Informing climate change studies using soil survey information

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Scope of presentation
- Motivation
- Earth system models and land benchmarks
- Representation of soil properties (soil organic carbon stocks, active-layer thickness, and spatial heterogeneity) in land models
- Concluding messages

Motivation
- Anticipated changes in climate will alter future state of ecosystems (Sillmann et al., 2013; Seneviratne et al., 2012).
- Permafrost systems are most susceptible to climate warming, store almost double amount of carbon in soils in comparison to the atmosphere (Hugelius et al., 2014).
- Current earth system models (ESMs) do not agree on the magnitude and timing of greenhouse gas emission from permafrost systems and their impact on future climate change (Shuur et al., 2015; Schaefer et al., 2011).
- Soil survey generates wealth of soil information, which could potentially help in improving our scientific understanding by reducing model uncertainties.

What are Earth System Models?
21 ESMs participated in 5th assessment of IPCC [100-250 km resolution], DOE is creating its own ESM called ACME [10 km spatial resolution].

In ESMs different components of earth system can be coupled and used to study the feedbacks; these models are also called state-of-the-science models.

Potential benchmarks for Community Land Models

Representation of soil organic carbon in CMIP5 ESMs
Soil organic carbon stocks are initialized assuming heterotrophic respiration equals Net primary productivity

Soil profile of organic soil (Historthel) formed under a black spruce forest, northern Alaska.

Role of soil forming factors?
Interesting insights about model representations of soil organic carbon

Perspective

Persistence of soil organic matter as an ecosystem property

Empirical estimates to reduce modeling uncertainties of soil organic carbon in permafrost regions: a review of recent progress and remaining challenges

This assumption is untrue everywhere as current models lack edaphic factors.

This assumption is violated strongly at high latitudes because SOC in permafrost persists from prior climates, for example, with the formation of Pleistocene loess or Holocene peat deposits.

The Way Forward

If we can achieve agreement between empirical estimates of SOC stocks and baseline ESM SOC stocks we can reduce the existing uncertainty in predicting permafrost carbon-climate feedbacks by 50%.

Active-layer thickness an important biophysical property

A 348 ton Disparity to 1 m depth (472 Pg)

Comparing geospatial and ESM estimates of SOC stocks

Representation of active-layer thickness in CMIP5 ESMs

Spatial variability of SOC stocks vary widely among ESM models
Spatial variability in ESM models do not match with observations due to lack of pedogenic processes of Arctic system

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(SPDR and UNDR)

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Active-layer thickness an important biophysical property

Accuracy of spatial representation of the active-layer thickness in Earth System Models is critical to predict permafrost carbon-climate feedbacks.

In global ESMs active-layer thickness is represented by mean annual temperature and its amplitude of seasonal cycle.

$Z_{thaw} = aT_{mean} + bT_{seasonal} + c$

(Schaefer et al. 2011)
Spatial variability of Active-layer thickness across Alaska

\[ AL(x, y) = f \text{ (air temperature, land cover type, slope angle)} \]

Spatial heterogeneity of land surface: a critical uncertainty in ESMs

- Land surface interacts with atmosphere at different spatial scales; spatial heterogeneity affects the land-atmosphere exchanges of energy, moisture, and greenhouse gases (Clark et al., 2011; Li and Avisar, 1993).
- Information collected at one spatial scale is often used to infer properties or processes at either smaller or larger scales (Li and Rodell, 2013).
- We investigated impact of scaling on environmental controls, spatial structure, and statistical properties of Alaskan SOC stocks.

Comparing observation-based estimates with eight best ESM predictions

Geospatially predicted active-layer thickness = 0.14 – 0.93 m
Spatial average = 0.46 m
ESM range = 0.13 - 40 m

Environmental controllers of SOC as a function of scale

Environmental controllers of SOC stocks weakens with scale

The variance of SOC stocks decreases exponentially with scale up to 500 m and then remains constant thereafter.

Spatial heterogeneity of Alaskan soil organic carbon

- Observed spatial structure of Arctic/boreal SOC stocks are only consistent up to 100 m spatial scale.
- Understanding scaling behavior of environmental controls and statistical properties of SOC stocks will allow the spatial heterogeneity of biogeochemistry to be represented at scales finer than currently resolved by ESMs.

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Concluding messages

- Substantial disparity exists between observation-based and earth system model representations of soil properties of permafrost systems.

- Soil information generated through soil survey can be used for:
  - Land model initialization
  - Constraining process rates through model parameterization
  - Model benchmarking

- Soil information is currently under utilized in climate change studies, and soil scientists have a prominent role to play in this emerging domain.

Acknowledgement

Thank you for attention!