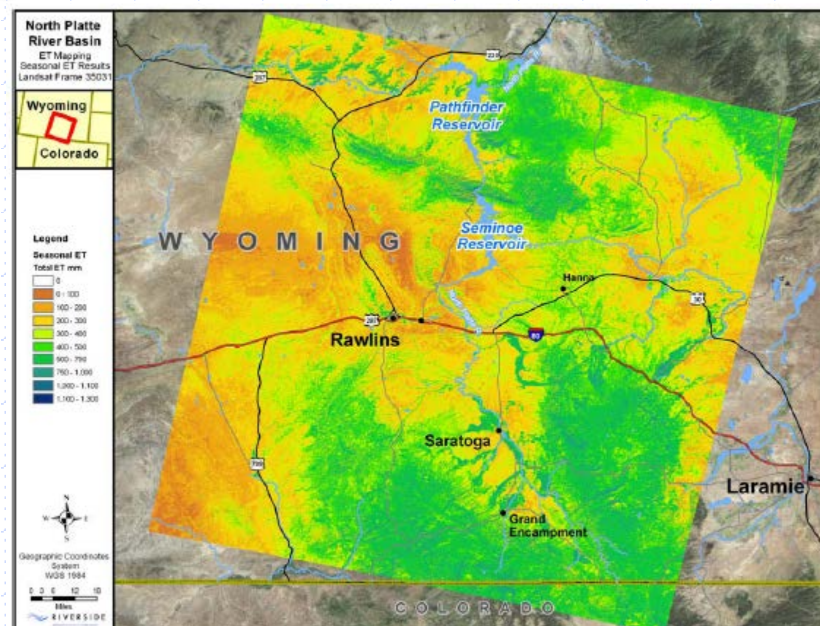
Other METRIC Applications in Western Water Management

- North Platte Water Decree
  - Nebraska / Wyoming / Colorado settlement in 2001
  - States proportion ET among themselves
  - High resolution monitoring is needed due to narrow irrigation corridors along streams





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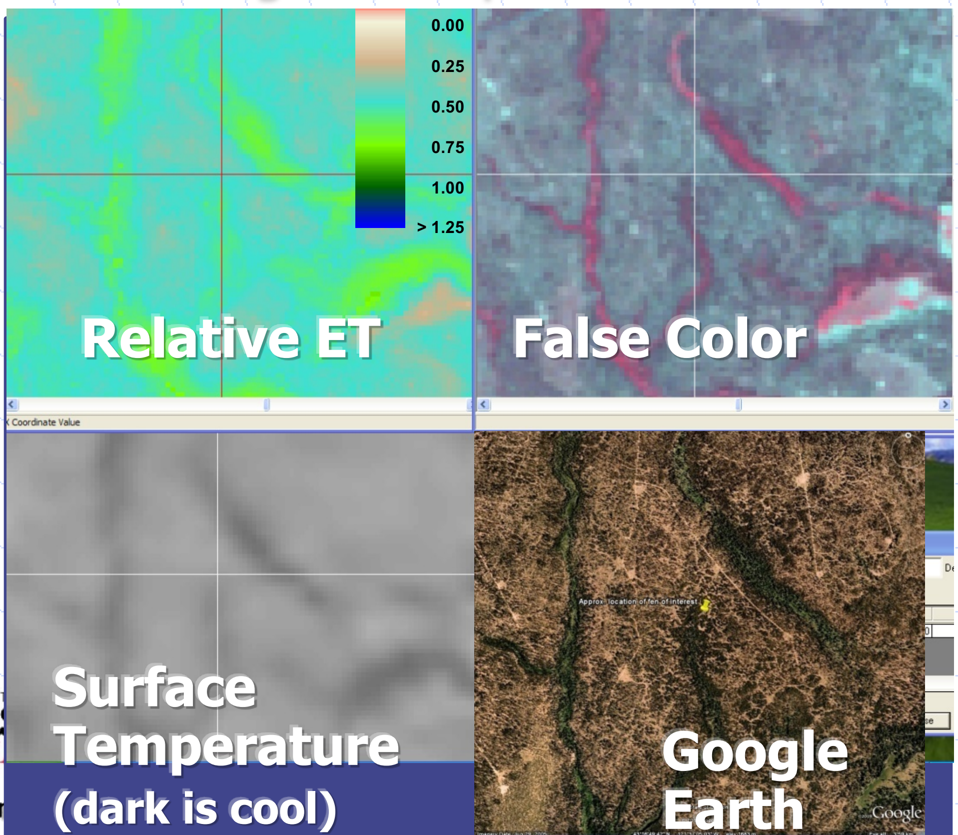
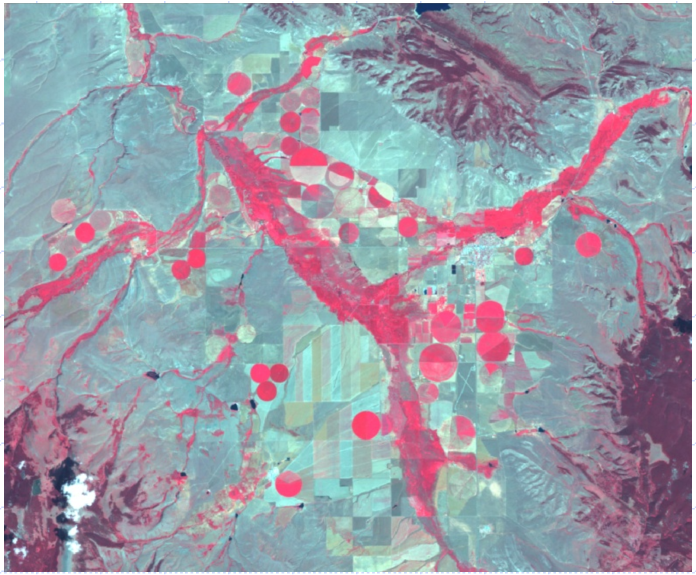
Other METRIC Applications in Western Water Management

- Oregon
  - "Fen" areas north of Klamath Basin where Stock Water Supplies for Grazing compete with local Ecosystems supplied by Springs *(USFS) - narrow systems require hi-res. thermal of Landsat*
  - Irrigation Depletions in the Klamath Basin



Other METRIC Applications in Western Water Management

- Central Montana
  - Ground-water Recharge estimation in four different basins in a single path!
  - Customer: USGS and Montana Bureau of Mining and Geology
  - Recharge ≈ Precipitation – Evapotranspiration
  - *High resolution is needed due to narrow domains of irrigation*



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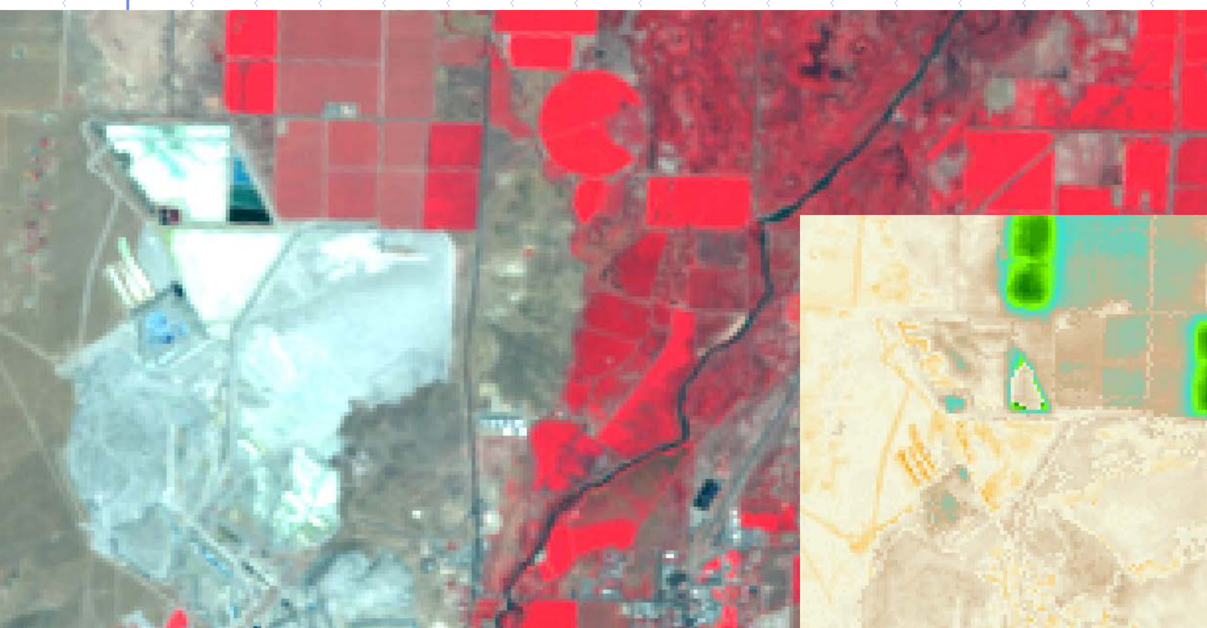
Other METRIC Applications in Western Water Management

- Nevada – UI partnership with DRI
  - Water transfers from Irrigated Ag. to Reno/Las Vegas
  - Water transfers from phreatophytes and playa to Las Vegas
  - *Need High Resolution thermal for narrow irrigation corridors and sometimes narrow phreatophytic systems*



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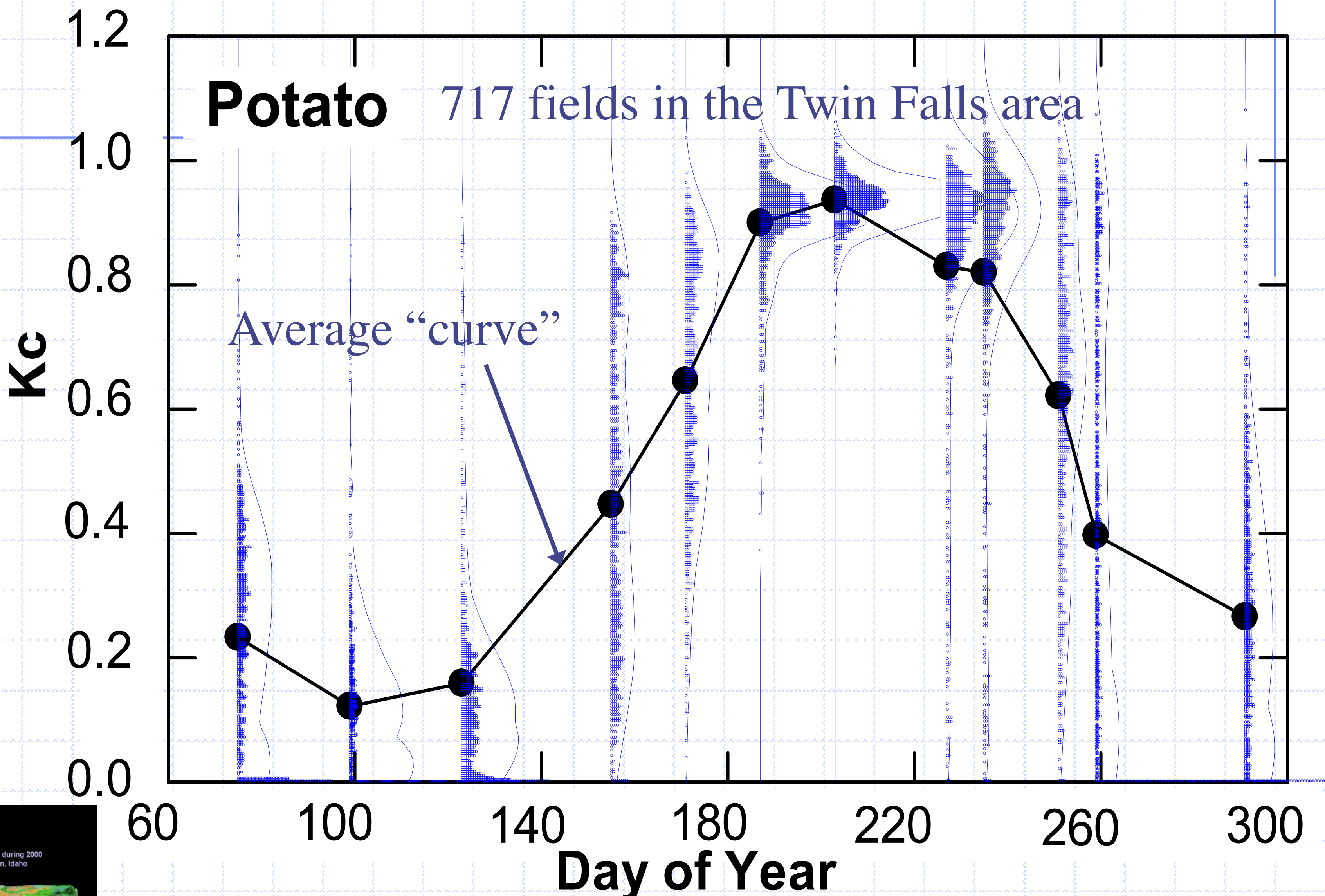
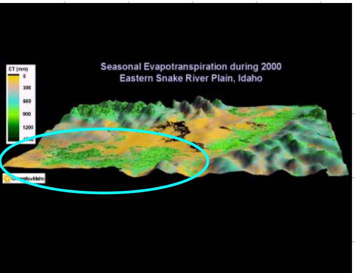
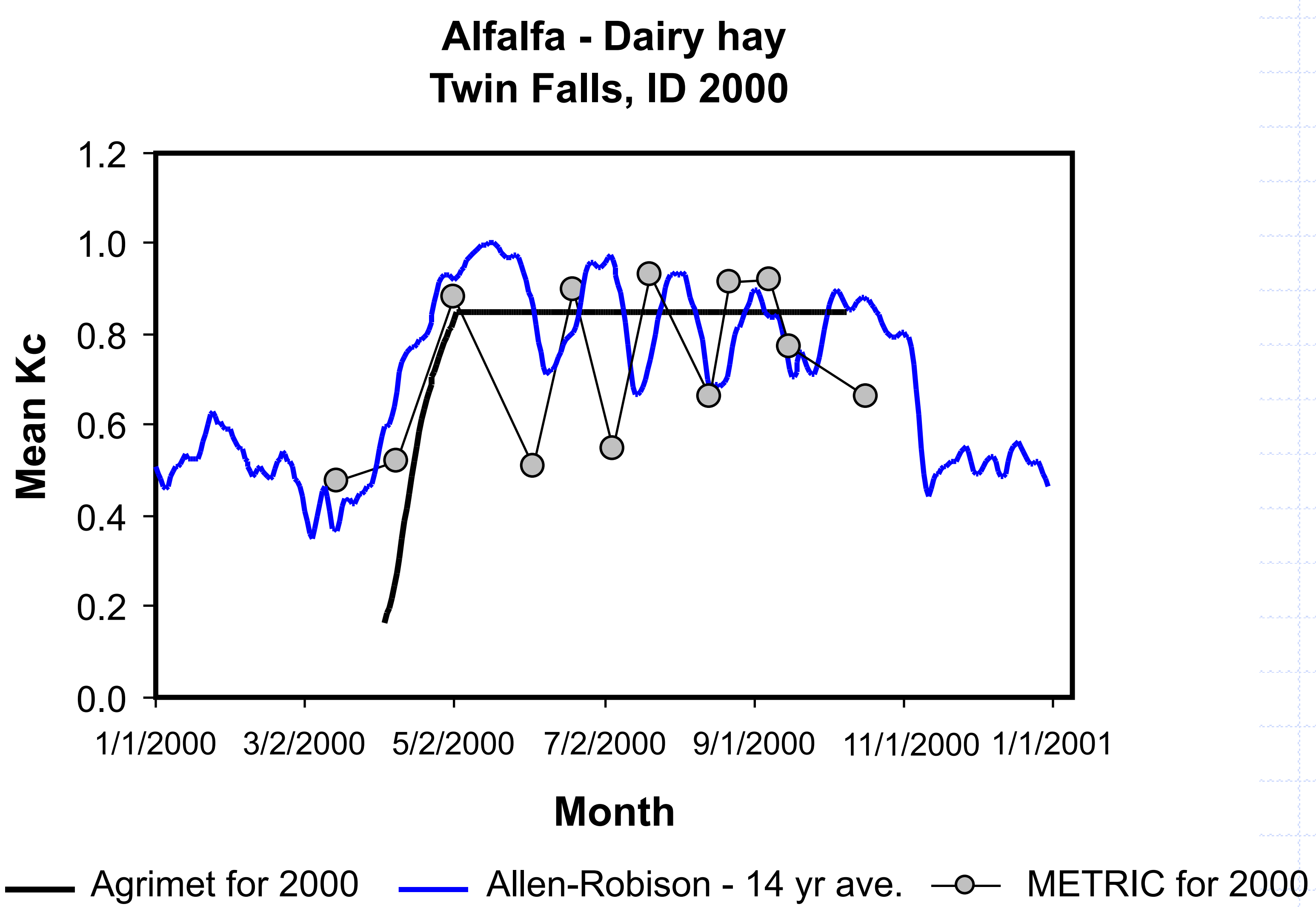
Use to Refine Local ET and Kc Information

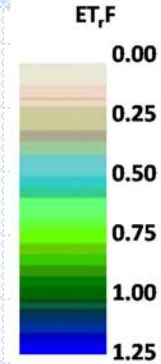


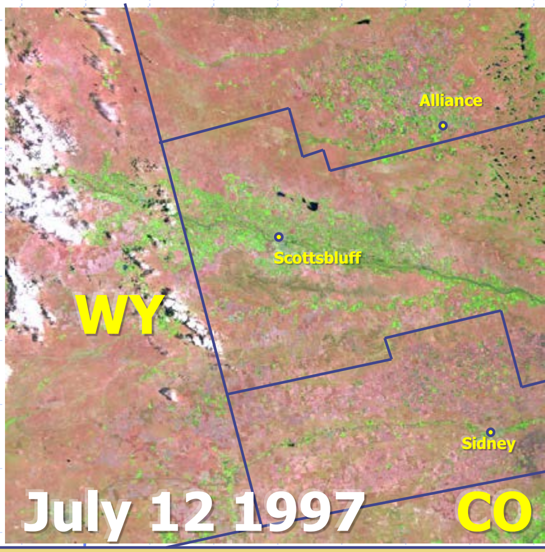


Comparison with K_c from METRIC and K_c based Methods



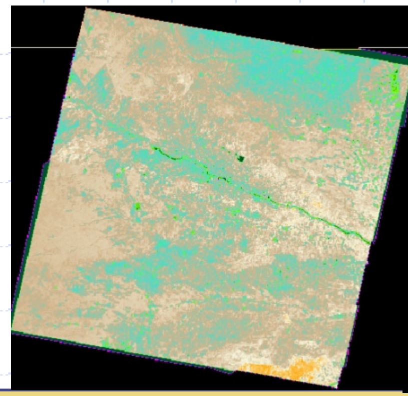
Relative ET during the growing season showing impacts of wetting events – This can bias the seasonal estimate – *need to 'adjust' images*



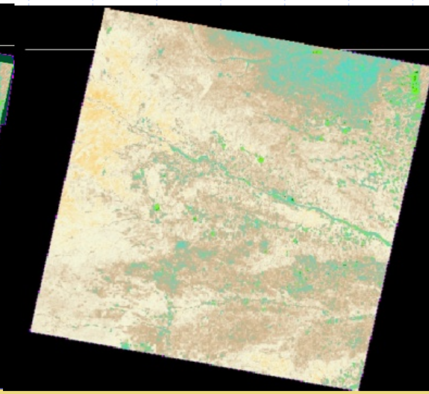


Landsat true color

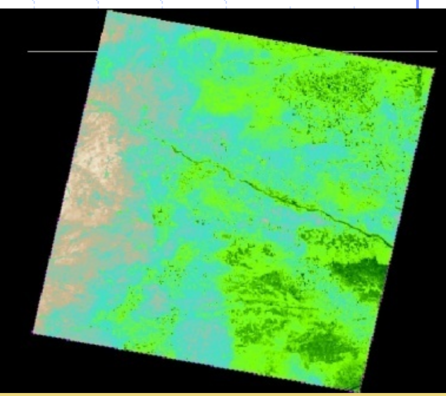
1997 image date relative ET estimates



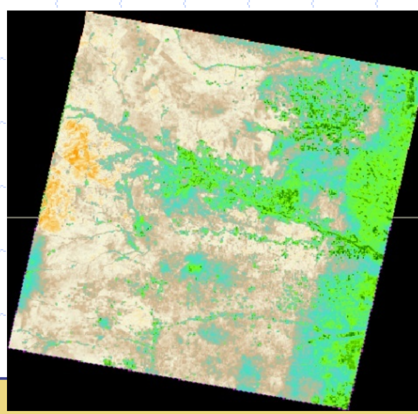
April 23



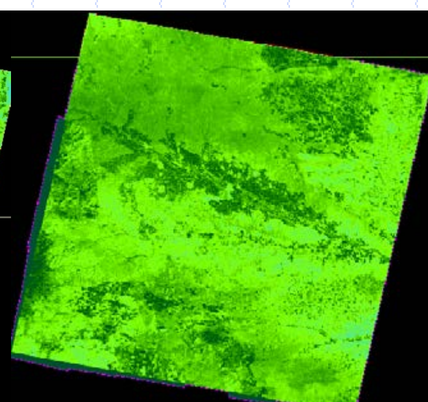
May 9



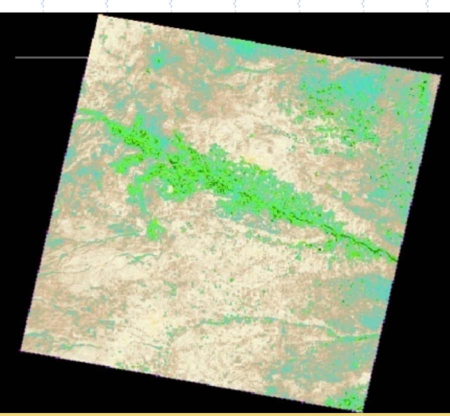
June 26



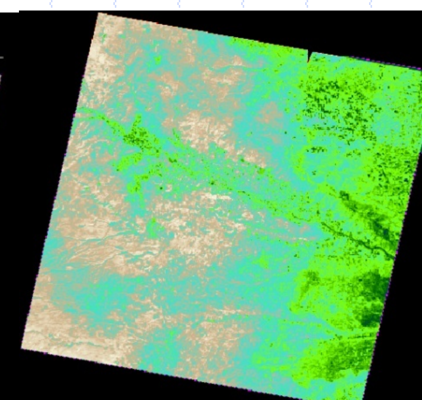
July 12



August 13

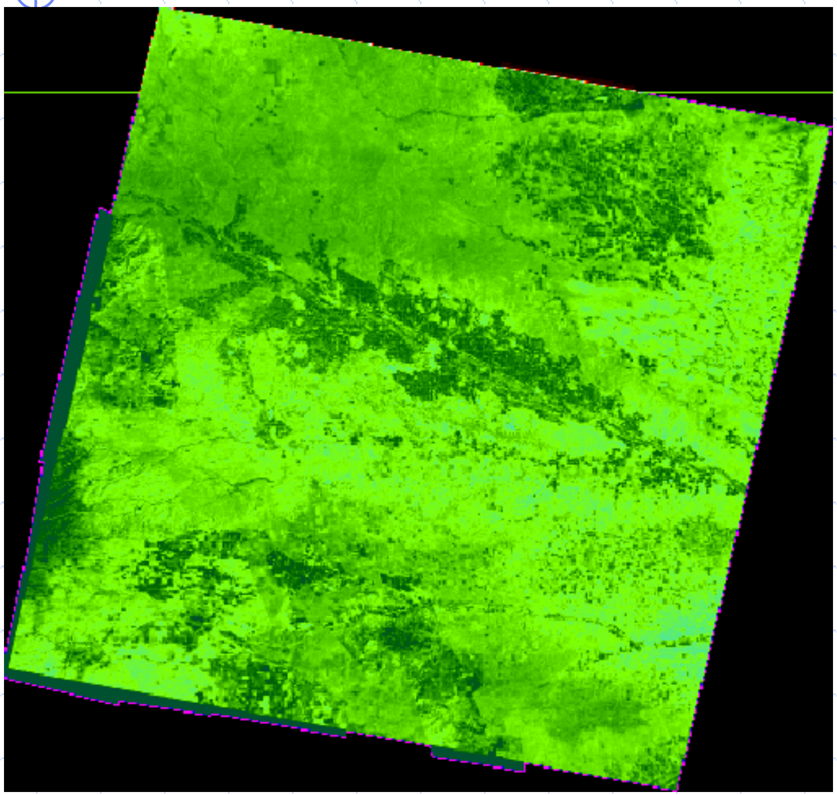


September 30

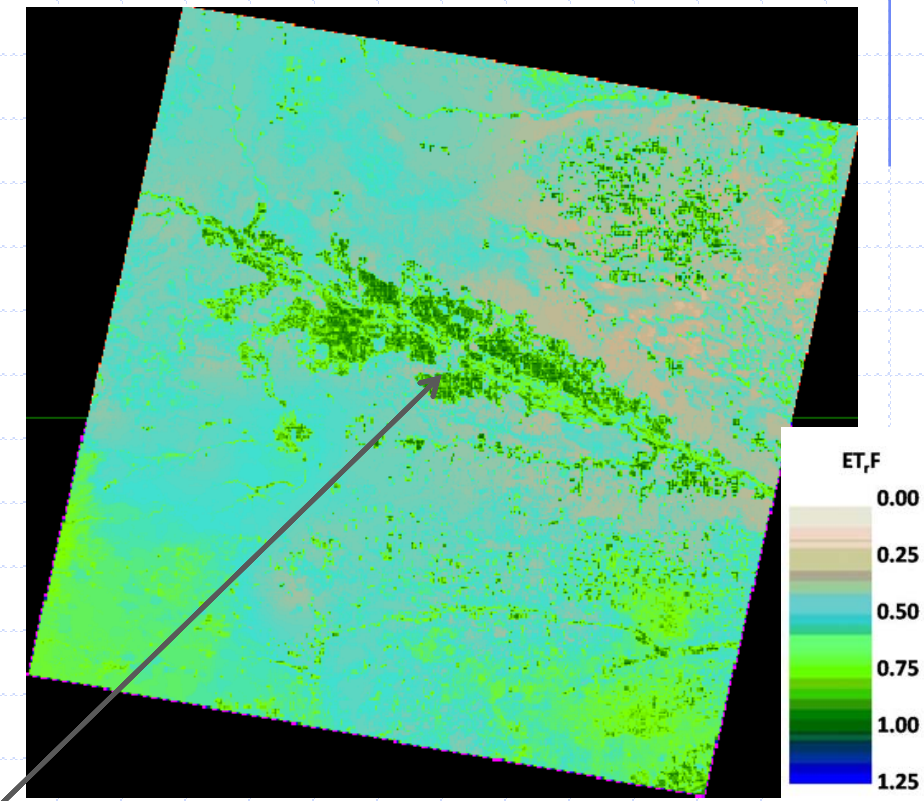


October 16

Adjusting for **background evaporation** from day of image to monthly period *(using a gridded daily evaporation process model)*

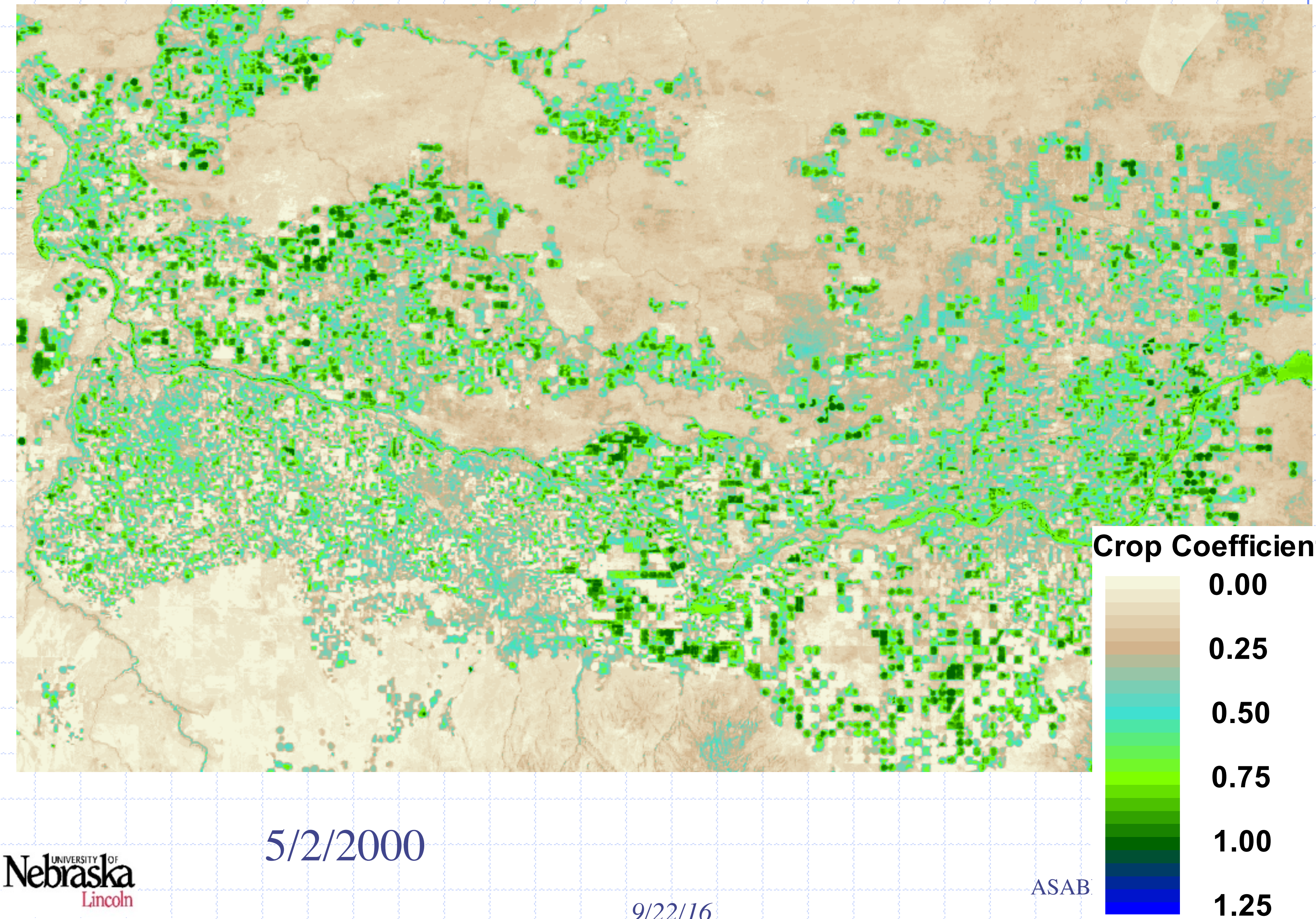


ET from August 13 1997 before adjustment

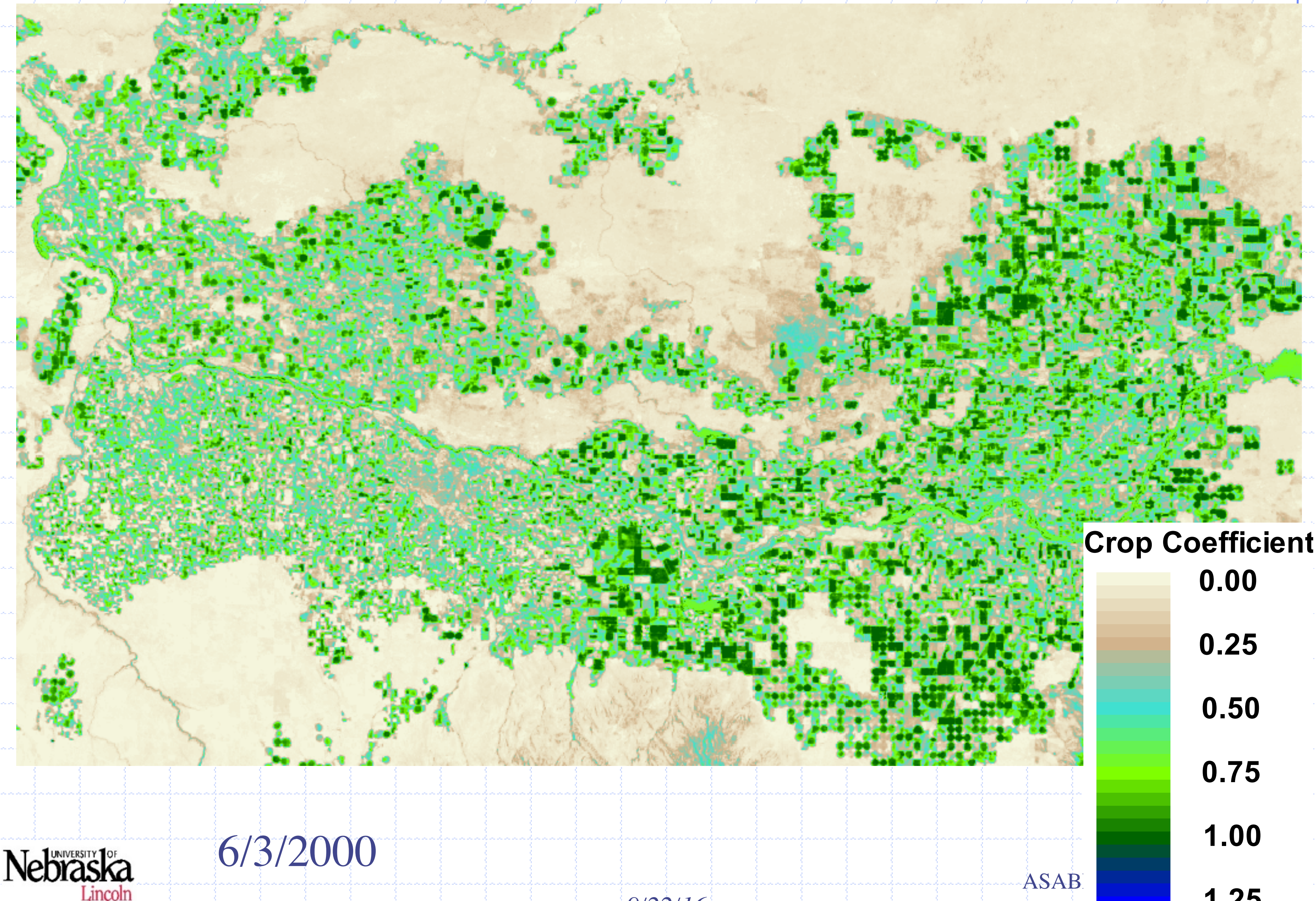


ET from August 13 1997 adjusted to represent August

Irrigated Agriculture



5/2/2000



6/3/2000

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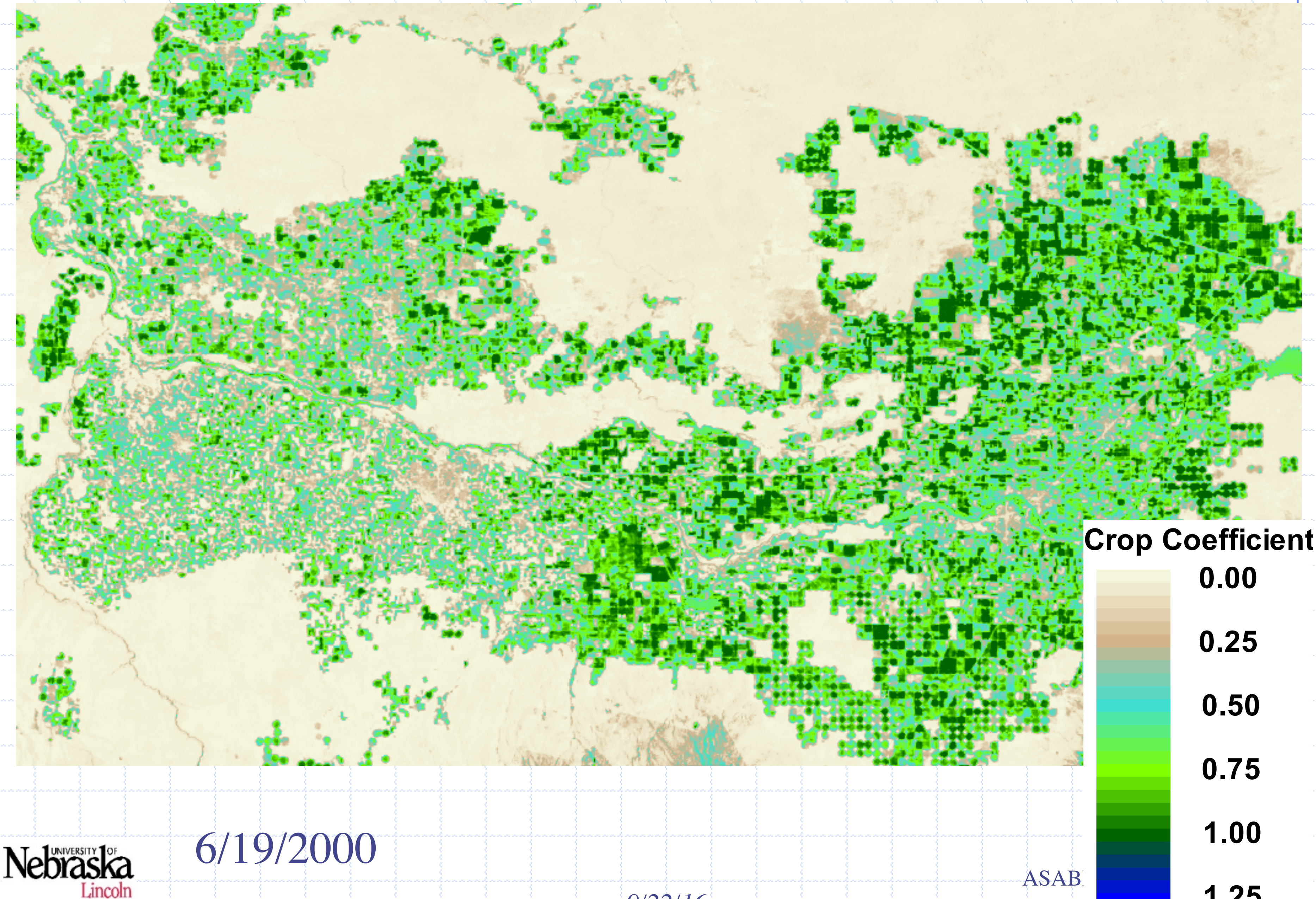
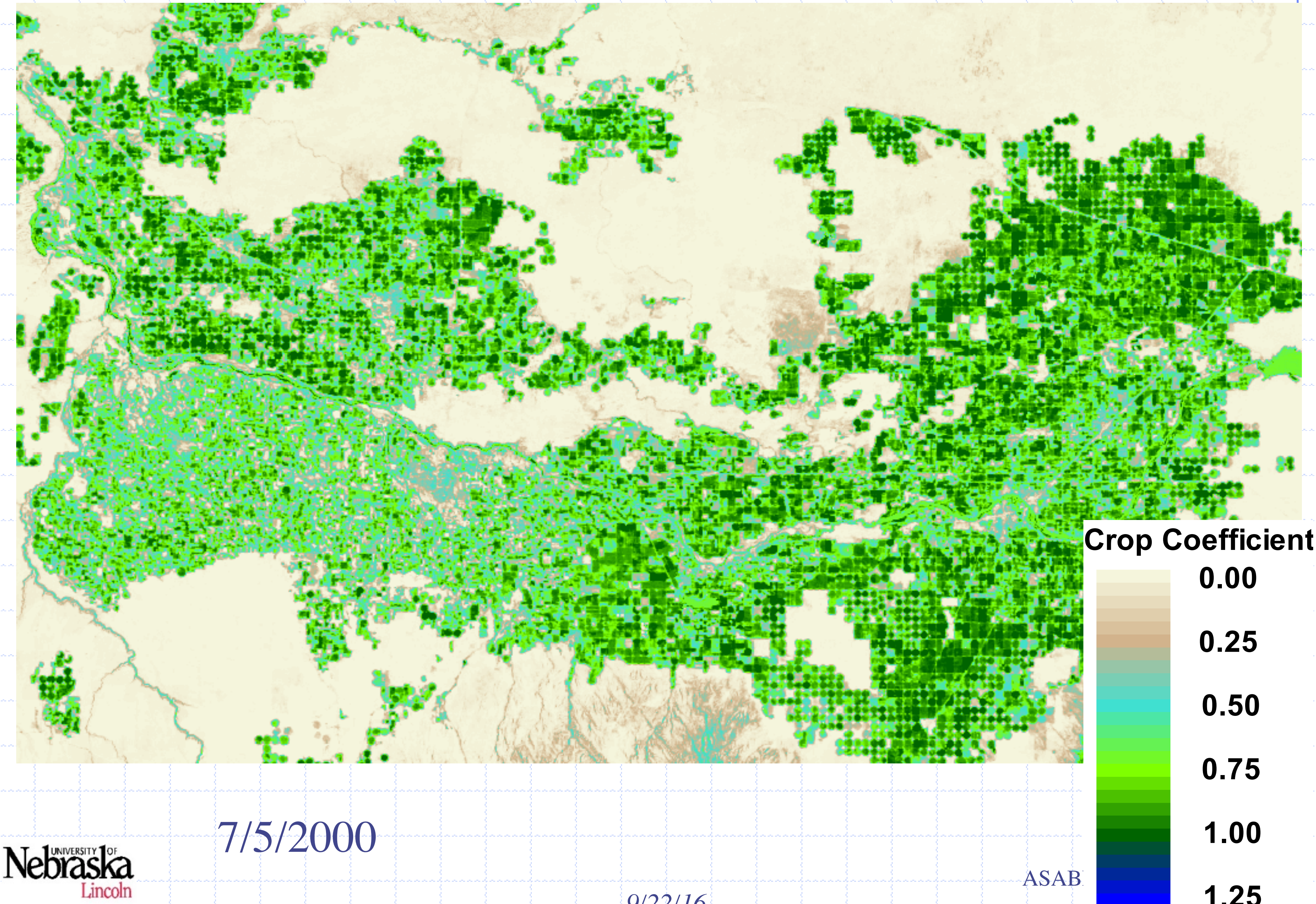


6/19/2000



7/5/2000

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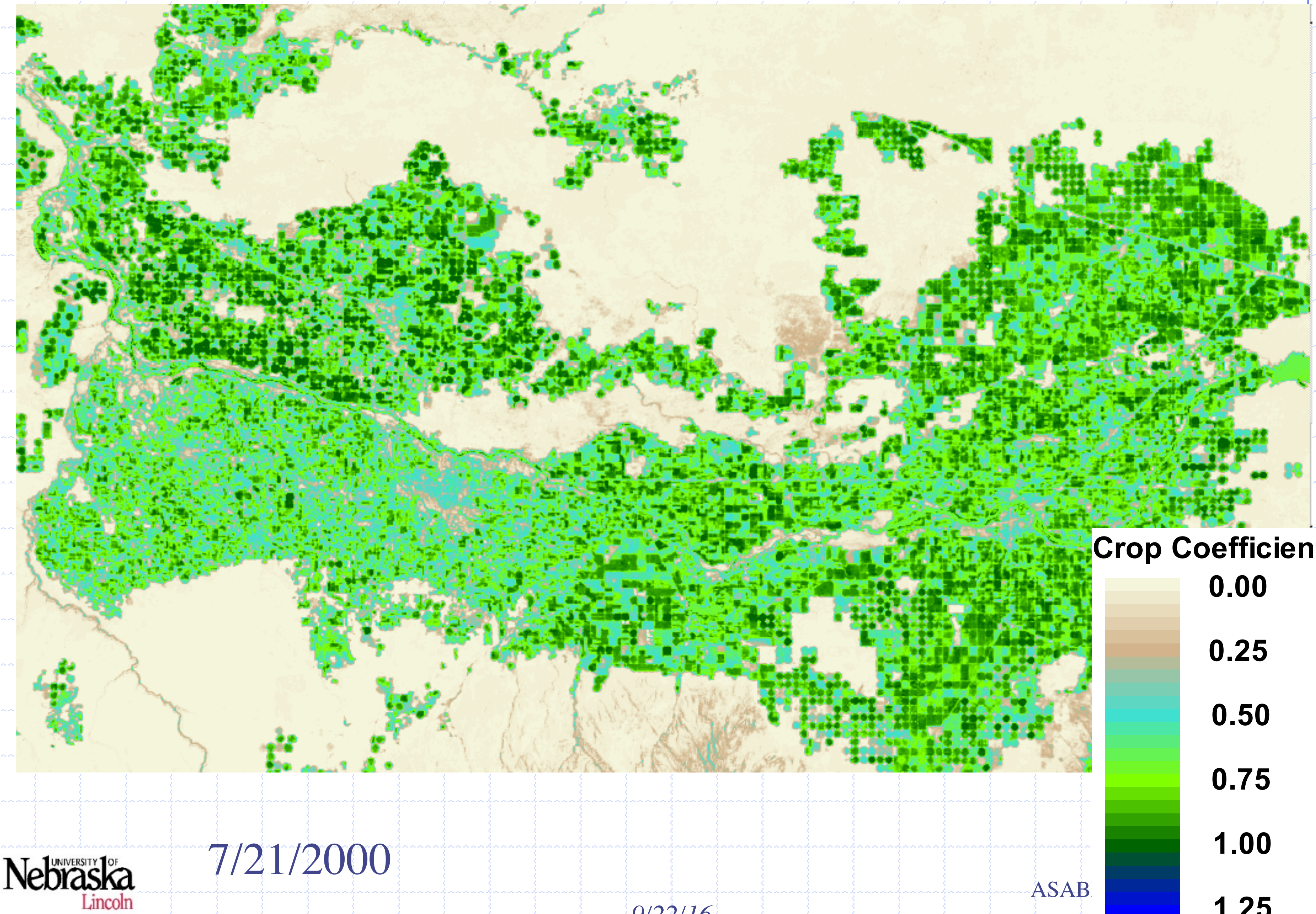
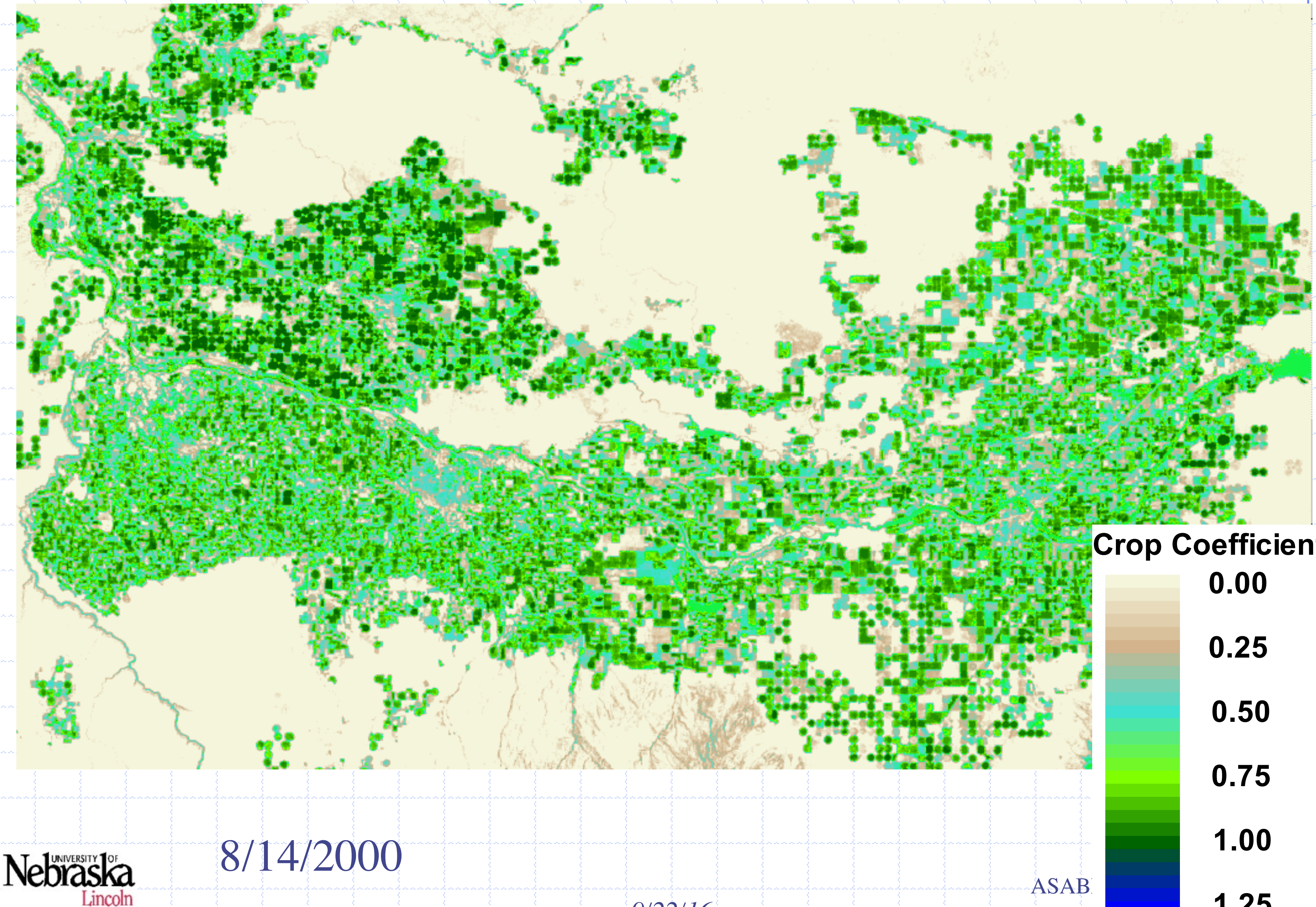
ASAB

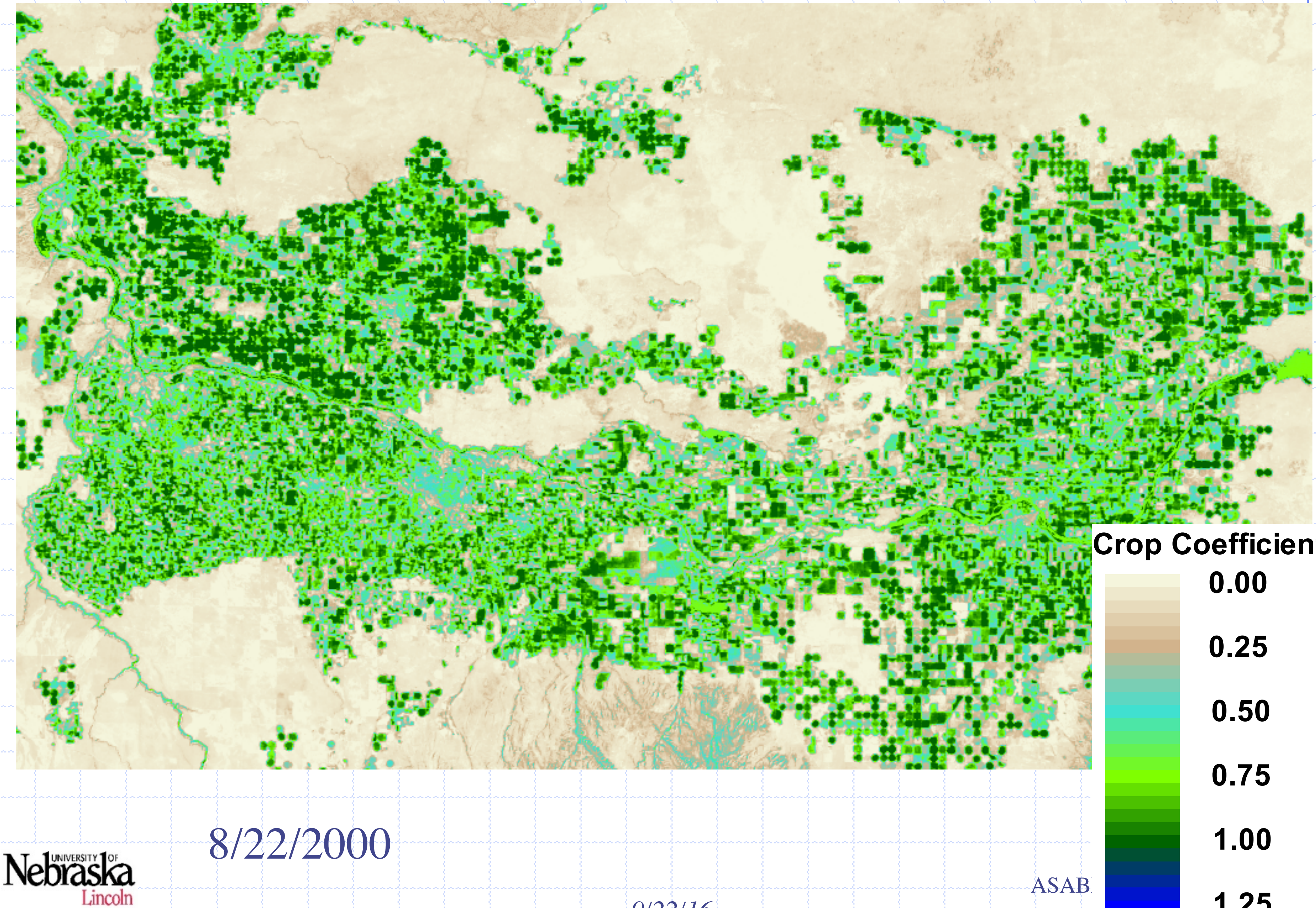


7/21/2000

ASAB

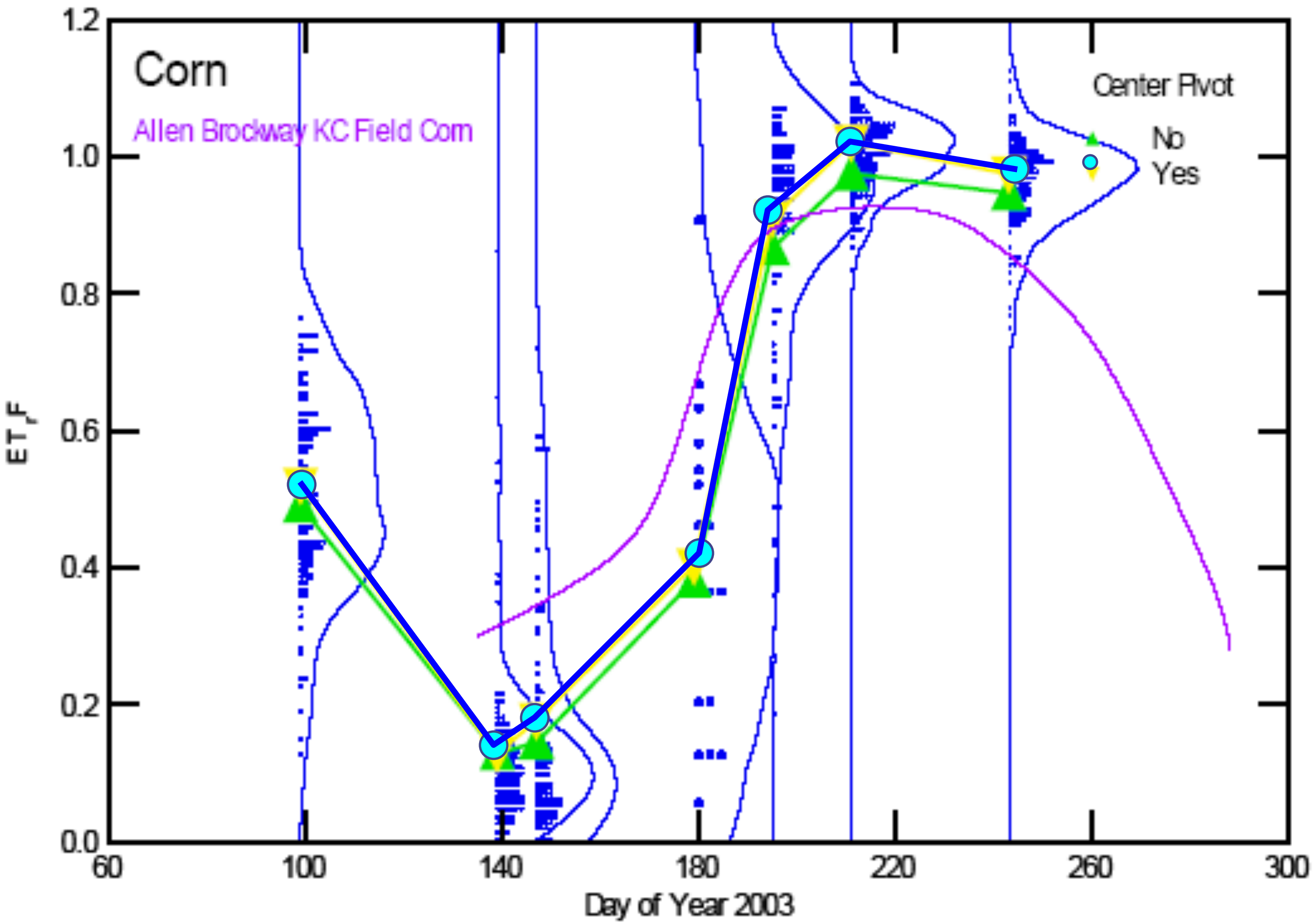


8/14/2000



8/22/2000

Impact of Irrigation System Type



Each "blue dot" is one field.

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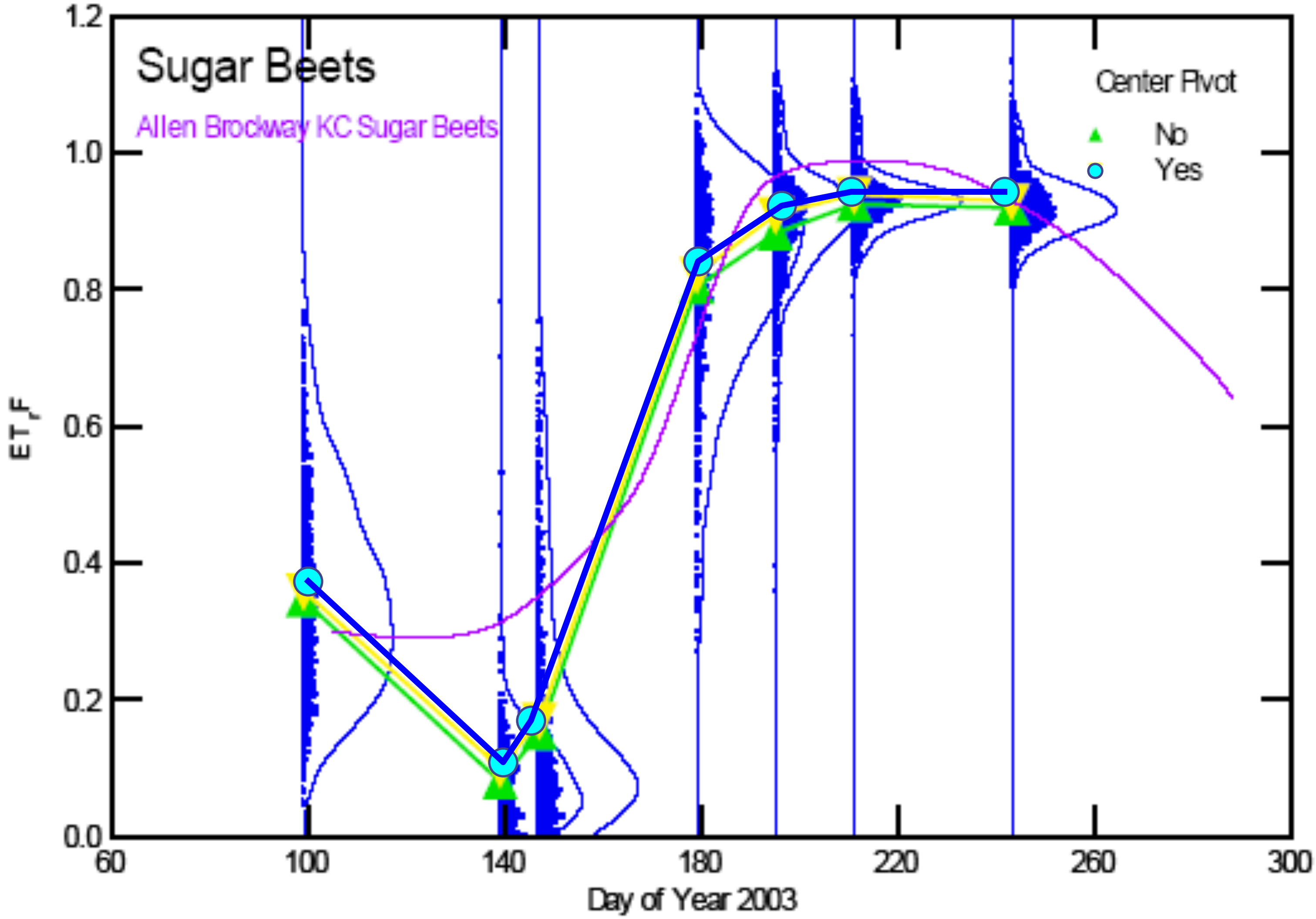
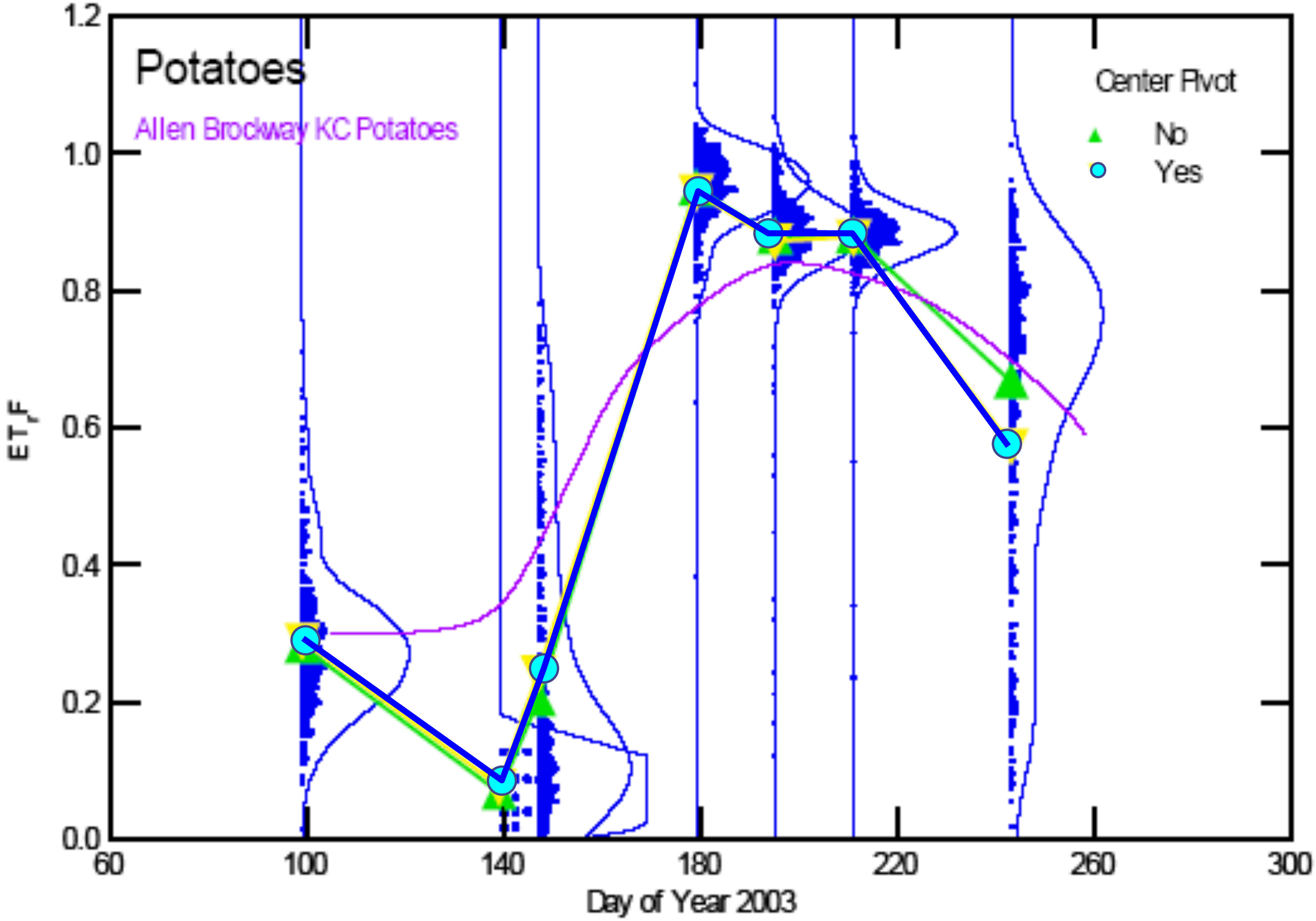
Impact of Irrigation System Type



Impact of Irrigation System Type



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