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Theoretical and empirical basis for a remote sensing estimation of crop water productivity

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OUTLINES

- *(Re) Analysis of the relationship between spectral vegetation indices and crop transpiration*
- *Empirical and theoretical basis for the relationship between plant transpiration and crop yield*
- *Estimation corn and soy productivity at regional scale in central Nebraska*

(Re)Analysis of the relationship between spectral vegetation indices and plant transpiration

- *Theoretical approach to Biomass production at canopy scale and plant transpiration or transpiration coefficient (Kt) (Steduto et al. 2007)*
  - *Ktmin=0 (for bare soil) and Ktmax≈mid season Kcb (Raes et al. 2012)*
- *Well established relationship between SAVI and plant transpiration*
  - *This rrelationship is generally established in terms of basal crop coefficient (Kcb), Kcb=0.15 for bare soil and Kcb=max for SAVI max or LAI threshold at effective cover (Neale et al 1989, Bausch 1993). These approaches may overestimate biomass production for low coverage canopies.*
  - *But, Choudhury et al. (1994) proposed a non-linear relationship with Kcbmin=0 and Kcbmax=mid season Kcb*

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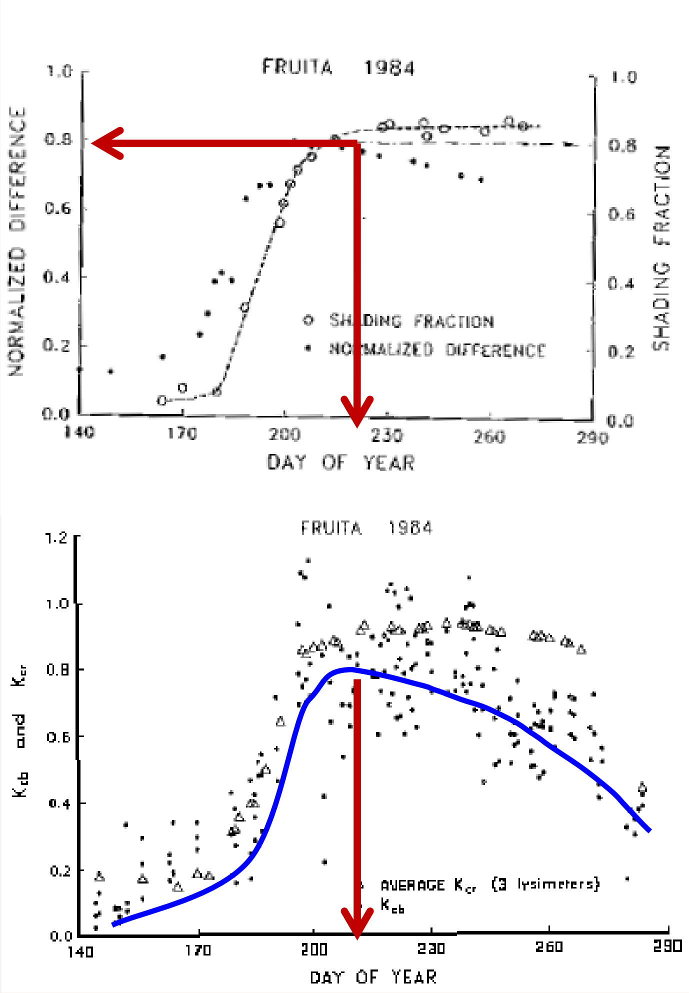
(Re)Analysis of the relationship between spectral vegetation indices and plant transpiration

- *The need to reanalyze the Kcb-VI relationship for corn is because of possible effects of changes in canopy architecture*

  Neale et al. (1989) established the saturation of the LAI-Kcb relationship for LAI>3.2, coinciding with NDVI>0.8.

  Bausch (1993) Proposed that Kcb should be capped at effective cover (LAI=3) because the SAVI index still increases for LAI>3.

  The development of new corn varieties with high LAI and vertical leaf architecture point to the possible change of the effective cover date vis-à-vis the SAVI index and LAI



Neale et al, 1989

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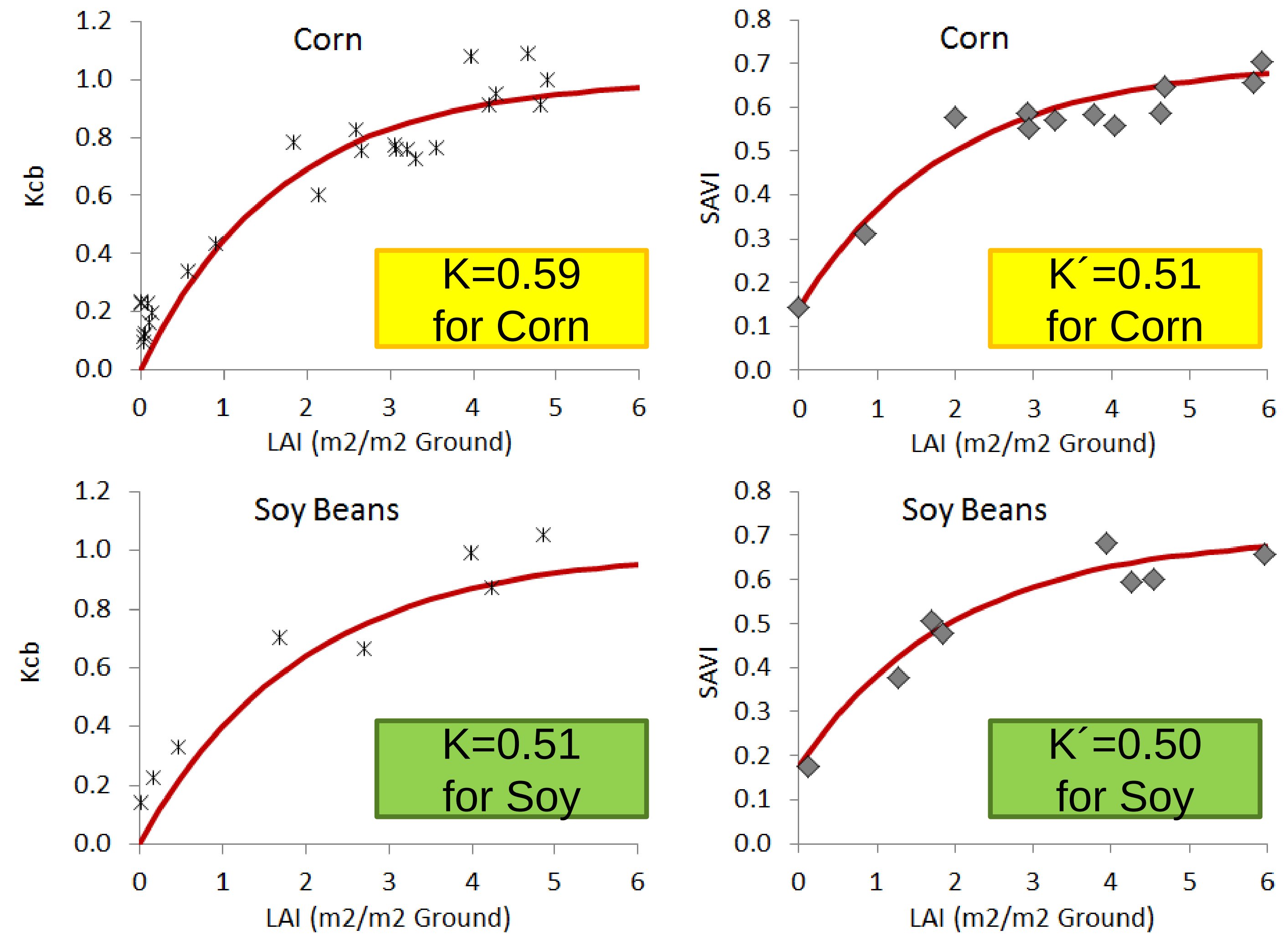
(Re)Analysis of the relationship between spectral vegetation indices and plant transpiration

Based on the relationships between
<u>Kcb-LAI-SAVI</u>
(Choudhury et el. 1994)

$$K_t = 1 - e^{(-k \times LAI)}$$

$$VI = VI_{max} - (V_{max} - V_{min}) \times e^{(-K' \, LAI)}$$

- *No saturation effect on the LAI-Kcb relationship for LAI values up to 5 in corn*



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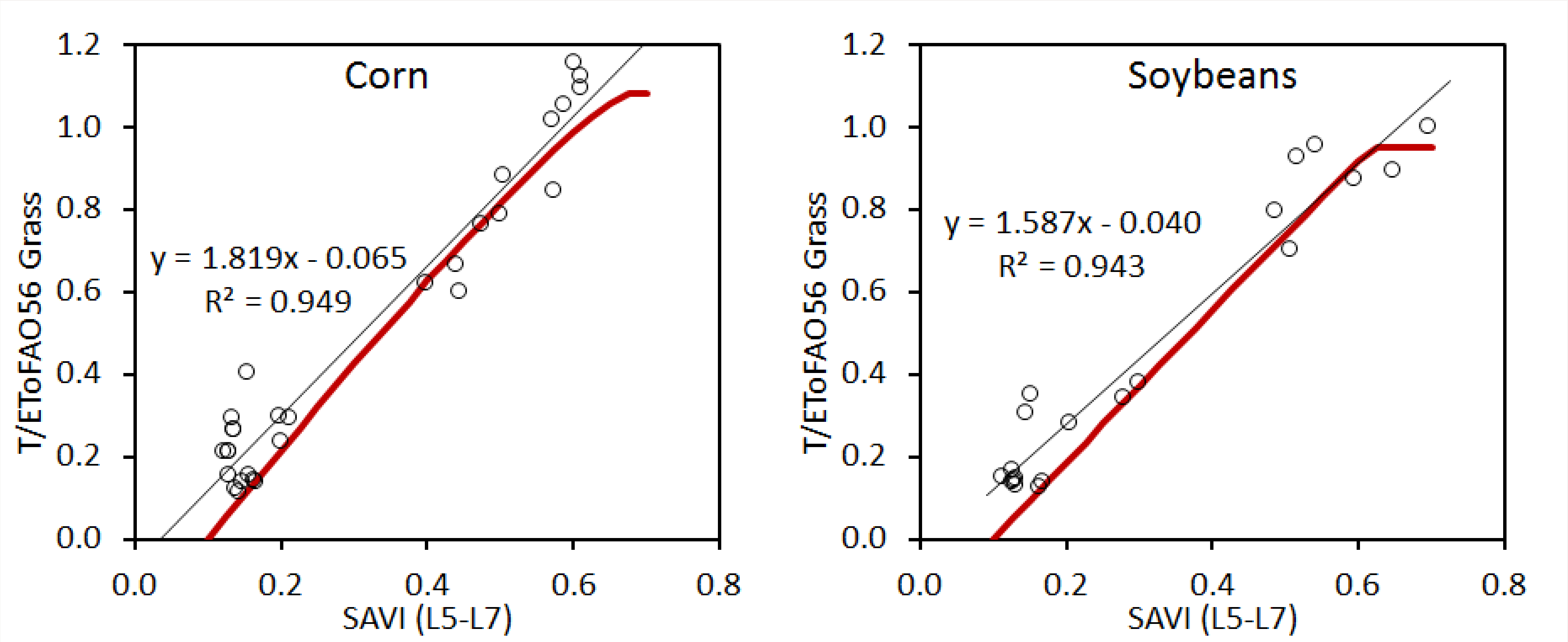
(Re)Analysis of the relationship between spectral vegetation indices and plant transpiration



Red Line is Choudhury's empirical relationship.

- *The consideration of a Kcb=0.15 for bare soil is necessary to reproduce the ET process at canopy scales, but may lead to an overestimation of the yield-biomass production*

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Empirical and theoretical basis for the relationship between plant transpiration and crop yield: FAO-66

- *<u>Initial approaches:</u> FAO-33 manual Crop yield response to water by Doorenbos and Kassam (1979) pointed to the direct relationship between crop yield with respect to crop transpiration.*
- *Improvements gathered in FAO-66 manual (Steduto et al., 2012):*
  - ✓ *The FAO-66 methodology considers the separation of the non-productive consumption of water (soil evaporation) from the productive consumption of water (*transpiration, Tadj*)*
  - ✓ *The crop yield is estimated as a variable to the proportion of biomass that goes into the harvestable parts depending on biotic and abiotic stresses,* Harvest Index (HI)
  - ✓ *Considers the demonstrated dependence of the water productivity with respect to atmospheric conditions proposing the use of* normalized water productivity WP*

$$Yield = \sum_{n}^{i=1} \frac{T_{adj}}{ETo} \times WP_B^* \times HI$$

Empirical and theoretical basis for the relationship between plant transpiration and crop yield

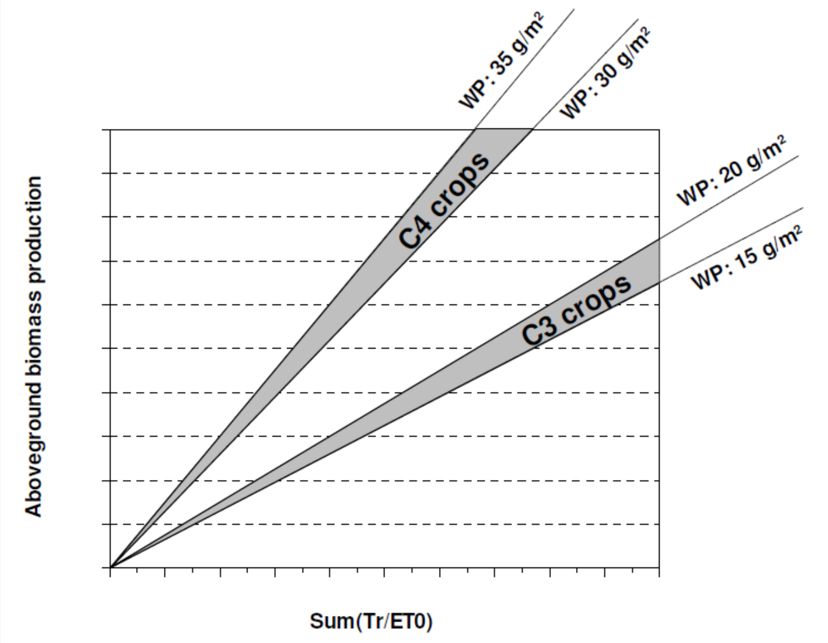
Preliminary analysis of WP* based on FAO-66 model

<u>Strengths</u>

- Does not depend on crop species (but is different for C3 and C4 crops)
- Narrow range of variability with respect to CO2 concentration, phenology and soil fertility
- Normalized for atmospheric demand

<u>Weaknesses</u>

- Does not consider further reductions of biomass production influenced by incoming solar radiation



(Raes et al. 2012)

Empirical and theoretical basis for the relationship between plant transpiration and crop yield

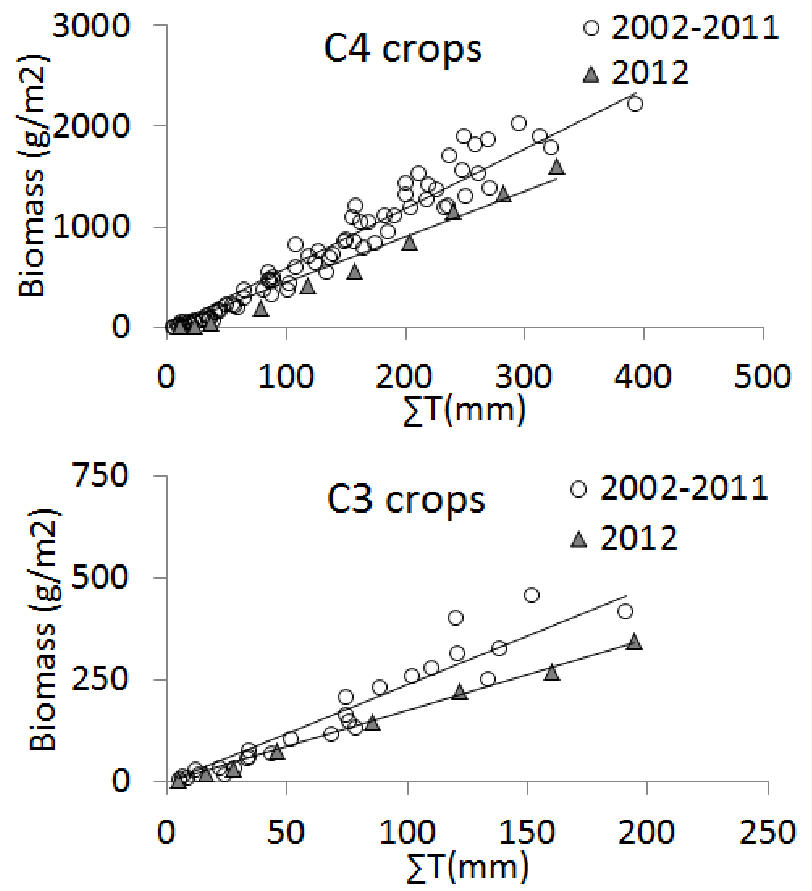
Effect of atmospheric demand on water productivity

<u>Strengths</u>

- Good correlation between cumulative transpiration (considering water stress) and biomass production

<u>Weaknesses</u>

- Strong effects from the increase of atmospheric demand, reducing the water productivity

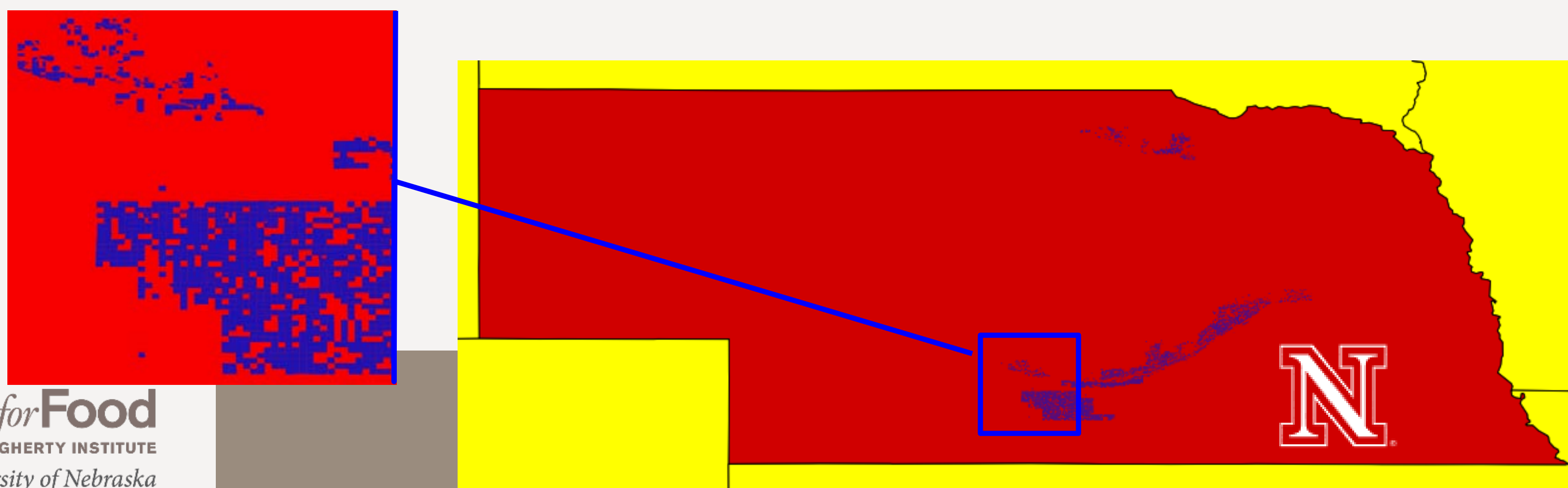


Estimation corn productivity at regional scale in central Nebraska

- *Objective: Estimation of corn yield in selected areas of central Nebraska*

- *Materials and methodology:*
  - ✓ *Temporal evolution of SAVI, based on L5-L8 images for the period 2011-2012*
  - ✓ *Crop production data*
  - ✓ *Analytical relationship between Kcb and SAVI*

  X *<u>Harvest index at regional scale</u>: The analysis of selected plots shows the effect of management and meteorological conditions in the HI, varying between <u>0.45 and 0.55</u> for rainfed and irrigated corn in Nebraska*



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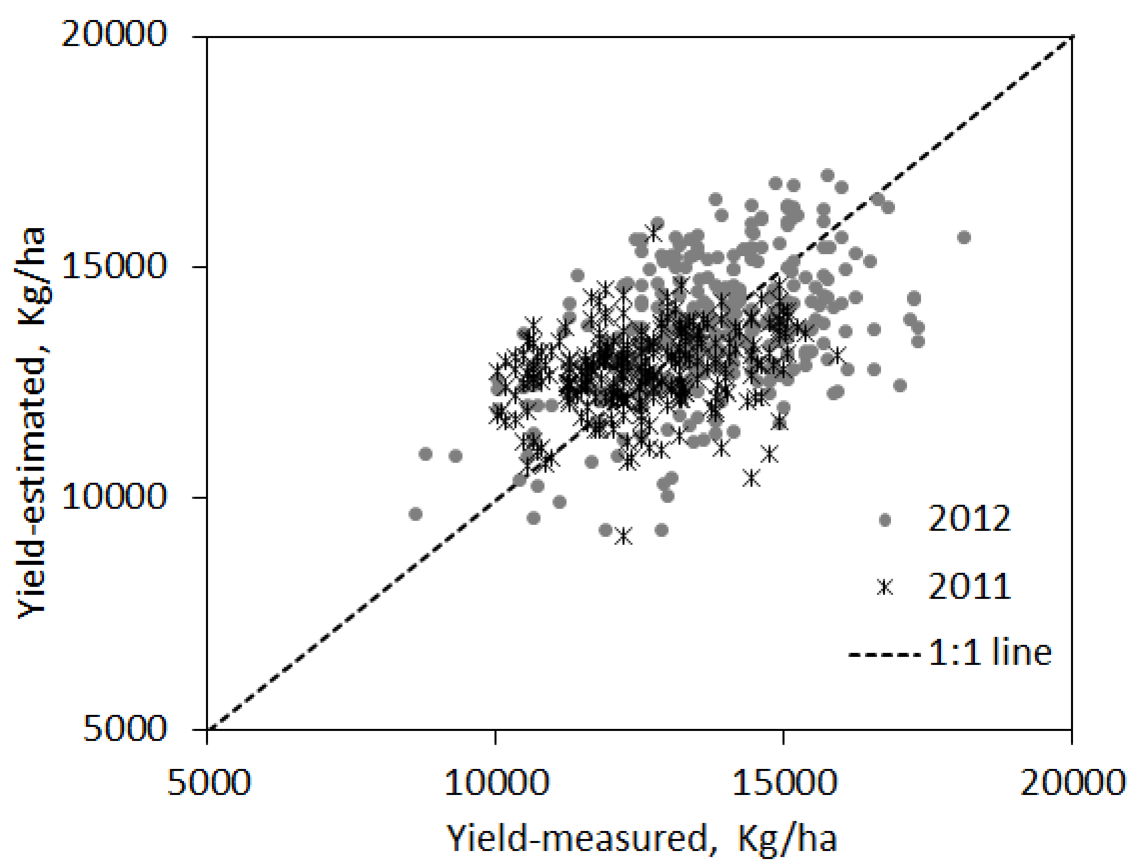
Estimation corn productivity at regional scale in central Nebraska

- *Relative good but noisy agreement for both analyzed campaigns*
- *Higher yields in 2012, extremely dry year (flash drought in the mid-western US)*
- *Sensitive to the greater range of corn yields in 2012*

Comparison of measured and modelled yield for corn plots in 2011 and 2012 campaigns in Nebraska



HI = 0.47

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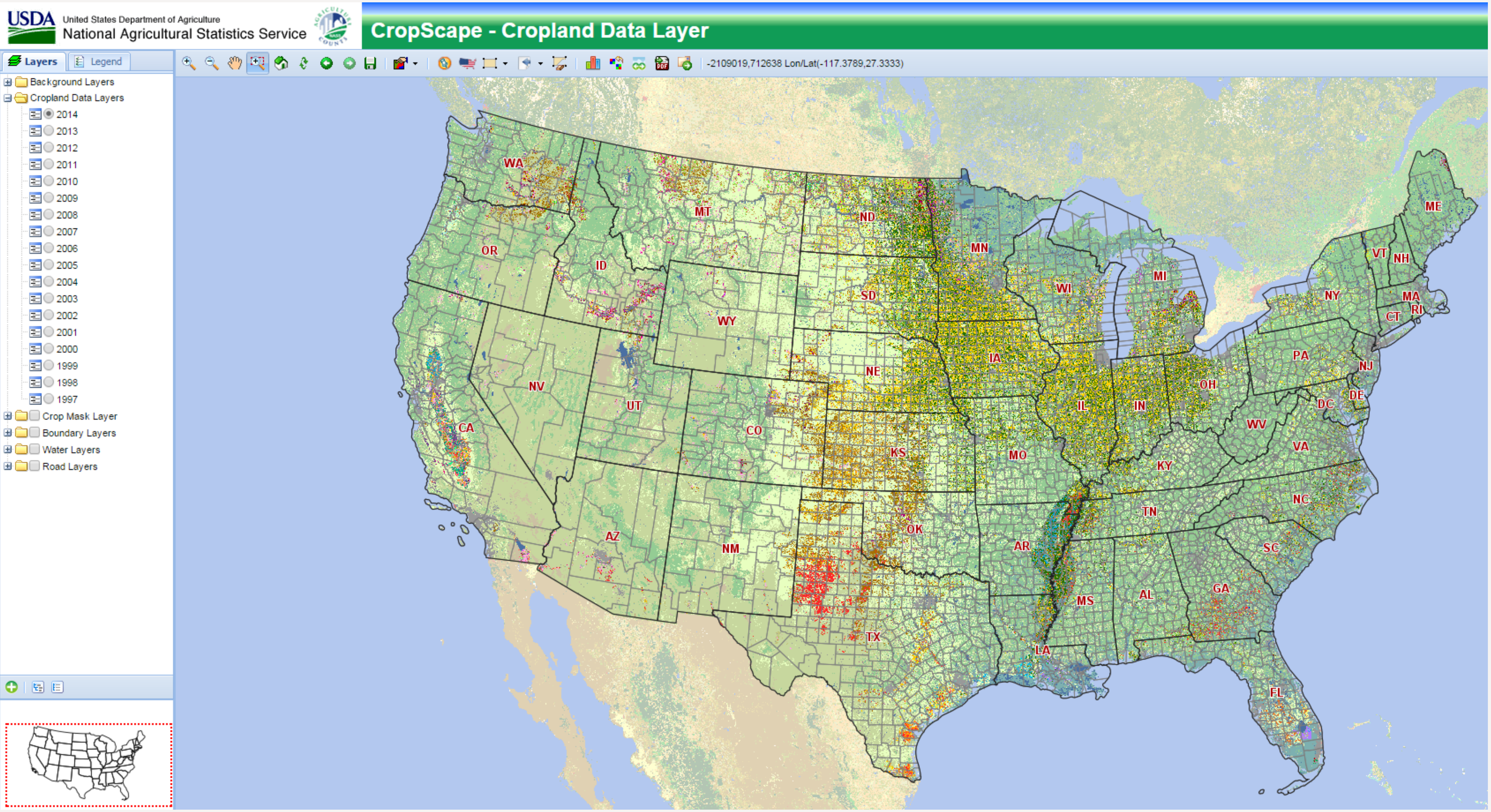
Conclusions and remarks

This preliminary research has indicated:

- *Need for of a new analysis of the Kcb-VI relationship for certain crops*
- *Strong basis for the VI-Biomass production*
- *Need for additional modeling approaches to partition between biomass and grain production for different crops*

Crop Classification Layers



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

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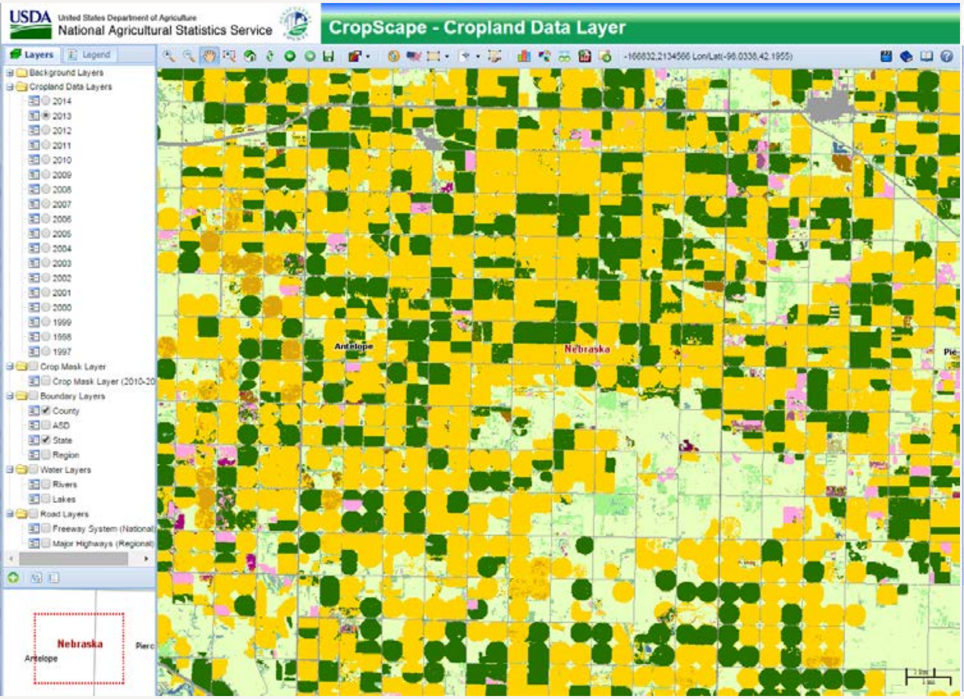
Northeastern Nebraska Corn/Soybean Rotation

2013



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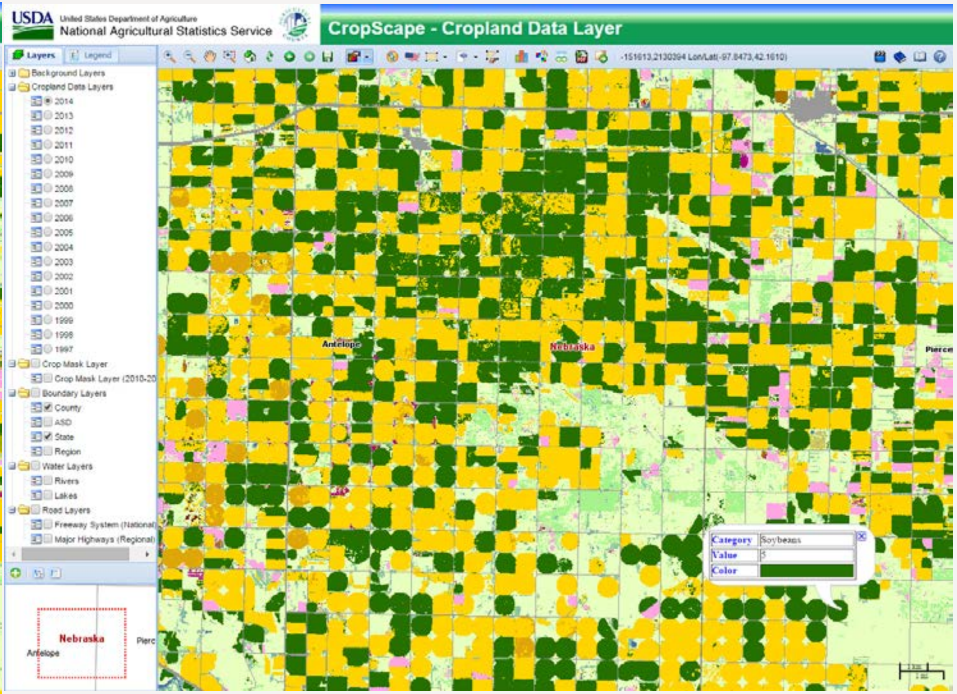
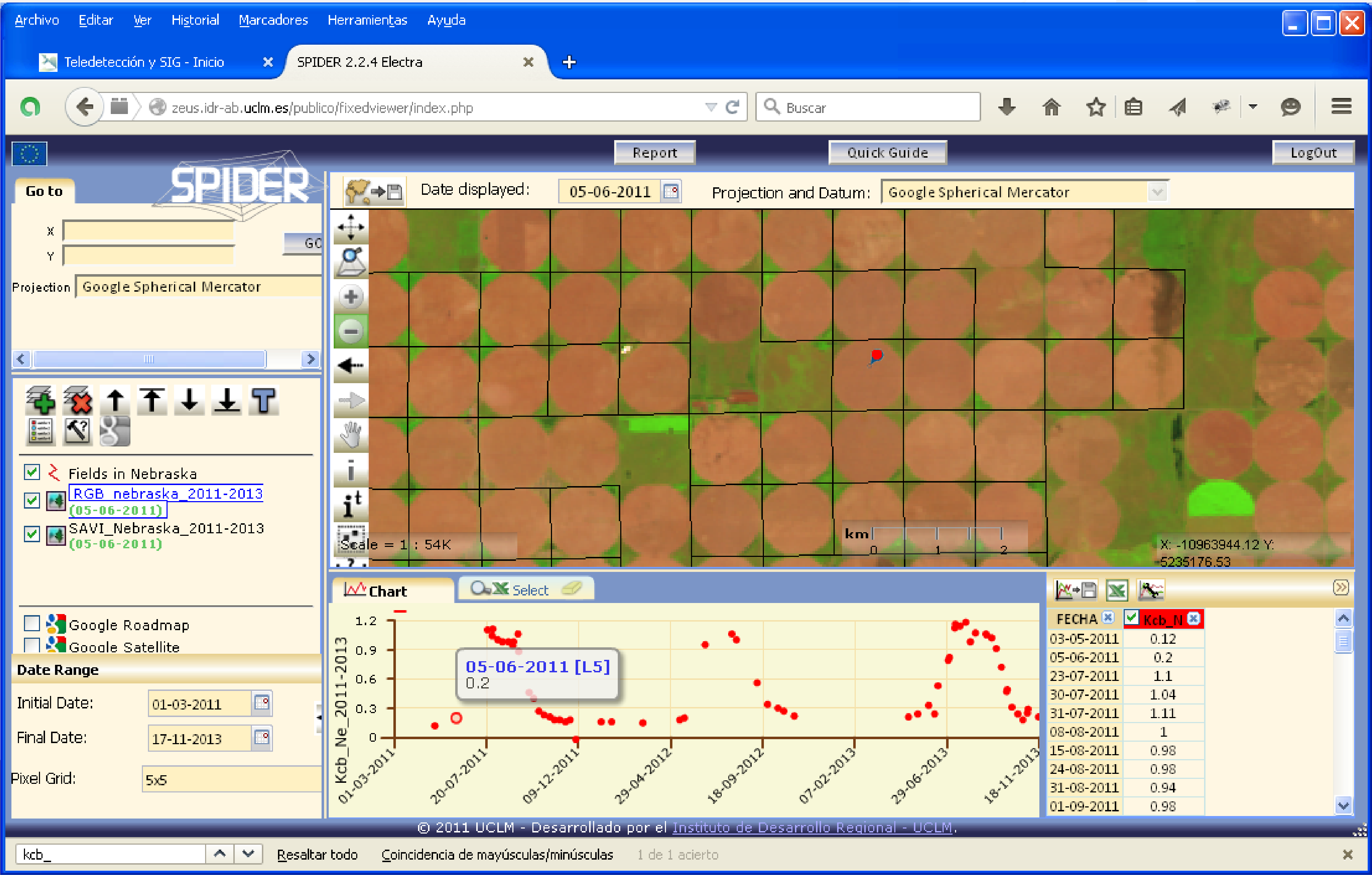


Many satellite-based evapotranspiration models require the knowledge of the crop type at the surface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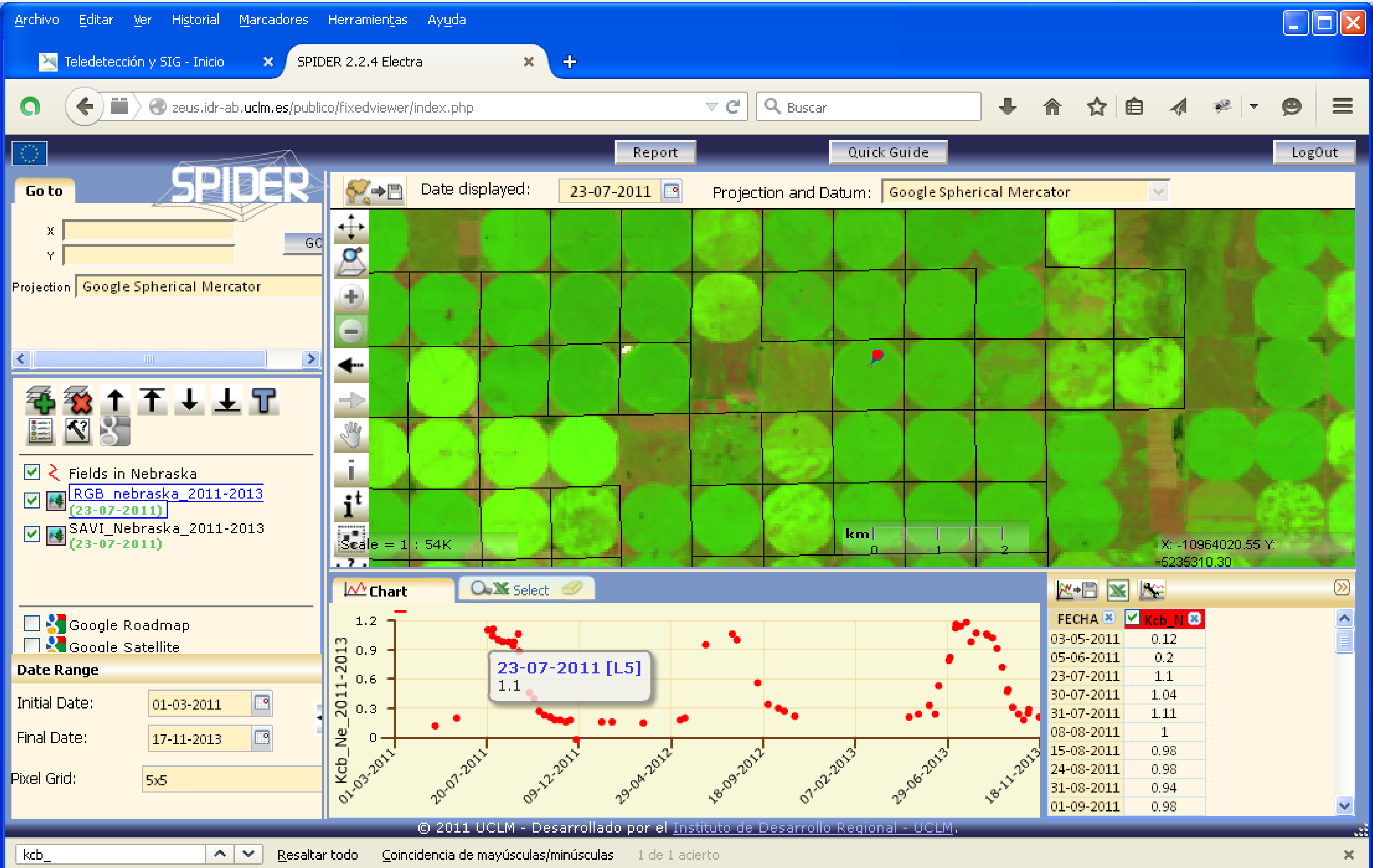
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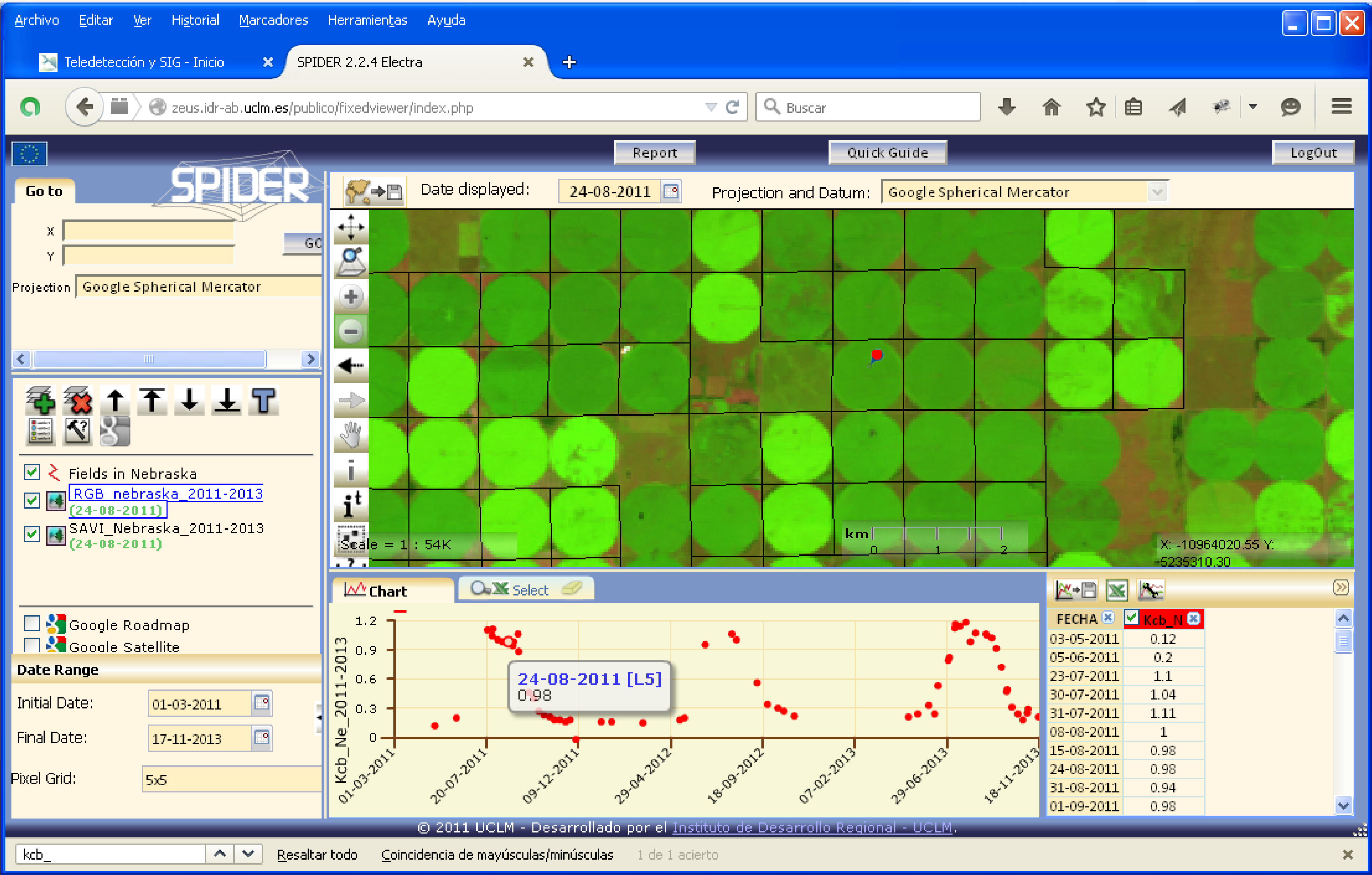
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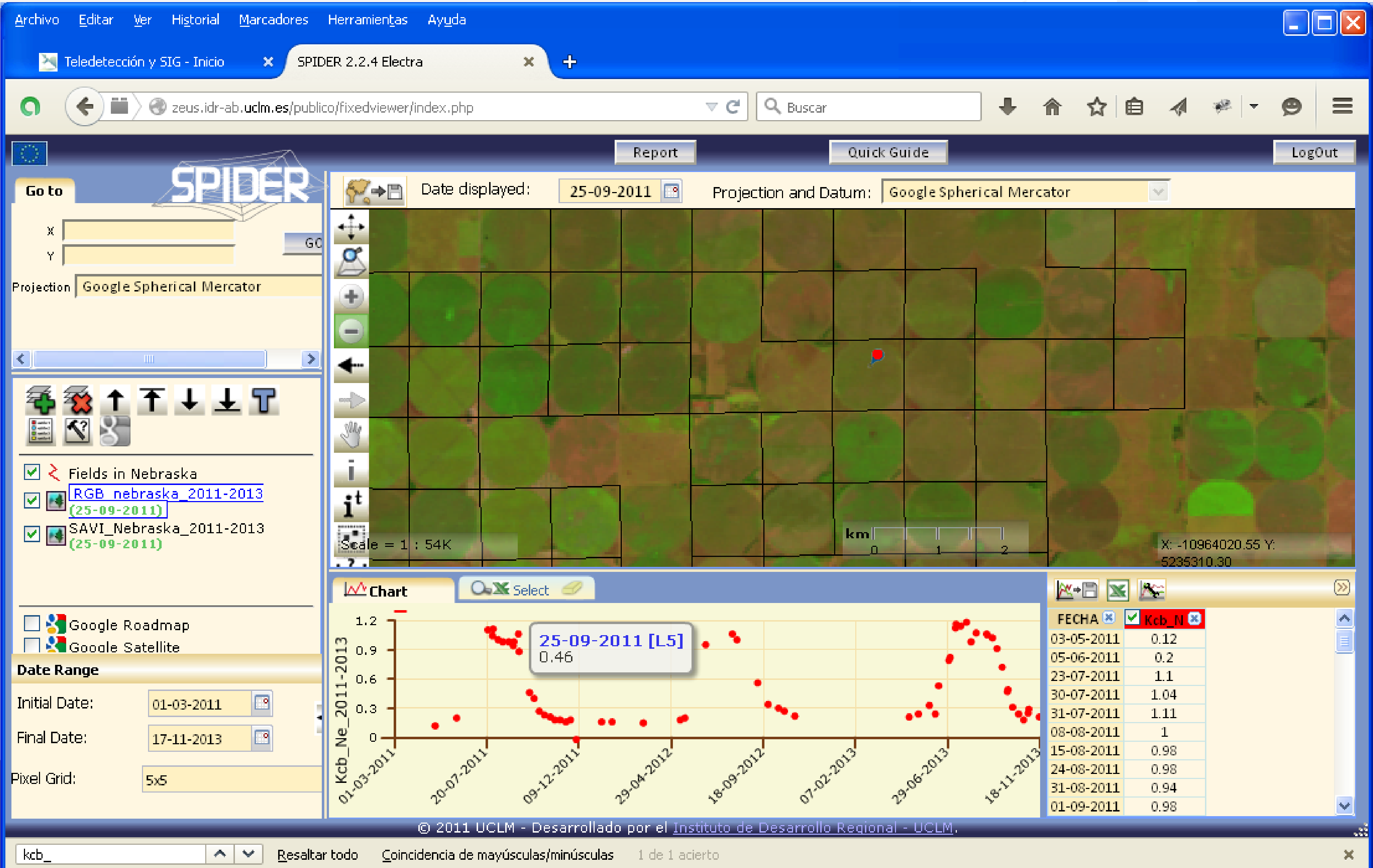
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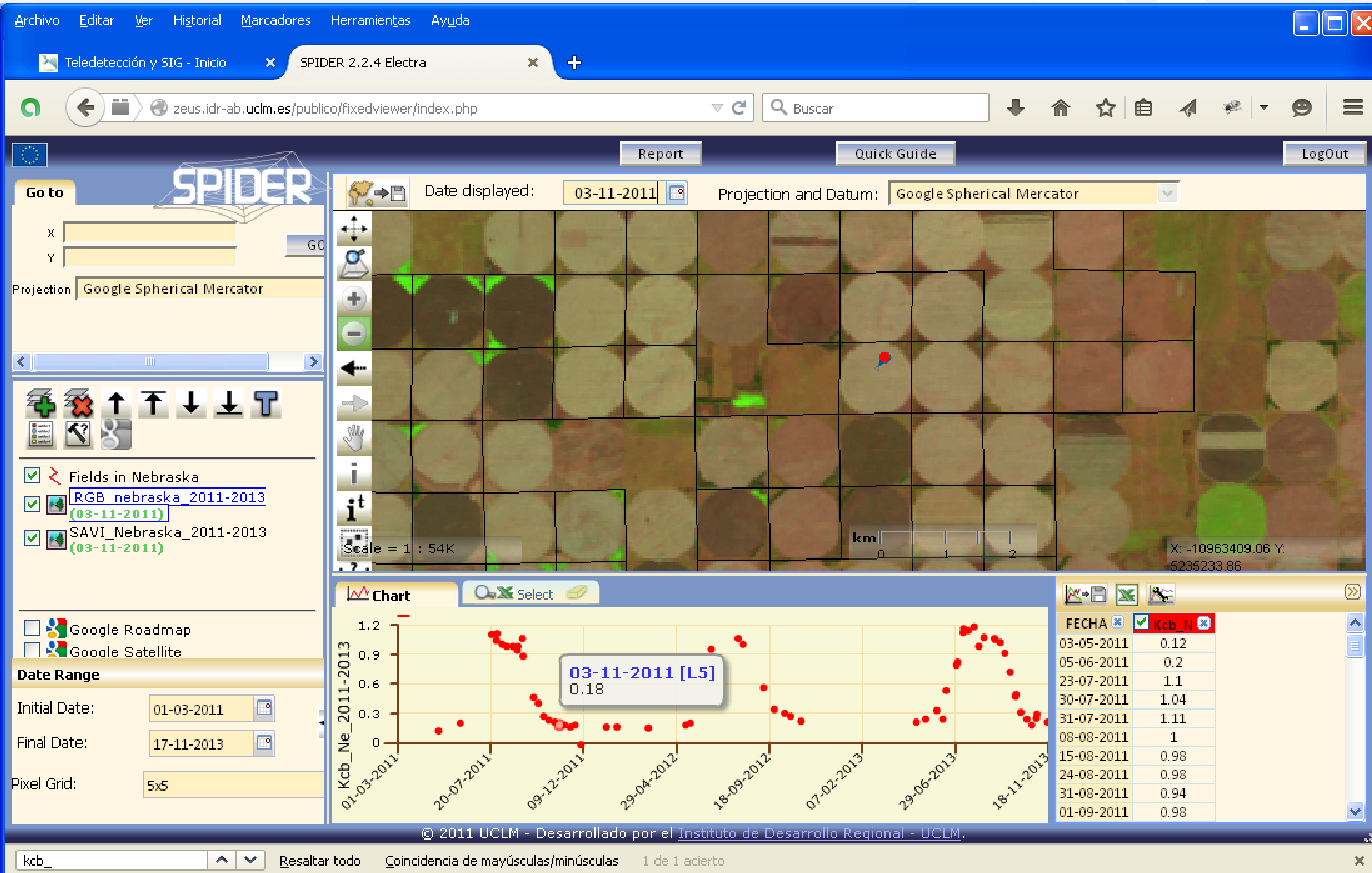
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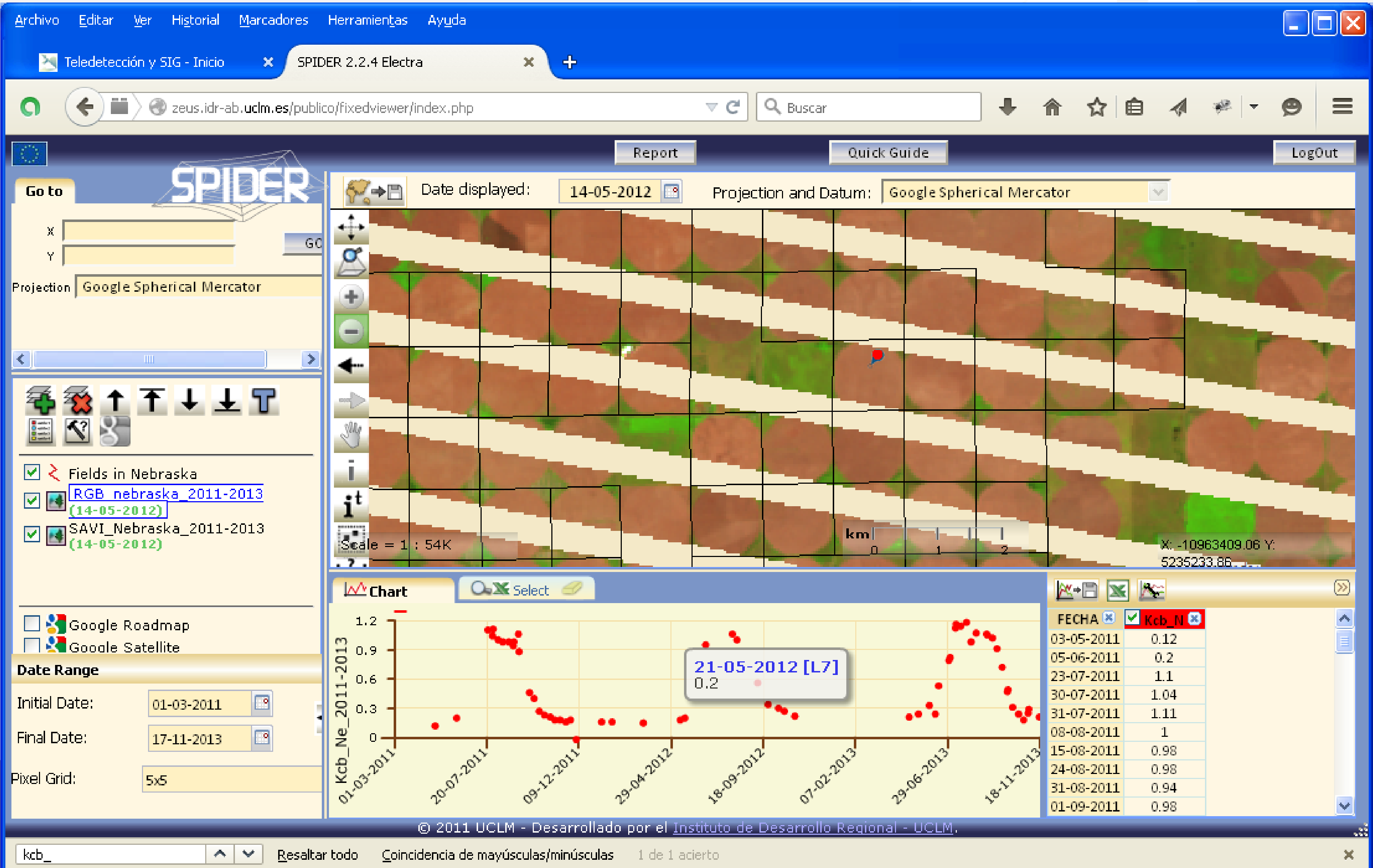
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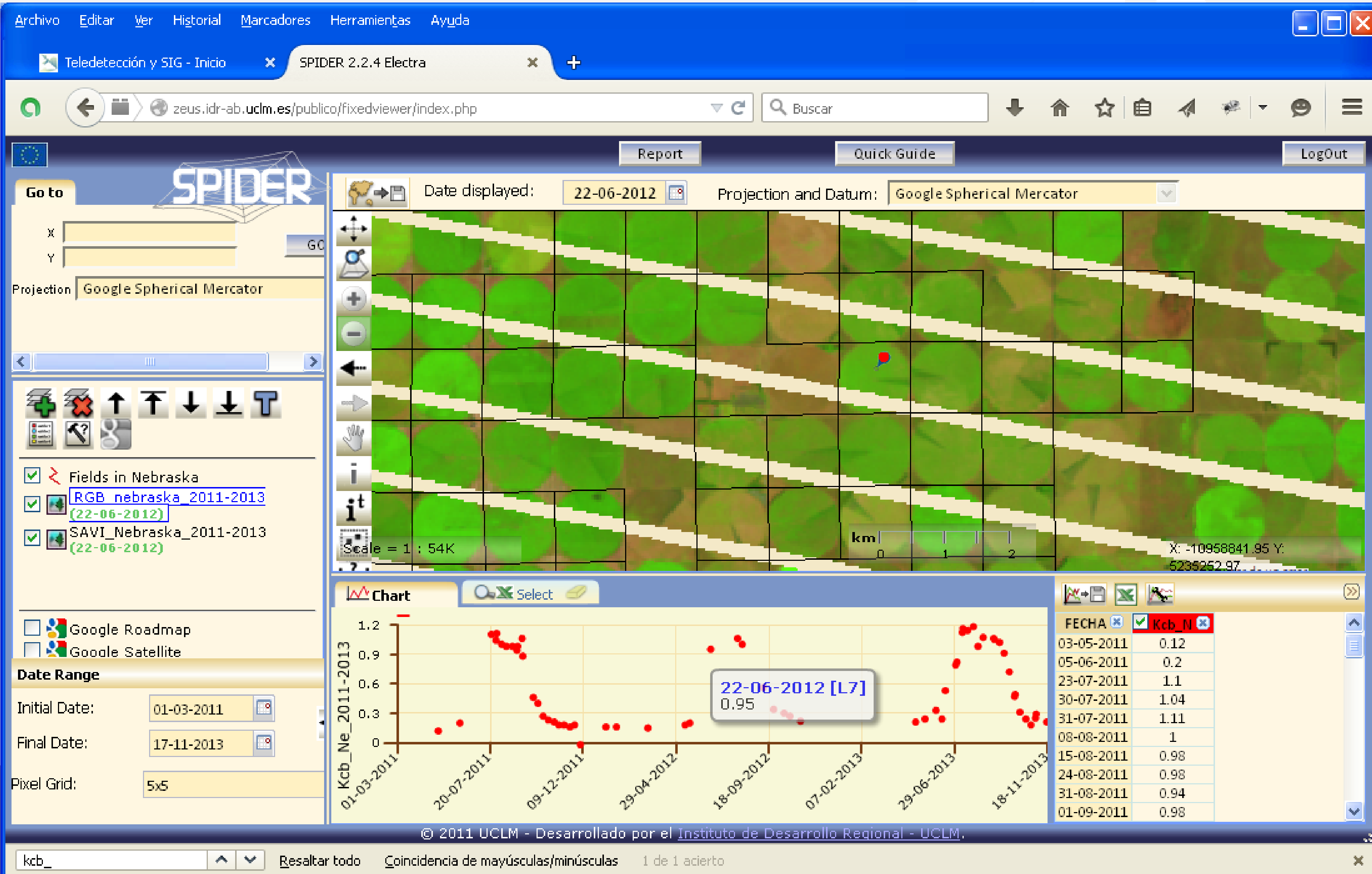
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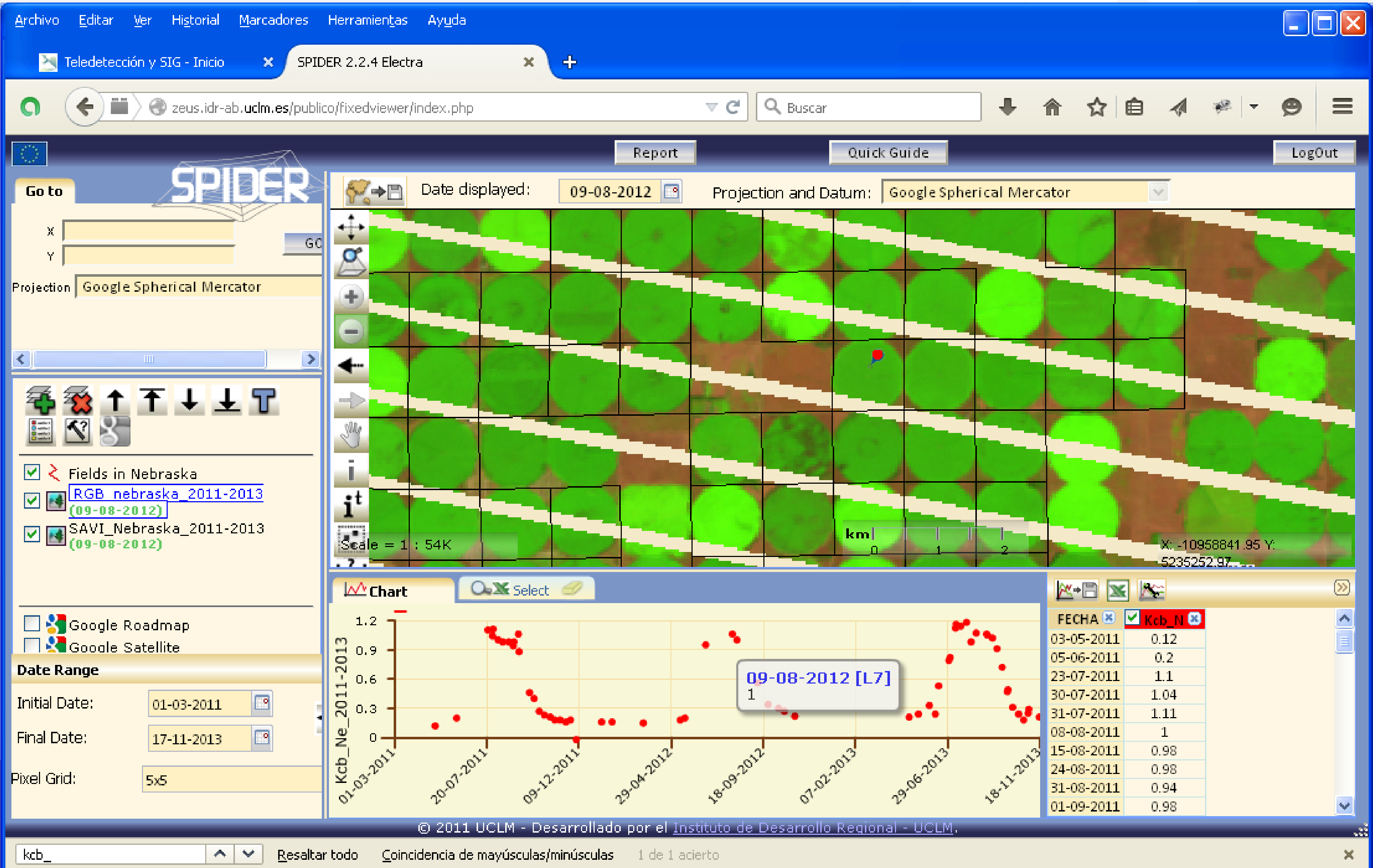
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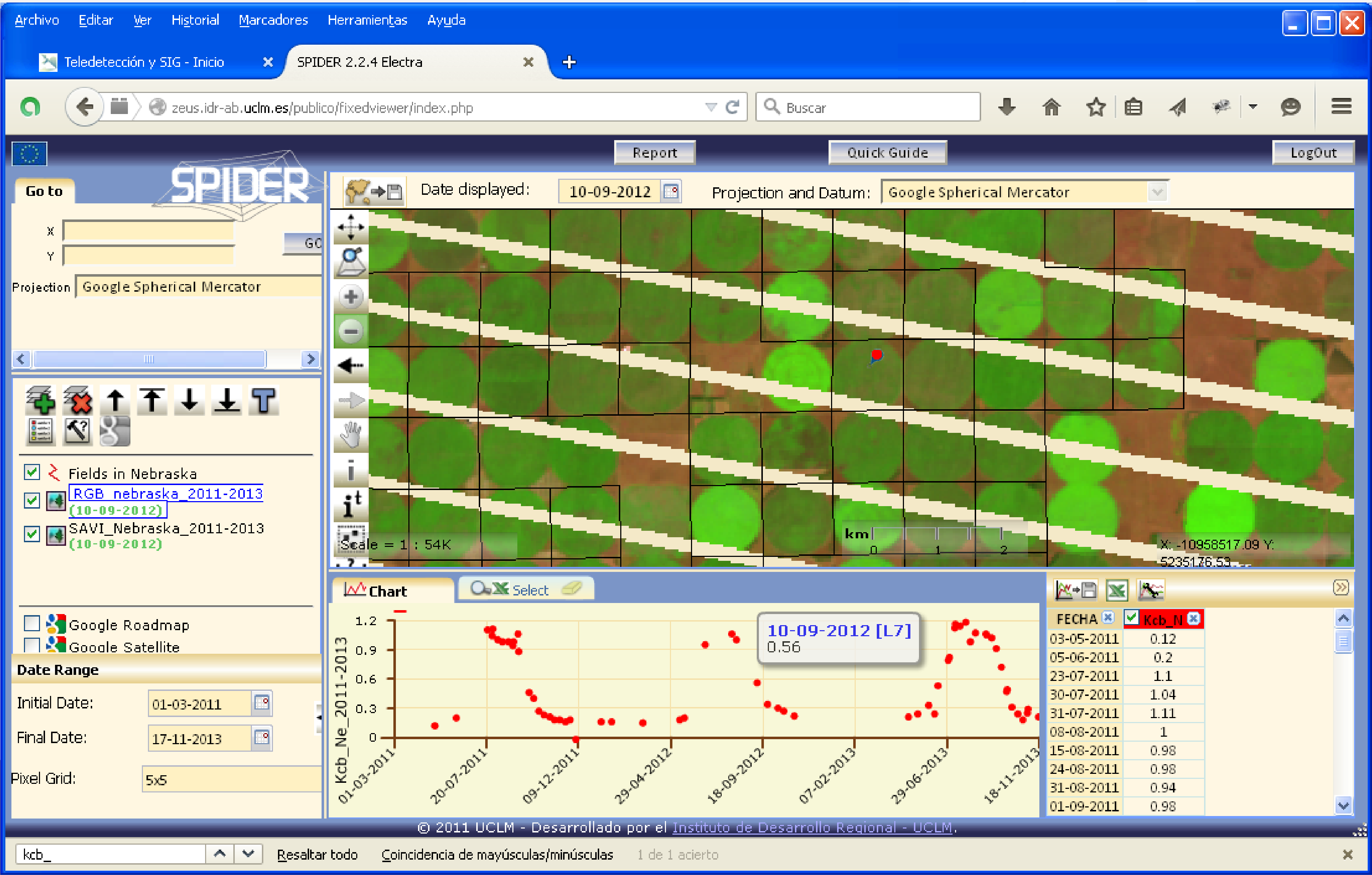
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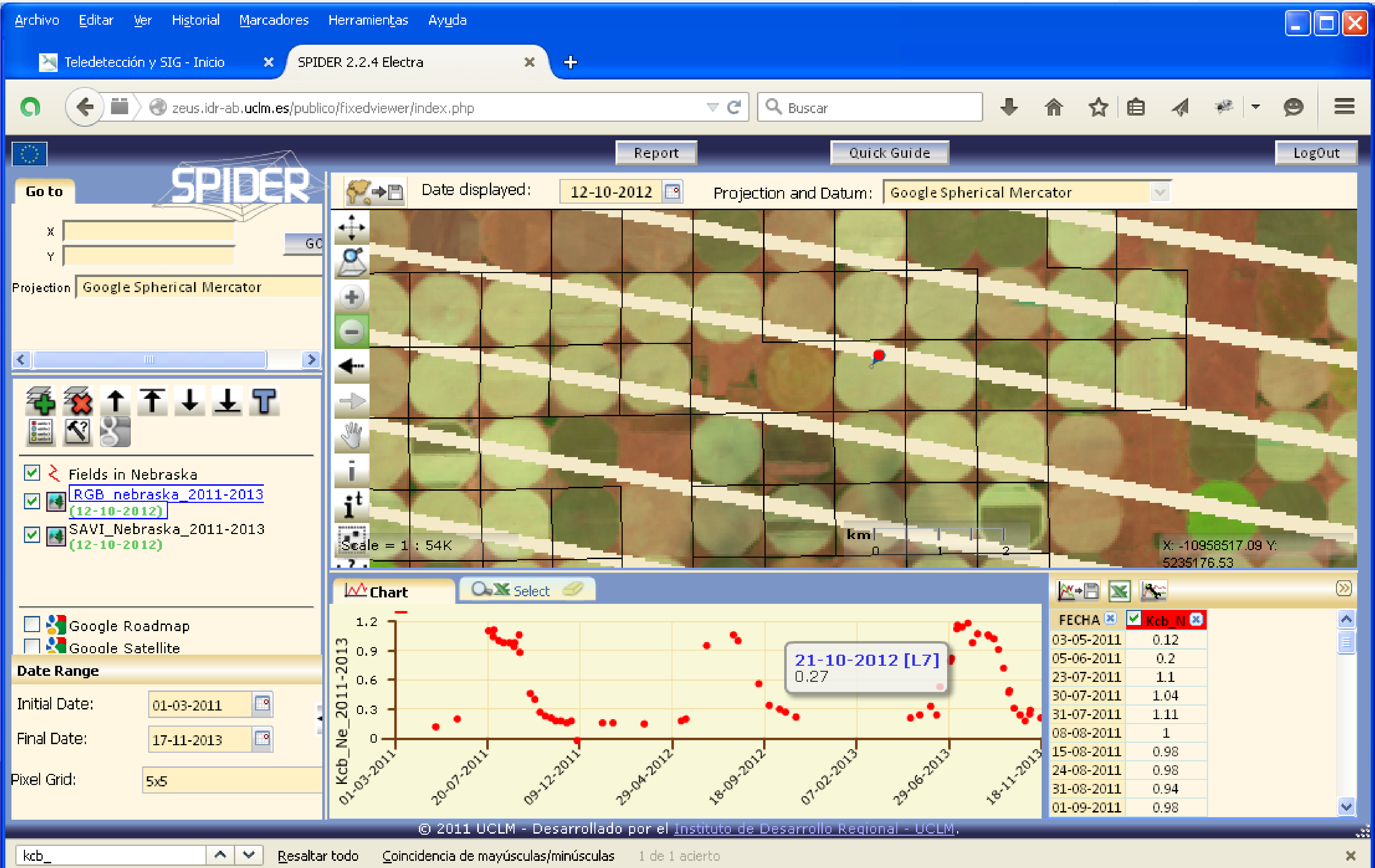

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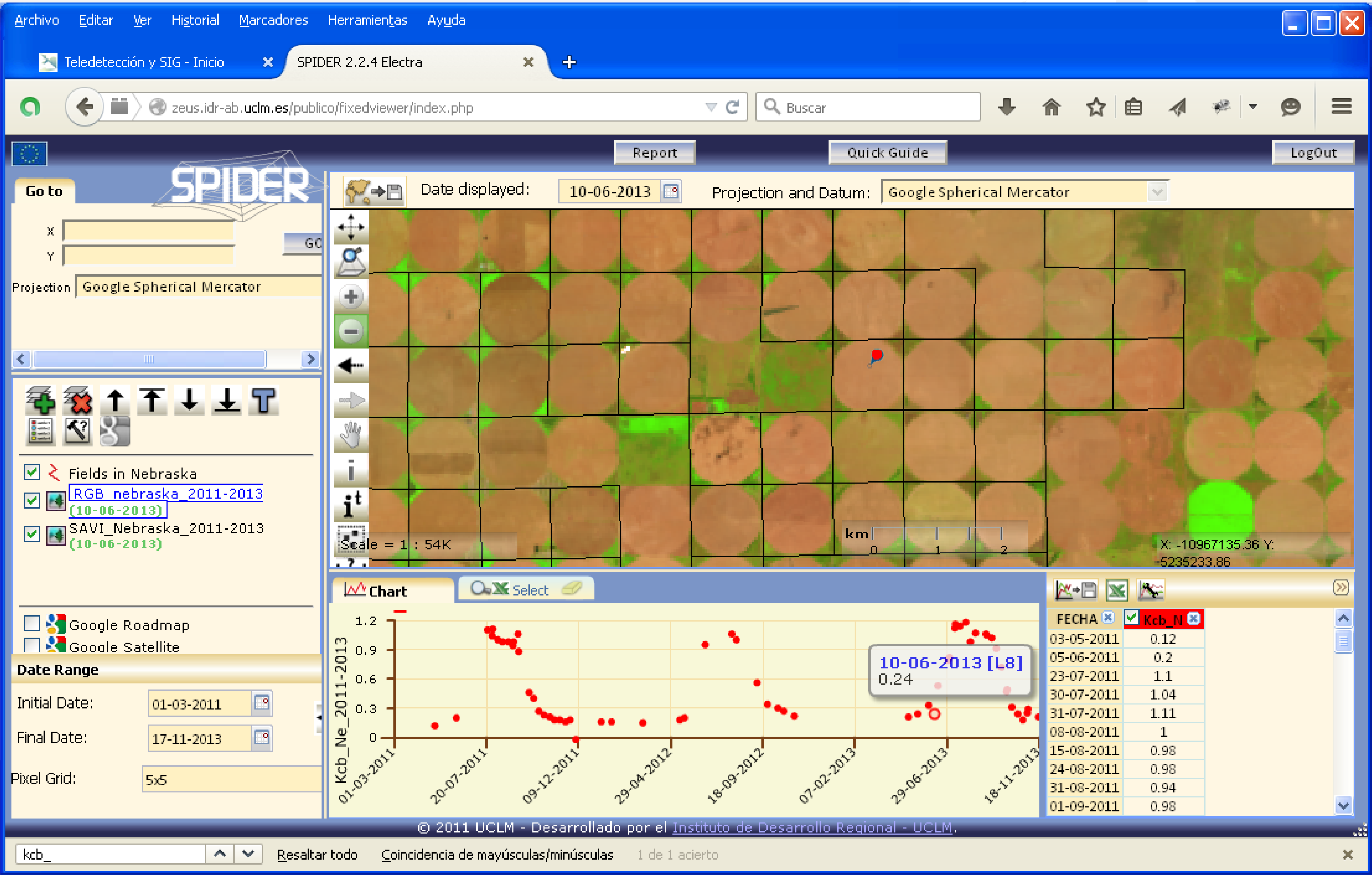

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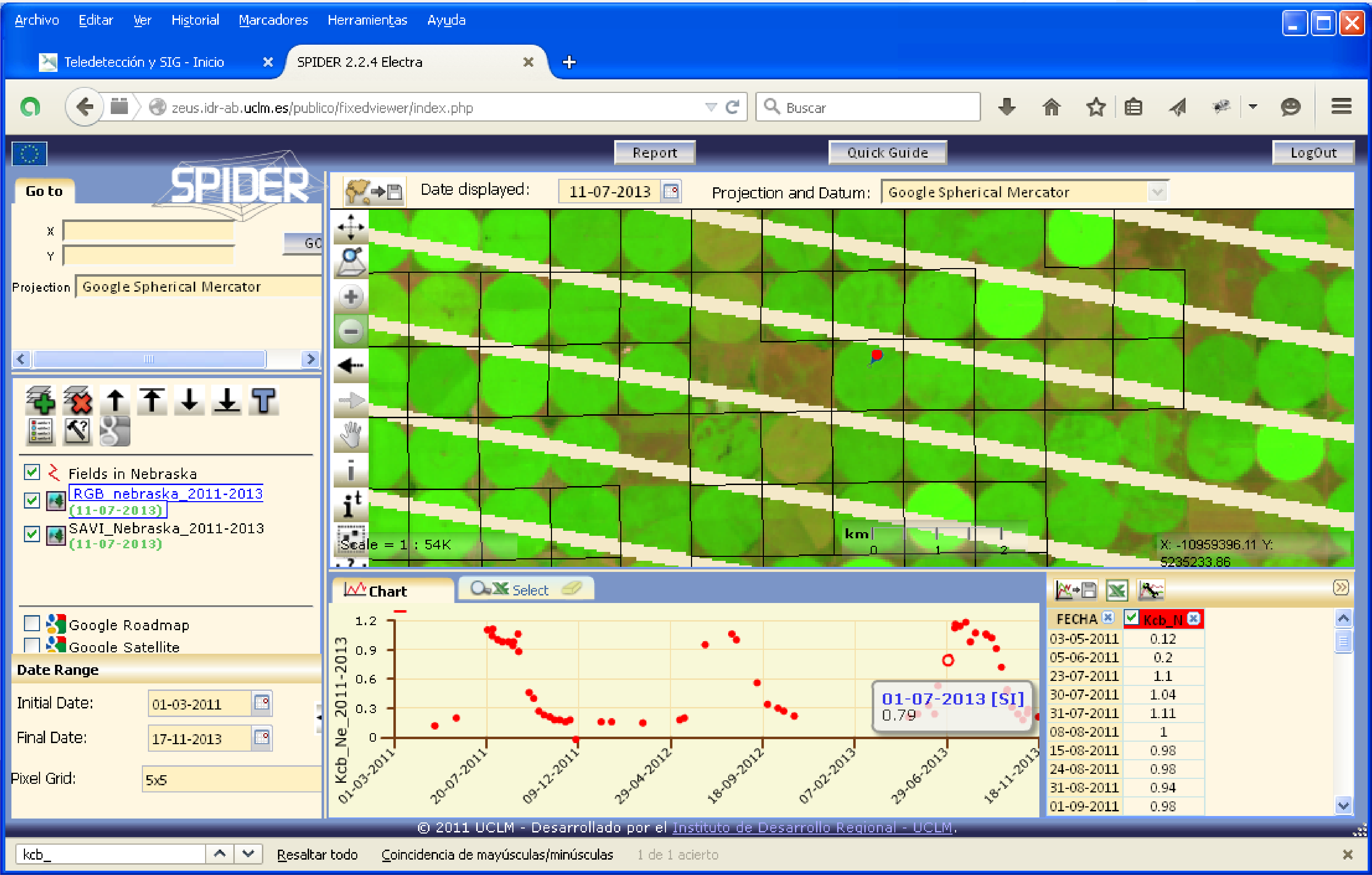

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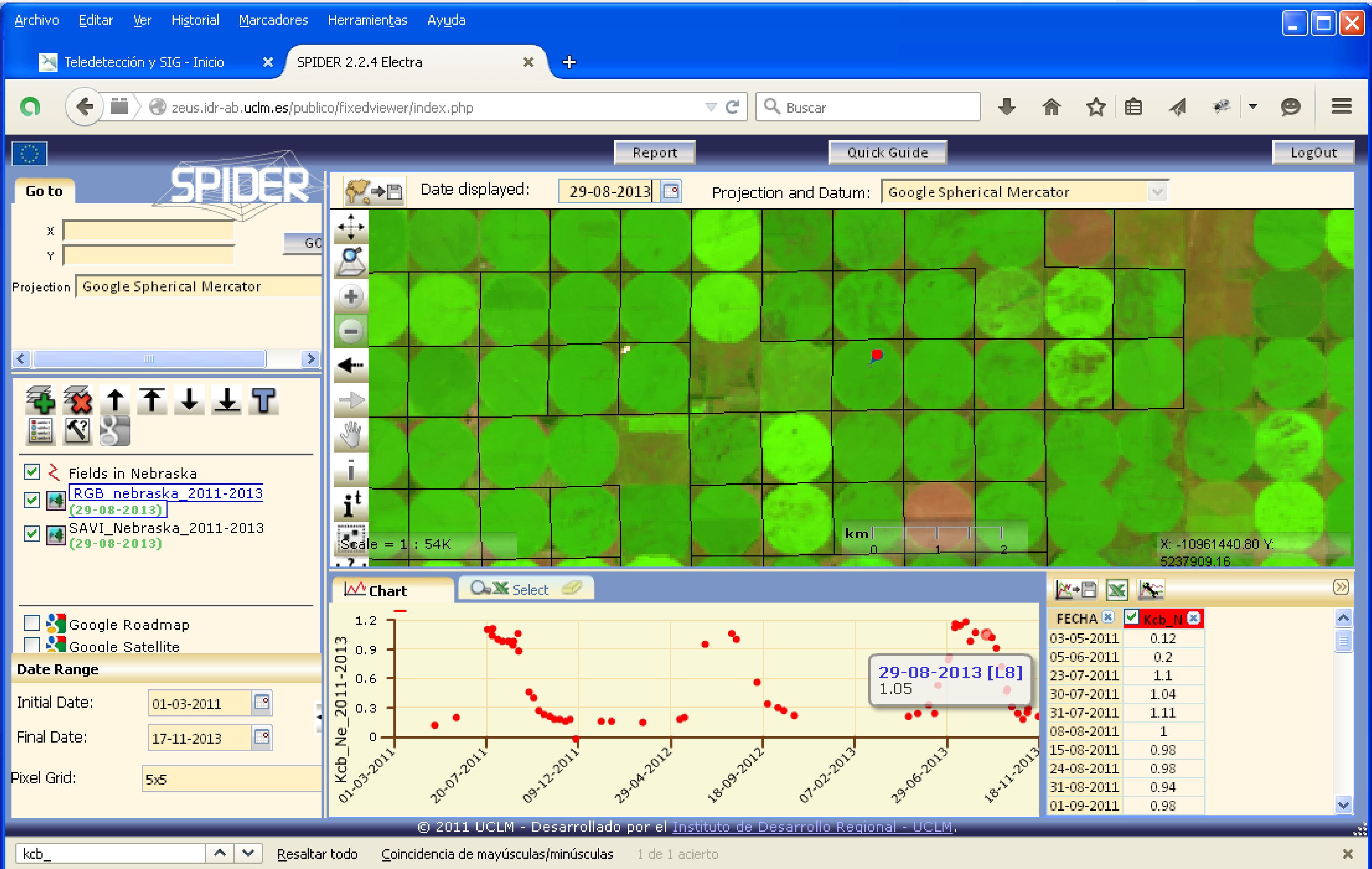
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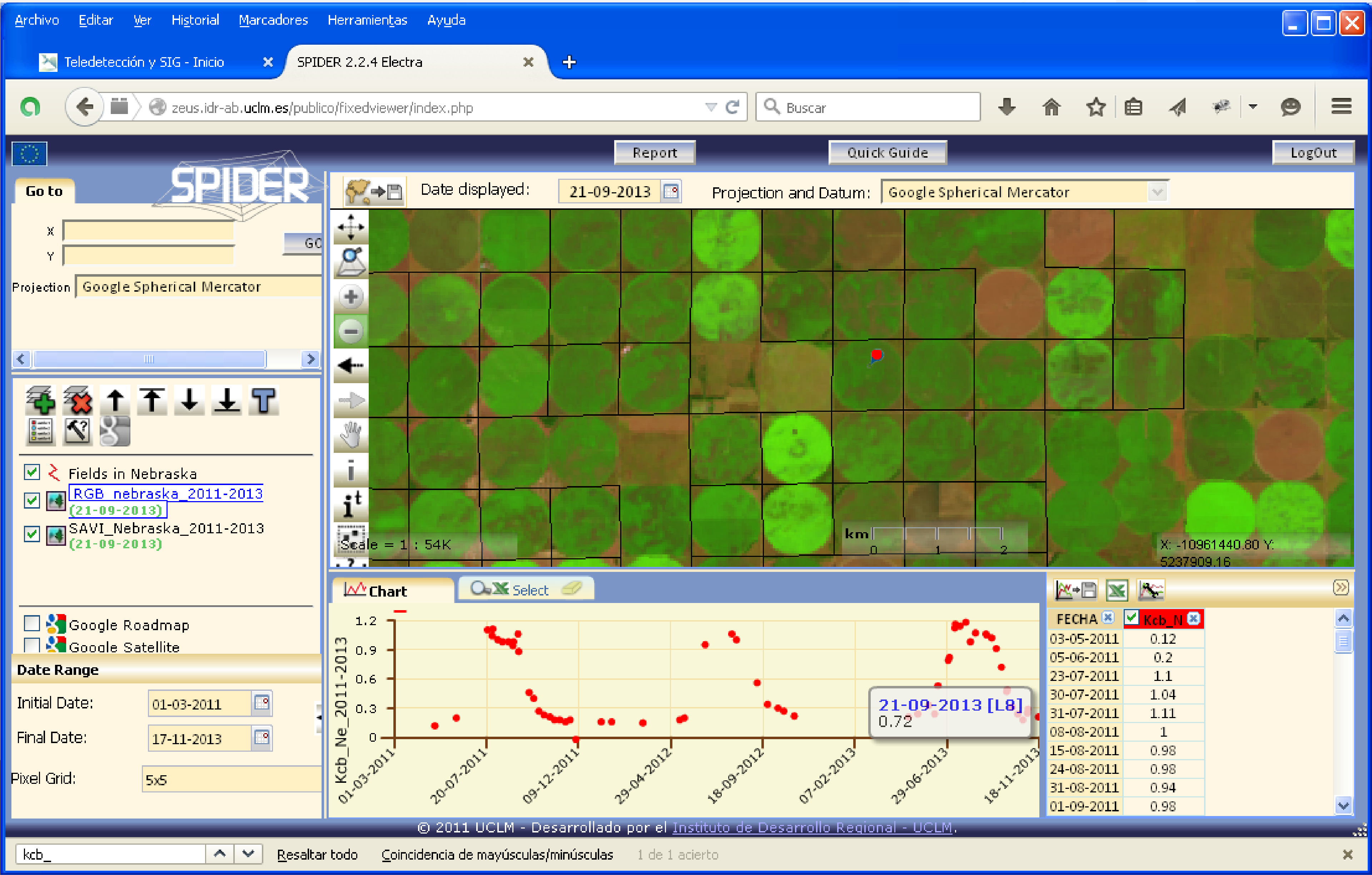
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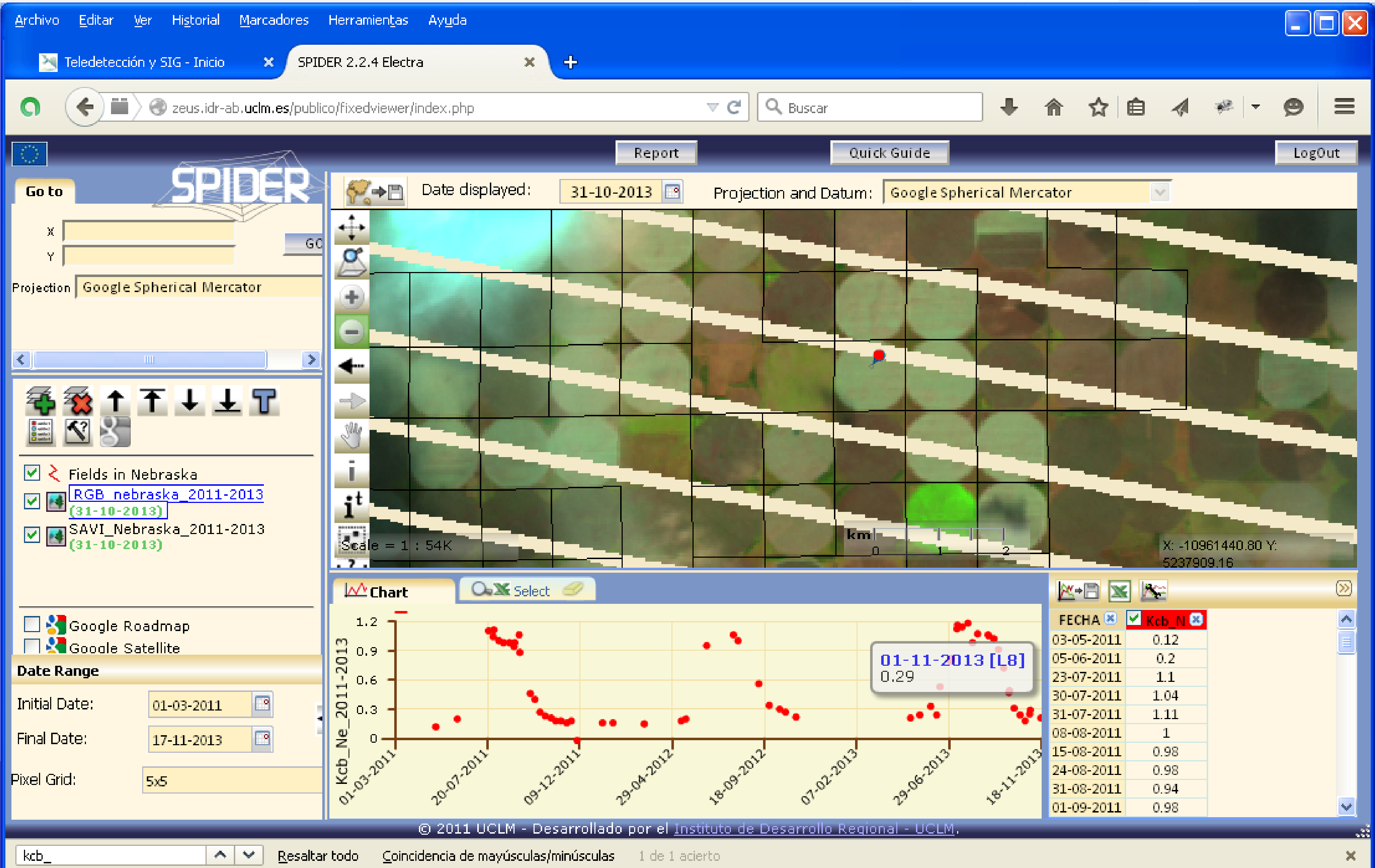
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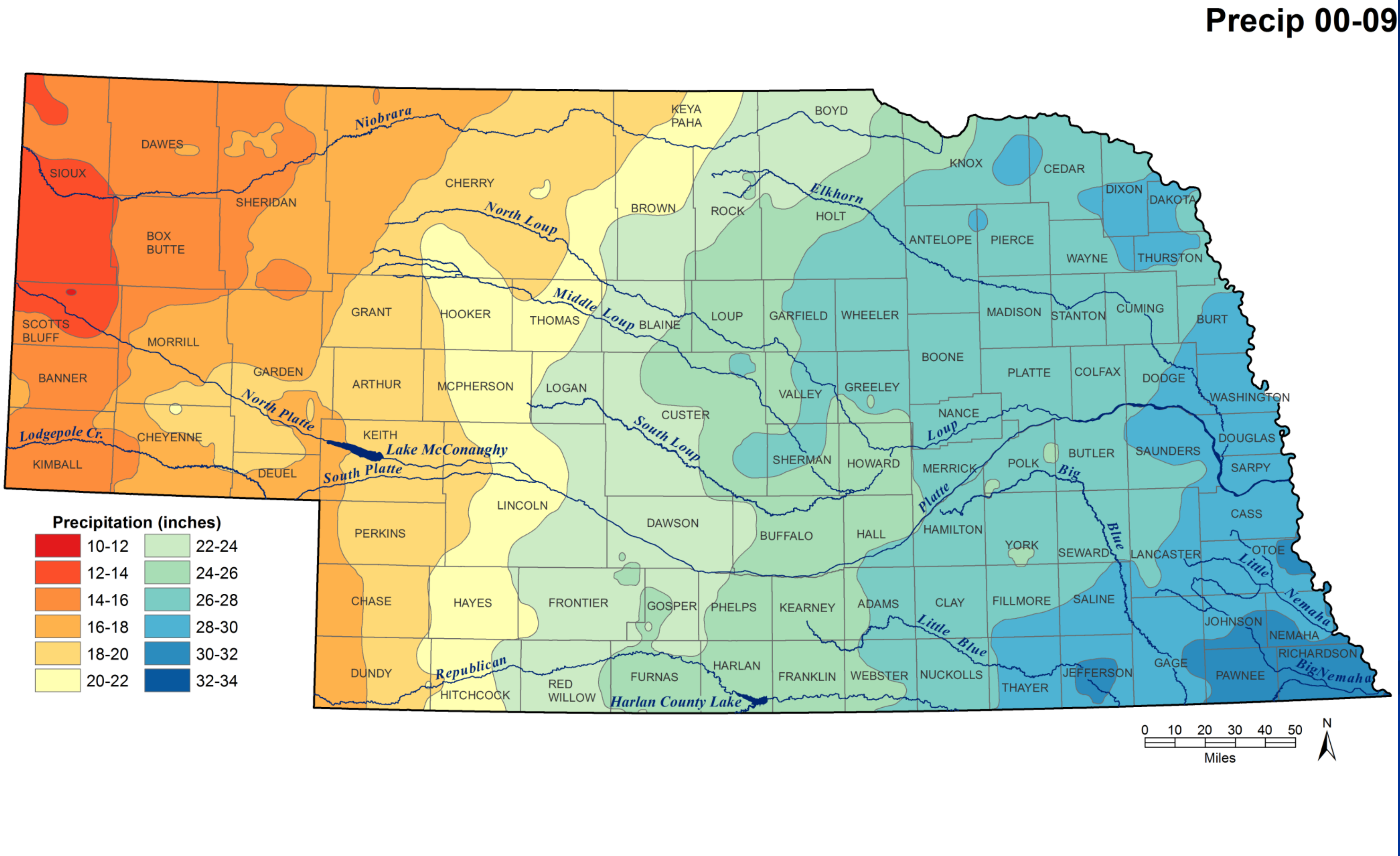
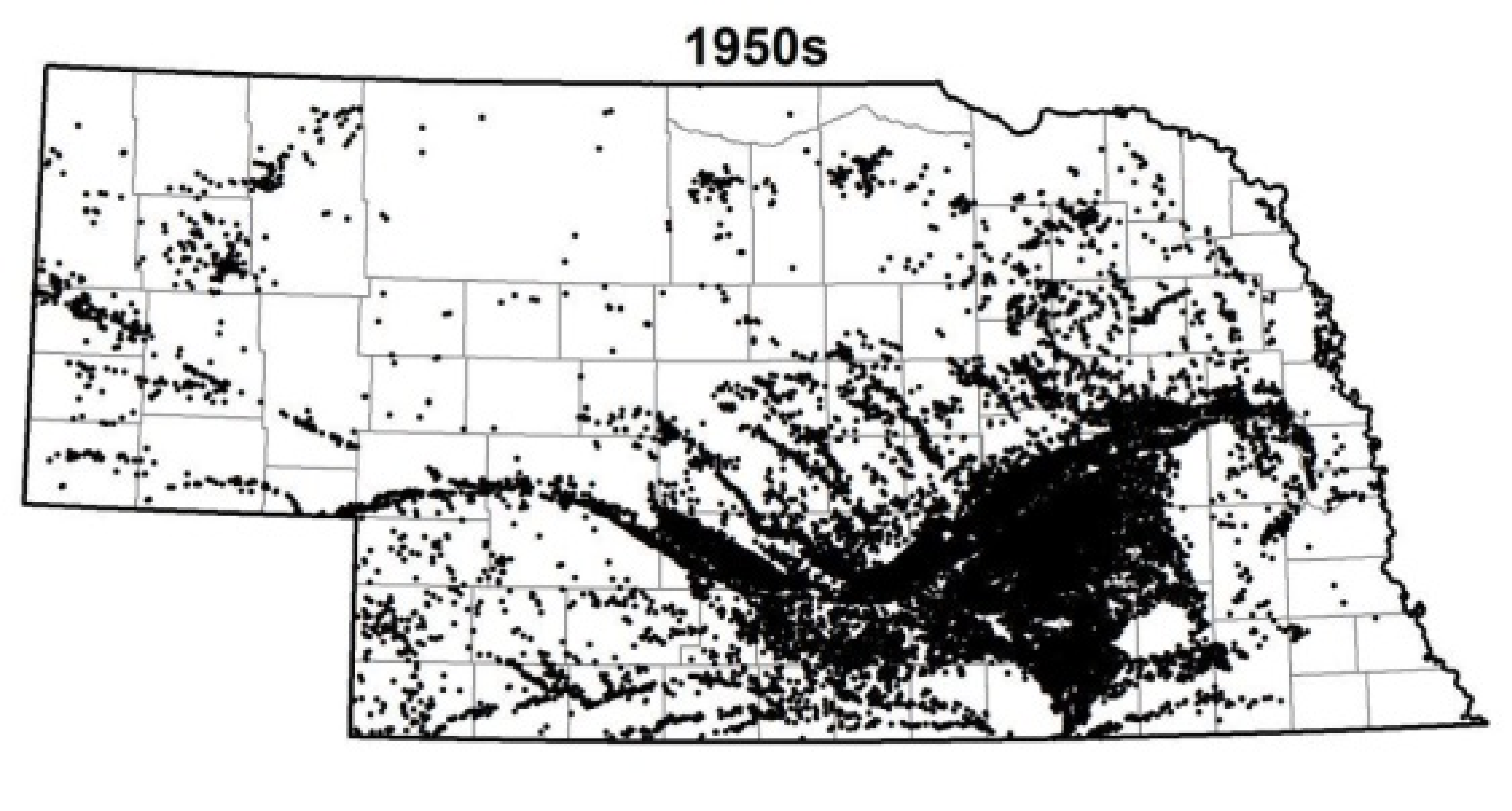
Average Annual Precipitation



Wells Drilled by Decade



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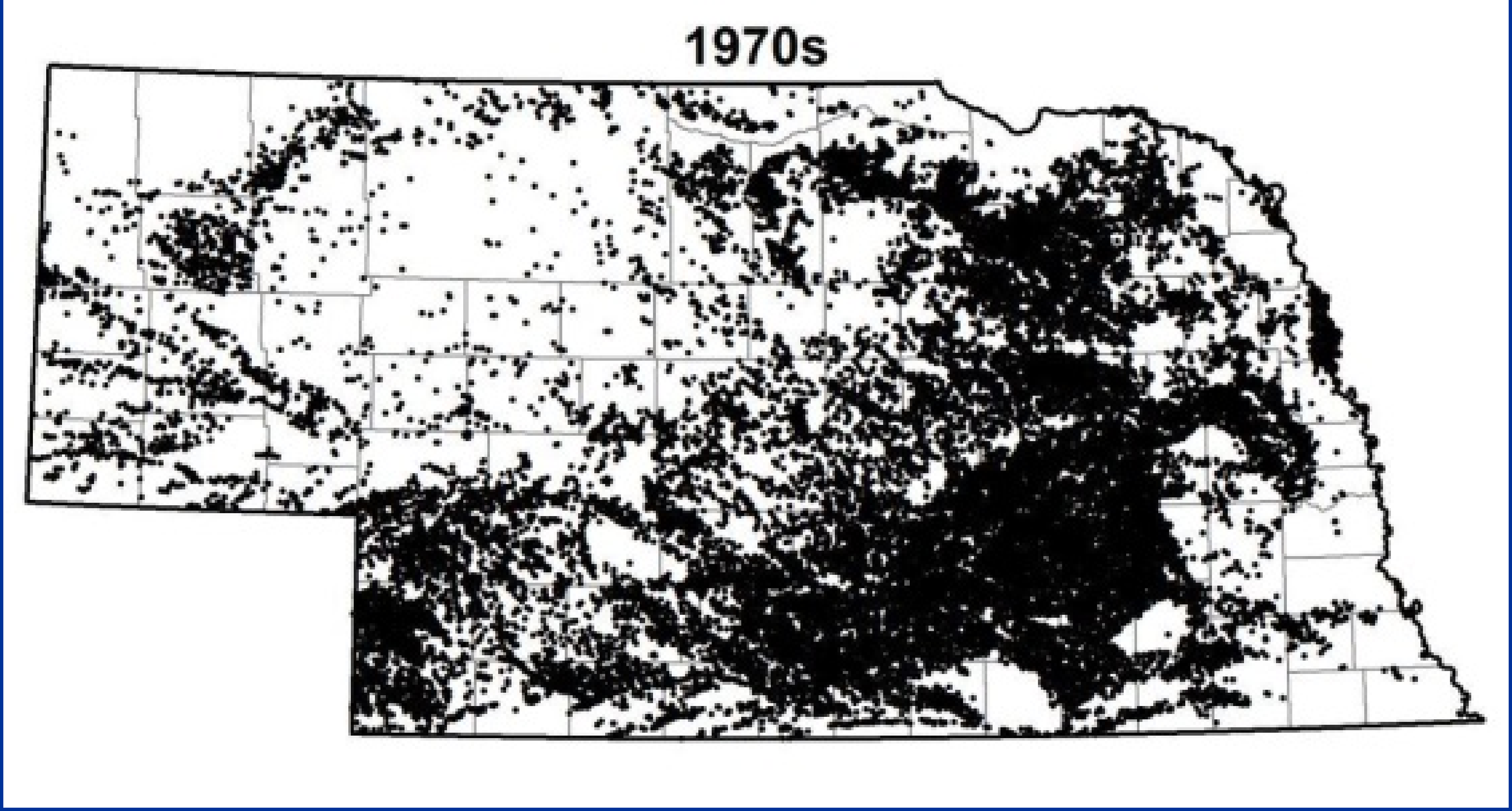

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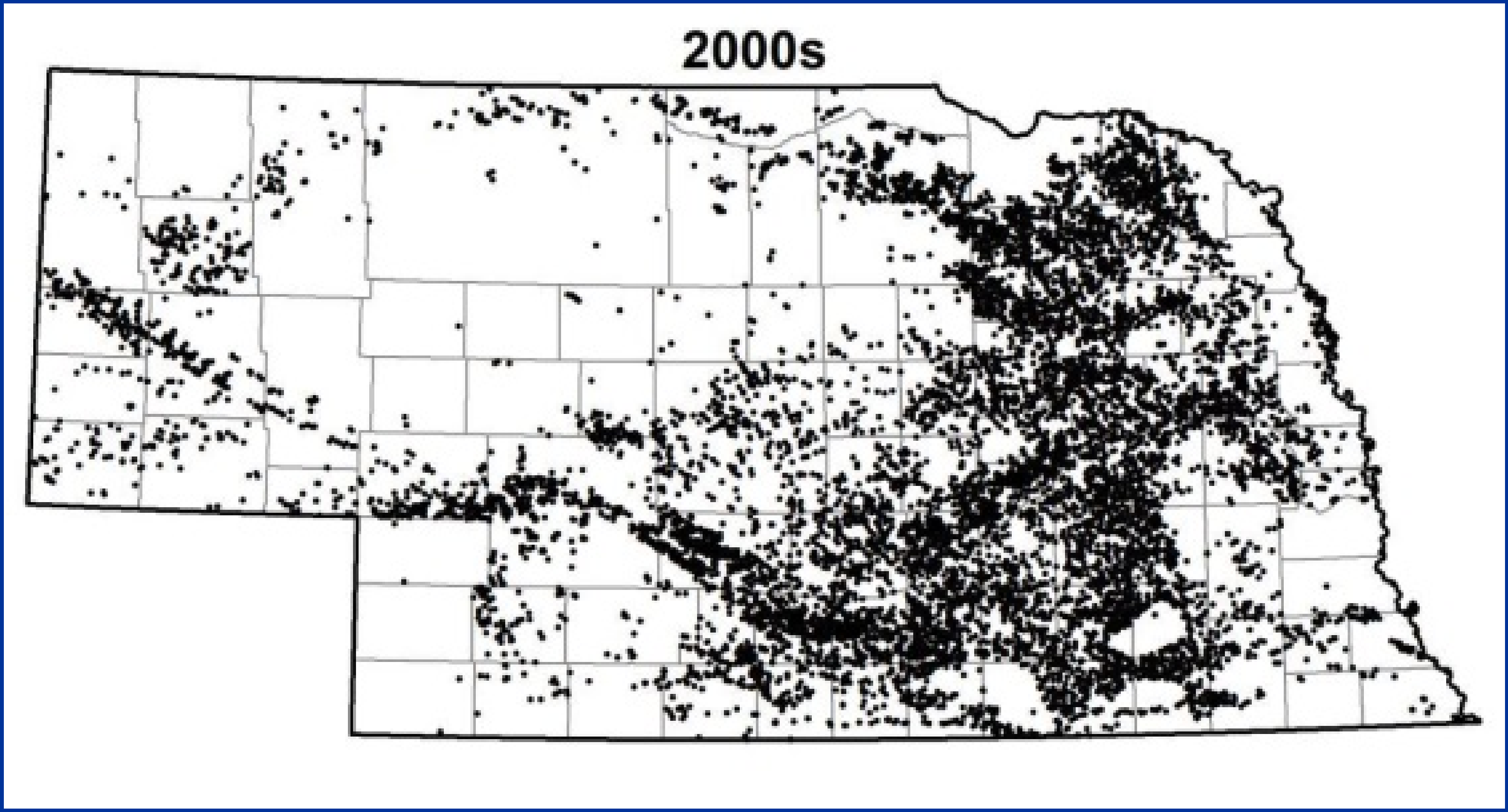
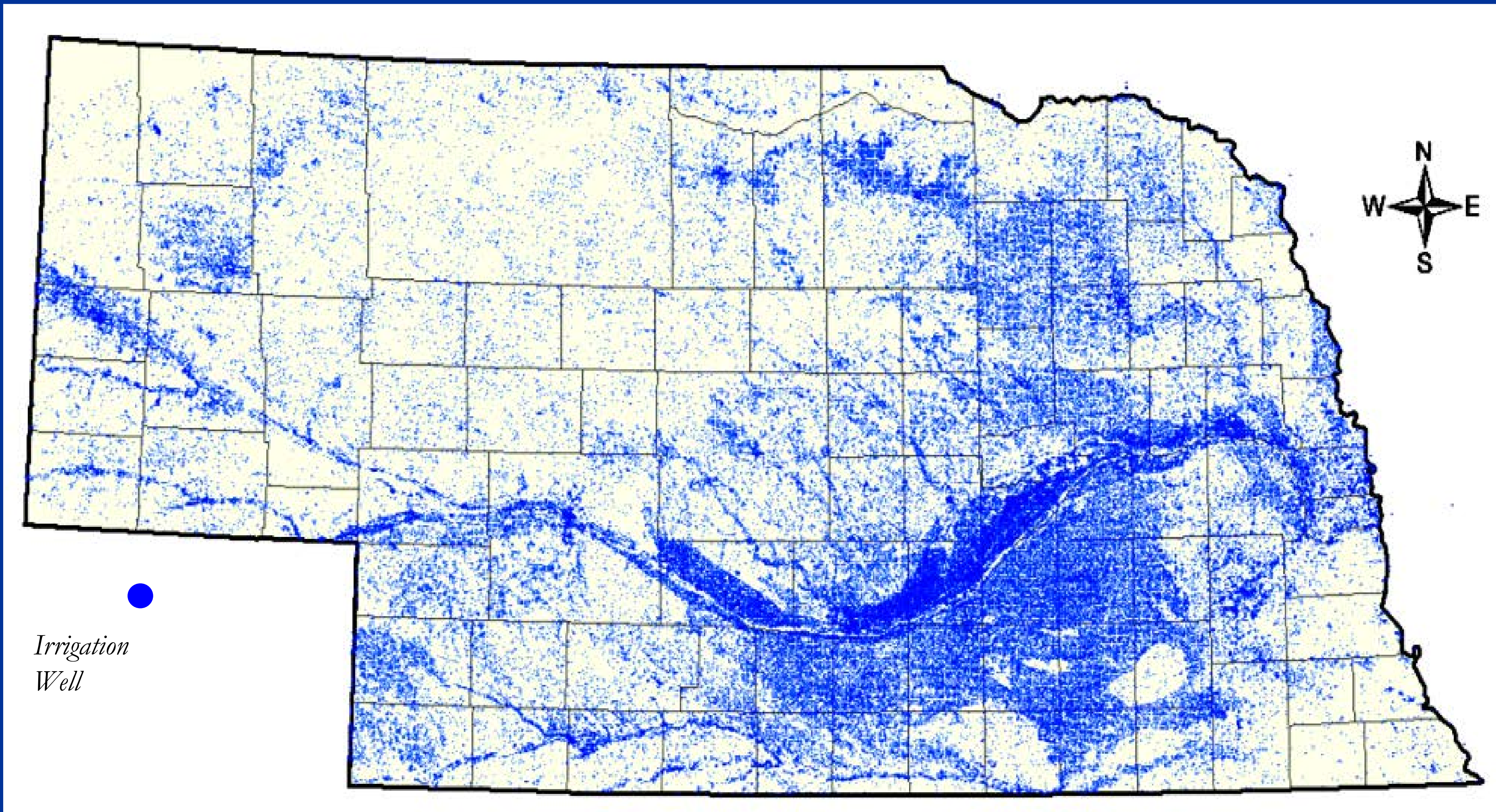
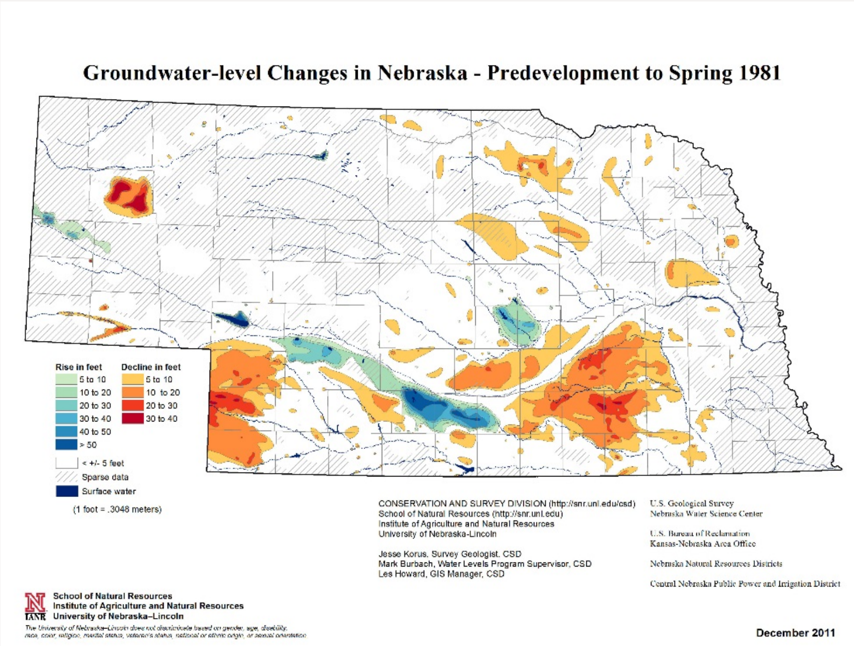


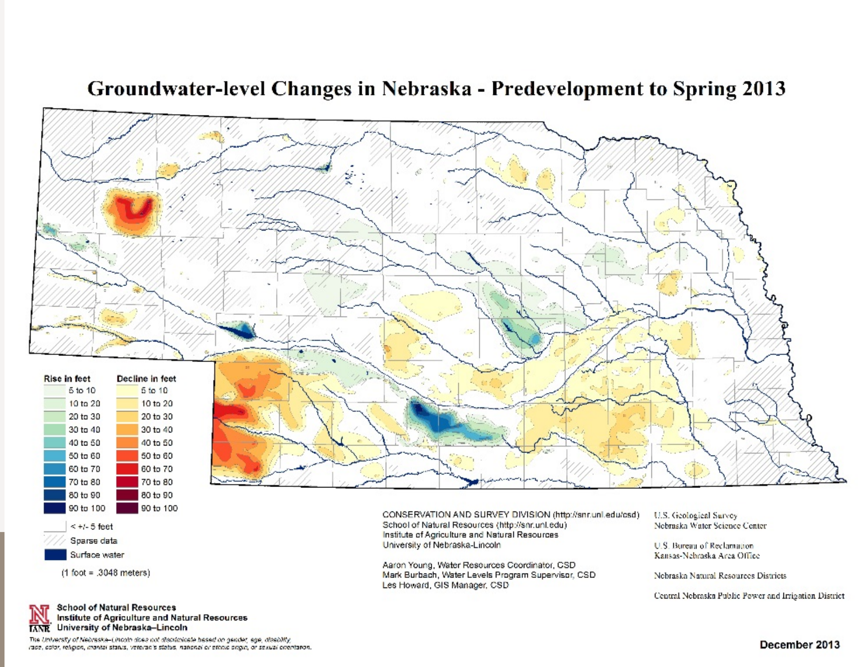
Irrigation Wells – Oct. 2012 = 124,697

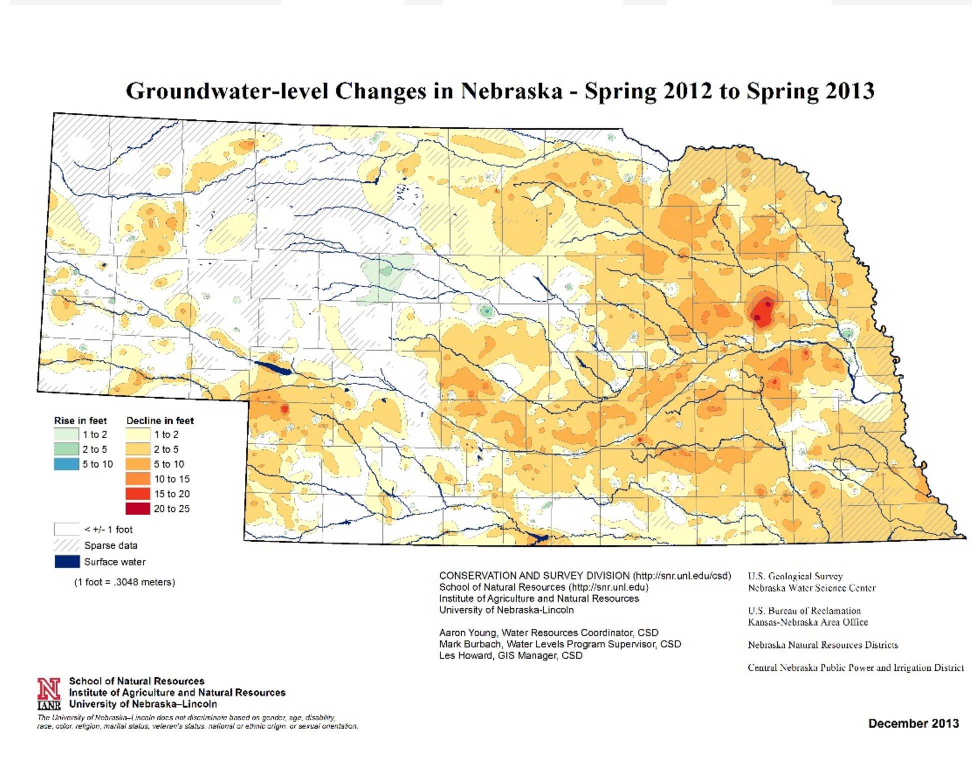


2015: approximately 95000 active wells
85% center pivot sprinkler irrigation, 15% surface irrigation

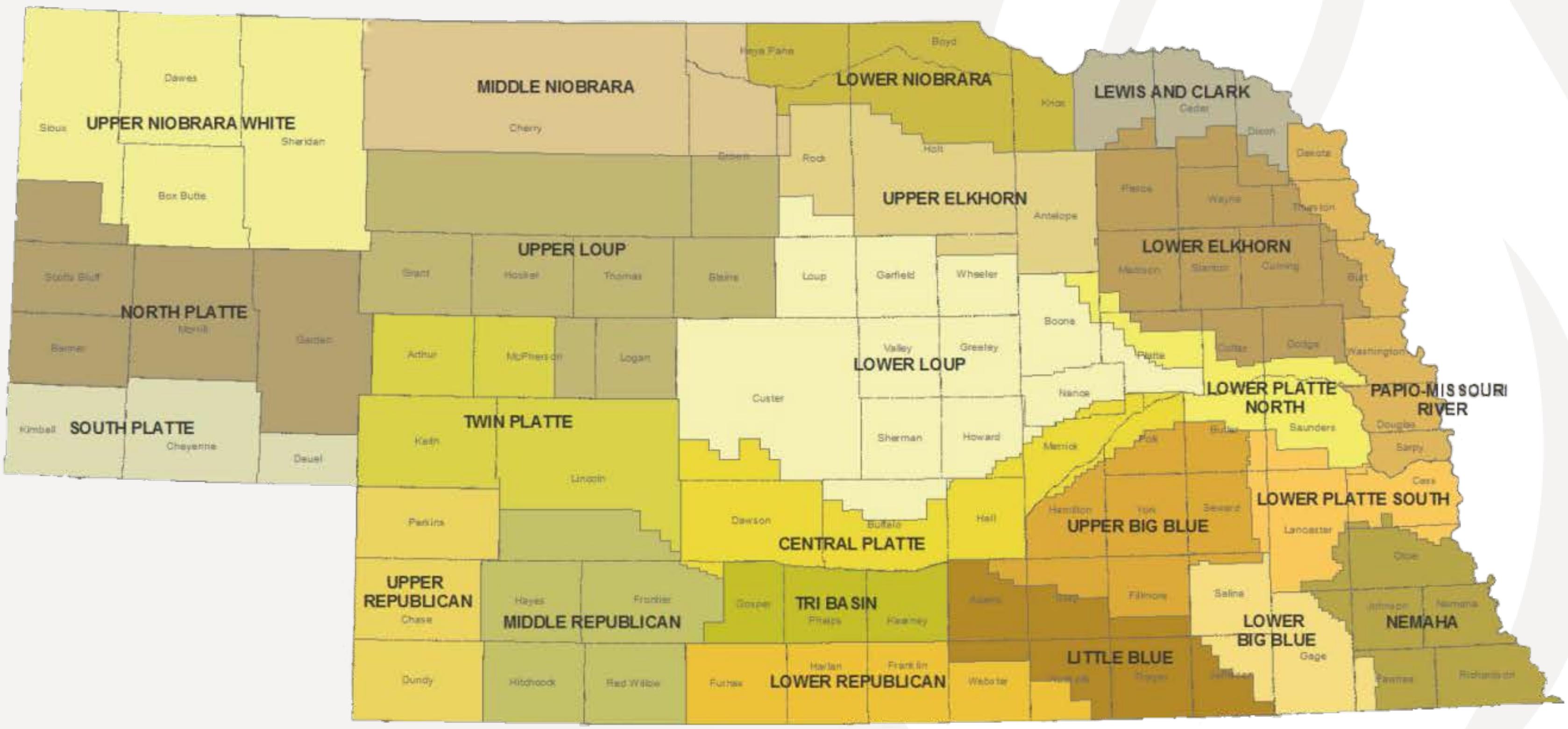
Effect of 2012 Drought on Nebraska Groundwater







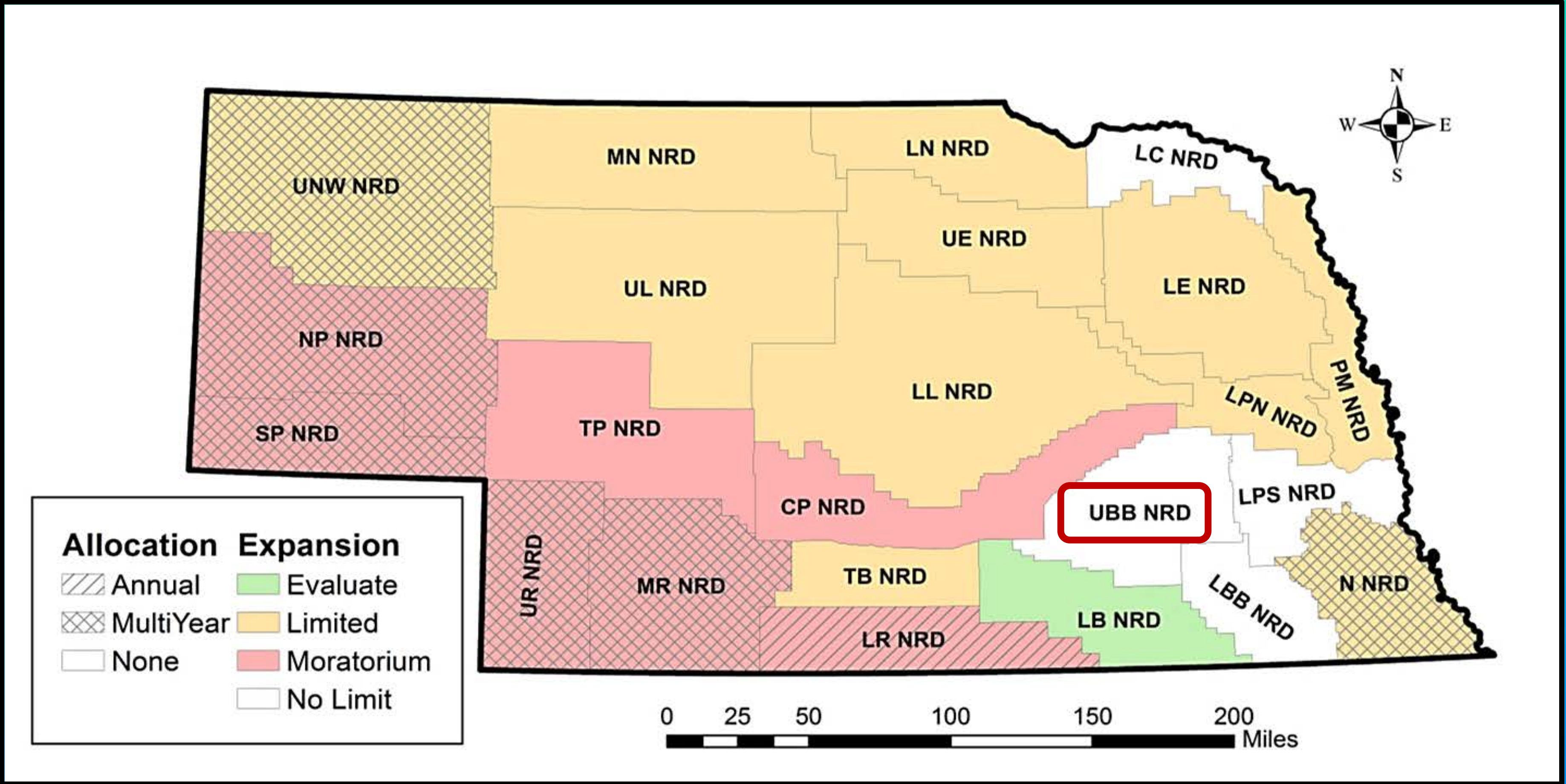
Nebraska's 23 Natural Resource Districts



Nebraska's Natural Resource Districts: Why are they significant?

- Cover entire state (total of 23 NRDs)
- Created in 1972, ahead of major expansion of irrigation
- Local authorities
  - Not state government
  - Not federal government
- Locally elected boards of directors
- Professional staffs
- Revenue – Property Tax (set by the boards)
  - Other $$ - Federal/State/private grants, Fees, Sales, etc.

Water Control Programs in Nebraska



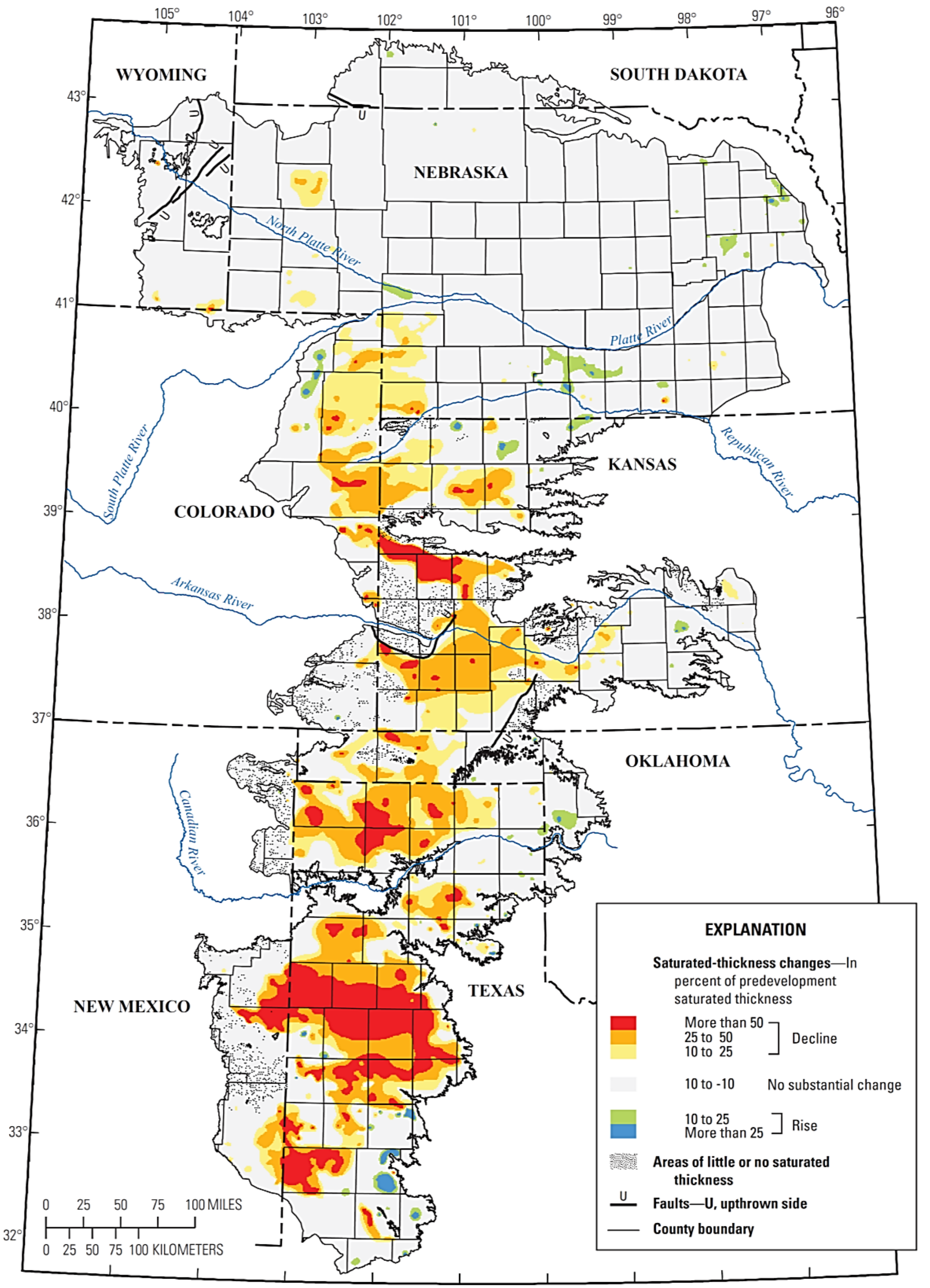
- Allocation Programs Limit Volume of Pumpage Over a Period of Time
- Expansion Limits Restrict Development of New Wells or New Irrigated Areas
- Upper Big Blue Considering Allocation Program
- Other Western States Have Similar Issues/Programs

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



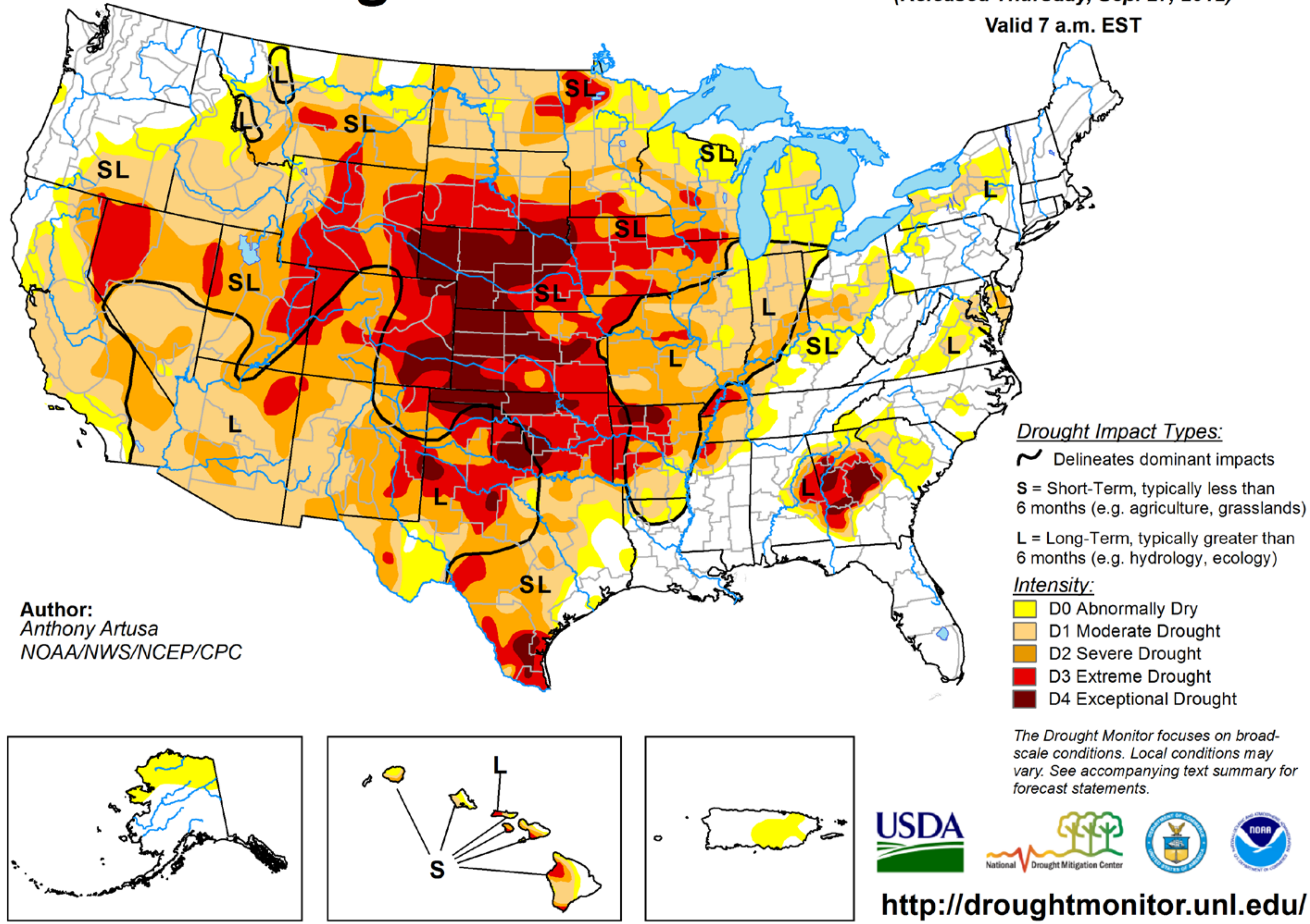
Derrel Martin,
Biological Systems Engineering

U.S. Drought Monitor

September 25, 2012

(Released Thursday, Sep. 27, 2012)

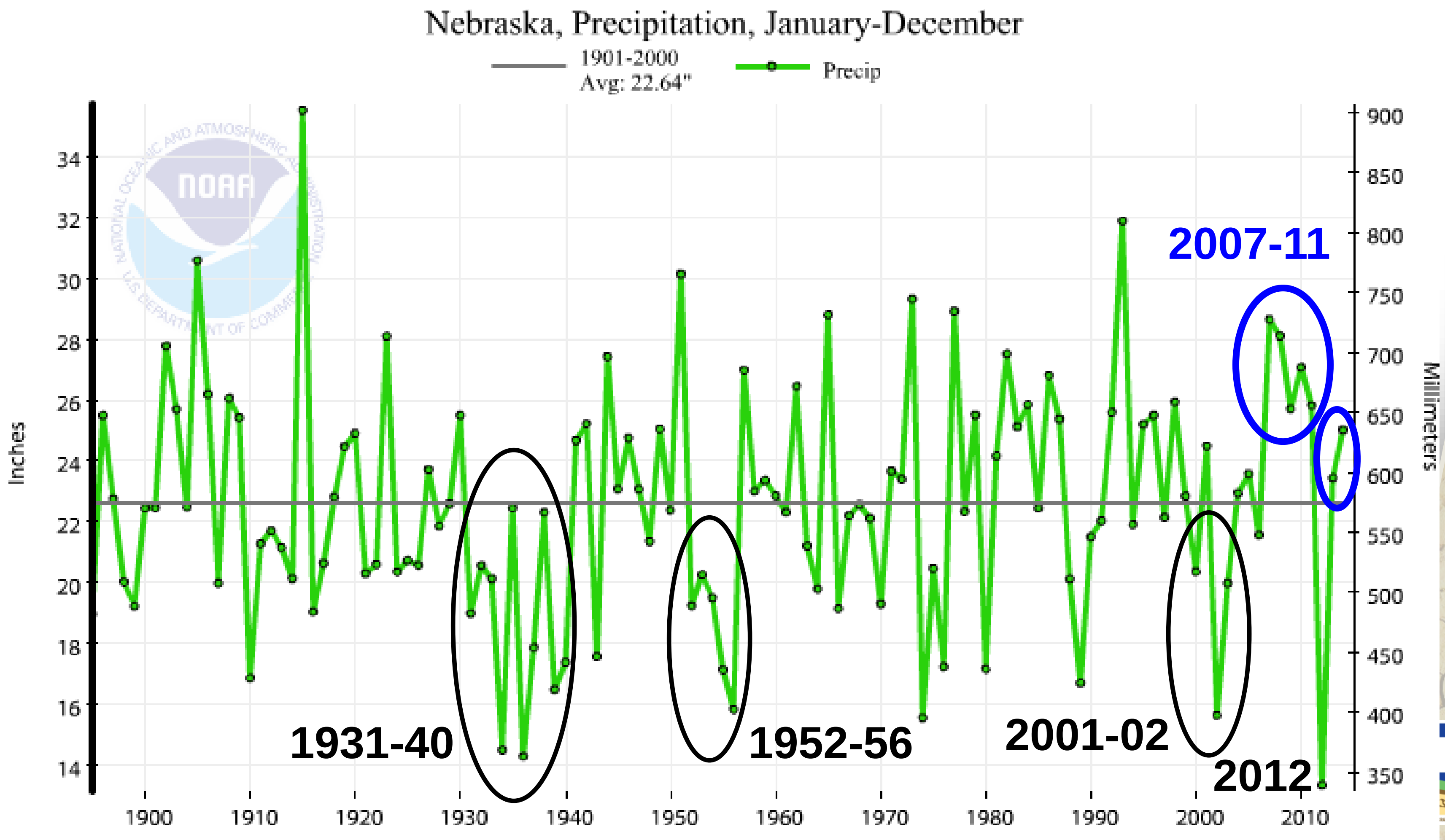
Valid 7 a.m. EST



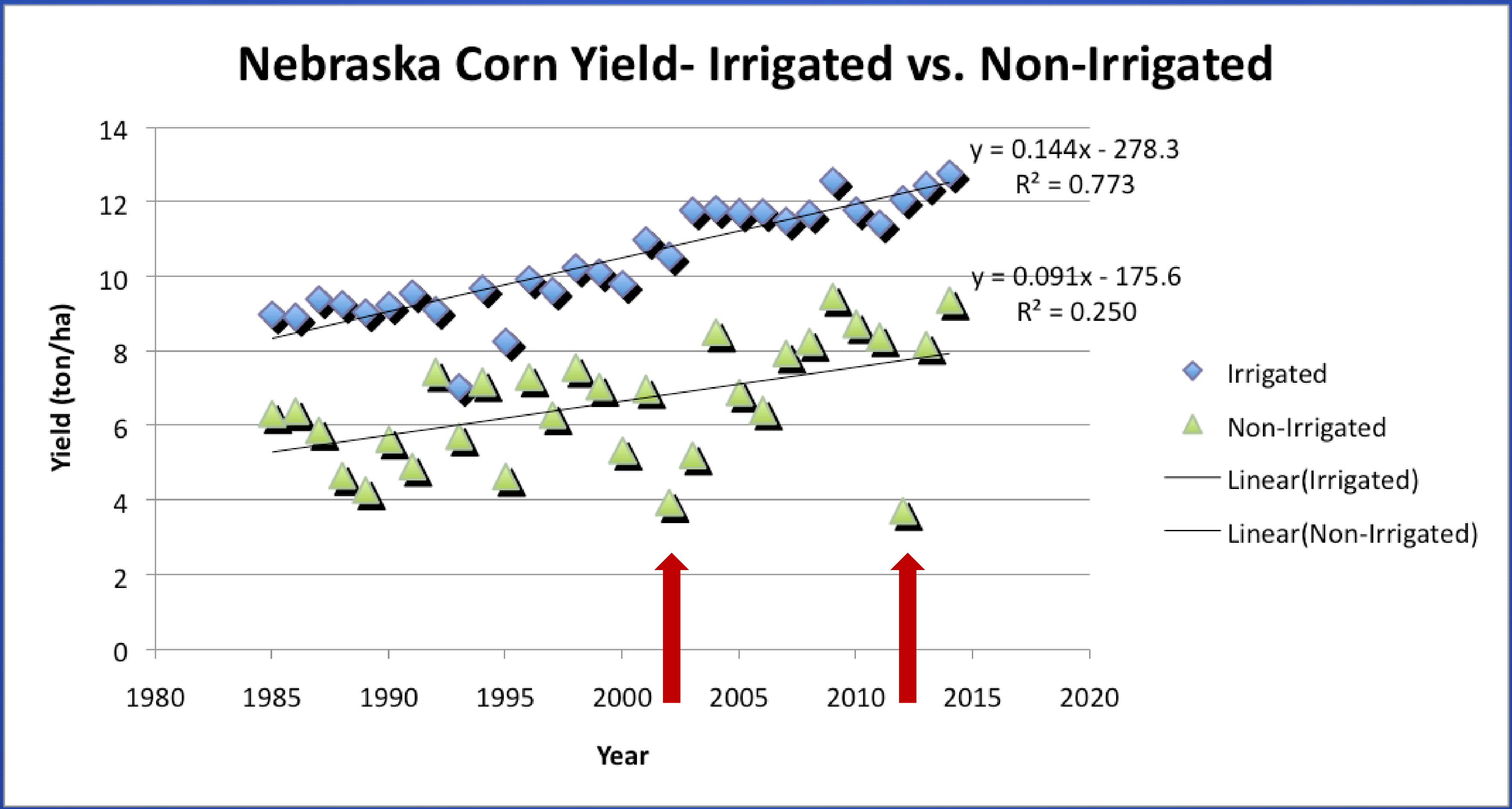
2012 Drought Impacts

- Economic loss estimates
  - **$30 billion**, NCDC
- Crop indemnities: **$17 billion**
  - 2011 the previous record with $10.8 billion
- Wildfires
  - Colorado

Nebraska Annual Precipitation, 1895-2014



Nebraska Corn Yield



Water *for* Food
ROBERT B. DAUGHERTY INSTITUTE
at the University of Nebraska

Thank You

Christopher Neale
Director of Research
cneale@Nebraska.edu