The role of soil properties in land surface–atmosphere interactions

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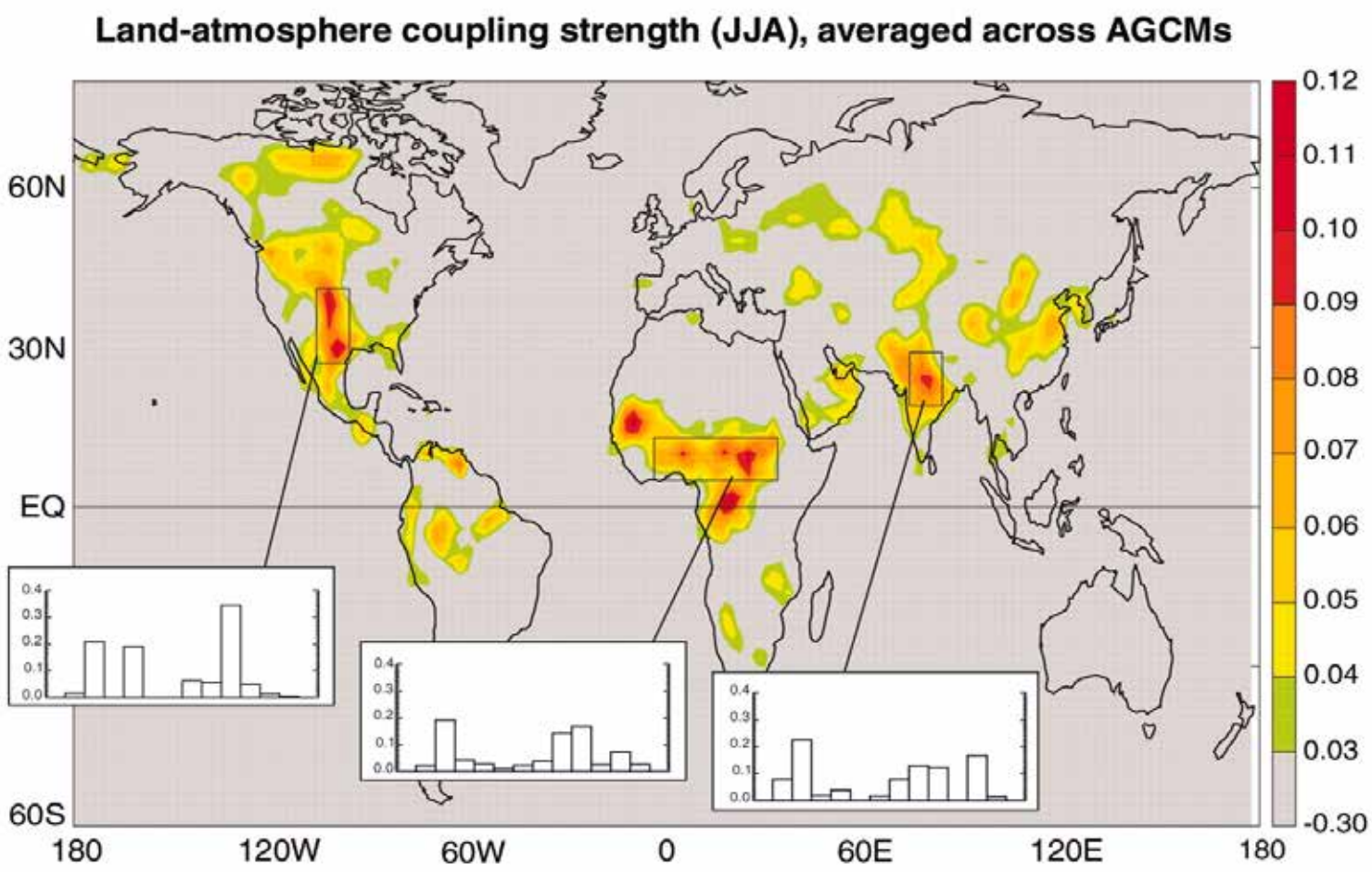
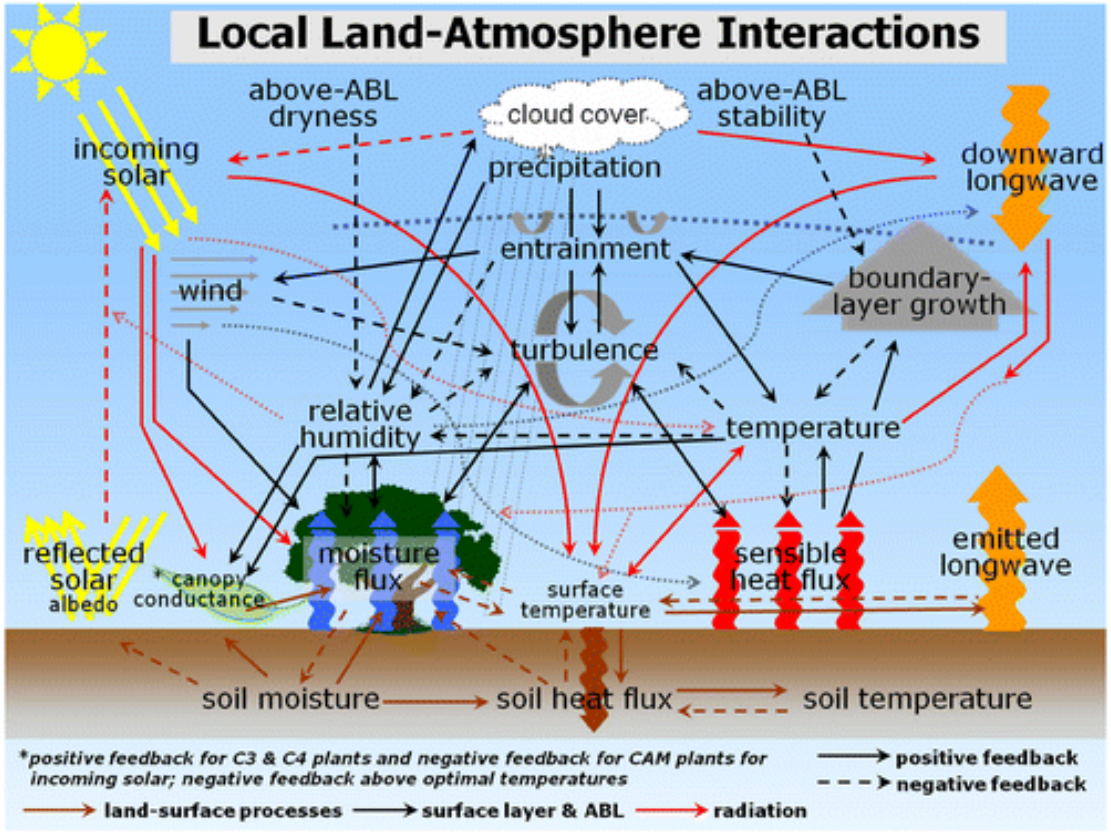
- Soil moisture is a key factor for determining the nature of land surface–atmosphere interactions and coupling
- L-A coupling tends to occur in preferred regions
- However, models show dispersion in the coupling strength

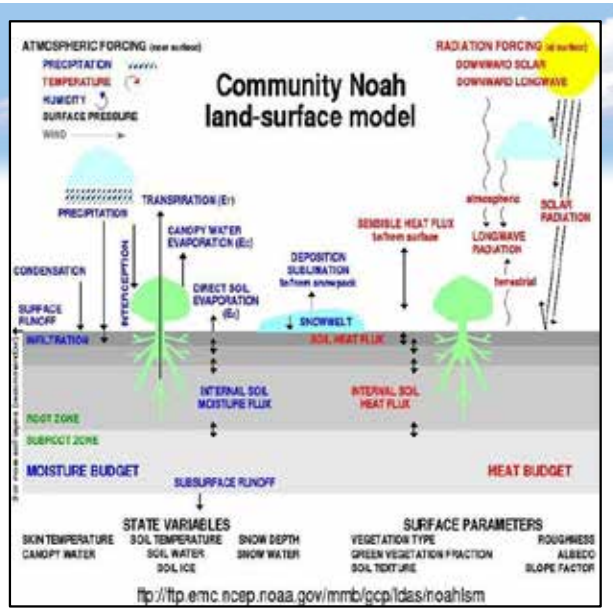


Koster et al. 2004

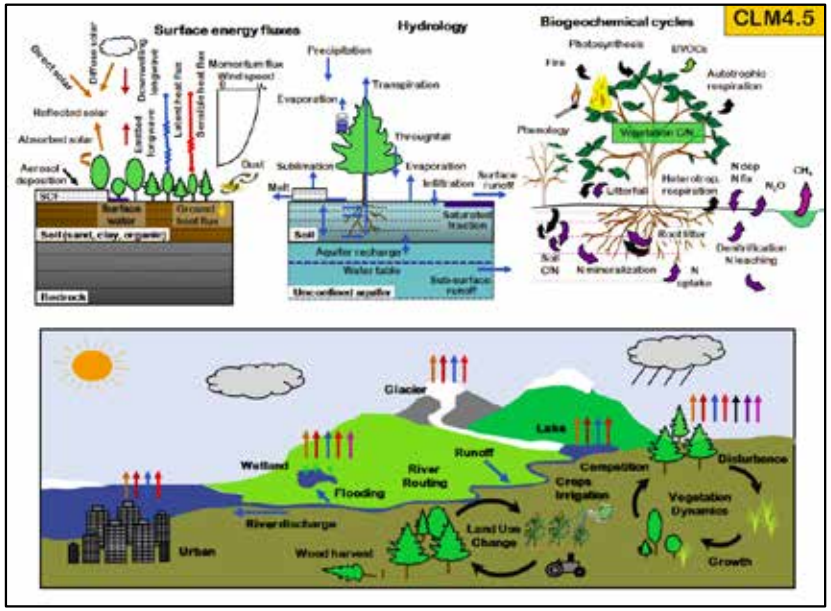
Land Surface Processes



Courtesy of Mike Ek



Noah LSM



CLM

How do the soil properties affect the surface fluxes and the PBL?

Numerical Experiments

WRF Model Simulations:

- 15-km horizontal grid spacing
- 51 vertical levels (13 in the lowest 1 km)
- Period: JJA 2017

Relevant parameterizations:

- **LSM:** CLM version 4; Noah-MP
- **PBL Scheme:** MYNN2
- **Surface Layer Scheme:** MYNN (compatible with PBL Scheme)

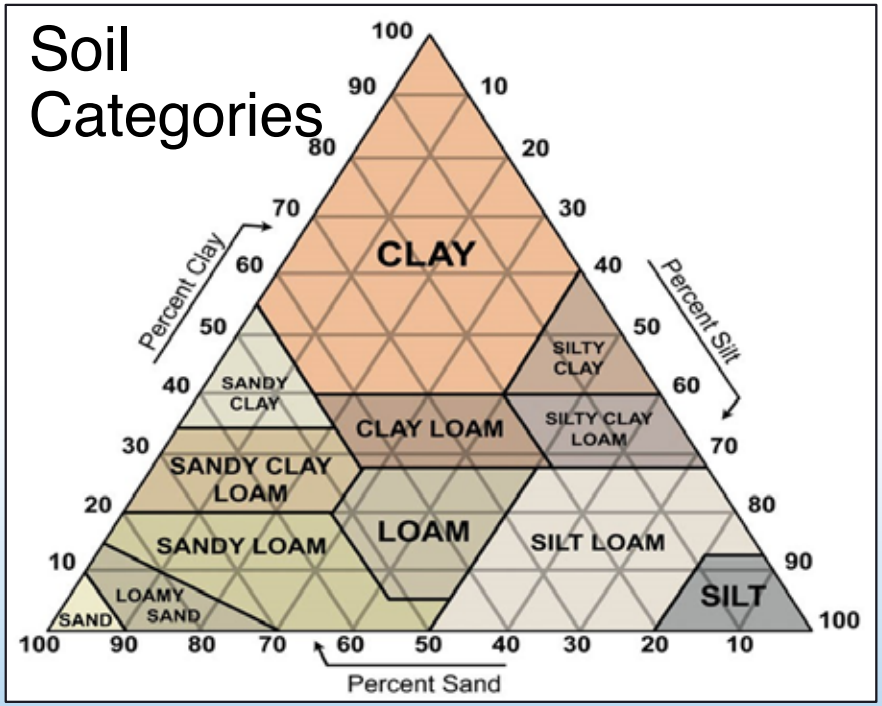
Soil Texture Datasets:

- USDA STATSGO (WRF default)
- GSDE from Beijing Normal University

How are the hydro-physical properties represented in LSMs?

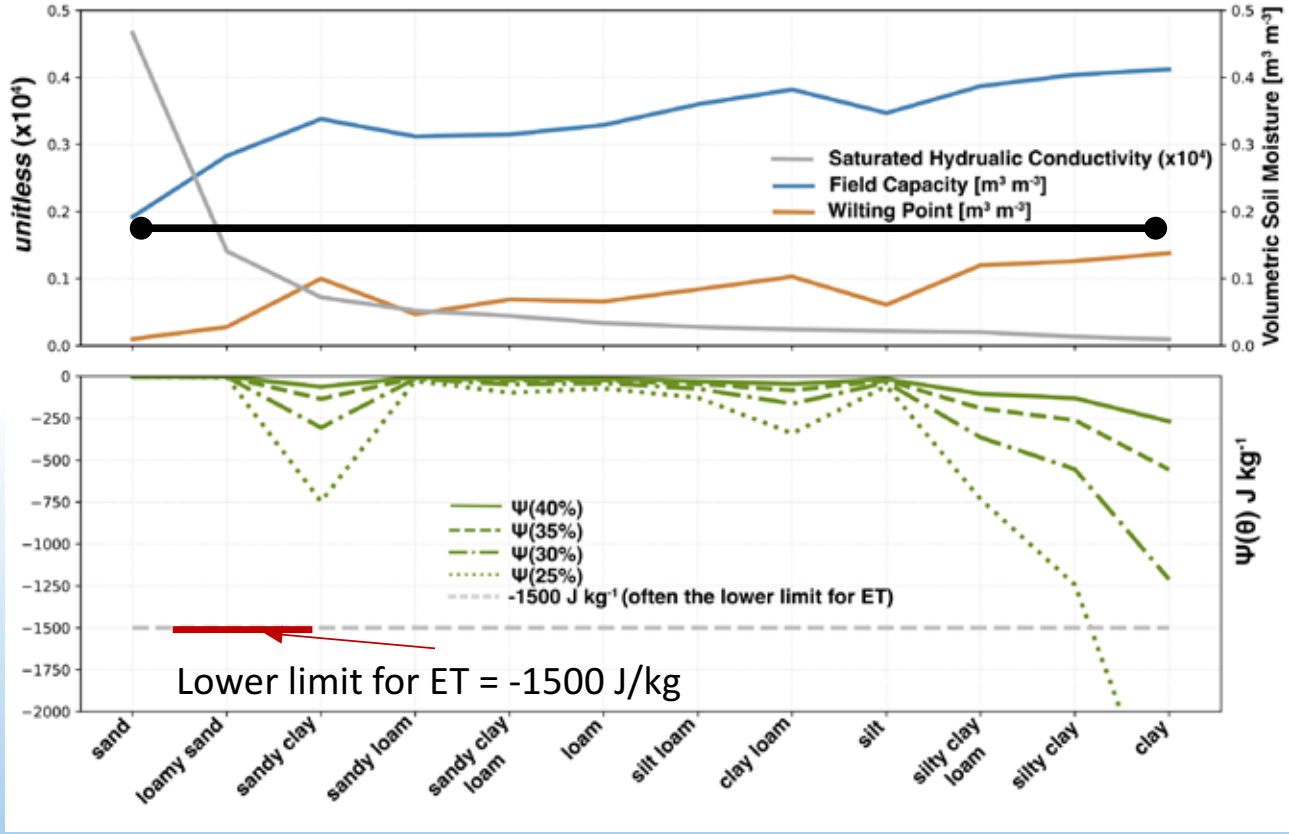
Soil texture refers to the proportions of ***sand, silt, and clay***

The *size of soil grains determines the hydro-physical characteristics* of the soil (capillarity, porosity, adhesion, etc.)



For each category, hydro-physical *parameters are defined through a table*, and they are then used for specific process parameterizations.

Soil Parameters



Ordered from largest grain size to smallest grain size (left to right)

Sat. Hydraulic Conduct.

Field Capacity

Wilting Point

Matric potential describes *how much energy is required to remove moisture from the soil system*

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

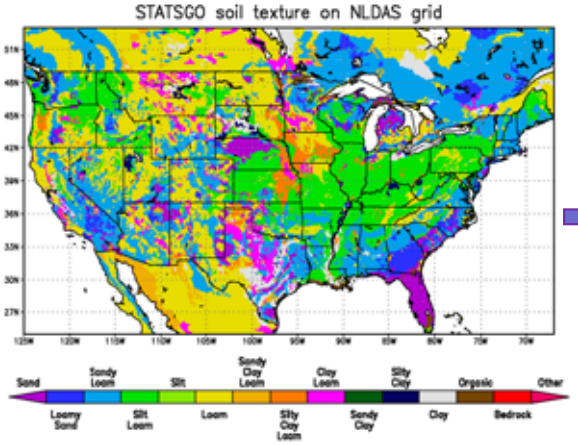
Soil Categories (Texture)

Look-up Table of

Hydraulic Parameters:
Wilting point,
Field Capacity,
…

Parameterizations:

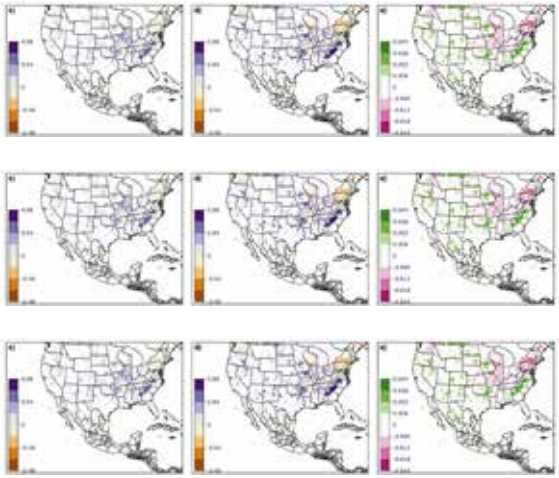
Surface Fluxes,
Runoff,
…



Properties

Soil category

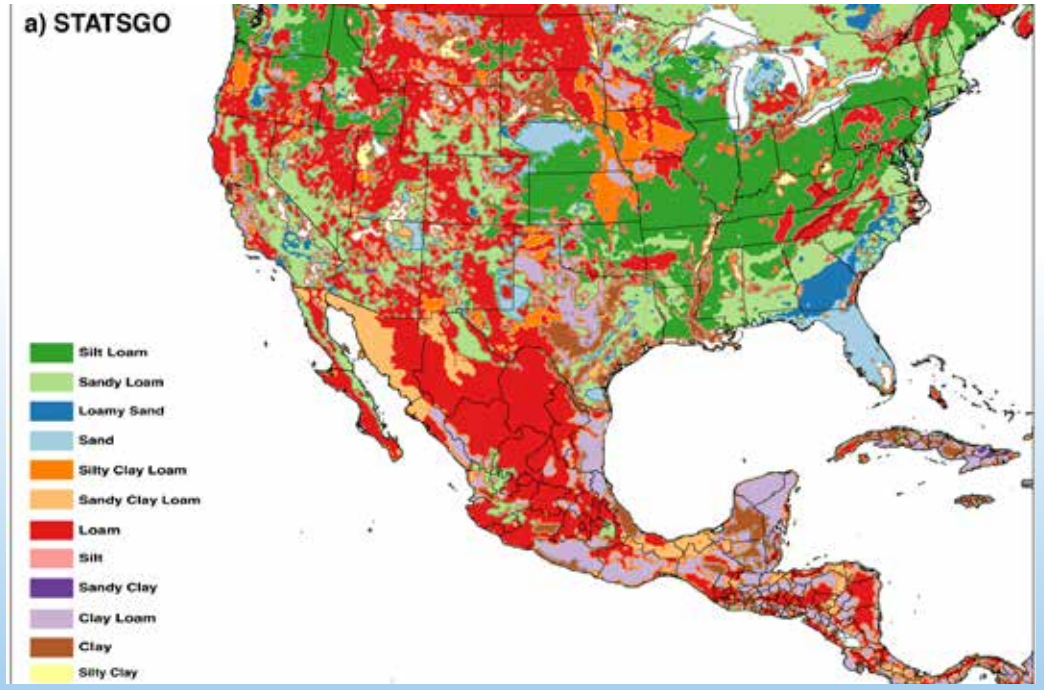
soil texture category	wilting point	field capacity	porosity	saturated hydraulic conductivity (x1000)	b	matric potential at saturation
sand	0.01	0.192	0.339	0.0466	2.79	0.069
loamy sand	0.028	0.283	0.421	0.0141	4.26	0.036
sandy loam	0.047	0.312	0.434	0.00523	4.74	0.141
silt loam	0.084	0.36	0.476	0.00281	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

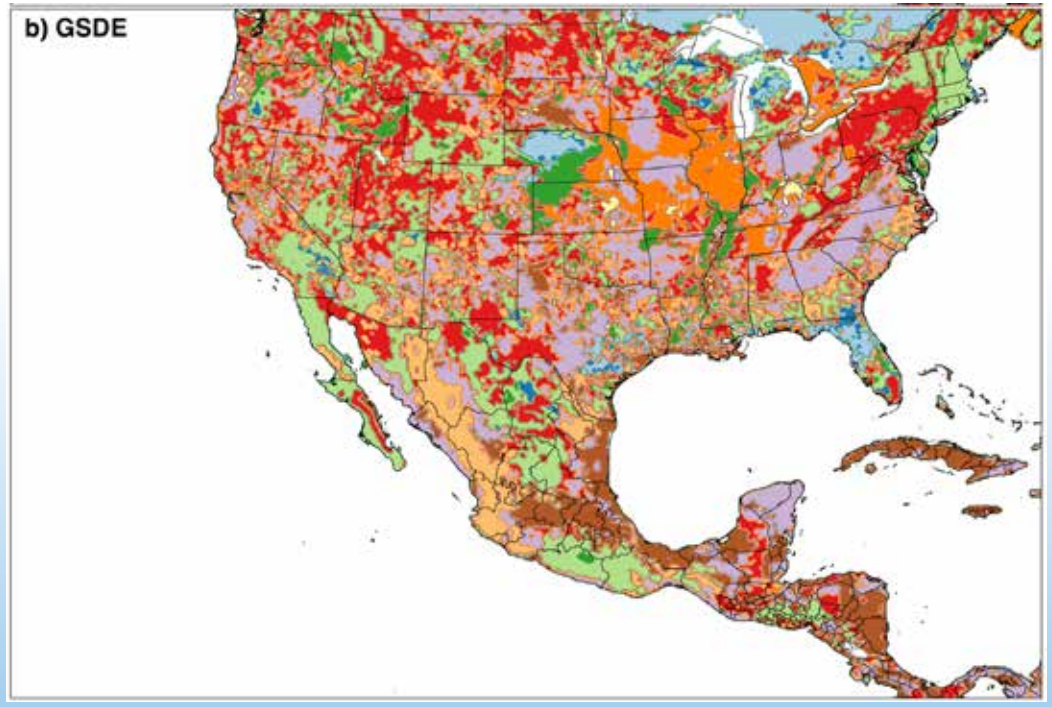
Soil Datasets

STATSGO (USDA)



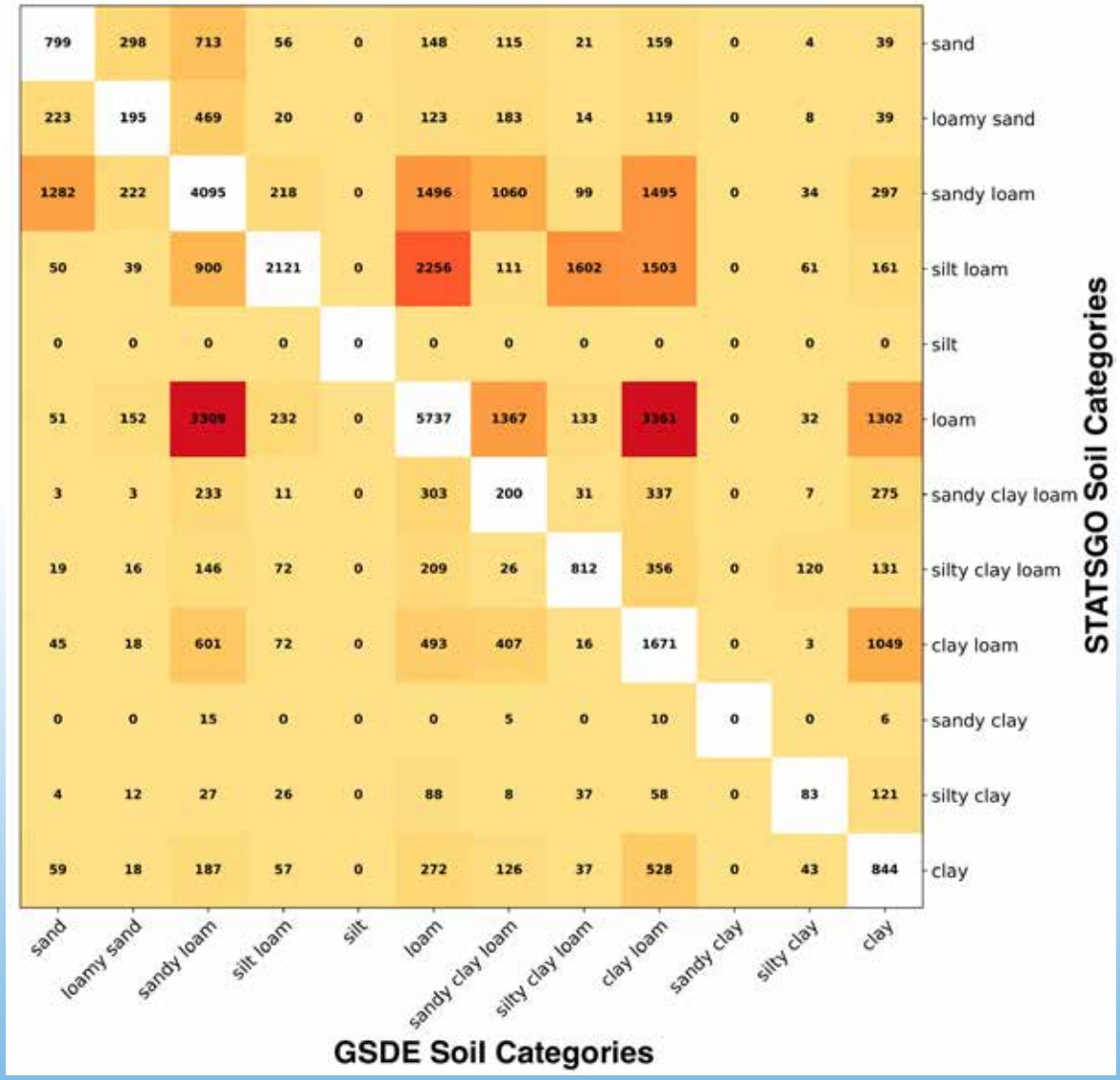
STATSGO: State Soil Geographic Database

GSDE (BNU)



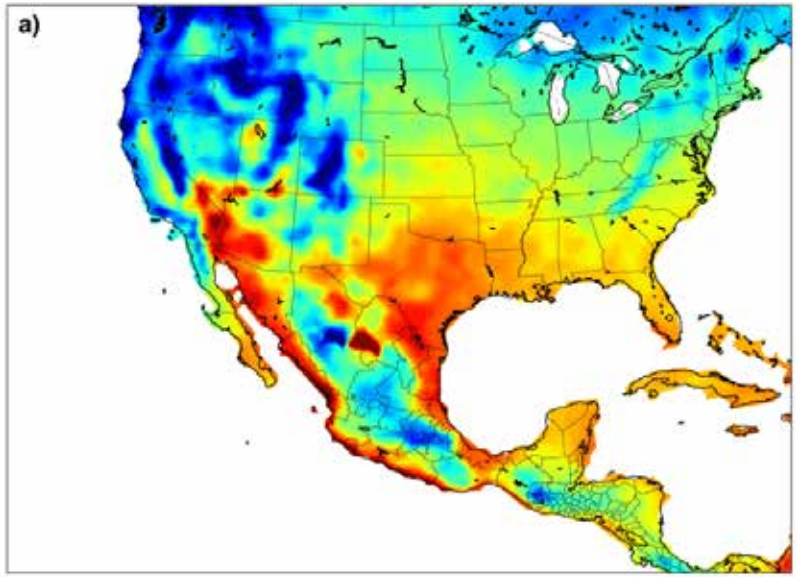
GSDE: Global Soil Dataset for use in Earth System Models

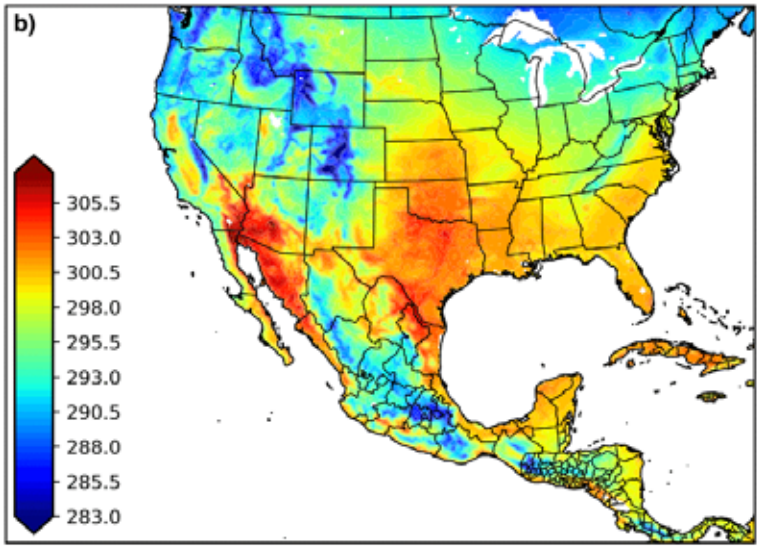
Number of grid points that show a transition between soil categories



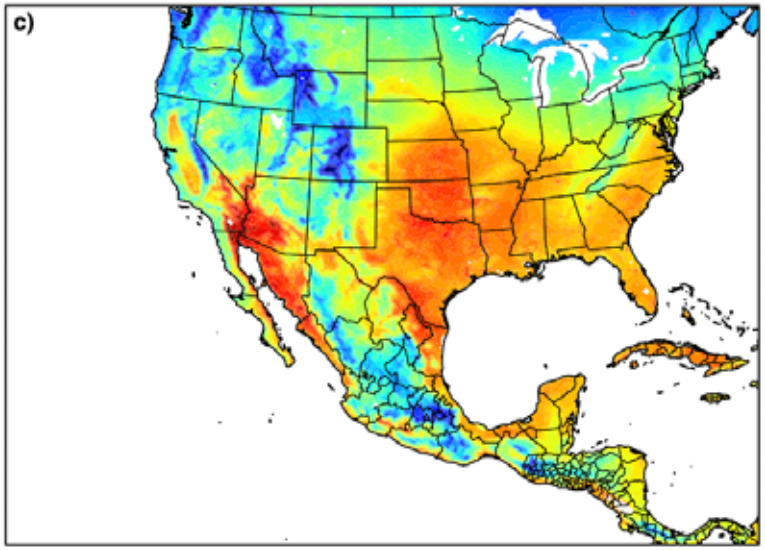
T2m

Observations



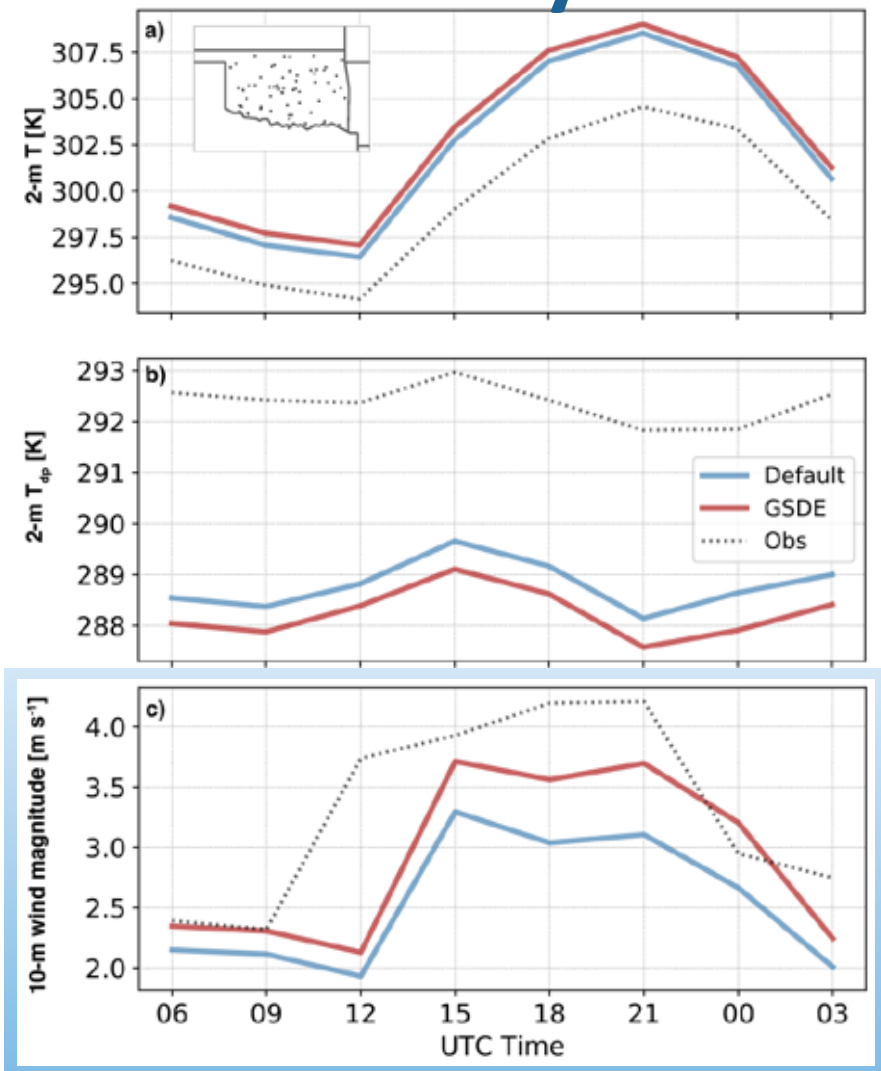


WRF/CLM with STATSGO



WRF/CLM with GSDE

Diurnal Cycle



OBS

STATSGO

GSDE

T2:

- Timing consistent with the observations
- The bias is smaller at night, larger during daytime.

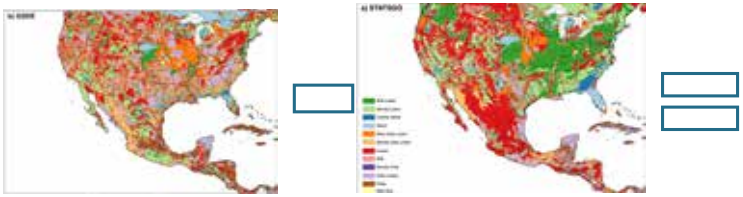
Td2:

Simulations have a slight shift (3-hr) for minimum Td min.
The timing of the Td max is with observations

Wind:

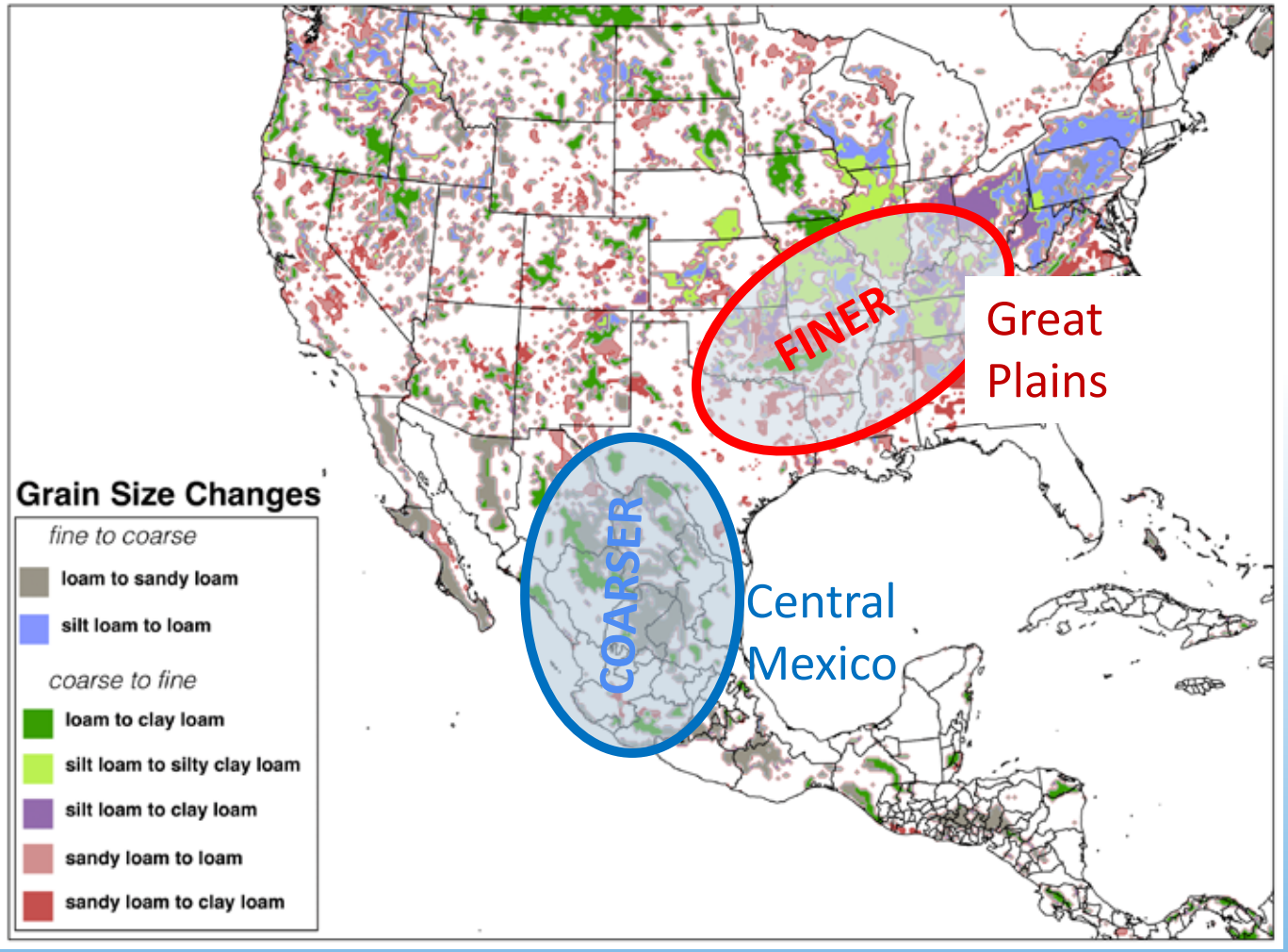
- The overall features are similar: minimum wind magnitudes at night, largest values in the afternoon/evening.
- Simulations show the Min values about 3 hs later than what is observed, while the Max tends to occur about 6 hs earlier than in observations
- Unlike T and Td, the GSDE wind biases are about 1/2 of those in STATSGO

Changes in grain size from STATSGO to GSDE

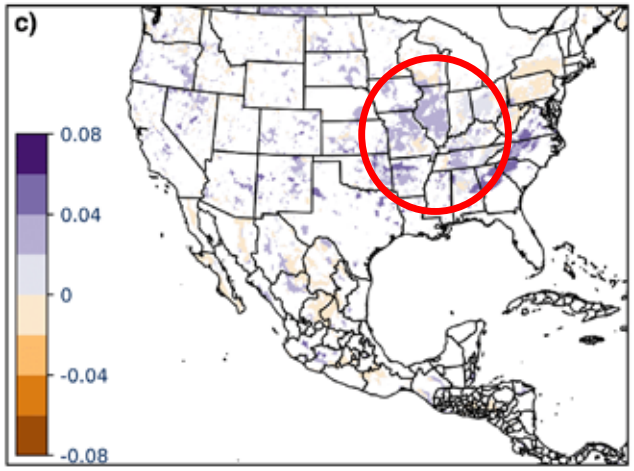


Fine to coarse

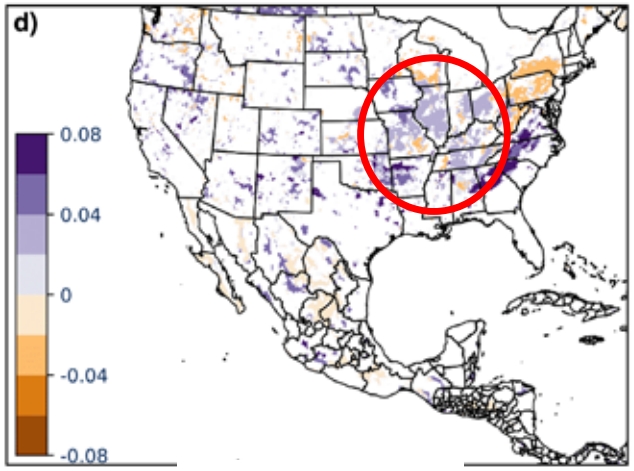
Coarse to fine



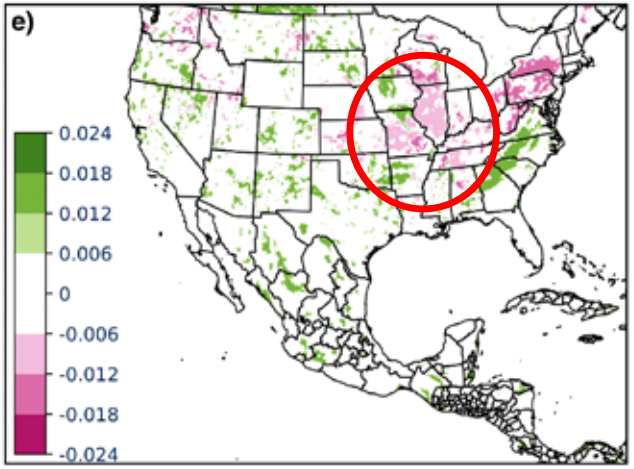
Field Capacity



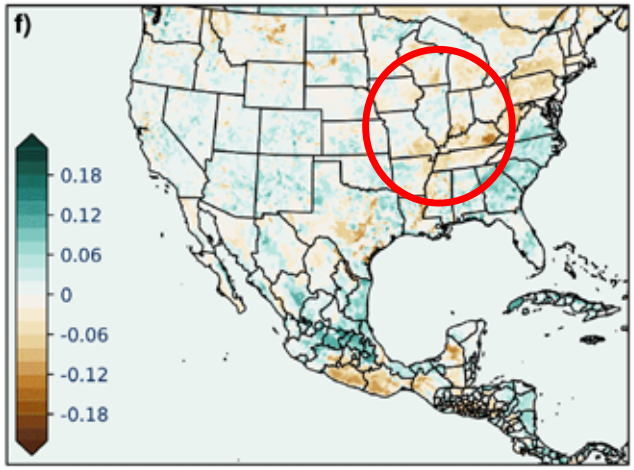
Wilting Point



Extract. Water



Soil Moisture



Changes in soil parameters from STATSGO to GSDE

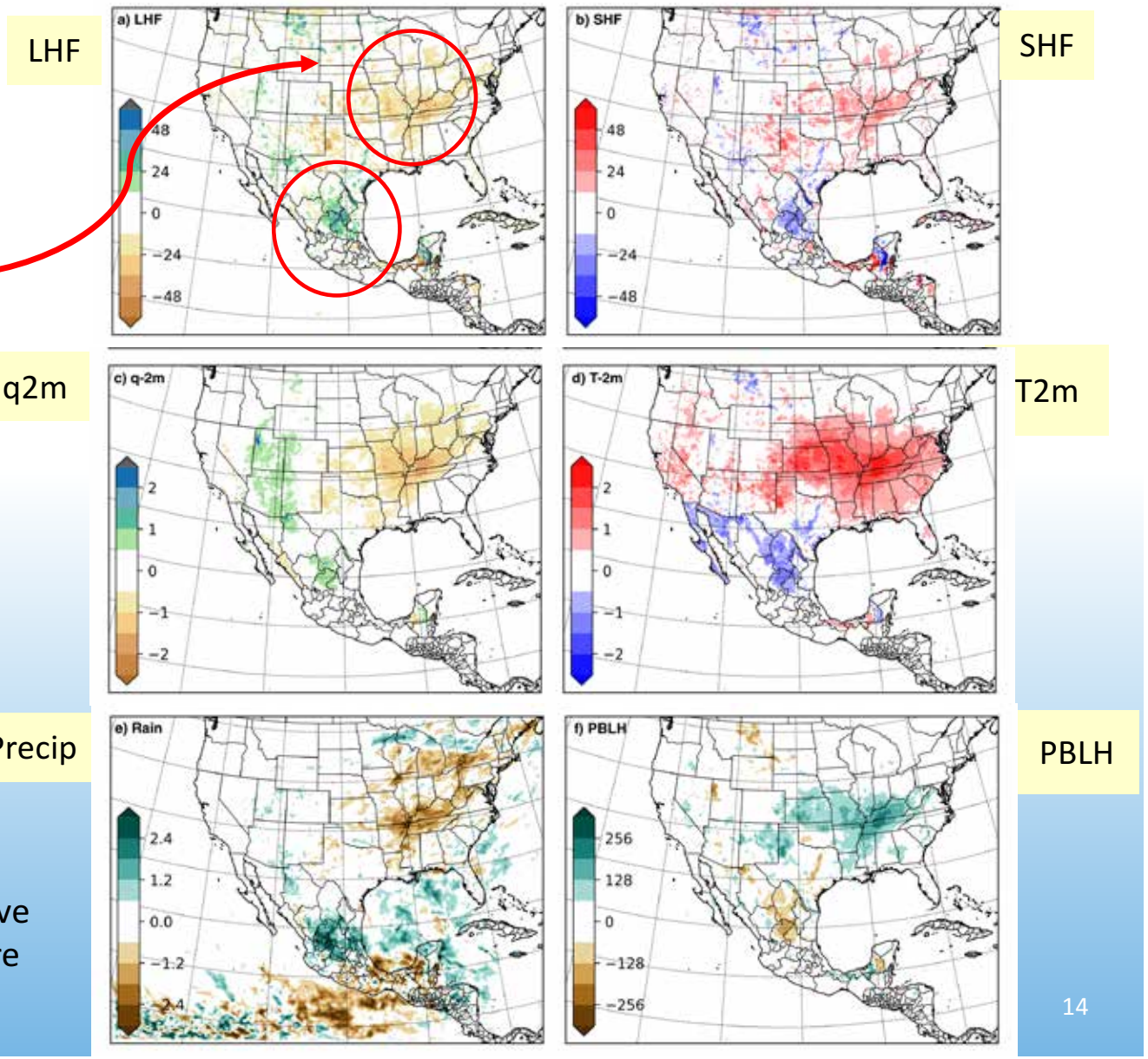
Continental Results

*The values represent **(GSDE–STATSGO)** seasonal differences*

- Finer soil particles retain soil moisture more vigorously
- Energy that does not contribute to removing moisture gets partitioned into sensible heat flux

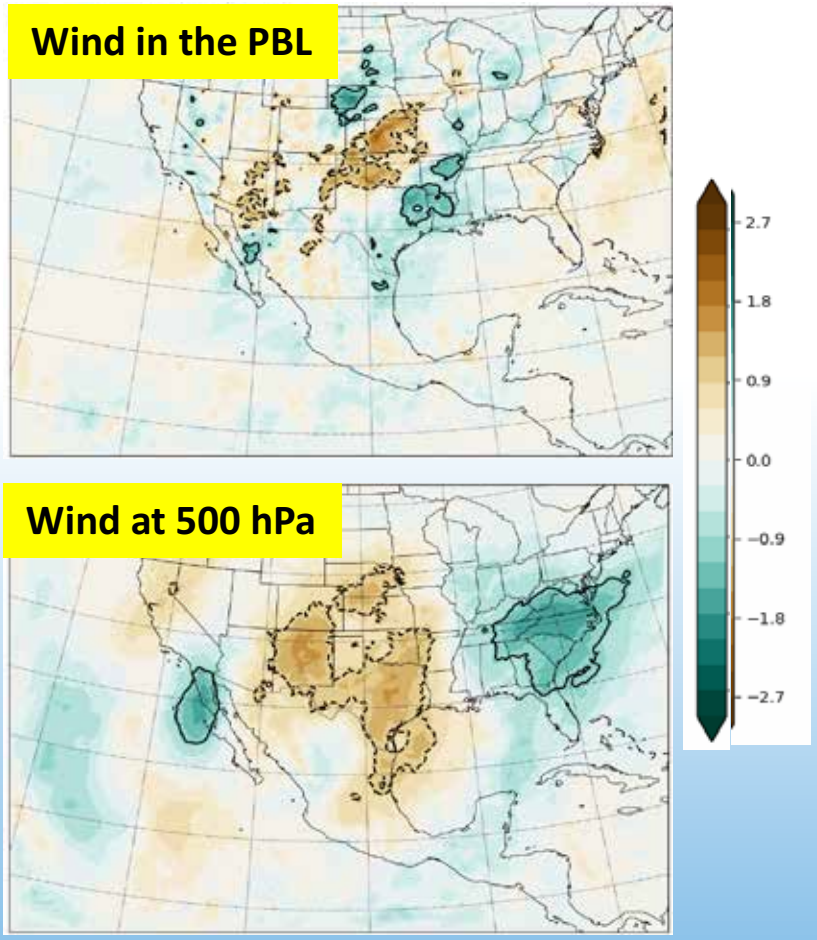
- Temperature and mixing ratio at 2-m, generally follows the pattern of the surface fluxes (though not perfectly due to advective processes)

- Integrative processes (i.e., precip and boundary layer evolution) also follow intuitive patterns, though the correspondence is more complicated.

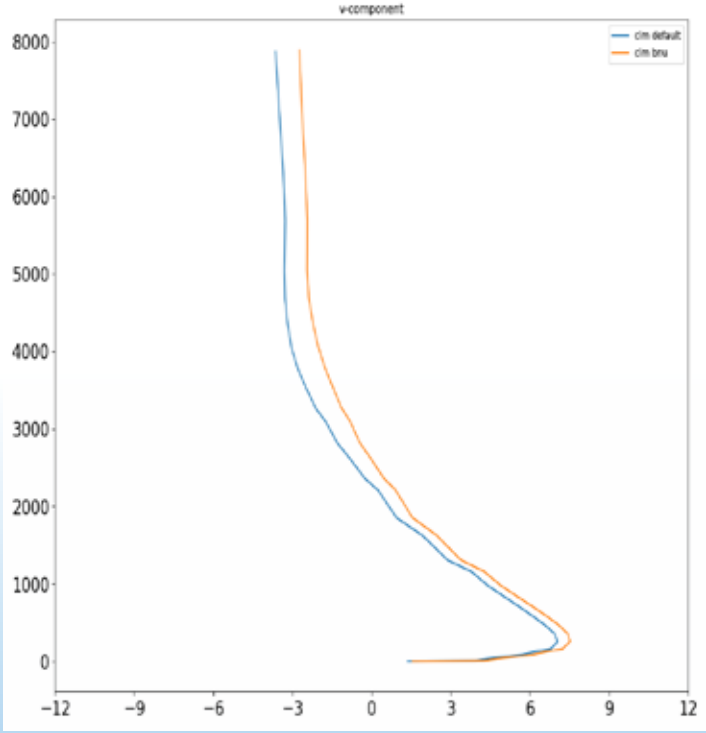


GSDE – STATSGO

Wind in the PBL

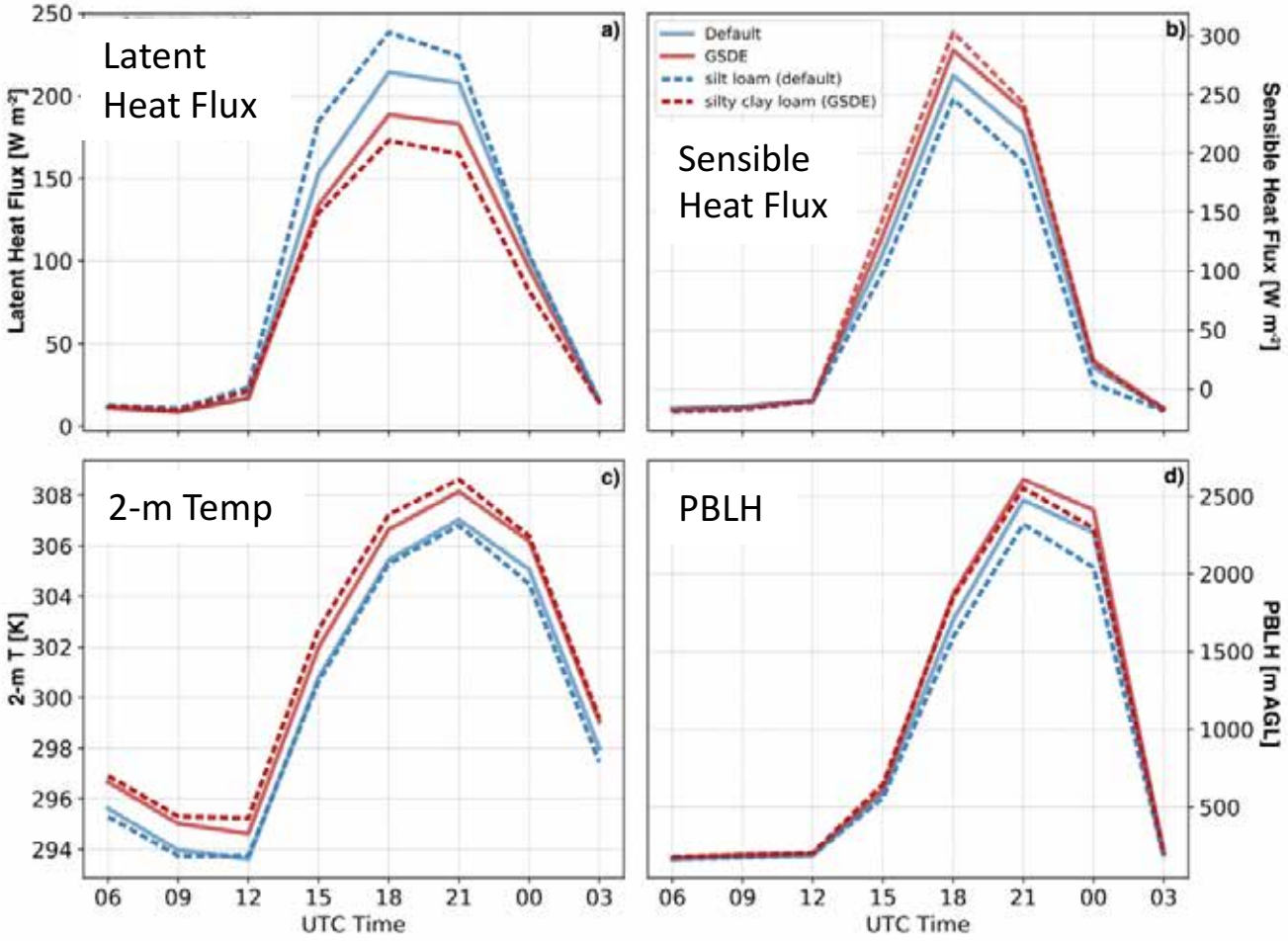


Wind at 500 hPa



Vertical profiles of nighttime wind in the Southern Great Plains region
Blue: STATSGO simulation,
Orange: GSDE simulation.

Results: Great Plains



STATSGO
(silt loam; coarser)

GSDE
(silty clay loam; finer)

Solid lines: area average for all categories in GP

Conclusions (1 of 2)

- Important *differences in soil texture and degree of heterogeneity* are found over the Great Plains and Central Mexico

- Differences between simulations with the two soil texture datasets are *as large as those resulting from using different LSMs* (not shown)

- Parameters associated with soil texture control the availability of soil moisture; *soils with finer grains retain water more strongly than coarser grain soils, affecting most processes at the surface*.

Conclusions (2 of 2)

- *Surface fluxes and near surface variables respond to the changes in soil properties* and drive the boundary layer evolution facilitating feedbacks that influence the regional climate.

- Because soil hydro-physical properties influence surface fluxes, *the use of different soil texture databases will influence the local land-atmosphere (LA) coupling*.

Thank you.

Soil Texture Parameters

TABLE 1. Select soil parameter values extracted from the WRF model look-up table, SOILPARM.TBL. The parameter 'b' is the Brooks-Corey exponent in the relation between soil moisture and matric potential. The rest of the parameters use full, descriptive names.

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
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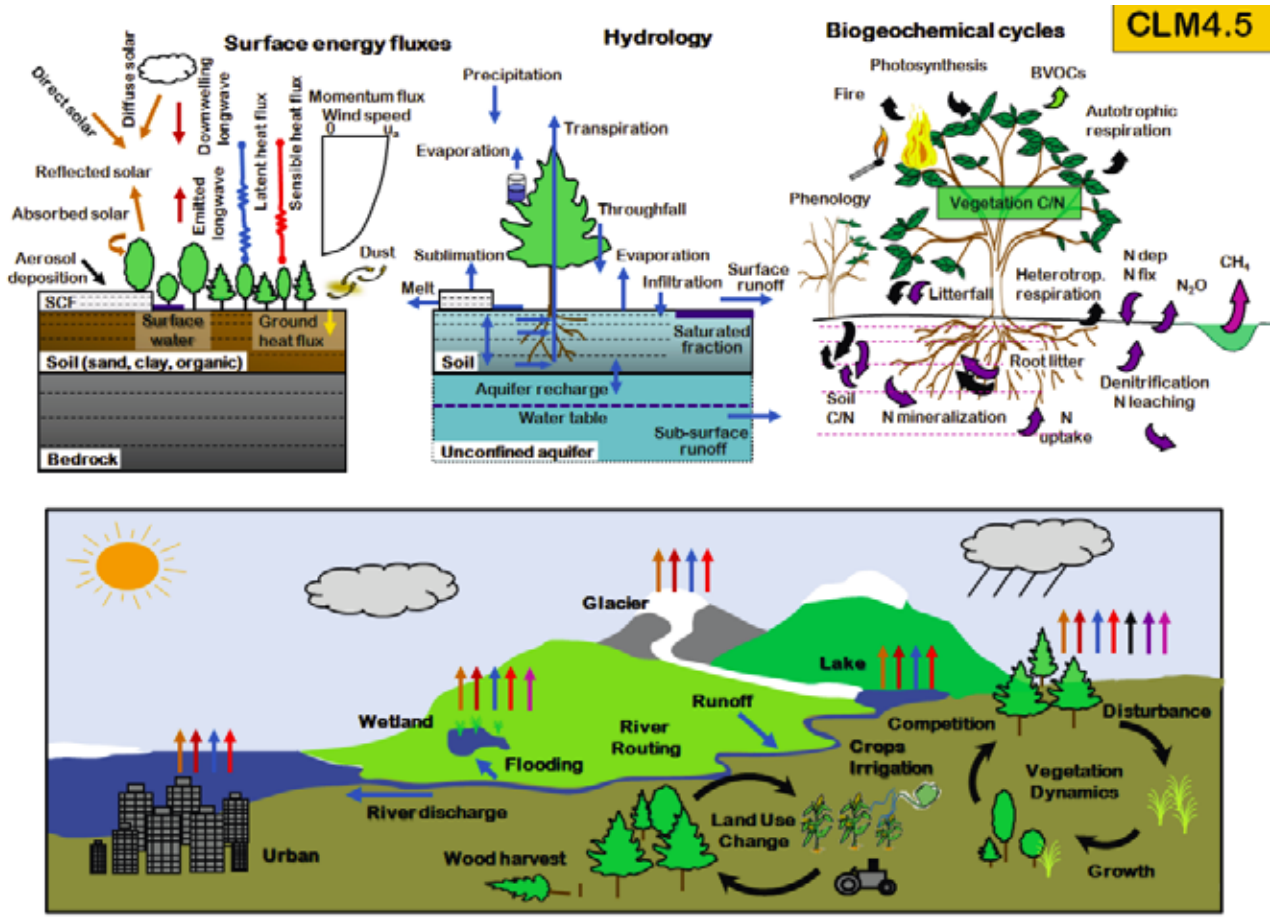
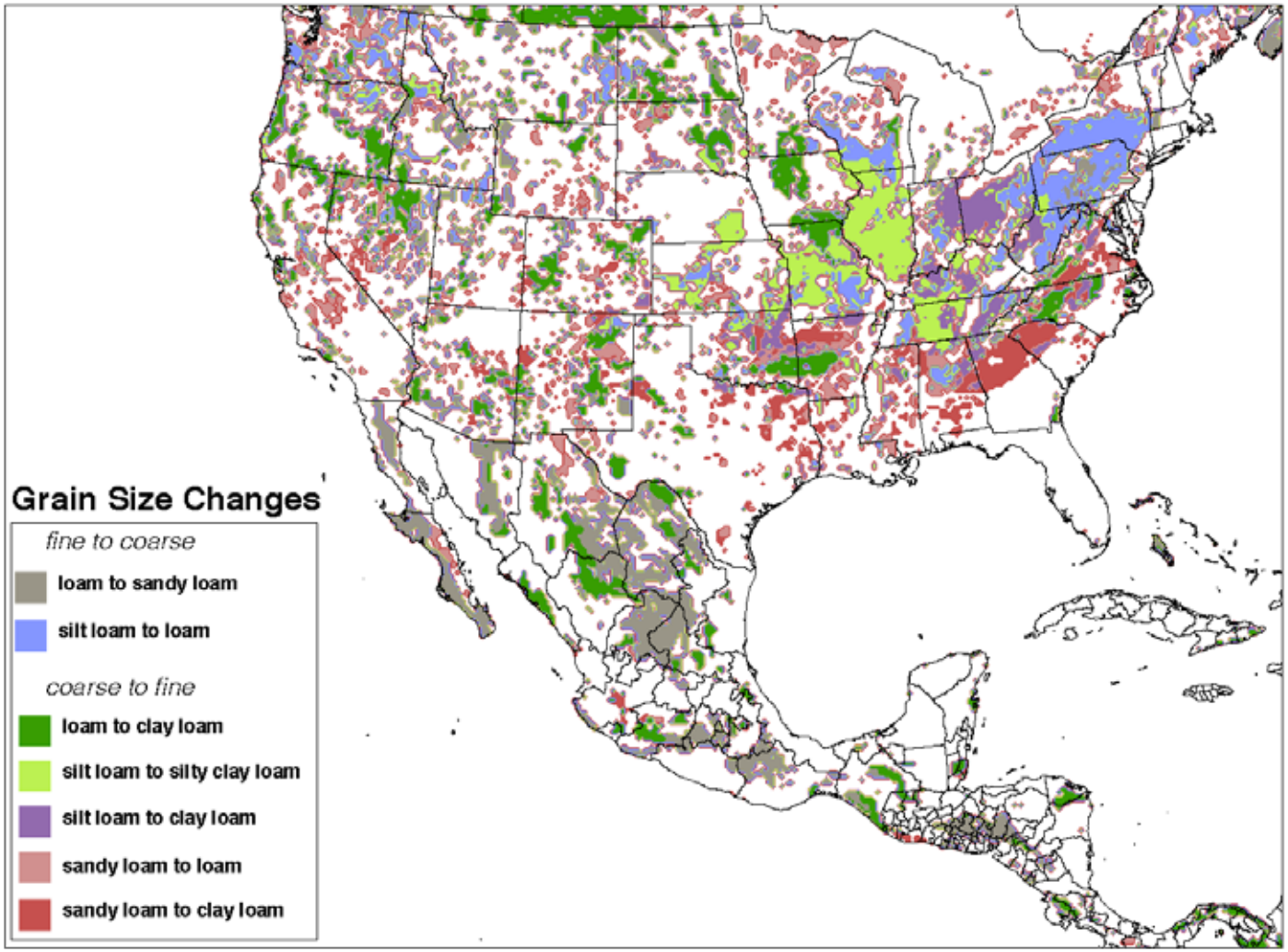
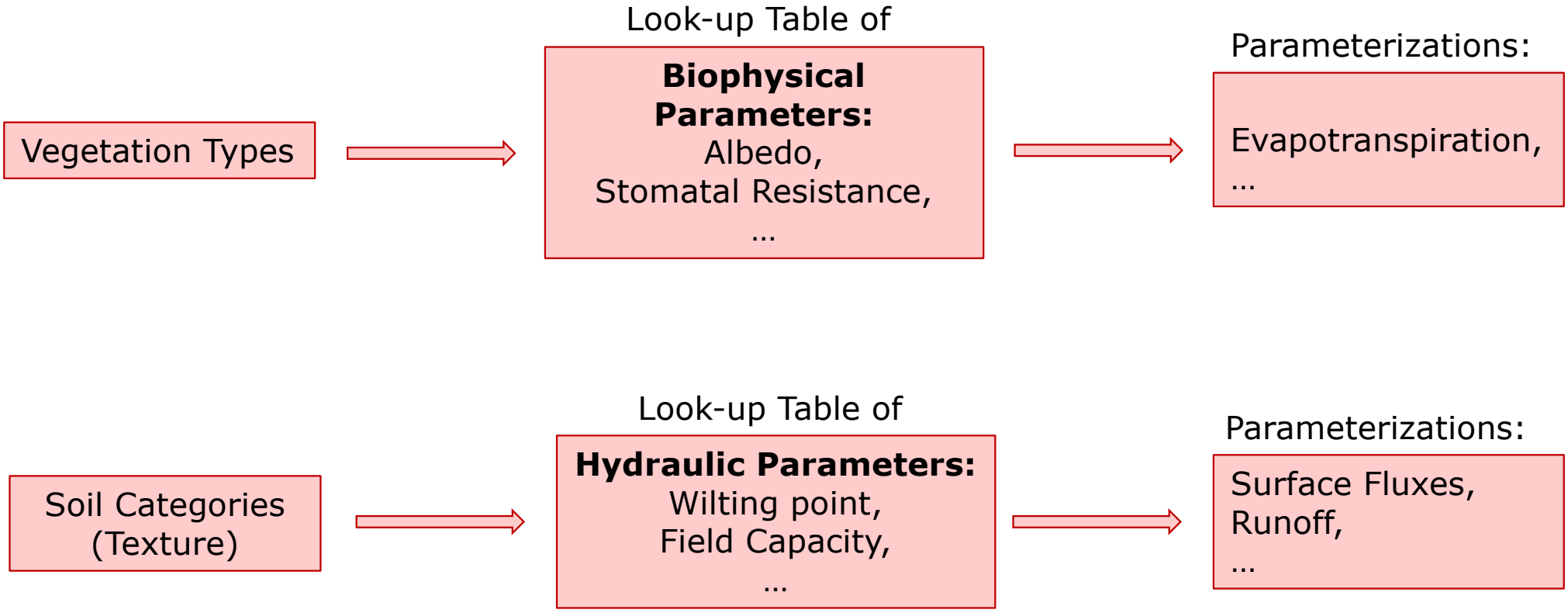

CLM4.5
Surface energy fluxes
Direct solar
Diffuse solar
Downwelling longwave
Reflected solar
Absorbed solar
Emitted longwave
Latent heat flux
Sensible heat flux
Momentum flux
Wind speed
Aerosol deposition
Dust
SCF
Surface water
Ground heat flux
Soil (sand, clay, organic)
Bedrock
Hydrology
Precipitation
Transpiration
Evaporation
Throughfall
Sublimation
Evaporation
Melt
Infiltration
Surface runoff
Saturated fraction
Soil
Aquifer recharge
Water table
Sub-surface runoff
Unconfined aquifer
Biogeochemical cycles
Photosynthesis
BVOCs
Fire
Autotrophic respiration
Phenology
Vegetation C/N
N dep
N fix
CH_4
N_2O
Litterfall
Heterotrop. respiration
Root litter
Denitrification
N leaching
Soil C/N
N mineralization
N uptake
Glacier
Lake
Wetland
Runoff
River Routing
Flooding
Competition
Disturbance
Crops
Irrigation
Vegetation Dynamics
River discharge
Land Use Change
Urban
Wood harvest
Growth


Grain Size Changes
fine to coarse
loam to sandy loam
silt loam to loam
coarse to fine
loam to clay loam
silt loam to silty clay loam
silt loam to clay loam
sandy loam to loam
sandy loam to clay loam

Land Surface Models have substantial simplifications



Results in the Great Plains

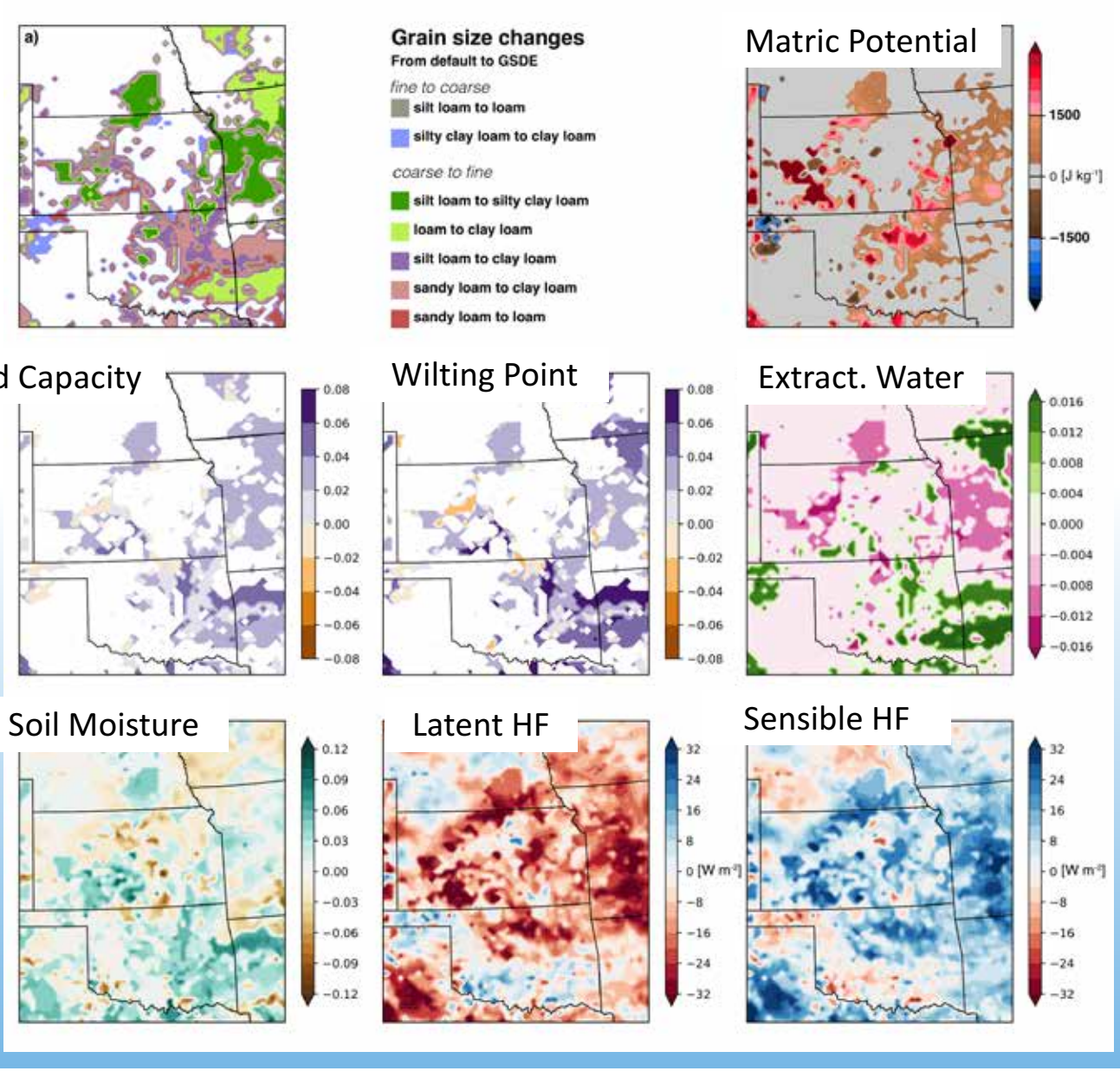
Top left figure shows soil texture transitions between datasets from default to GSDE

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: 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