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

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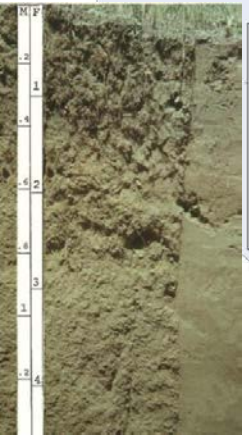
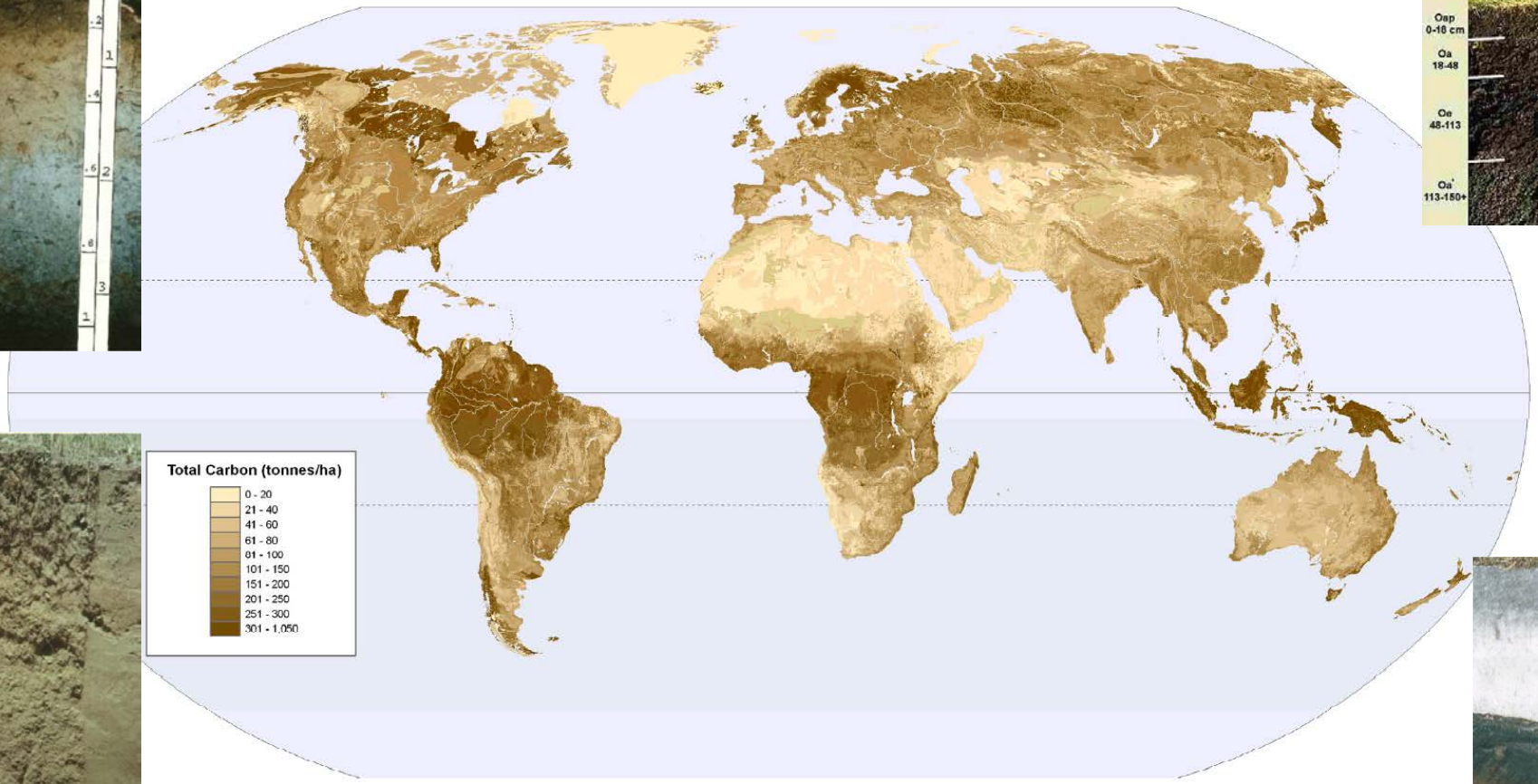
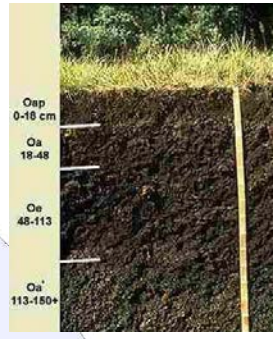
Global Estimates of Terrestrial Carbon Stocks







UNEP-WCMC. http://www.carbon-biodiversity.net/GlobalScale/Map
Scharlemann et al. (2009): Harmonized World Soil Database (2009)-SOC values up to 1 m depth (1 km spatial resolution) & Ruesch and Gibbs (2008): Biomass carbon map using IPCC Tier 1 methodology and GLC 2000 land cover data.

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

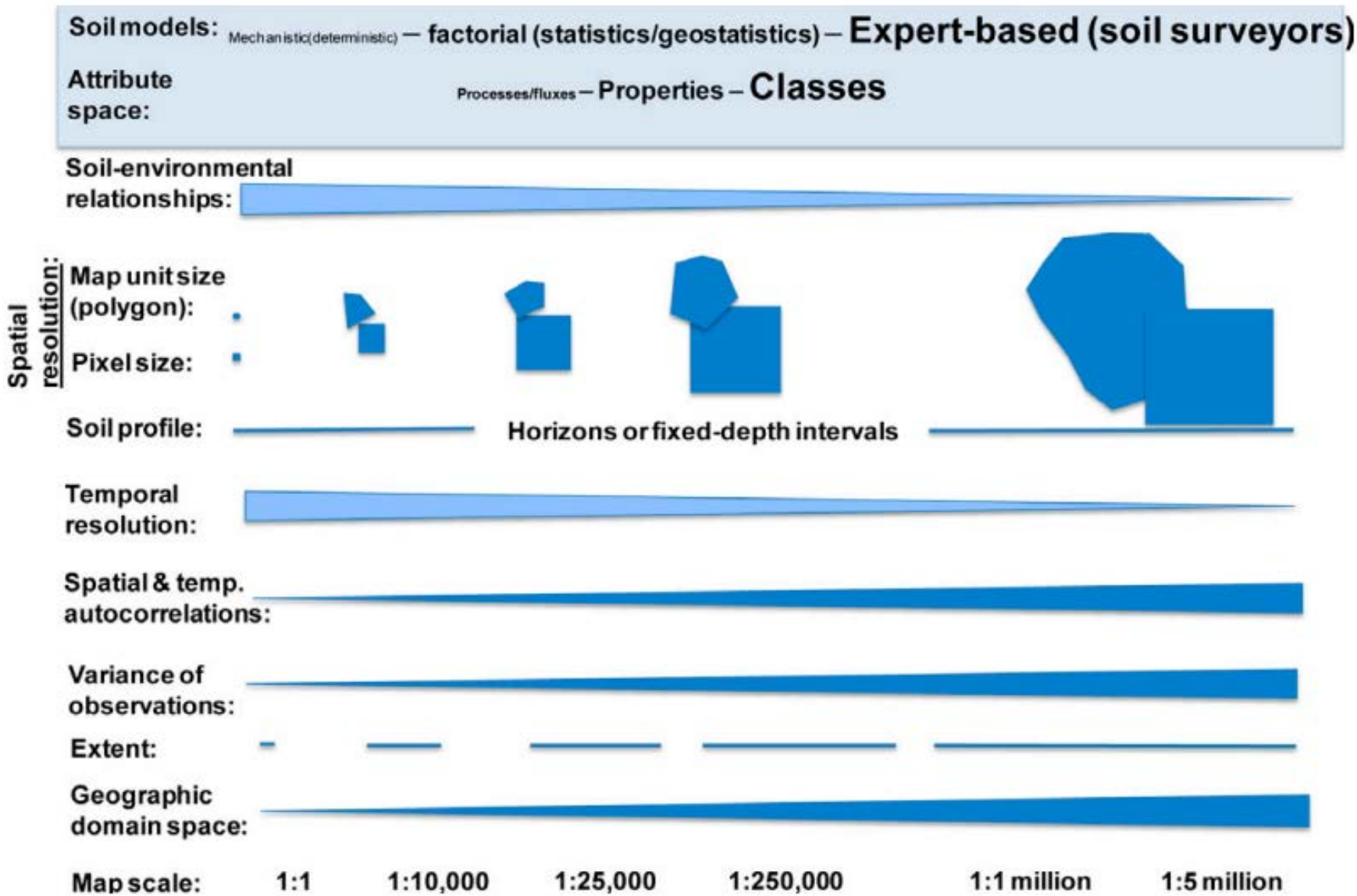
Soil Carbon Assessment at Global Scale

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)

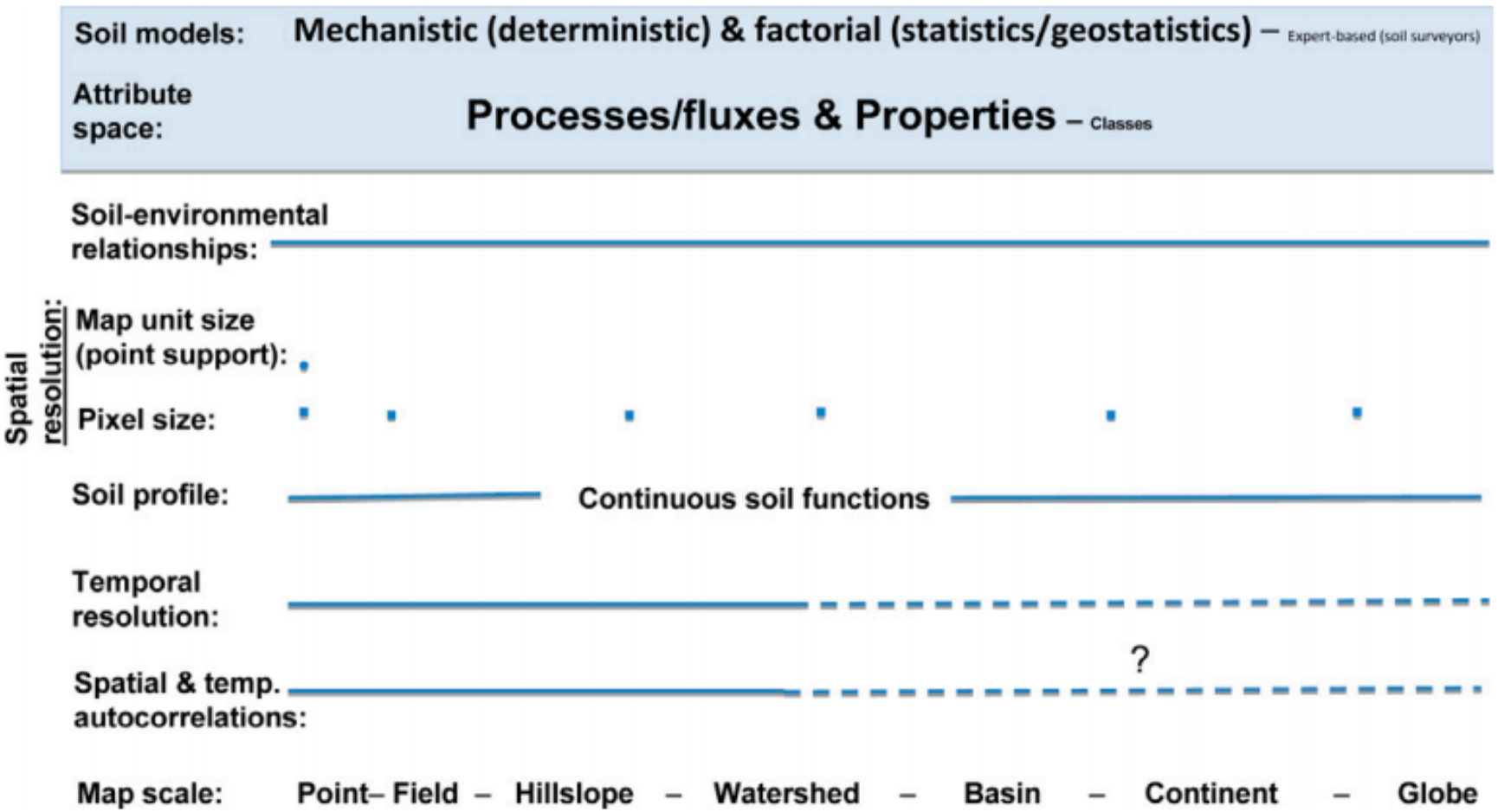
Soil Carbon Variability

Soil Mapping and Modeling



Grunwald, Thompson, and Boettinger. 2011. SSSAJ.

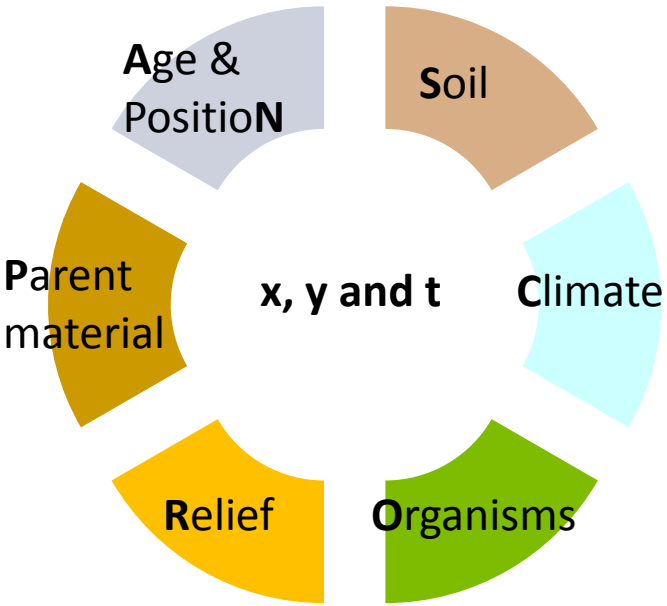
Envisioned Future of Digital Soil Mapping and Modeling



Grunwald, Thompson, and Boettinger. 2011. SSSAJ.

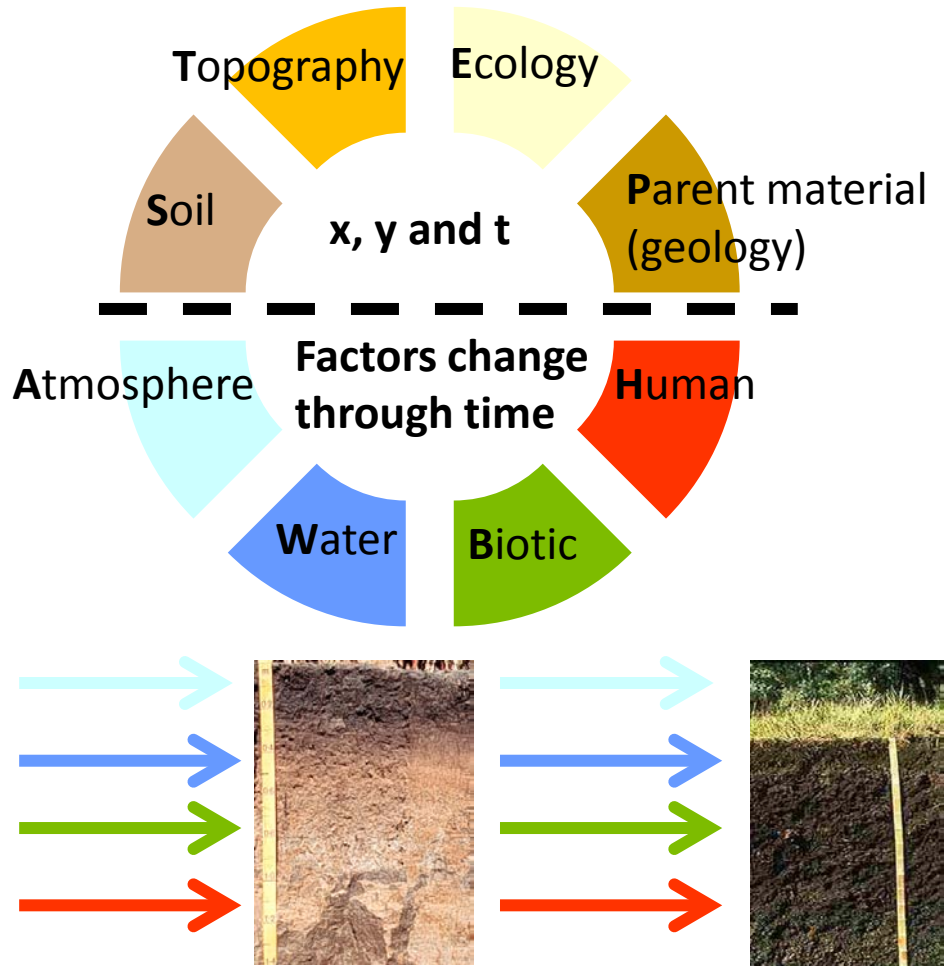
SCORPAN Model

McBratney et al. (2003)
Geoderma



STEP-AWBH Model

Grunwald et al. (2011)
SSSAJ



Δ AWBH → Δ S → Δ AWBH → Δ S

Space-Time Soil Model: STEP-AWBH

Target soil property, rate, change, other

Parent material

Ecology

Topography

Soil

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

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

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

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

Atmosphere

Water

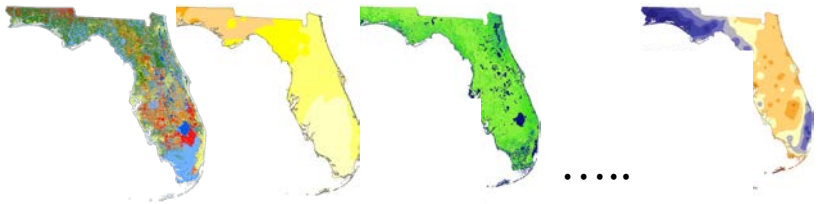
Biota

Human

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

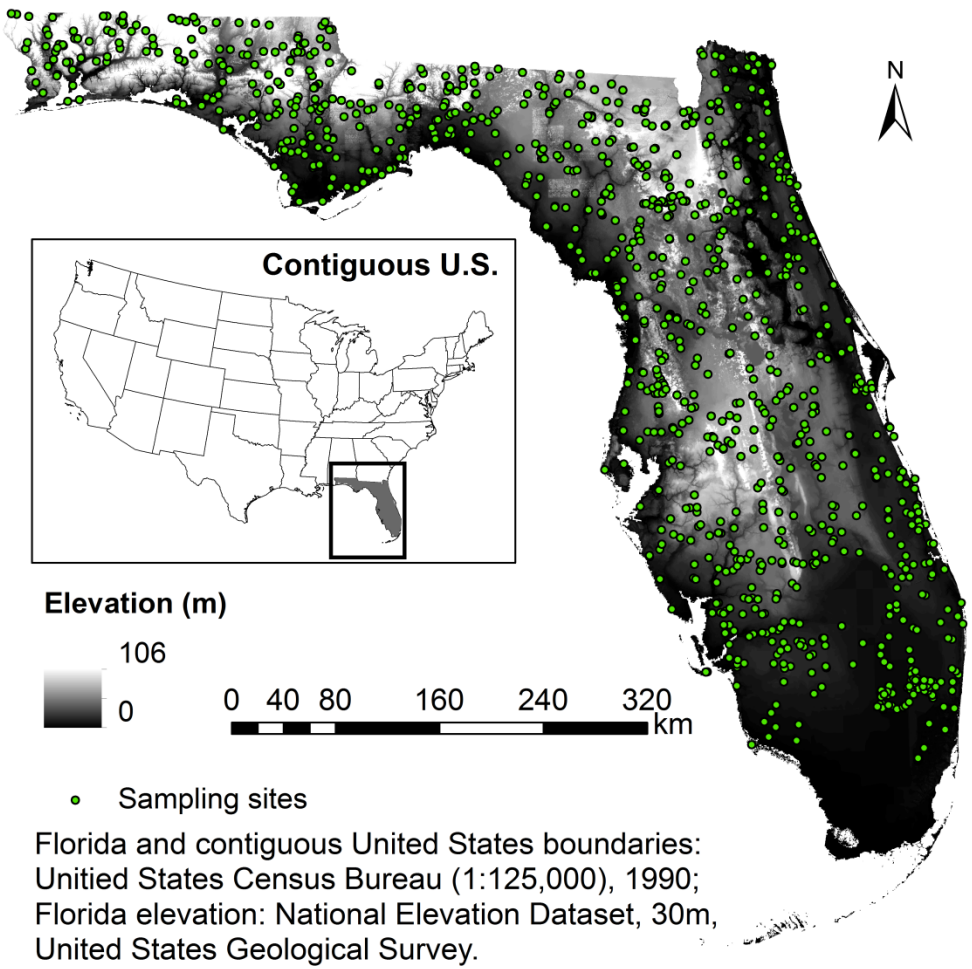
Predict soil-properties:
- Historic SOC
- Current SOC
- Total C
- SOC seq.
- Carbon pools
- Nitrogen pools
- Phosphorus pools
- … and more

Model validation / uncertainty assessment

Digital Soil Carbon Mapping Based on STEP-AWBH in Florida, USA

1080 Soil TC observations (0-20cm)

- 70% for calibration
- 30% for validation

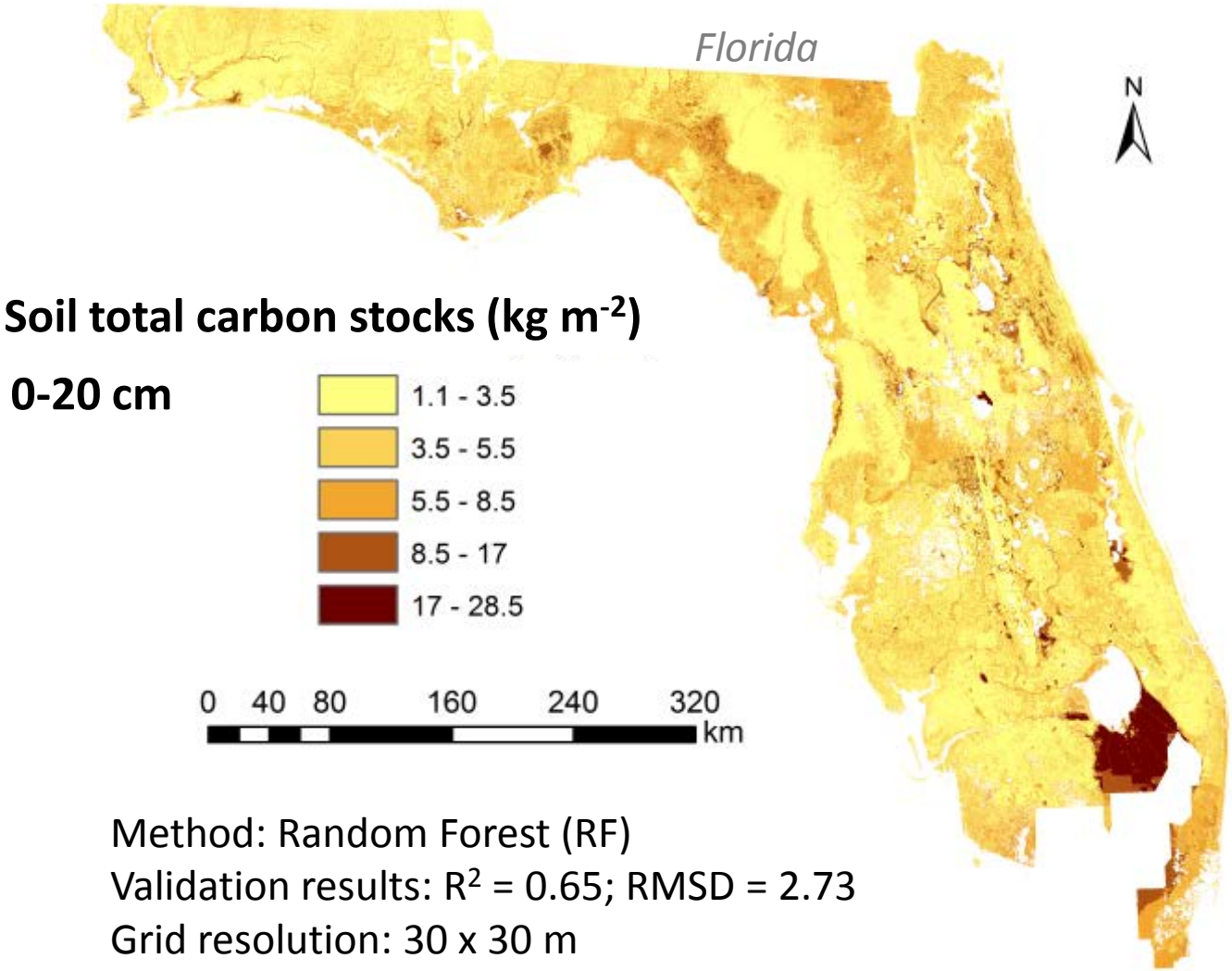


Xiong X., S. Grunwald et al. (2012)

Env. Covariates

STEP – AWBH factors	Data sources	Number of variables
Soil / water	USDA – NRCS's soil survey / state geographic database (Soil Data Mart)	31
Topography	USGS's national elevation dataset	4
Topography	USGS's digital elevation model	8
Ecology	FDEP's ecoregions	1
Parent material	USGS's physiography	2
Parent material	USGS's geology	4
Climate	NREL's spectral solar radiation data base	14
Climate / water	PRISM climate dataset	39
Biota	LANDFIRE's national vegetation products	14
Biota	National land cover data	3
Biota	National biomass & carbon dataset	3
Biota	Landsat ETM	18
Biota	MODIS for NACP	64
Biota / human	National cropland data layer	1
Biota / human	FFWCC's land cover / land use	2
Water	Soil moisture and other	4

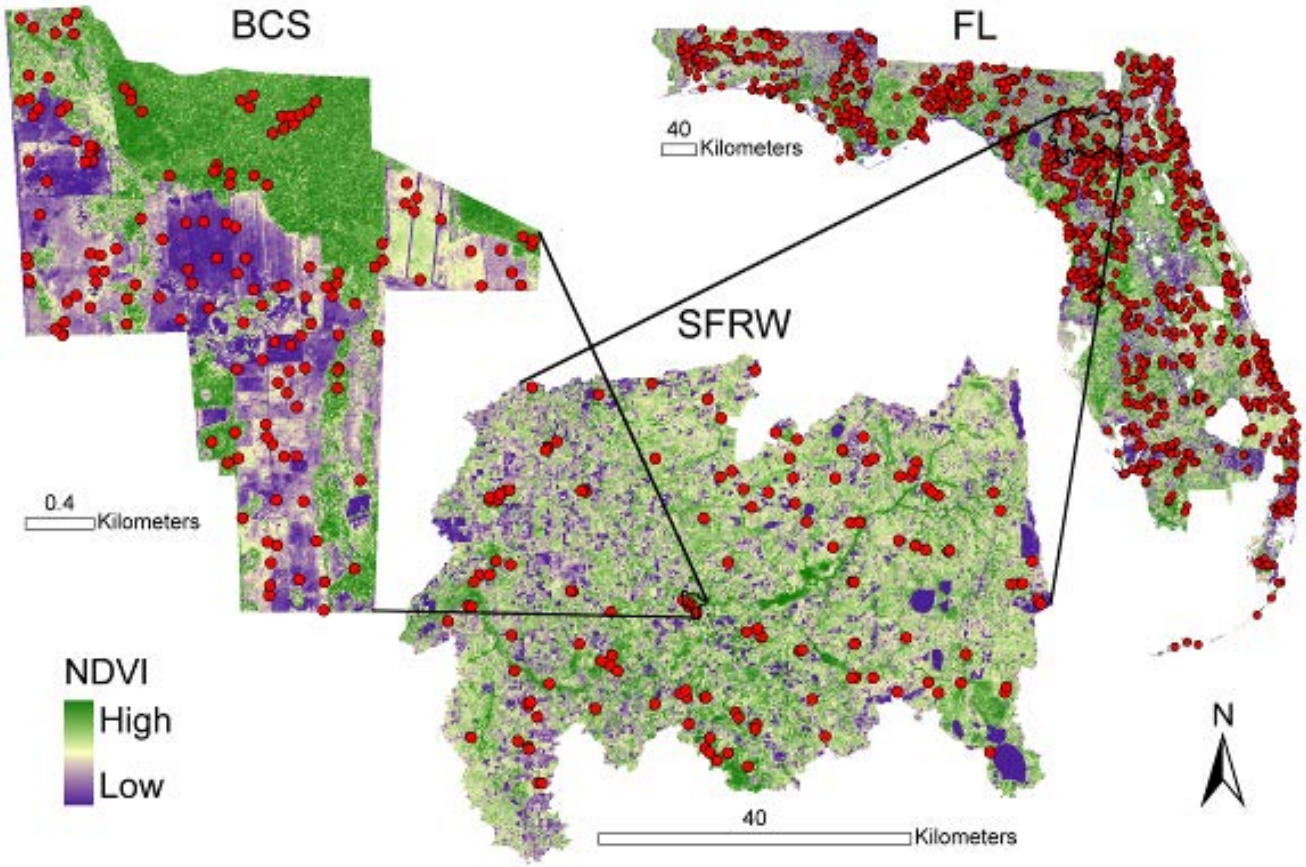
Digital Soil Carbon Mapping Based on STEP-AWBH in Florida, USA



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)

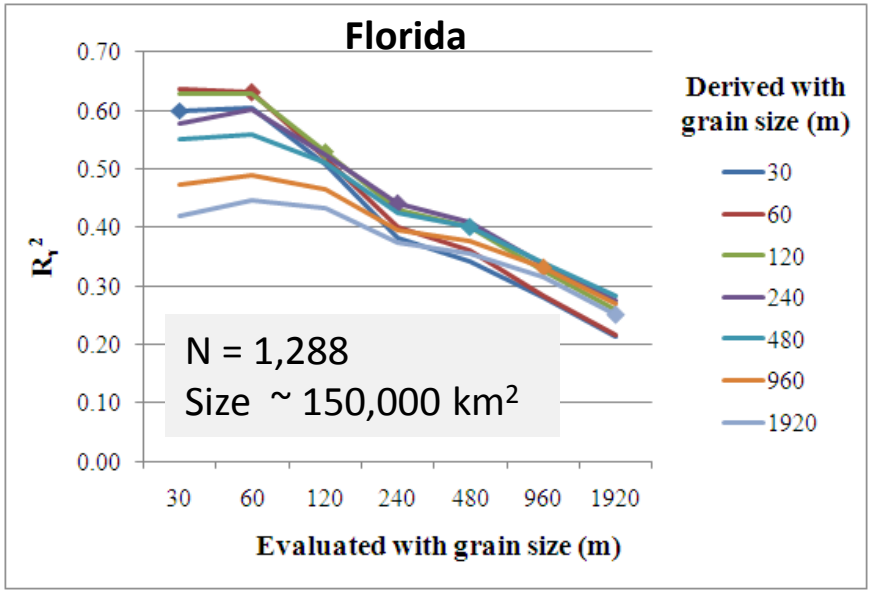
Multi-scale Soil Carbon Mapping

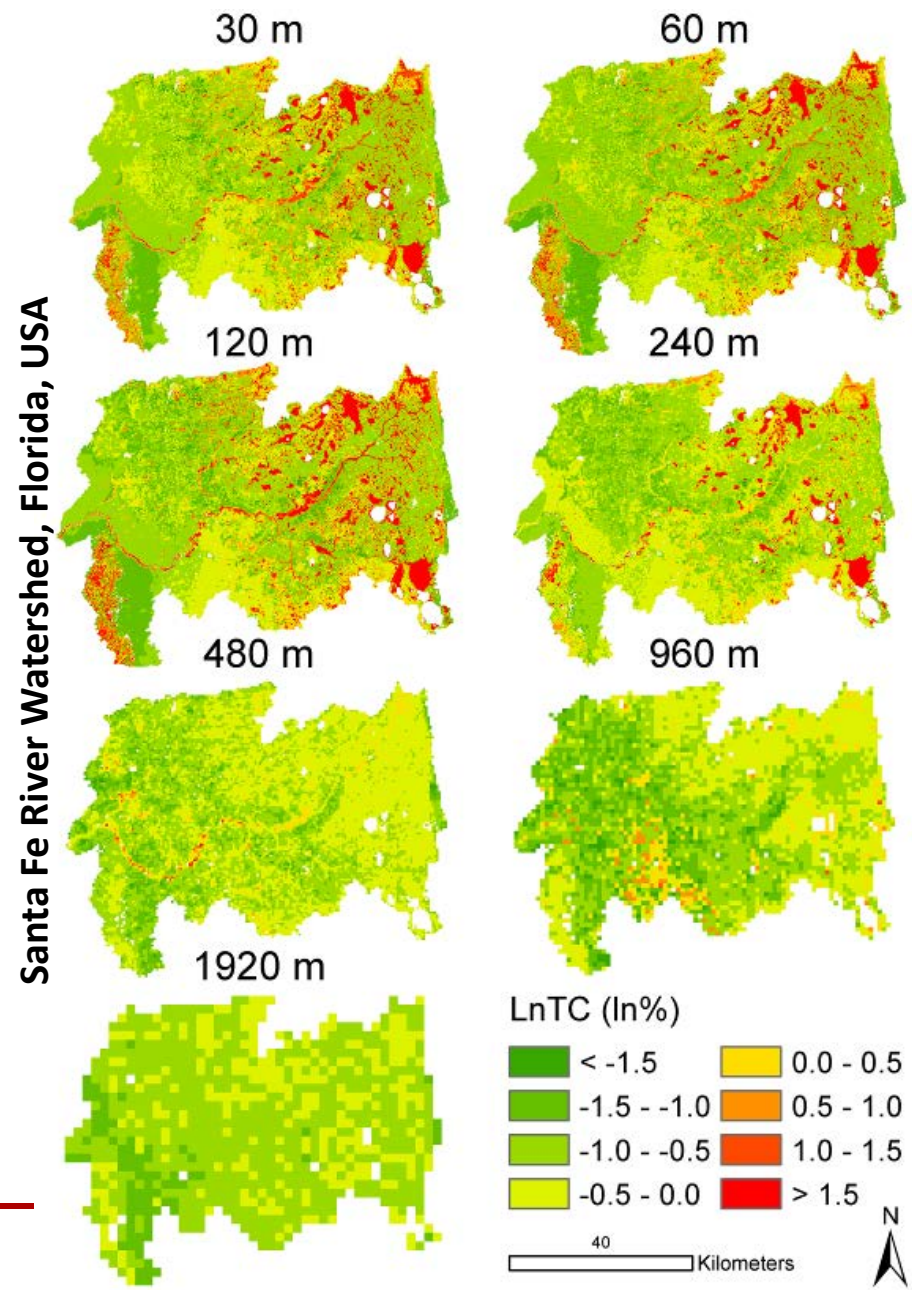


Total Soil Carbon (0-100 cm)
N = 1,486 (pooled dataset: BCS + SFRW + FL)

Vasques G.M., S. Grunwald and D.B. Myers. 2012.
Geophysical Res. J. Biogeosciences.

Grain Effects on Soil Carbon Modeling (Validation Results)



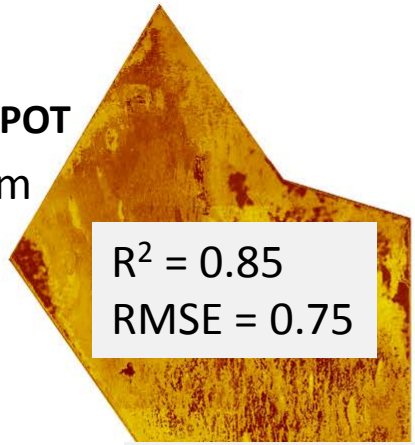


Vasques G.M., S. Grunwald and D.B. Myers. 2012. Geophysical Res. J. Biogeosciences.

Soil Total Carbon Stocks (kg m^{-2}) in a High Carbon Ecosystem (WCA-2A, Everglades, FL, USA)

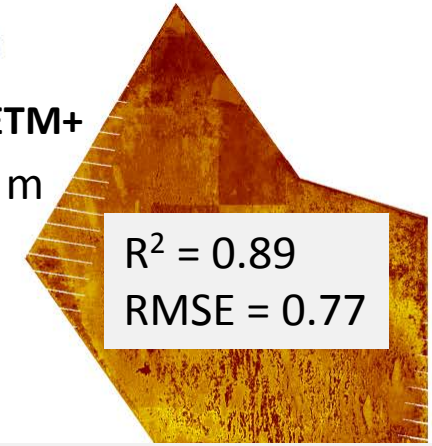
Soil depth
0 – 10 cm

a)
RF_{SPOT}
10 m



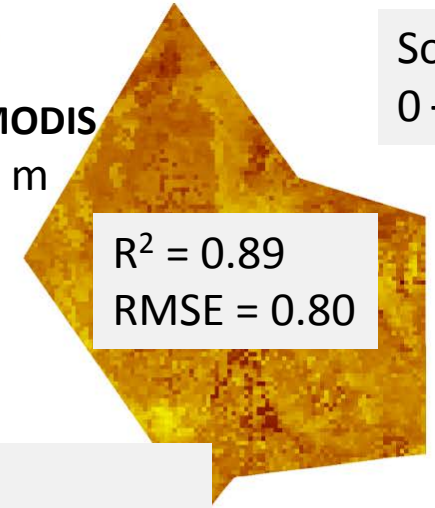
R^2 = 0.85
RMSE = 0.75

b)
RF_{ETM+}
30 m



R^2 = 0.89
RMSE = 0.77

c)
RF_{MODIS}
250 m



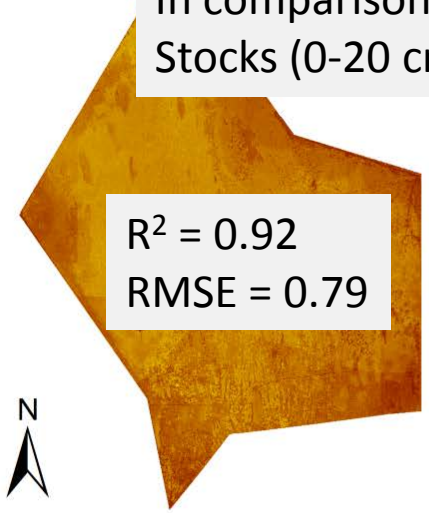
R^2 = 0.89
RMSE = 0.80

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)

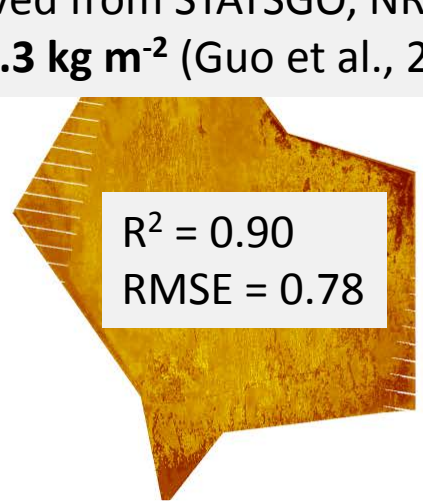
In comparison [derived from STATSGO, NRCS]:
Stocks (0-20 cm) = **7.3 kg m^{-2}** (Guo et al., 2006)

Soil depth
10 – 20 cm

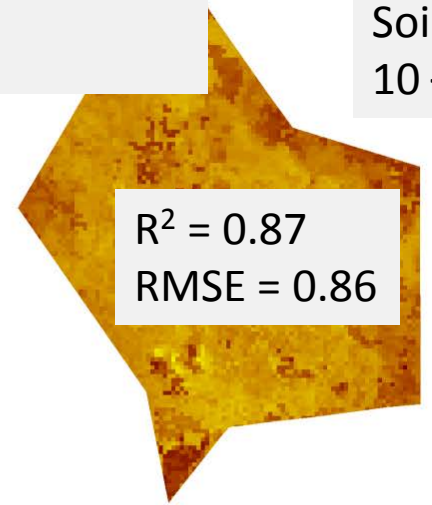
a)



R^2 = 0.92
RMSE = 0.79



R^2 = 0.90
RMSE = 0.78



R^2 = 0.87
RMSE = 0.86

N

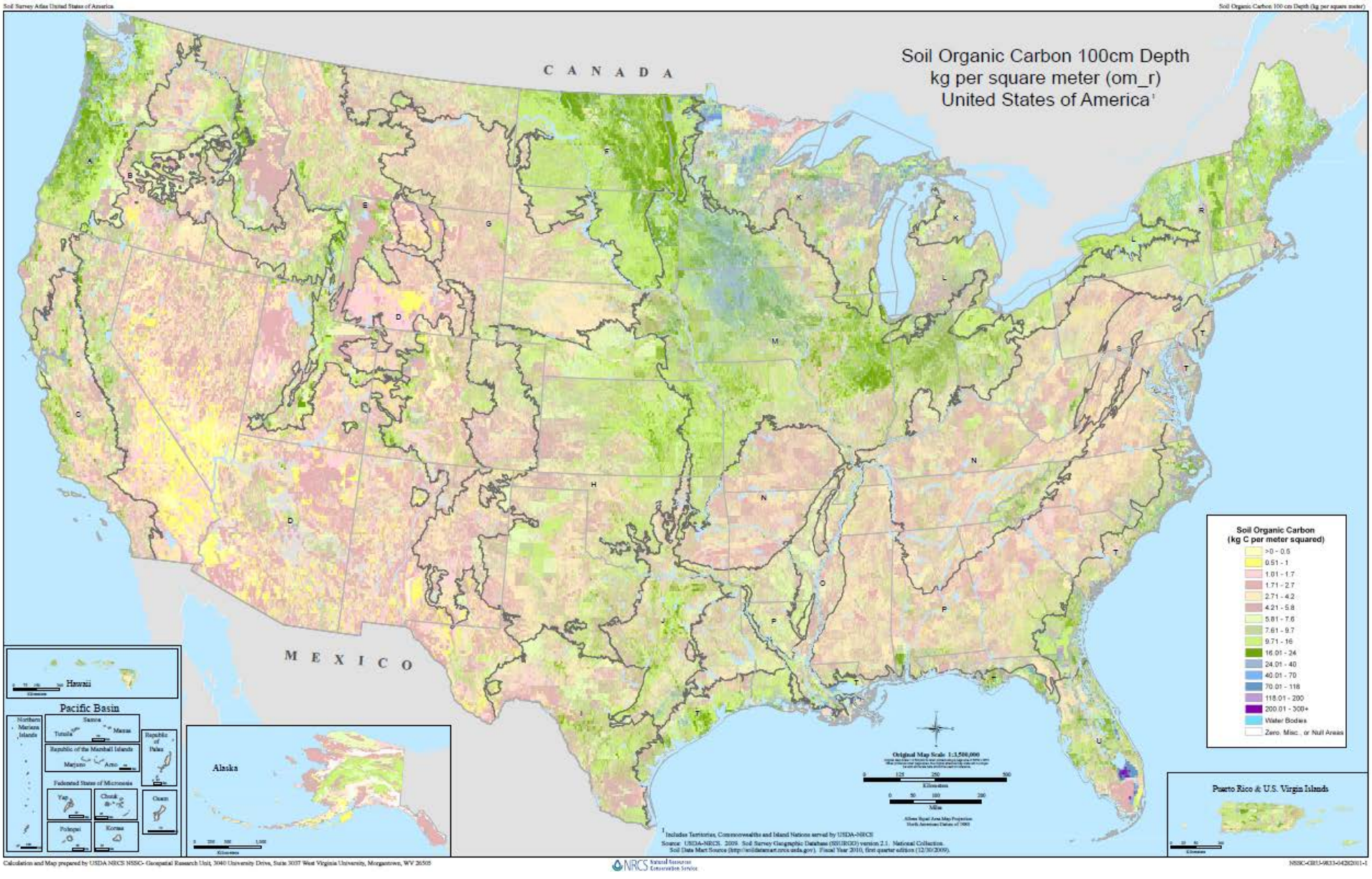
0 5 10 20 Kilometers

N = 108

Total carbon stocks (kg/m2)
High : 8.5 Low : 3.0

Kim J., S. Grunwald et al. (2012)

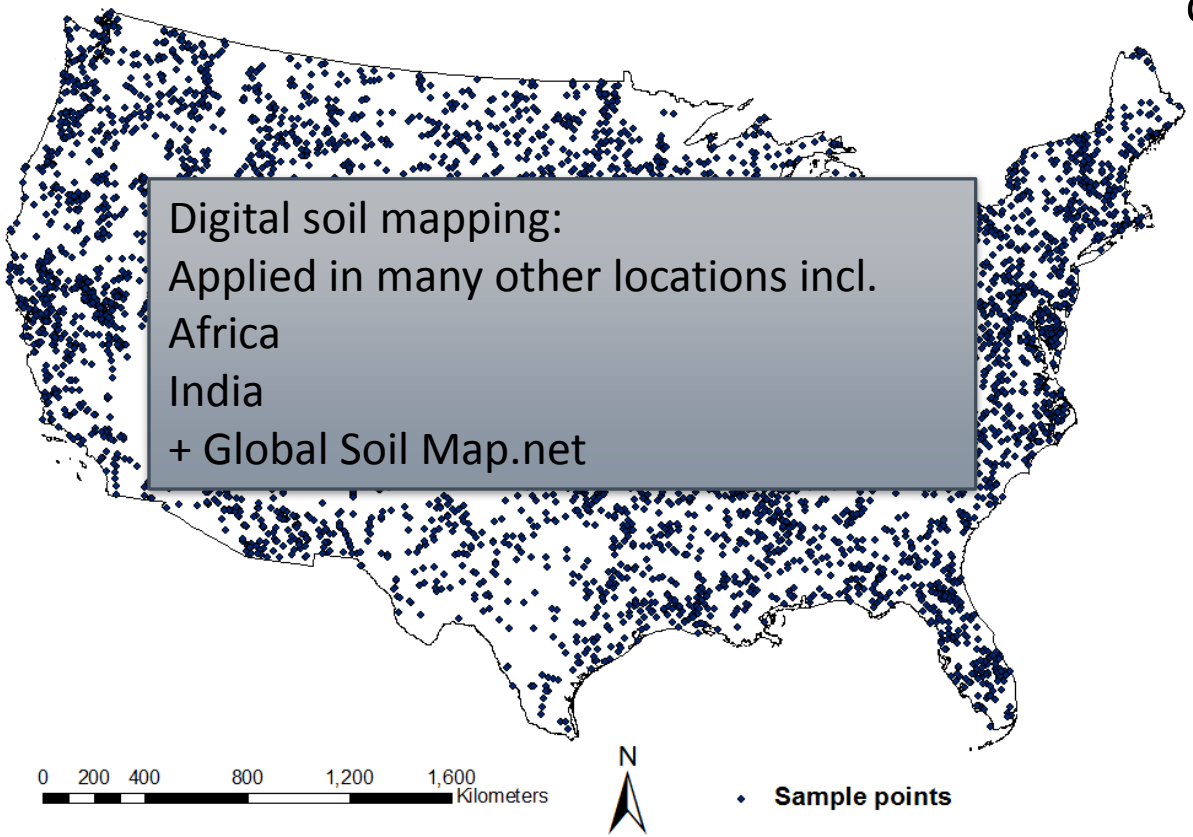
Historic Soil Organic Carbon across the U.S. (SSURGO, NRCS)



New National Soil Carbon Assessment (U.S.)

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

Research methods:
VNIR spectroscopy + combustion
digital soil mapping



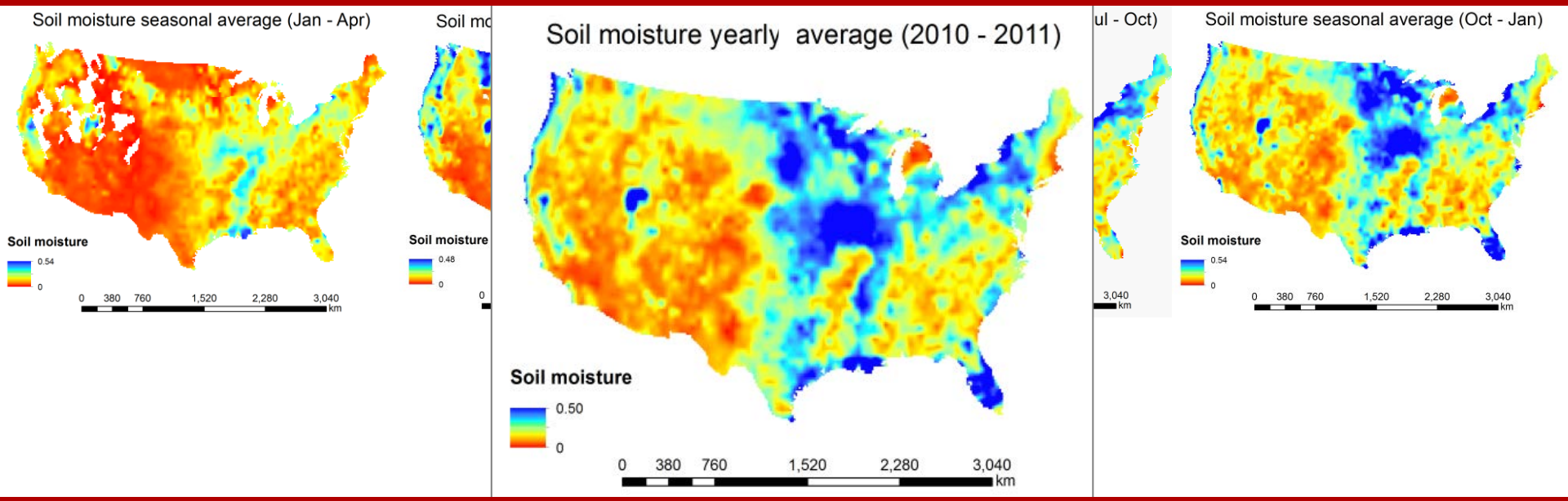
Digital soil mapping:
Applied in many other locations incl.
Africa
India
+ Global Soil Map.net

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

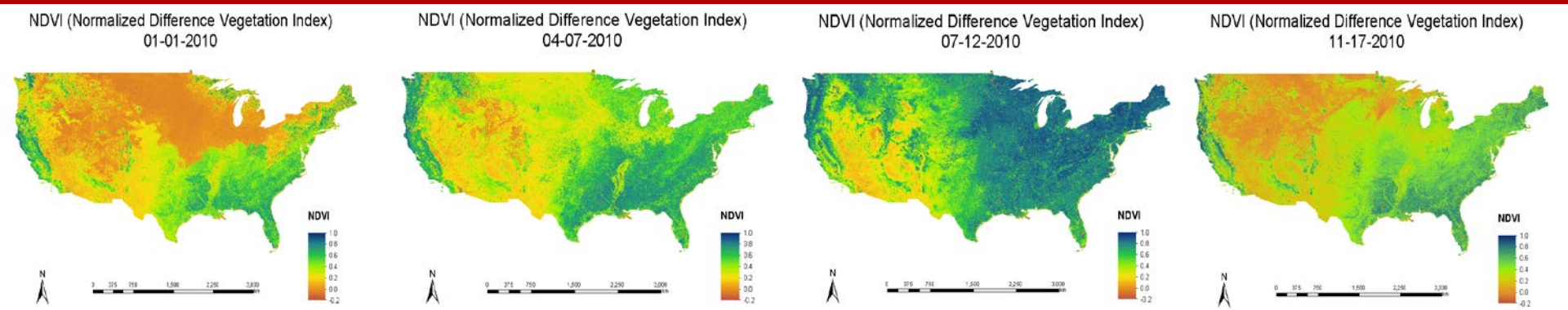
RaCA Digital Soil Mapping and Modeling :
Grunwald S., A.B. McBratney, and B. Minasny

Rapid Carbon Assessment Project (RaCA)

SMOS (Soil Moisture & Ocean Salinity) Satellite Measurements – European Space Agency (ESA)



Moderate Resolution Imaging Spectroradiometer (MODIS) – NASA



+ 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

United States Department of Agriculture

National Institute of Food and Agriculture

Funding source: National Research Initiative Competitive Grant no. 2007-35107-18368 USDA NIFA - AFRI

Natural Resources Conservation Service

National
Science
Foundation

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