EVAPOTRANSPIRATION ESTIMATES AT DIFFERENT SCALES USING REMOTE SENSING

Christopher Neale
Daugherty Water for Food Global Institute

2018 MOISST Workshop

Water for Food
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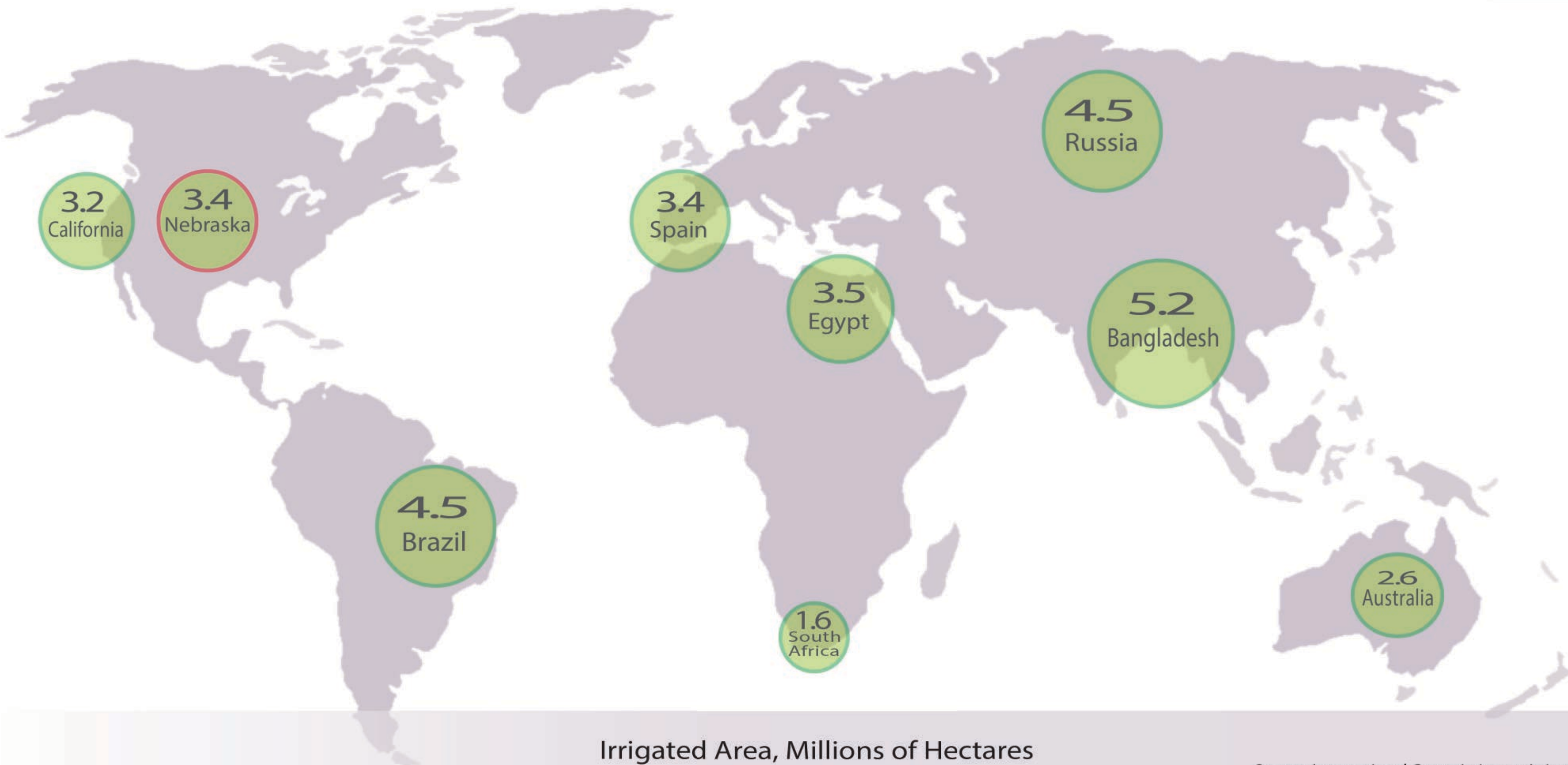
at the University of Nebraska

Outline

- Remote sensing approaches for monitoring evapotranspiration
- Satellite based approaches for irrigation water management and crop water productivity at field scales
- Global Daily ET retrieval application

Nebraska: A Substantial Irrigator



Irrigated Area, Millions of Hectares

Source: International Commission on Irrigation and Drainage

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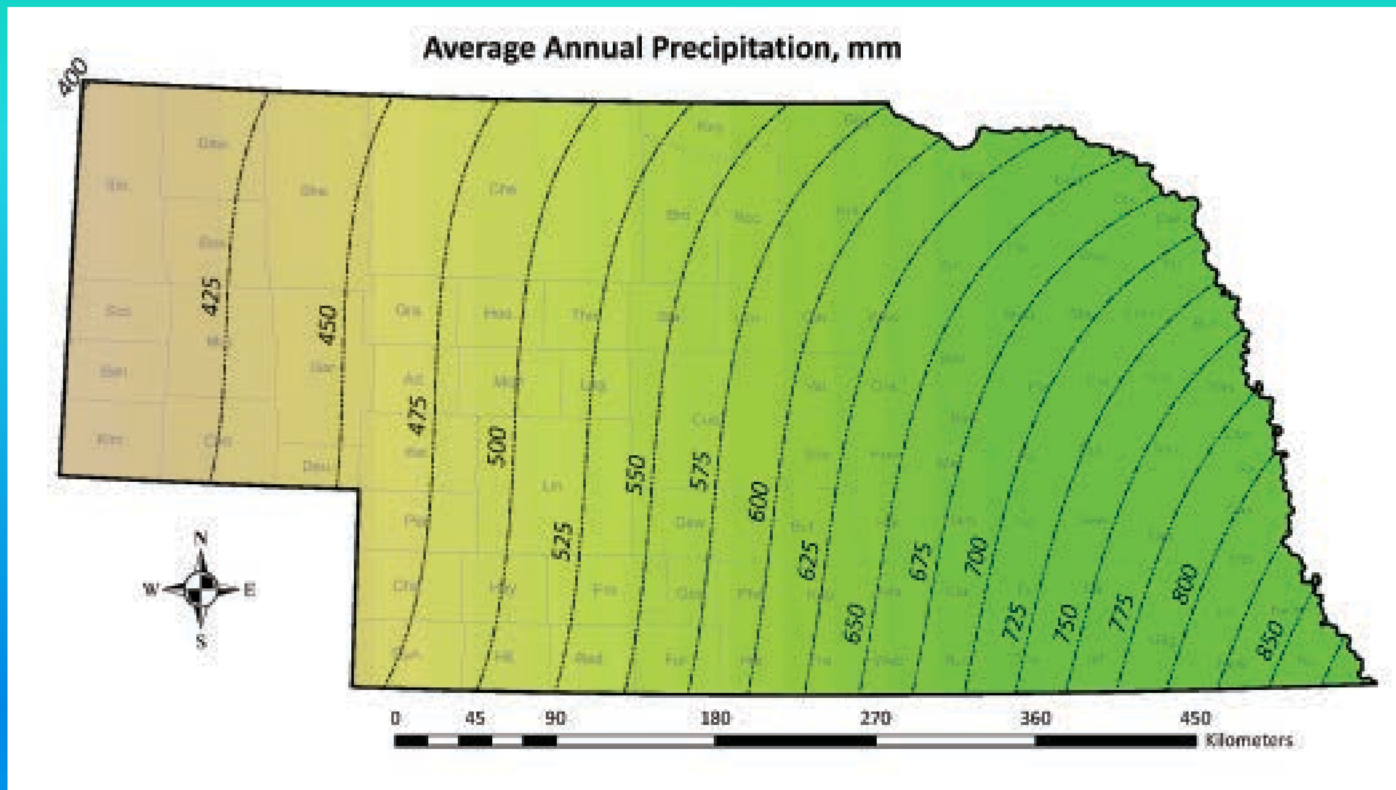
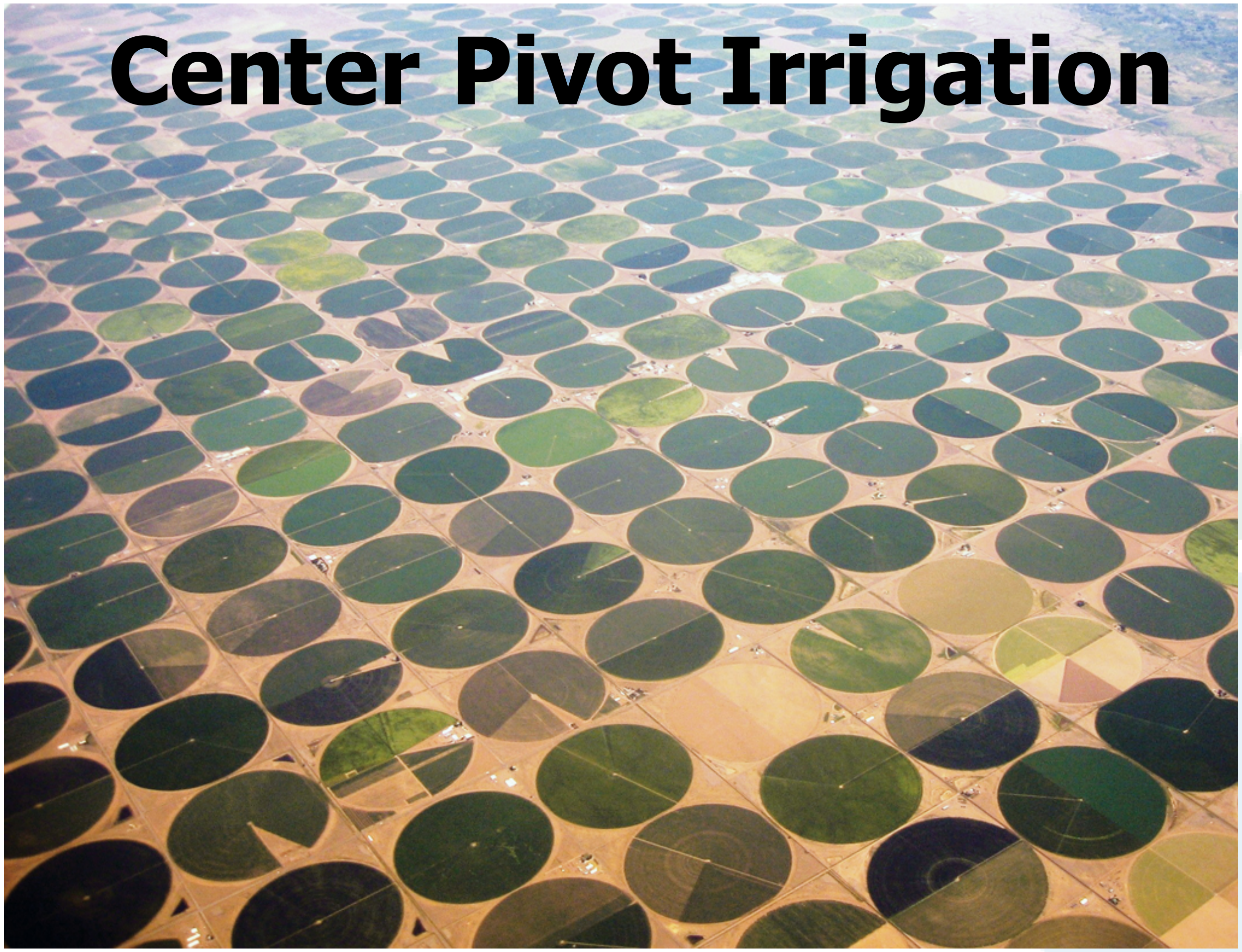
Precipitation is the Ultimate Water Source



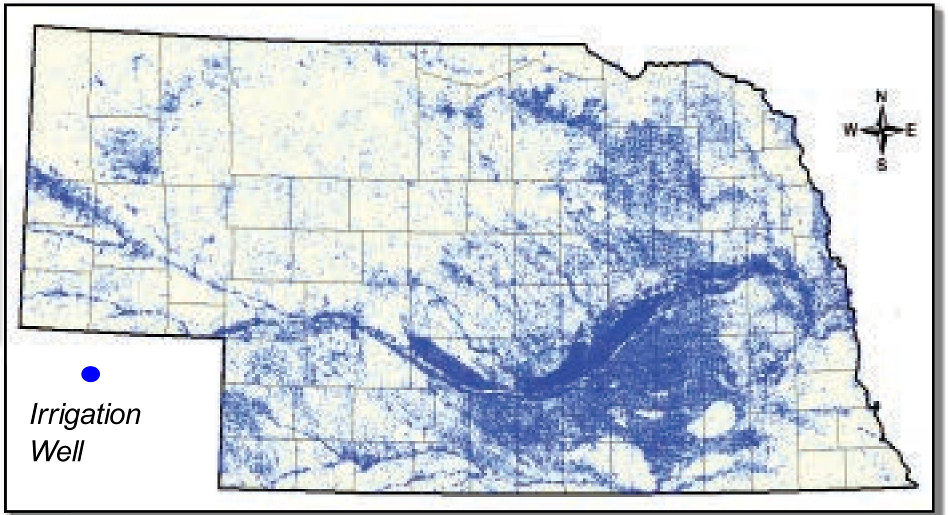
Average Annual Precipitation Decreases at About 75 mm per 100 km

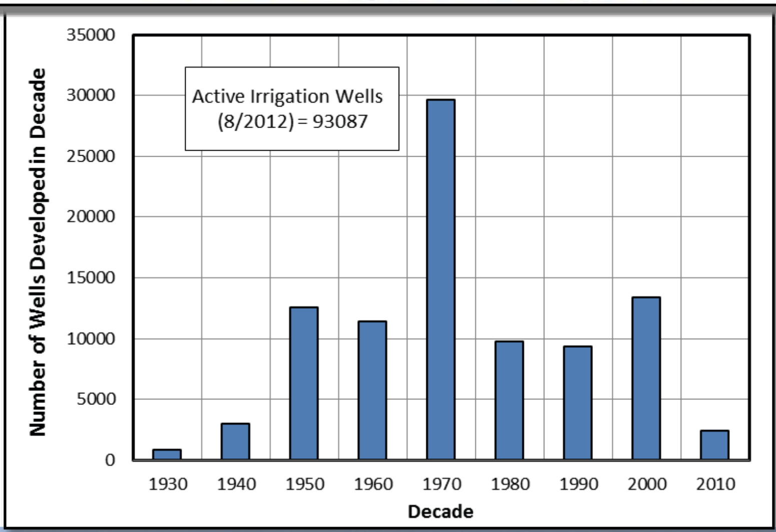
Center Pivot Irrigation



Irrigation Development

Active Irrigation Wells ~ 96,000
$6-8 Billion Investment

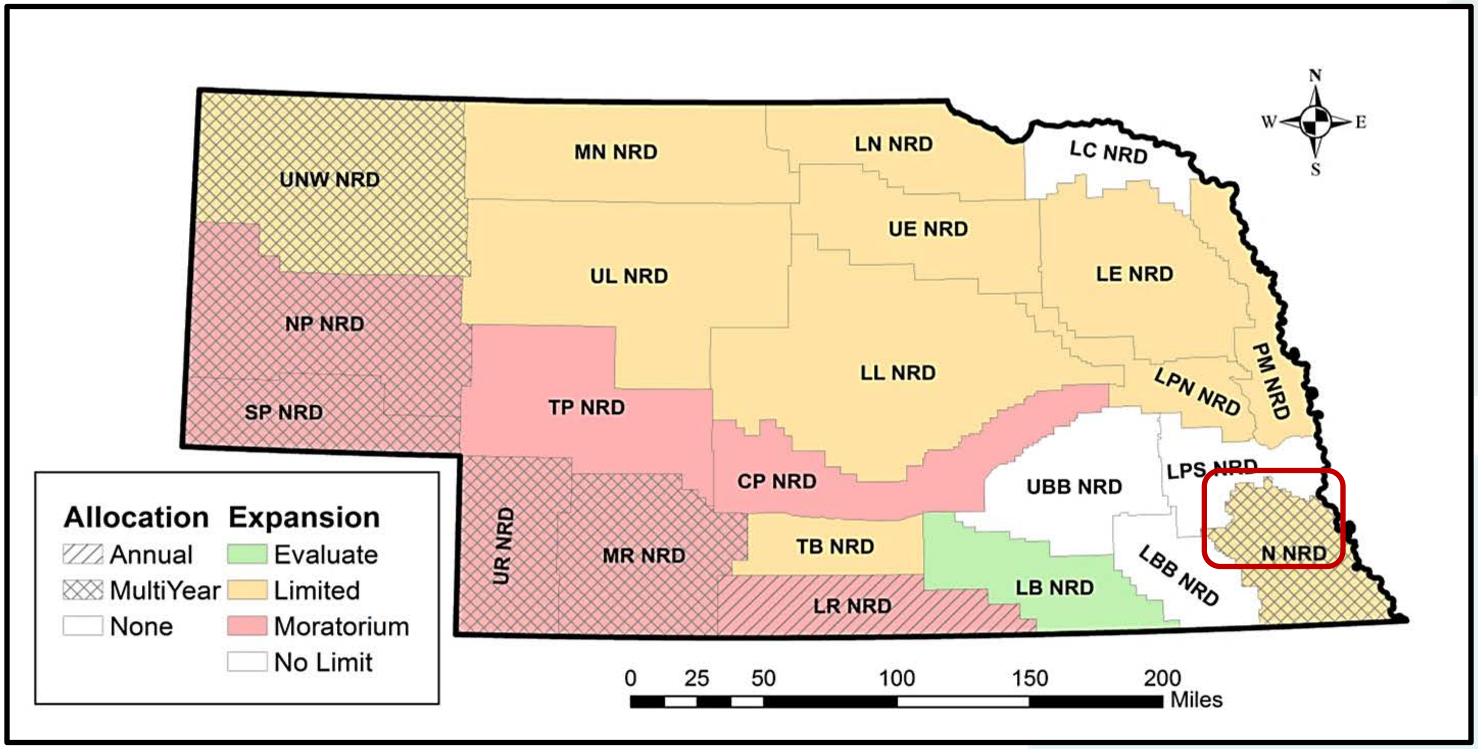




Major development occurred in 70's, but growth continues at about 2000 wells per year

Courtesy of Derrel Martin

Water Control Programs in Nebraska



- Allocation Programs Limit Volume of Pumpage Over a Period of Time
- Expansion Limits Restrict Development of New Wells or New Irrigated Areas
- Upper Big Blue Considering Allocation Program
- Other Western States Have Similar Issues/Programs

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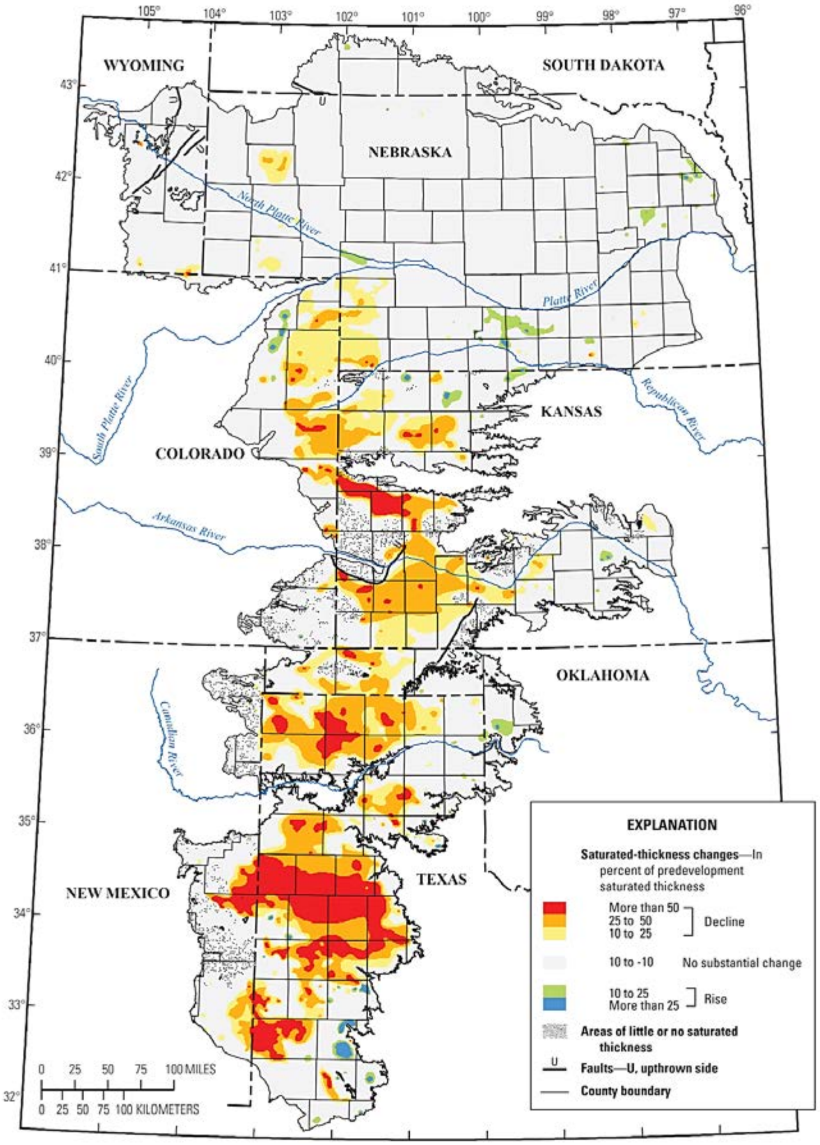
Depletion as Fraction of Saturated Thickness of the Aquifer

(McGuire , 2011)

Depletions in southern High Plains > 50% of saturated thickness

Small area in Nebraska > 25% of saturated thickness



Methods of Estimating Evapotranspiration (ET) from Remote Sensing:

Crop coefficient and reference ET:

- Reflectance-based crop coefficient models where vegetation indices are related to ET crop coefficients. Relationships are typically crop specific.

- Use shortwave (Visible, NIR) bands of UAV, airborne or satellite instruments.

Energy balance models:

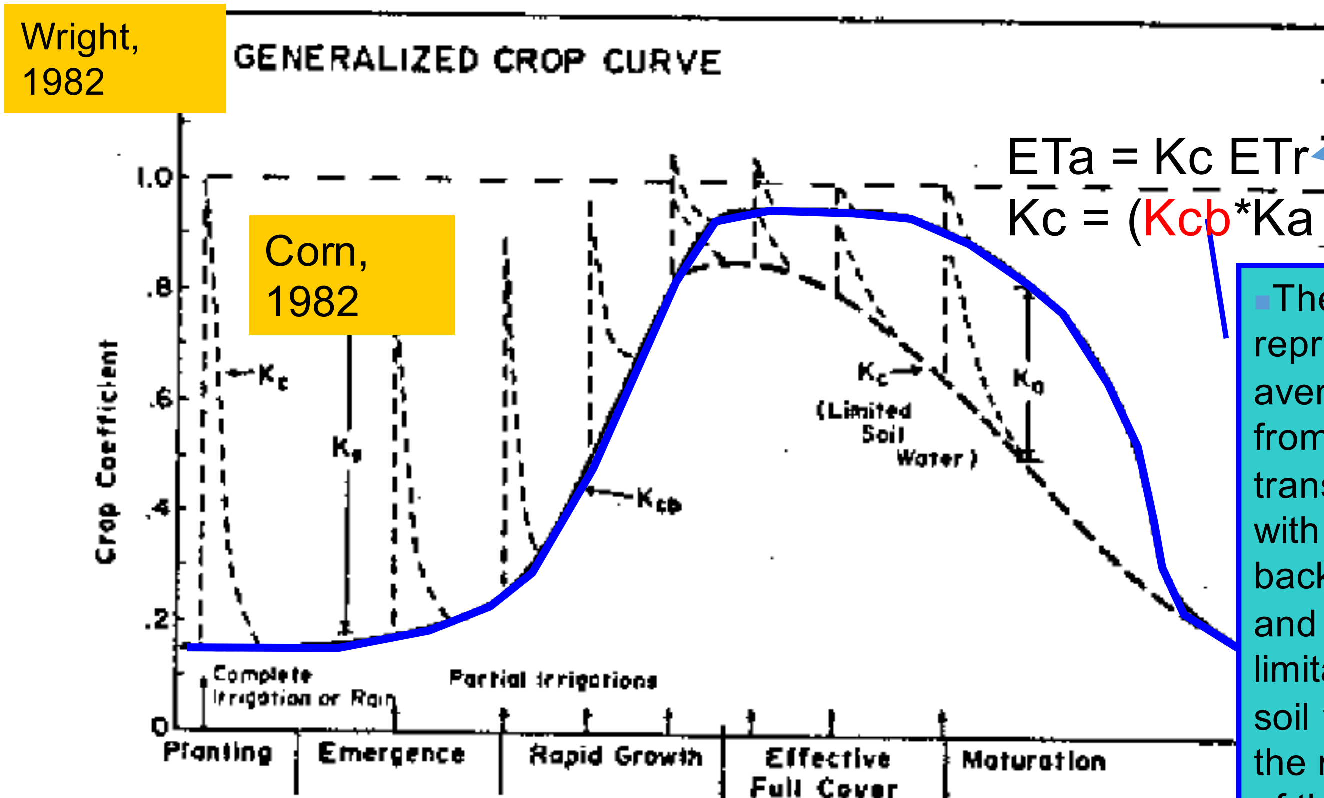
- One layer models examples: empirical models (OLEM), SEBS, SEBAL, METRIC, SSEBop
- Two-source model (TSM), ALEXI-DisALEXI
- Detailed Process models

- EB models require the use of both the thermal infrared and the Visible/NIR bands

Hybrid Methodologies:

- Combine energy and water balance models Hybrid ET (SETMI)

Reflectance-based Basal Crop Coefficient Kcb & Water Balance



Alfalfa Reference Crop

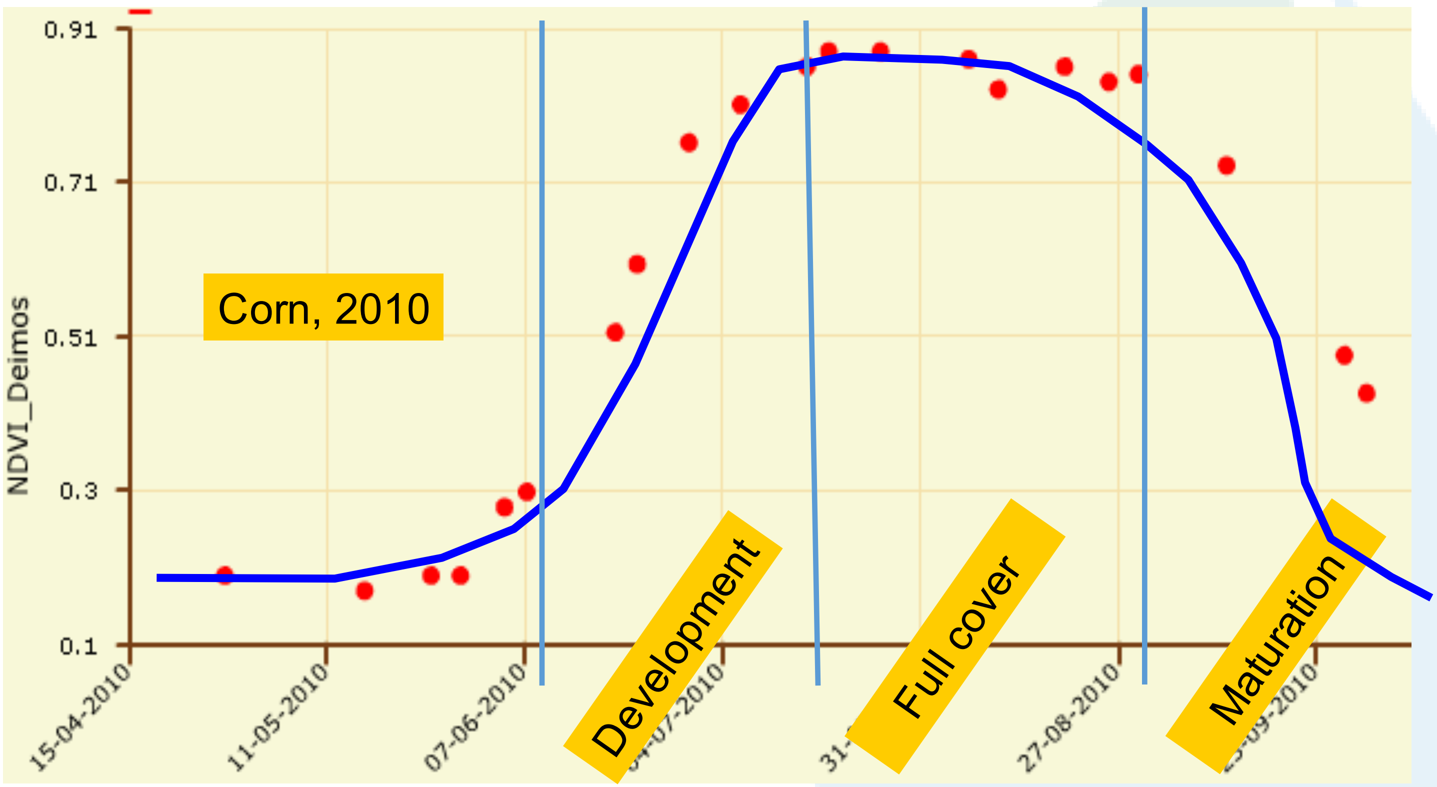
ETa = Kc ETr

Kc = (Kcb*Ka +Ks)

- The Kcb represents the average ET from plant transpiration with a dry soil background and no limitation of soil water in the root zone of the crop (From FAO56)

Neale, C. M. U., W.C. Bausch and D.F. Heermann. 1989. Development of reflectance based crop coefficients for corn. Transactions of the ASAE,Vol. 32(6):1891-1899

Evolution of Reflectance-based Crop coefficient (Kcbrf)



Rationale for re-examining Kbcrf for Corn

- Original research in the mid 1980's was based on very different varieties with a more planophile leaf structure, shorter plants and planted to a lower plant population reaching lower maximum LAI values in the field

- New hybrid varieties have an erectophile upper canopy, are taller and planted at a higher density reaching higher LAI values in the field

Reflectance based Kcb Transformations

Reflectance-based crop Coefficients

Are obtained by linearly relating the NDVI or SAVI of bare soil with the NDVI or SAVI at effective full cover the point of maximum ET on a crop coefficient curve

NDVI = (NIR – Red) / (NIR + Red)

SAVI = (NIR – Red) (1+L) / (NIR + Red + L)

Effective full cover occurs at LAI varying from 2.7 to 3.5 depending on the crop and with percent cover around 80%

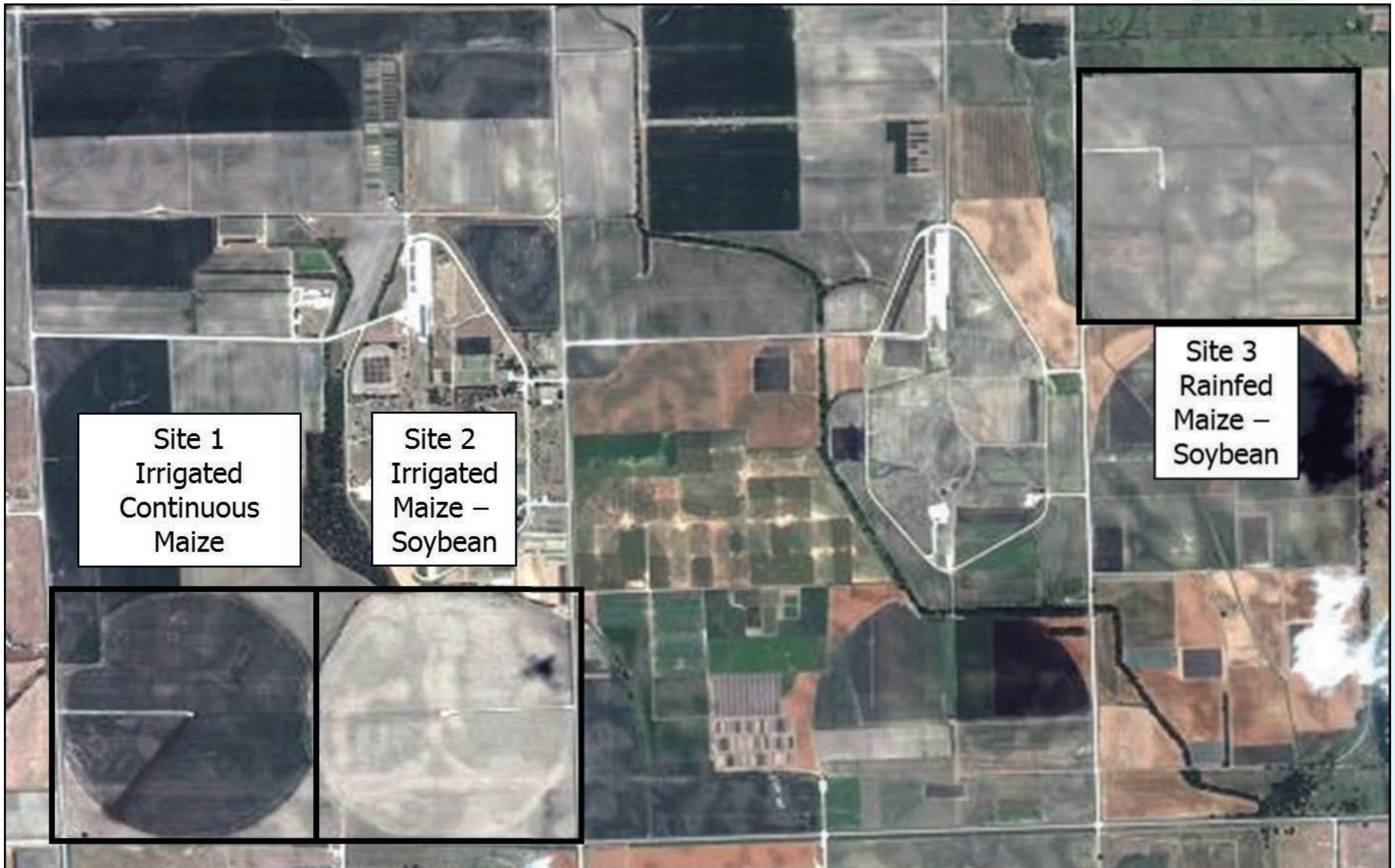
SAVI and NDVI are vegetation indices estimated from Red and Near-Infrared bands of satellite, airborne sensor or ground radiometers

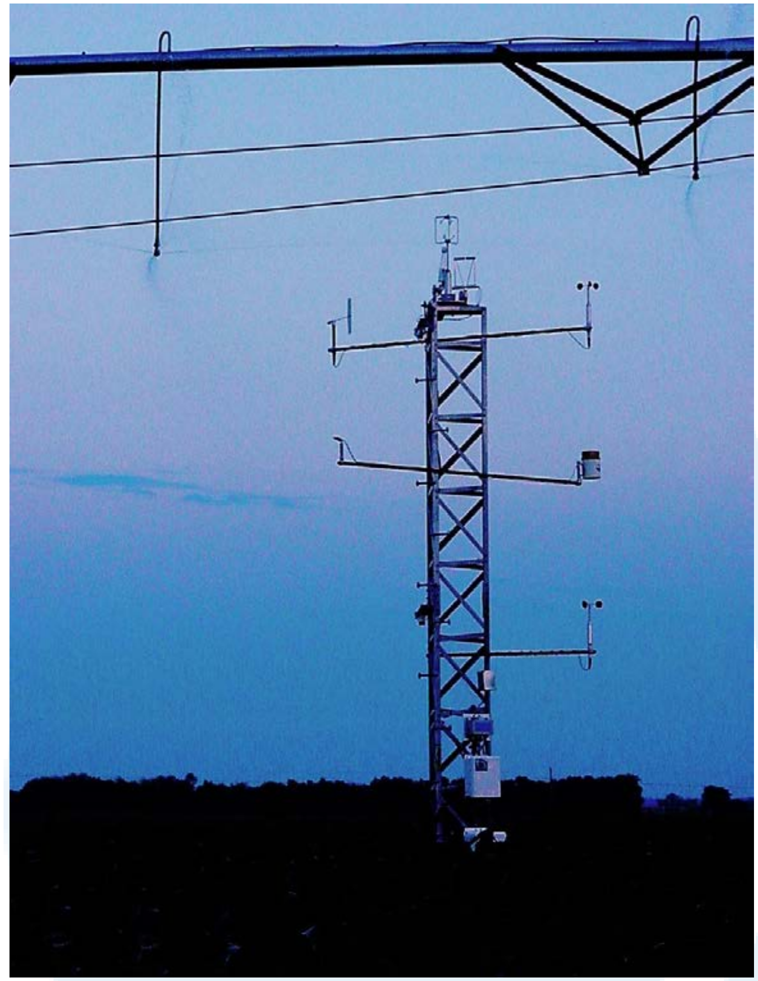
$$K_{crf} = \frac{(SAVI - SAVI_{BARE\ SOIL}) * (K_{cb\ EFC} - K_{cb\ BARE\ SOIL})}{(SAVI_{EFC} - SAVI_{BARE\ SOIL})} + K_{cb\ BARE\ SOIL}$$

Neale et al., 1989; Bausch and Neale, 1989
Bausch, 1993

Carbon Sequestration Research Facility

at the UNL Agricultural Research and Development Center, Mead

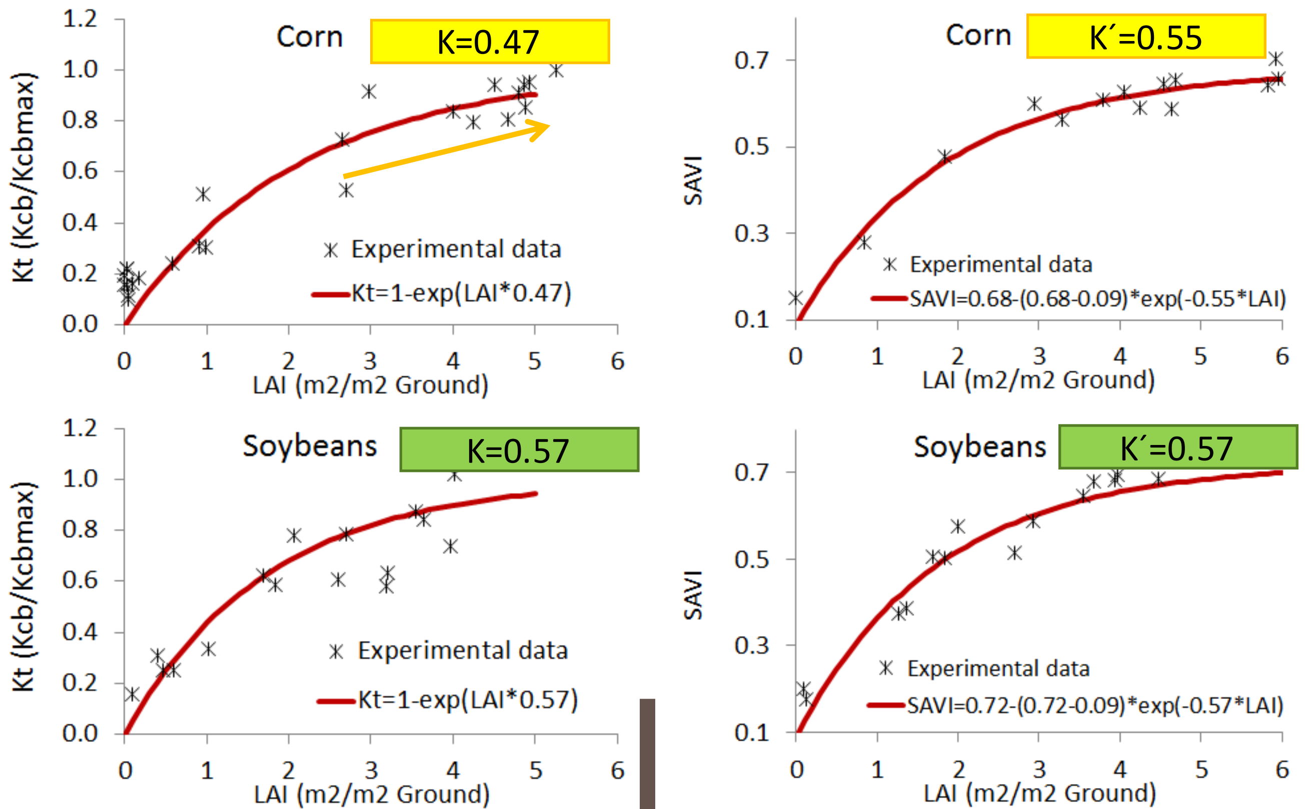




Re-analyzing the approach to convert VI (SAVI) in crop coefficients for irrigation management.

Empirical demonstration for Corn and Soybeans

$$K_t = 1 - e^{(-K \times LAI)} \qquad VI = VI_{max} - (VI_{max} - VI_{min}) \times e^{(-K' \times LAI)}$$



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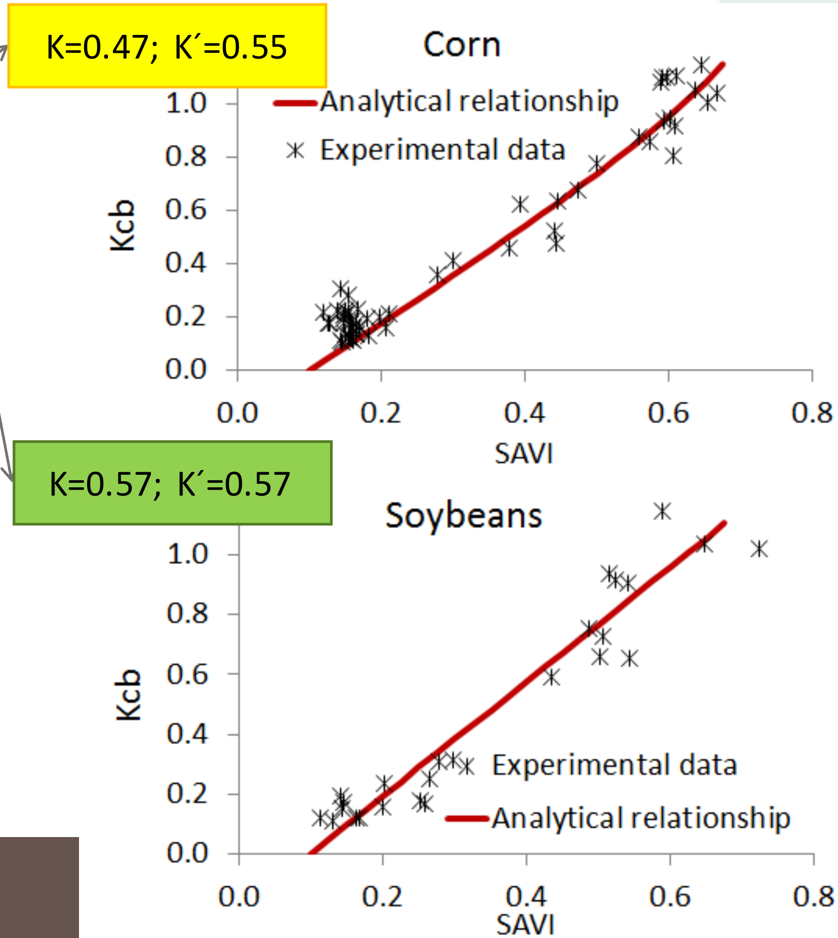
Re-analyzing the approach to convert VI in crop coefficients for irrigation management.

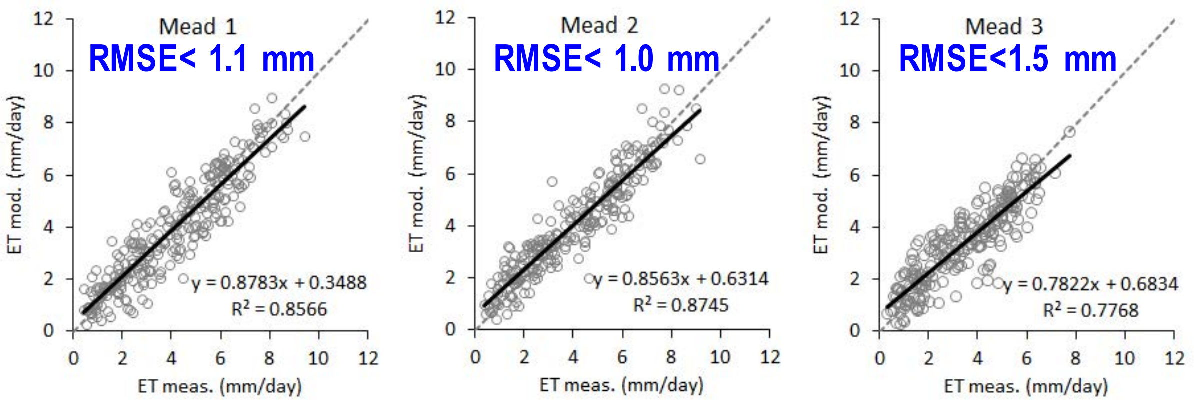
$$K_{cb} = K_{cb,max} \times \left[1 - \left(\frac{VI_{max} - VI}{VI_{max} - VI_{min}} \right)^{k/k'} \right]$$

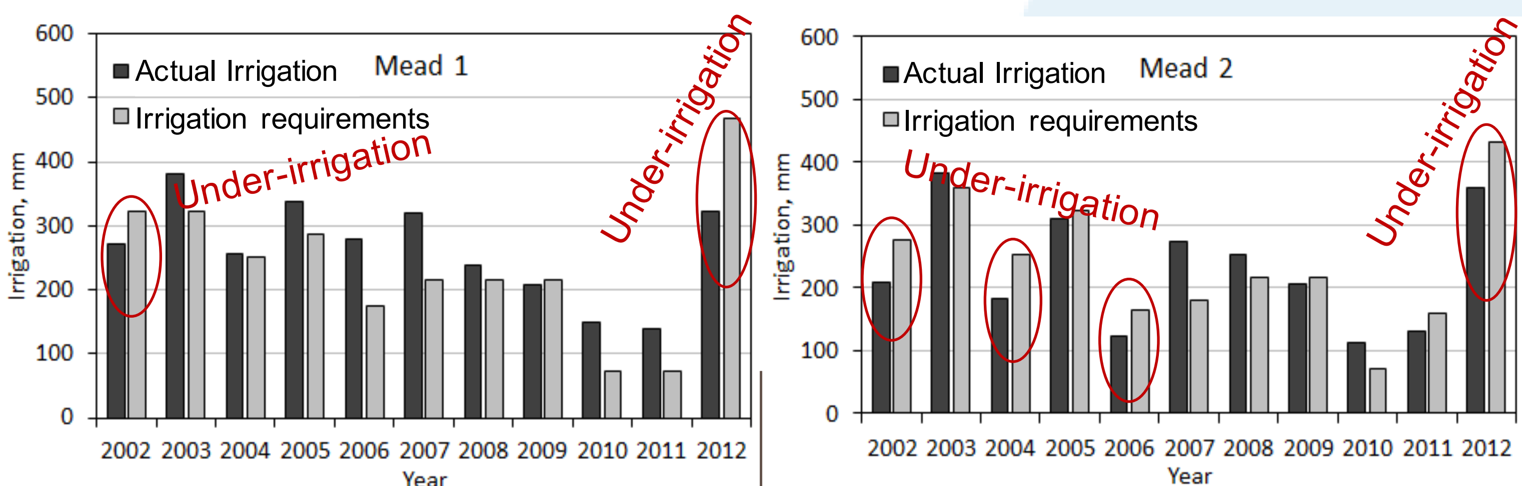
- Non-linear relationships for both crops
- General good agreement with moderate differences for minimum SAVI values
- Need to consider the role of bare soil in ET rates also in the absence of plant development



New Reflectance based Kcb for Corn and Soybeans

Application for ET and Irrigation requirements for Corn and Soybeans





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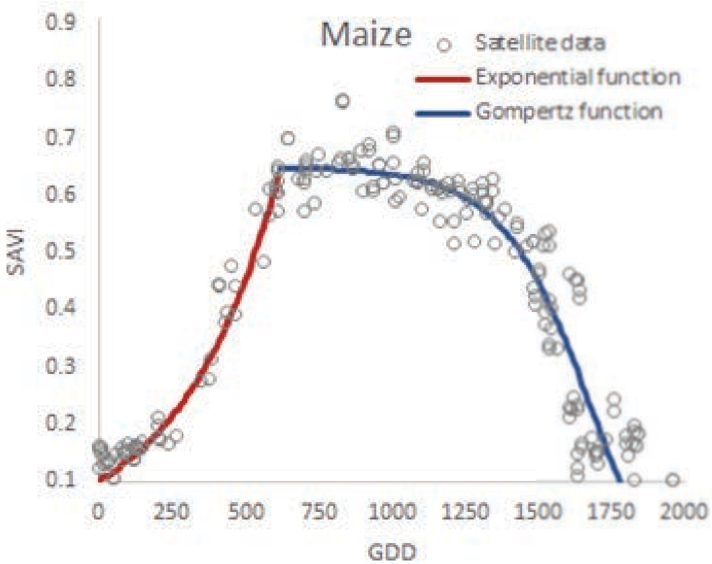
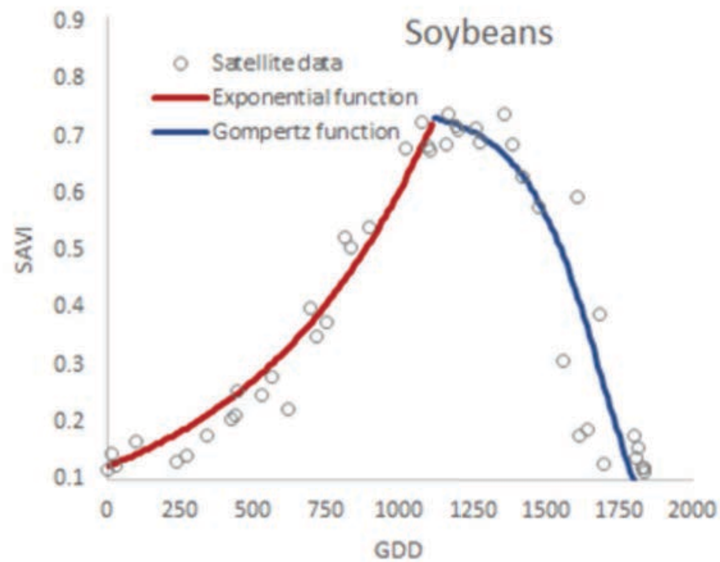
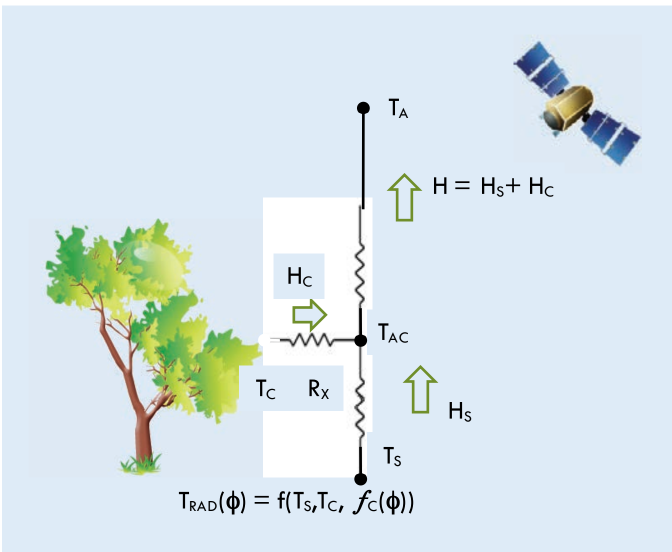




Reflectance-based Crop Coefficients Redux: For Operational Evapotranspiration Estimates In The Age Of High Producing Hybrid Varieties. 2017. Isidro Campos; Christopher M.U. Neale; Andrew E. Suyker; Timothy J. Arkebauer; Ivo Z. Gonçalves. Agricultural Water Management.. Vol. 187, Pages 140-153.
http://dx.doi.org/10.1016/j.agwat.2017.03.022

The Hybrid ET model[1]

Diagnostic SVAT Scheme
The Two-Source Energy Balance Model (TSEB)[2,3]

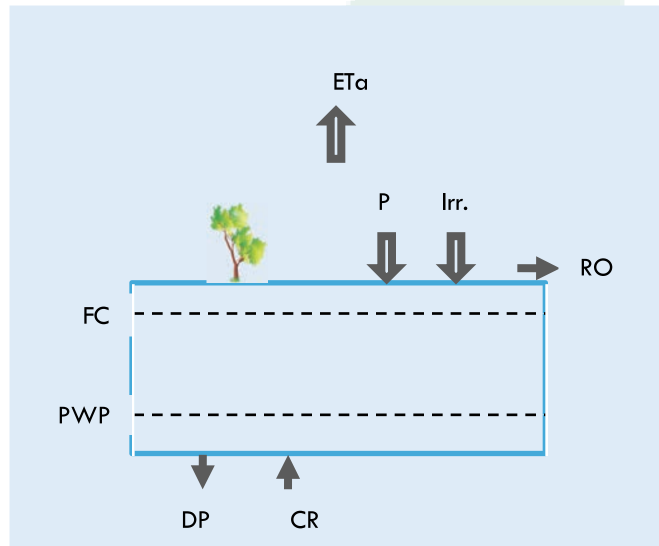


Series Resistance Formulation

$$LE = Rn - G - H$$

[2] Norman and Kustas (1995), [3]Li , et al.(2005)

Prognostic Modified FAO-56[4]
water balance in the root zone



Modified with reflectance -based basal crop coefficient (Kcbrf)[5]

[4] Allen et al. (1998), [5]Neale et al. (1989)

ET_0 estimated using Penman-Monteith Equation

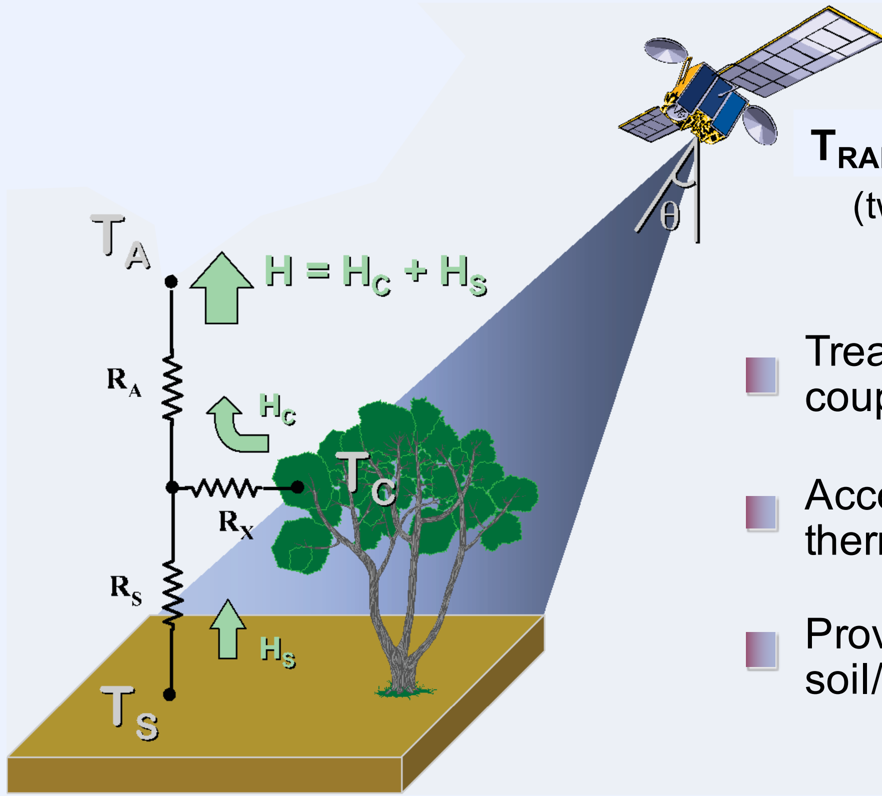
Grass Reference Crop

$$ET_a = K_c \, . ET_0$$

$$K_c = K_{cbrf} \, . \, K_a + K_e$$

[1]Neale et al. (2012), Soil water content estimation using a remote sensing based hybrid evapotranspiration modeling approach. In Advances in Water Resources, Volume 50, December 2012, Pages 152-161, ISSN 0309-1708

Two-Source Energy Balance Model (TSEB)



$T_{RAD}(\theta) \sim f_c(\theta)T_c + [1\text{-}f_c(\theta)]T_s$

(two-source approximation)

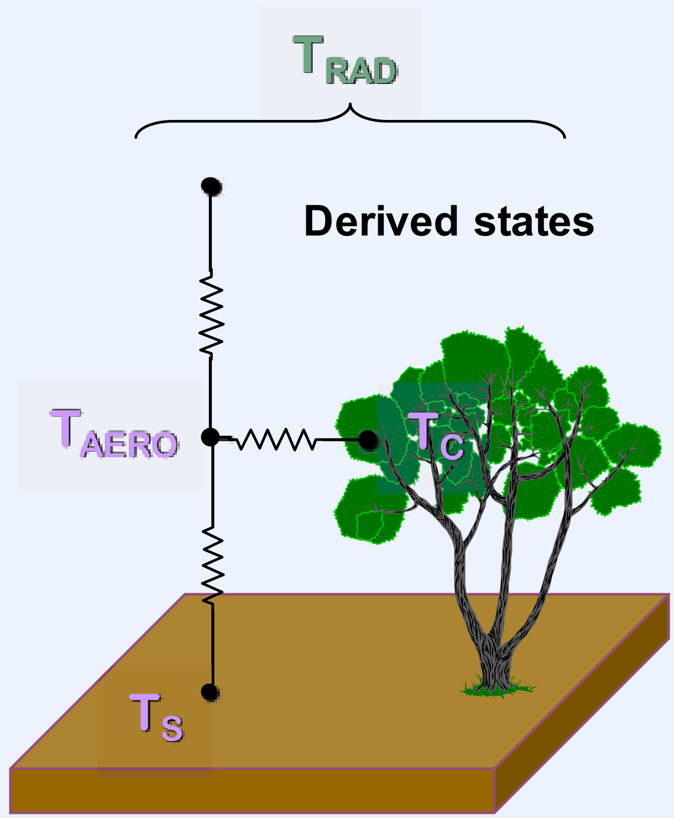
Norman, Kustas et al. (1995)

- Treats soil/plant-atmosphere coupling differences explicitly
- Accommodates off-nadir thermal sensor view angles
- Provides information on soil/plant fluxes and stress

System and Component Energy Balance

SYSTEM	RN	=	H	+	λE	+	G
	=		=		=		
CANOPY	RN_C	=	H_C	+	λE_C		
	+		+		+		
SOIL	RN_S	=	H_S	+	λE_S	+	G

Derived fluxes



The Hybrid Model

- Combined K_{cbrf} water balance with TSEB
- Water balance (WB) ET updated using statistical interpolation (Geli, 2012; Neale et al., 2012):

$$ET_{WB-adjusted} = ET_{WB} + W(ET_{TSEB} - ET_{WB})$$

- *W* is a function of the respective "error variance" of each model
- Differences are attributed to K_s and thus modeled depletion. Both are subsequently updated.

Geli, H.M.E. 2012. *Modeling Spatial Surface Energy Fluxes of Agricultural and Riparian Vegetation Using Remote Sensing.* Ph.D. Dissertation. Civil and Environmental Engineering Department, Utah State University, Logan, UT. Paper 1165. Available at: http://digitalcommons.usu.edu/1165.

Neale, C.M.U, H.M.E. Geli, W.P. Kustas, J.G. Alfieri, P.H. Gowda, S.R. Evett, J.H. Prueger, L.E. Hipps, W.P. Dulaney, J.L. Chávez, A.N. French, T.A. Howell. 2012. "Soil water content estimation using a remote sensing based hybrid evapotranspiration modeling approach." *Adv. in Water Res*. 50: 152-161. DOI: 10.1016/j.advwatres.2012.10.008

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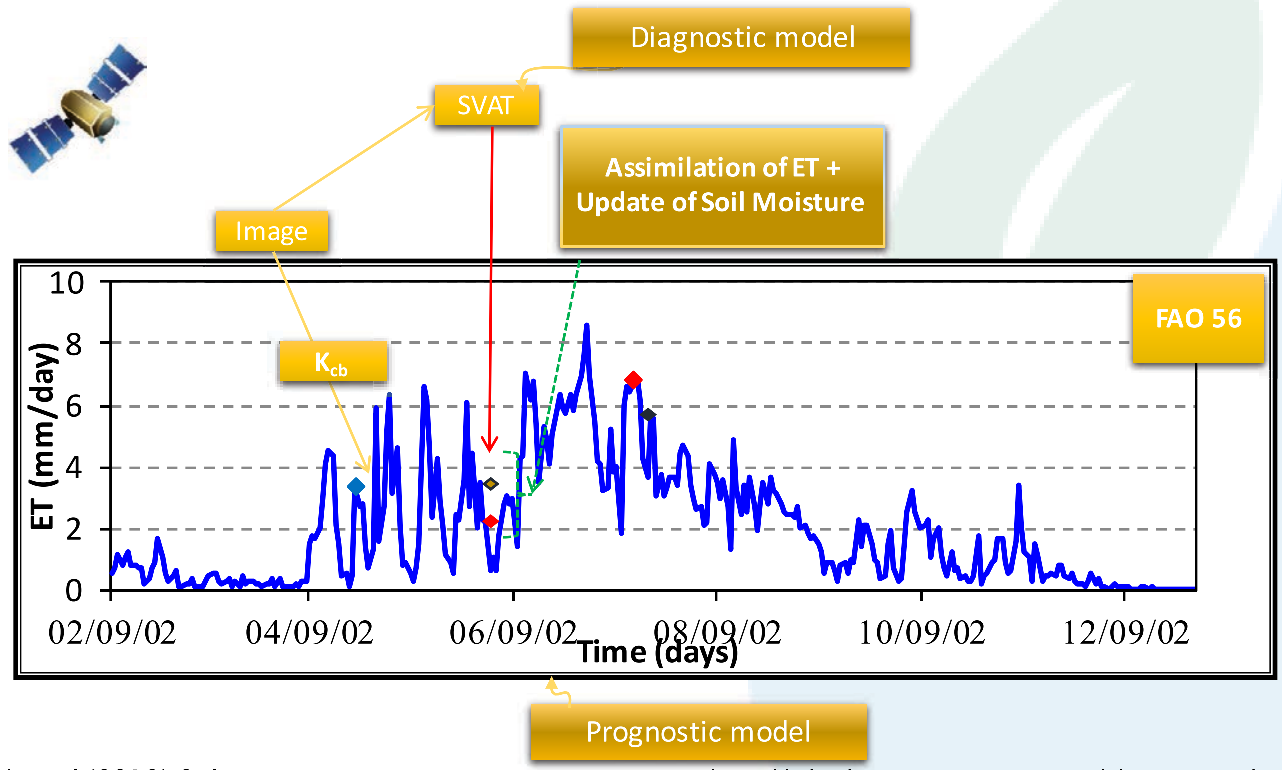
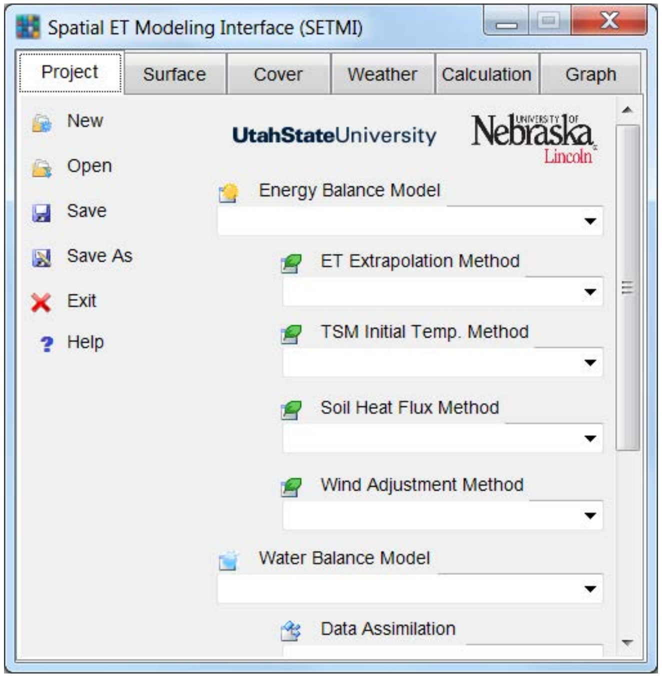
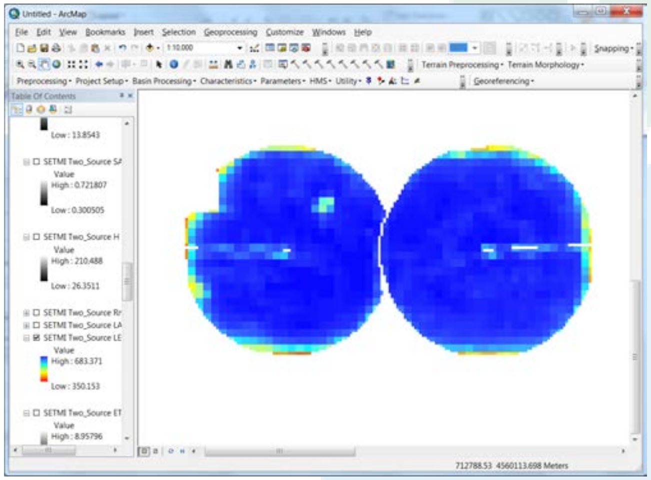


[1]Neale et al. (2012), Soil water content estimation using a remote sensing based hybrid evapotranspiration modeling approach. In Advances in Water Resources, Volume 50, Pages 152-161, ISSN 0309-1708, 10.1016/j.advwatres.2012.10.008.

Methods – SETMI Interface

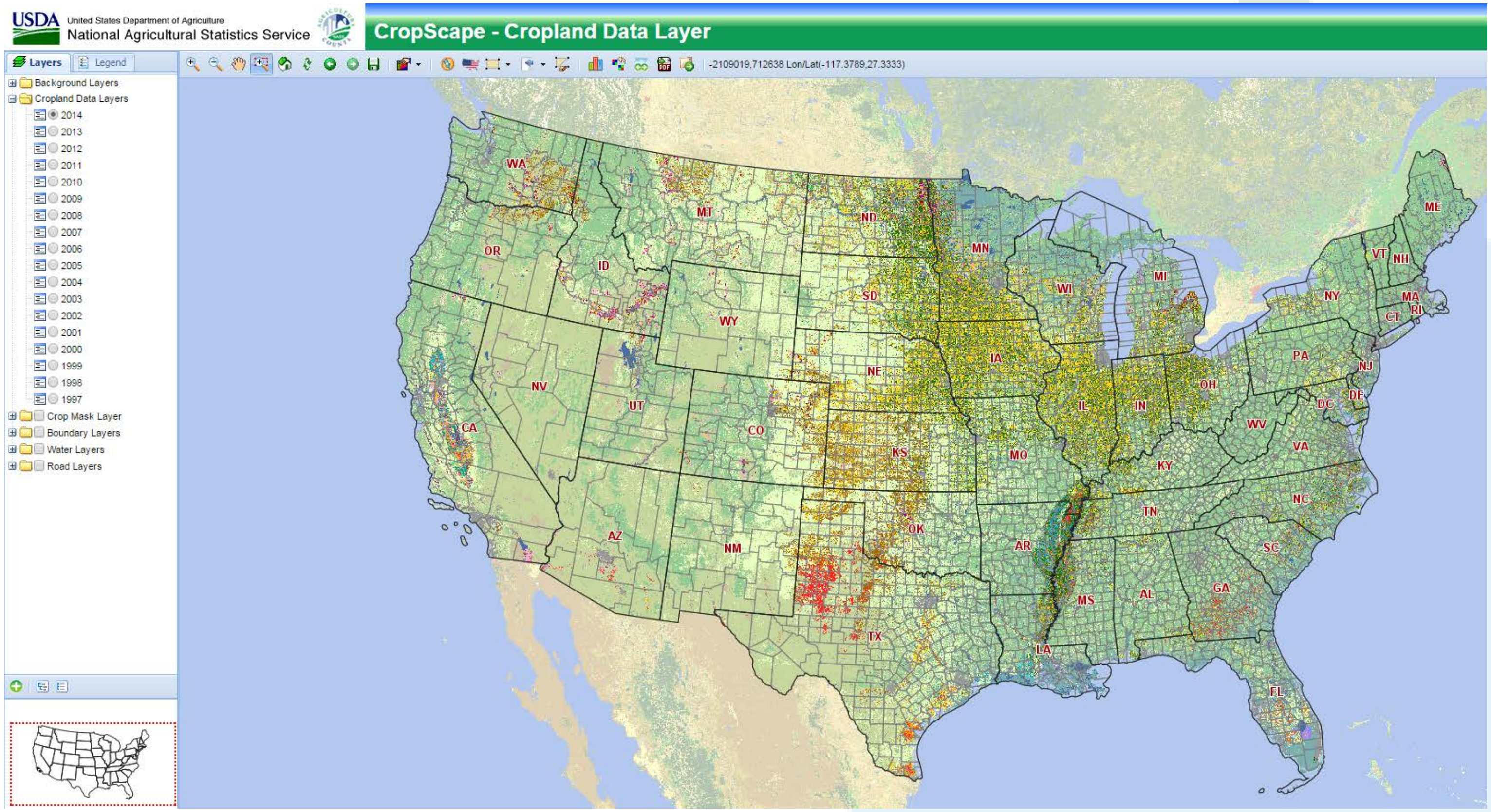


- Spatial EvapoTranspiration Modeling Interface (SETMI)
- Operates in ArcGIS Environment



Geli, H. M. E. and C.M.U. Neale, (2012), Spatial evapotranspiration modeling (SETMI), Proc. IAHS 352, Remote Sensing and Hydrology (September 2010), ISSN 0144-7815

Geo-spatial Data: Crop Classification Layers



Provided by USDA NASS, based on Landsat Thematic mapper and other satellite image data

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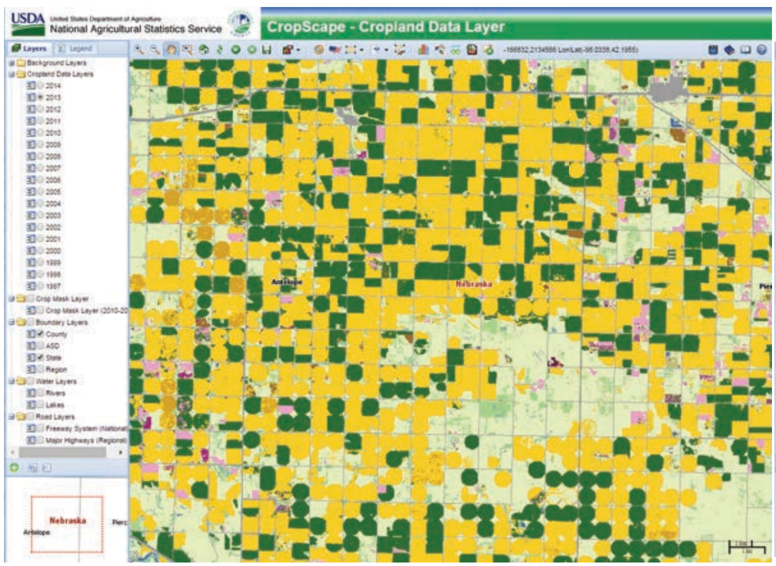
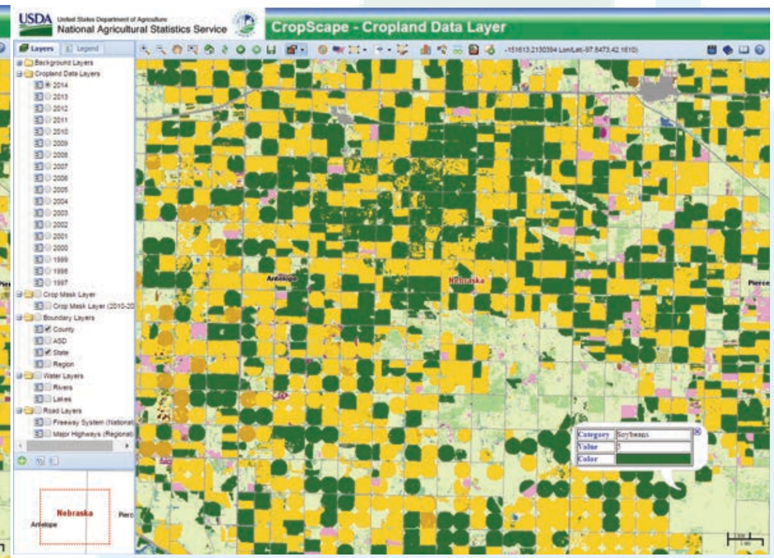
Northeastern Nebraska Corn/Soybean Rotation

2013



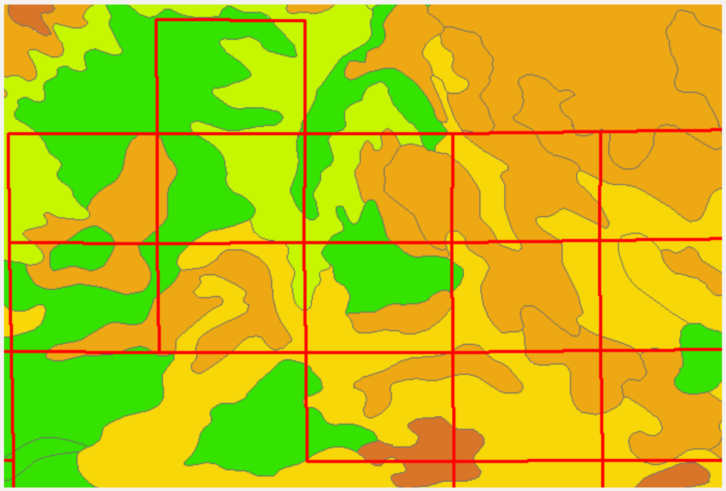
2014



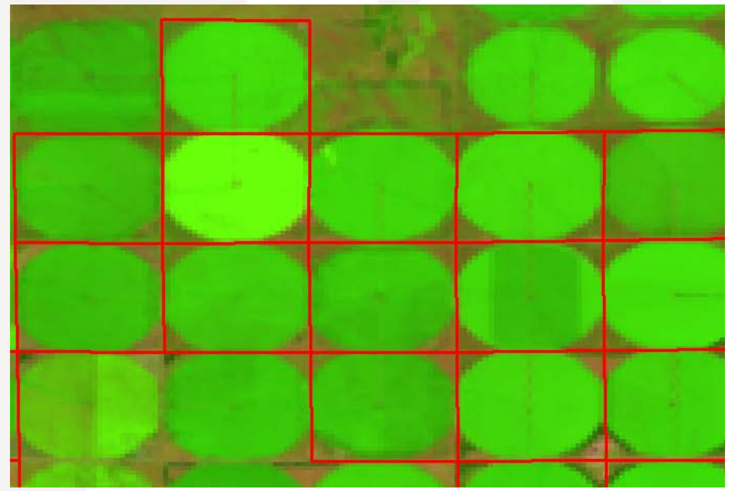
Many satellite-based evapotranspiration models require the knowledge of the crop type at the surface

Digital Soil Survey Information

Map of water holding capacity in the 1st m. profile



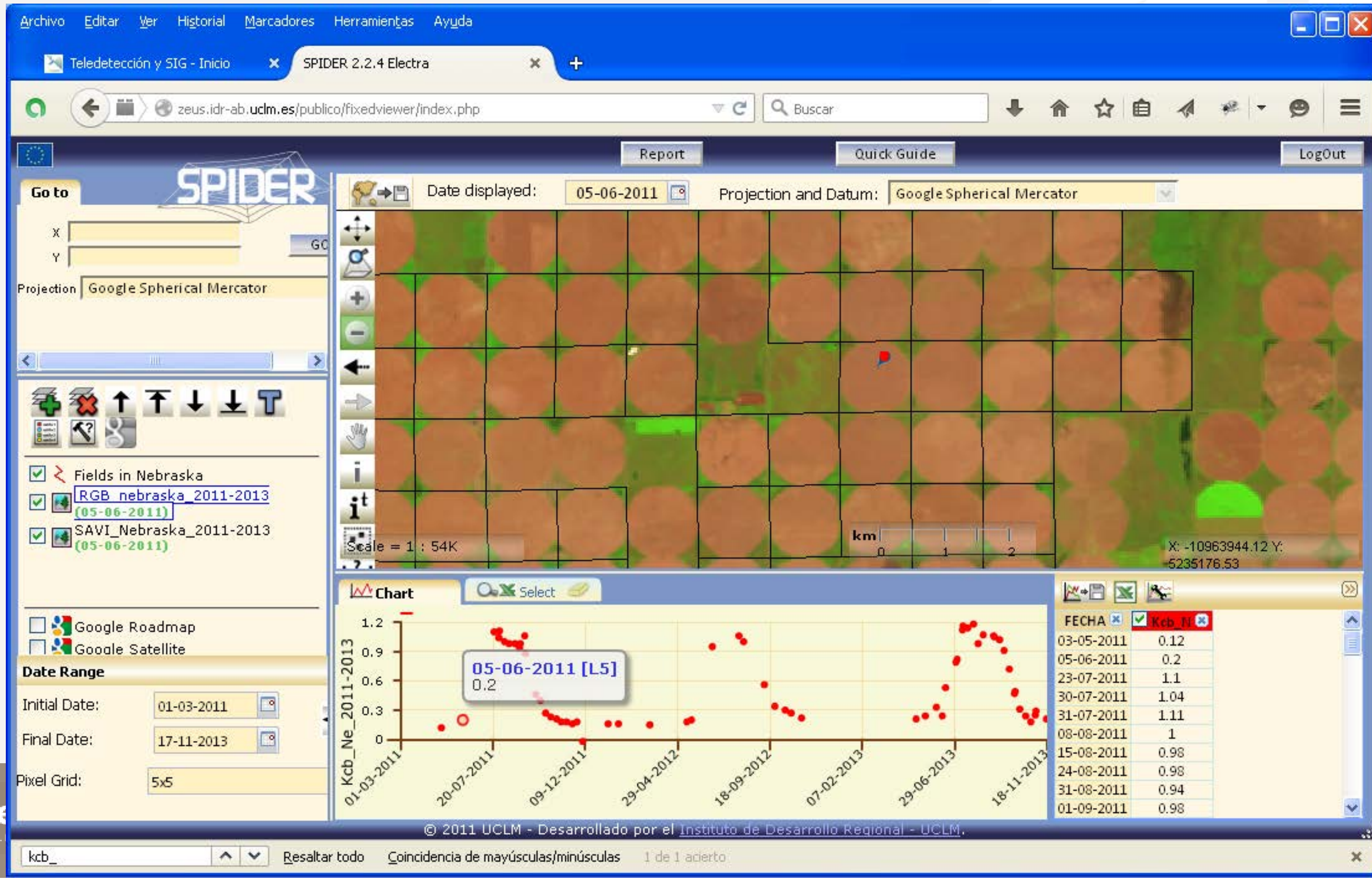
RGB color composition, L8 Date 07/19/2913

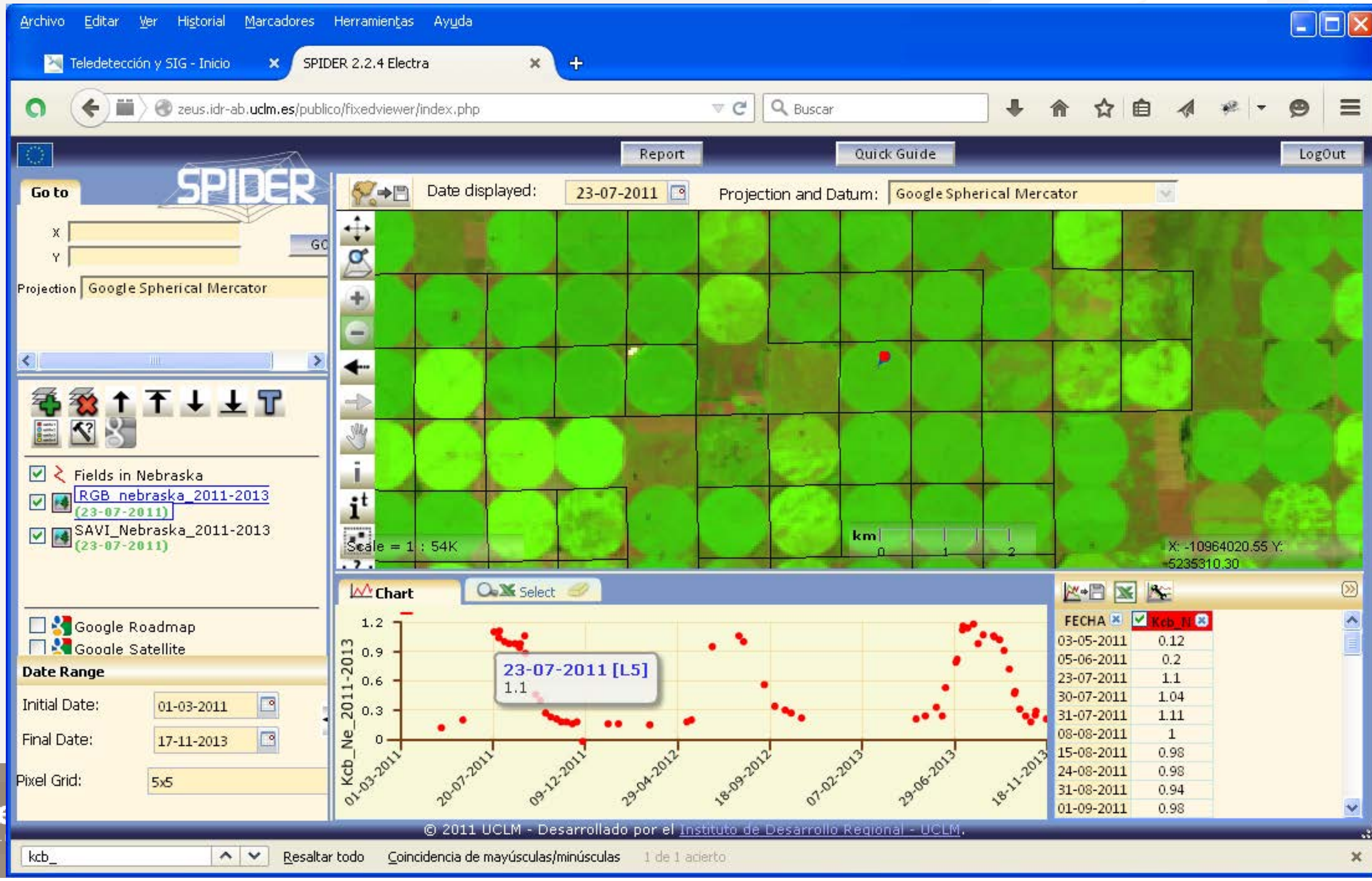


Source: USDA Natural Resource Conservation Service (http://websoilsurvey.sc.egov.usda.gov/App/WebSoilSurvey.aspx)

Variables include: Soil type, texture, depth, layers, water holding capacity, infiltration rates, organic matter content etc.

Landsat 5, 7, 8 sequence displayed Using the SPIDER Software from UCLM, Spain

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(23-07-2011)
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Google Satellite
Date Range
Initial Date: 01-03-2011
Final Date: 17-11-2013
Pixel Grid: 5x5
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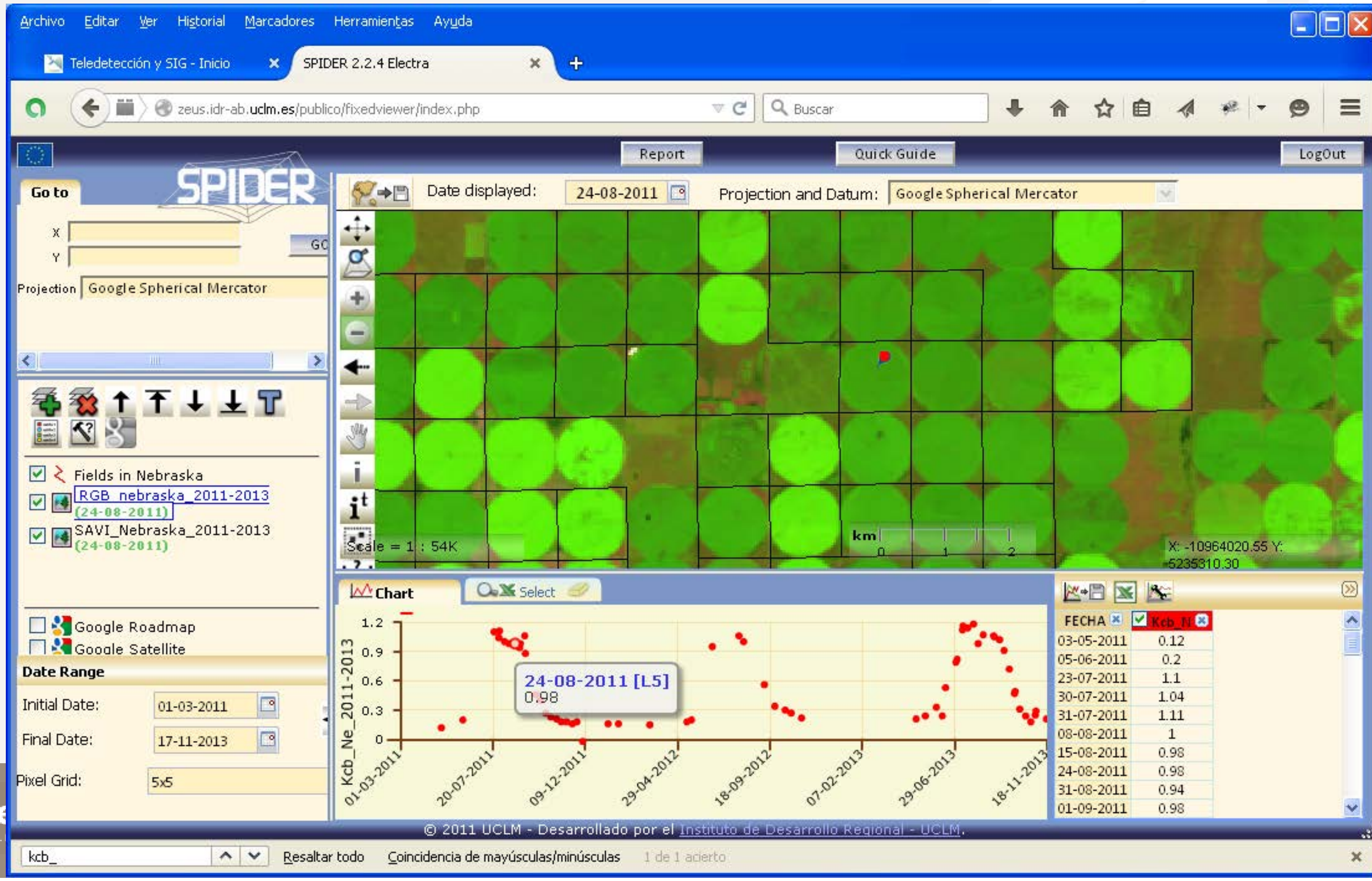

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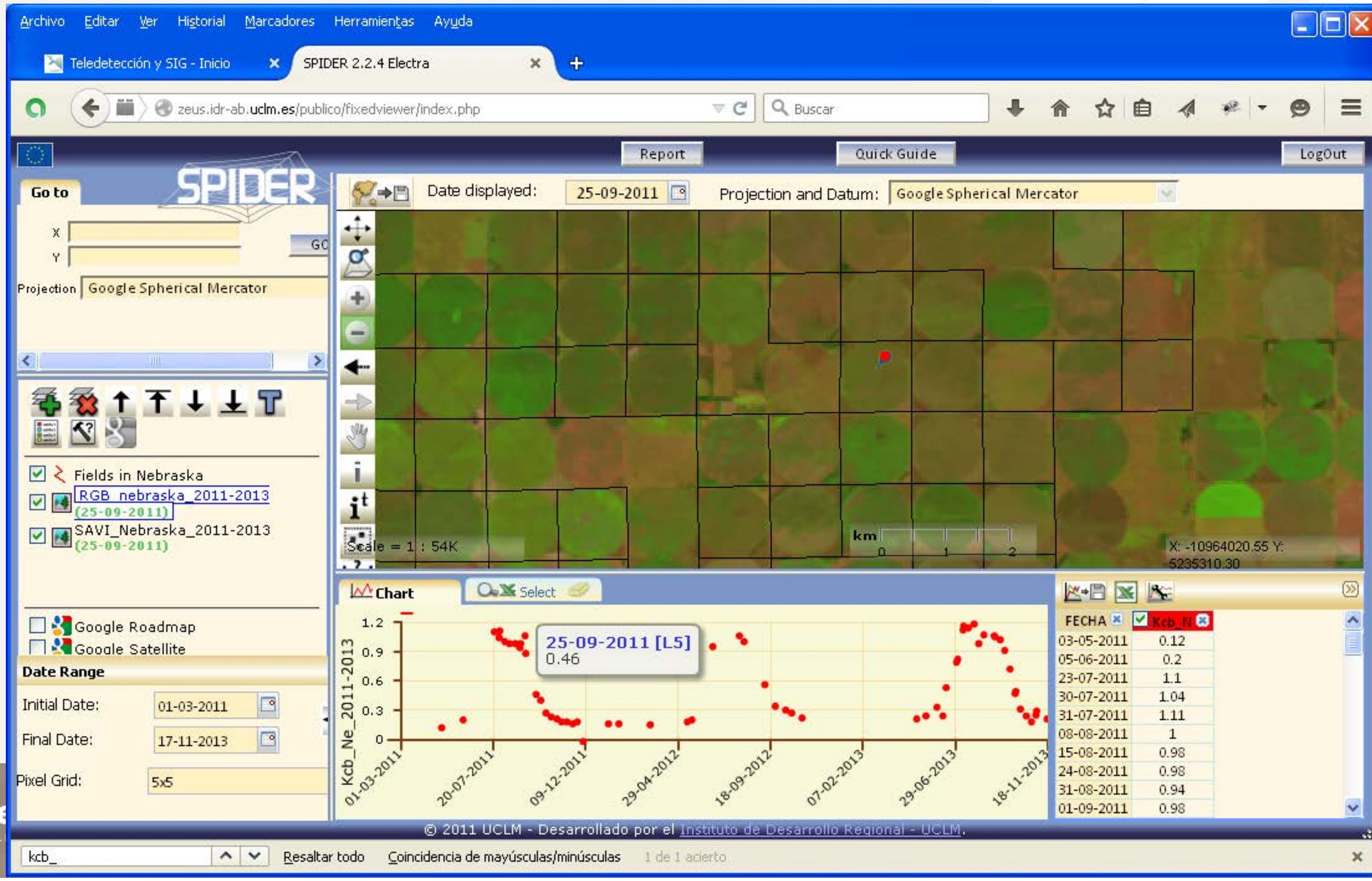

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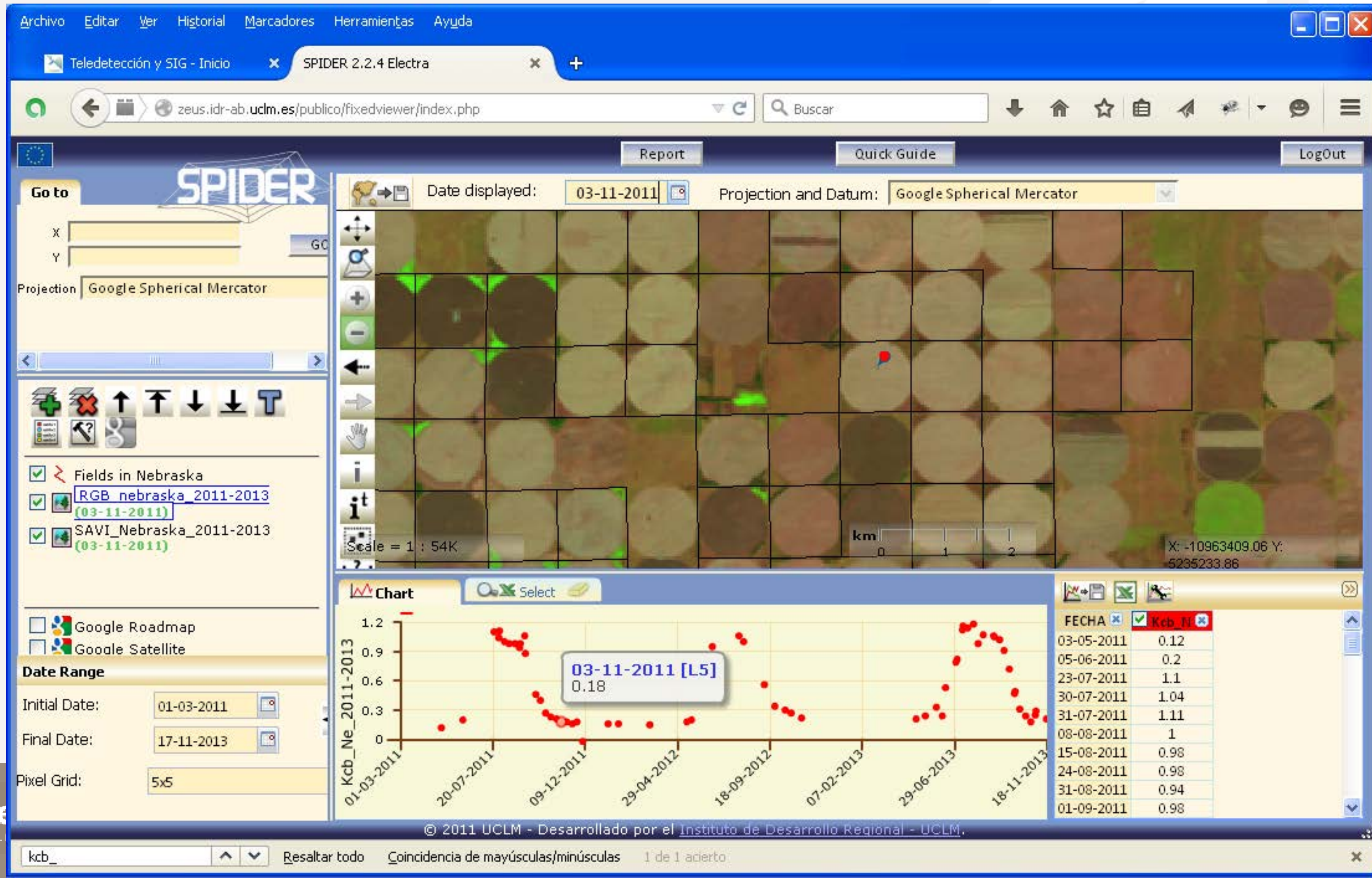

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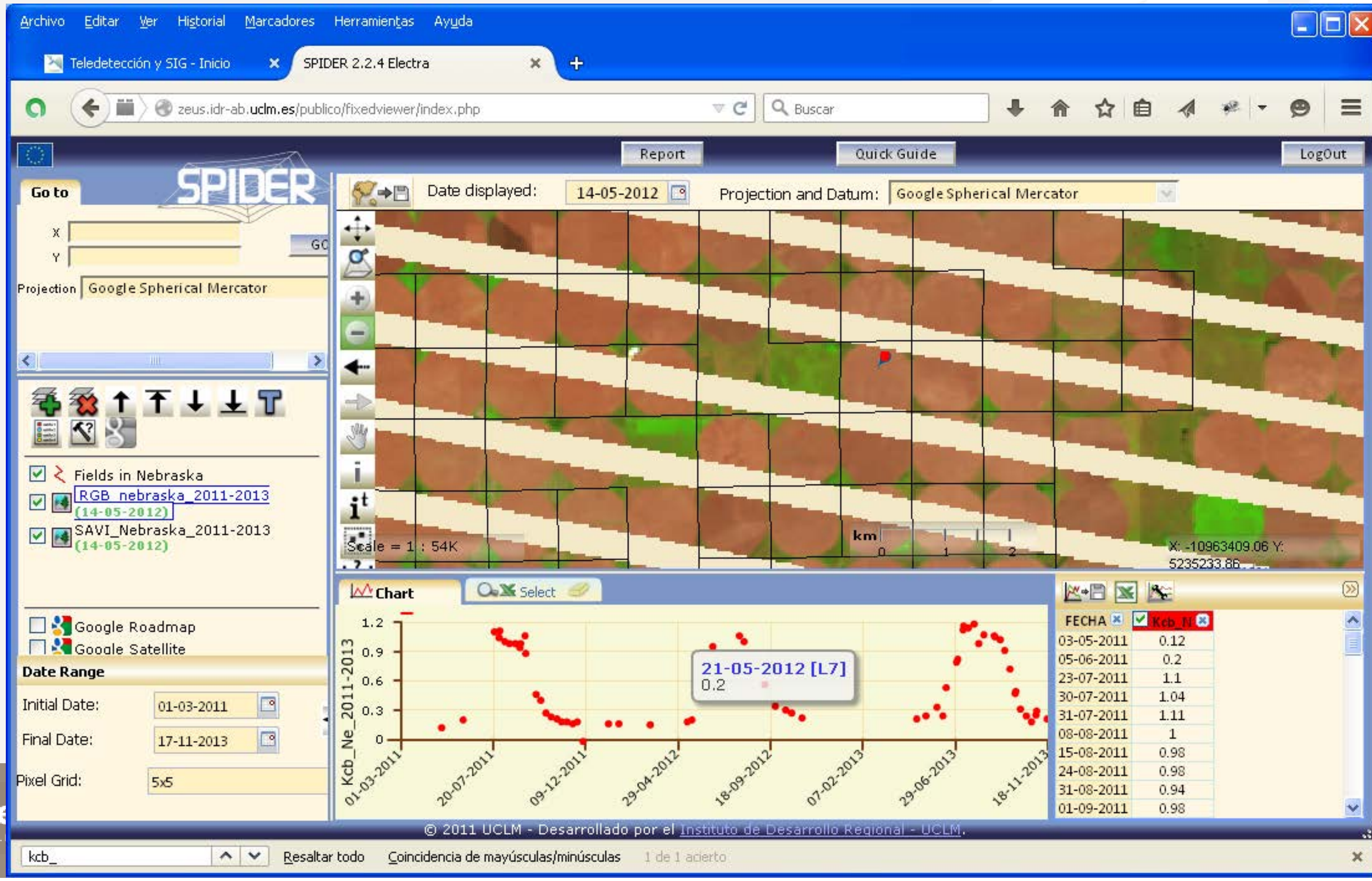

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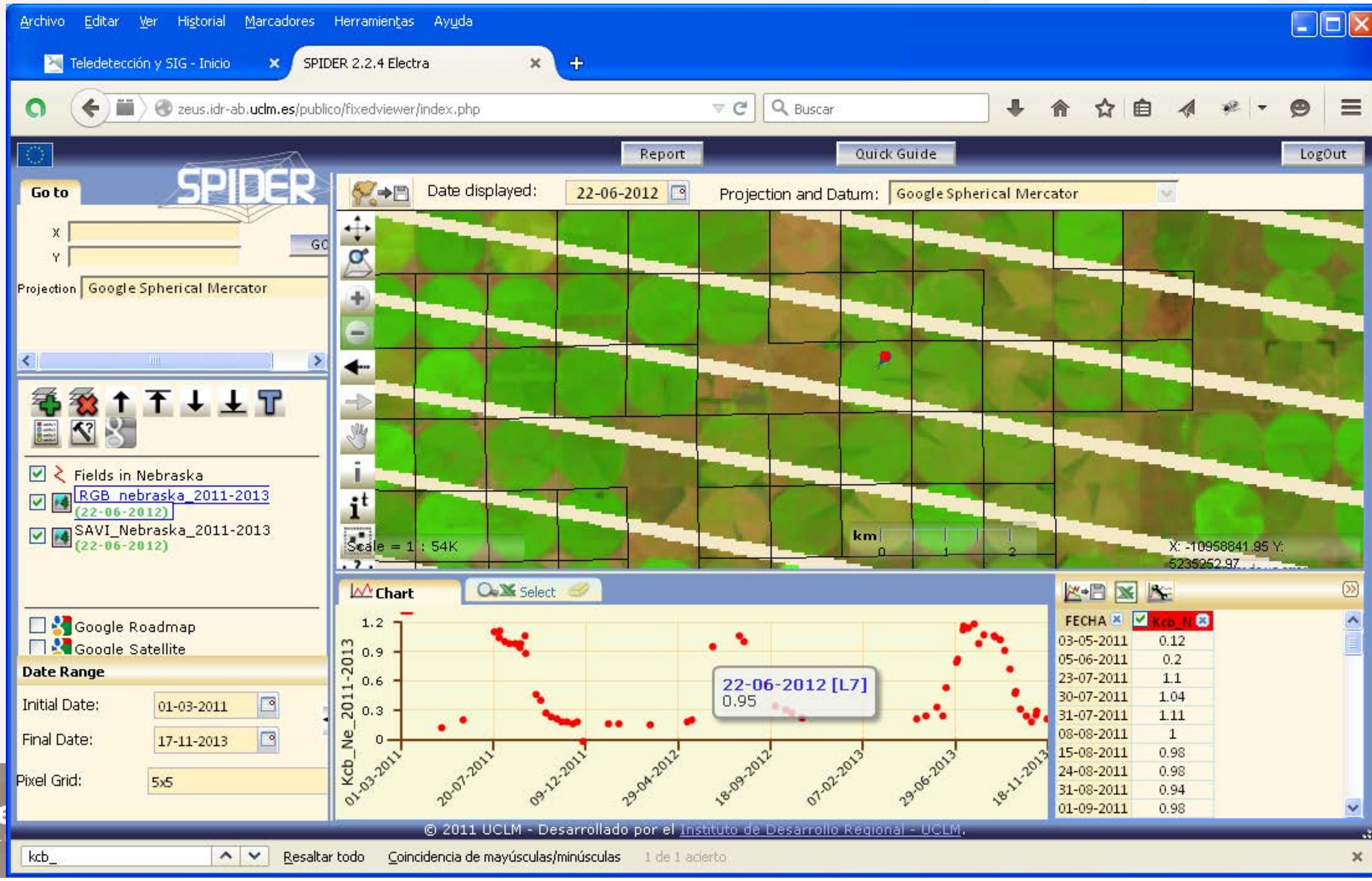
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01-09-2011 | 0.98
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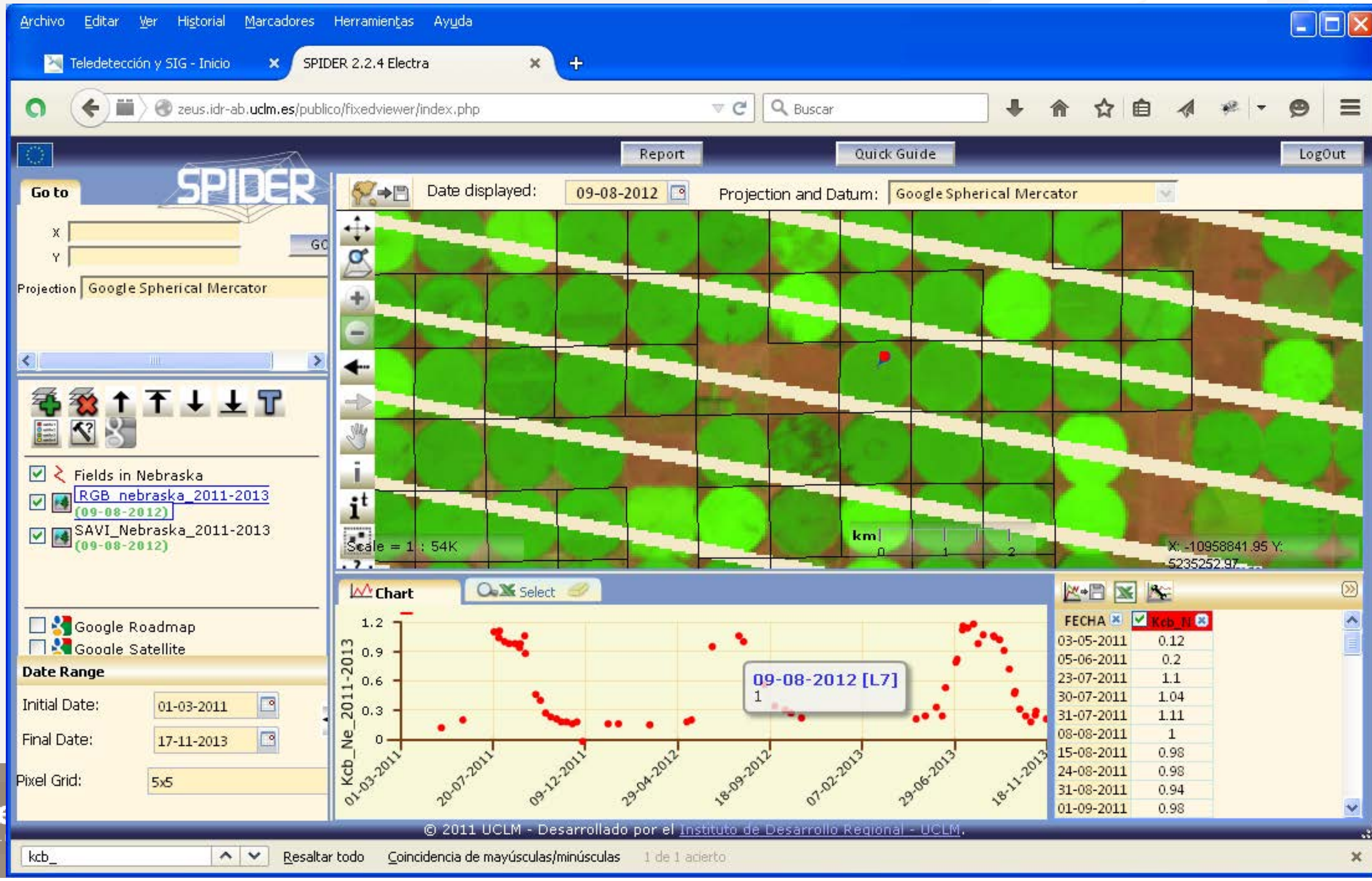
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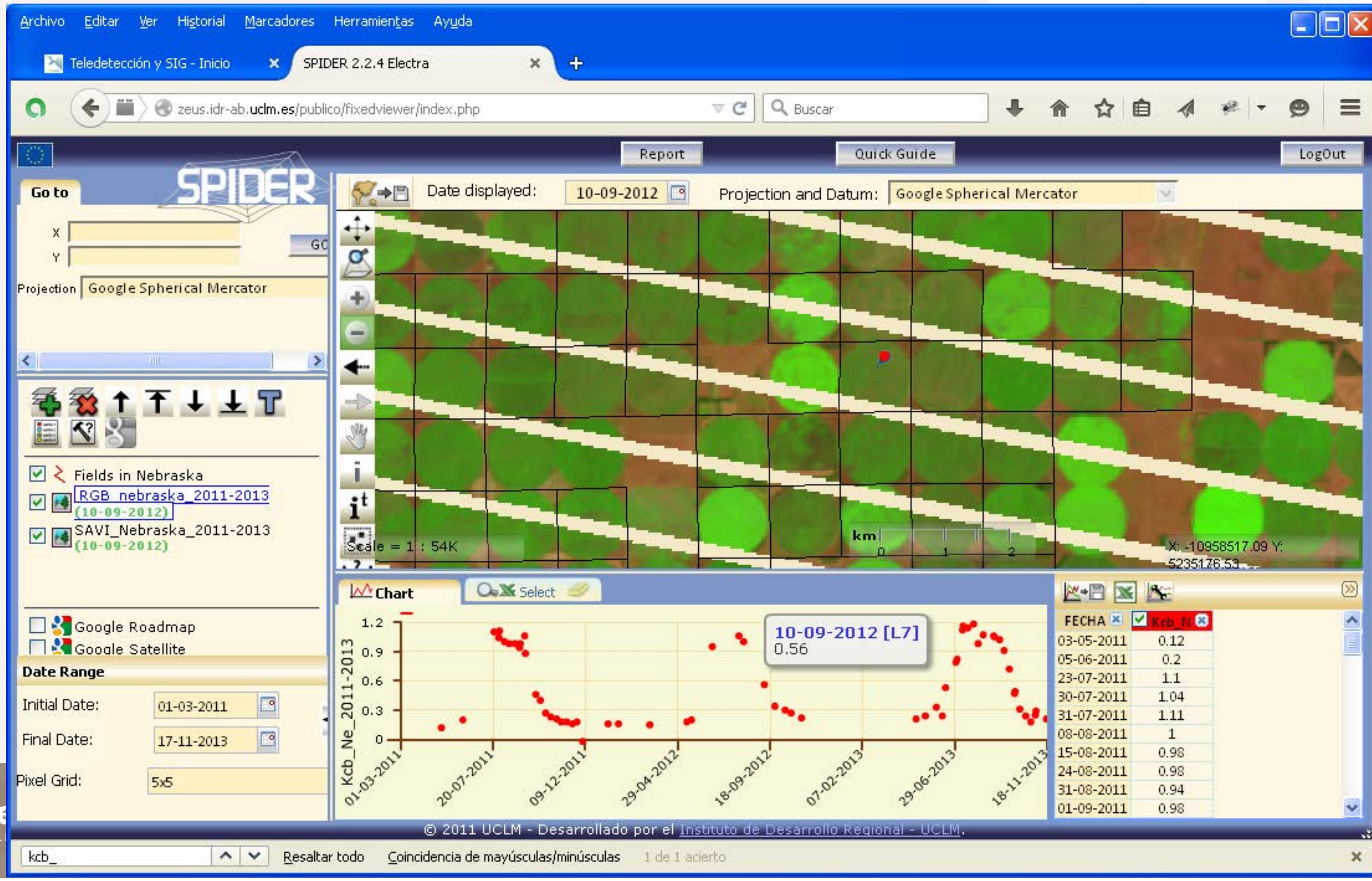

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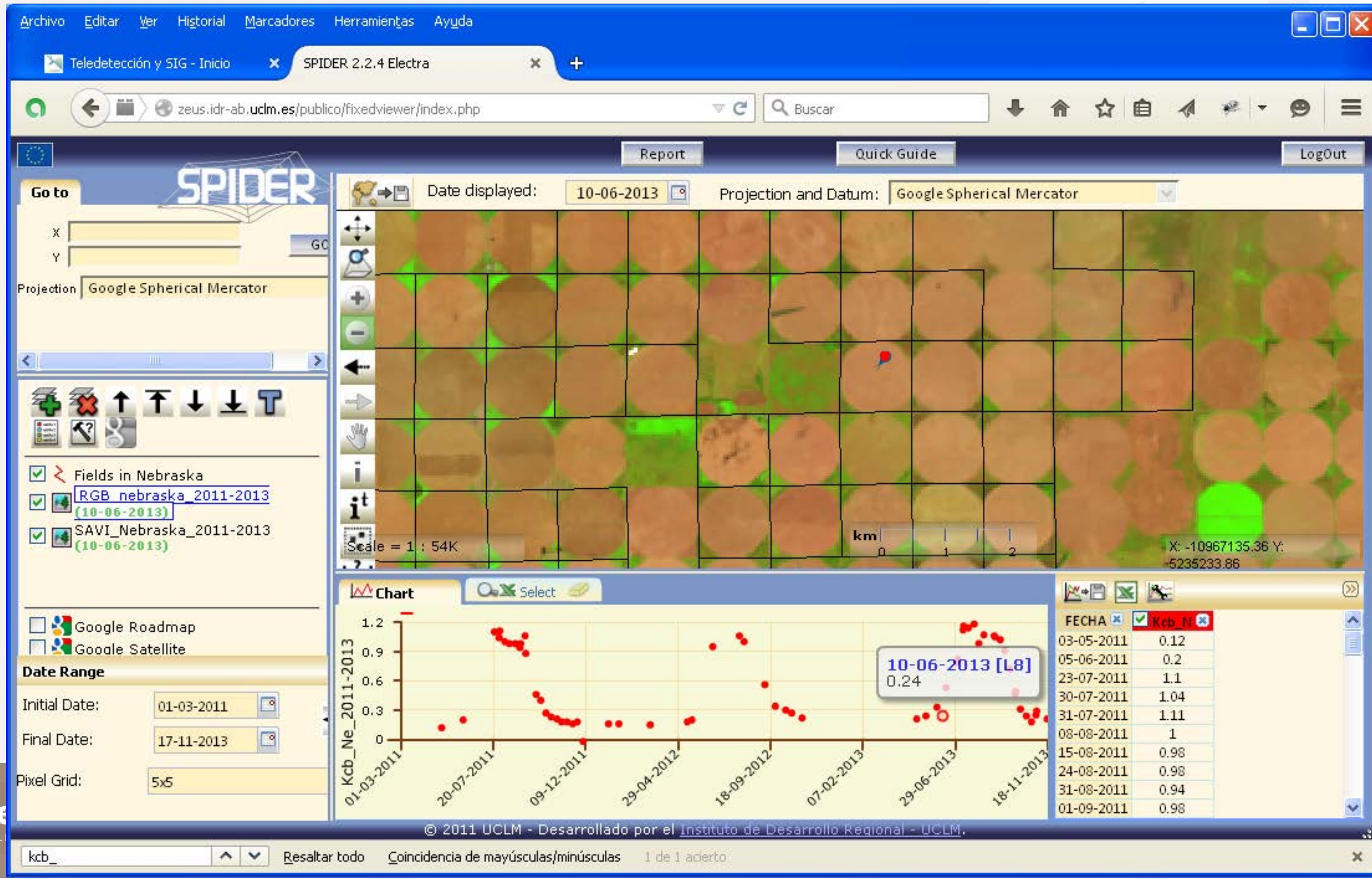
ood.nebraska.edu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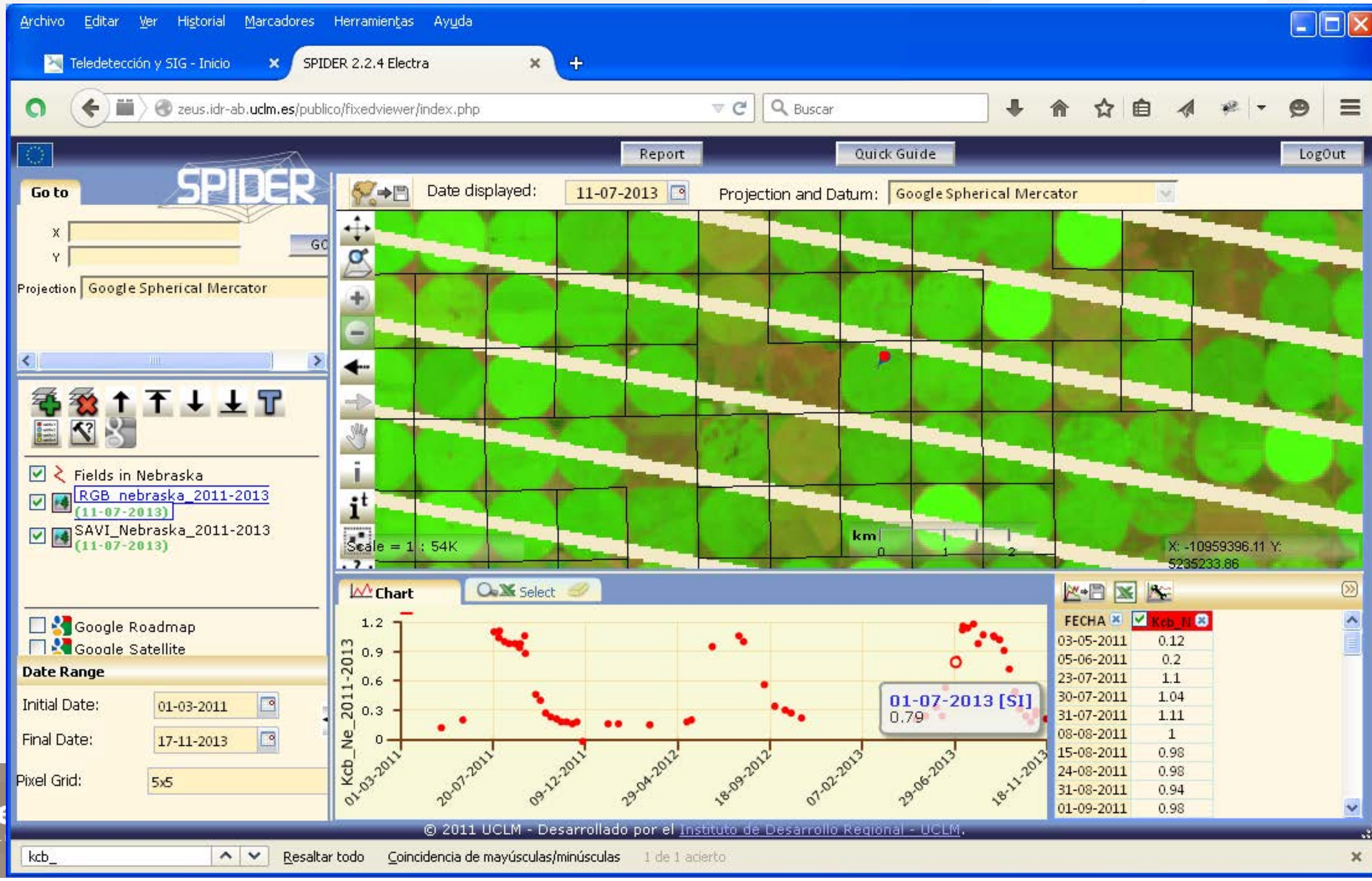
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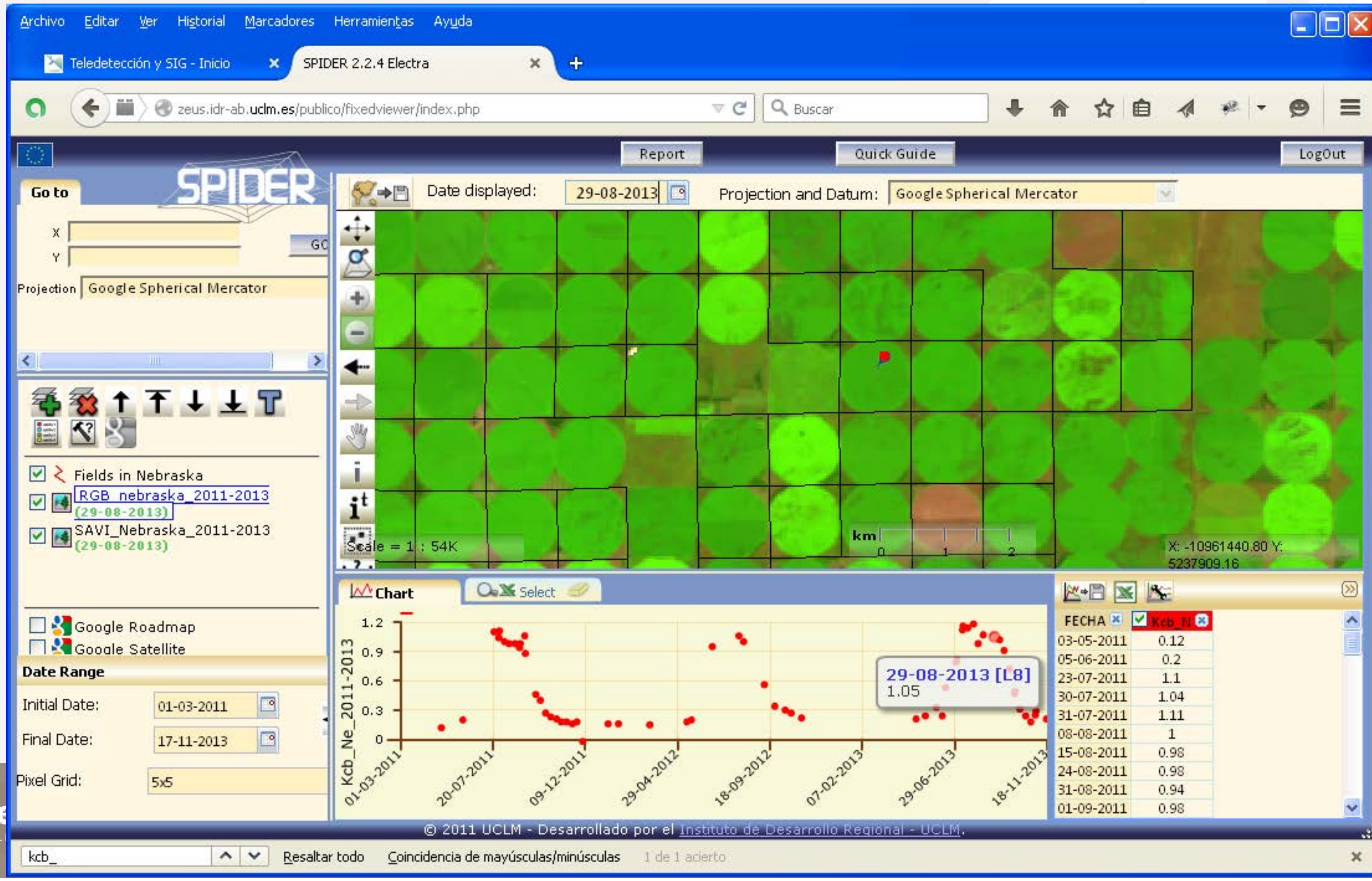
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Google Satellite
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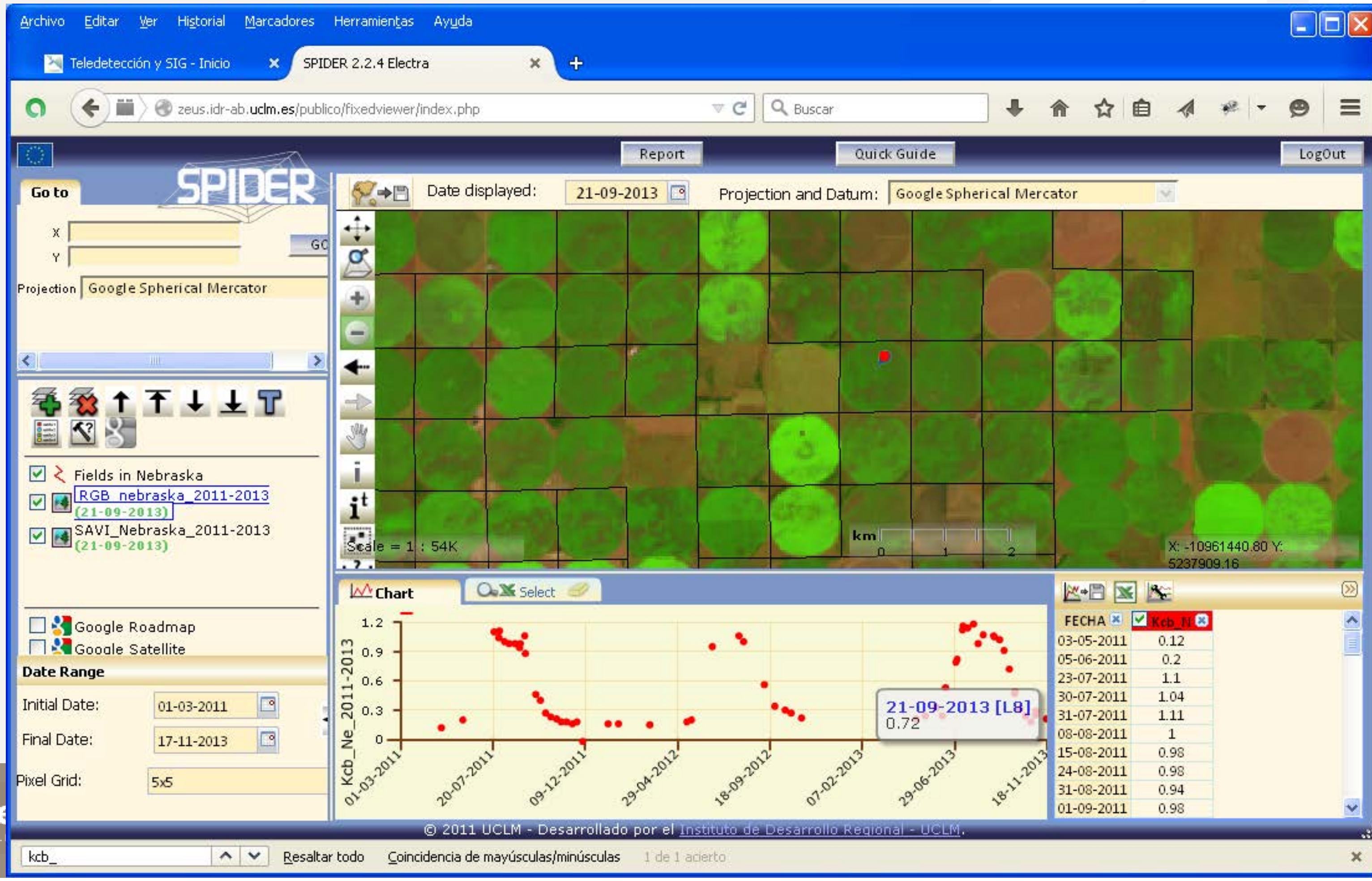

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Resaltar todo
Coincidencia de mayúsculas/minúsculas
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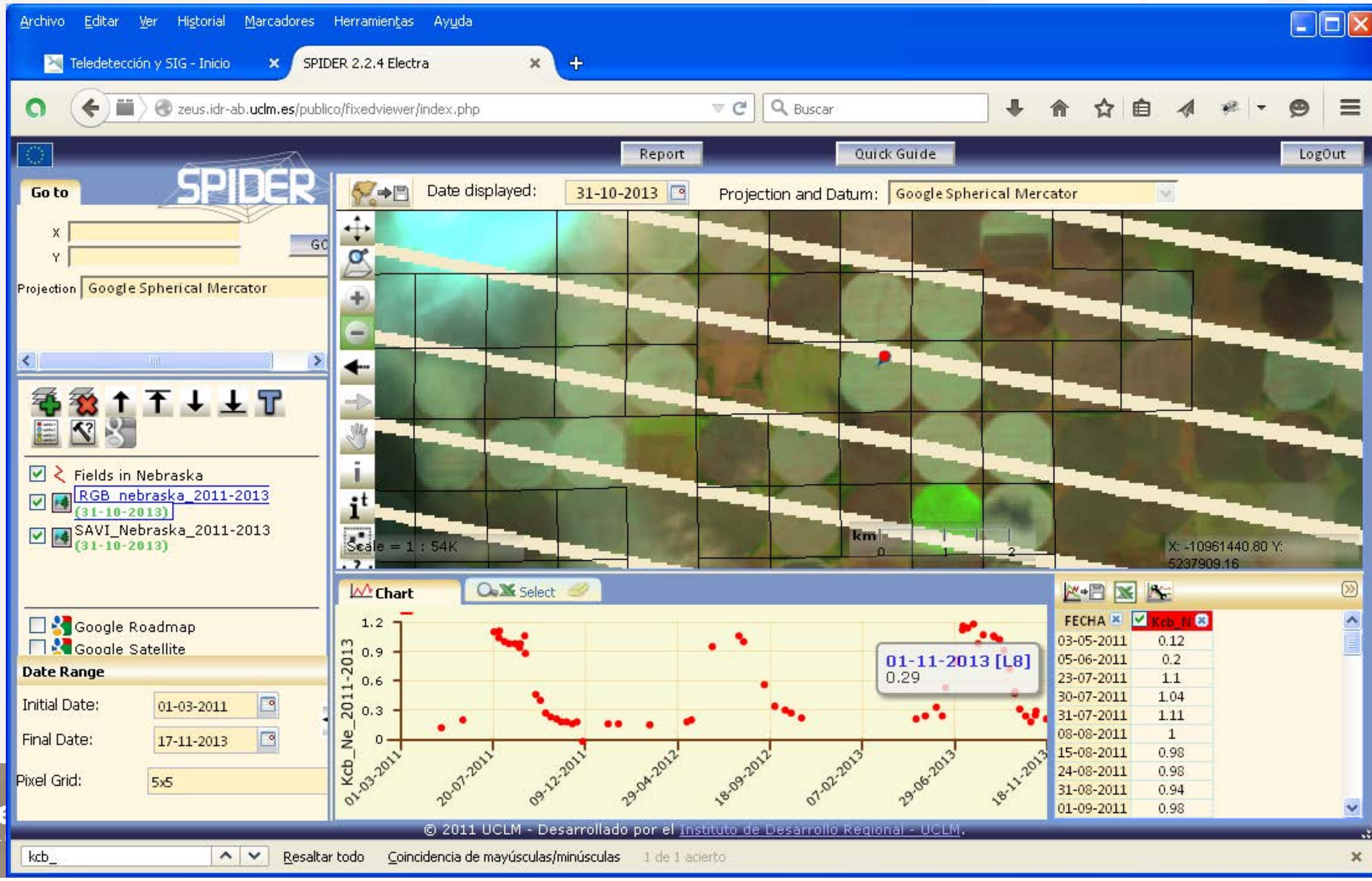
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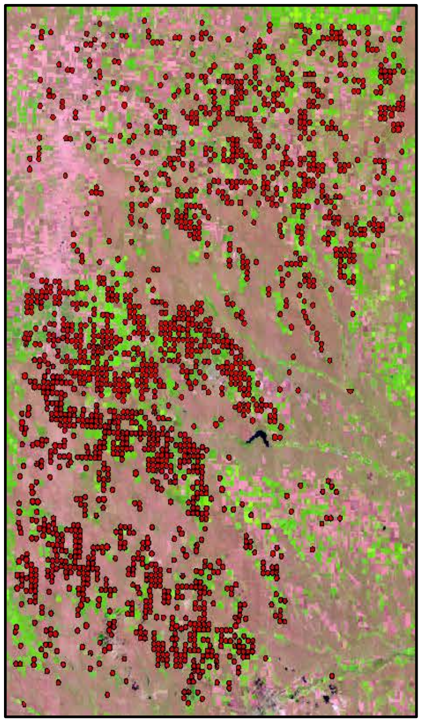
Coincidencia de mayúsculas/minúsculas
1 de 1 acierto

Operational EO satellites with medium to high spatial resolution

Satellite/Sensor	Time Resolution	Image size	Spatial resolution
Landsat 8 LDCM	16 days	185 km x 185 km	30-100 m
Landsat 7 ETM+	16 days	185 km x 185 km	30-60 m
DMC constellation	Up to daily revisit	Up to 600 x 600 km	Up to 20 m
Sentinel-2	15 days	290 km x 290 km	10 m
IRS-AWIFS-P6	6 days	740 x 740 km	56 m
IRS LISS III-1C	24 days	142km x 142km	23 m
IRS LISS III-1D	25 days	148km x 148km	23 m
CBERS CCD	26 days	113km x 113 km	20 m
SPOT 5	Up to daily revisit	60 km x 60 km	10 m
FORMOSAT	Up to daily revisit	24 km x 24 km	8 m
Rapid eye	Up to daily revisit	25 km x 25 km	5 m
IKONOS	3 days	13 km x 13 km	4 m
QUICKBIRD	1-5 days	16.5 km x 16.5 km	2.44 m

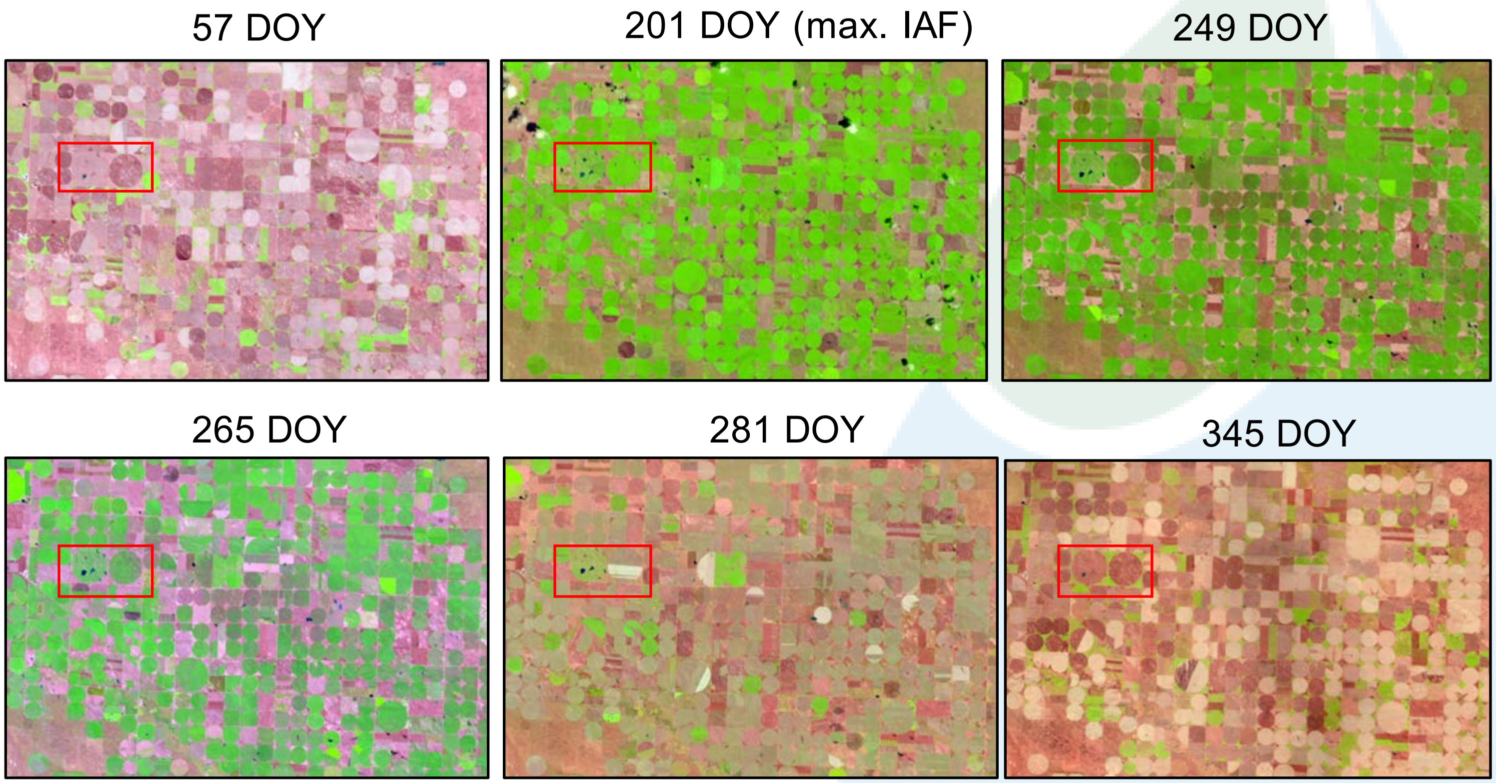
Example of Application in Nebraska



• Center Pivots

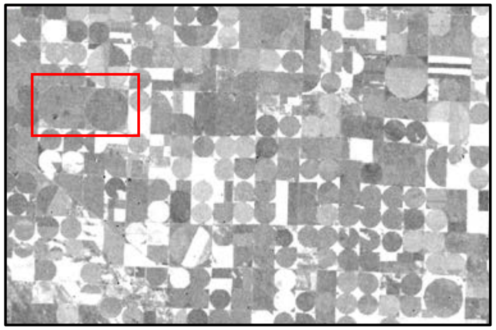
Location of the Upper Republican River Basin in southwest Nebraska

UPPER REPUBLICAN RIVER BASIN

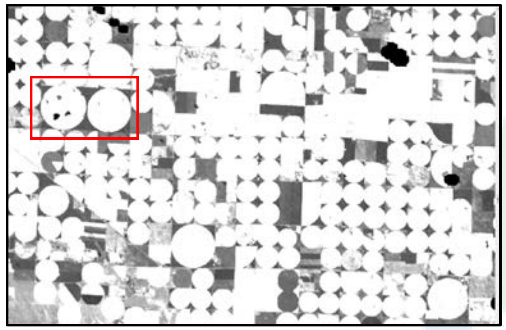


Soil Adjusted Vegetation Index - SAVI

57 DOY



201 DOY (max. SAVI)



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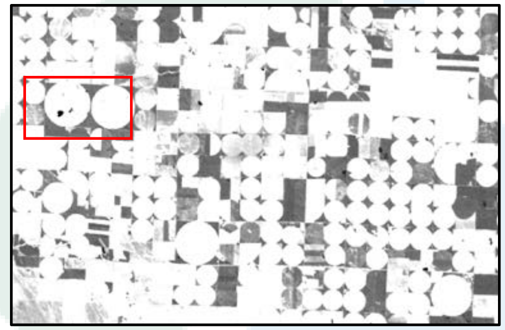

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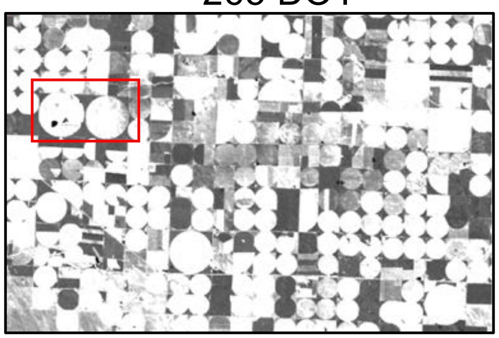

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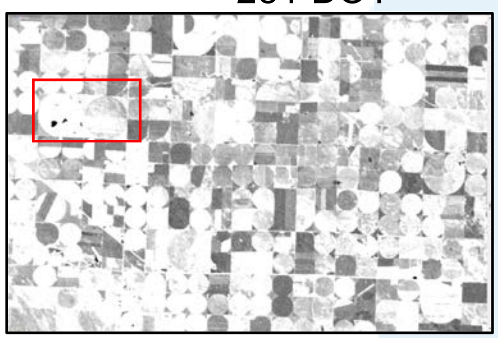

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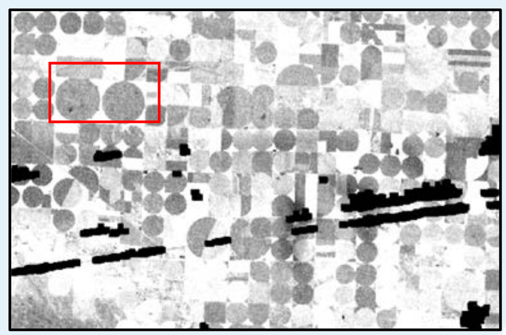
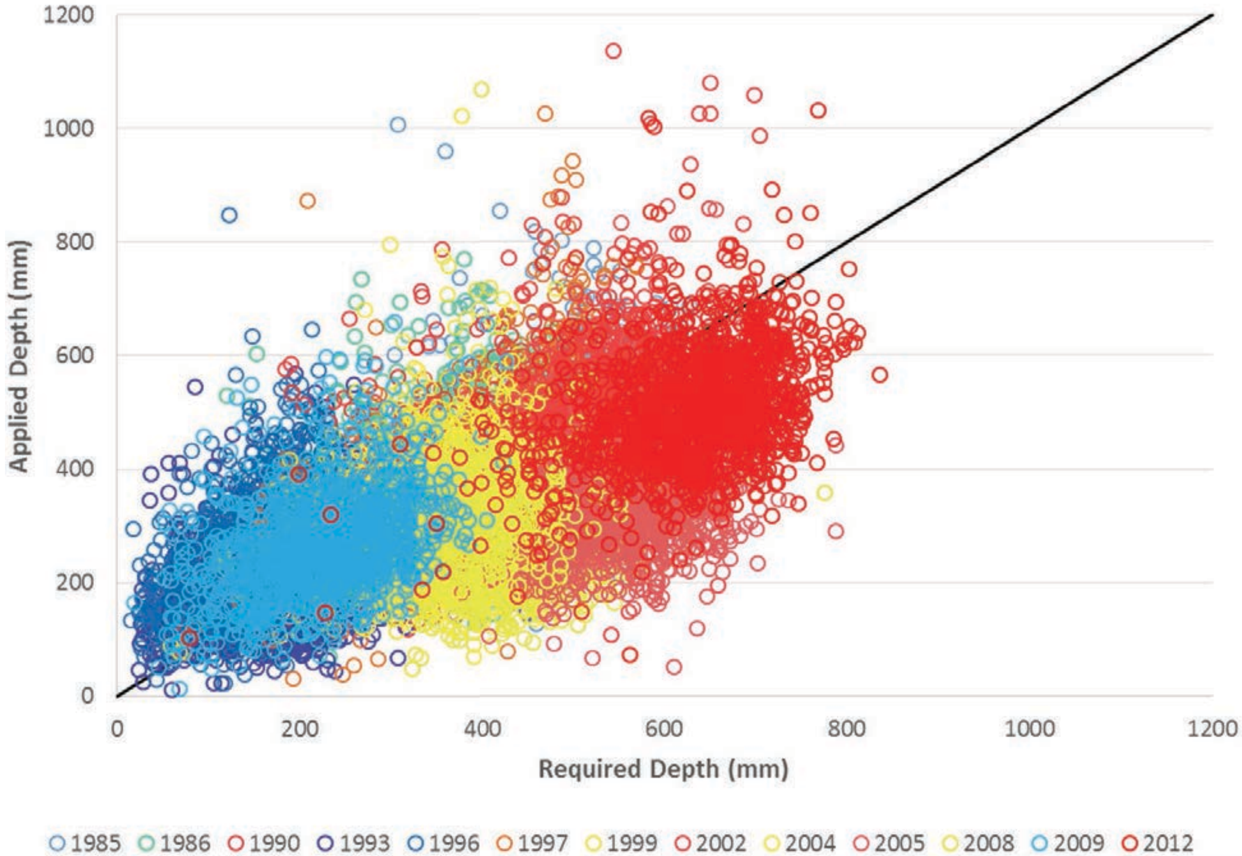
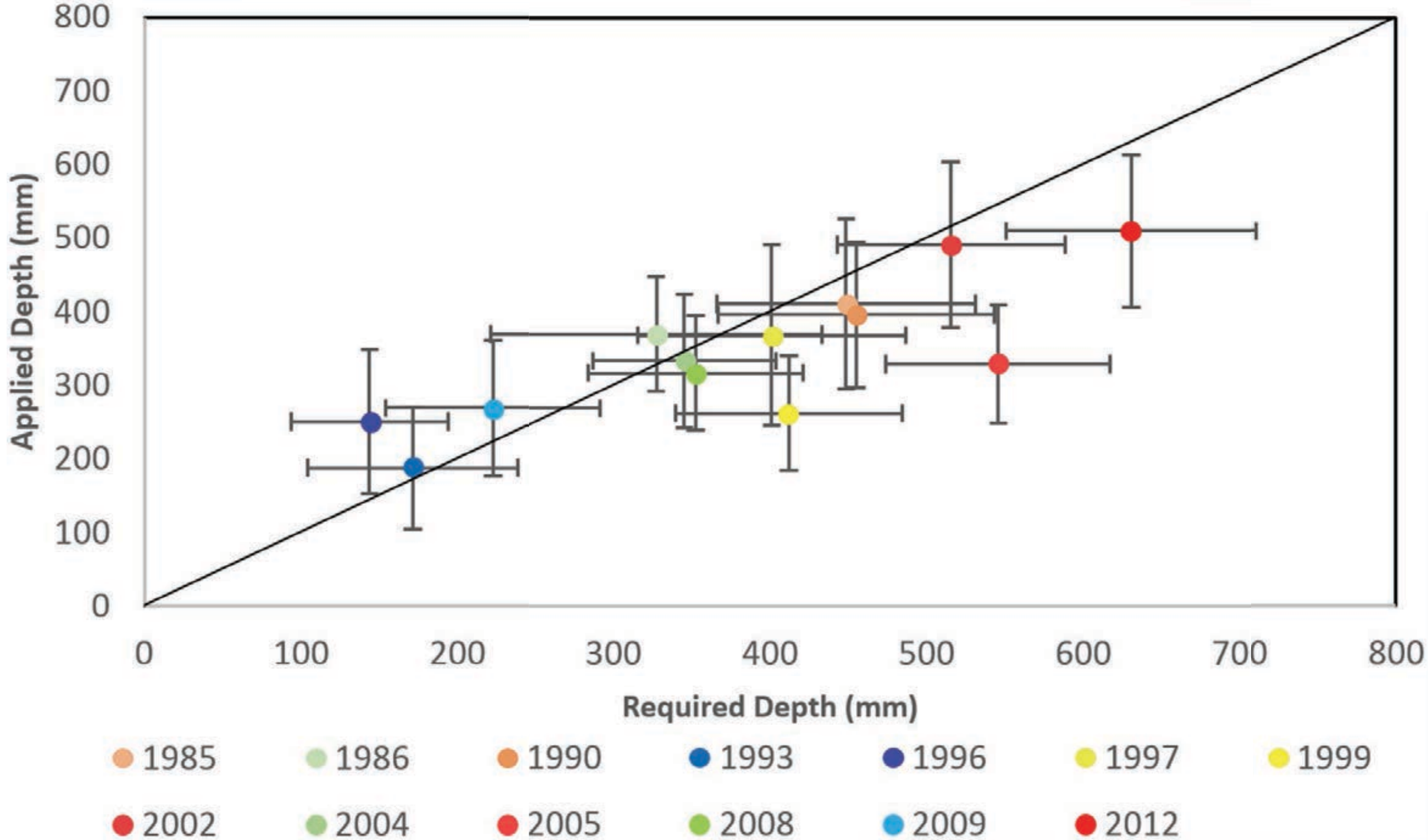


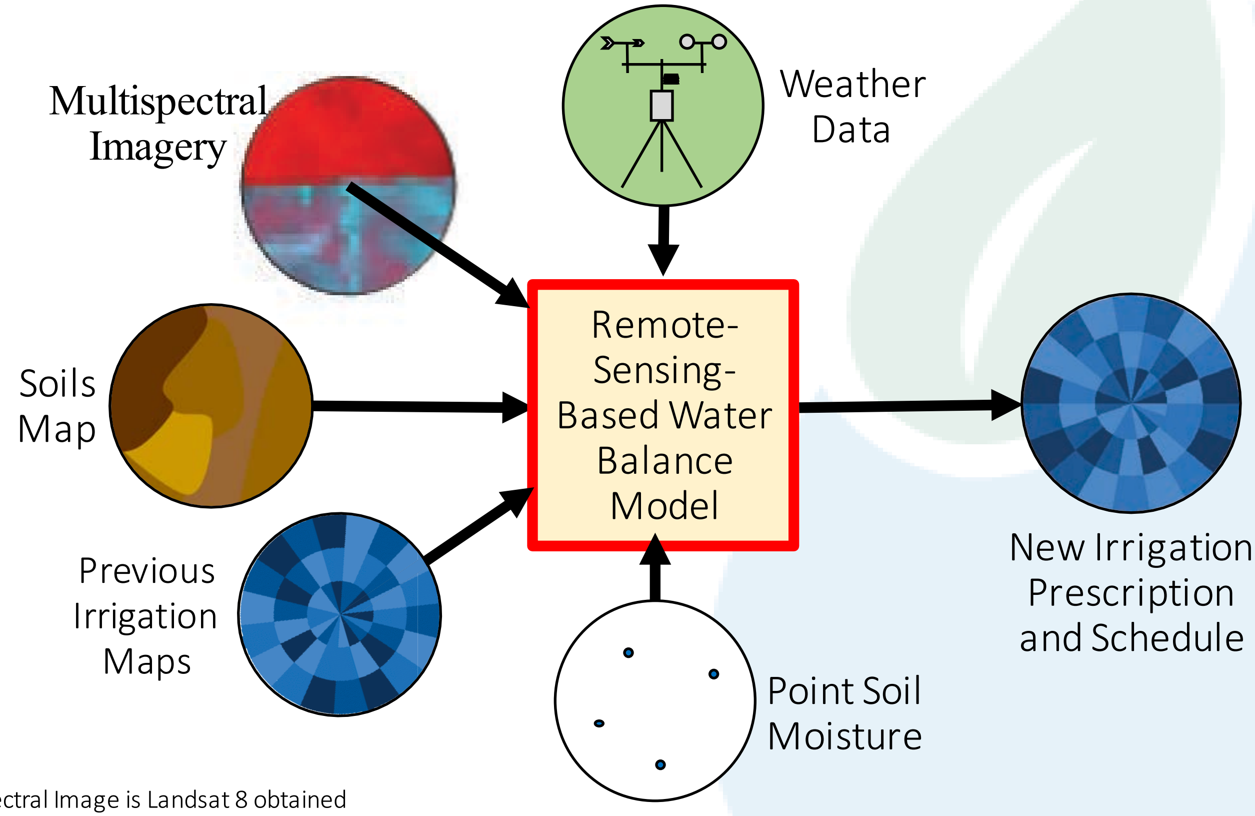
Upper Republican River Basin, NE



Upper Republican River Basin, NE



Concept: Prescriptions for Managing Variable Rate Irrigation



Multispectral Image is Landsat 8 obtained from the U.S. Geological Survey.

Operational Evapotranspiration Determination in the MENA Region for ESI and Drought Monitoring

Christopher Neale
Water for Food Institute
University of Nebraska

Christopher Hain
NASA MSFC, Alabama

Martha C. Anderson
USDA-Agricultural Research Service, Hydrology and Remote Sensing Laboratory

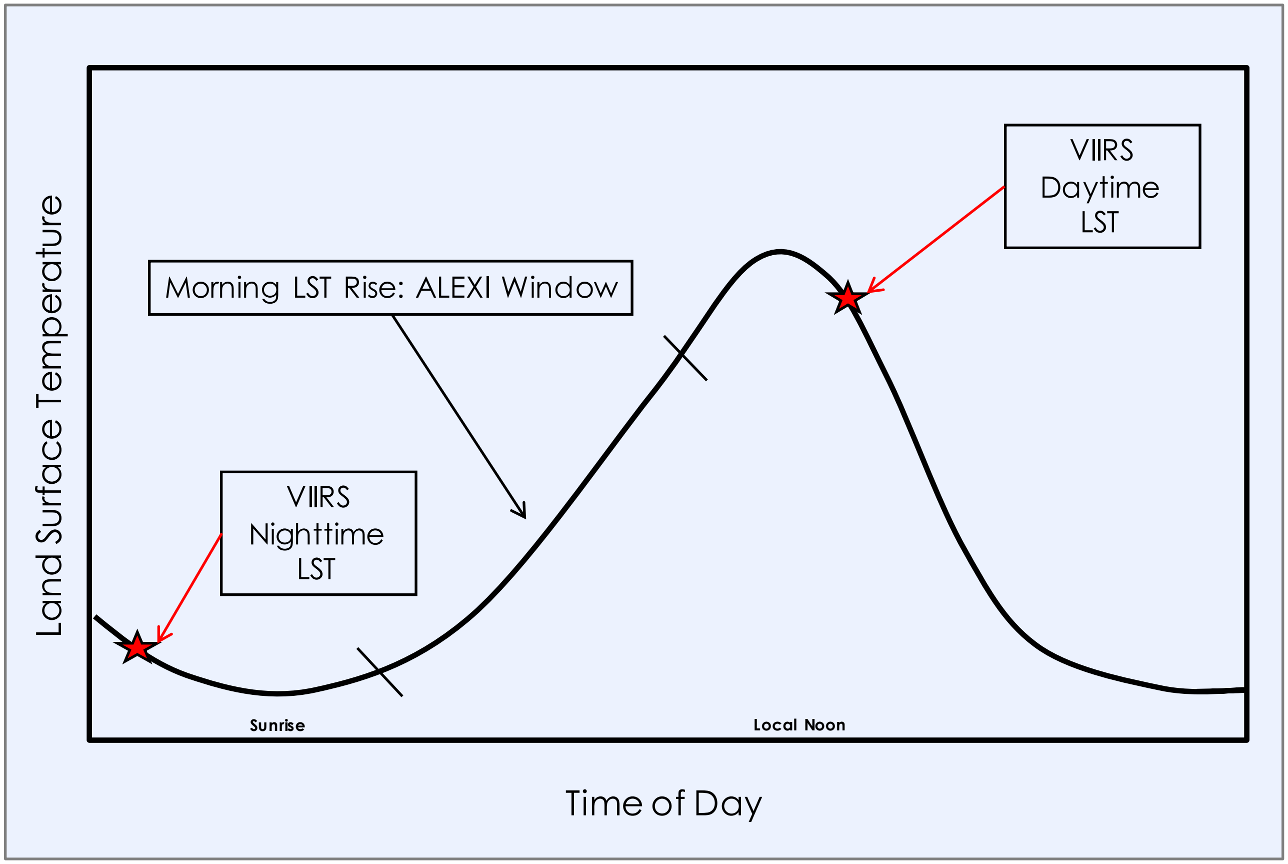
Mitch Scull
ESSIC, University of Maryland

What we are Conducting for the MENA Region

- Use of ALEXI energy balance model to obtain daily surface ET at 375 m resolution from the VIIRS Satellite Instrument
- This ET product will be used for the estimation of the Evaporative Stress Index, used in the Composite Drought Index
- Disaggregate ET using DisALEXI models for field scale water productivity estimates (crop yield and actual ET)
- Other benefits: the 375 m ET product can also be used for water accounting and availability in watersheds and river basins

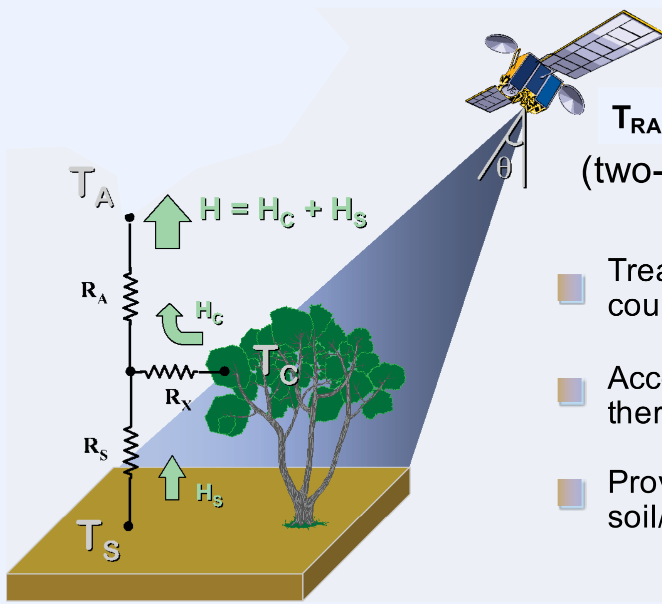
Supplementing ALEXI Capabilities with Polar Orbiting Sensors

A technique has been developed and evaluated using GOES data to train a regression model to use day-night LST differences from MODIS to predict the morning LST rise needed by ALEXI. The regression model can provide reasonable estimates of the mid-morning rise in LST (RMSE ~ 5 to 8%) from the twice daily VIIRS LST observations.



The ALEXI model runs the TSEB

Two-Source Energy Balance Model (TSEB)



$T_{RAD}(\theta) \sim f_c(\theta)T_c + [1\text{-}f_c(\theta)]T_s$

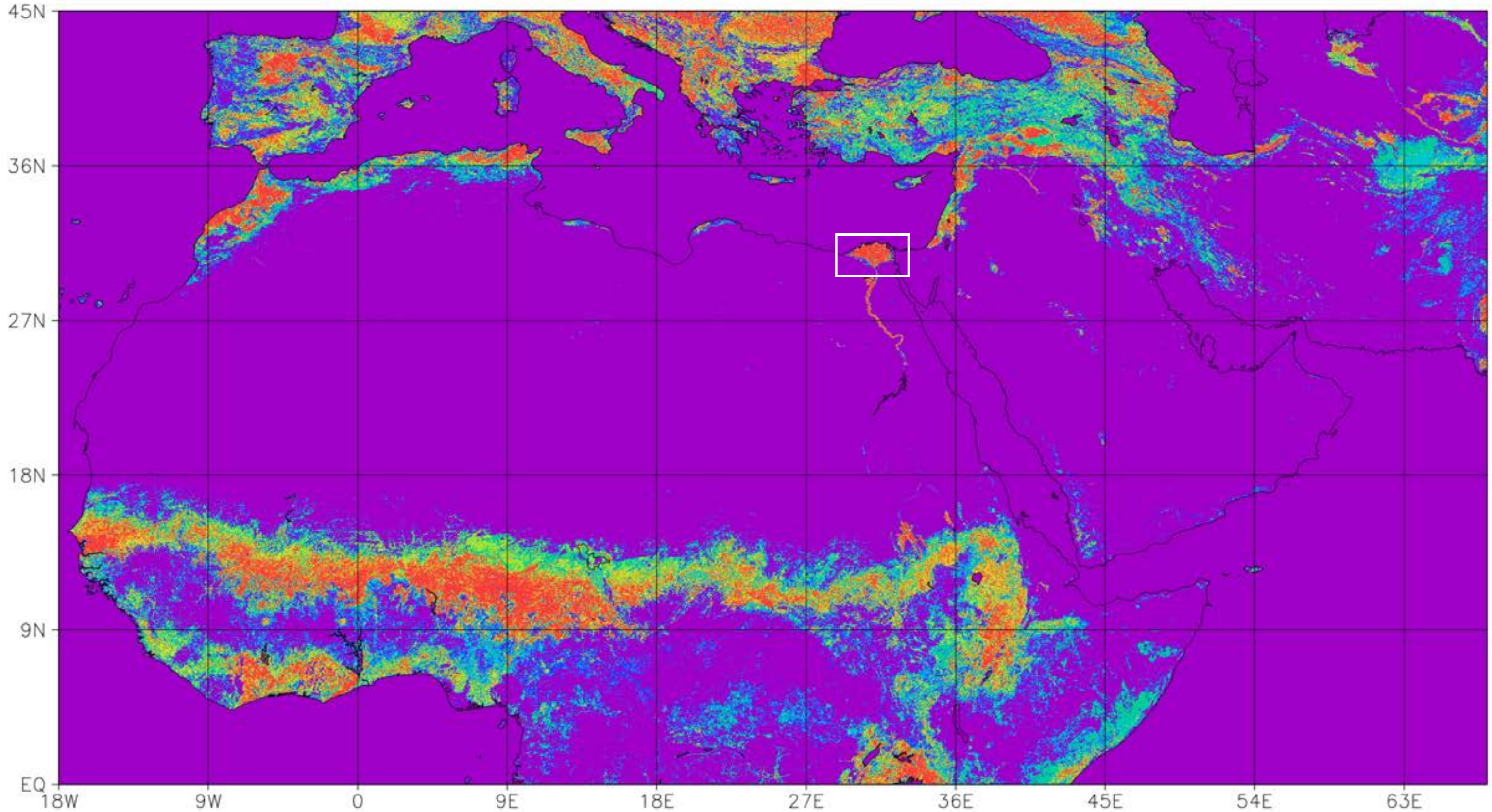
(two-source approximation)

Norman, Kustas et al. (1995)

- Treats soil/plant-atmosphere coupling differences explicitly
- Accommodates off-nadir thermal sensor view angles
- Provides information on soil/plant fluxes and stress

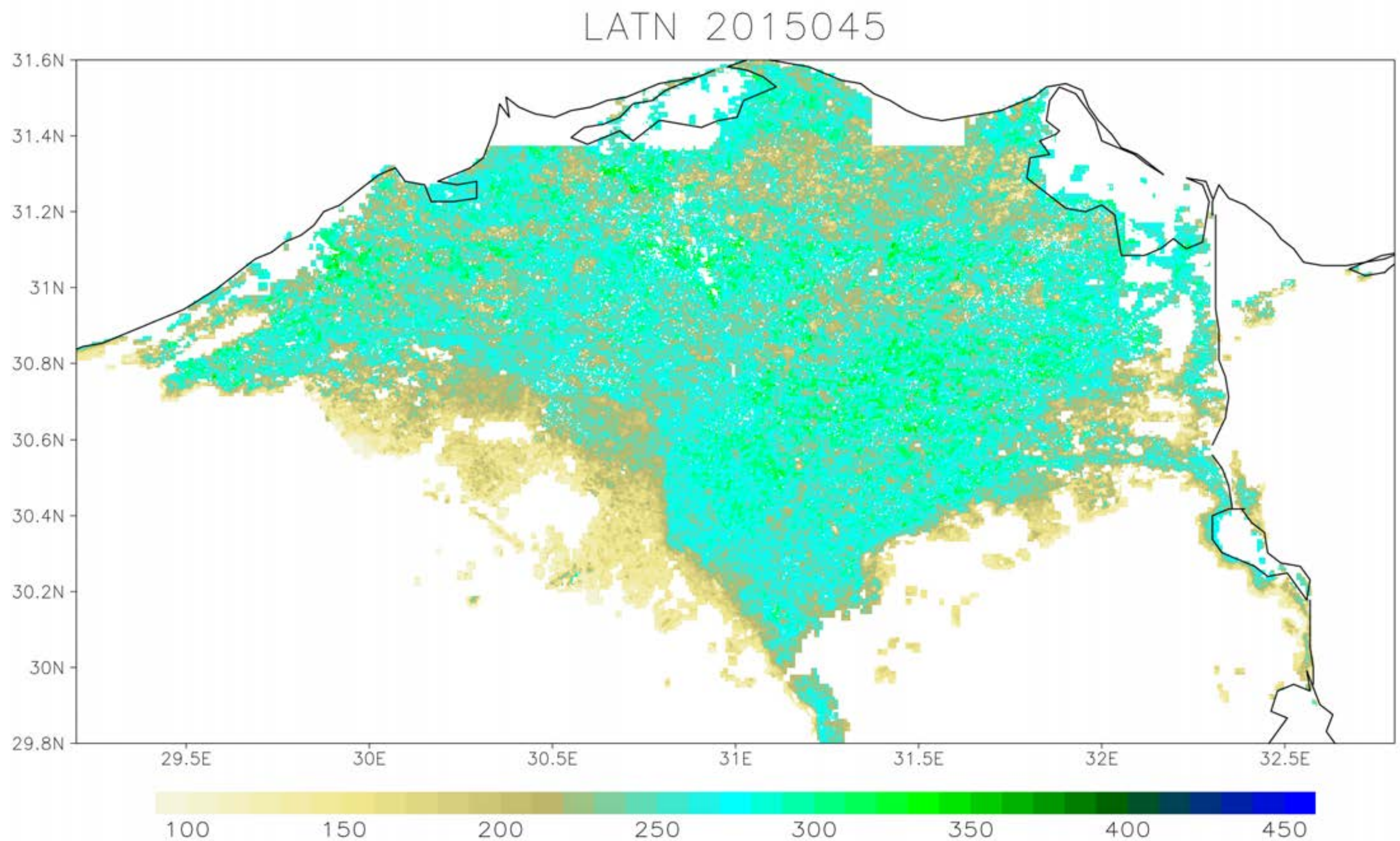
Development of a High-Resolution (375-m) VIIRS ET Product

Data coverage for VIIRS ET product. Sample location at Nile Delta



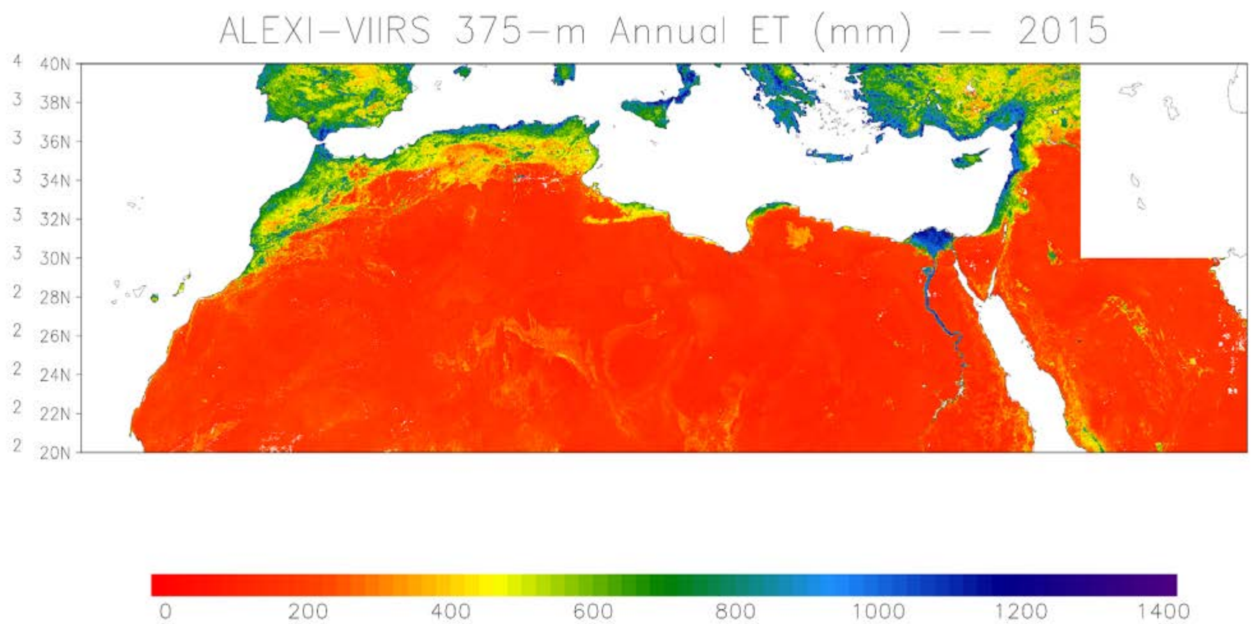
*Shading indicates 1-km percentage of cropland from global synthesis of several RS-based land use maps

Current VIIRS Latent Heat Flux (W m^{-2}) Capability (375-m)



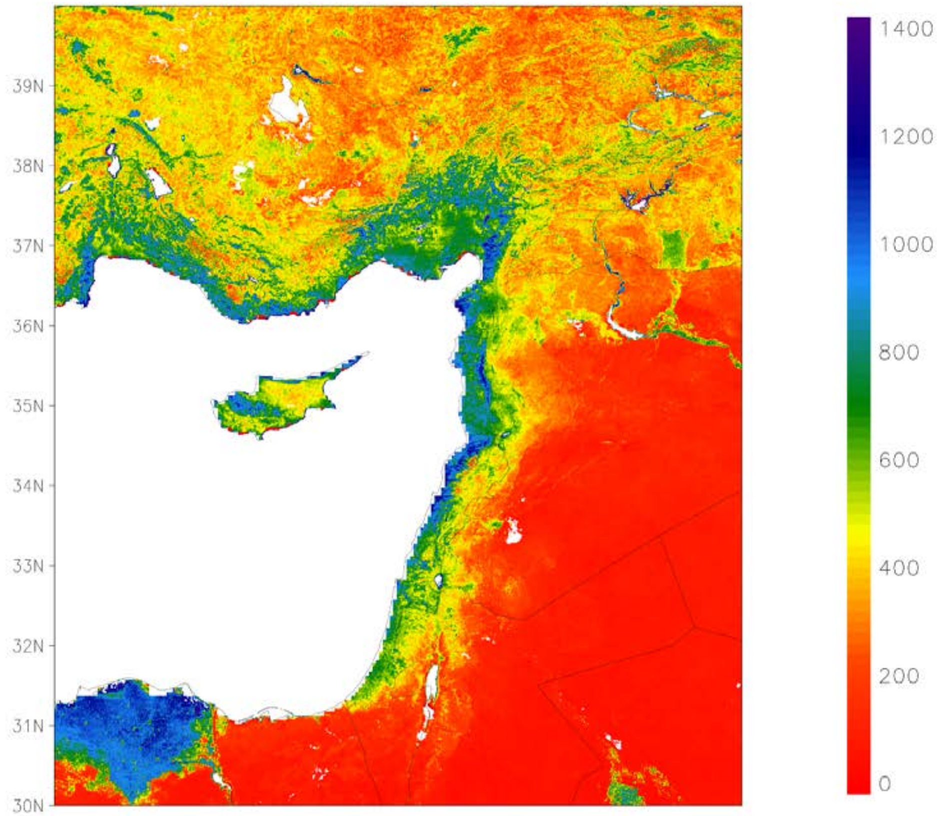
Development of a High-Resolution (375-m) VIIRS ET Product

Annual ET estimated from integrating daily values for 2015



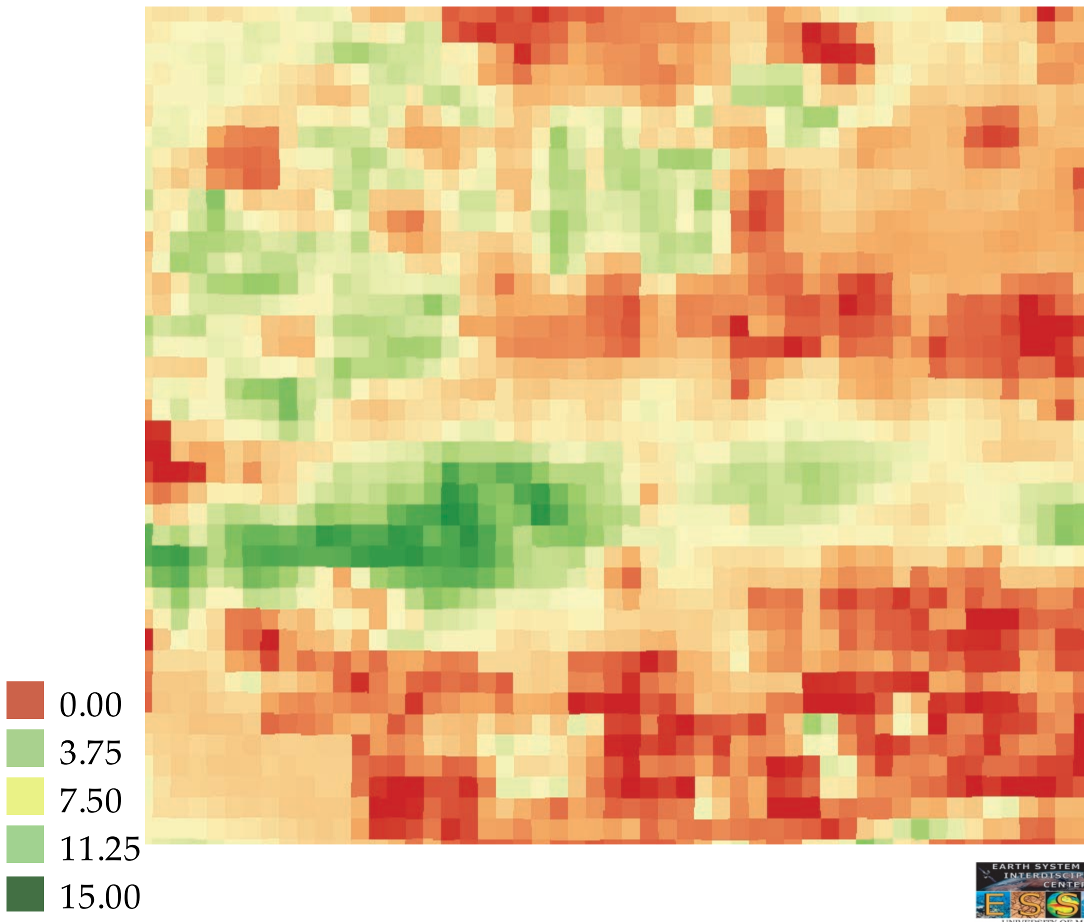
Development of a High-Resolution (375-m) VIIRS ET Product

VIIRS 375 m Annual ET (mm)



Input data: ALEXI daily ET

Nile Delta Irrigation

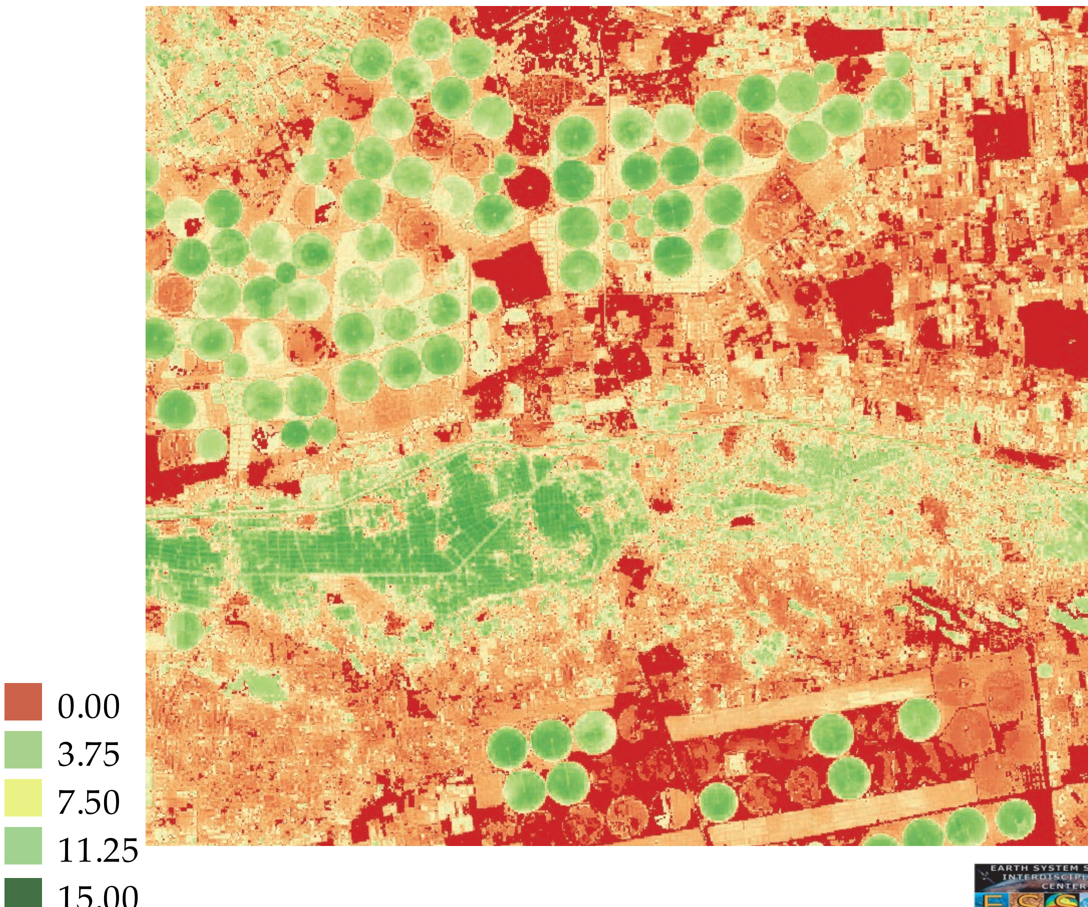


VIIRS daily ET mm/d

- Daily ET calculated at VIIRS 375 m data using the ALEXI model.

Initial results: Landsat daily ET

Nile Delta Irrigation

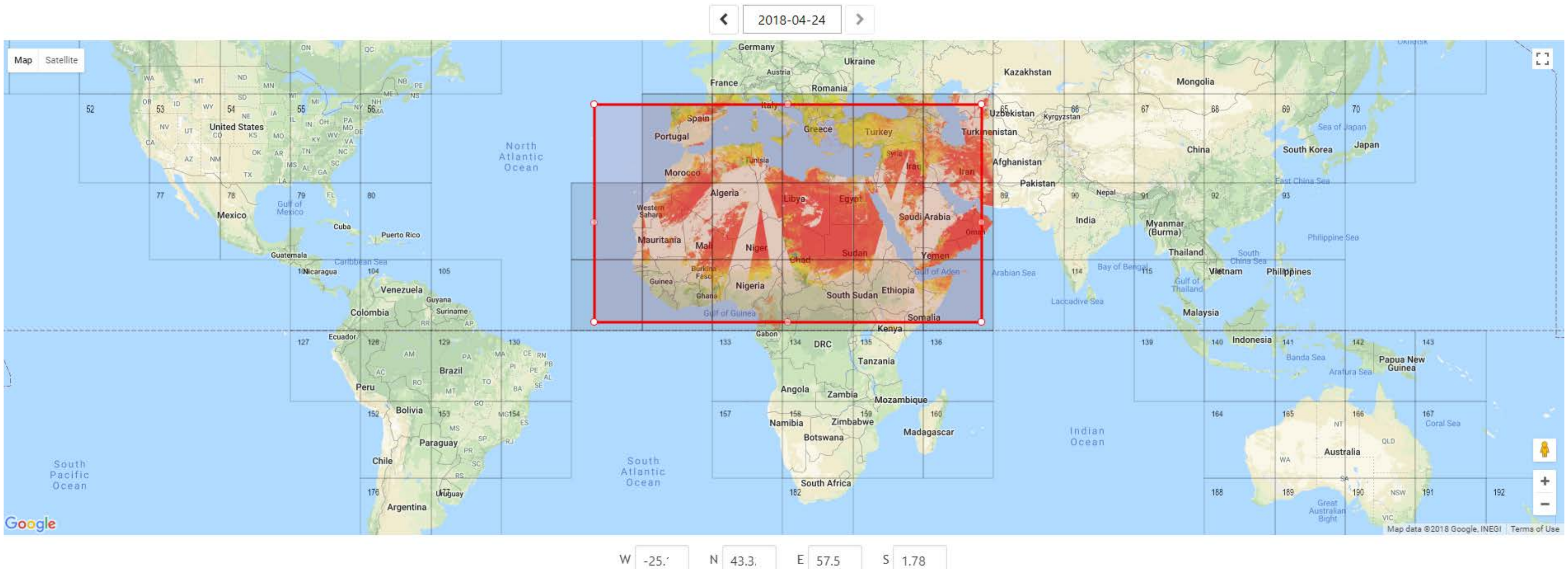


Landsat daily ET mm/d

- Landsat Daily ET downscaled from ALEXI using the PyDisALEXI model.

VIIRS Satellite Global Daily ET Product (GLODET) WEB Interface

- Users will register to view and download the product
- Updates, track the applications and research using the product



Water *for* Food
DAUGHERTY GLOBAL INSTITUTE
at the University of Nebraska

USDA ARS Agricultural Research Service

NASA

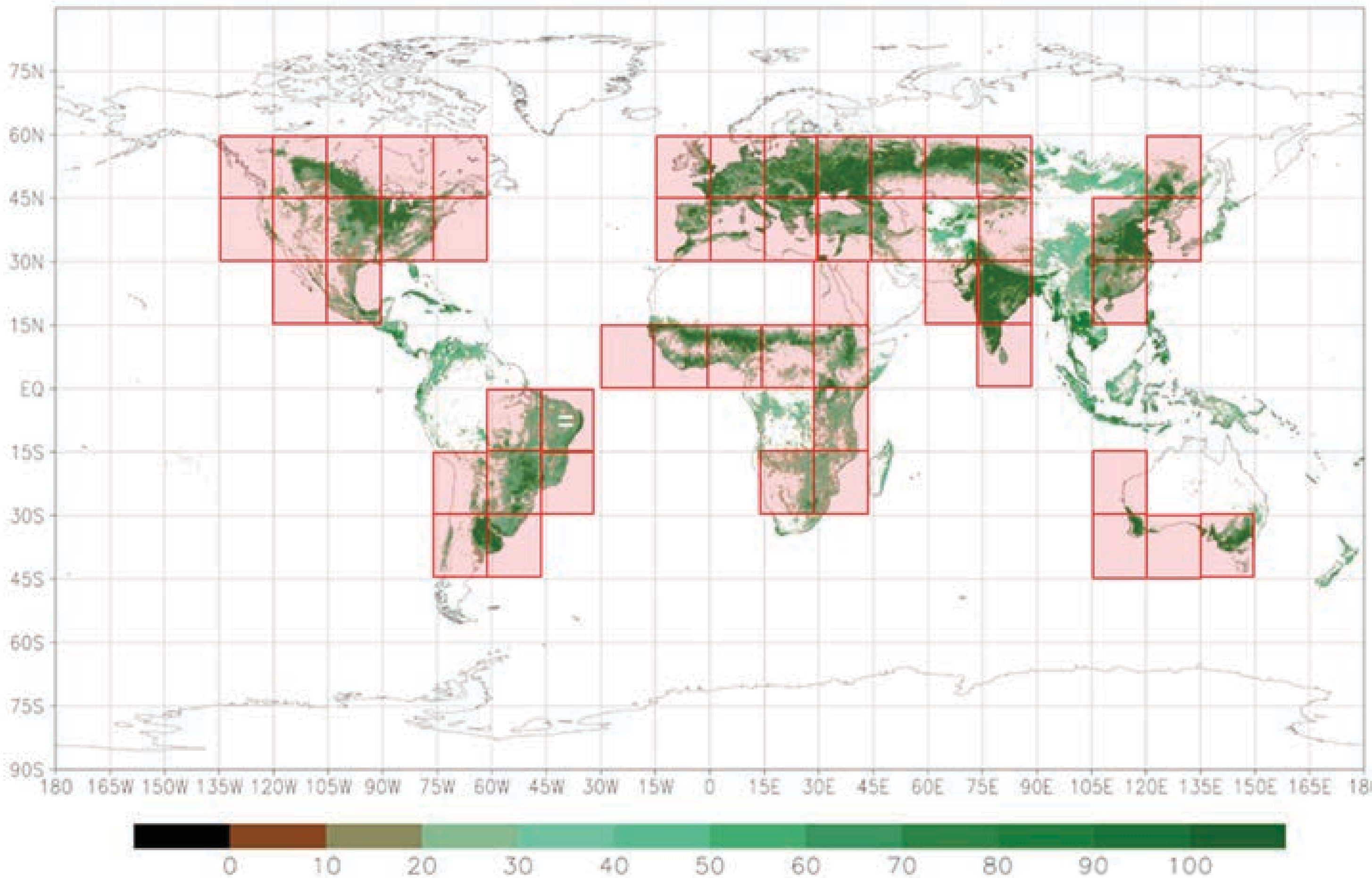
EARTH SYSTEM SCIENCE INTERDISCIPLINARY CENTER
ESSIC
UNIVERSITY OF MARYLAND

NDMC NATIONAL DROUGHT MITIGATION CENTER
UNIVERSITY OF NEBRASKA

USAID
FROM THE AMERICAN PEOPLE

ICBA
AGRICULTURE FOR TOMORROW

Proposed 15 x 15 degree processing tiles (375-m) VIIRS ET Product

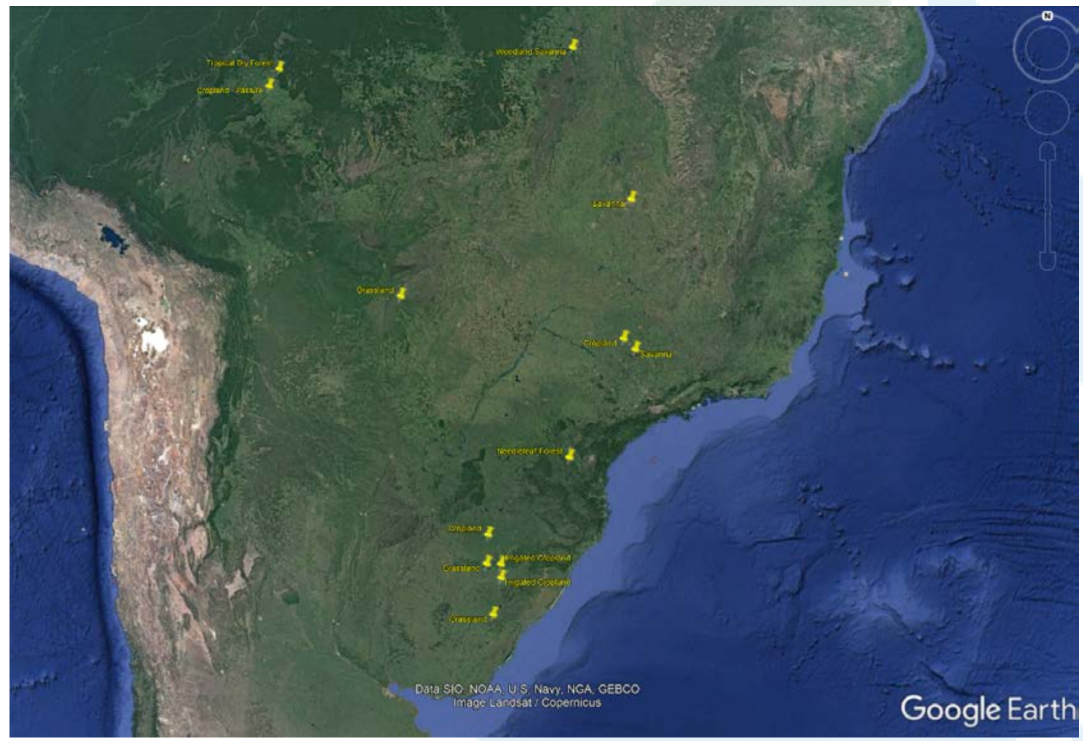


erforFood
Daugherty Institute
University of Nebraska

Expansion of GLODET

- Funded project with University of Sao Paulo by CAPES/ANA: Brazilian Federal Research and Water Resources Agencies"Estimation of Evapotranspiration through Remote Sensing for Management of Water Resources in Brasil"
- Collaboration between University of SaoPaulo, DWFI and US Partners, Federal University of Rio Grande do Sul, Federal University of Santa Maria and INPE (the Brazilian Space Agency)

- Funding will cover the costs of travel and per-diem for exchange of researchers US/Brazil and post-docs and PhD students.
- Main objective: Verification of Daily ET product using network of flux towers and watershed/basin scale water balance estimates



Proposed Production TimeLine For the Global VIIRS ET Product:

- Testing the product in different regions of the world with local partners that are running eddy covariance flux towers or networks of automated weather stations
- MENA effort: Tunisia, Morocco, Egypt, Spain, Southern France, Italy
- Other Countries: India, Brazil, USA
- Ameriflux, FluxNet
- Serve the daily ET product to collaborators in different countries and provide PyDisALEXI for downscaling

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at the University of Nebraska