Monitoring evapotranspiration (ET) from irrigated lands using satellite imagery: on-farm validation in the Mississippi River Floodplain

W. Dean Hively and John W. Jones
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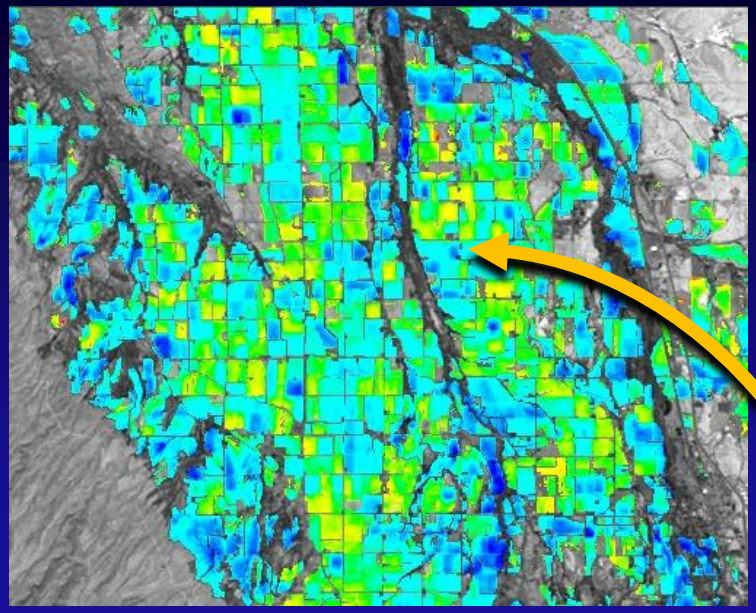
Additional information from Eric Evenson, James Verdin, and Gabriel Senay
USGS Western Geographic Science Center, EROS Data Center
USGS Water Census / WaterSMART

U.S. Department of the Interior
U.S. Geological Survey

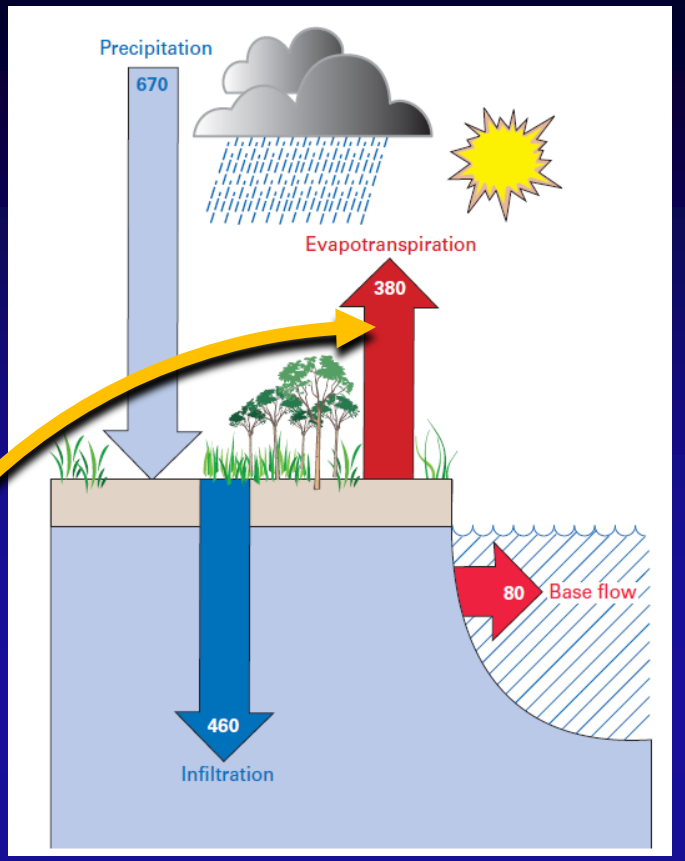
SMAP Joint Mission Tutorial
Reston, VA - Oct 17th , 2012

USGS



D. Eckhardt, USBR

ET



Water Use Evaluation:

- Consumptive use by irrigated crops
- Crop water productivity

12 digit HUC Watershed

Water Availability:

Landscape ET as a component of the overall water budget

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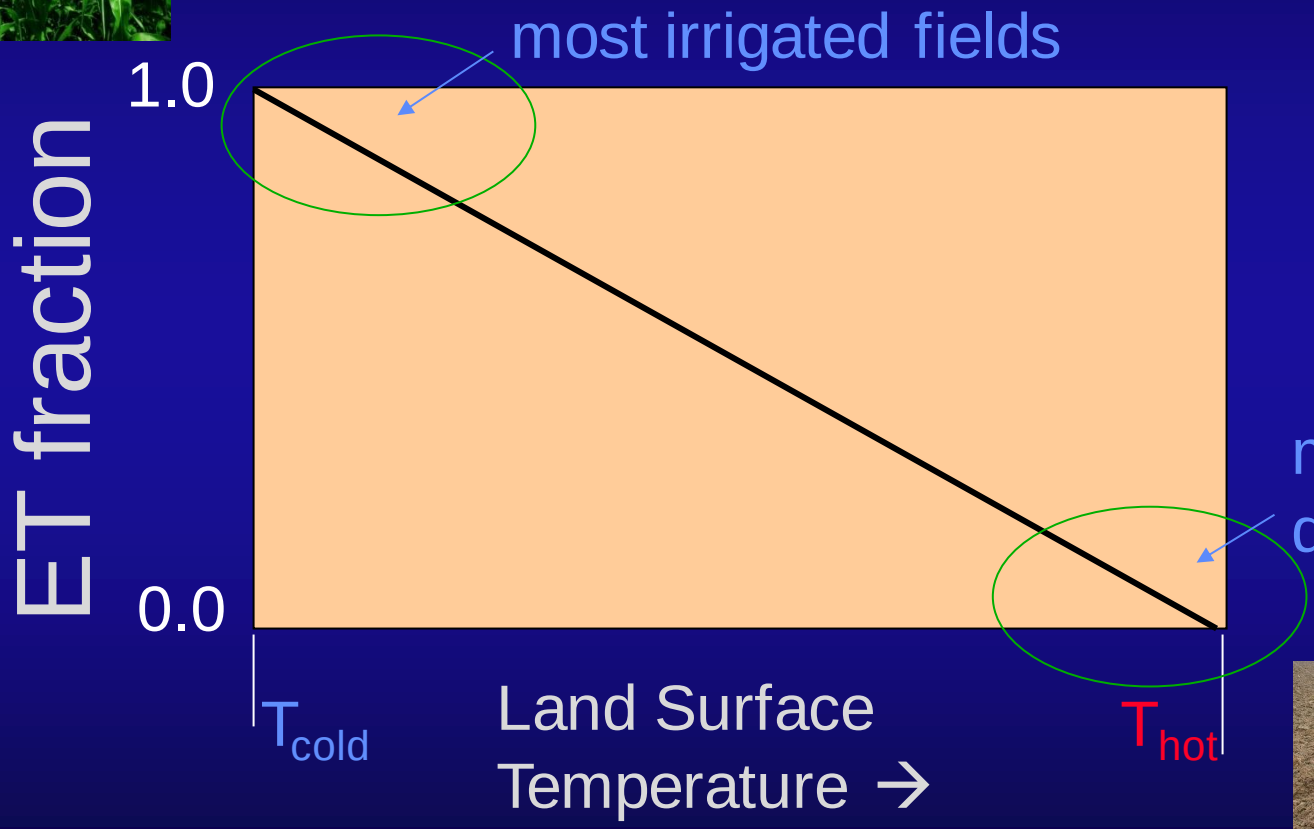
Deriving ET from satellite imagery

Relies on data from the thermal bands (evapotranspiration is a cooling process)



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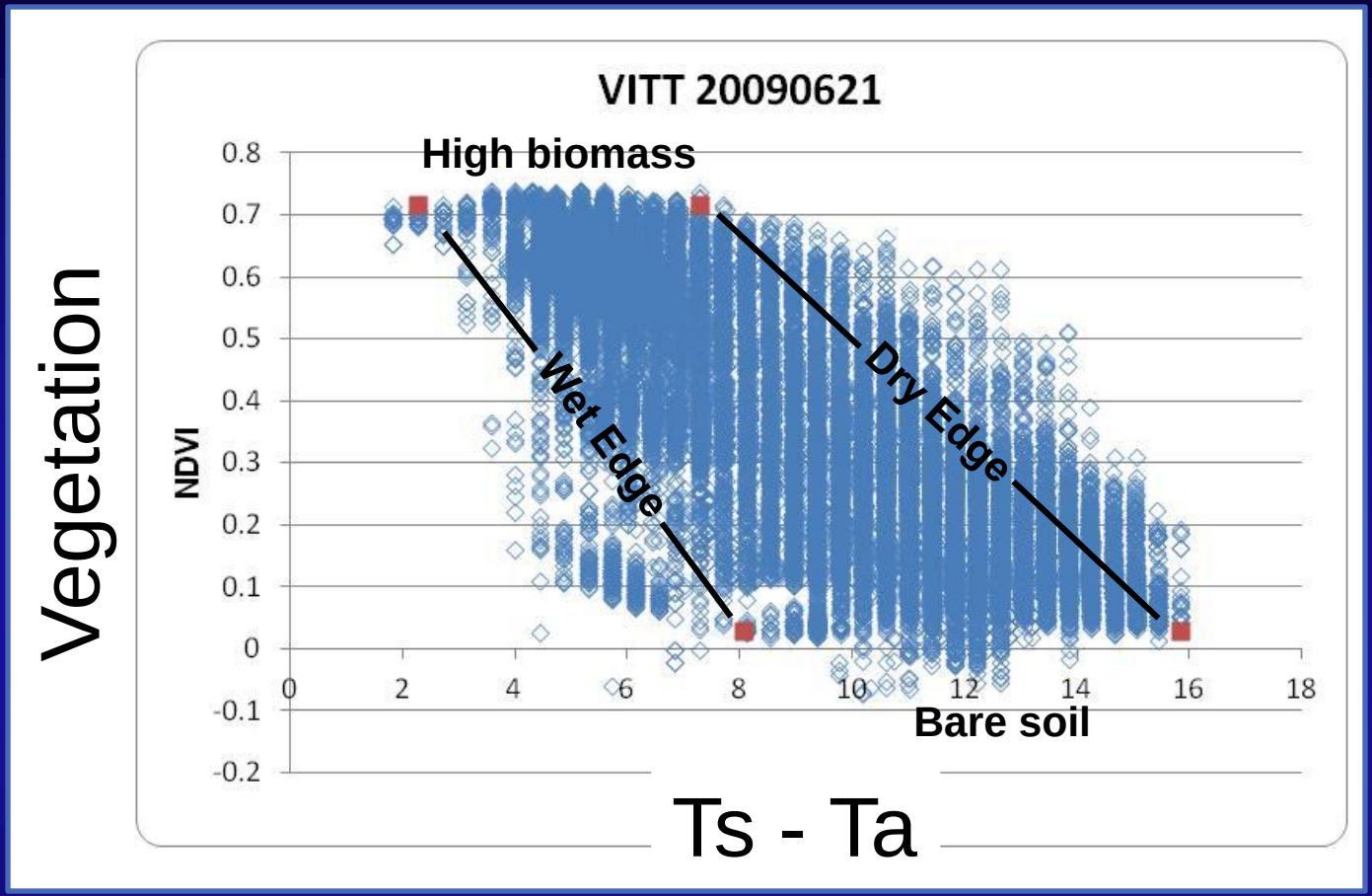
Vegetation Index Temperature Trapezoid (VITT)



This approach requires only the satellite image and an estimate of air temperature

- **Surface canopy temp - Atmospheric temp, NDVI => VITT**
- **Slope and intercept of bounding lines used to calculate AET/PET**

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Modeling and measuring ET

- Thermal infrared
  - Two Source Energy Balance (USDA ARS Kustas, Norman)
  - ALEXI-DisALEXI (USDA-ARS Anderson, Norman)
  - SEBAL (Bastiaanssen), METRIC (Allen)
  - SEBI-SEBS, S-SEBI, SEBS (Su, Roerink, Menenti)
  - SSEB (Senay)
- Reflectance/crop coefficient
  - USBR Lower Colorado River Accounting System
  - NASA Ames (Melton)
- Hybrid thermal/reflectance approach
  - USU (Geli & Neale)
  - VITT (Jones)
- Satellite P-M: U Montana MODIS (Mu); de Bruin
- Satellite Priestley-Taylor: JPL (Fisher)

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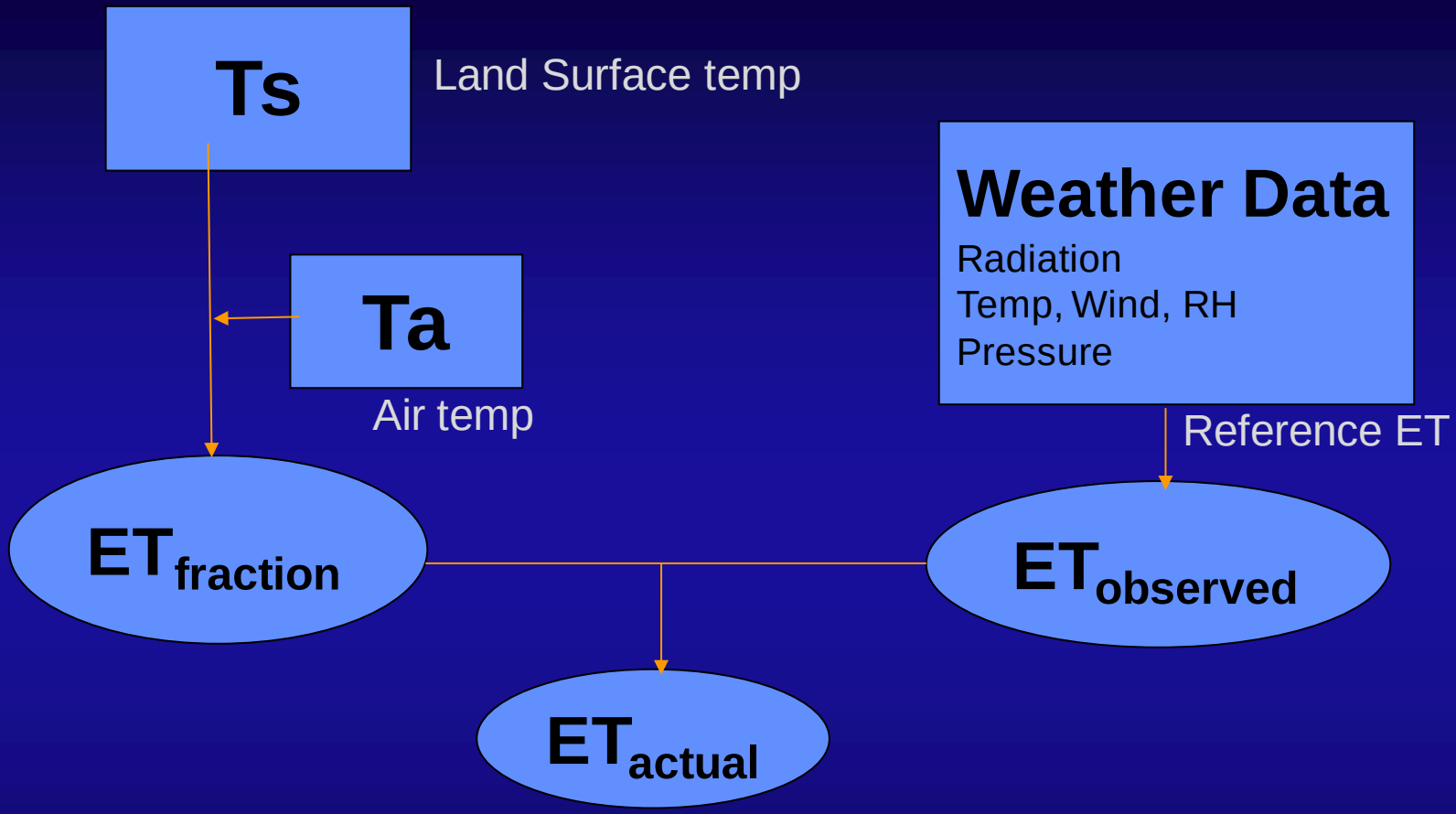
Operational Simplified Surface Energy Balance (SSEBop) Approach



Adapted the "hot" and "cold" pixel concept from SEBAL (Bastiaanssen et al., 1998) and METRIC (Allen et al., 2005) to calculate ET fraction and combine it with ETobserved.

Senay, et al., 2007 Sensors; AWM 2011; Hydrological Processes 2011, JAWRA 2012 (Accepted))

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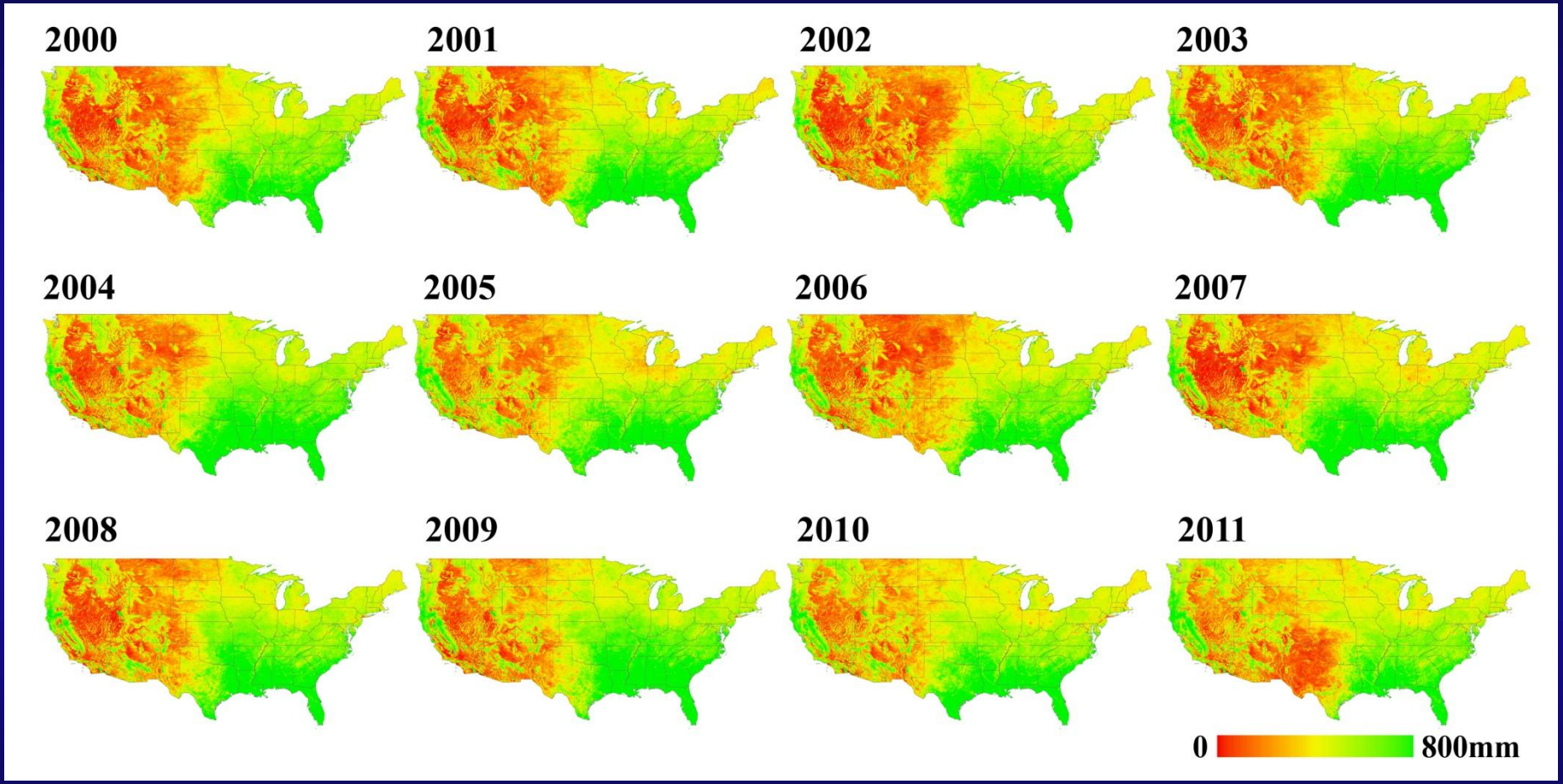
Annual ET Totals from MODIS



Have completed monthly CONUS landscape ET at MODIS 1-km scale (2000–2012) using the SSEBop model – see references at end of presentation

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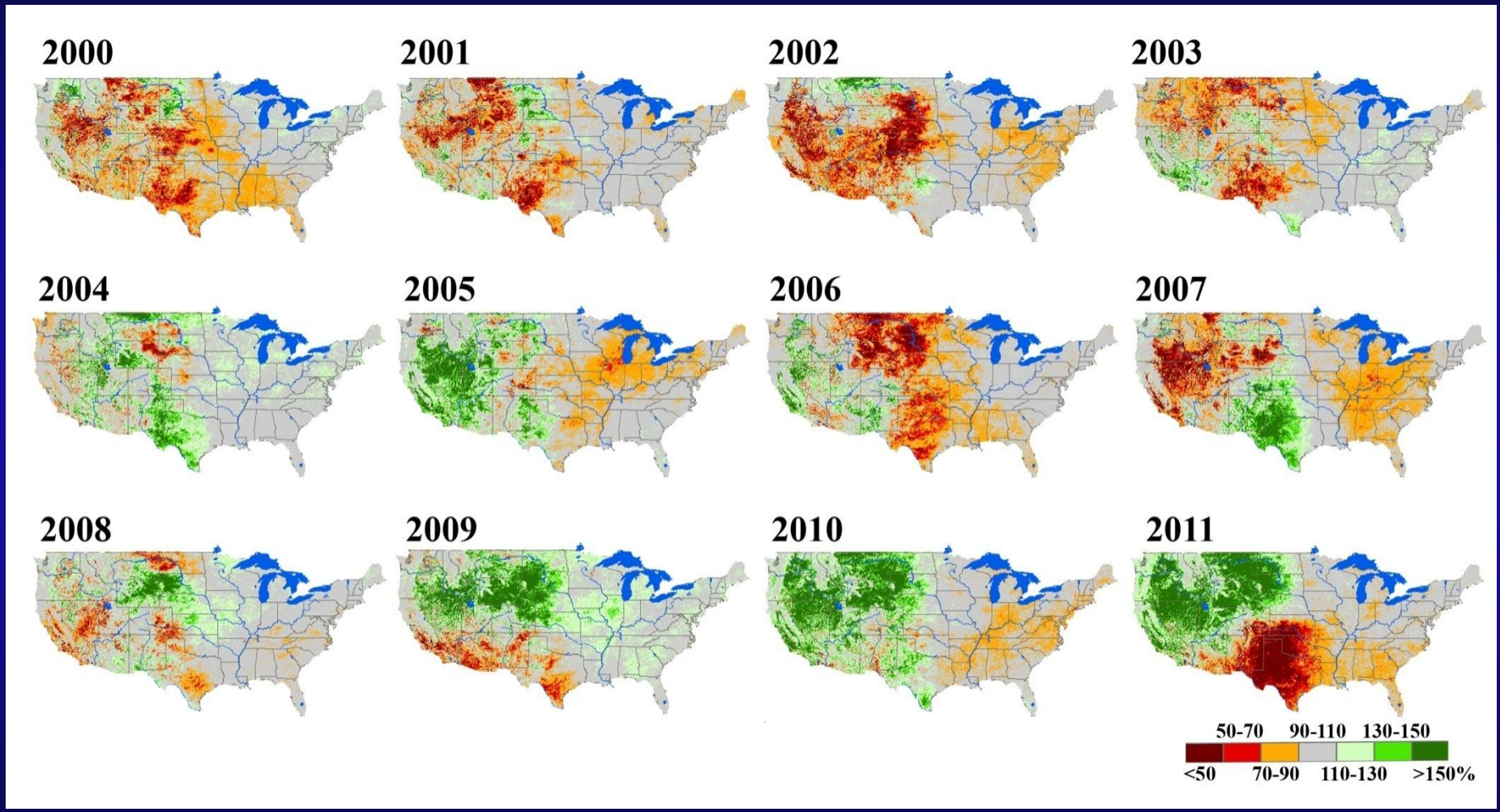
Annual ET Anomalies from MODIS



– see references at end of presentation

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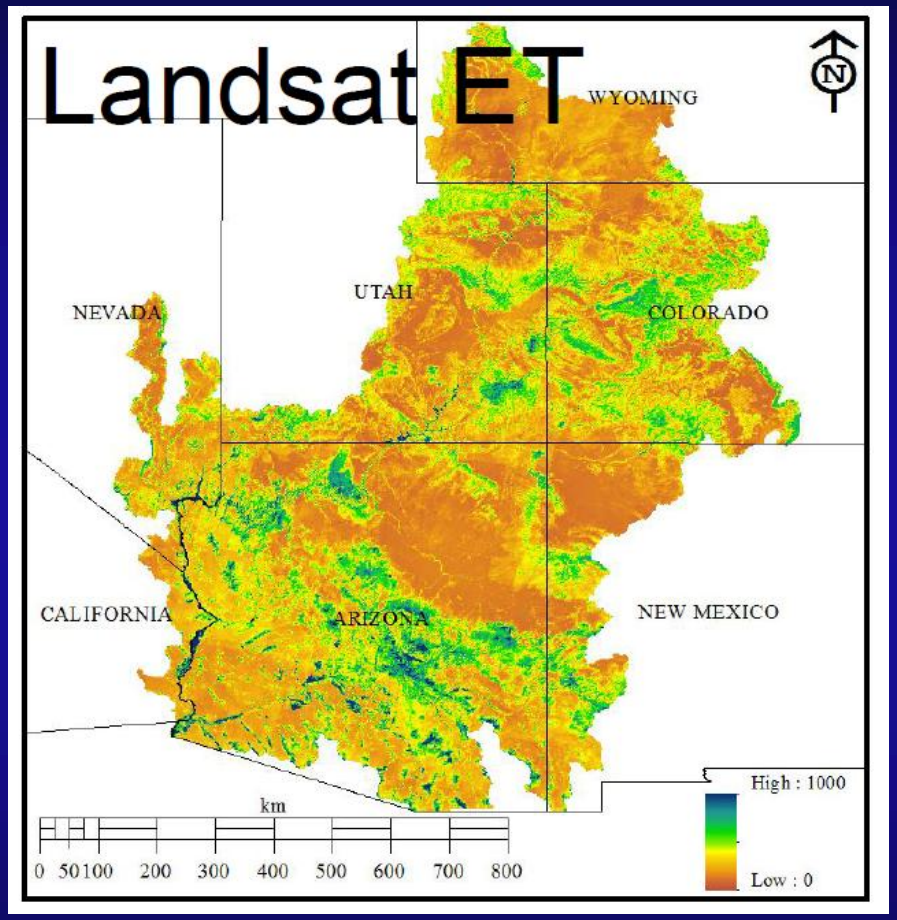
Annual ET Totals from Landsat



Have completed Landsat-based monthly 2010 ET mapping for the Colorado River basin, using the SSEBop model
– see references at end of presentation

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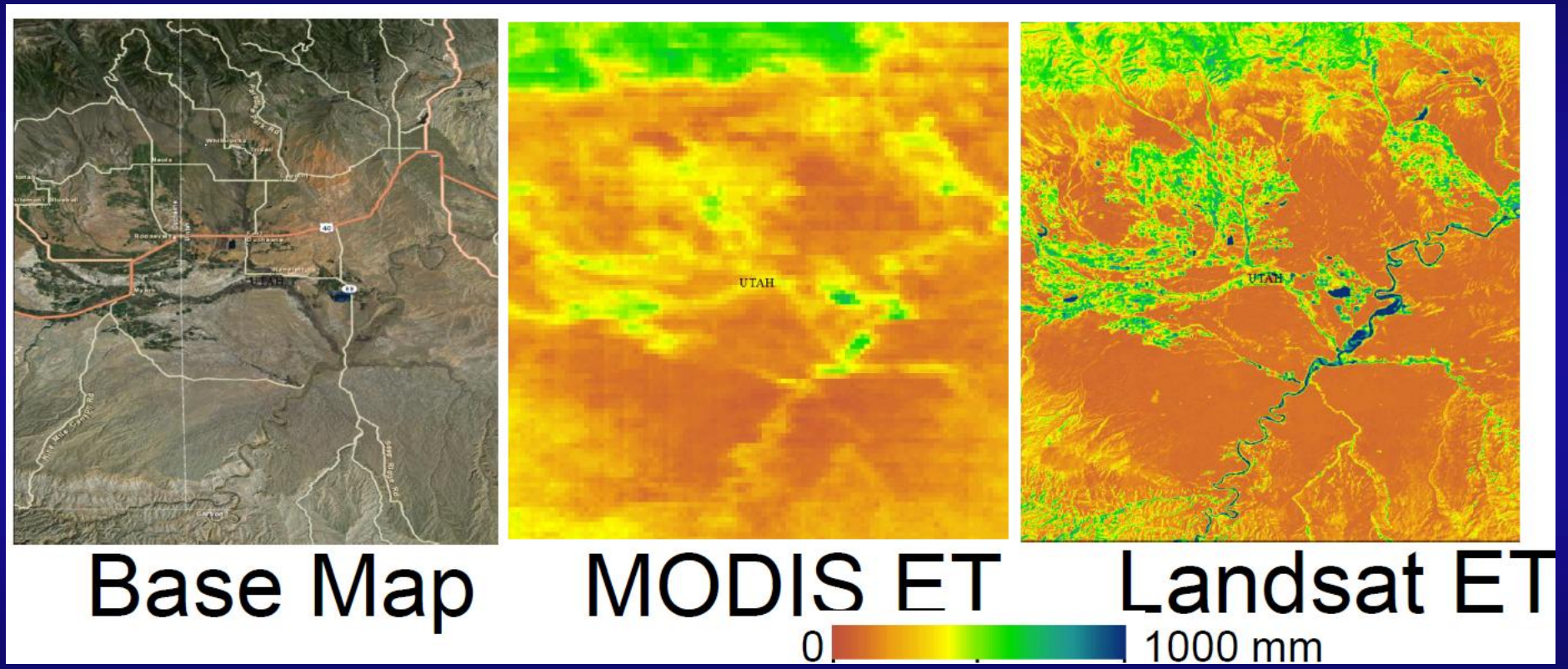
Comparison of Annual ET for 2010 Duchesne, Utah



– see references at end of presentation

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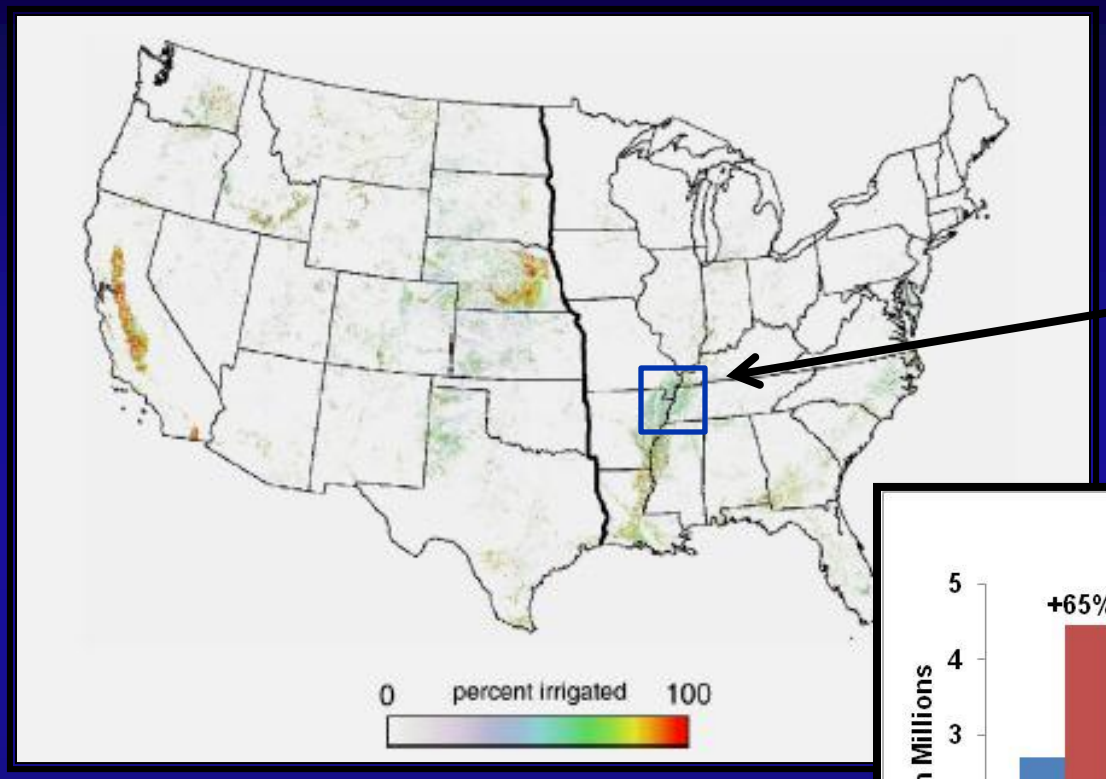
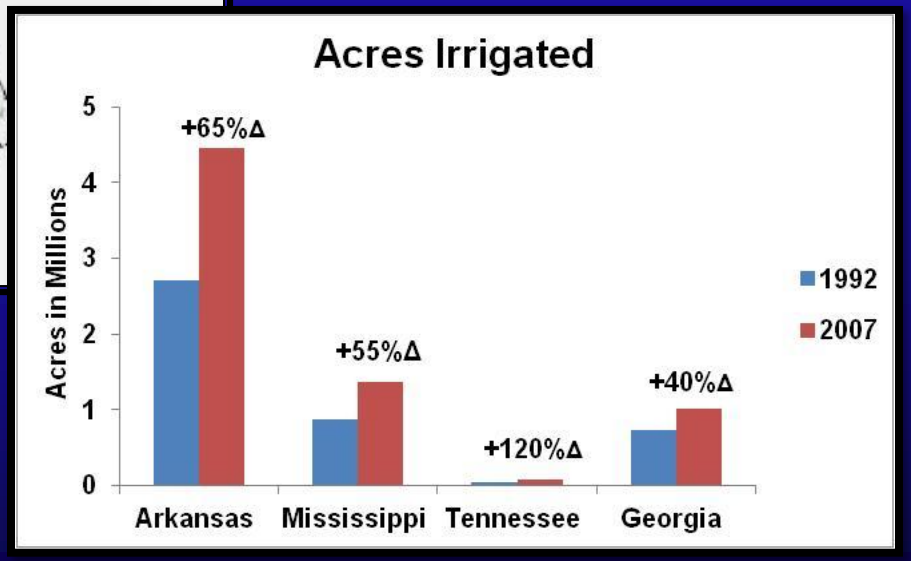
Irrigation in the Eastern U.S.



Mississippi County, AR (Landsat P23 R35)

Image From: Ozdogan, M. and Gutman, G. *Remote Sensing of Environment* 112 (2008) 3520-3537



From the USDA Censuses of Agriculture: 2007 and Earlier

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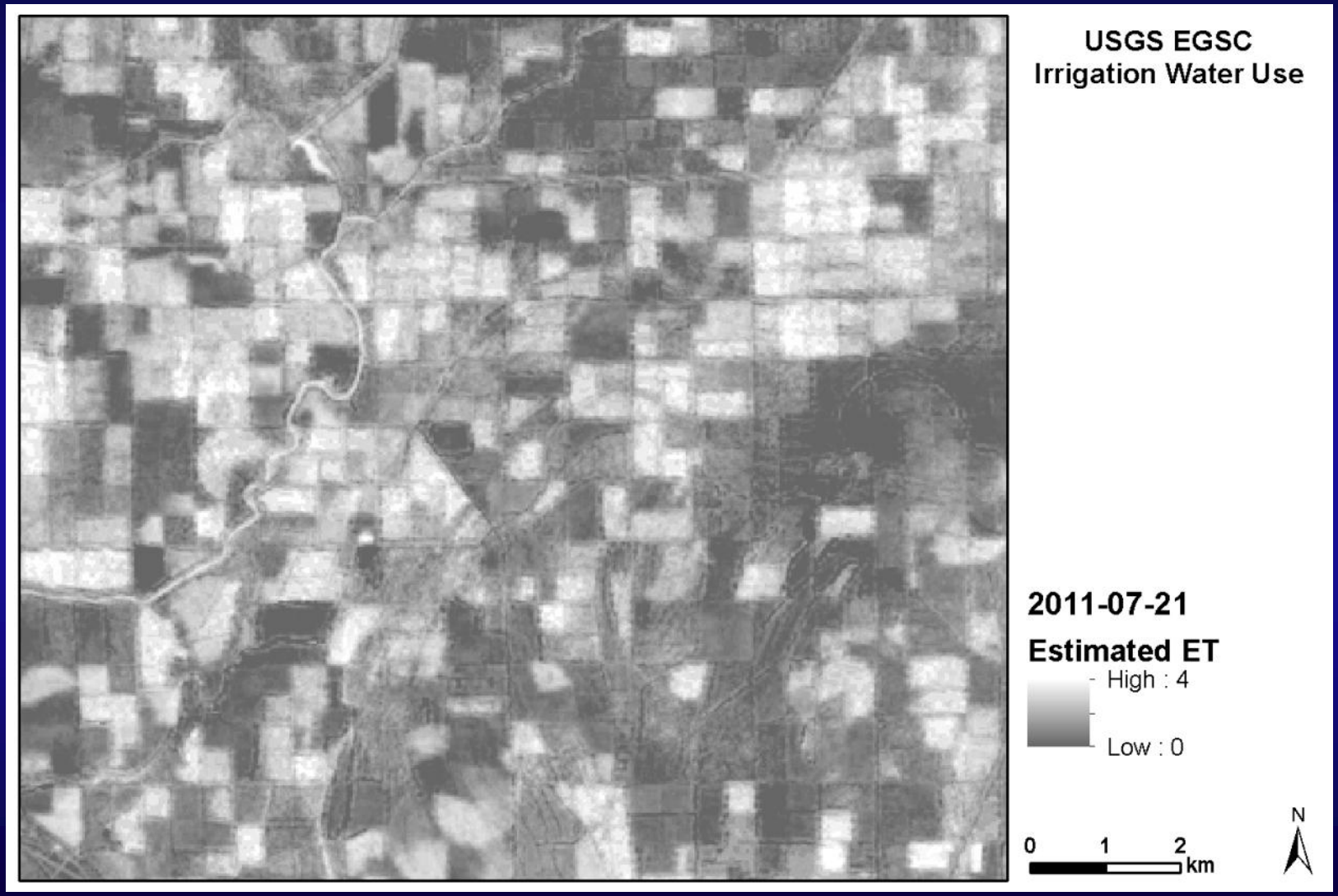
Mapping ET via VITT method



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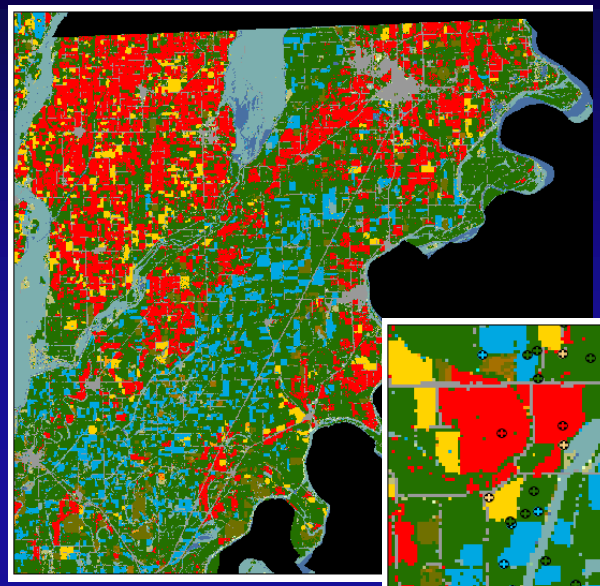
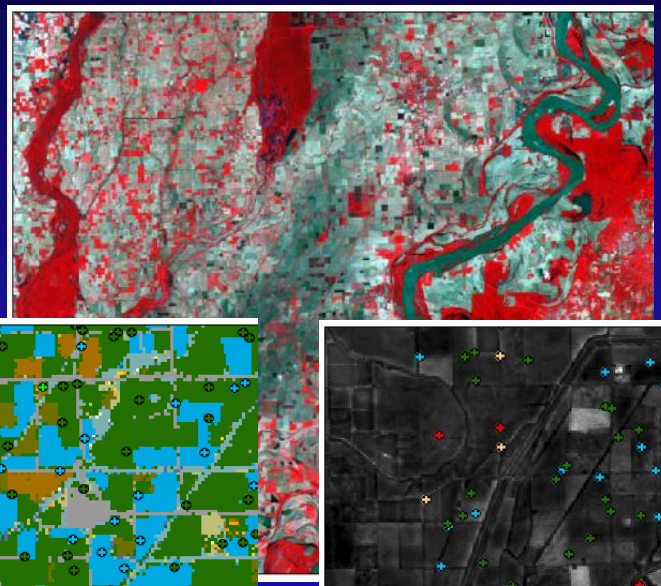
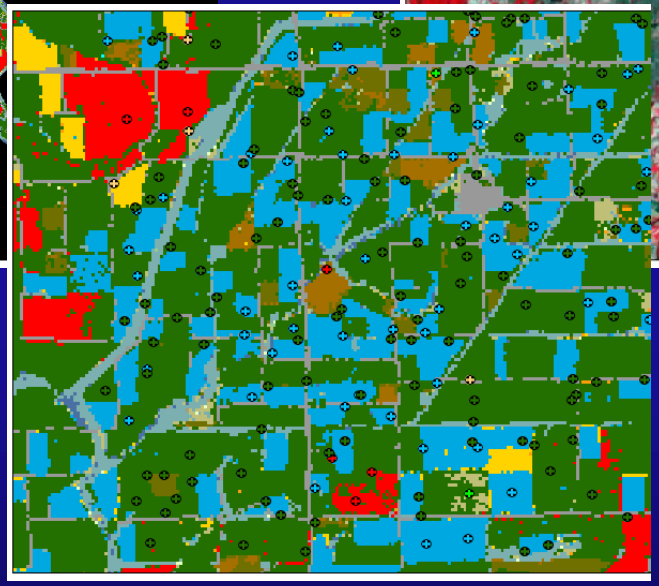
Data Integration

National Cropland Data Layer

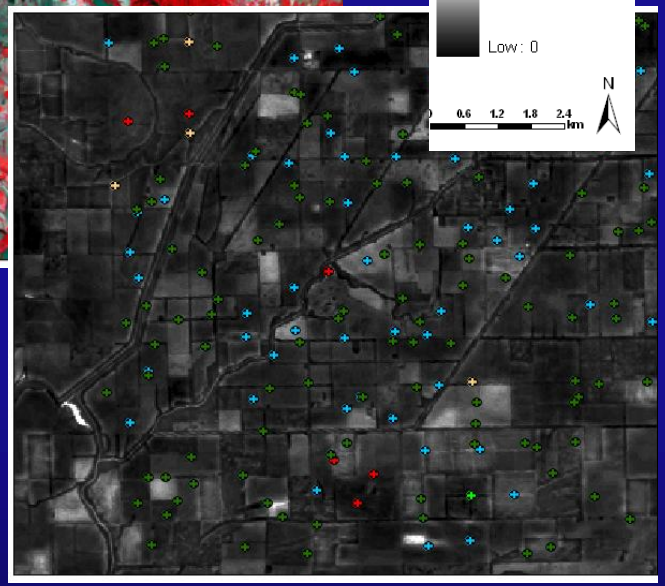


Landsat Imagery Archive





Crop type and well head water use



Calculated evapotraspiration

- On-farm irrigation pump records (daily and annual flow)
- Field boundaries (common land use data, shape files)

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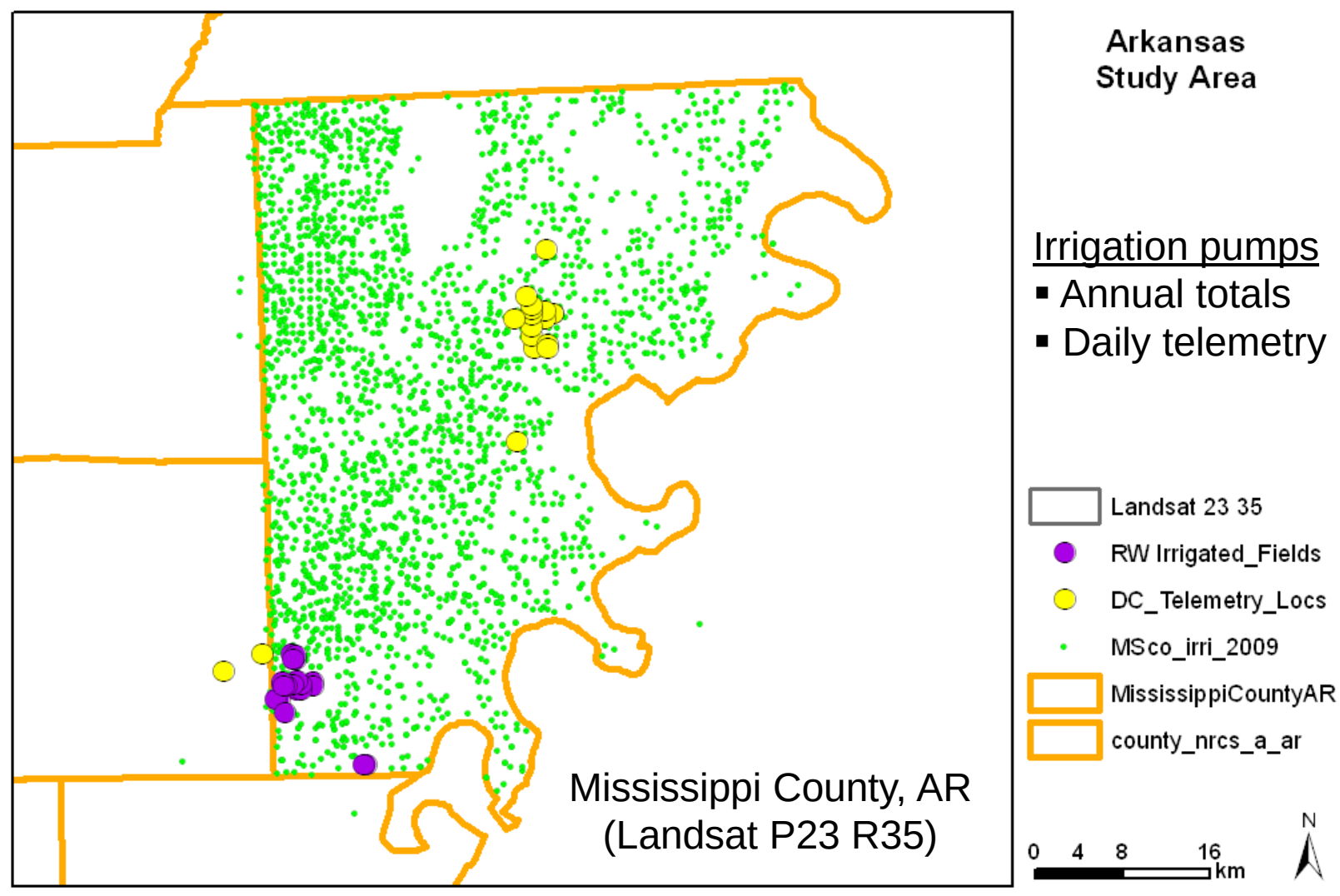
Field-specific irrigation records



Collaborators:

- **Dennis Carman (White River Irrigation District)**
- **Michele Reba (USDA-ARS Oxford, MS)**
- **AR and MS USGS Water Science Centers**

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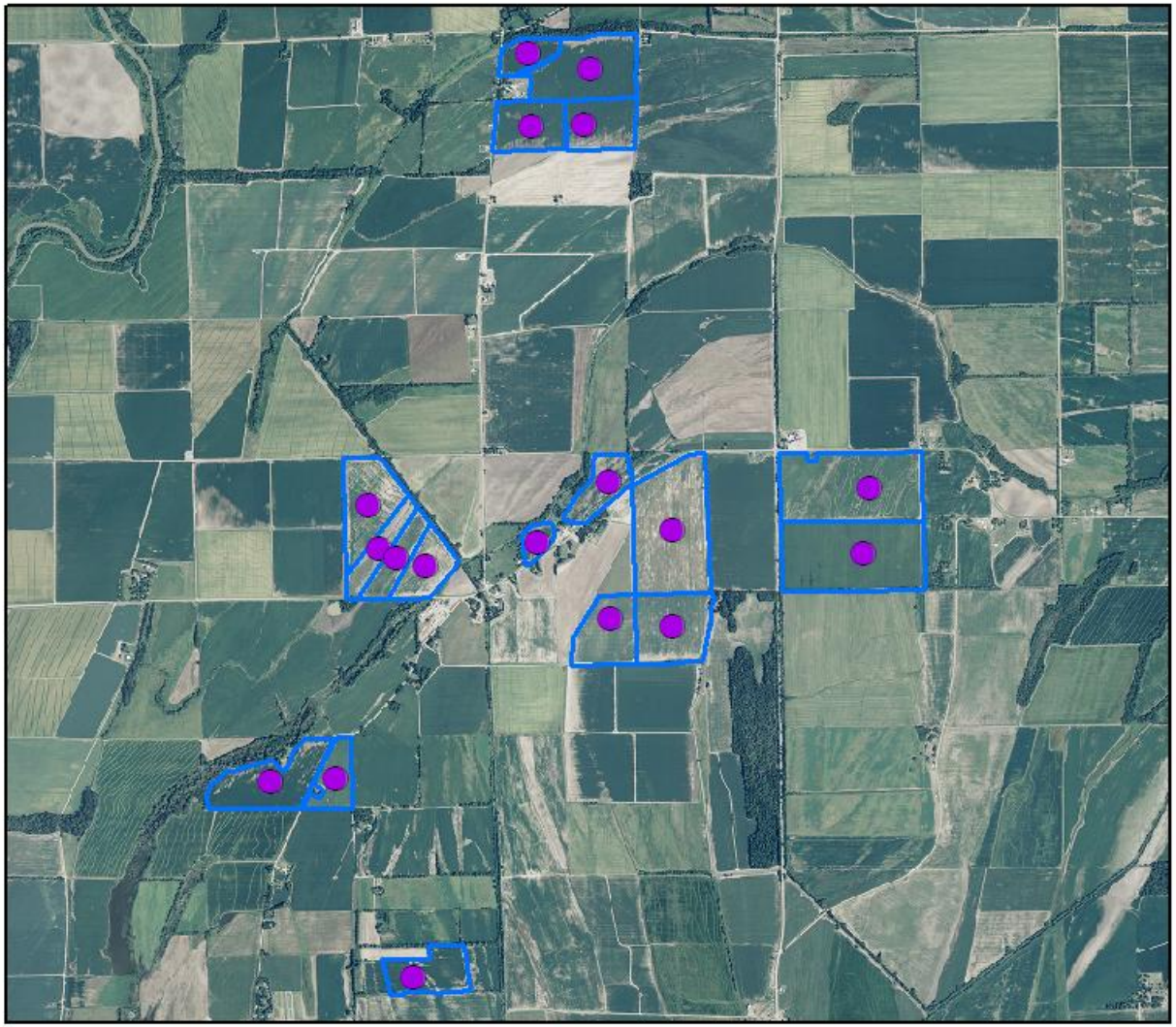
Field-specific irrigation records



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Field-specific irrigation records

RWFarm 2011 Irrigation records

Acres	Crop	Irrigation Method	# of Irrigations	Irrigation #1		Irrigation #2		Irrigation #3		Irrigation #4		Days before Landsat imagery		
				Start Date	Length	Start Date	Length	Start Date	Length	Start Date	Length	7/21	8/6	8/30
			#	mm/dd	hr	mm/dd	hr	mm/dd	hr	mm/dd	hr	days	days	days
80	Cotton	Furrow	4	6/30	46	7/17	48	8/3	51	9/1	16	4	20	27
30	Cotton	Furrow	4	7/2	21	7/18	24	8/3	24	8/30	8	3	19	0
30	Cotton	Furrow	3	6/30	24	7/15	25	8/1	32			6	22	29
16	Cotton	Furrow	3	7/1	8.5	7/16	6	7/31	17			5	21	30
30	Cotton	Furrow	3	7/1	18.5	7/17	22	8/2	15.5			4	20	28
30	Cotton	Furrow	3	6/29	22	7/15	24	8/2	28			6	22	28
40	Cotton	Furrow	3	6/30	30	7/16	30	8/3	36			5	21	27
10	Cotton	Furrow	3	6/30	6	7/15	8	8/5	10			6	22	28
17	Cotton	Furrow	5	6/29	20.5	7/14	20	7/21	18	8/2	17.5	7	16	1
40	Cotton	Furrow	3	7/1	52	7/15	48	8/3	56.5			6	22	27
20	Cotton	Furrow	3	6/28	24	7/15	30	8/2	43			6	39	28
40	Rice	Flood										na	na	na
50	Rice	Flood										na	na	na
80	Soybeans	Flood	2	7/20	96	8/29	73					1	1	1
14	Soybeans	Furrow	4	7/3	24	7/20	24	8/4	27	8/29	24	1	17	1
25	Soybeans	Flood	3	7/19	43	8/9	39.5	9/2	48			2	18	21
6	Soybeans	Flood	3	7/18	11.5	8/9	13.5	8/31	12			3	19	21
25	Soybeans	Flood	4	7/1	24	7/18	24	8/4	24	8/29	12	3	19	1
10	Soybeans	Furrow	2	7/19	10	8/5	18					2	18	25
15	Soybeans	Flood	1	8/9	39							na	na	21
70	Doublecrop Soybeans	Furrow	3	6/6	80	8/5	88	8/29	96			45	1	1

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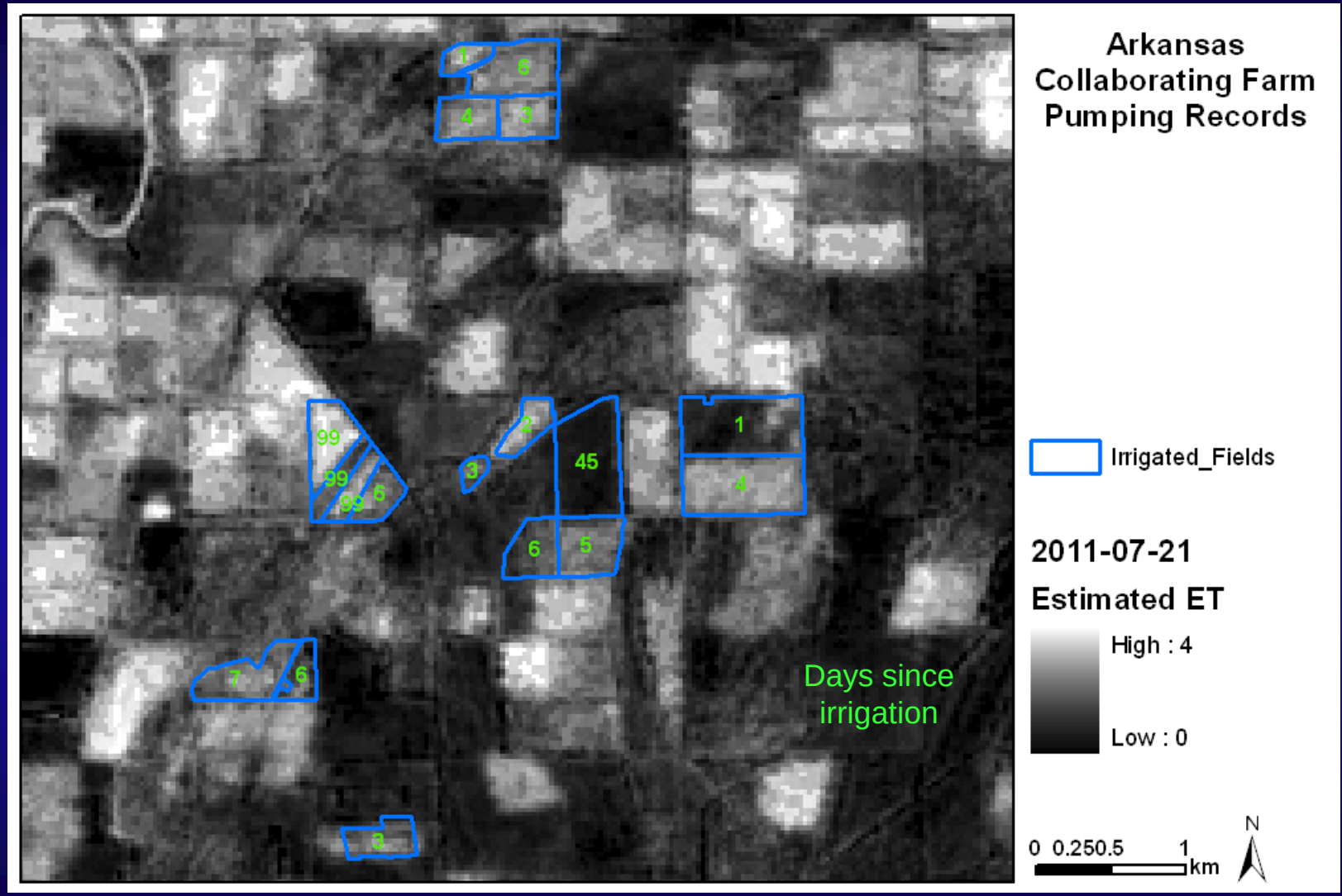
Field-specific irrigation records



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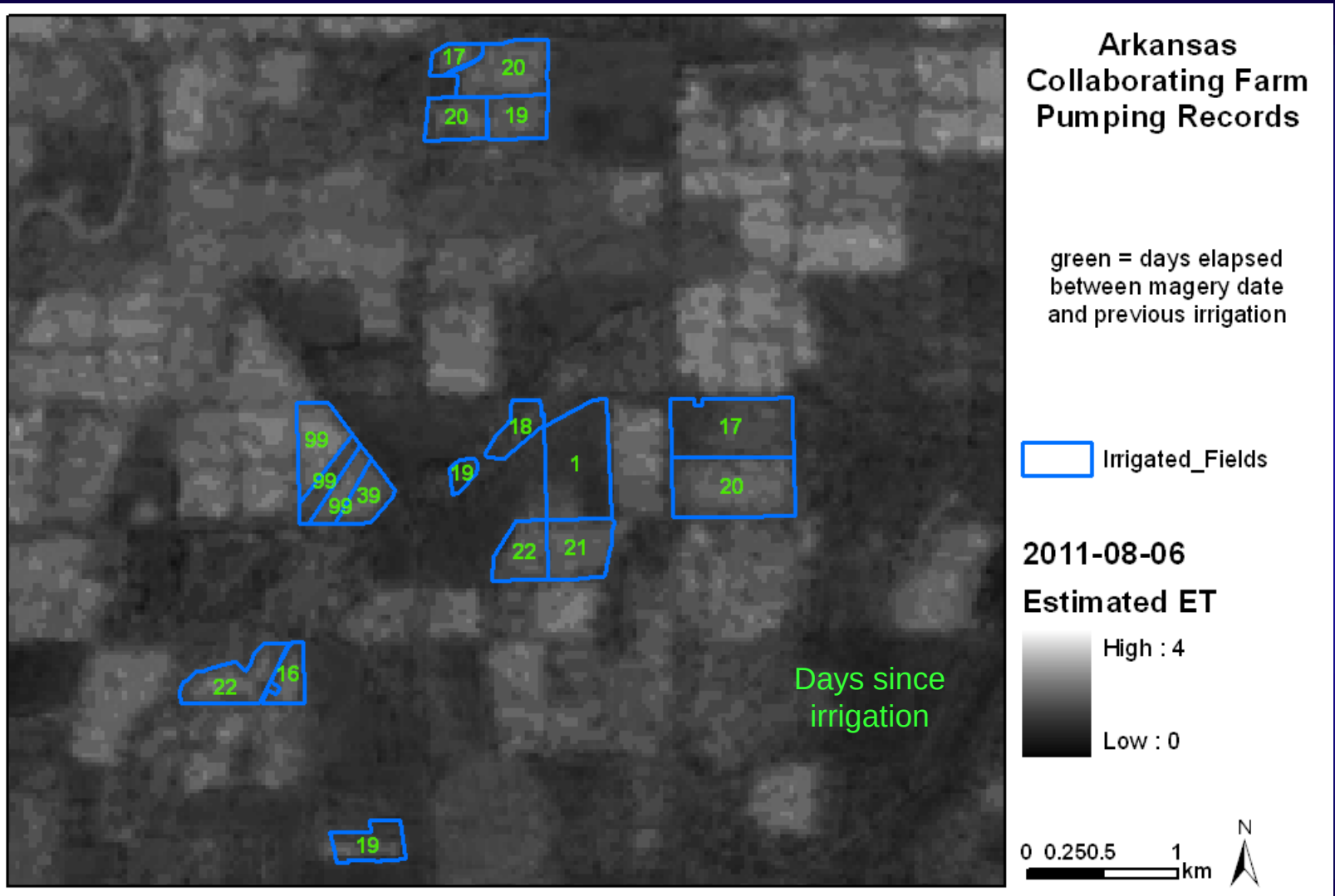

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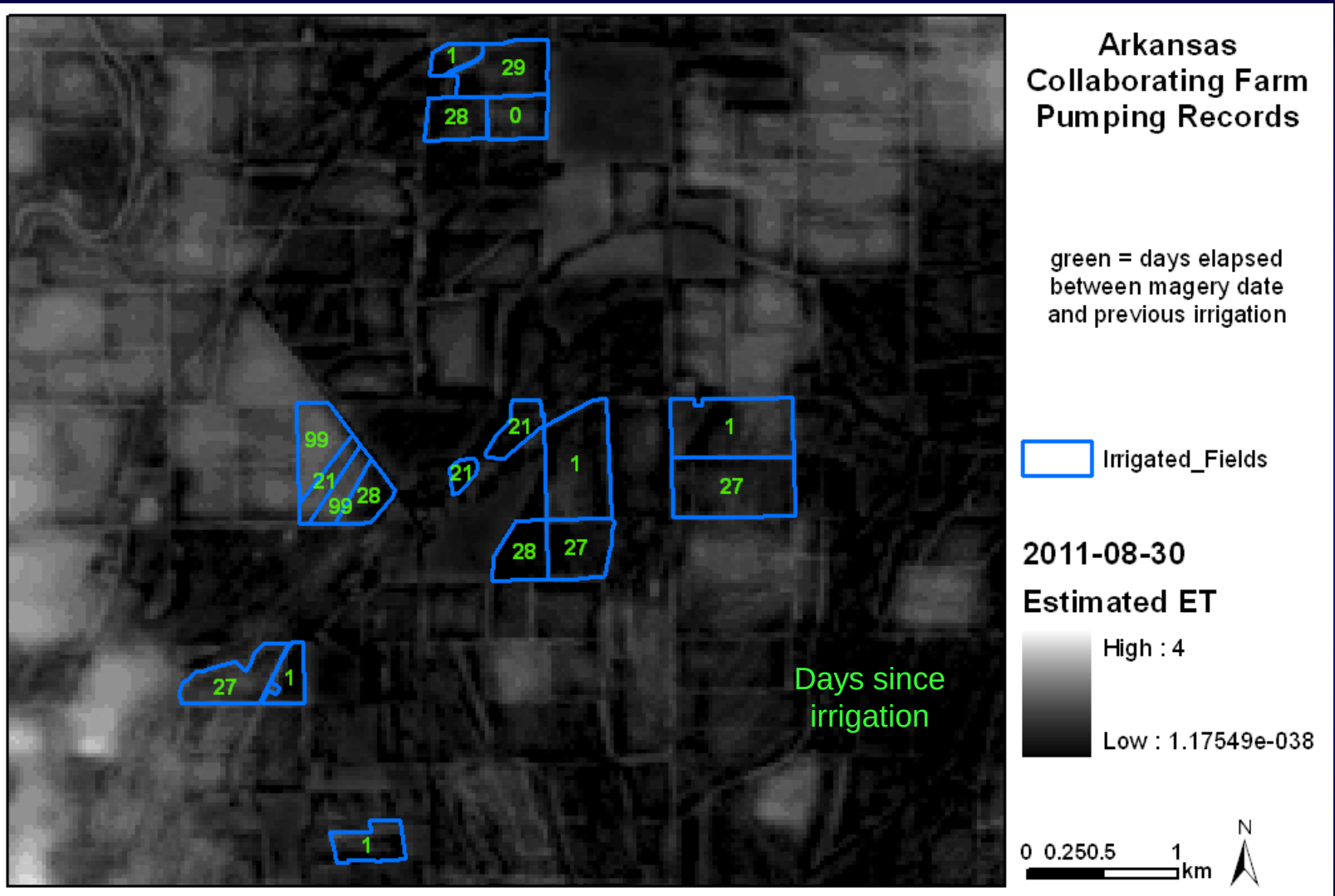

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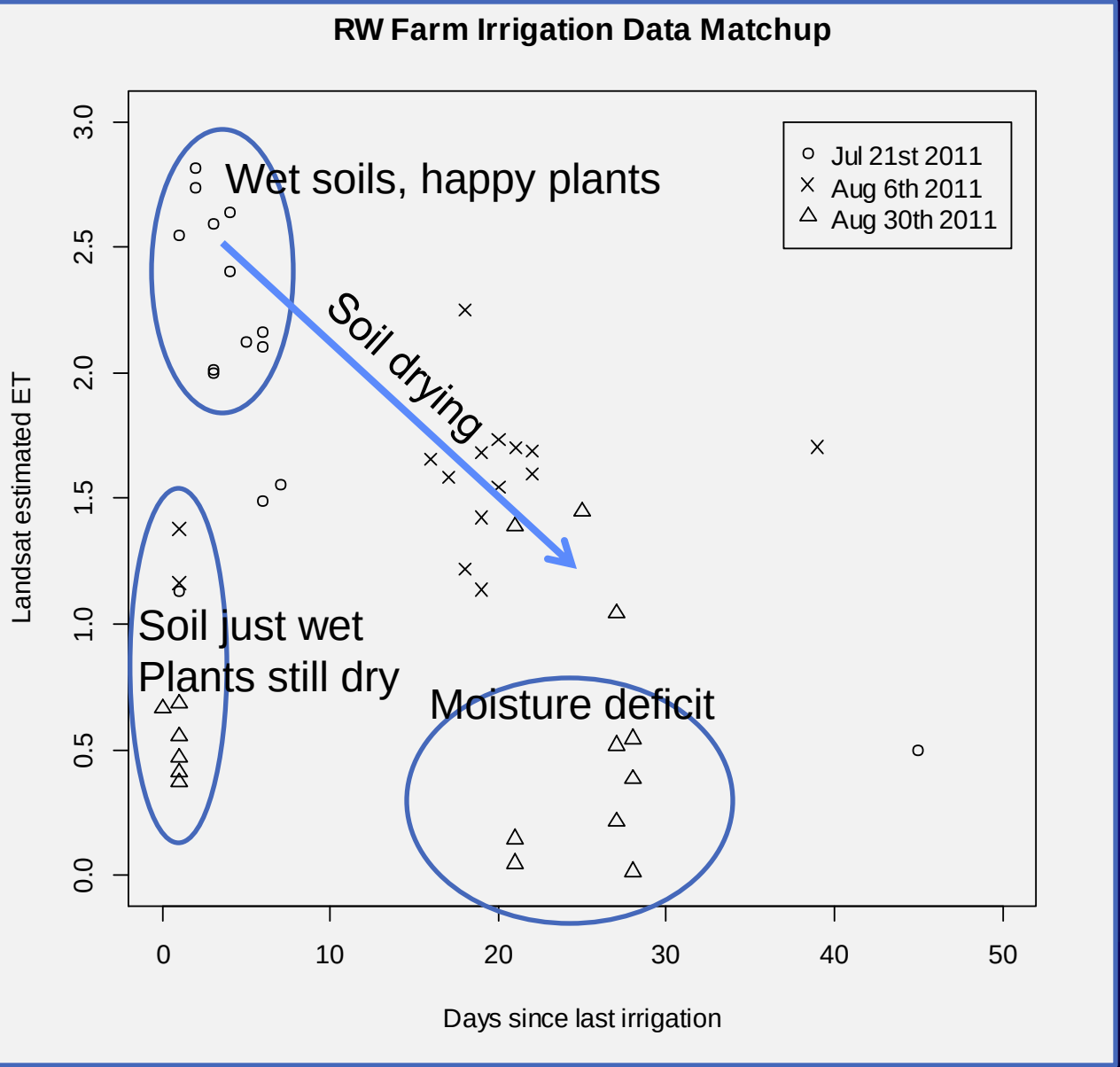

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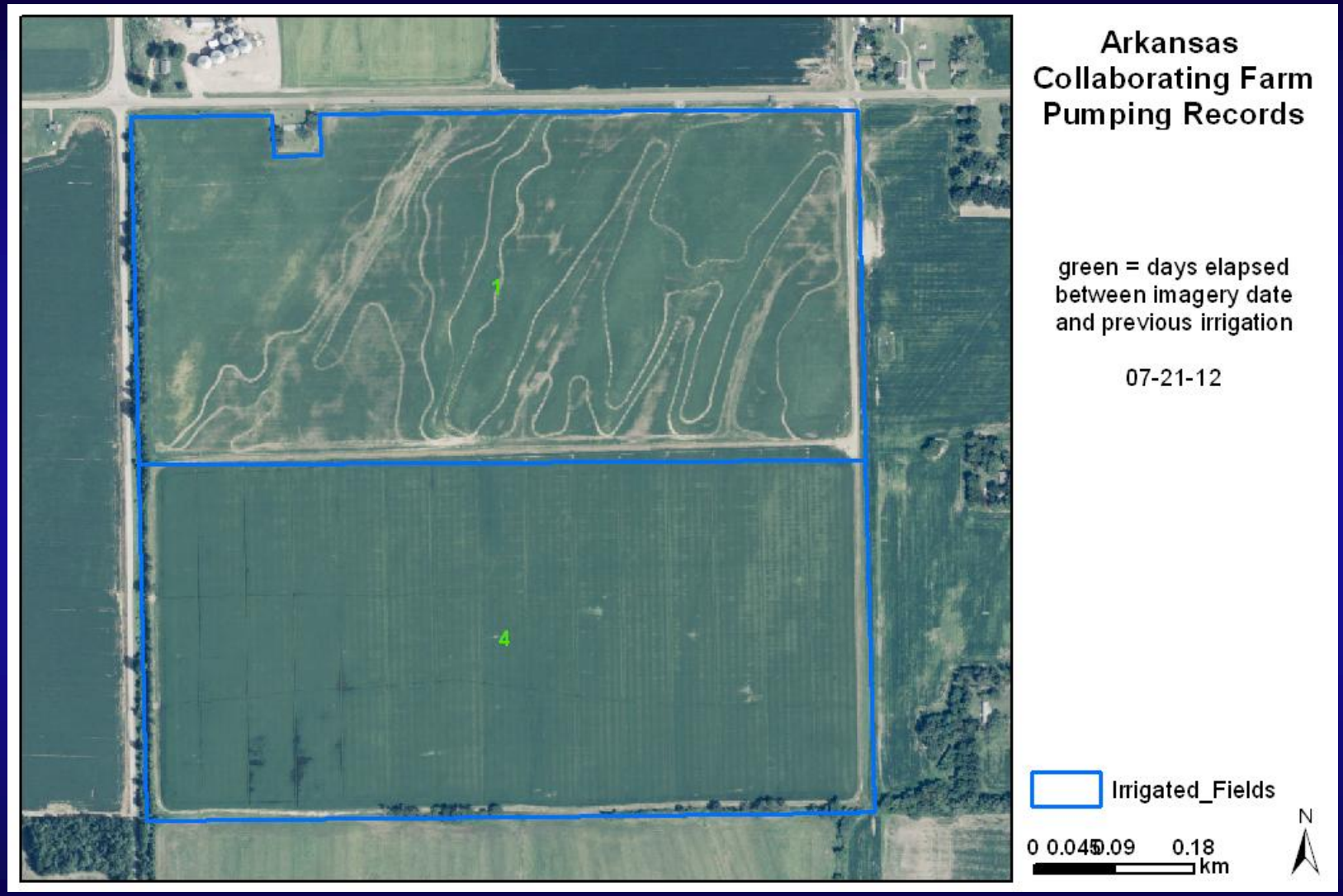

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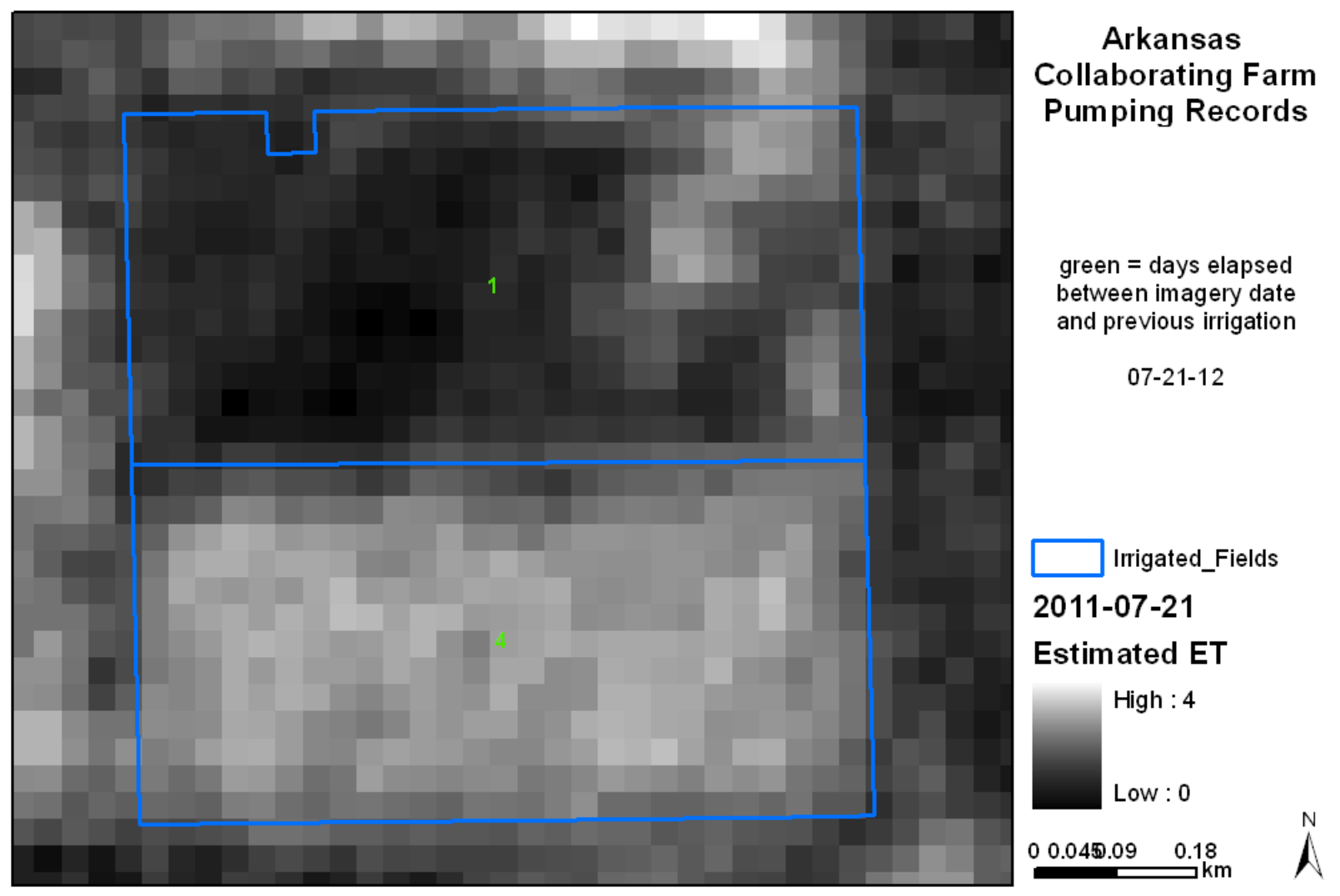

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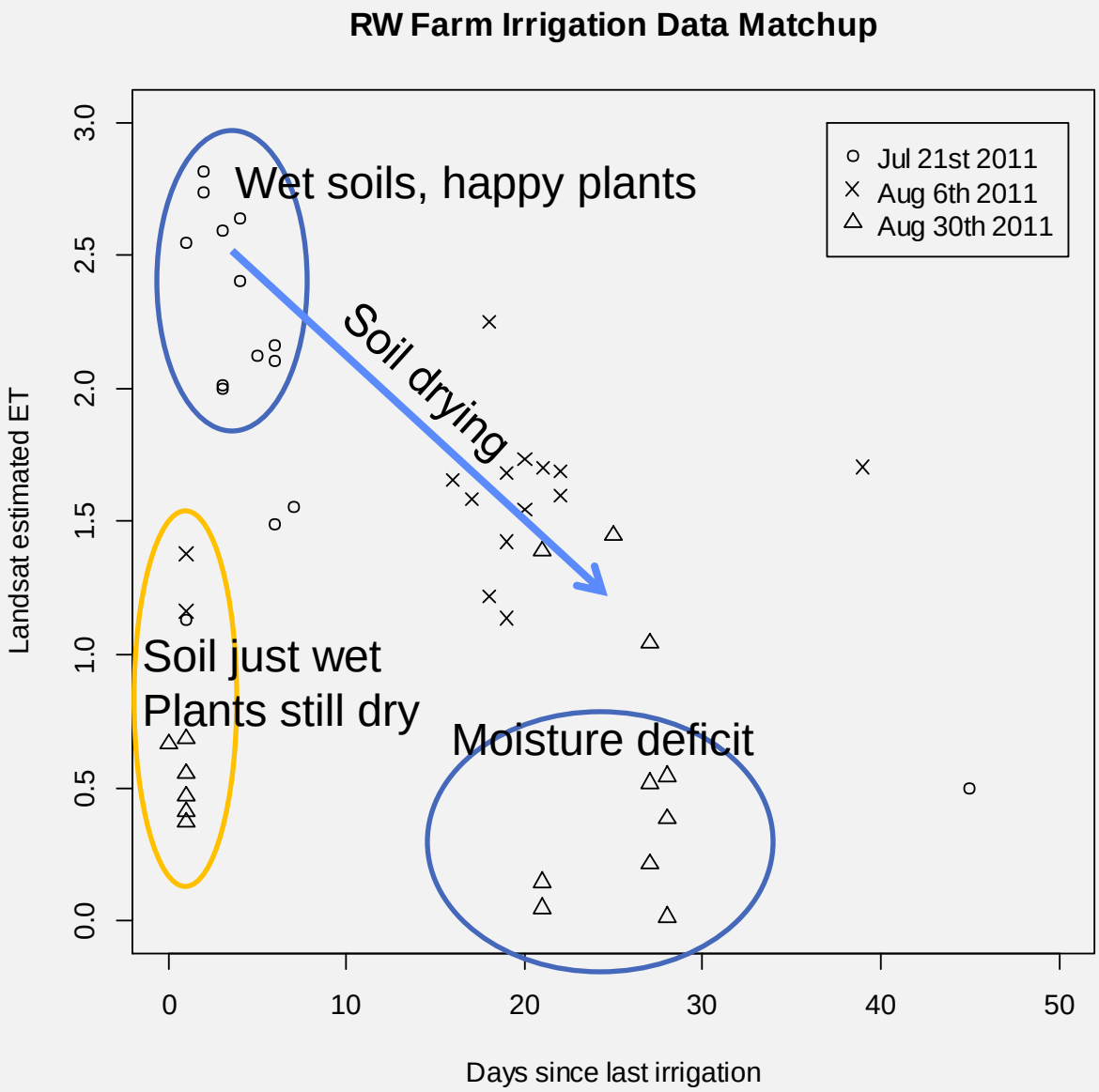

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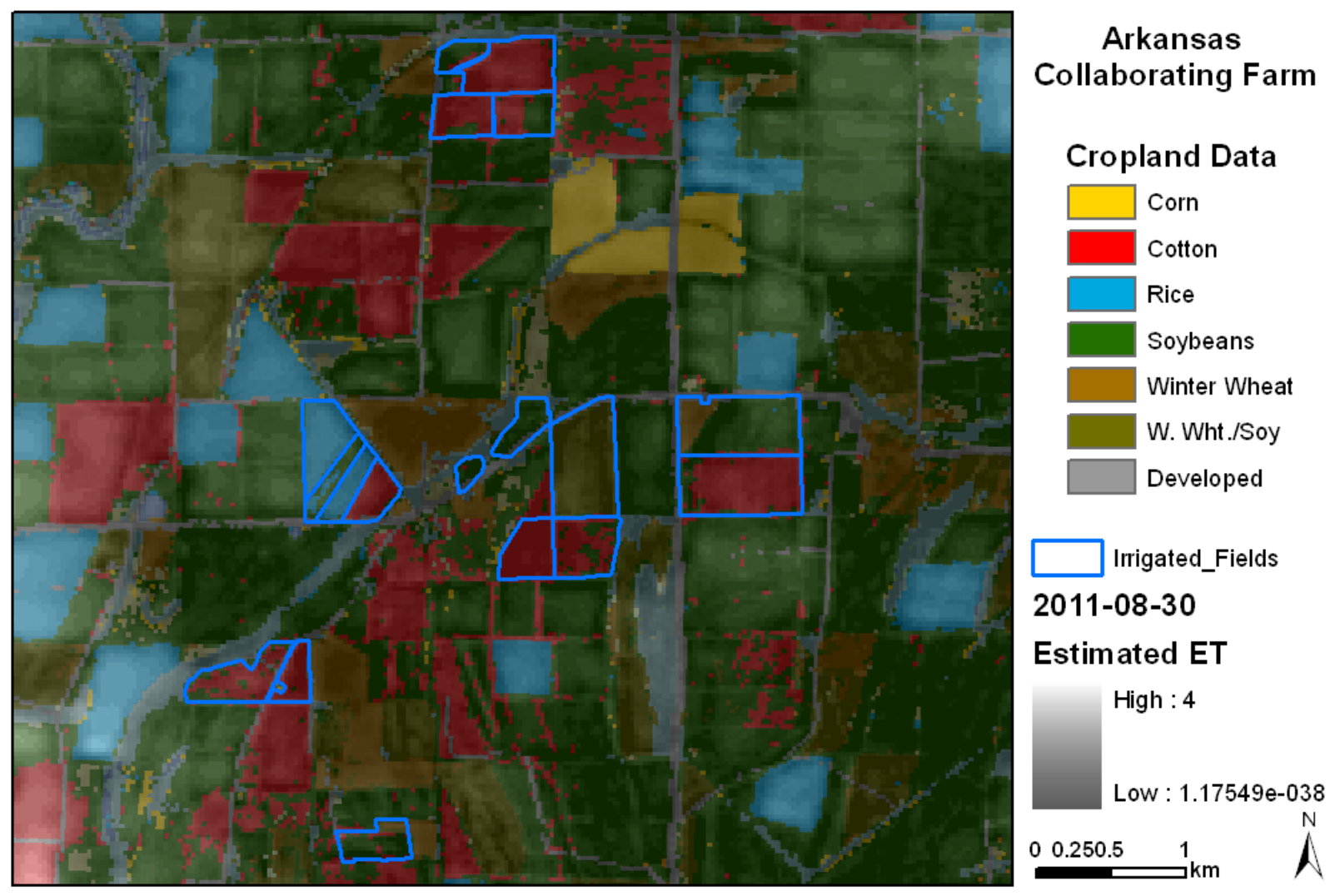
Goal: Annual water use by crop type



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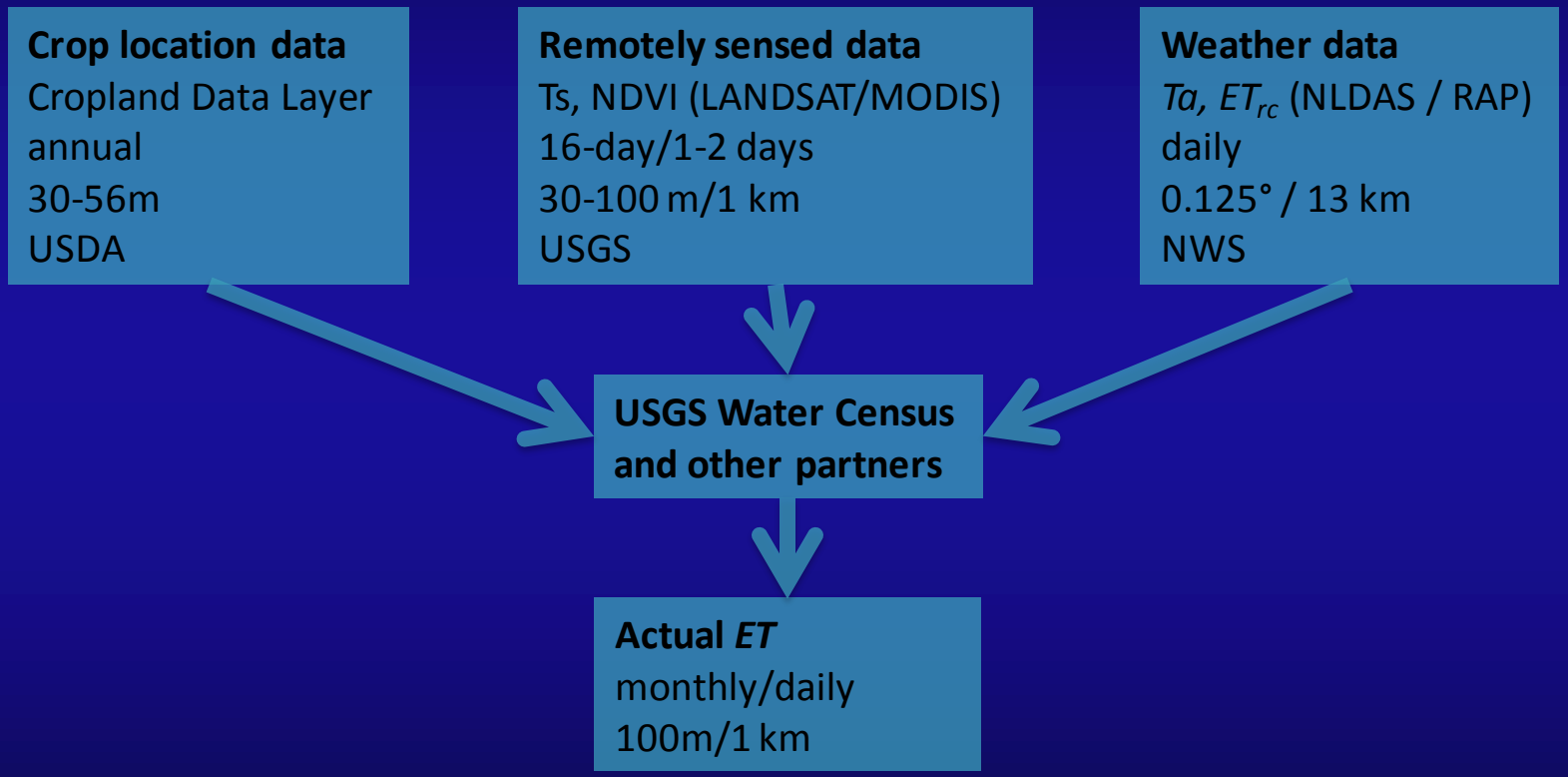
Summary

- Developing novel ways to use ground-based data for validation of irrigation maps
- Initial “simple” Landsat-based model has been semi-automated (ArcGIS, ENVI, Excel)
- VITT and GIS-based analysis are yielding distinct, logical, spatial and temporal patterns
- Now evaluating cost / benefit of increased ET model complexity vs. obtaining ET through national collaboration

ET guidelines and specifications

- **Common framework of practice**



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Evenson, Verdin, Senay / mod. Hively

ET guidelines and specifications

Consistent input data reduces uncertainty

- Pre-processed imagery (Landsat from USGS)
  - Consistent with requirements for Essential Climate Variables
  - USGS EROS Data Center is developing capacity to release LEDAPS surface reflectance and cloud masks directly via Earth Explorer (John Dwyer)
- Maps of crop type (NCDL from USDA-NASS)
- Gridded reference ET and Ta (from NOAA)
- Spatial precision in all datasets, frequent data
- National ET map as essential climate variable

New sensors will be helpful

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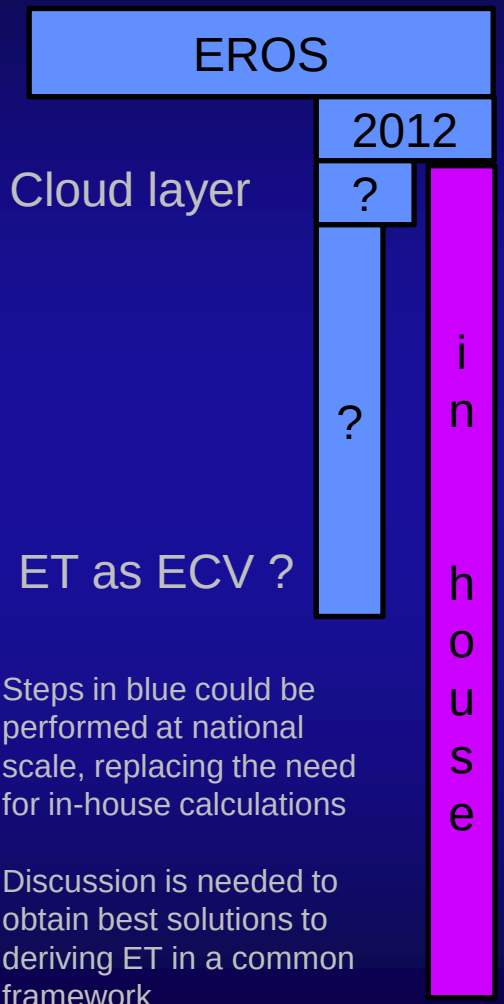
Data Processing Work Flow – Arkansas project



Steps in blue could be performed at national scale, replacing the need for in-house calculations

Discussion is needed to obtain best solutions to deriving ET in a common framework

Landsat Acquisition
- LEDAPS surface reflectance => band ratios
- LDOPE => Cloud mask

Transform to VITT
- Vegetation index (NDVI) to determine fractional cover
- Ts-Ta (canopy surface temperature - air temperature)

Transform to ET
- Determine dry and wet edges of VITT
- Estimate ET as a ratio of actual and potential ET

Interpret Output
- Link to ancillary datasets (crop type, field boundaries)
- Validate with field measurements (pump data)

Communicate Results to Collaborators
- Integrate with local research objectives
- Regional and National Programs

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Cloud mask information in Landsat

Bit no.	Parameter name	Value	Interpretation
1	Valid data	0	yes
		1	no
6	Dense dark vegetation (DDV)	0	DDV absent
		1	DDV present
8	Surface reflectance cloud mask	0	clear
		1	cloudy
9	Cloud shadow mask	0	cloud shadow absent
		1	cloud shadow present
10	Surface reflectance snow mask	0	snow absent
		1	snow present
11	Spectral test land/water mask	0	water
		1	land
12	Adjacent cloud	0	adjacent cloud absent
		1	adjacent cloud present

John W. Jones et al., 2012: LANDSAT SURFACE REFLECTANCE QUALITY ASSURANCE EXTRACTION [Operators manual for using LDOPE to extract data quality information from Landsat images, in press USGS Techniques and Methods]

Thank You

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  jjones@usgs.gov - 703-648-5543

USGS

Citations

Please see these references for the work done by Senay et. al:

Senay, G.B., M.E. Budde, J.P. Verdin and A.M. Melesse, 2007. A coupled remote sensing and simplified surface energy balance approach (SSEB) to estimate actual evapotranspiration from irrigated fields. Sensors, 7:979-1000.

Senay, G.B., J.P. Verdin, R. Lietzow, and A.M. Melesse, 2008. Global daily reference evapotranspiration modeling and validation. Journal of the American Water Resources Association (JAWRA) 44(4):969-979.

Senay, G.B., 2008. Modeling Landscape Evapotranspiration by Integrating Land Surface Phenology and a Water Balance Algorithm. Algorithms, 1(2), 52-68. doi:10.3390/a1020052

Senay, G.B, M.E. Budde and J.P. Verdin, 2011. Enhancing the Simplified Surface Energy Balance (SSEB) Approach for Estimating Landscape ET: Validation with the METRIC model. Agricultural Water Management, 98:606-618.

Senay, G., S. Bohms, R. Singh, P. Gowda, N. M. Velpuri, H. Alemu and J. Verdin, in press, Operational Evapotranspiration Mapping Using Remote Sensing and Weather Datasets: A New Parameterization for the SSEB Approach, Journal of the American Water Resources Association (JAWRA)

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