The Rapid Carbon Assessment Project: a modern soil carbon stock baseline for the conterminous United States

Skye Wills, Terry Loecke, Stephen Roecker, Zamir Libohova, and Soil Survey Staff
29 June 2017
Presentation for Pedometrics 2017
Objective: Base-line inventory of soil carbon stocks for conterminous U.S.

Evaluate impact of ecosystems, land use and cover
Multi-stage Stratified Random Sampling

- Not enough resources to sample all soil series

- Target sampling
  - Stratified Random Sampling
    - 17 regions
      - (conterminous U.S.)
  - Within region Stratification
    - 8 – 20 groups of soil series*
    - 6 LULC
      - 5 types of Land use / cover (LULC): Cropland, Pastureland, Rangeland, Forest land, Wetland

*Wills et al., 2013
RaCA Data Collected

Information collected on

- 6,147 sites
- 32,053 pedons
- 144,833 samples
RaCA Data Collected

Site Information: landscape, vegetation, management

Pedon Description and sample collection
- 5 pedons described
- Samples collected by horizon to 1m
- Bulk density samples collected to 50cm

Lab Analysis
- All pedons
  - Bulk Density*
  - Visible – Near Infrared Spectra
- Central pedon (1 per site)
  - Combustion – total carbon
  - Calcimeter – inorganic carbon

*Sequiera et al., 2014
Land Use – Land Cover SOC stocks stacked by depth increment
Area Weighted - Land Use – Land Cover
SOC stocks stacked by depth increment

SOC stock (Mg/ha)

0
50
100
150

Wetland
Forest land
Pastureland
Rangeland
Cropland

Land Use - Land Cover Class

Depth Increment
- 0 to 5 cm
- 5 to 30 cm
- 30 to 100 cm

Rapid Carbon Assessment of US
RaCA Regions
Weighted Mean SOC Stocks to 100cm

Source: RaCA region (MOs) weighted averages using LUGR means according to the Rapid Assessment of Carbon Methodology.
Prepared by: Skye Wills, 2016
RaCA - SOC stocks - Mg/ha to 100cm
LUGR means on gSSURGO grid

RaCA Sites SOC stocks to 100cm (Mg/ha)

Source: Prepared using LUGR means attached to the 2013 gSSURGO grid. Hillshade background.
Prepared by: Skye Wills, 2016
Total Conus SOC stocks: Bayesian Estimation Procedure

- Used Bayesian Monte Carlo package Rstan
- Simulates posterior probability distribution of mean and variance
  - Used MCMC implementation - NUTS sampler
- Conditional and cumulative variance estimated using a hierarchical Bayesian linear regression model to accommodate the experimental design
  - within LUGR, among LUGR, among Soil Group, and among Regions
  - the within LUGR level ($\epsilon_{sLGR[D]}$) contains all of variance due to the random selection of sites, intersite spatial variation, and field and laboratory sampling and analysis errors.
- Total SOC stocks were estimated
  - 4 parallel independent chains (each with 5500 independent estimates after warm-up and thinning)
- Priors from Guo et al., 2006 estimates
  - found to be uninformative
### SOC pools (Pg C) by Land Use – Land Cover class and fixed depth Interval

<table>
<thead>
<tr>
<th>Land Use – Land Cover</th>
<th>0 - 5 cm Total SOC (Pg C)</th>
<th>0 - 30cm Total SOC (Pg C)</th>
<th>0 - 100cm Total SOC (Pg C)</th>
<th>Area/Prop Conus*</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>LCI</td>
<td>Med</td>
<td>UCI</td>
<td>LCI</td>
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<td>Cropland</td>
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<td>Pastureland</td>
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<td>Rangeland</td>
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<td>Wetland</td>
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<tr>
<td><strong>All Observed</strong></td>
<td>11.1</td>
<td>11.5</td>
<td>11.8</td>
<td>35.8</td>
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</tbody>
</table>
Total CONUS SOC pool (Pg C)
Conclusions

- RaCA collected 6,000 pedons across the conterminous United States
- SOC stocks are skewed with a few very high values
- Most SOC occurs within 5 – 30cm of the soil surface
- Wetlands have the highest typical SOC stocks and Rangelands have the lowest
- A satisfactory map was made across the conterminous US
- Bayesian linear regression model was used to estimate total stocks
  Similar to, but more precise than, previous estimates

<table>
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<th>Depth Increment</th>
<th>lower CI</th>
<th>median</th>
<th>upper CI</th>
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</thead>
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<tr>
<td>0 - 5 cm</td>
<td>11.1</td>
<td>11.5</td>
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<tr>
<td>0 - 30 cm</td>
<td>35.8</td>
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<tr>
<td>0 - 100 cm</td>
<td>63.3</td>
<td>65.7</td>
<td>68.6</td>
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</tbody>
</table>
Questions?
Data Availability

Search engine: RaCA soil

All methodology and data prior to Bayesian Analysis (including R scripts used to make most figures)

[Full url: https://go.usa.gov/xXCjD](https://go.usa.gov/xXCjD)

R package: soilDB

fetchraca()
References


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Bayesian Implementation Details

- The model was fit using the Bayesian Monte Carlo package RStan (Stan development team, 2016).
- It simulates the posterior probability distribution of the mean and variance parameters given the data and prior information using a Hamiltonian implementation of Markov chain Monte Carlo known as the No U-Turn Sampler (NUTS) (Hoffman and Gelman, 2014).
- The model also uses prior distributions from previous observations (Guo et al., 2006) as well as uninformative flat priors in separate runs.
- Implementation details include 4 parallel independent chains, each with 6000 iterations, a warmup of 500 iterations was discarded, and a thinning rate (to reduce autocorrelation) of 75% resulting in posterior probability distribution (SOCppd) of 5500 iterations for each parameter (equations 3-10). Each of the 5500 iterations can be interpreted as independent estimates of each parameter, which allows for credible intervals to be derived from each ppd. Here we designate the lower credible interval as the 2.5% quantile and the upper credible interval as the 97.5% quantile of each SOCppd.
The total OCS (TOCS) for each LULC, region, and CONUS levels were derived by converting the OCSppds from the effects parameterization (as shown in equations 3-10) to the mean parameterization, back-transforming the OCSppds for the ith LUGR level (to generate the geometric mean for each iteration), multiplying these by the total pixel count of each LUGR *polygon* and the area of each pixel and then aggregating these LUGR-OCSppds to the LULU, regional, and CONUS scales as:

\[
LULC_{TOCS_{ppd[D]}} = \sum_{1}^{L} \text{LUGR}_{i_{OCSppd}} \times P \times \text{Pixel count}_{LUGR_{i}}
\]

\[
Region_{TOCS_{ppd[D]}} = \sum_{1}^{R} \text{LUGR}_{i_{OCSppd}} \times P \times \text{Pixel count}_{LUGR_{i}}
\]

\[
CONUS_{TOCS_{ppd[D]}} = \sum \text{LUGR}_{i_{OCSppd}} \times P \times \text{Pixel count}_{LUGR_{i}}
\]

Bayesian Implementation Details
### Cumulative and Partitioned Variance

<table>
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<tr>
<th>Soil depth</th>
<th>Levels</th>
<th>2.5%</th>
<th>50%</th>
<th>97.5%</th>
<th>n eff</th>
<th>Rhat</th>
<th>% variance</th>
<th>cumulative % variance</th>
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<td>31.6</td>
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</table>
Example slides to follow...........
Heat Map of Relative SOC stocks (Mg/ha to 5 cm)

Heat Map of Relative SOC stocks (Mg/ha to 1m)
MO 5 Example Pedons
SOC stocks by Depth Increment

Depth Increment
- 0 to 5 cm
- 5 to 30 cm
- 30 to 100 cm

Type of Pedon
- Wetland
- Forestland
- Pastureland
- Rangeland
- Cropland

SOC stock (Mg/ha)
- Max. Pedon
- Mean
- Median Pedon
- Min. Pedon
USDA CARBONSCAPES

A national look at carbon landscapes and meeting place for the USDA Carbon inventory and modeling community.

James A. Thompson
West Virginia University, Division of Plant & Soil Sciences

Sharon W. Waltman
National Soil Survey Center-Geospatial Research Unit

Kurt Donaldson, Frank Lafone, Maneesh Sharma
West Virginia GIS Technical Center

Michael Wilson, Skye Wills
USDA – NRCS
This new 2017 report describes the role of forests and grasslands in the carbon cycle and outlines considerations for managing for carbon as one of many environmental benefits provided by natural ecosystems.
History (2010-2012): USDA Carbon Data Visualization Tool

Scope

• To organize and make readily accessible carbon-related information owned or used by USDA via a single web site.

• Will include GIS data layers, model information; model results, and tools to improve access to and display of the information.

• Target users include USDA personnel, researchers and scientists from other agencies, and the public.

USDA Team assembled to formulate requirements and review final product

NRCS – Carolyn Olson, Adam Chambers, Jeff Goebel, Sharon Waltman
OCE - Marlen Eve
USFS – Greg Reams, Chris Woodall, Rich Birdsey
NASS – Rick Mueller
ARS – Ray Hunt
2012-Present: USDA CarbonScapes

Project Goals

- Bring USDA scientists and models together with ready access to national digital map layers
- Improve assessments of soil/plant carbon sequestration for multiple uses
- Use geoplatform principles (OMB Federal Geographic Data Committee [http://www.geoplatform.gov](http://www.geoplatform.gov)) for efficient use/management of federal geographic or mapped data

A national look at carbon landscapes and a central location for USDA Carbon inventory, modeling and mapping of terrestrial biosphere carbon

Cooperative effort of USDA-NRCS and University of West Virginia
2013: Focus group Survey

Included representatives suggested by the former CDVT USDA Team members.

Key findings:

- Carbon stock and mass units matter!
- Everyone want to take the data with them or add to local GIS project
- Everyone prefers different summary regions (States, counties, MLRA, Ecoregions, basins)
- Everyone prefers their own model
- Most don’t stray far from their own terrestrial carbon cycle pool 😊
http://carbonscapes.org/

USDA CARBONSCAPES

A national look at carbon landscapes and meeting place for the USDA Carbon inventory and modeling community.
Answer questions such as:

1. How many million metric tons (MMT) of soil carbon are in the upper meter of soil in Lancaster County, NE?

2. What is the CO2-equivalent per hectare (or per acre) for the C stock in the upper meter of soil in the Salt Watershed in NE (8-digit or 12-digit HUC)?

3. How many MMT of soil carbon are in the upper meter of soil in the Nebraska/Kansas Loess Drift Hills Ecological Region?

4. How many acres of forest would it take in one year to sequester the mass of C in the upper meter of soil in MLRA 103 (Des Moines Lobe)?
USDA CarbonScapes
A useful and easy-to-navigate web map application to educate and answer questions about USDA inventory, modeling, and mapping of terrestrial biosphere carbon pools across the landscape.

Four major sections:
(1)ATLAS: A quick snapshot of different carbon pools by particular geographies
(2)EXPLORER: A visual and investigative view of USDA terrestrial models and data
(3)DATA: Access to current USDA terrestrial carbon models and data
(4)LEARN: Educational resources for the K-12/STEM classrooms or scientific communities about terrestrial carbon landscapes

http://carbonscapes.org/
Summarizes reports for specific carbon pools in the landscape for C stock or mass within a particular area within the conterminous United States.
CarbonScapes ATLAS

- Provides SOC stock and mass estimates of five C pools
  - Forest aboveground
  - Forest belowground
  - Soil (0-30 cm)
  - Soil (0-100 cm)
  - Total

- Forest C derived from USDA Forest Inventory and Analysis (FIA)
- Soil C derived from gSSURGO

- In the future, will be possible to add C stock, mass, and flux estimates provided by and other inventory/modeling sources for cropland and rangeland.
Click the map on the left to discover Carbon potential for a particular area, such as county.

Map Controls
- Use the "Geographic Area" pull down to change to watersheds or ecological regions.
- Use the "Carbon Pool" drop down to find other stores of carbon in the soil or plant life.
- Use the "Stock" button to switch between Stock, a measure of concentration, and Mass, a total measure.
- Use "Choose Carbon Units" to change the conversion factor for the carbon units.
- The +/- buttons zoom the map in and out and the "House" button returns the map to default.
- The "Opacity" slider changes the visibility of the data.
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Calculated Mass equivalence numbers from equations found - EPA conversion calculation equations
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Calculated mass equivalence numbers from equations found: EPA conversion calculation equations.
Provides advanced users more in-depth tools to visualize and analyze carbon models and associated map layers as well as create maps, share geospatial links, and extract GIS data.

Large collection of USDA Carbon Inventory data
- Crop Data Layers and Change Detection
- Gridded SSURGO/STATSGO2 Carbon stocks
- PRISM
- FIA and Forest Cover

USDA Models and some run results
- USFS Models (COLE, ForCarb, CCT, etc.)
- NRCS Models (DayCent, COMET, etc.)
- ARS Models (CQUESTOR)
The USDA CarbonScapes Data catalogs and links users to USDA terrestrial carbon data and model resources published on Data.gov and other web sites.

Launch Data
• Catalogs and provides easy access for users to USDA terrestrial C data and model resources
• Links to data.gov and other related websites
The element carbon is the foundation for all life. Many compounds formed from carbon are essential to life on earth. Carbon is an invaluable resource and it is continually cycled through Earth’s ecosystems—taken from the atmosphere by plants, used by animals that consume those plants, deposited in the soil, and returned to the atmosphere by plants and animals.

While there is concern over rising levels of carbon (in the form of carbon dioxide) in the atmosphere, understanding the carbon cycle helps us recognize that soils and plants can store carbon in the biosphere. In fact, there is approximately three times as much carbon stored in the Earth’s soils than is contained in the atmosphere.

Knowing where current carbon stocks in the United States are higher and where they are lower can be used to guide wise decision making about land use and management, helping us choose practices that favor carbon storage in soils and plants.
https://toolkit.climate.gov/tool/carbonscapes
About USDA CarbonScapes

The goal of USDA CarbonScapes is to provide a useful and easy to navigate web map application to educate and answer questions for stakeholders about USDA inventory, modeling, and mapping of terrestrial biosphere carbon across the landscape. USDA NRCS Funded CESU 68-7482-13-511
A collaboration between the USDA and West Virginia University

Quick Links

- User Feedback
- Flyer
- Quick Start Guide
- Webinar
- Overview (video)
- Atlas and Data (video)
- Explorer (video)