Simulating Regional Climate: What is the role of soil texture?

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Local Land–Atmosphere Coupling

- **Soil moisture** is a key factor for determining the nature of land surface–atmosphere interactions and coupling
- **L-A coupling** tends to occur in preferred regions
- Yet, models show **dispersion** in the coupling strength

(Koster et al 2004)
What is **soil texture**?

Soil texture refers to the proportions of **sand**, **silt**, and **clay**

How could it be relevant?

The size of each soil grain determines the hydro-physical properties of the soil (capillarity, porosity, adhesion, etc.)

How can we relate this to regional climate?

These **hydro-physical properties can dictate the availability of soil moisture**; and therefore determine the nature of the LA coupling
We know that land surface characteristics control the fluxes of moisture to the atmosphere, but the impact of soil texture on land-atmosphere (LA) coupling has not been quantified.

**HYPOTHESIS:**

- Because soil hydro-physical properties can influence surface states, changing the soil texture will influence the local land-atmosphere (LA) coupling.
Soil Texture on Maps

- GSDE from BNU
- ISRIC
- STATSGO soil texture on NLDAS grid
WRF Model Simulations:
15-km horizontal grid spacing
51 vertical levels (13 in the lowest 1 km)
Simulation length: 92 days (June 1 through August 31)

Relevant parameterizations:
Land Surface Scheme: CLM version 4
PBL Scheme: MYNN2
Surface Layer Scheme: MYNN (compatible with PBL Scheme)
Other schemes are available if you are curious.

Soil Texture Datasets:
1. USDA STATSGO (WRF default)
2. GSDE from Beijing Normal University
Soil Categories
(Texture)

Hydraulic Parameters:
Wilting point,
Field Capacity,
...

Surface Fluxes,
Runoff,
...

Look-up Table of

Soil Properties in a look-up table

<table>
<thead>
<tr>
<th>soil texture category</th>
<th>wilting point</th>
<th>field capacity</th>
<th>porosity</th>
<th>saturated hydraulic conductivity (x1000)</th>
<th>b</th>
<th>matric potential at saturation</th>
</tr>
</thead>
<tbody>
<tr>
<td>sand</td>
<td>0.01</td>
<td>0.192</td>
<td>0.320</td>
<td>0.0460</td>
<td>2.70</td>
<td>0.060</td>
</tr>
<tr>
<td>loamy sand</td>
<td>0.029</td>
<td>0.283</td>
<td>0.421</td>
<td>0.0411</td>
<td>4.36</td>
<td>0.066</td>
</tr>
<tr>
<td>sandy loam</td>
<td>0.067</td>
<td>0.312</td>
<td>0.431</td>
<td>0.0203</td>
<td>1.74</td>
<td>0.181</td>
</tr>
<tr>
<td>silty loam</td>
<td>0.084</td>
<td>0.36</td>
<td>0.475</td>
<td>0.0221</td>
<td>5.33</td>
<td>0.259</td>
</tr>
<tr>
<td>silt</td>
<td>0.091</td>
<td>0.347</td>
<td>0.464</td>
<td>0.0218</td>
<td>5.60</td>
<td>0.155</td>
</tr>
<tr>
<td>loam</td>
<td>0.066</td>
<td>0.320</td>
<td>0.439</td>
<td>0.0218</td>
<td>7.25</td>
<td>0.255</td>
</tr>
<tr>
<td>sandy clay-loam</td>
<td>0.066</td>
<td>0.315</td>
<td>0.404</td>
<td>0.00445</td>
<td>7.77</td>
<td>0.135</td>
</tr>
<tr>
<td>silty clay-loam</td>
<td>0.32</td>
<td>0.382</td>
<td>0.404</td>
<td>0.00403</td>
<td>8.70</td>
<td>0.617</td>
</tr>
<tr>
<td>clay</td>
<td>0.183</td>
<td>0.382</td>
<td>0.405</td>
<td>0.00424</td>
<td>8.17</td>
<td>0.363</td>
</tr>
<tr>
<td>sandy clay</td>
<td>0.1</td>
<td>0.288</td>
<td>0.496</td>
<td>0.00727</td>
<td>10.23</td>
<td>0.096</td>
</tr>
<tr>
<td>silty clay</td>
<td>0.128</td>
<td>0.404</td>
<td>0.496</td>
<td>0.00744</td>
<td>10.30</td>
<td>0.328</td>
</tr>
<tr>
<td>clay</td>
<td>0.130</td>
<td>0.412</td>
<td>0.498</td>
<td>0.00974</td>
<td>11.55</td>
<td>0.468</td>
</tr>
</tbody>
</table>

Land Surface Models have substantial simplifications
• Ordered from largest grain size to smallest grain size (left to right)
• **Matric potential** describes how much energy is required to remove moisture from the soil system

\[ \Psi = \Psi_{sat} \left( \frac{\theta}{\theta_s} \right)^{-b} \]

\[ \Psi(0.192)_{sand} = -0.33 \text{ J/kg} \]

\[ \Psi(0.192)_{clay} = -13786 \text{ J/kg} \]
Results

[Image of a map and a table showing grain size changes and soil texture classes]

- **Grain Size Changes**
  - **Coarser to Finer**
    - loam to clay loam
    - silt loam to clay loam
    - sandy loam to clay loam
    - sandy loam to loam

- **Finer to Coarser**
  - loam to sandy loam
  - silt loam to loam
  - clay to sandy clay
  - clay to loam

[Statistical data and classifications for soil texture classes]
Continental Results

The values represent seasonal differences (GSDE–default)

- Finer soil particles retain soil moisture more vigorously
- Energy that does not contribute to removing moisture gets partitioned into sensible heat flux
- Temperature and mixing ratio at 2-m, generally follows the pattern of the surface fluxes (though not perfectly due to advective processes)
- Integrative processes (i.e., precip and boundary layer evolution) also follow intuitive patterns, though the correspondence is more complicated.
Results: SGP

Top left figure shows soil texture transitions between datasets from default to GSDE

All other figures show differences (GSDE—default)

Matric Potential given by:

$$\Psi = \Psi_{sat} \left( \frac{\theta}{\theta_s} \right)^{-b}$$

Neither soil moisture, nor soil parameters solely control surface fluxes, but rather the combination of both is important
Results: SGP

Solid lines indicate full areal-averaged diurnal cycle

Dashed lines only include specific soil categories

- Specific categories accentuate the areal averages
- Maximum latent heat flux differences between specific categories is about 75 W m\(^{-2}\)
The majority of the region underwent an increase in soil grain size (loam to sandy loam, gray)

Example 1:
Despite minimal differences in soil moisture, the fluxes **were different** because parameters allowed the soil moisture to be emphasized

Example 2:
Despite substantial differences in soil moisture, the fluxes **were NOT different** because parameters overshadowed those impacts
Conclusions (1 of 2)

1. Important **differences in soil texture** and the degree of heterogeneity were found over the Great Plains and Central Mexico.

2. Parameters associated with soil texture control the availability of soil moisture; **soils with finer grains retain water more strongly than coarser grain soils**.
3. Surface fluxes and near surface variables respond to the changes in soil properties, and drive the evolution of the boundary layer facilitating feedbacks that influence regional climate. Therefore, because soil properties control surface fluxes, the use of different soil texture databases was able to influence the local land surface–atmosphere (LA) coupling.
Thank you.
Next step: Non-Local, dynamic coupling

The Great Plains Low-level Jet is a prominent feature in the US Great Plains linking large-scale circulation to regional climate.

Physically, it is a nocturnal low-level, southerly wind maxima.

Hypothesis:
Because soil properties influence the diurnal PBL evolution, they will also modulate low-levels jets.