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

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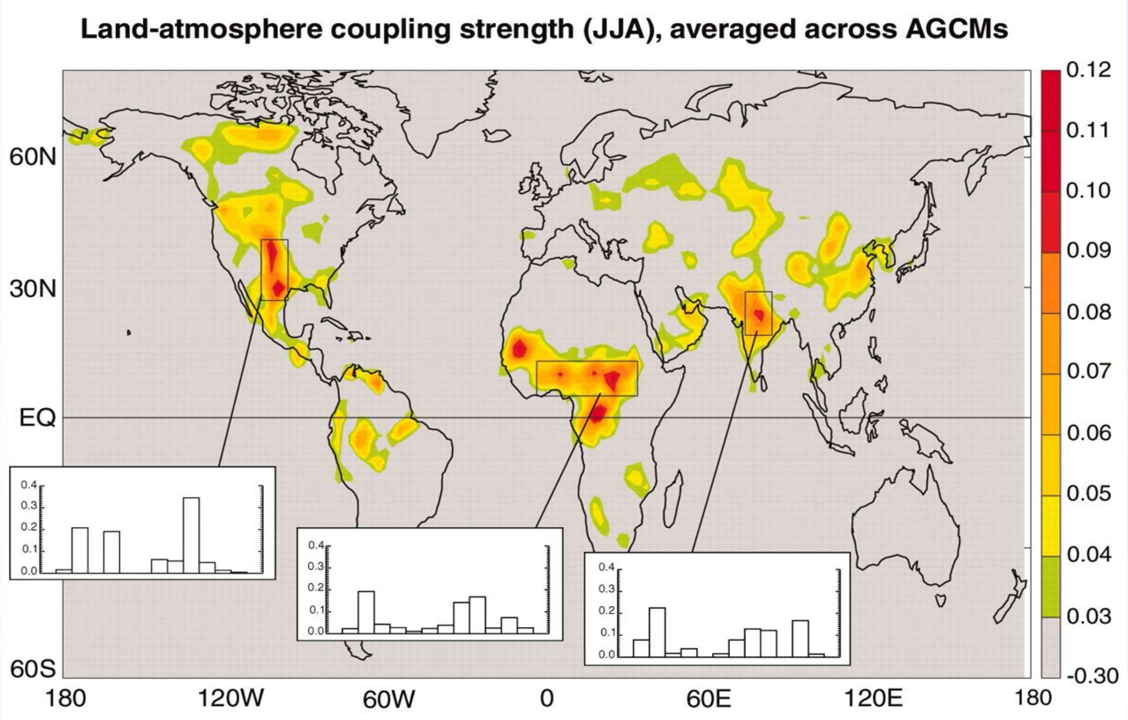
CISESS Science Meeting 2019

November 13, 2019

College Park, MD

Local Land–Atmosphere Coupling

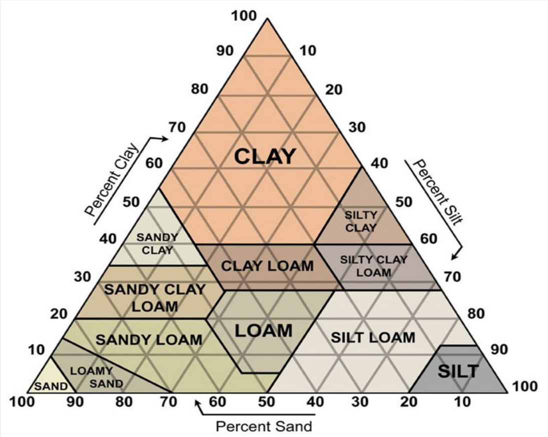
- Soil moisture is a key factor for determining the nature of land surface–atmosphere interactions and coupling
- L-A coupling tends to occur in preferred regions
- Yet, models show dispersion in the coupling strength



(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?

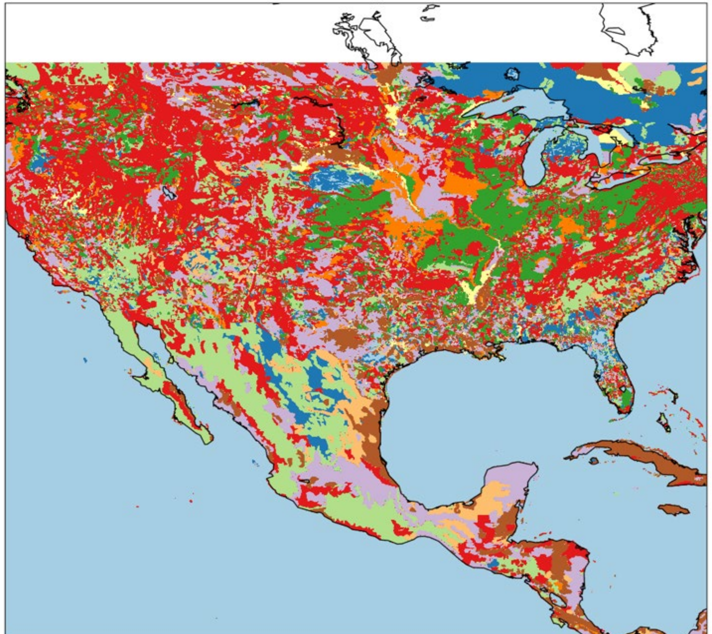
These **hydro-physical properties can dictate the availability of soil moisture**; and therefore determine the nature of the LA coupling

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.

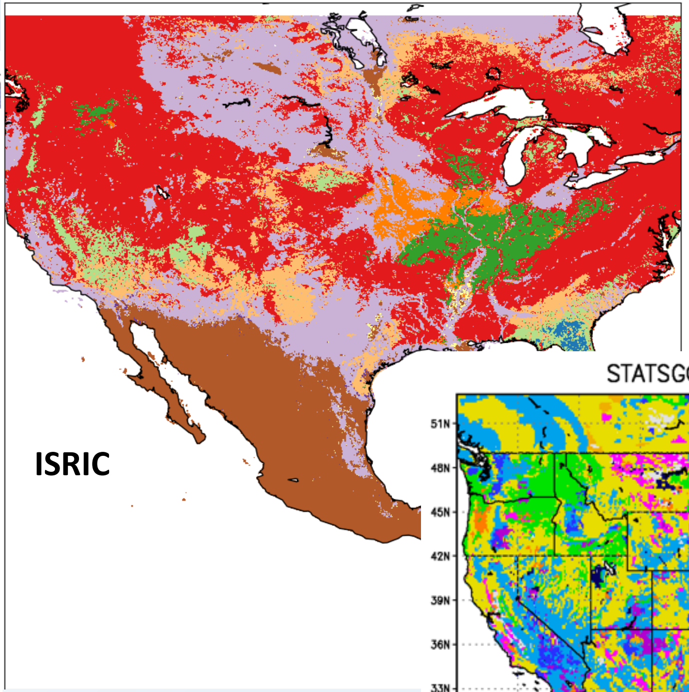
HYPOTHESIS:

- 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



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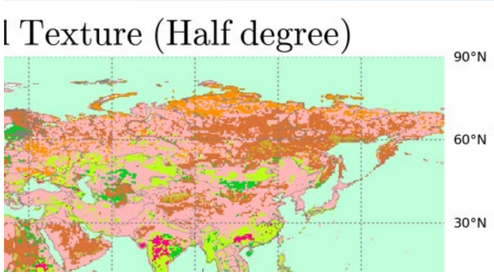
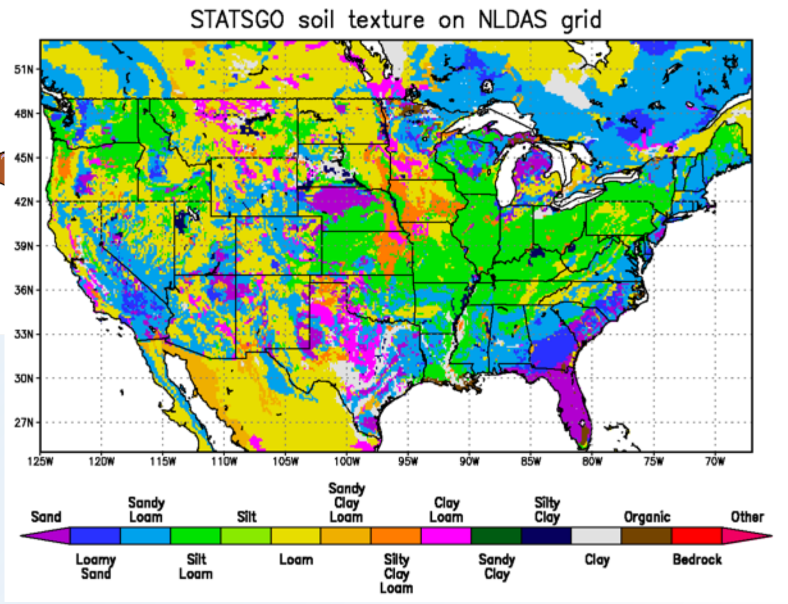




Experiment

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)

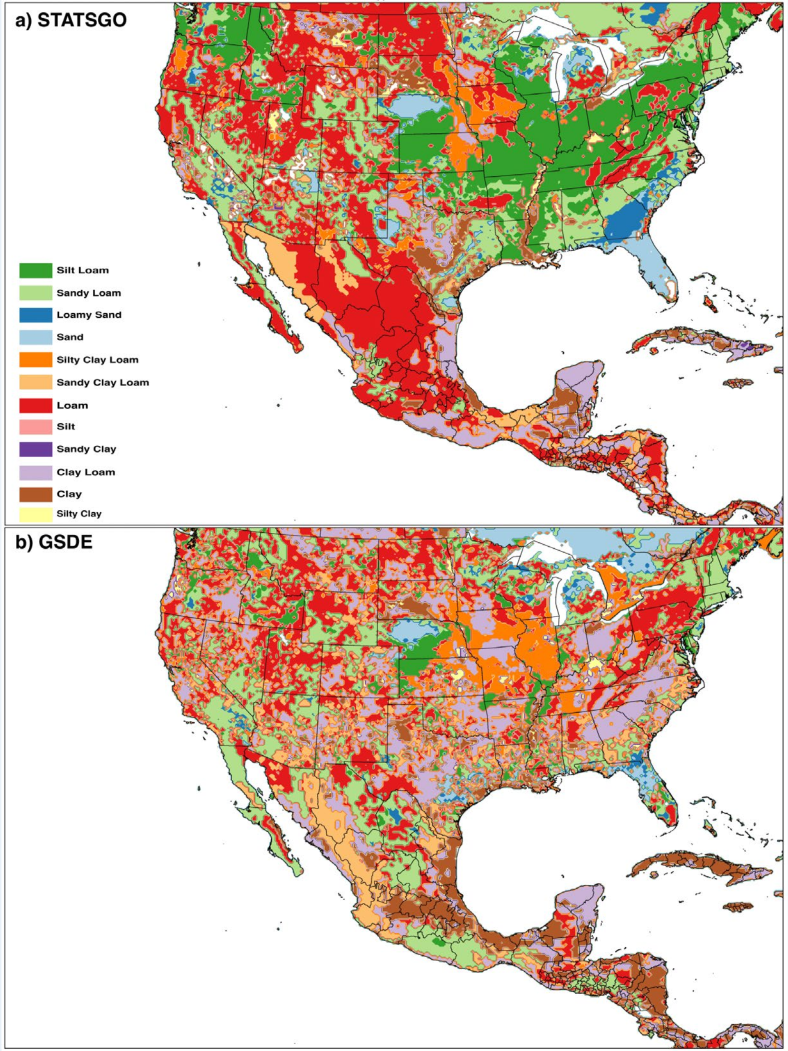
Relevant parameterizations:

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



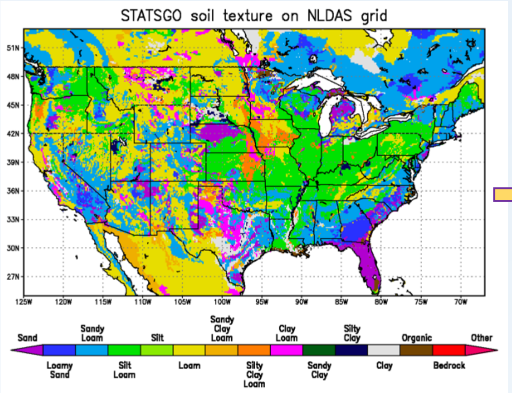
Look-up Table of

Hydraulic Parameters:
Wilting point,
Field Capacity,
…

Parameterizations:

Soil Categories (Texture)

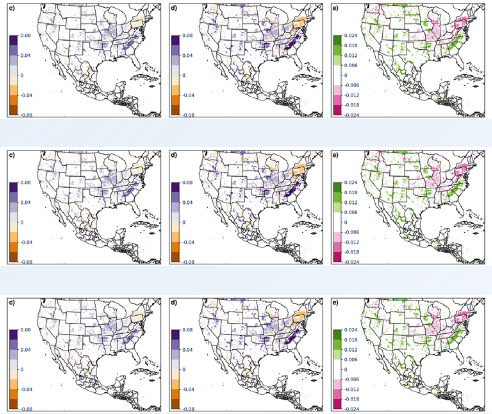
Surface Fluxes,
Runoff,
…



Soil Properties in a look-up table

Soil category

soil texture category	wilting point	field capacity	porosity	saturated hydraulic conductivity (x1000)	b	matric potential at saturation
sand	0.01	0.192	0.339	0.0466	2.79	0.069
loamy sand	0.028	0.283	0.421	0.0141	4.26	0.036
sandy loam	0.047	0.312	0.434	0.00523	4.74	0.141
silt loam	0.084	0.36	0.476	0.00281	5.33	0.759
silt	0.061	0.347	0.484	0.00218	3.86	0.955
loam	0.066	0.329	0.439	0.00338	5.25	0.355
sandy clay loam	0.069	0.315	0.404	0.00445	6.77	0.135
silty clay loam	0.12	0.387	0.464	0.00203	8.72	0.617
clay loam	0.103	0.382	0.465	0.00245	8.17	0.263
sandy clay	0.1	0.338	0.406	0.00722	10.73	0.098
silty clay	0.126	0.404	0.468	0.00134	10.39	0.324
clay	0.138	0.412	0.468	0.000974	11.55	0.468



Land Surface Models have substantial simplifications

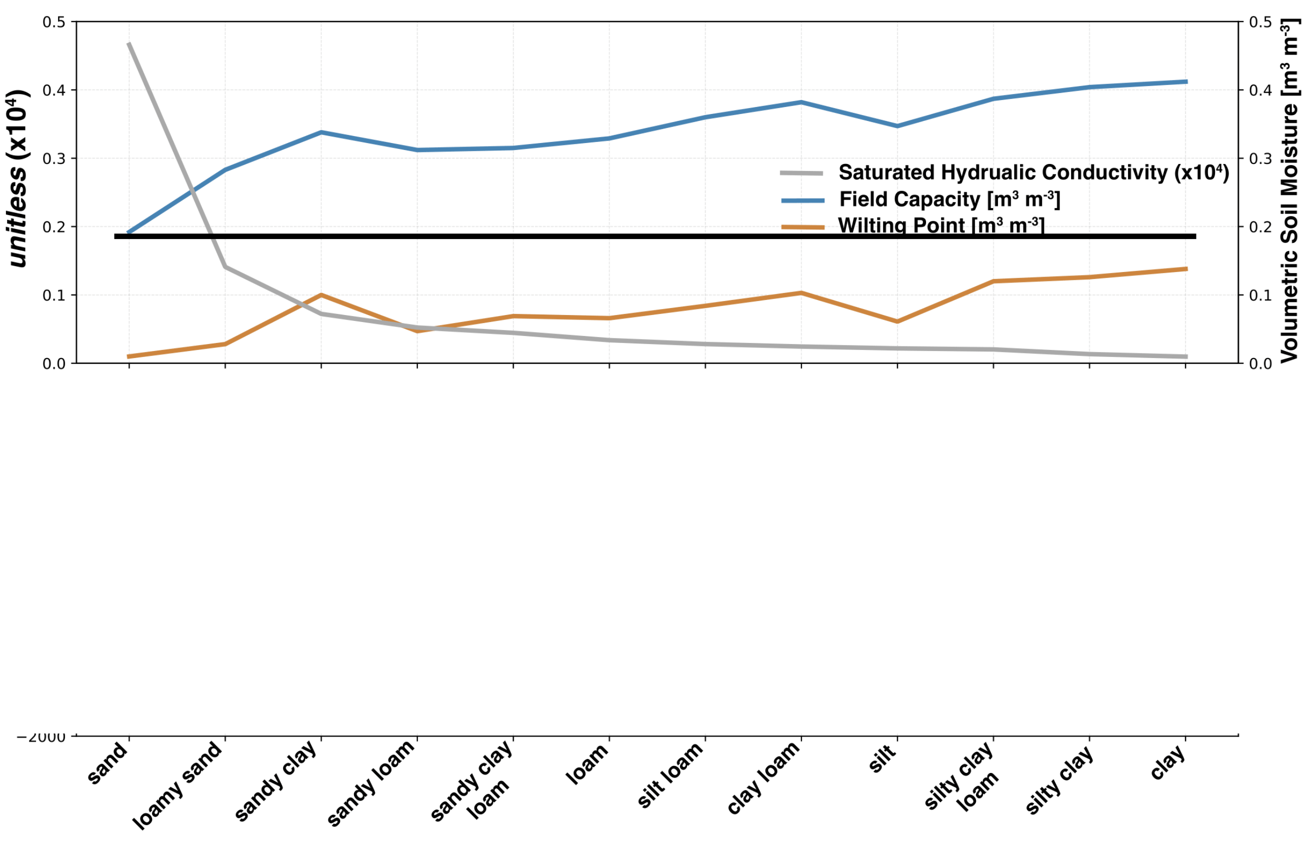
Soil Hydro-physical Properties

- 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 J/kg**

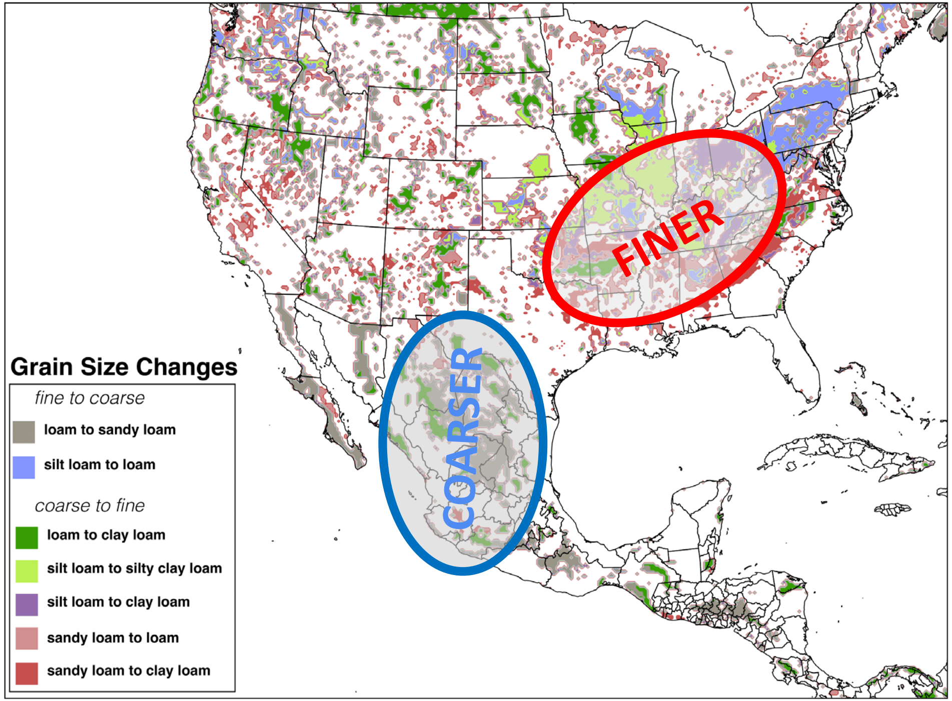
$\Psi(0.192)_{clay}$ = **—13786 J/kg**



Results

STATSGO Soil Texture Classes \ GSDE Soil Texture Classes	sand	loamy sand	sandy loam	silt loam	silt	loam	sandy clay loam	silty clay loam	clay loam	sandy clay	silty clay	clay
sand		298	713	56	0	148	115	21	159	0	4	39
loamy sand	223		469	20	0	123	183	14	119	0	8	39
sandy loam	1282	222		218	0	1496	1060	99	1495	0	34	297
silt loam	50	39	900		0	2256	111	1602	1503	0	61	161
silt	0	0	0	0		0	0	0	0	0	0	0
loam	51	152	3309	232	0		1367	133	3361	0	32	1302
sandy clay loam	3	3	233	11	0	303		31	337	0	7	275
silty clay loam	19	16	146	72	0	209	26		356	0	120	131
clay loam	45	18	601	72	0	493	407	16		0	3	1049
sandy clay	0	0	15	0	0	0	5	0	10		0	6
silty clay	4	12	27	26	0	88	8	37	58	0		121
clay	59	18	187	57	0	272	126	37	528	0	43	

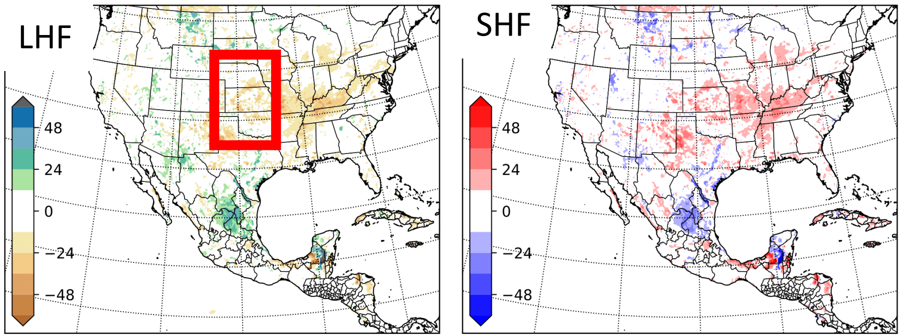
GSDE Soil Texture Classes



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:

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

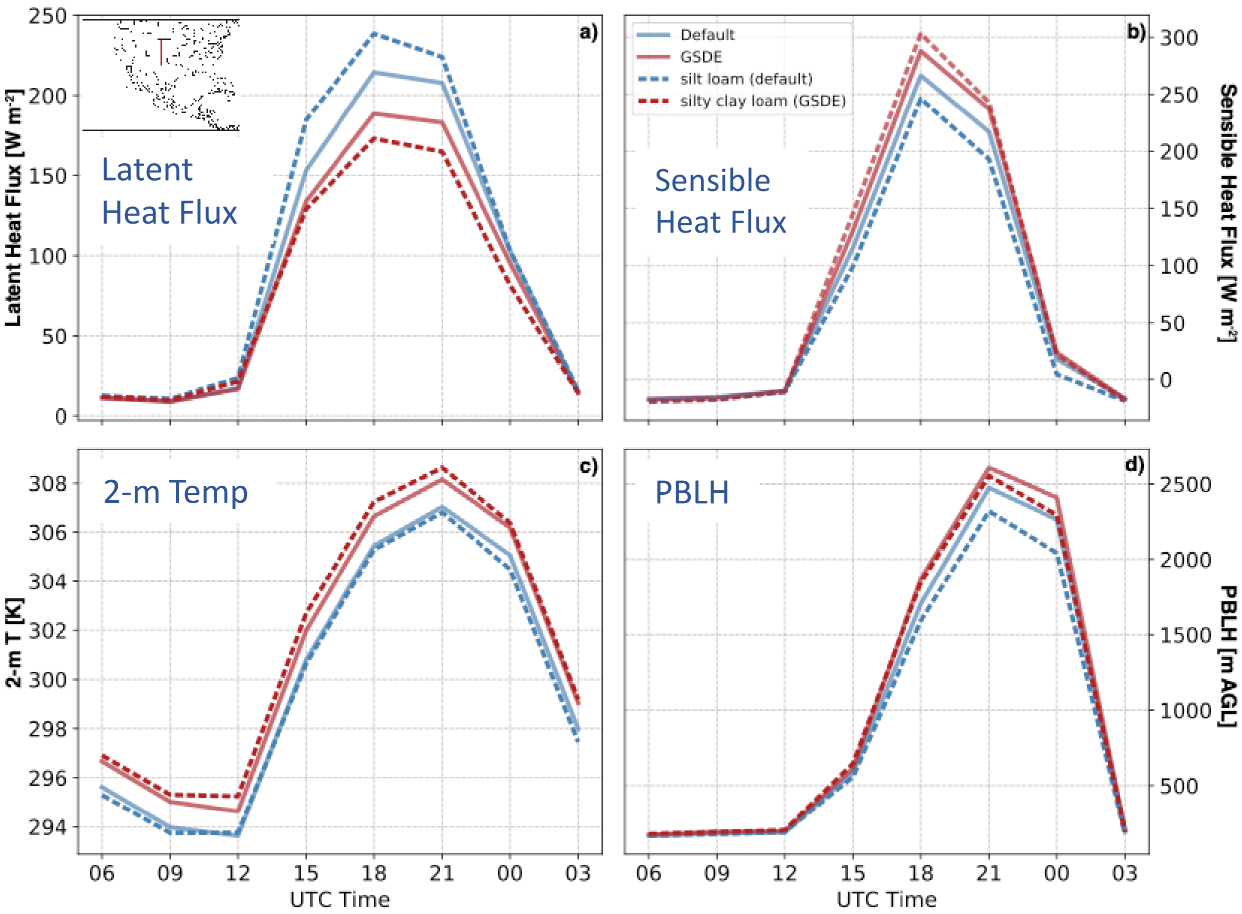
Neither soil moisture, nor soil parameters solely control surface fluxes, but rather the **combination of both** is important

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}

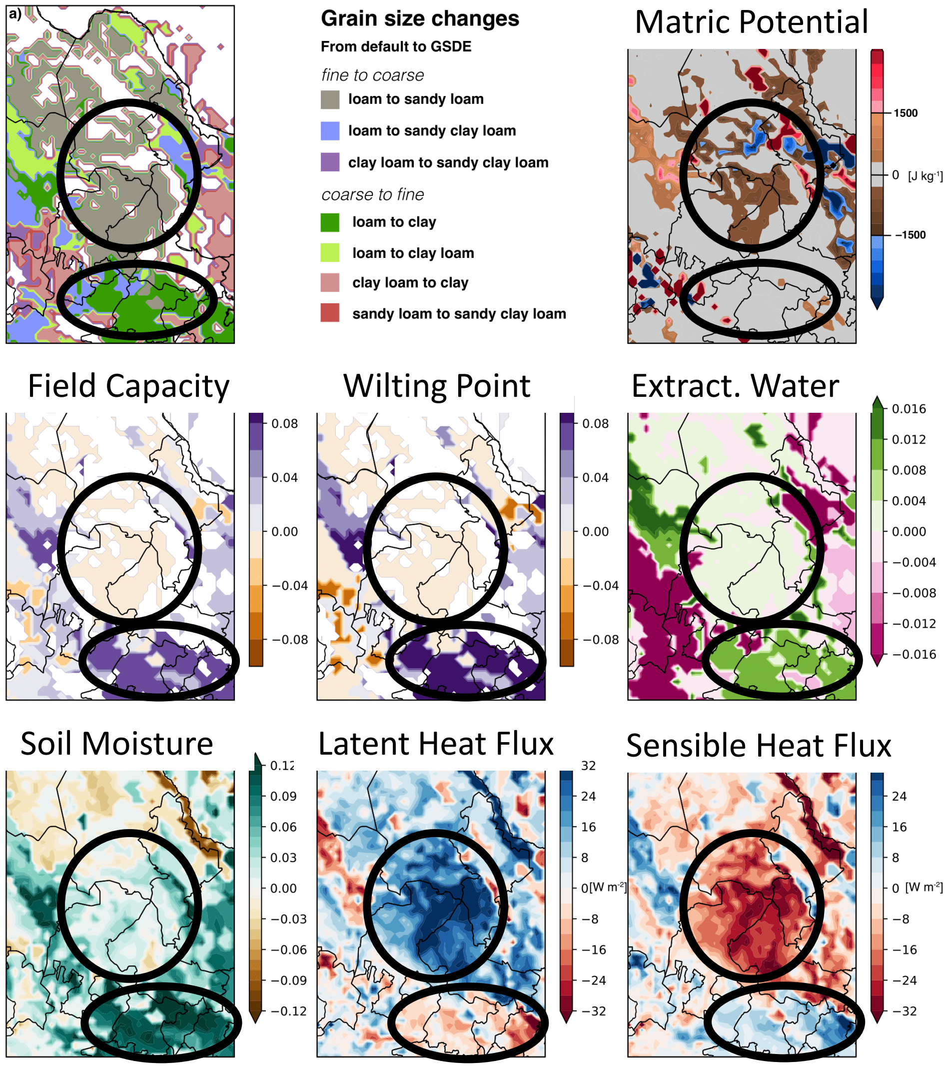


Results: Mex.

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



CISESS 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**

Conclusions (2 of 2)

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

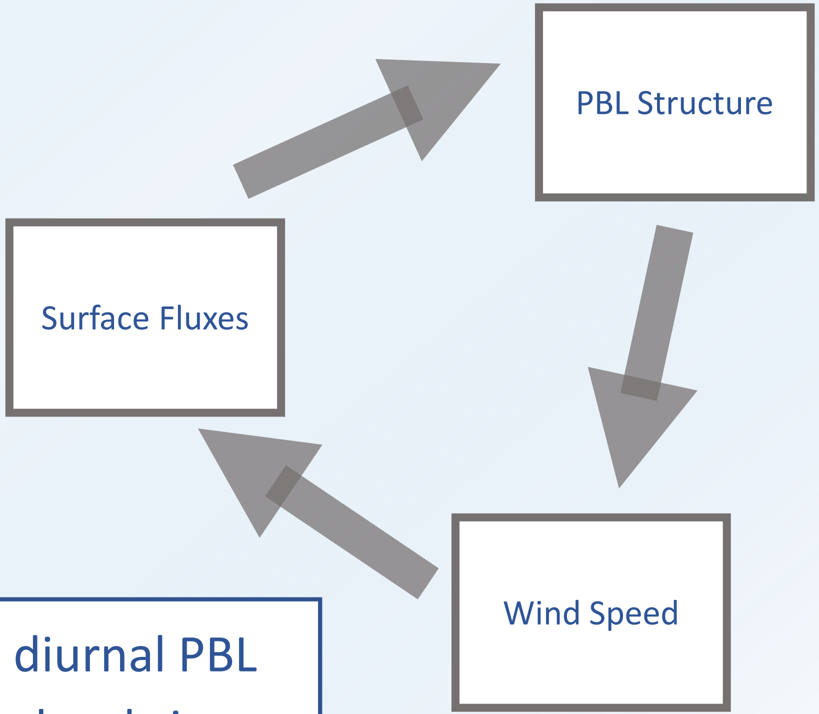
Therefore, because soil properties control surface fluxes, **the use of different soil texture databases was able to influence the local land surface–atmosphere (LA) coupling**

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.