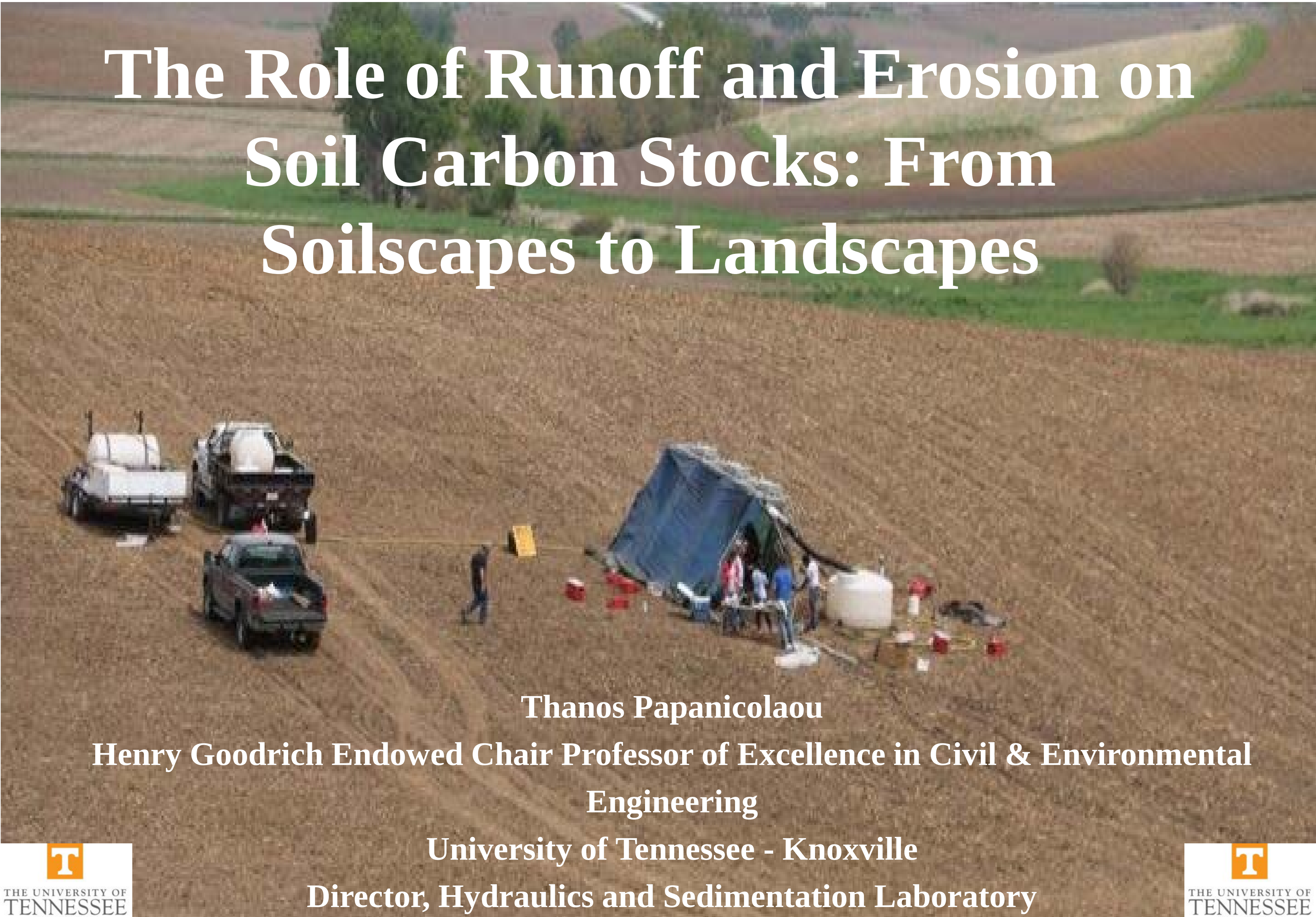

The Role of Runoff and Erosion on Soil Carbon Stocks: From Soilscapes to Landscapes

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HYDRAULICS & SEDIMENTATION LAB

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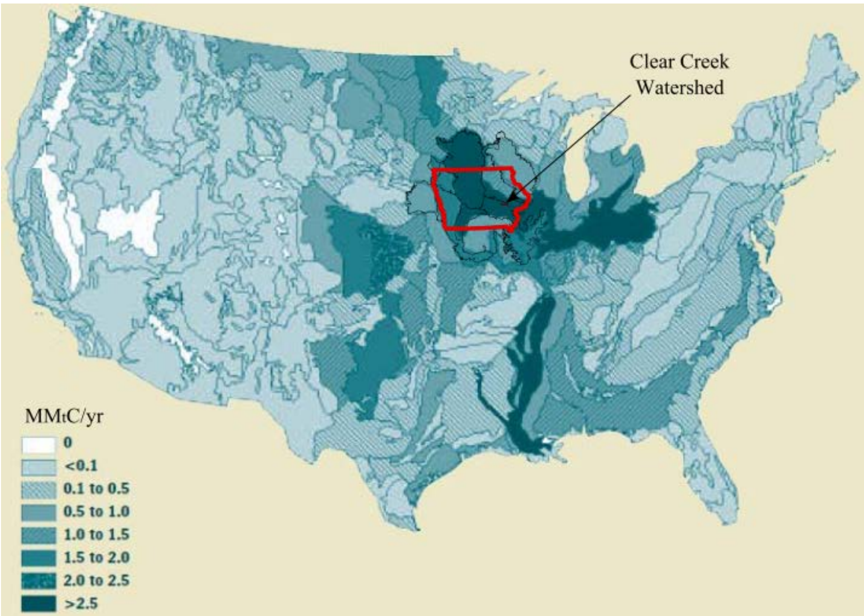
HYDRAULICS & SEDIMENTATION LAB

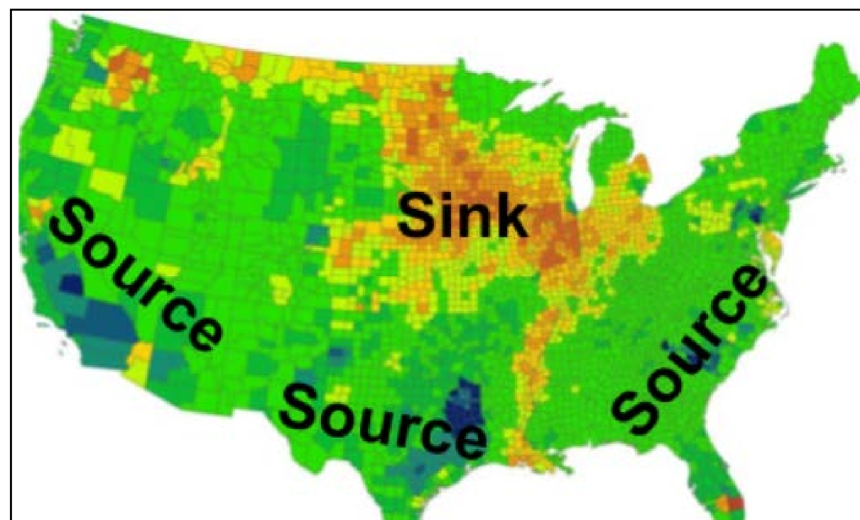
Carbon Sequestration Potential in the U.S.



From Sperow et al. (2003).

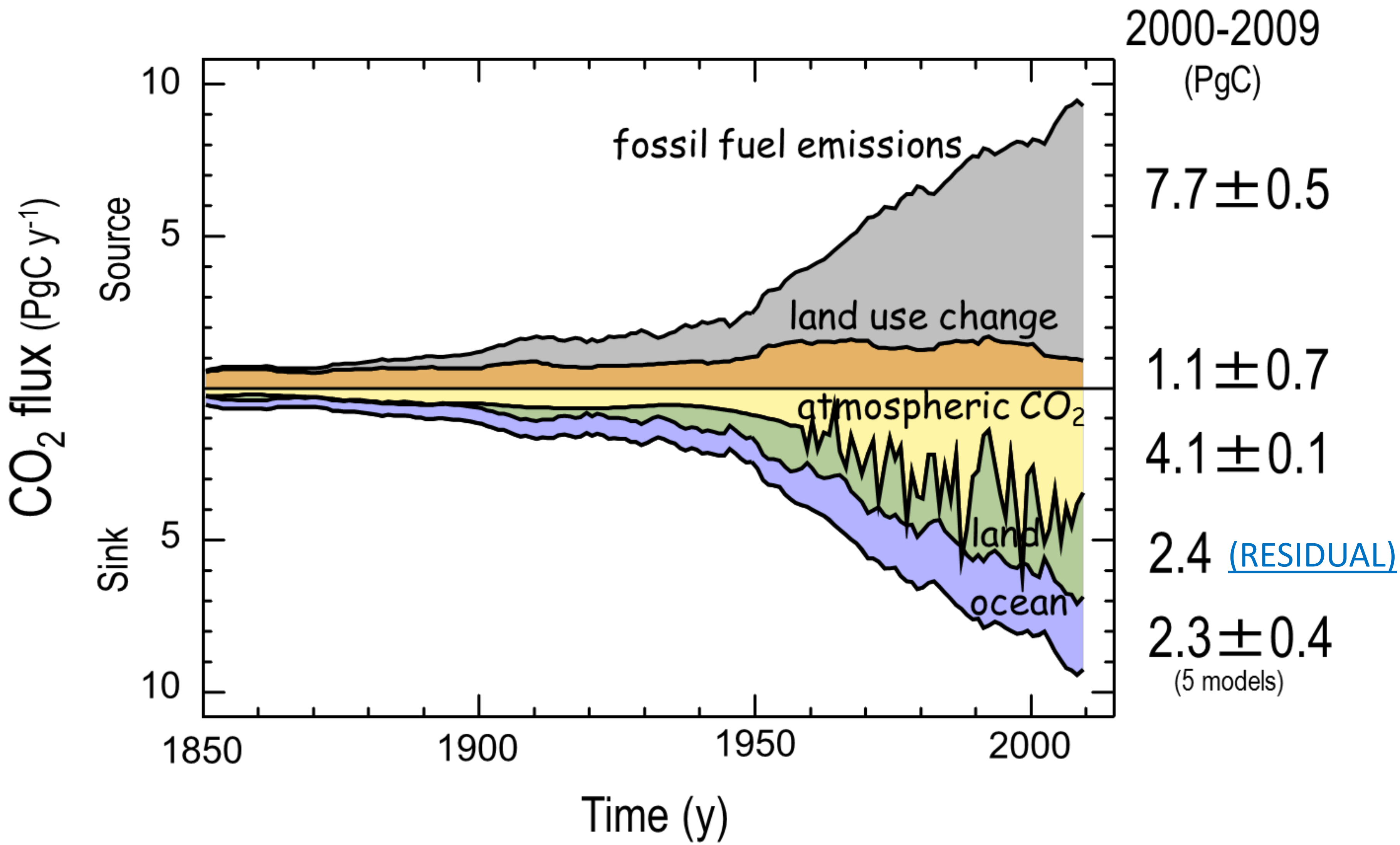
The Midwestern United States has a high potential to sequester carbon due to specific soil types and crop management practices.

To access fully the carbon sink, carbon budgets are used.
However, we need to improve our accounting methods.



From West et al. (2010).

General Global Carbon Budget



Global Carbon Project (2010); Updated from LeQuere et al. (2009) and Canadell et al. (2007).

General Global Carbon Budget

Source

- **Fossil fuels**. Uncertainty of global fossil fuel CO_2 emissions estimate is about ± 6%. Calculations are provided by Oak Ridge National Laboratory and the University of Tennessee - Knoxville.

- **Emissions from land use change**. Uncertainty on this flux is the highest of all budget components due to soil erosion and soil respiration. CO_2 emissions from land use change are calculated by using a book-keeping method.

Sink

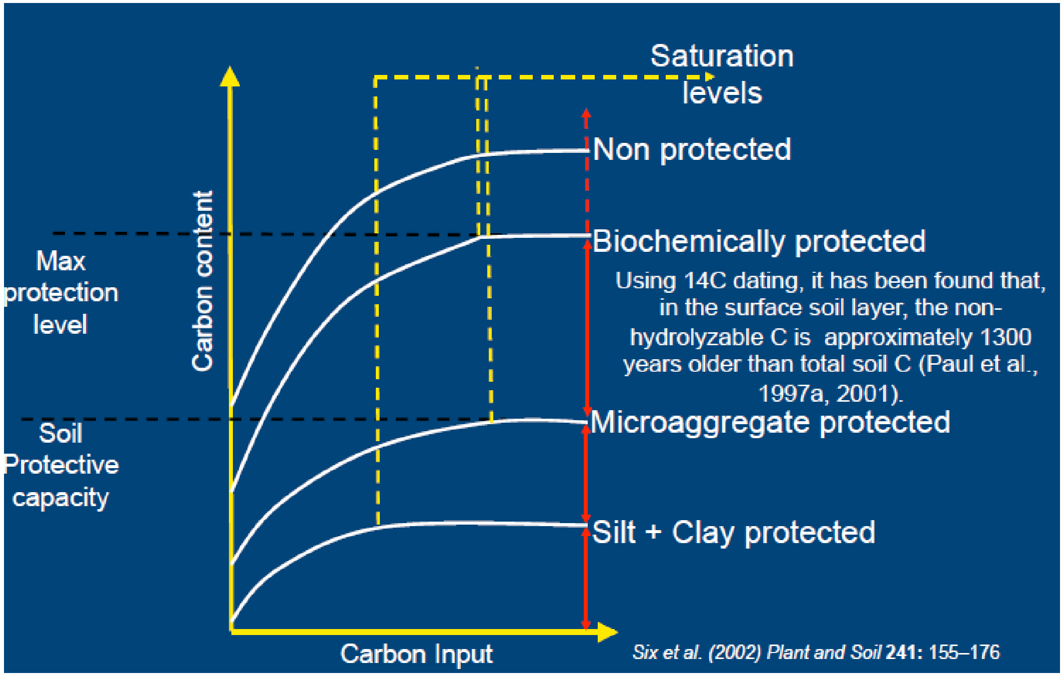
- **Atmospheric CO_2.** Accumulation of atmospheric CO_2 is the most accurately measured quantity with an uncertainty of about 4%.

- **Ocean CO_2.** Current uncertainty is around 0.4 PgC/ yr. Estimated using an ensemble of five ocean process models and meteorological data.

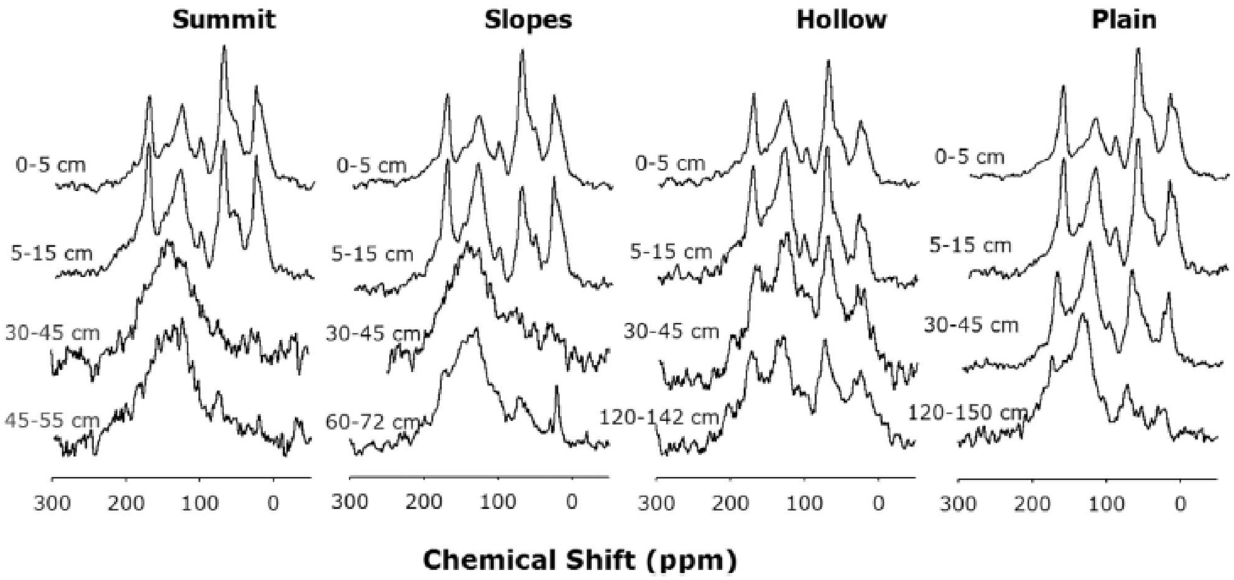
- **Land CO_2.** The terrestrial sink is estimated as a **residual** from the sum of all sources minus the ocean and atmosphere sinks. No direct measures exist. The sink can be estimated using terrestrial biogeochemical models but scales of using these models are limited and accuracy questionable.

From Canadell et al. (2011).

Column Variability - Biogeochemistry

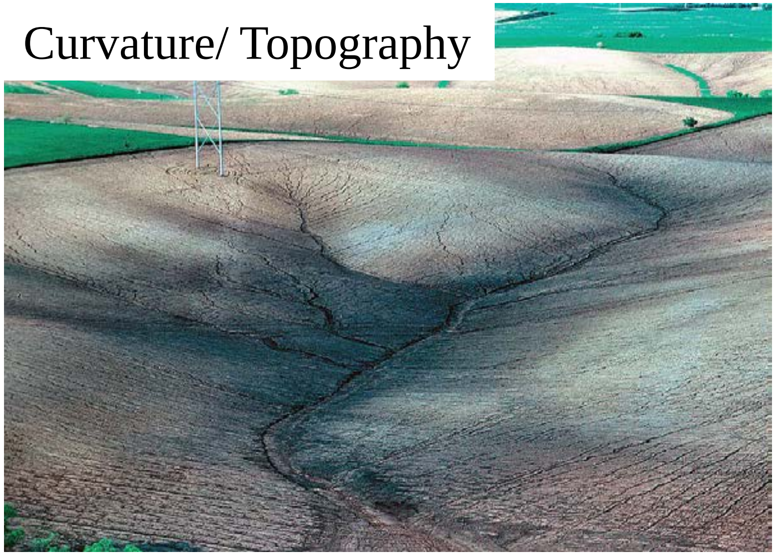


^{13}C NMR Spectra for bulk SOM
(Berhe et al., 2012)

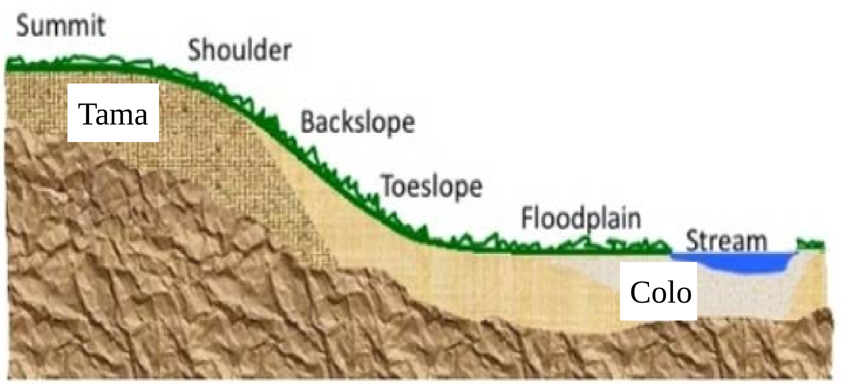


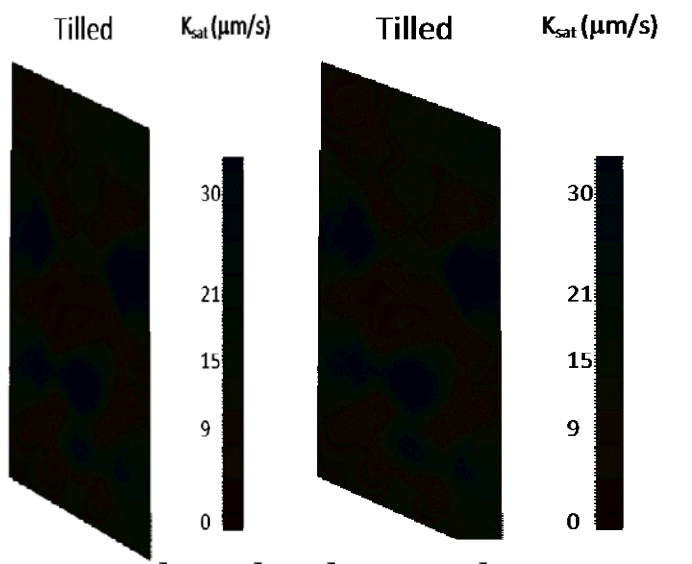
Landscape Variability – Bulk Properties

Curvature/ Topography



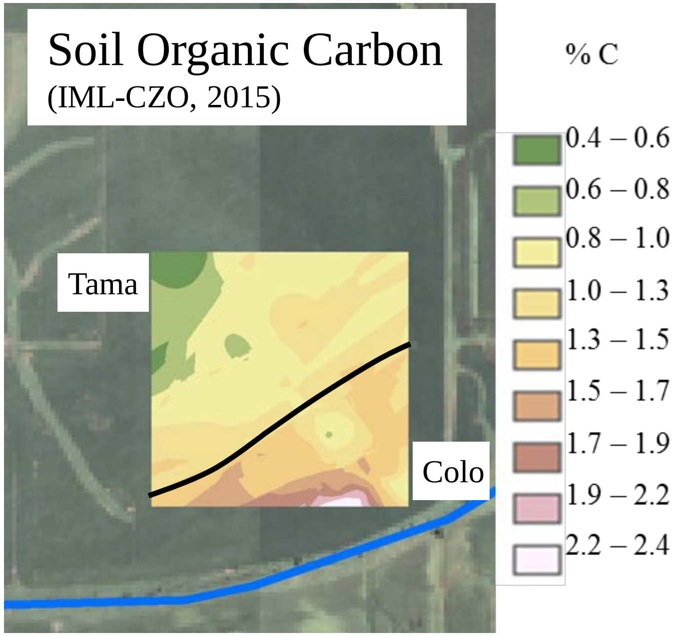
Soil Type Variability



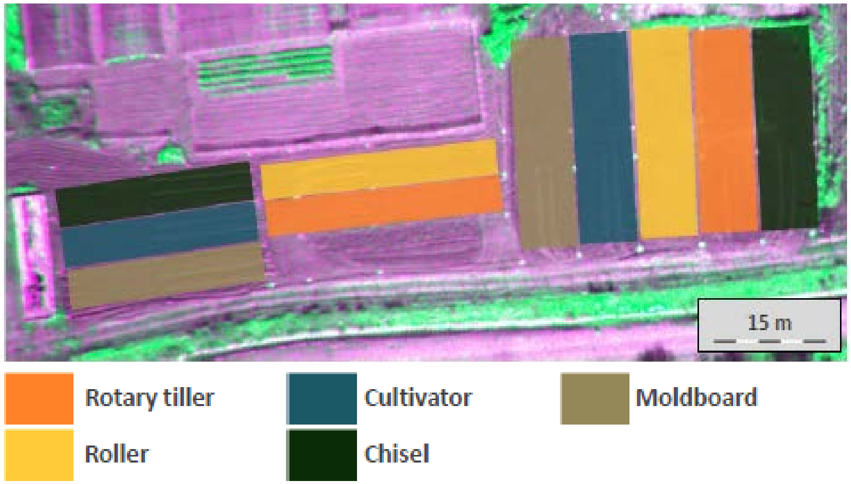


Saturated Hydraulic Conductivity
(Papanicolaou et al., 2015)

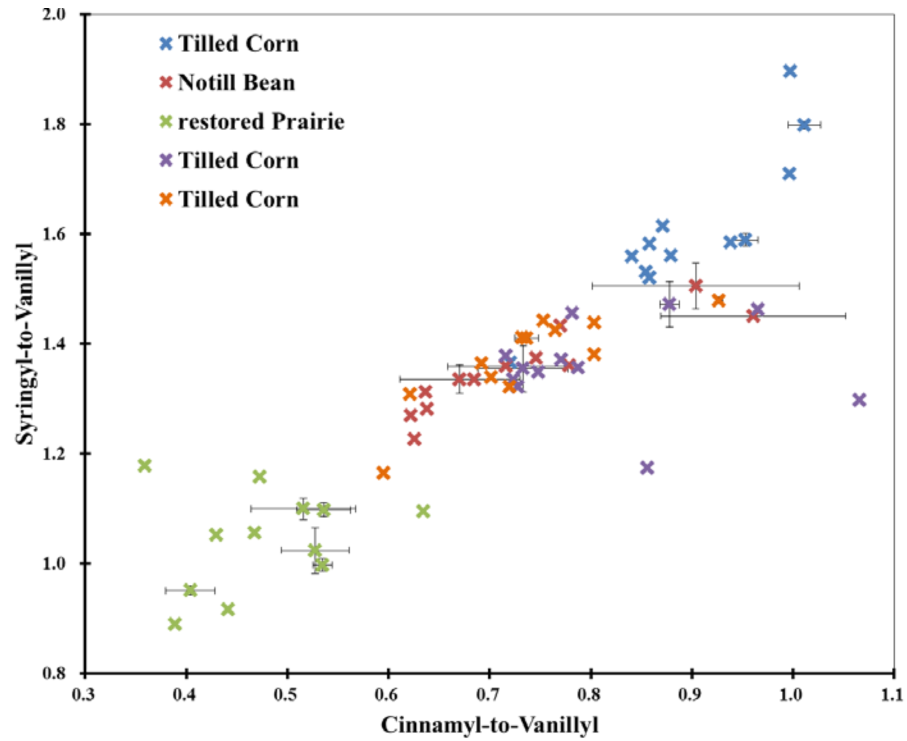
Soil Organic Carbon
(IML-CZO, 2015)



Dynamic Landscape Variability - Management



Lignin Source
(IML-CZO, 2015)



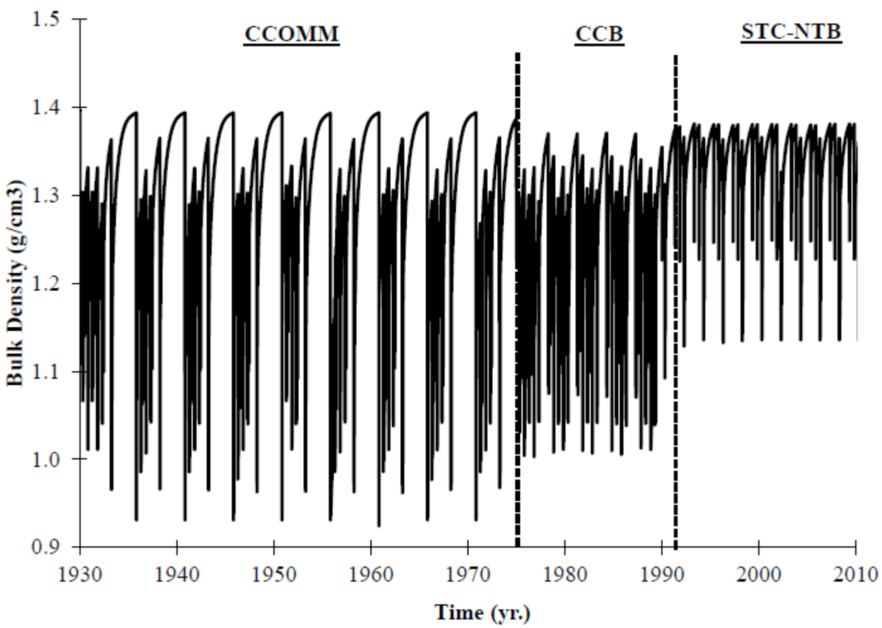
Source Proxies

S/V (high = soy + corn)
C/V (high=corn)

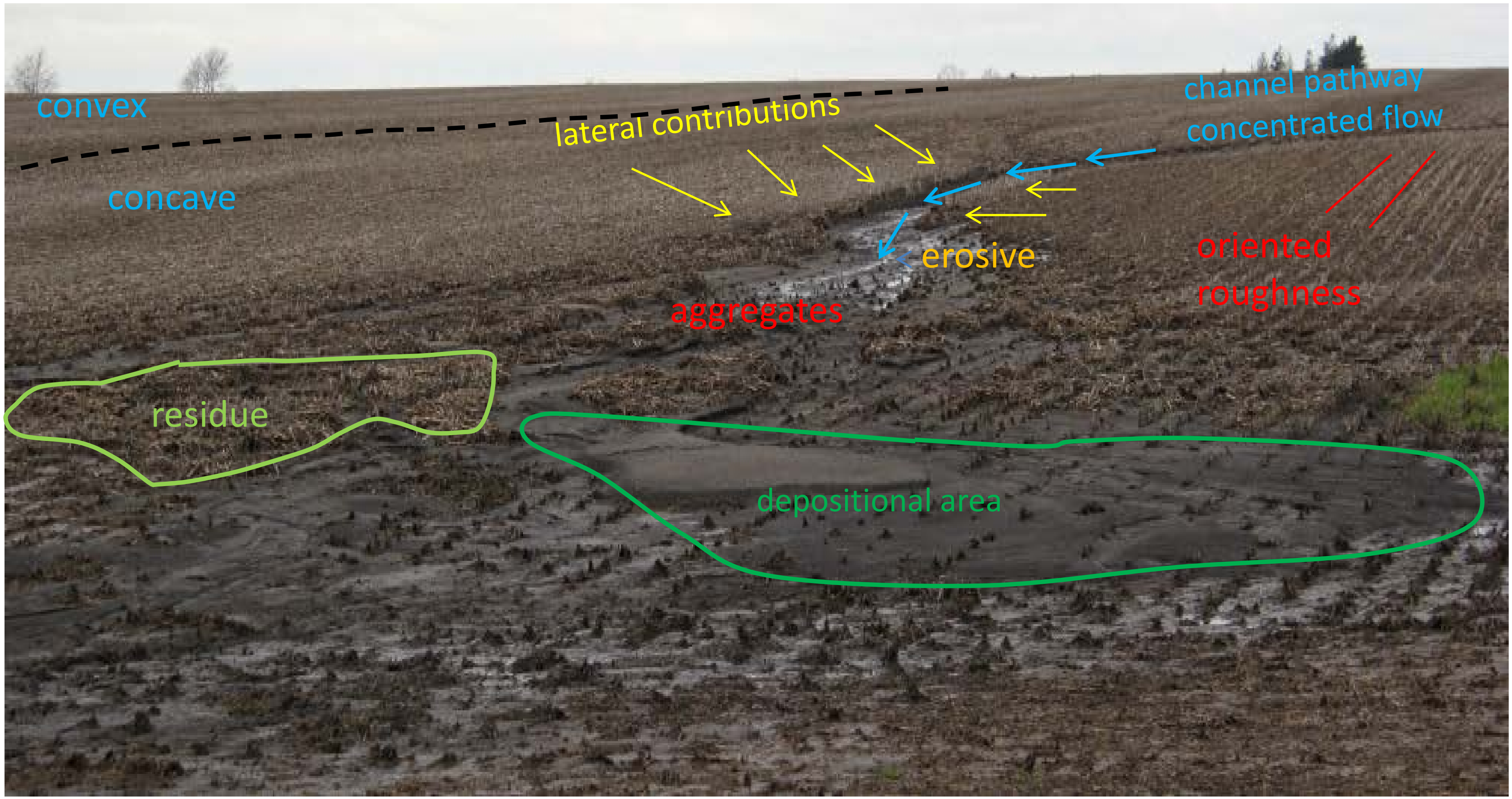
Decay Proxy (Ac/Al)

For Undegraded Plants
Ac/Al < 0.2

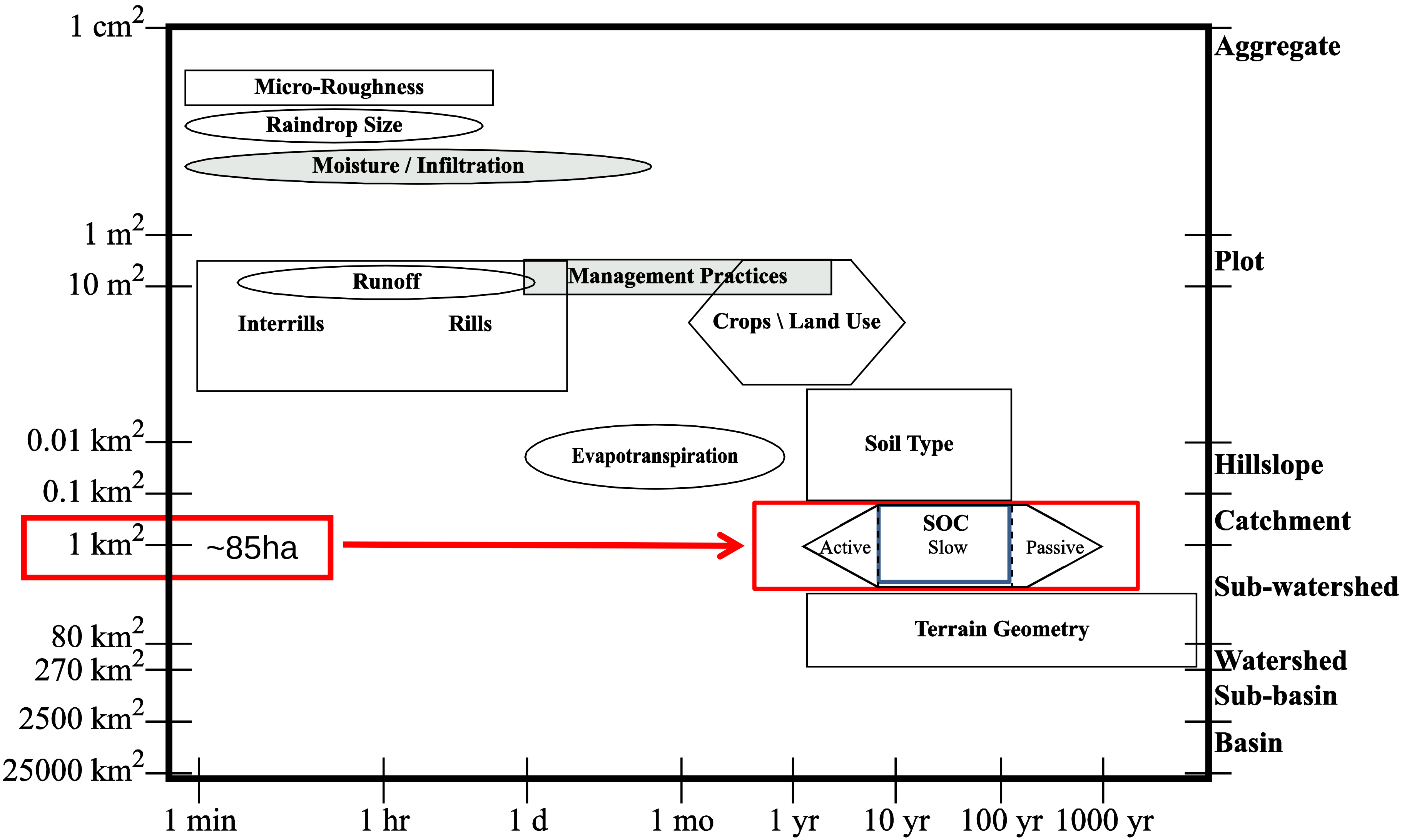
Bulk Density
(Papanicolaou et al., 2015)



Dynamic Landscape Variability - Redistribution



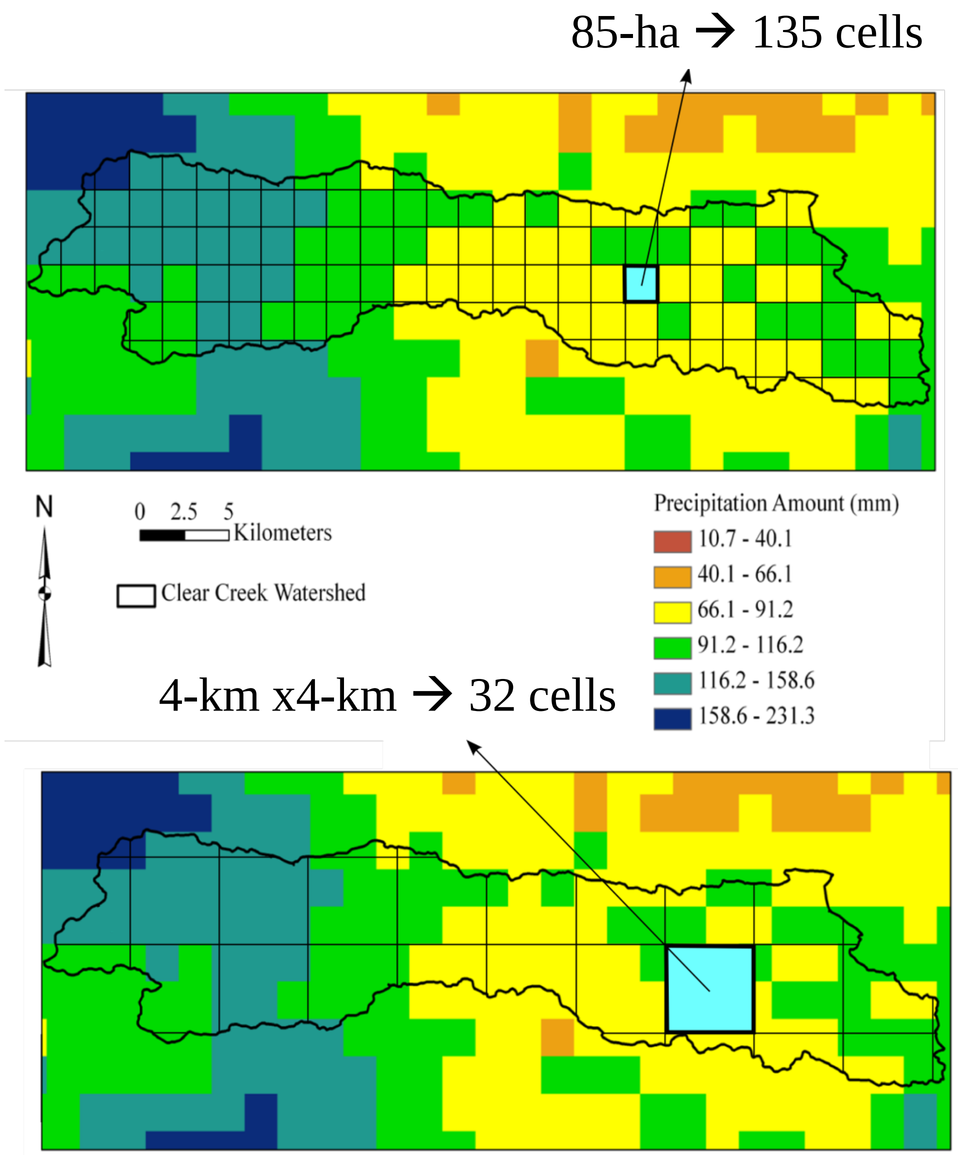
Carbon across Scales



In order to properly perform the carbon budget, it is important to use a characteristic scale (unit).

Papanicolaou, Wilson, et al., (2006)

Characteristic Scale unit



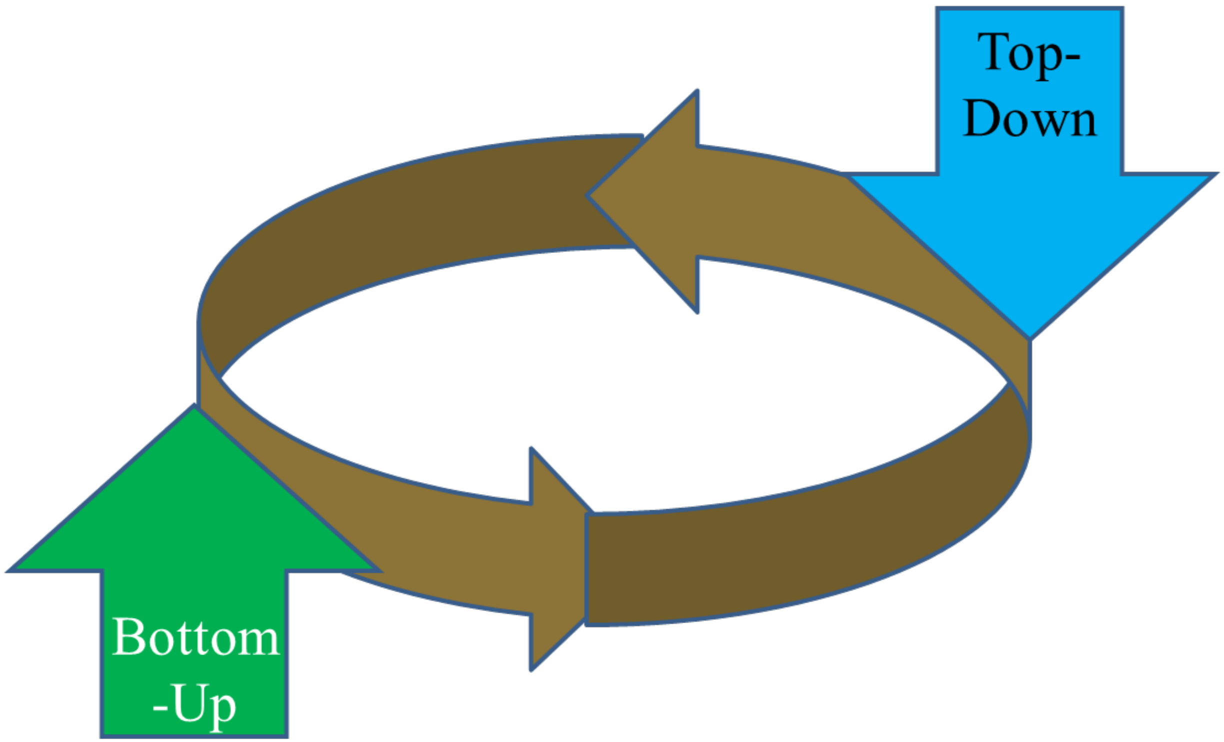
The unit where the party starts…..

Clear Creek, IA is a 260-km^2 mixed agricultural –urban watershed.

Using the 85-ha scale, which corresponds to the MODIS land cover spatial unit, Clear Creek will have 135 cells.

Some larger-scale models use a 4-km x 4-km grid cell, which leave on 32 cells in Clear Creek.

Combining bottom-up and top-down approaches to quantify soil carbon budgets



This requires the intermingling of different tools:

- Long-term monitoring
- Dynamic experiments
- In situ sensors
- Models
- Remote sensing

1. **NOAA-AVHRR** (1km)
   - Surface temperature
2. **MODIS** (250m-1km)
   - Surface temperature, albedo, reflectance, Biomass, Photosynthetic Active Radiation, Leaf Area, Index, Light Use Efficiency, Net Primary Production
3. **ASTER** (15-90m)
   - Surface temperature, reflectance, elevation, 3D images, crop residue, lignin, cellulose
4. **Radar-SAR** (30m)
   - Surface roughness, topography, moisture content, canopy cover
5. **Landsat** (30m)
   - Soil Moisture, Biomass
6. **Ikonos , Quickbird** (1-3m)
   - Land-use classification and change
7. **Lidar** (down to 1m)
   - Canopy height/cover, topography, elevation

Climatic Sources

1. **Mesonet**
   - Precipitation, temperature, solar radiation, soil moisture and temperature
2. **CO_2 Towers**
   1. Net Ecosystem Production

Top Down

Integrated Erosion-Biogeochemical Models

(WEPP-CENTURY)

Bottom Up

1. **VNIR**
   - Soil Organic Matter, clay mineralogy, microbial activity, soil composition
2. **Eddy Covariance**
   - Net Ecosystem Exchange
3. **Laser Scanner** (0.5 mm)
   - Topography, roughness, erosion/deposition
4. **PP Systems Chamber**
   - Soil respiration
5. **Decagon Sensors**
   - Soil moisture, soil temperature
6. **Litterfall Traps**
   - Residue cover
7. **Field Studies**
   - Plant/root Biomass, Soil Organic Carbon, nutrients, erosion/deposition

Climatic Sources

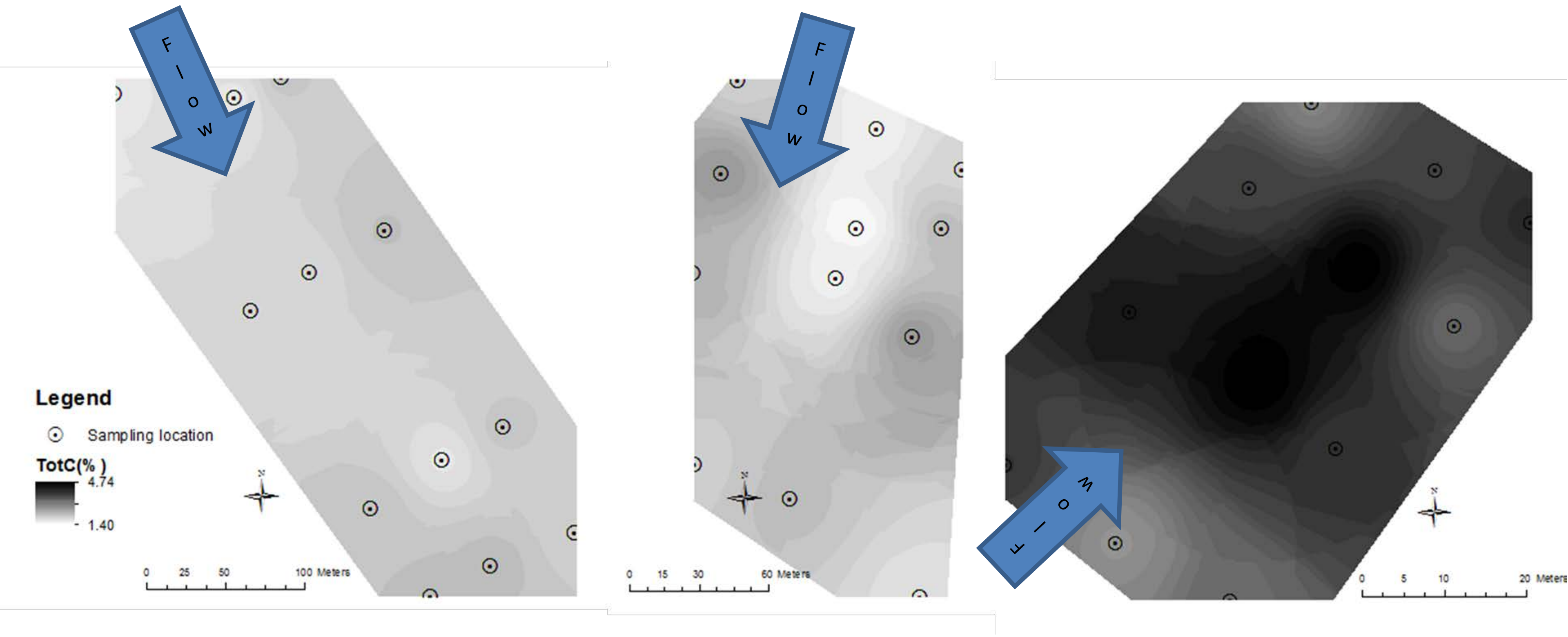
1. **Tipping Bucket**
   - Surface Temperature, Precipitation

Bottom-up Studies

The **Bottom-up Approach** looks at carbon processes & fluxes through field sampling, dynamic experiments and CENTURY modeling at the hillslope scale.

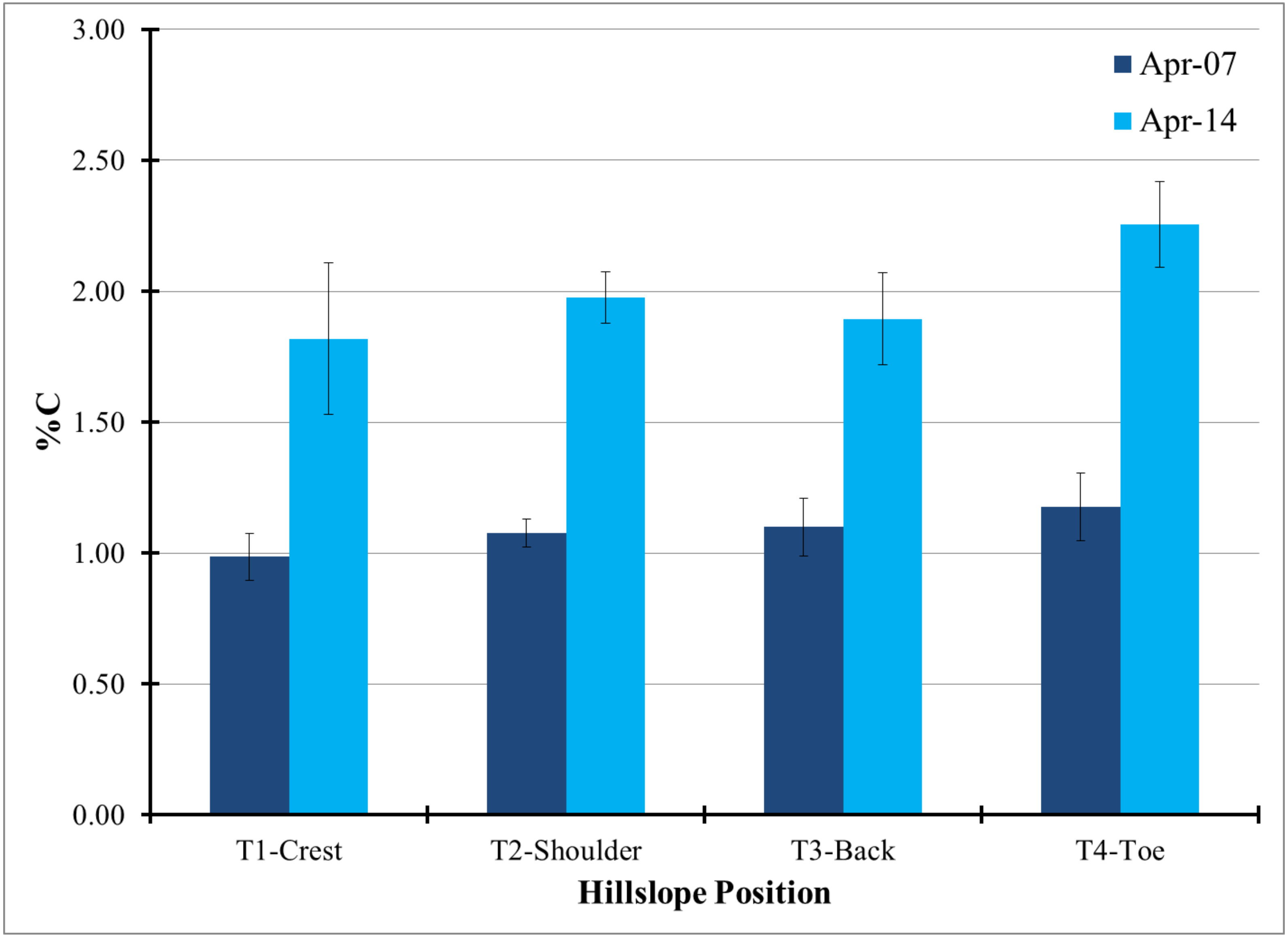
Baseline Soil Sampling – April 2014

Hillslope Variability in %Carbon



Corn **Bean** **Prairie**

Change in %C from 2007 to 2014



Dynamic Testing- ER Experiments

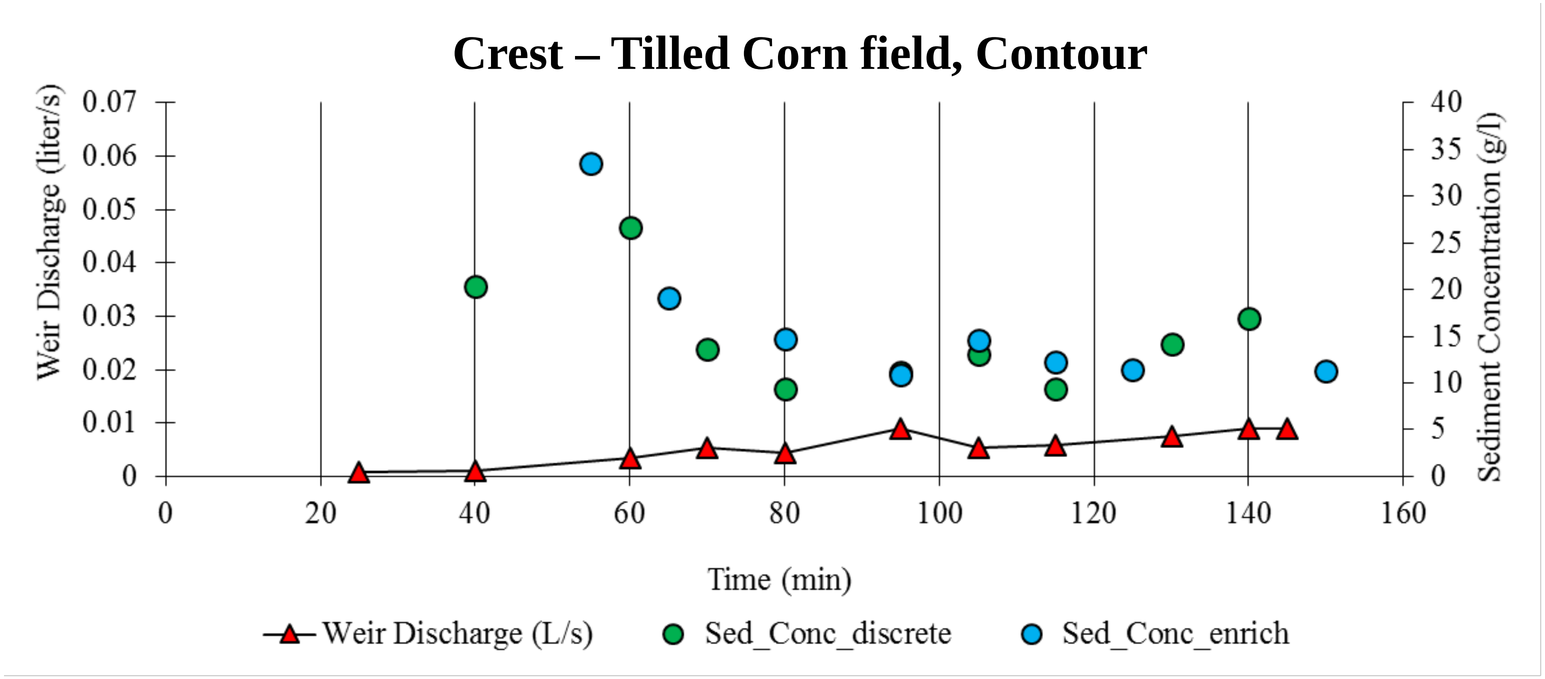
Data Collected

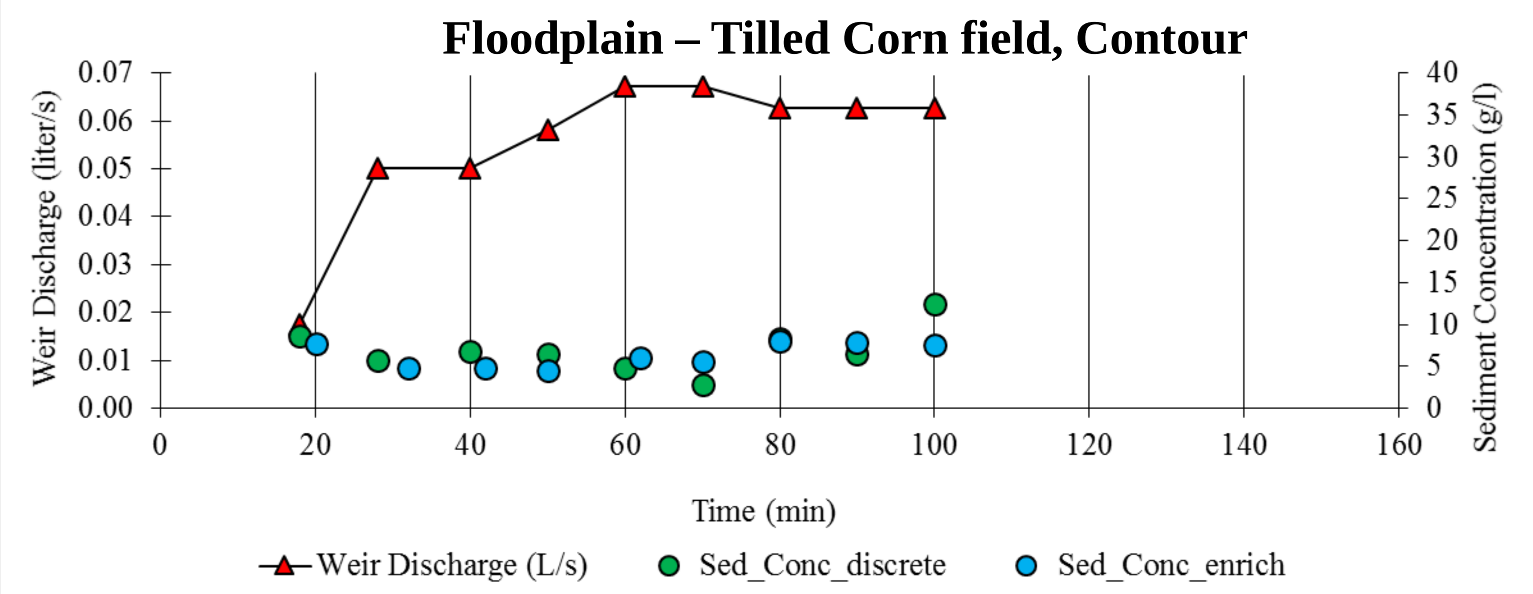
- Runoff
- Aggregates
  - LG,SM
- Litter
- Soil Moisture
- Soil Temperature
- *in situ* soil sample

What we can get

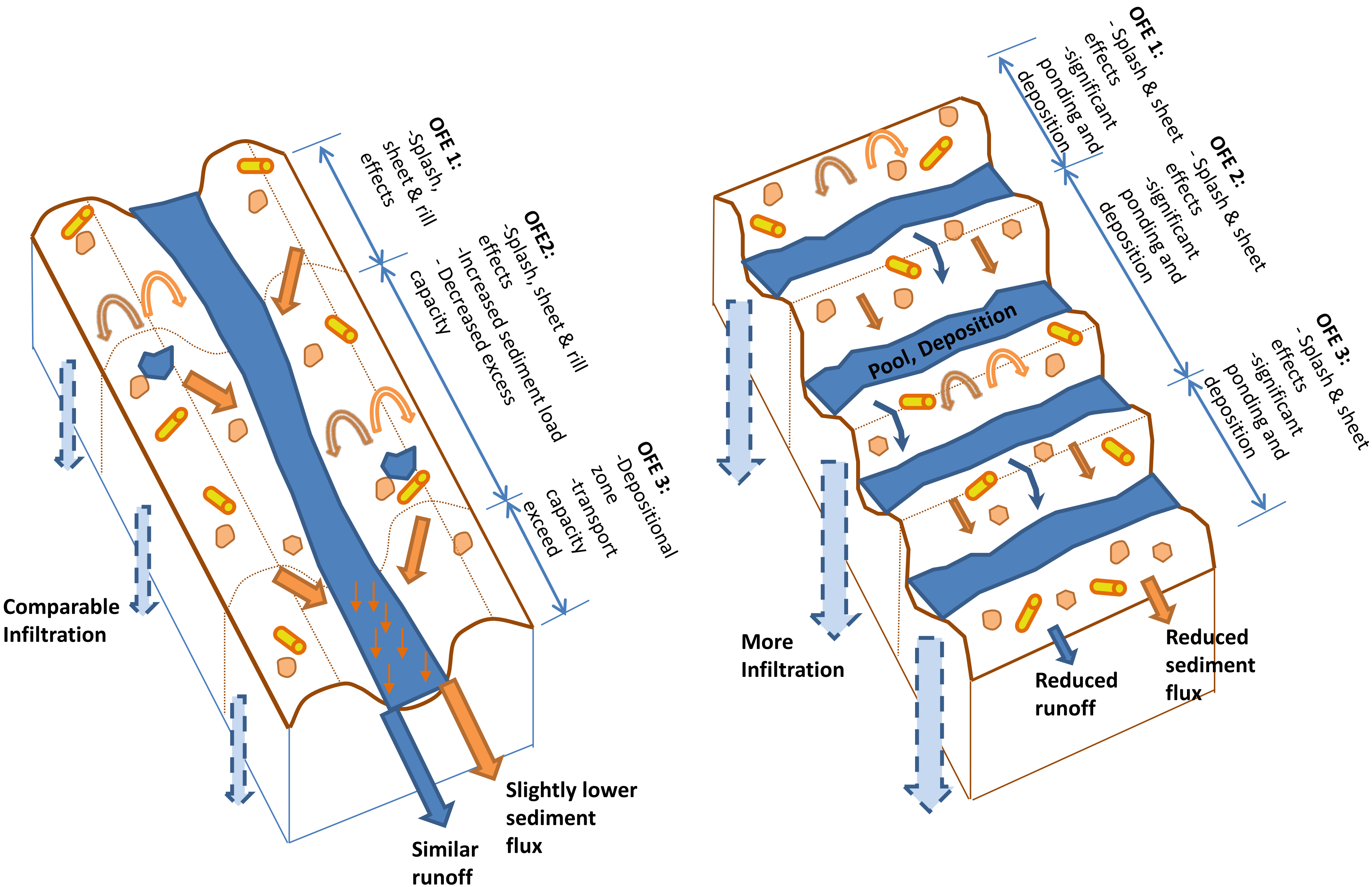
- Erosion runoff rates
- Enrichment Ratio
  - steady/unsteady
  - size fractions
  - aggregates
- Transported litter

ER Experimental Results

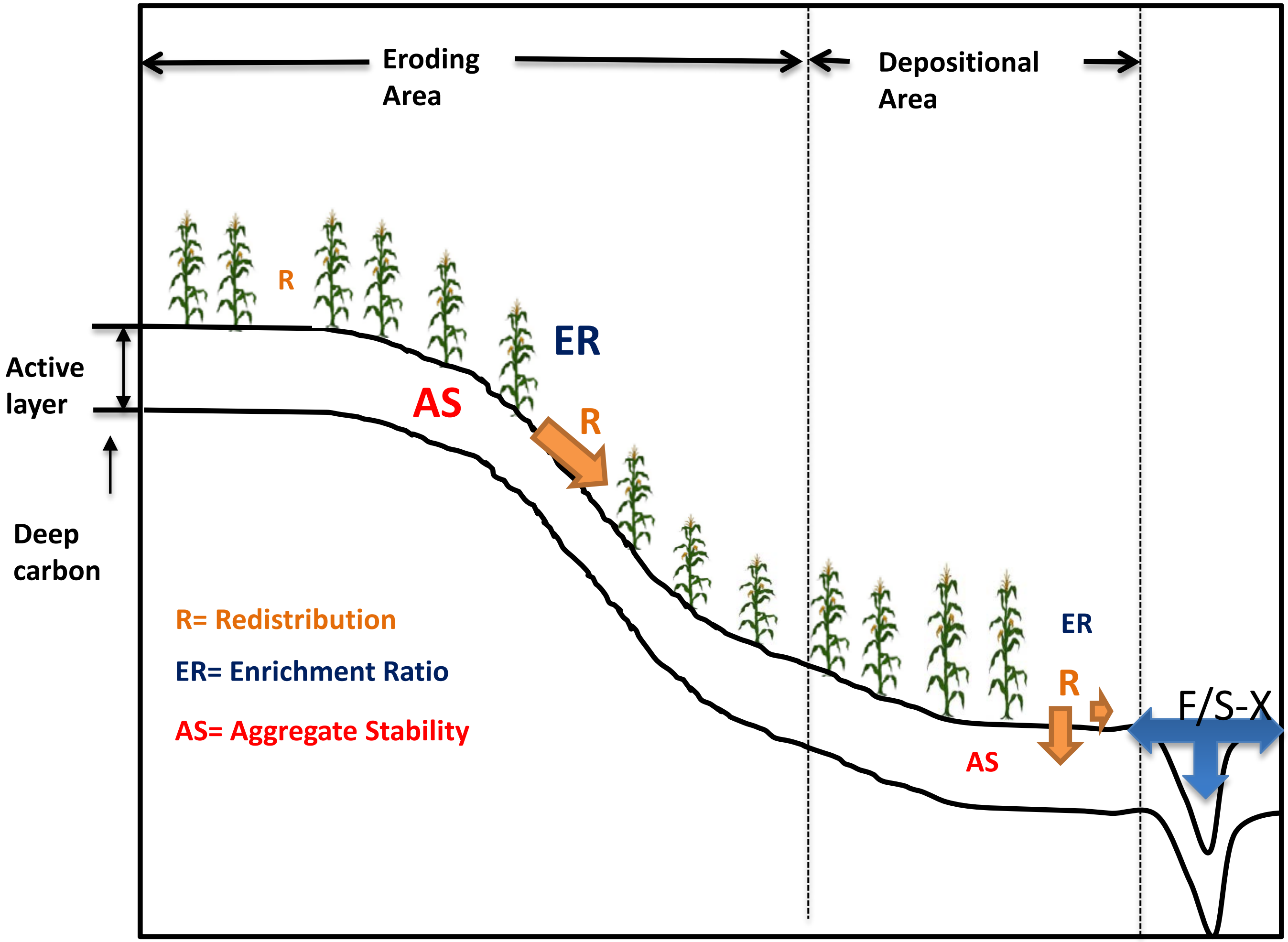




Importance of Flowpaths



General Hillslope Trends

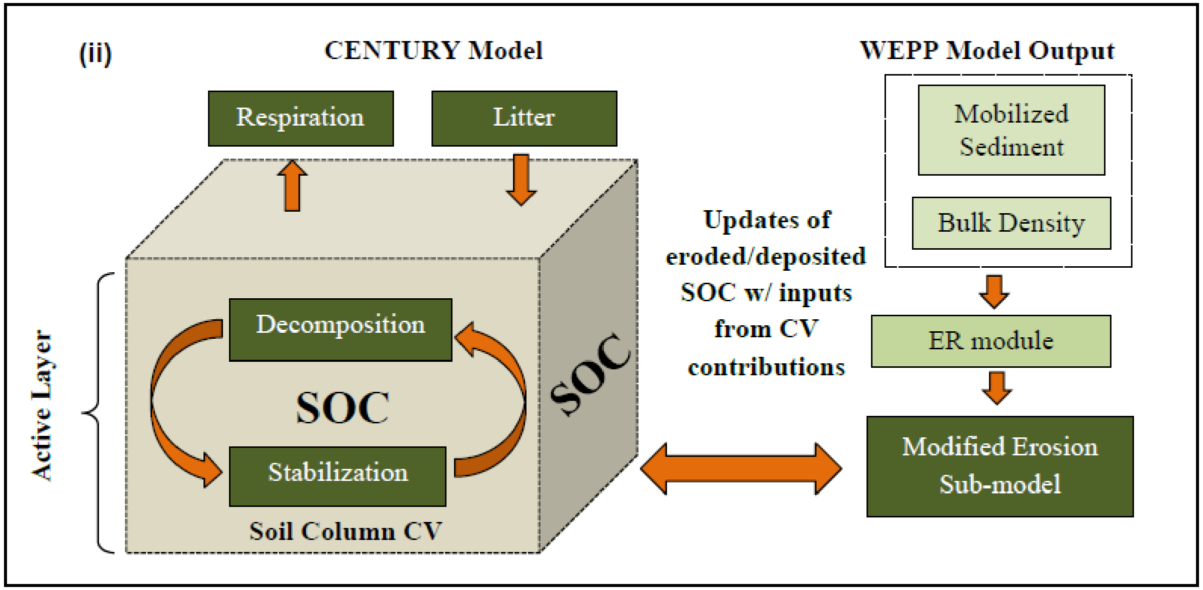


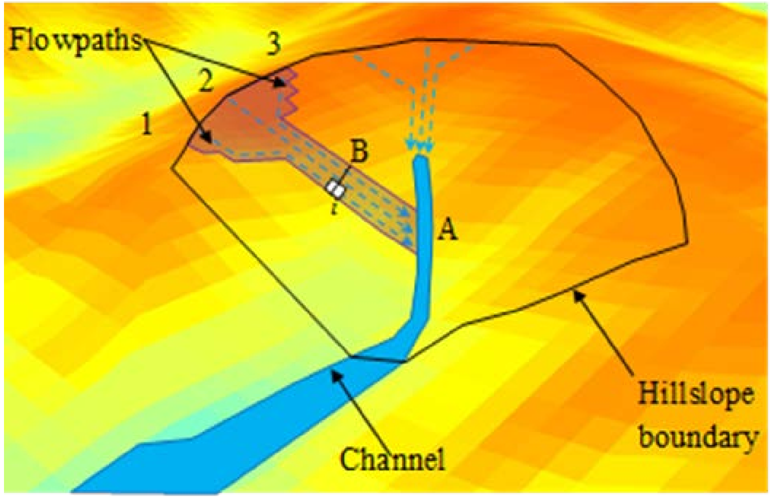
Coupled Erosion-Biogeochemical Models

Most biogeochemical models focus within a soil profile and cannot adequately resolve selective entrainment of lighter organic rich soil fractions.

An Enrichment Ratio module was linked with CENTURY and WEPP to consider runoff, erosion, tillage, fertilization, soil cover and roughness on SOC redistribution and storage.

$$ER = \frac{SSA_{erod}}{SSA_{in\ situ}} = \frac{SOC_{erod}}{SOC_{in\ situ}}$$



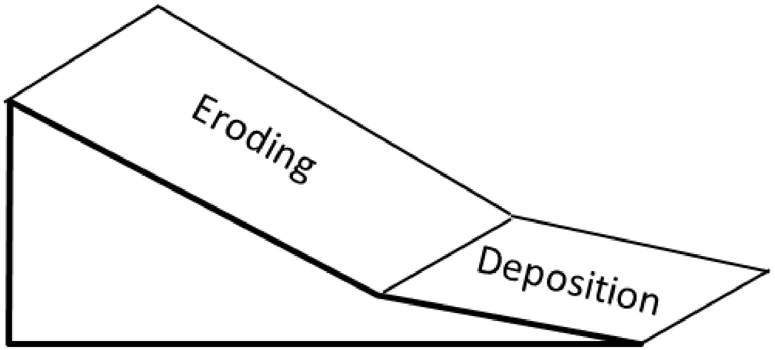


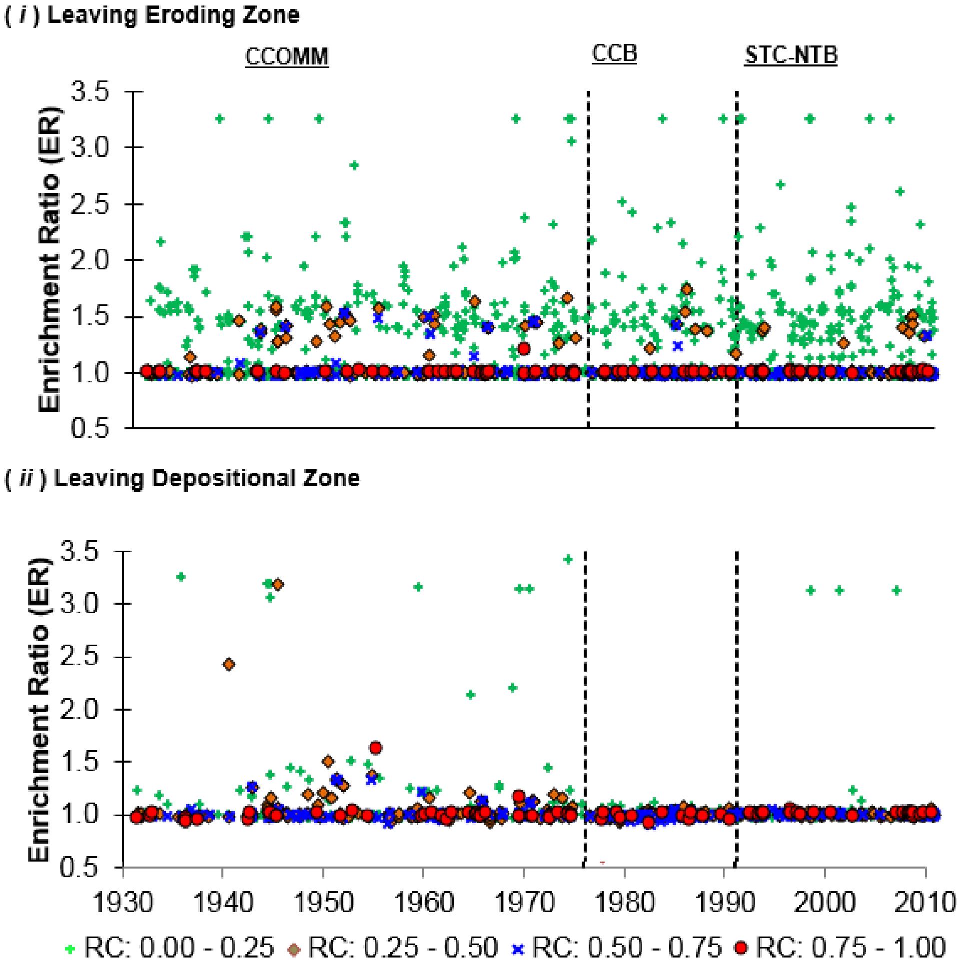
The flowpath approach follows water, soil, carbon moving from one cell to the next due to topographic changes.

From Papanicolaou et al. (in review).

ER Modeling Results

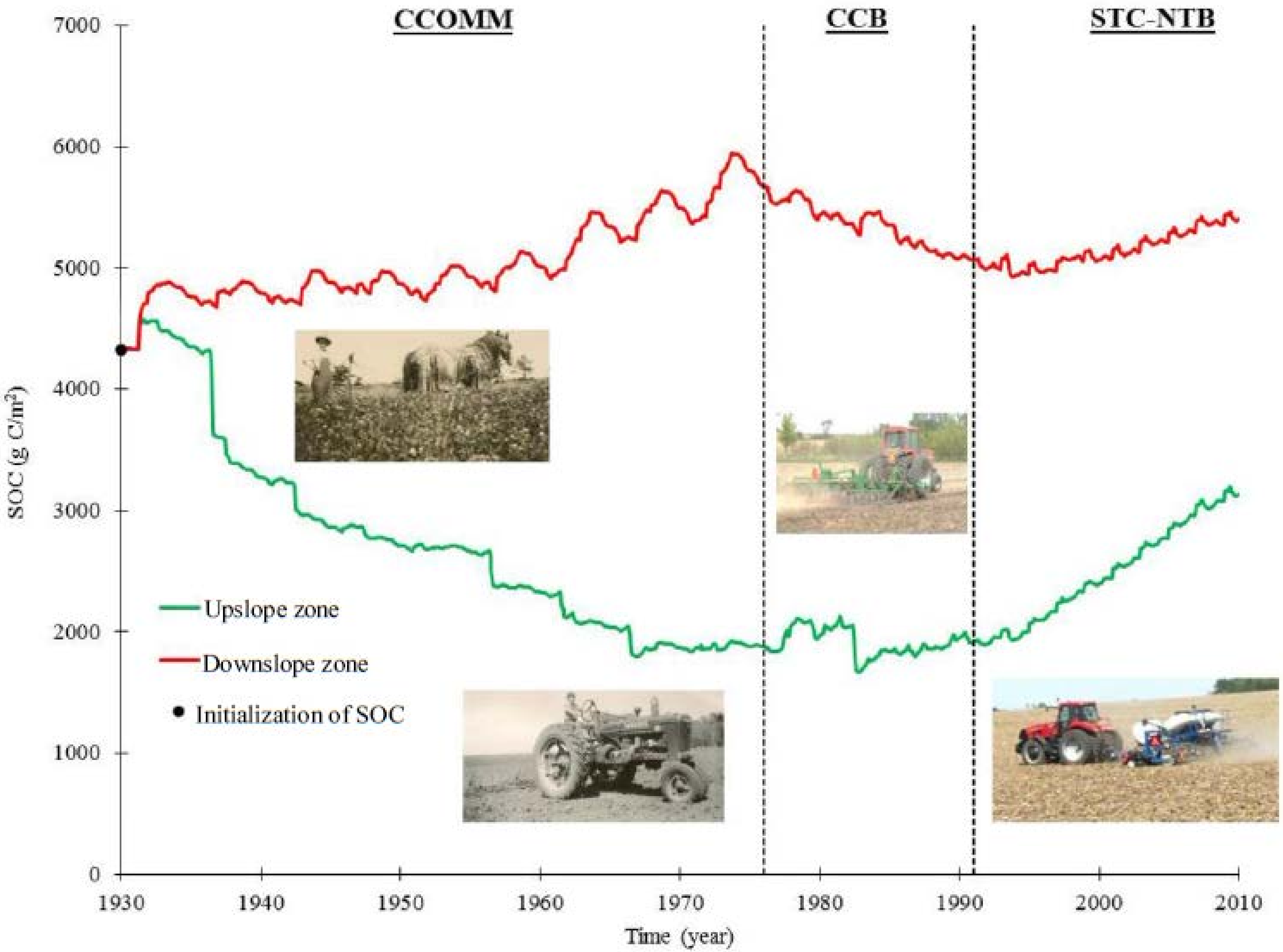
- ER values were found to be higher in eroding zone than in depositional zone of a hillslope
- Higher runoff coefficients produce ER values near unity. Larger flow conditions move all size fractions.





From Papanicolaou et al. (in review).

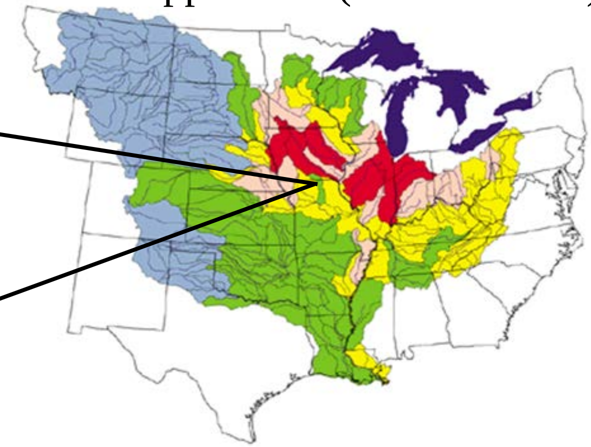
ER Modeling Results



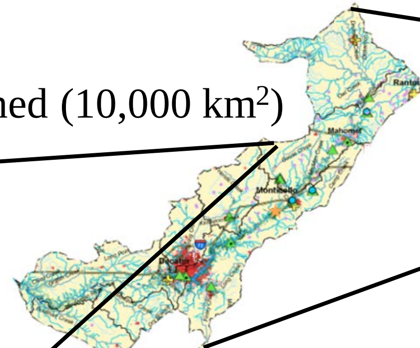
From Papanicolaou et al. (in review).

Scaling

Mississippi Basin (3 million km^2)

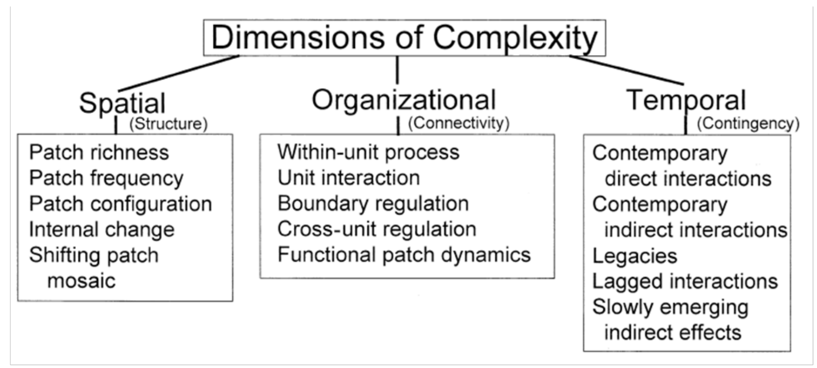


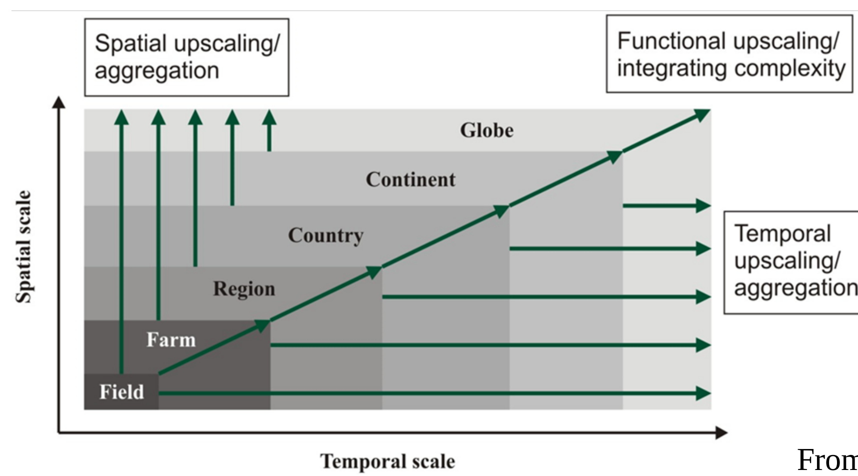
Watershed (10,000 km^2)



Tile Network (100 km^2)

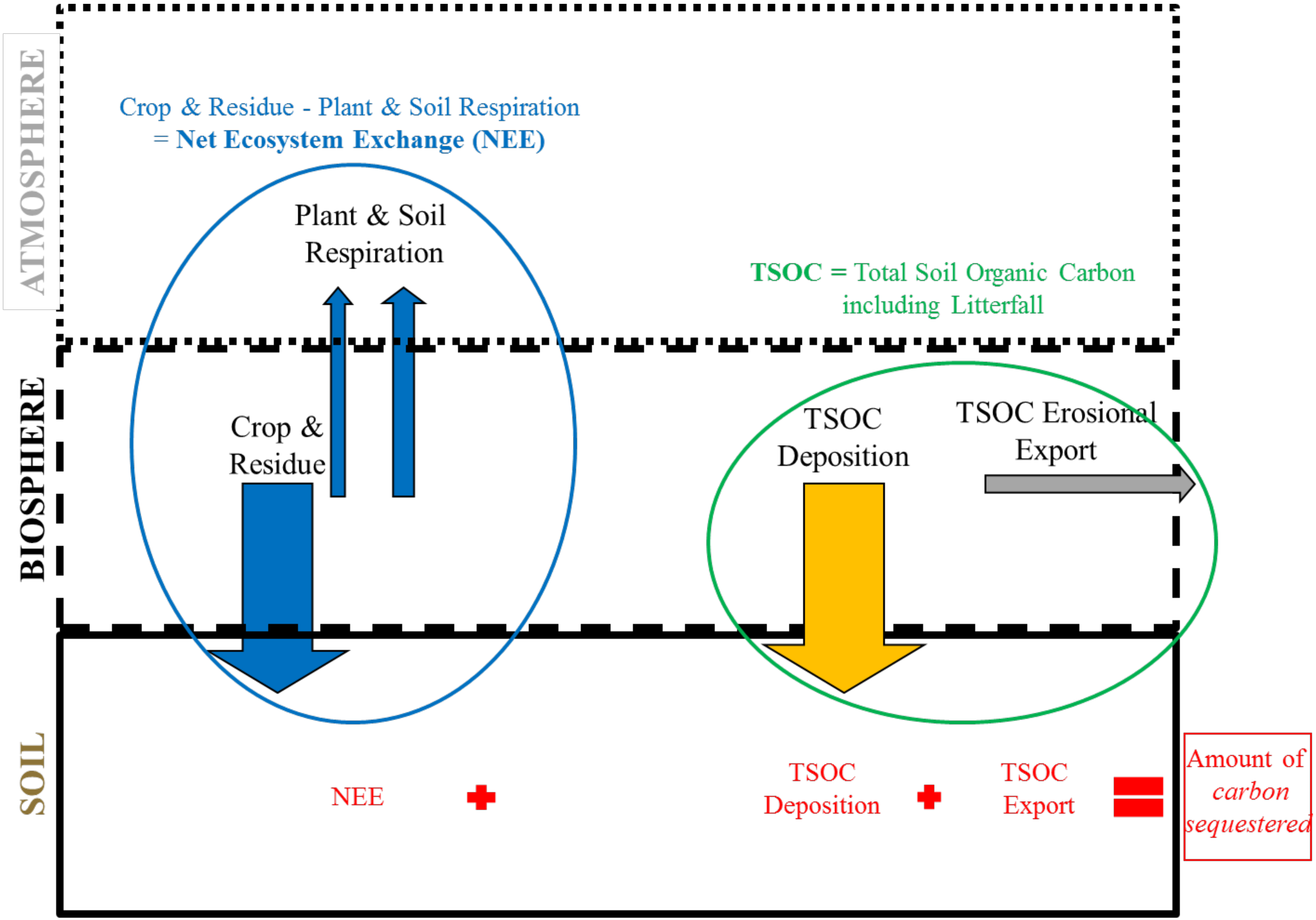
Single Tile (1km^2)



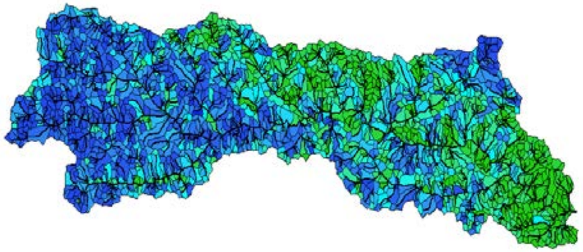


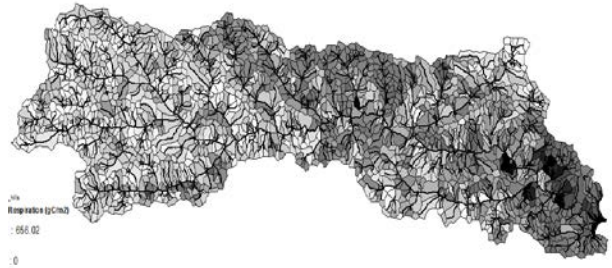
From Ewert (2012)

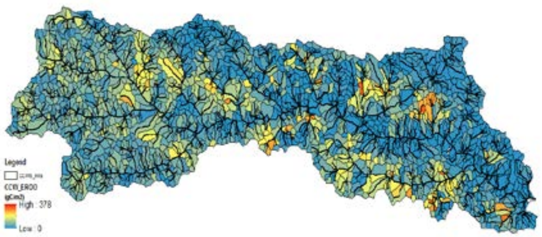
Soil Carbon Budget Components



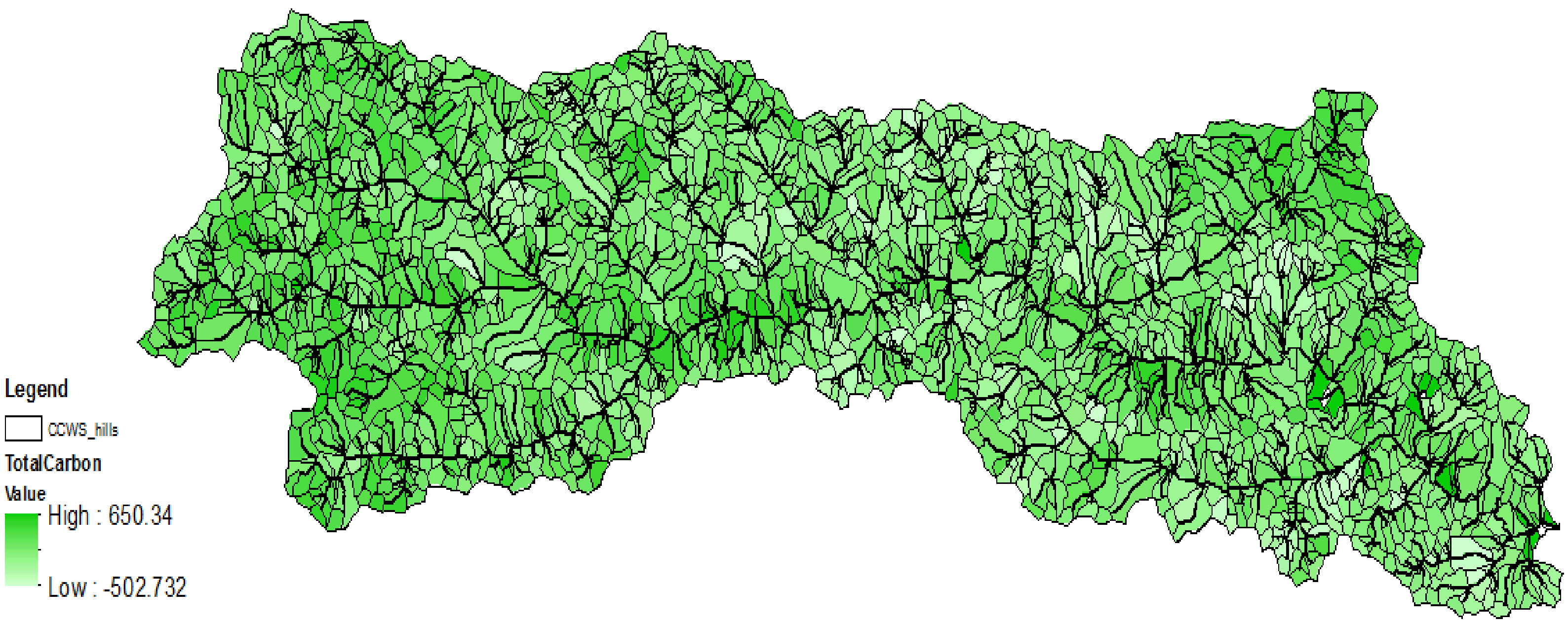
Total SOC Budget



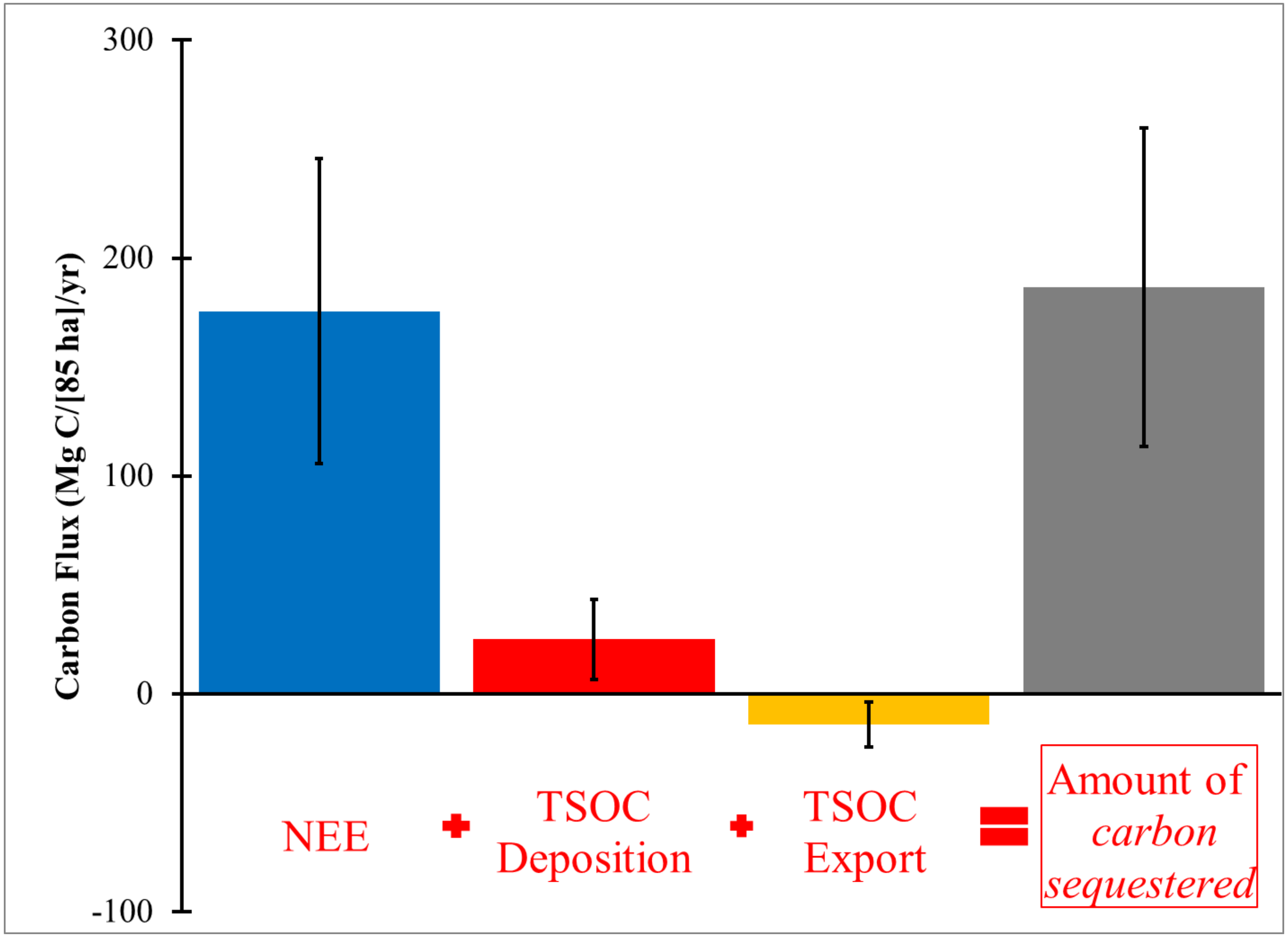




Net Primary Production (NPP) - Respiration - Erosion/Deposition



Example of a Soil Carbon Budget



Notes:

-The Clear Creek, IA system has net carbon sequestration (grey box) of 187 ± 73 Mg C/ [85 ha]/yr

-Other ranges of sequestration potential in the Midwest include Lal (2004): 4 – 518 Mg C/ [85 ha]/yr; Causarano et al. (2008): 285 – 373 Mg C/[85 ha]/yr; Sperow et al. (2003): >229 Mg C/ [85 ha]/yr.

Top-down Studies

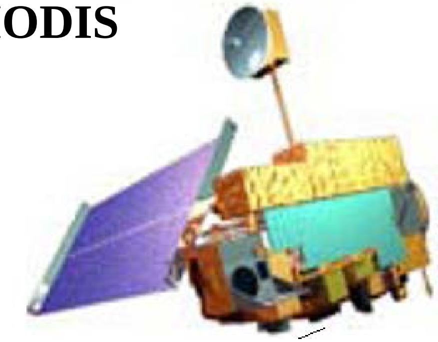
The **Top-down Approach** looks at the end result to determine the source of the fluxes.

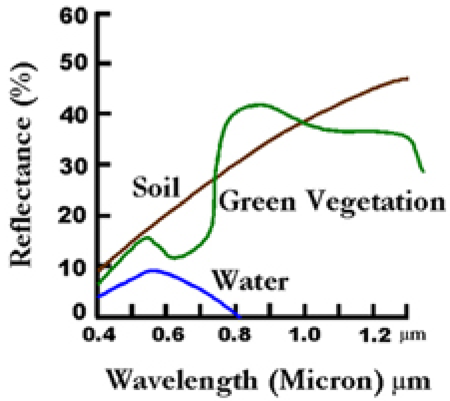
NOAA Tall Tower in West Branch, IA
-photo by A. Pettibone

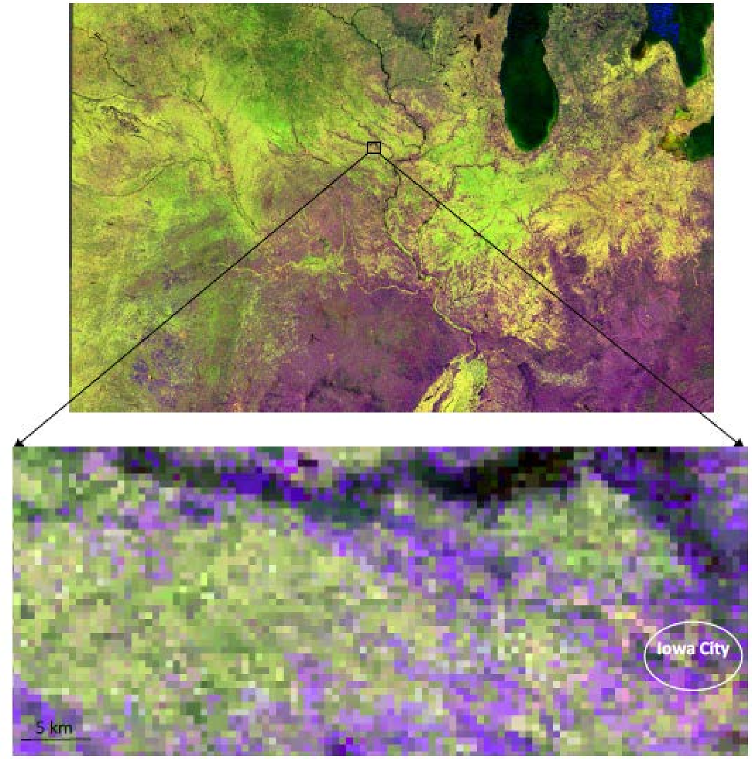
Remote Sensing data from satellites like MODIS

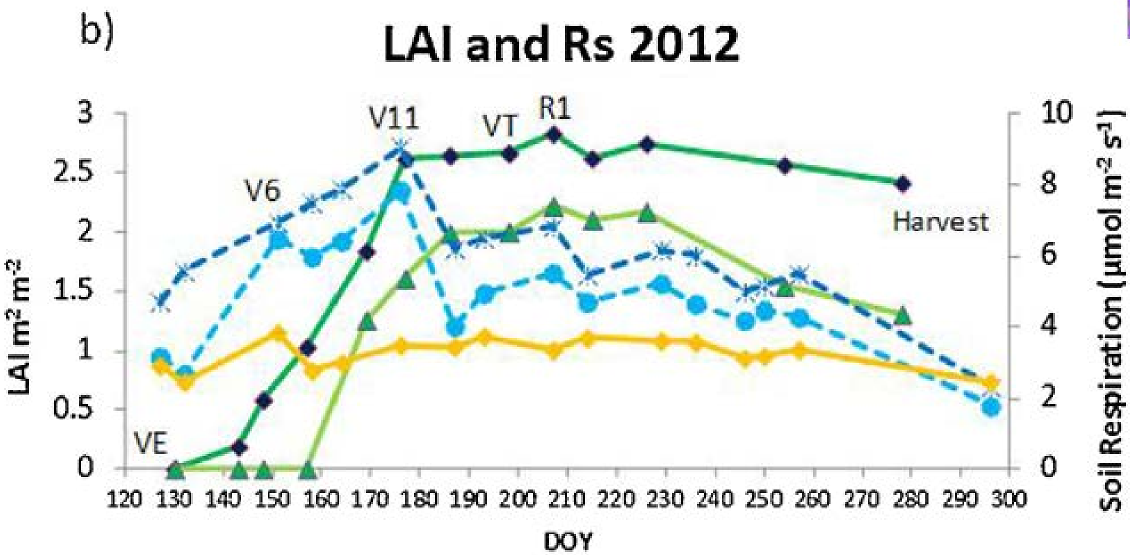
Remote Sensing – Production

MODIS





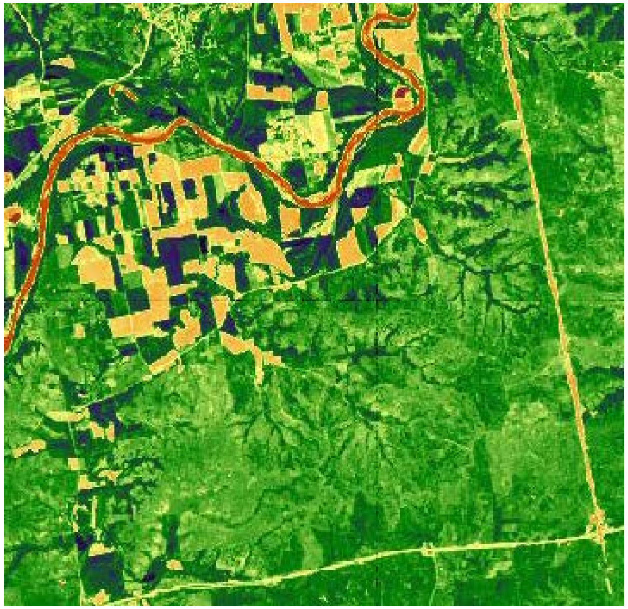




P is at the plant; I is in between rows, S is bare soil

From Cicuendez et al. (2013)

Remote Sensing - Erosion



NDVI from MODIS

Alternatively, erosion can be calculated remotely along a downslope:

$$E = E_{30} * \left(\frac{S}{S_{30}}\right)^{0.9}$$

where *S* is the gradient of the downslope, S_{30} is tan(30º), and E_{30} is a baseline erosion rate i.e., the rate of soil erosion on a 30º slope and is defined as:

$$E_{30} = e^{\left(\frac{Log\ 0.132 - Log\ 17.12}{NDVI_{max} - NDVI_{min}} * (NDVI - NDVI_{min}) + Log\ 17.12\right)}$$

where *NDVI* is the Normalized Difference Vegetation Index and varies per land use and management practice.

A Coupled WRF-VPRM Model

WRF-VPRM

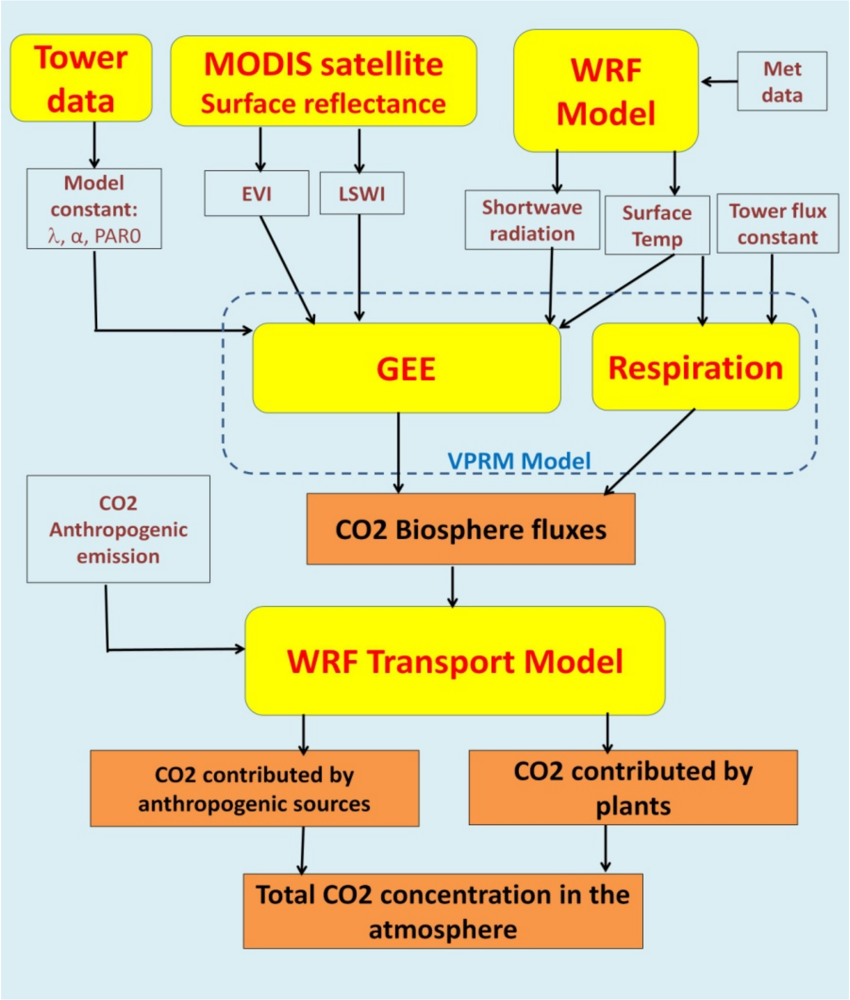
(Ahmadov et al., 2007)

WRF-Chem

Weather Research and Forecasting Model – Chemistry
A meso-scale numerical weather prediction system for both operational forecasting and atmospheric across scales from meters to 10^3 kilometers
(*Grell et al., 2005*)

VPRM

Vegetation Photosynthesis and Respiration Model
A diagnostic biosphere model to calculate CO_2 biosphere fluxes (plant and soil)
(Mahadevan et al., 2008)



WRF-VPRM Equations

Net Ecosystem Exchange

$$NEE = -GEE + R$$

Gross Ecosystem Exchange

$$GEE = (\lambda \times T_{scale} \times P_{scale} \times W_{scale}) \times FAPAR_{PAV} \times 1/(1+PAR/PAR_0) \times PAR$$

Effect of temperature

Effect of plant phenology calculated using EVI and LSWI

Effect of water stress

Effect of light (short wave radiation)

Respiration

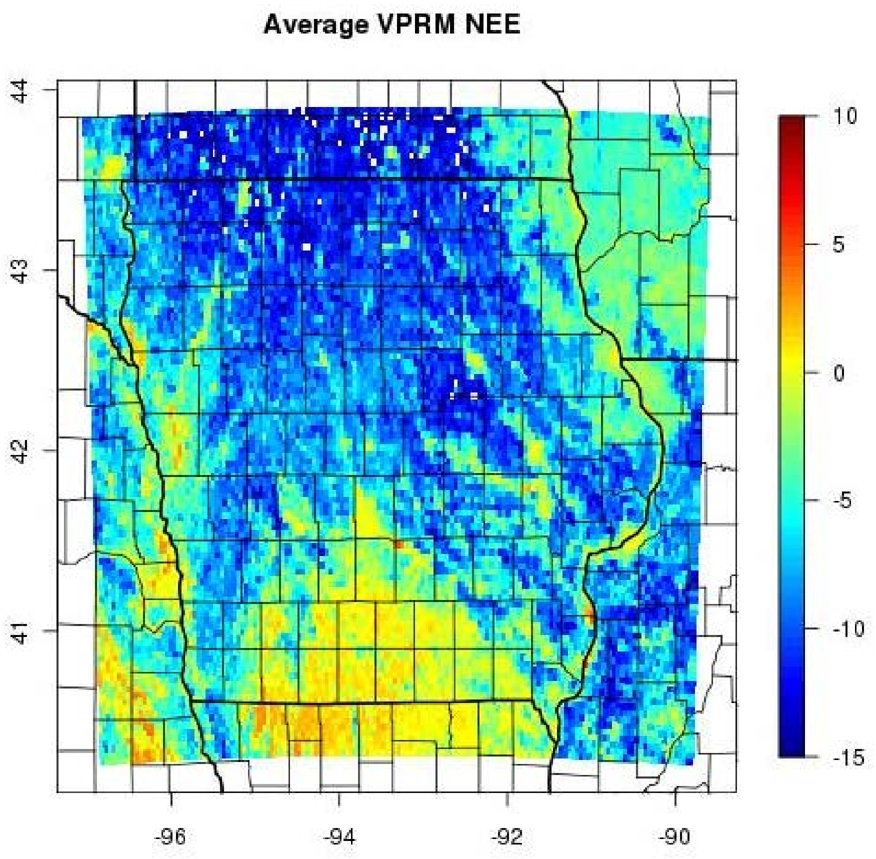
$$R = \alpha \times T + \beta$$

Effect of temperature

From Mahadevan et al., 2008

WRF-VPRM Model Results of NEE

WRF-VPRM, 4km resolution



WRF-VPRM average flux: 6.2 μmol/m²/s

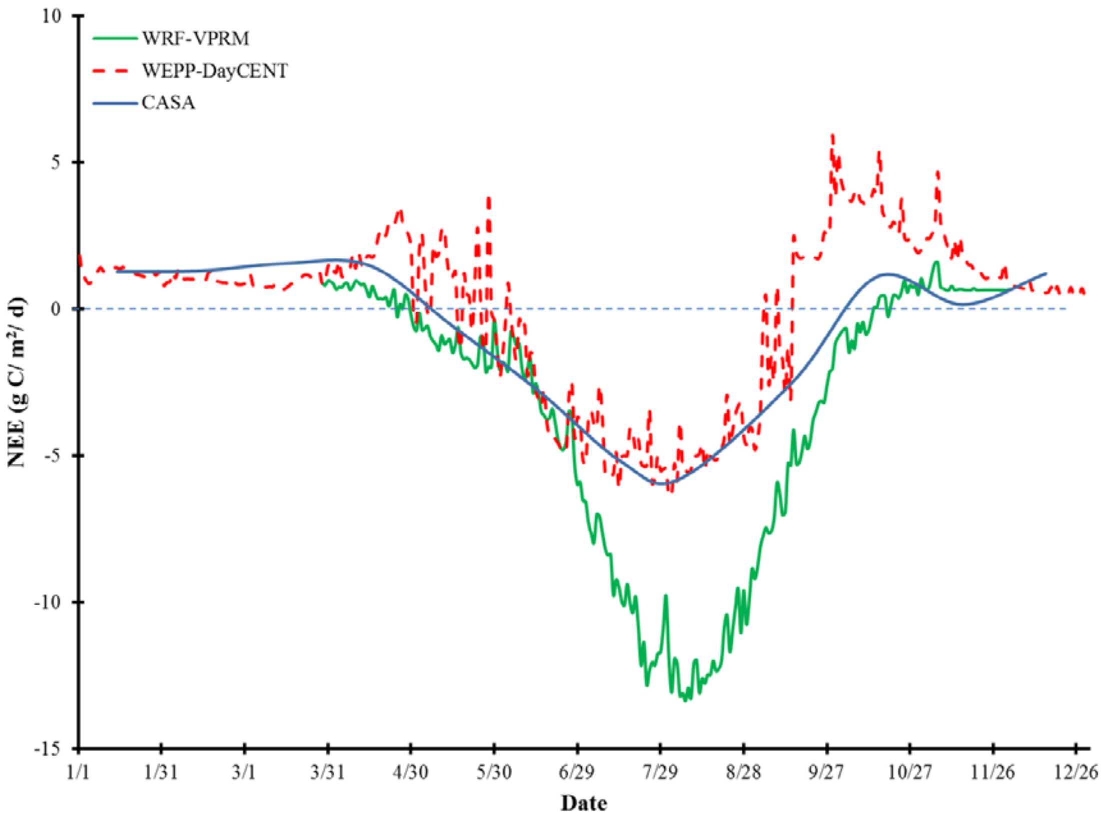
- WRF-VPRM gives high variation due to high resolution of land uses.
- The average fluxes for each cell show significantly differences.

A Comparison of Methods

<u>Production</u>

WEPP-CENTURY:
a plant growth model using a function of a crop-specific genetic maximum for each crop and scalars depending on soil temperature & moisture, shading, and seedling growth.

WRF-VPRM & CASA:
Regression equations using satellite imagery with temperature and moisture scalars



<u>Respiration</u>

WEPP-CENTURY: The maximum potential decomposition is adjusted based on texture, soil microclimate, anaerobic onditions and tllage

WRF-VPRM: A regression equation based on temperature.

CASA: Based on CENTURY.

Conclusions

- The terrestrial sink is estimated as the **residual** from the sum of all sources minus the ocean + atmosphere sinks. There are no direct estimates. The sink can also be estimated using terrestrial biogeochemical models but scales of using these models are limited and accuracy questionable.

- High variability across the landscape due to landscape features and biogeochemistry (static) as well as management and redistribution (dynamic).

- A coupled bottom-up/ top-down approach that crosses scales is helpful to capture carbon budgets. The coupled approaches are necessary to provide better estimates of the global terrestrial sink of carbon.

Dear Friends …please see answers below.

Has he done anything with the ability of cover crops to speed up the process of storing carbon? (within an agricultural setting that is)
Answer: Good question...with respect to cover crops we have looked 2 aspects. One has to do with erosion. Cover crops reduce erosion of the order of 20%-35% based on hillslope estimation scales therefore increasing the potential of C storage by at least so much. (See implications of residue (not cover crops) in Abaci and Papanicolaou Hydrological Processes, 2009)

The second has to do with increasing C stocks by tilling in the cover crops and
Root matter. No quantitative numbers on this one.

What effect do drain tiles have on erosion and SOC?
Answer: This is the 1 million dollar question. My answer again is limited to the hillslope scale. It is a starting point but we need to do better than that. We will need a landscape oriented approach.a

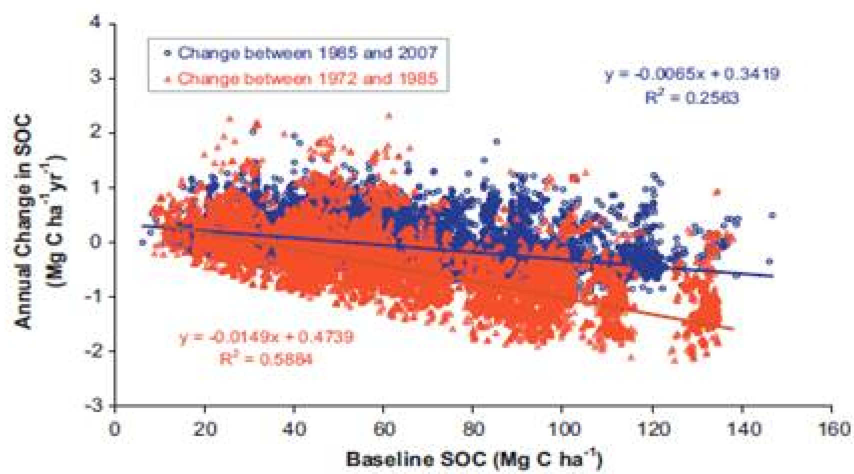


Fig. 5. Relation between annual SOC changes and the antecedent SOC stock levels in the top 20 cm depth of soils across Iowa croplands for two time periods: 1972 to 1985 (red line) and 1985 to 2007 (blue line).

My question refers to the slide dealing with LAI and other variables a s a function of time. Given that LAI is a function of the phasic development of the crop, the more or less invariable LAI at harvest compared to the vegetative phase?
Answer: LAI and LAD (Leaf Angle Distribution) represent the main drivers of canopy reflectance. Furthermore, it is legitimate to interpret subsoil information (e. g. SOC.) by analyzing upper soil surface characteristics (e.g. LAI) obtained through satellite images, provided that there is a strong correlation between the subsoil and upper soil data. I believe there is a good relationship between LAI and spectral vegetation indexes (SVIs) such as the NDVI. SVIs change during the lifecycle of the crop (Gupta and Prasad). So we can use it …however, it is easier to do the comparisons before crop growth and after the crop senescence than during. You get a measurable difference if you do the comparisons before and after. Excellent question.