Quantitative Soil Landscape Analysis – Analyzing the Spatial Distribution, Variability and Behavior of Soil Carbon

Sabine Grunwald
Global Estimates of Terrestrial Carbon Stocks

UNEP-WCMC. http://www.carbon-biodiversity.net/GlobalScale/Map
Global SOC Estimates (0-100 cm)

• 2,469 Pg (Köchy et al., 2012)
• 1,455 Pg (Hiederer et al., 2010)
• 1,589 Pg (Henry et al. 2009)
• 1,600 Pg plus 360 Pg in peat (Jacobson et al., 2004)
• 2,500 Pg (Lal, 2004)
• 1,550 Pg (Global Soil Data Task Group, 2000)
• 2,011 Pg (IPCC, 2000)
• 1,502 Pg (Jobbágy and Jackson, 2000)
• 1,463 Pg (Reich, 2000; NRCS-USDA)
• 1,462-1,548 Pg (Batjes, 1996)
• 1,395 Pg (Post et al., 1982)

Map scale: 1:5 million to 1:25 million

• High variability of soil C
• High uncertainty in mapping and modeling

Soil Carbon Assessment at Global Scale
Spatial Autocorrelations (Ranges) – Soil Organic C and Total C

- **20 to 325 m** (meta-analysis of nine different studies; McBratney and Pringle, 1999)
- **73 to 287 m** (0-50 cm; floodplain, bioenergy crop, hot-water extractable C, Texas; Sarkhot, Grunwald et al., 2011)
- **118 m** (hilly landscape on pasture and agriculture (wheat); Fromm et al., 1993)
- **104 to 129 m** (corn in Iowa; Cambardella et al., 1994)
- **500 m** (pasture in Amazon, Brazil; Cerri et al., 2004)
- **3.1 km** (forest in tropical Puerto Rico; Wang et al., 2002)
- **3.7 km** (0-10 cm, wetland, Everglades, Florida; Rivero, Grunwald et al. 2006)
- **5.6 km to 119 km** (0-20 cm, synthesis across multiple fields + watershed + large region (FL) scales) (Vasques, Grunwald et al., 2012)
- **6.5 to 11.6 km** (0-180 cm, Santa Fe River Watershed, Florida (Vasques, Grunwald et al., 2010)
- **9.2 to 11.3 km** (0-180 cm, Santa Fe River Watershed, Florida; Grunwald et al., 2010)
- **7.7 to 13.6 km** (0-20 cm; historic; basins in NE Florida; Ross, Grunwald et al., 2012)
- **11.8 to 12.9 km** (0-20 cm, wetland, Everglades, Florida; Bruland, Grunwald et al., 2006)
- **37.0 to 43.4 km** (0-20 cm; 2009/2010; basins in NE Florida; Ross, Grunwald et al., 2012)
Soil Mapping and Modeling

Grunwald, Thompson, and Boettinger. 2011. SSSAJ.
Envisioned Future of Digital Soil Mapping and Modeling

Grunwald, Thompson, and Boettinger. 2011. SSSAJ.
Digital Soil Mapping (DSM) // Soil Carbon Modeling

SCORPAN Model
McBratney et al. (2003)
Geoderma

STEP-AWBH Model
Grunwald et al. (2011)
SSSAJ

Factors change through time

Δ AWBH → Δ S → Δ AWBH → Δ S
Space-Time Soil Model: STEP-AWBH

Target soil property, rate, change, other

\[ SA(z, p_x, t_c) = f \left\{ \sum_{j}^{n} S_j(z, p_x, t_c), T_j(p_x, t_c), E_j(p_x, t_c), P_j(p_x, t_c) \right\} \]

Spatially-explicit, ~stable across time (human time frame)

\[ \int_{i=0}^{m} \left\{ \sum_{j}^{n} A_j(p_x, t_i), W_j(p_x, t_i), B_j(p_x, t_i), H_j(p_x, t_i) \right\} \]

Spatially-explicit + account for time-dependent variation of variables

Grunwald et al. (2011). SSSAJ.
Digital Soil Carbon Mapping Based on STEP-AWBH

Spatially & temporally explicit environmental co-variates

**STEP variables:**
- Soil
- Topography
- Ecology / geography
- Parent material

**AWBH variables:**
- Atmosphere / climate
- Water
- Biota: LU/LC
- Human

Soil observations (e.g., soil carbon measurements)

**Model development:**
- Random Forest (RF)
- or other ensemble regression trees
- or other stat./geostats methods

Predict soil-properties:
- Historic SOC
- Current SOC
- Total C
- SOC seq.
- Carbon pools
- Nitrogen pools
- Phosphorus pools
- ... and more

Model validation / uncertainty assessment
1080 Soil TC observations (0-20cm)

- 70% for calibration
- 30% for validation

Xiong X., S. Grunwald et al. (2012) Digital Soil Carbon Mapping Based on STEP-AWBH in Florida, USA

### Env. Covariates

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</table>
Soil total carbon stocks (kg m\(^{-2}\))

0-20 cm

Method: Random Forest (RF)
Validation results: \(R^2 = 0.65\); RMSD = 2.73
Grid resolution: 30 x 30 m

Xiong X., S. Grunwald et al. (2012)
Total Soil Carbon (0-100 cm)
N = 1,486 (pooled dataset: BCS + SFRW + FL)

Geophysical Res. J. Biogeosciences.
Grain Effects on Soil Carbon Modeling (Validation Results)


Florida

N = 1,288
Size ~ 150,000 km²

Santa Fe River Watershed, Florida, USA

LnTC (ln%)
-1.5 - 1.0
-1.5 - 0.0
-0.5 - 0.0
0.0 - 0.5
1.0 - 1.5
> 1.5
Soil Total Carbon Stocks (kg m\(^{-2}\)) in a High Carbon Ecosystem (WCA-2A, Everglades, FL, USA)

Stocks (absolute) in WCA-2A (418 km\(^2\)) = **4.2 Mt**
Stocks (0-20 cm) = **9.7 kg m\(^{-2}\)** (Kim, Grunwald et al., 2012)

In comparison [derived from STATSGO, NRCS]:
Stocks (0-20 cm) = **7.3 kg m\(^{-2}\)** (Guo et al., 2006)
Historic Soil Organic Carbon across the U.S. (SSURGO, NRCS)
Rapid Carbon Assessment Project (RaCA)

Soil organic carbon 0-100 cm
Data collected: 2011-2012

Research methods:
VNIR spectroscopy + combustion digital soil mapping

Digital soil mapping:
Applied in many other locations incl.
Africa
India
+ Global Soil Map.net

RaCA Sampling / Overall Project:
West Larry (NRCS) et al.

RaCA Digital Soil Mapping and Modeling:
Grunwald S., A.B. McBratney, and B. Minasny

New National Soil Carbon Assessment (U.S.)
SMOS (Soil Moisture & Ocean Salinity) Satellite Measurements – European Space Agency (ESA)

Soil moisture seasonal average (Jan - Apr)

Soil moisture yearly average (2010 - 2011)

Soil moisture seasonal average (Oct - Jan)

Moderate Resolution Imaging Spectroradiometer (MODIS) – NASA

NDVI (Normalized Difference Vegetation Index) 01-01-2010

NDVI (Normalized Difference Vegetation Index) 04-07-2010

NDVI (Normalized Difference Vegetation Index) 07-12-2010

NDVI (Normalized Difference Vegetation Index) 11-17-2010

+ other env. covariates

SOC (U.S.)

Environmental covariate extractions (U.S.): X. Xiong, S. Grunwald, Y. Qiu
Digital soil mapping and modeling:

• Spatial variability of SOC
• Temporal change in environmental covariates (AWBH factors), e.g. remote sensing derived properties → SOC change
• Coverage of large regions
• Measurements + evaluation (verification)

Linkages to UN – Global Environmental Facility
Core Project of the North American Carbon Program

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