INVESTIGATING SPATIAL RELATIONSHIPS BETWEEN SOIL MOISTURE AND TORNADO EVENTS USING SMAP

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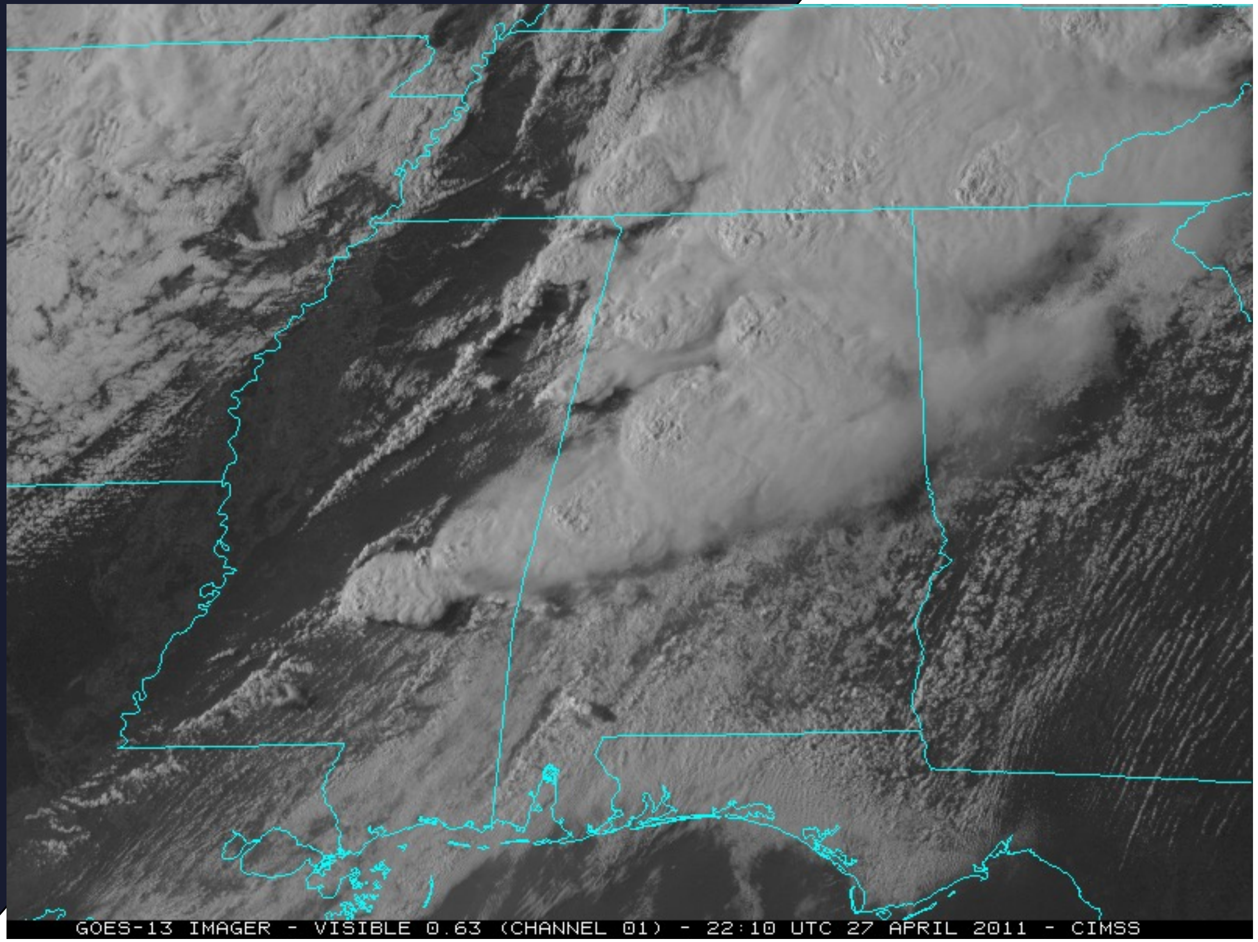


Crash course: How do tornadoes form?

Hot second on my high horse....

WHY DO WE STILL SAY TORNADOES "TOUCH DOWN"?!?!?!?!

Simply say: A tornado occurred, or was observed, or formed.

Or: "TORNADO ON THE GROUND"?!?!?!?

Processes that are important:

1. Generation of horizontal vorticity: Factors include temperature difference between storm and air, friction, temperature deficit of rear flank
2. Properties of the RFD: How cold (implications on stretching vorticity, downward advection of vorticity to the ground), proximity of RFD to updraft (implications on tilting from horizontal to vertical vorticity),
3. Intensity of low-level mesocyclone: tied to #1: Drives convergence below and focuses near-ground rotation

Motivation:

- Despite many recent and less-recent advances in tornado studies, we still don’t know why one storm will create a tornado and another, seemingly in a similar environment, does not.
- Two of the more skillful environmental parameters in differentiating are the Lifted Condensation Level height (LCL) and the low-level Convective Available Potential Energy (CAPE).

(Craven and Brooks 2004; Rasmussen 1998; Edwards and Thompson 2000)

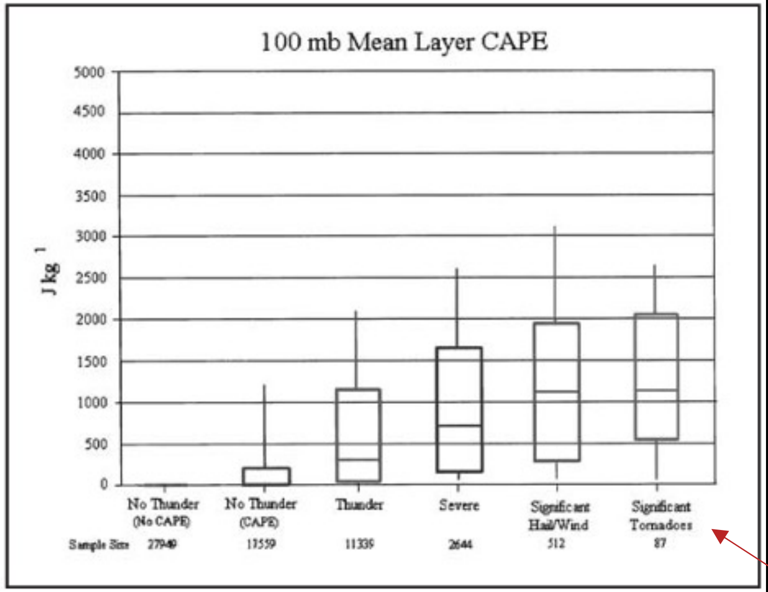


Fig. 1. Box and whisker plot of 100-hPa mean layer CAPE (J kg^{-1}). 10th, 25th, 50th, 75th, and 90th percentiles are shown.

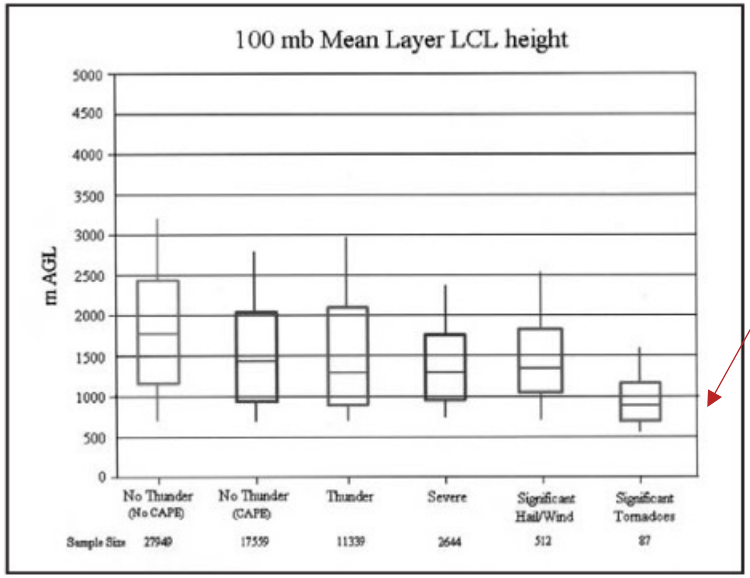


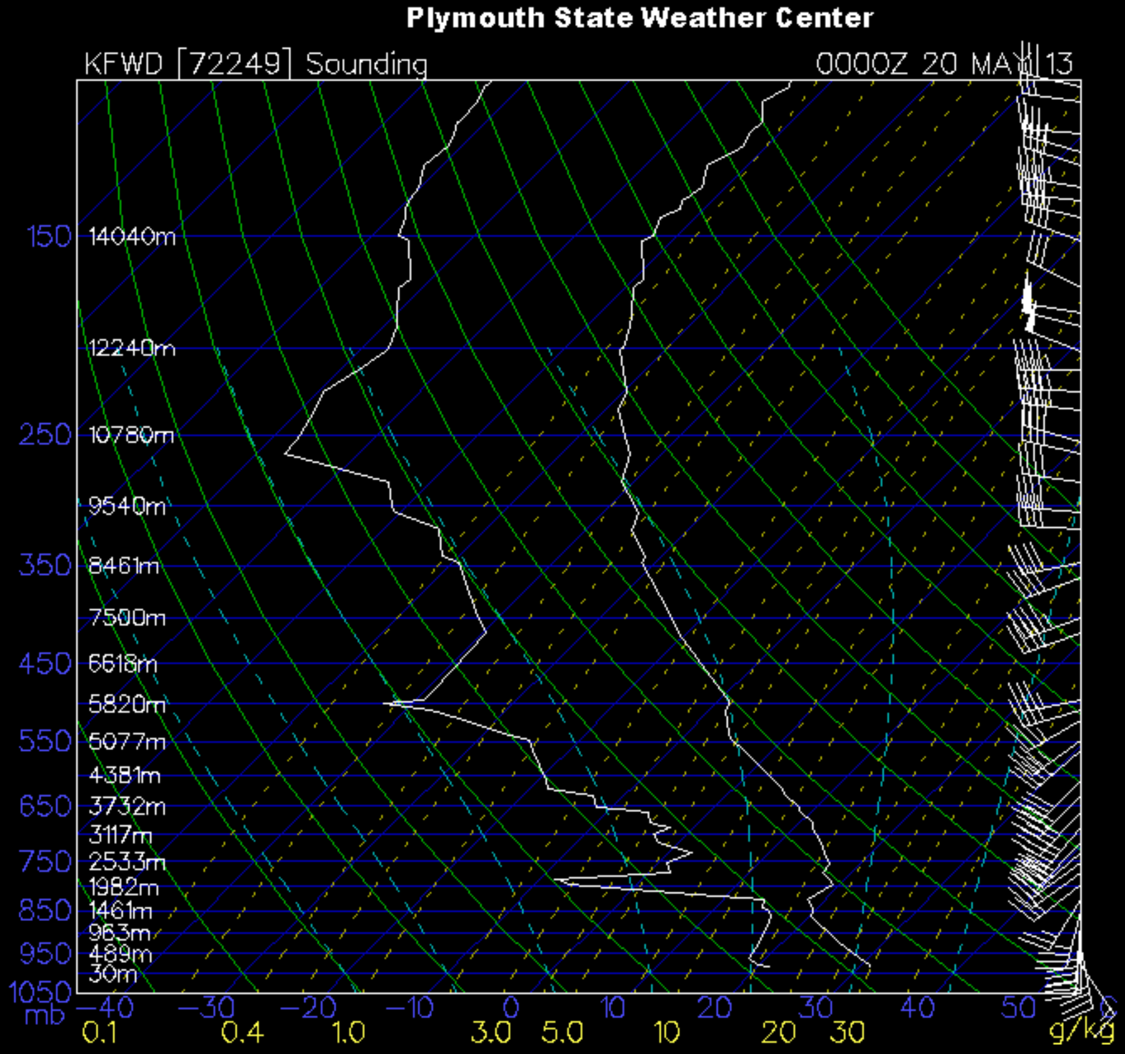
Fig. 5. As in Fig. 1, except for 100-hPa mean layer LCL (MLLCL) height (m AGL).

Sig. Tor

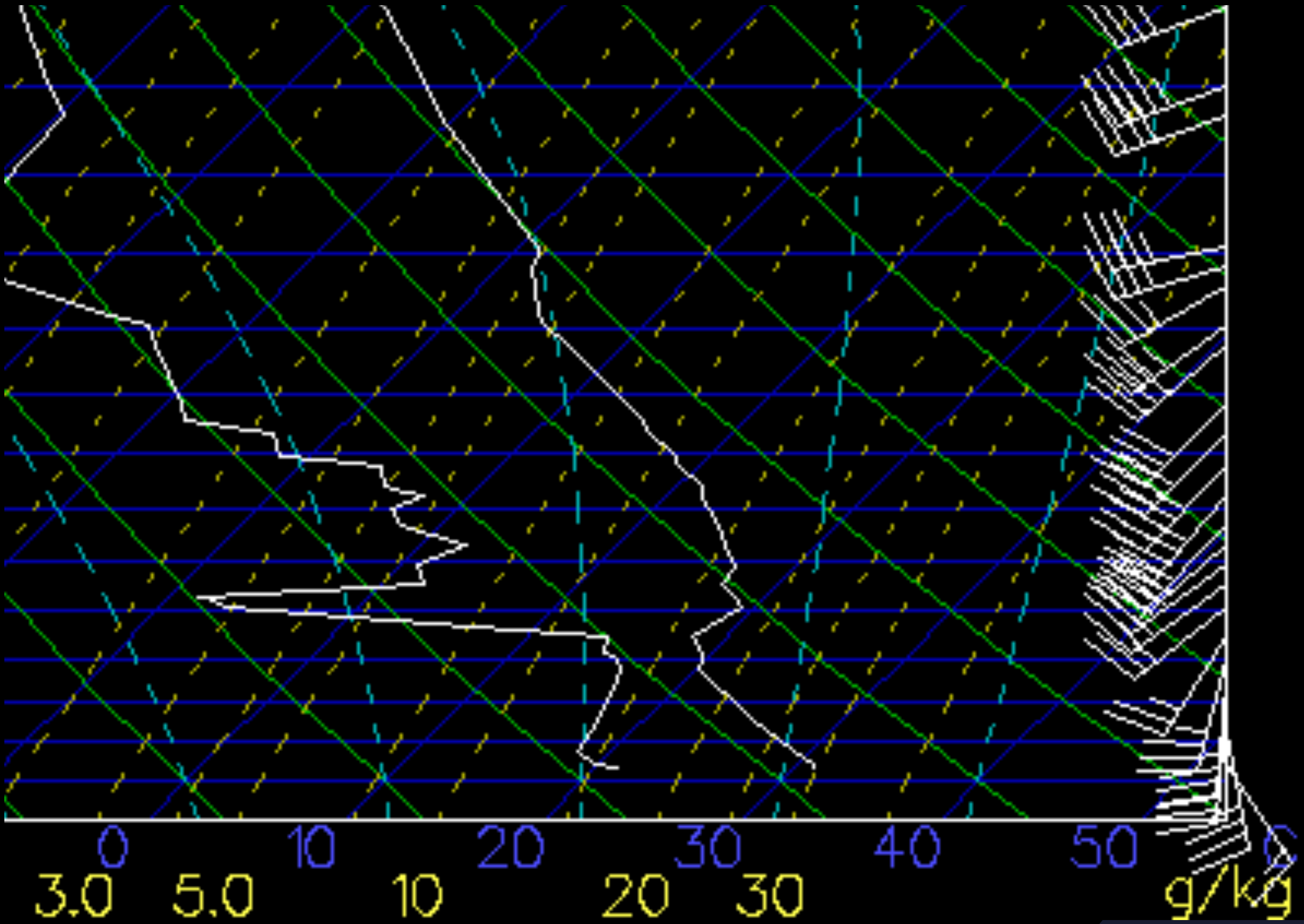
Why LCL Height and LL CAPE?

- Both are directly representative of boundary layer moisture.
- Moist environment = less evaporation = more buoyant RFD air (low LCL)
- Need moderately buoyant air in rear flank of storm for stretching to increase vorticity
- Higher LLCAPE = greater low-level buoyancy = greater stretching
(Markowski et al. 2000)

Adding boundary layer moisture: Skew-T perspective



Zoomed in:

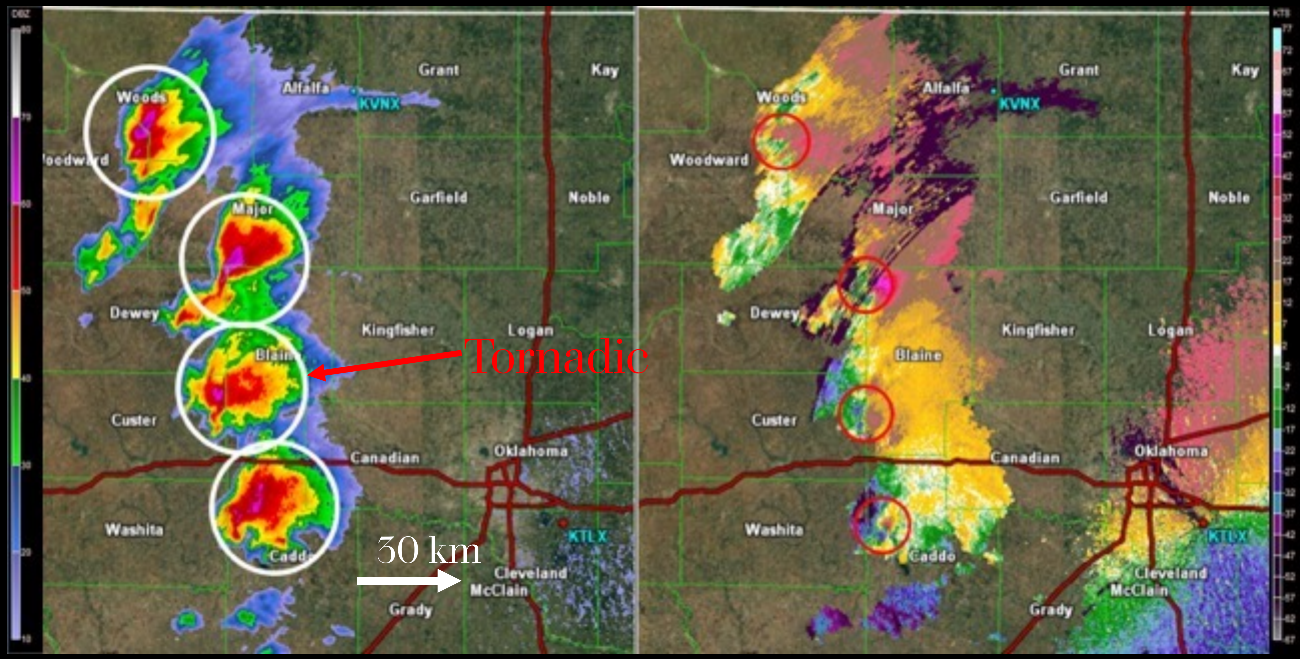



Non-tornado producers

Motivation:

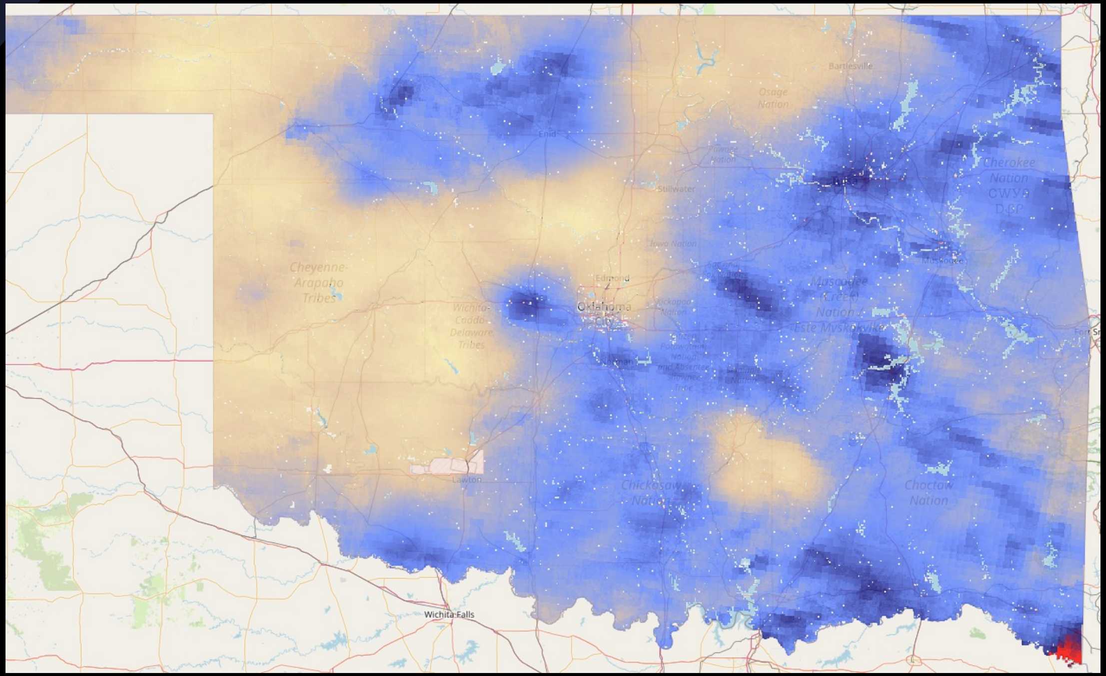
- Large scale environment conditions are helpful, but don’t tell the whole story
- Localized effects are often quite important
- Some localized effects may include local variations in thermodynamics, terrain induced shear increases, storm-storm interactions, etc.
- ***NOTE THE DISTANCE SCALE!

  40 km can separate two distinct storms from each other.



“String of pearls” supercells from 2019 UTC 24 May, 2011. Only 1 of these 4 storms was producing a tornado within 15 minutes of this image.

Soil Moisture

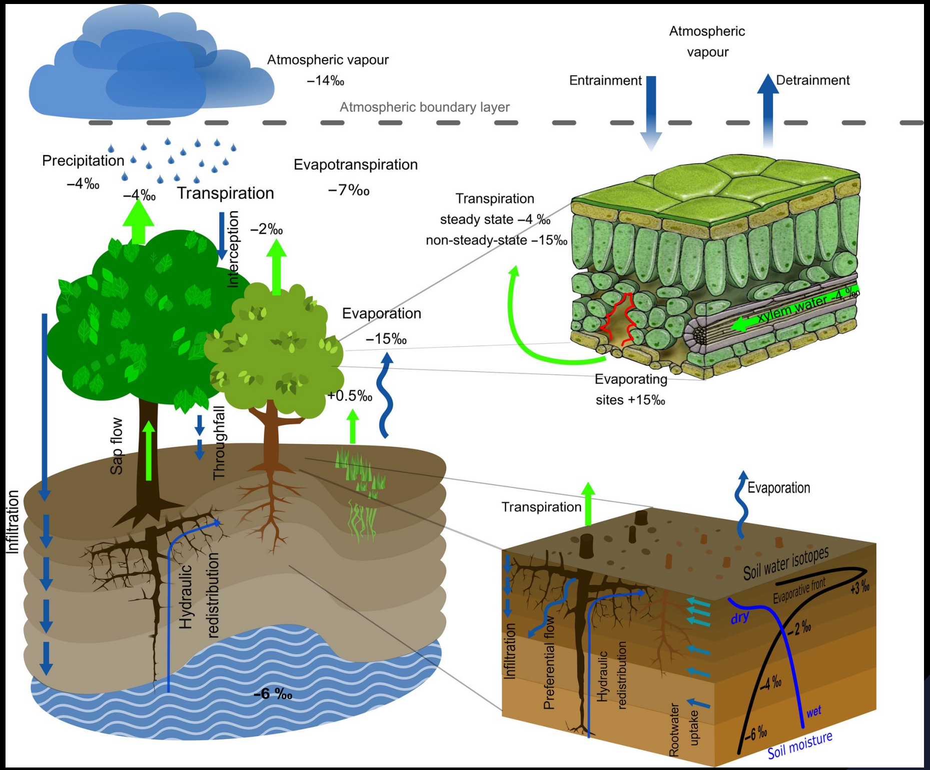


800 m resolution soil moisture volumetric water content at 5 cm depth, 10/5/2023 (Oklahoma State Soil Physics) http://soilmoisture.okstate.edu/

- Many factors are known to contribute to tornado production
- What role might soil moisture play? (Currently unknown)
- Soil water content is sometimes highly spatially variable

Why Soil Moisture?

- Soil moisture supplies water to the atmosphere through latent heat fluxes and indirectly through evapotranspiration
- Increasing the moisture in the boundary layer will lower the LCL height and increase low-level CAPE, which might contribute to locally more favorable tornadogenesis conditions



Dubbert and Werner (2018)

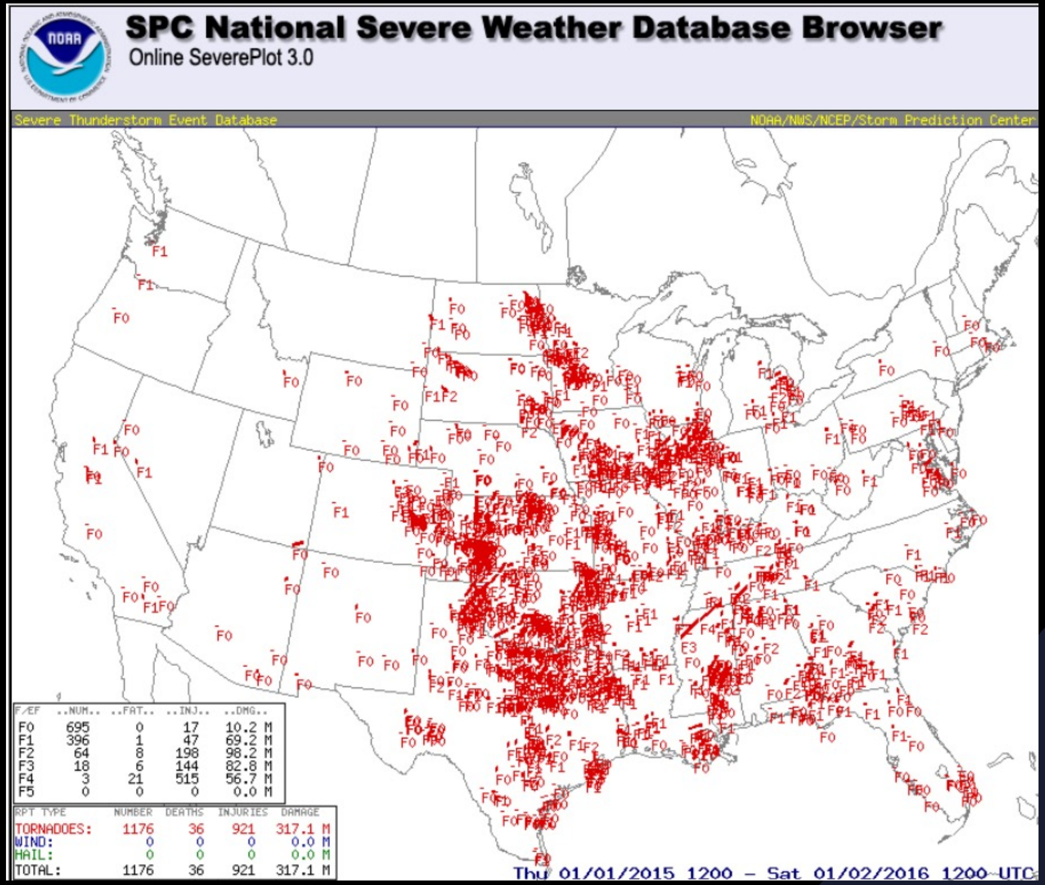
Science Q:

- Is there a spatio-temporal relationship between soil moisture and tornadoes?

- Hypothesis 1: Tornadoes will be more frequent in wet years than dry years
- Hypothesis 2: Tornadoes will occur preferentially over or near wet soils

Data:

- SPC ONE-TOR database for tornado reports (NCEI Storm Data is county-based; NOT what we want)
- Soil moisture from surface network RK
- SMAP data for a handful of individual events



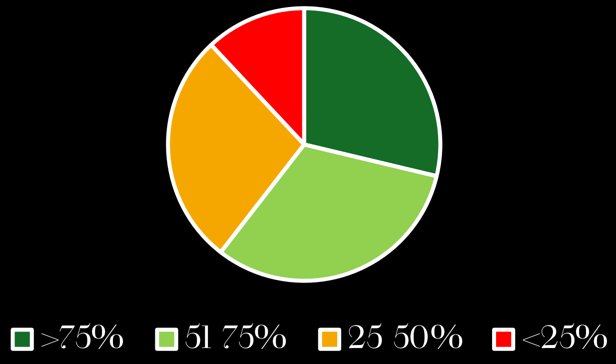
Preliminary Results:

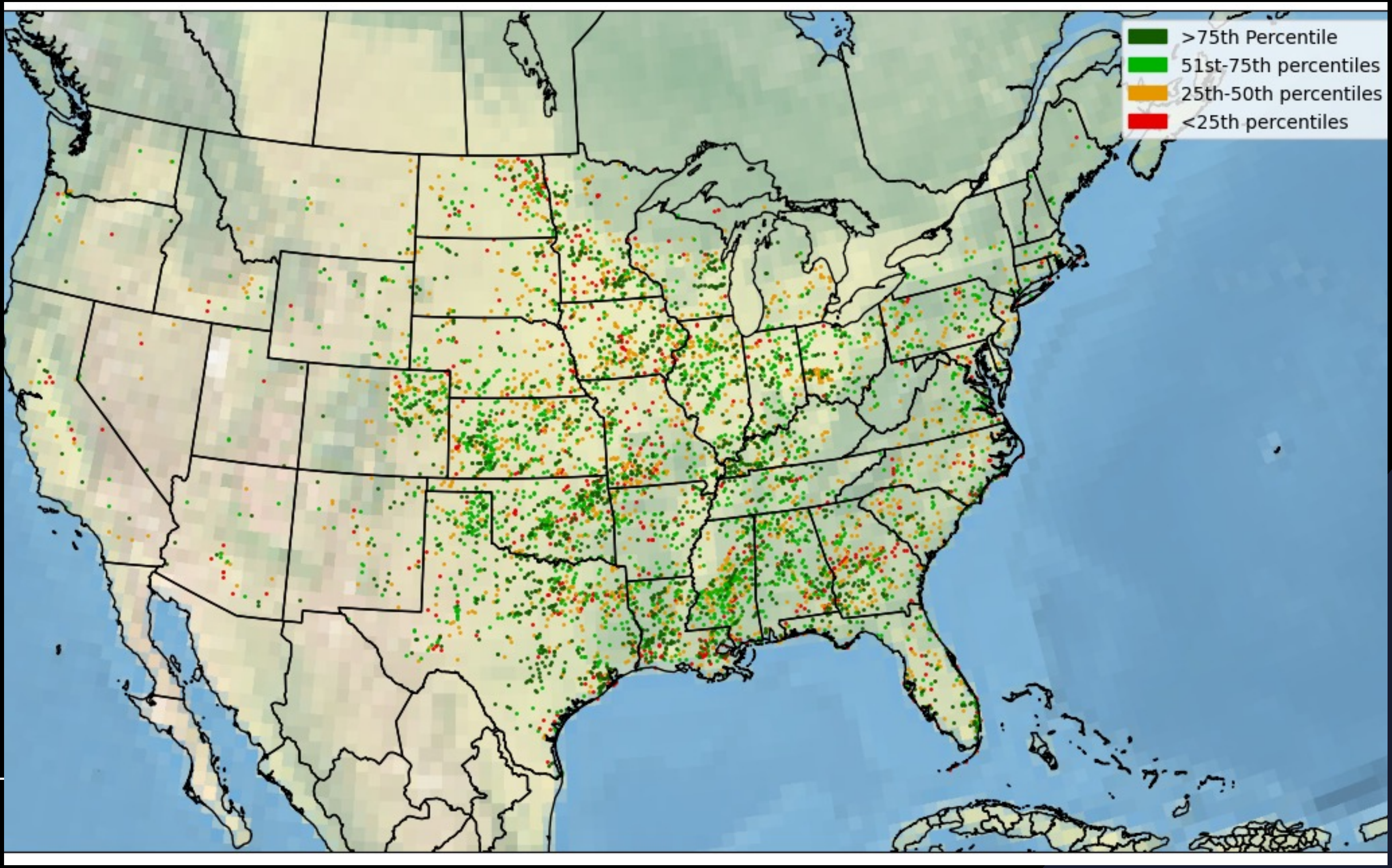
- National tornado reports from 2015-2019

Tornado Genesis Points and 5 cm Soil Moisture Percentiles

>75th percentile:
n=1700
51st-75th percentiles:
n=1880
25th-50th percentiles:
n=1630
<25th percentile:
n=708
(59% at > 50th percentile)

National Tornadoes by SM %

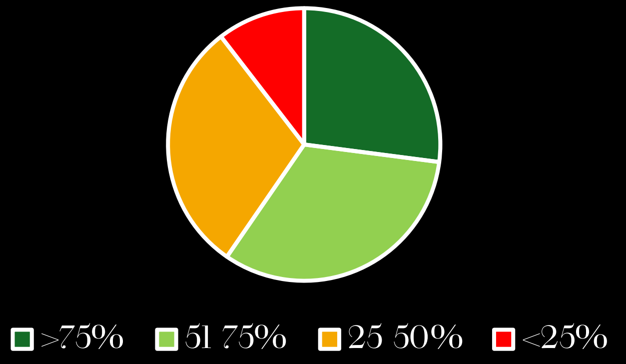


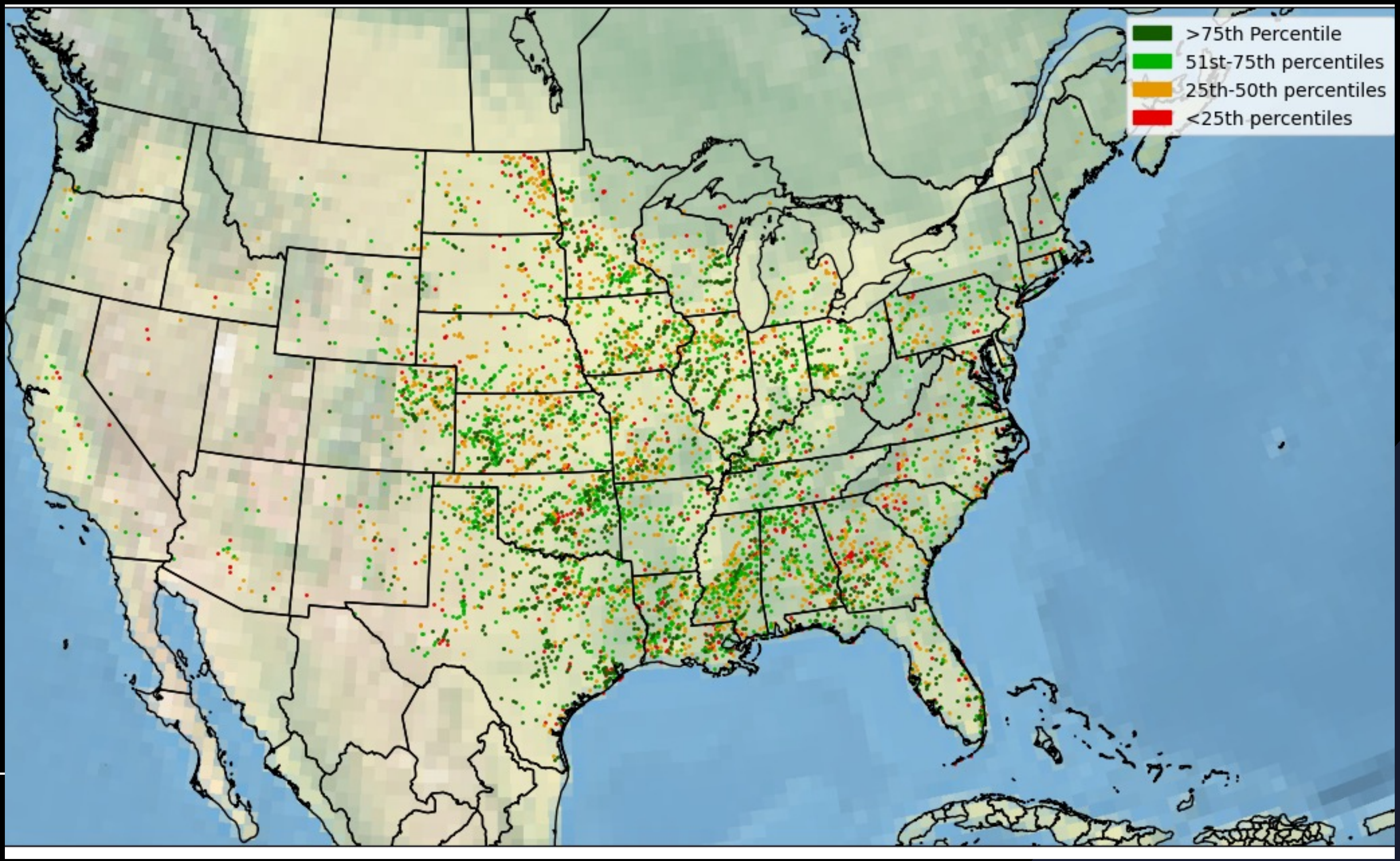


Tornado Genesis Points and 20 cm Soil Moisture Percentiles

>75th percentile:
n=1601
51st-75th percentiles:
n=1926
25th-75th percentiles:
n=1772
<25th percentile:
n=619
(59% at > 50th percentile)

National Tornadoes by SM %

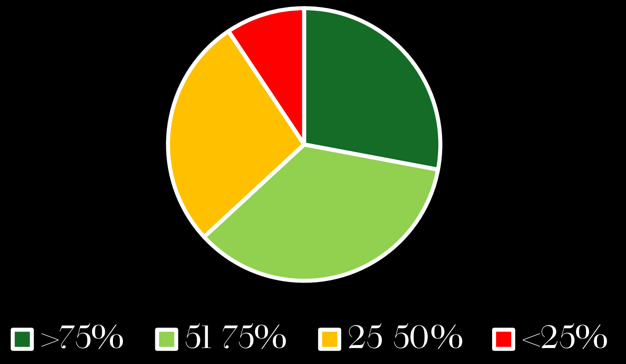


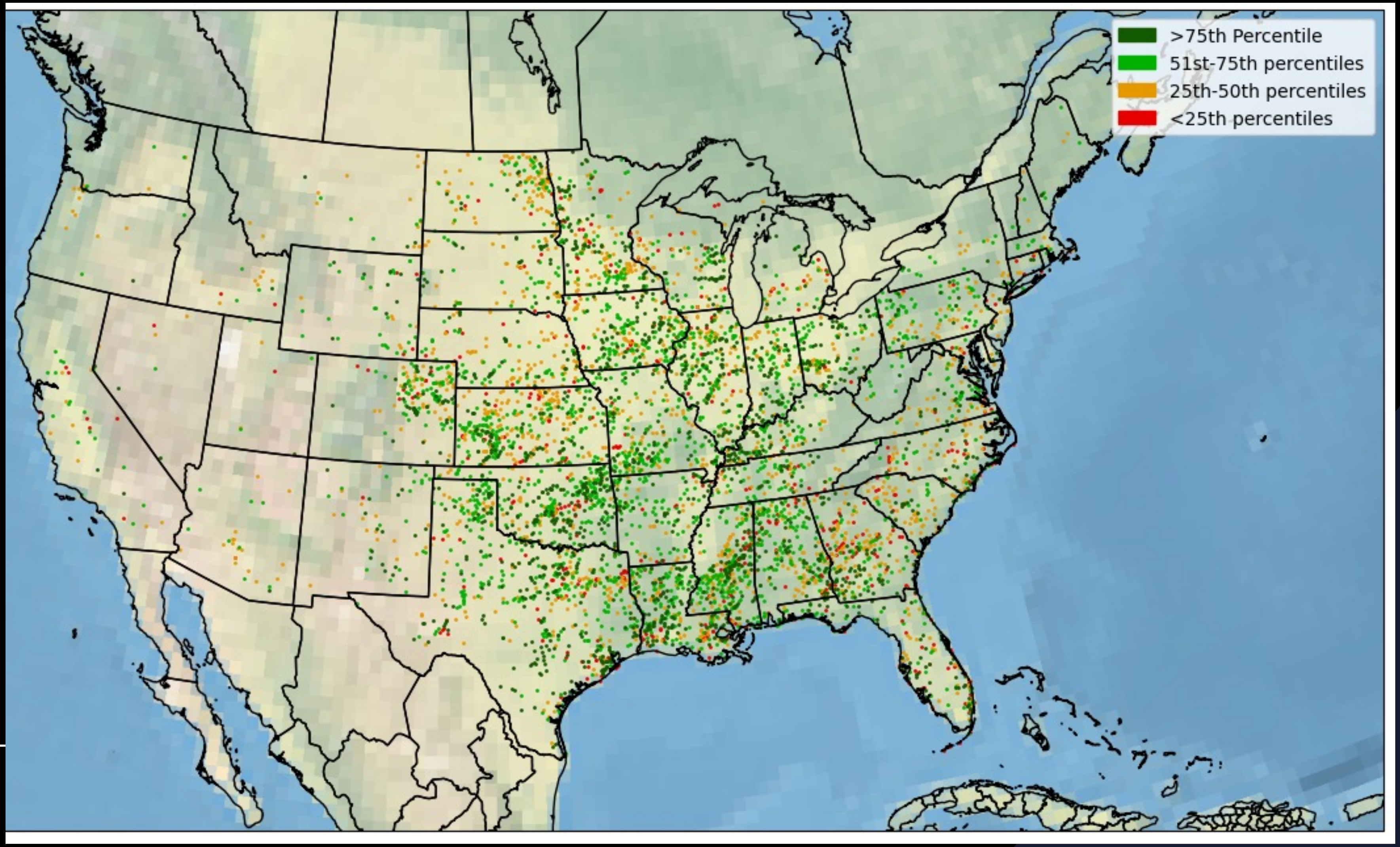


Tornado Genesis Points and 50 cm Soil Moisture Percentiles

>75th percentile:
n=1654
51st-75th percentiles:
n=2082
25th-50th percentiles:
n=1627
<25th percentile:
n=555
(63% at > 50th percentile

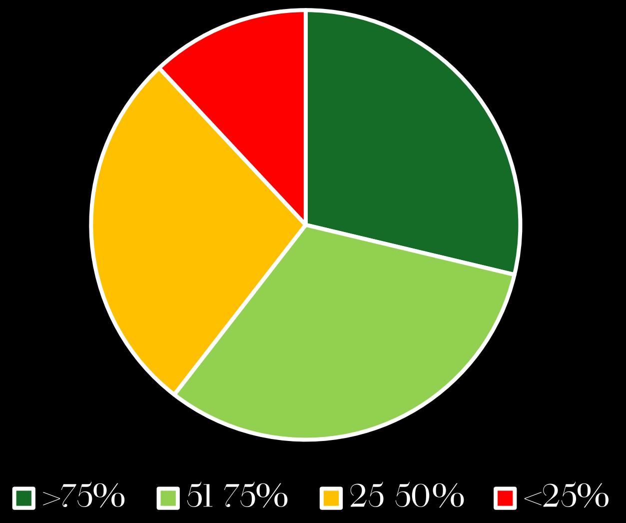
National Tornadoes by SM %



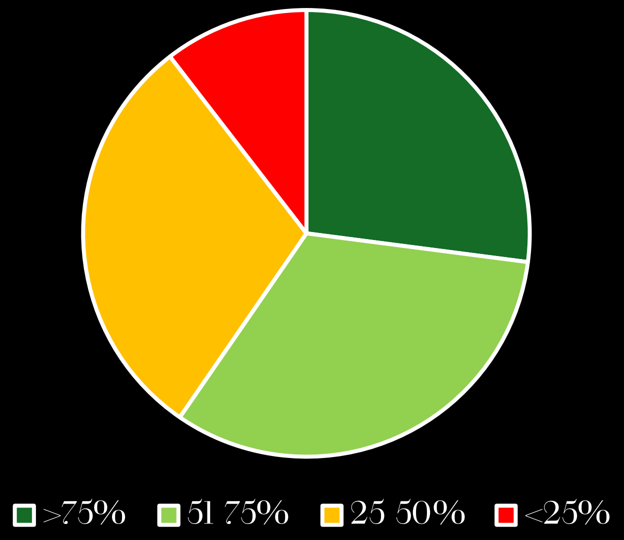


Comparisons by depth:

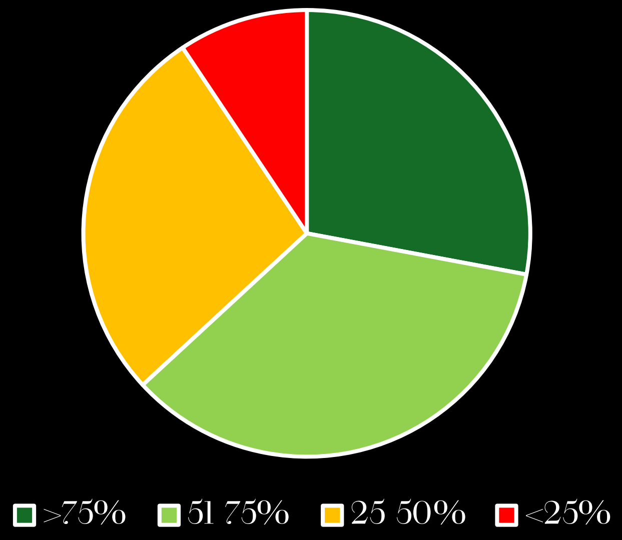
National Tornadoes by SM %
5 cm (59% > 50th)



National Tornadoes by SM %
20 cm (59% > 50th)



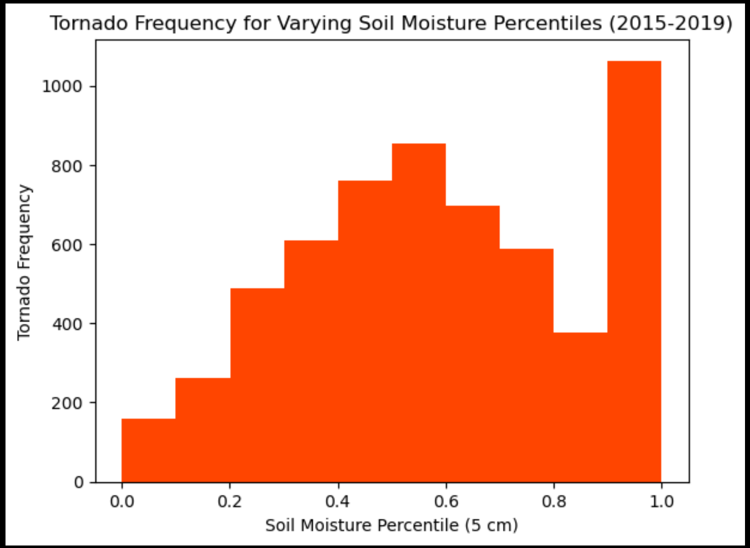
National Tornadoes by SM %
50 cm (63% > 50th)

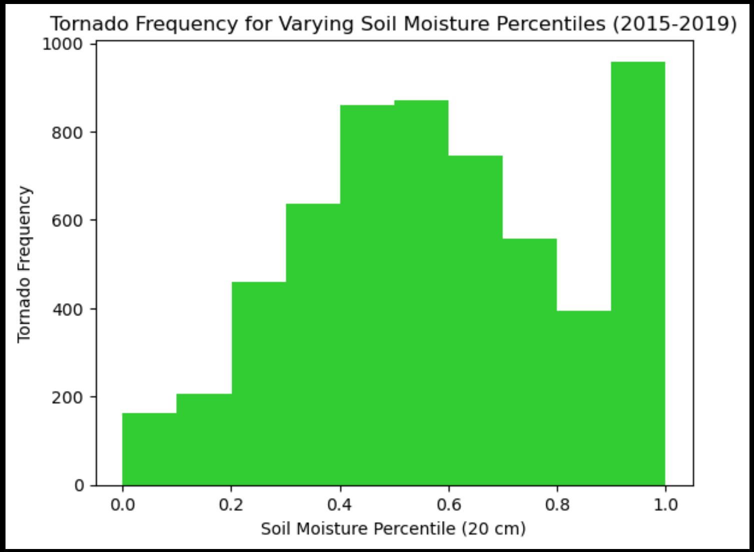


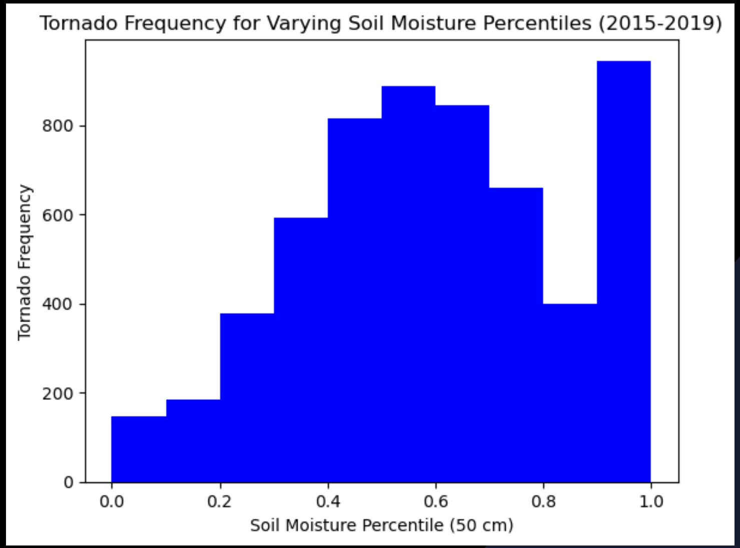
Depth variations do not seem to matter very much.
There is slightly more signal for more tornadoes when deeper soil moisture is moist.

Histograms of soil moisture percentiles vs tornado frequency for CONUS tornadoes:

- Somewhat Gaussian, but strong preference for upper 10^{th} percentile (i.e. really wet soils!)





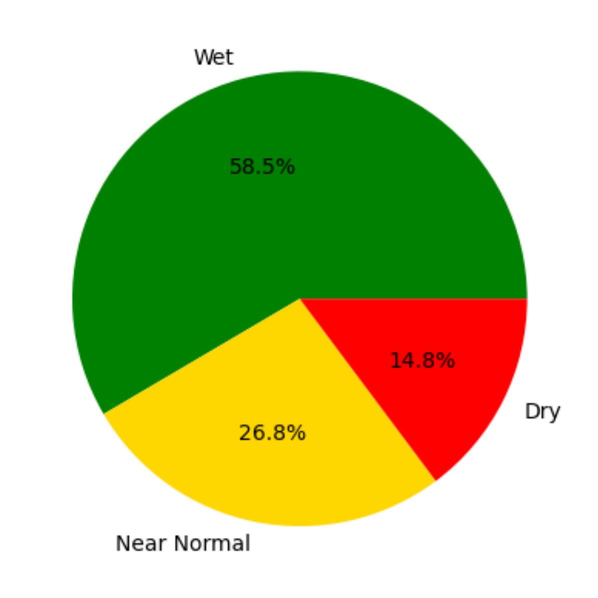


Average SM Percentiles BY YEAR

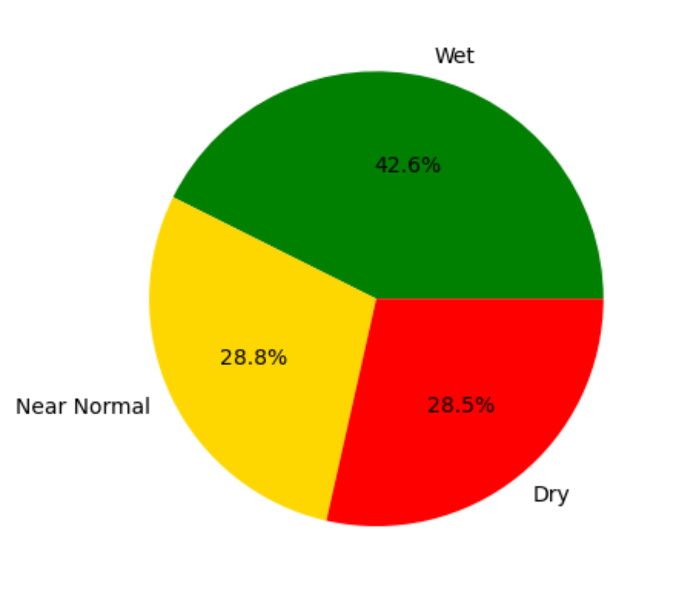
Results: most tornadoes form under wet conditions; minority form with dry soil conditions.
Some inter-annual variability

Wet: >60^{th} percentile
Near Normal: 40^{th} 60^{th} percentiles
Dry: <40^{th} percentile

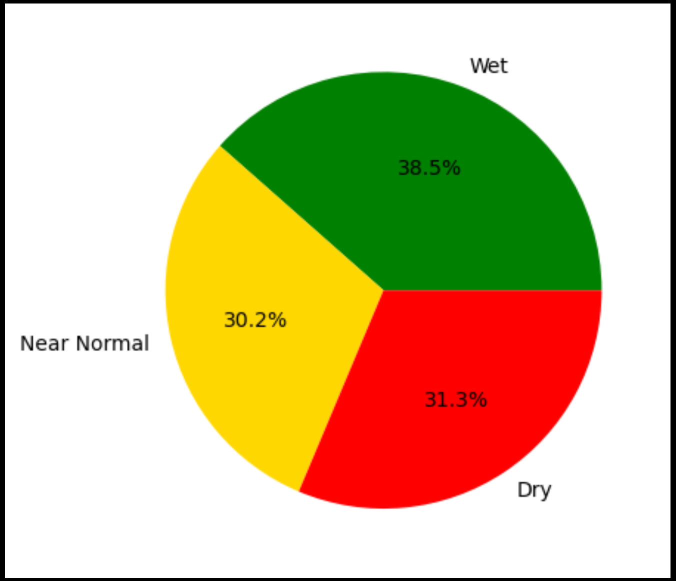
2015 (n = 1170)



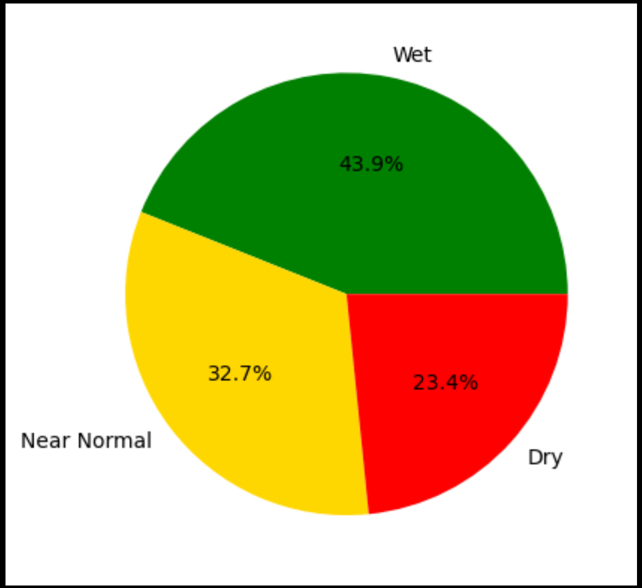
2016 (n = 936)



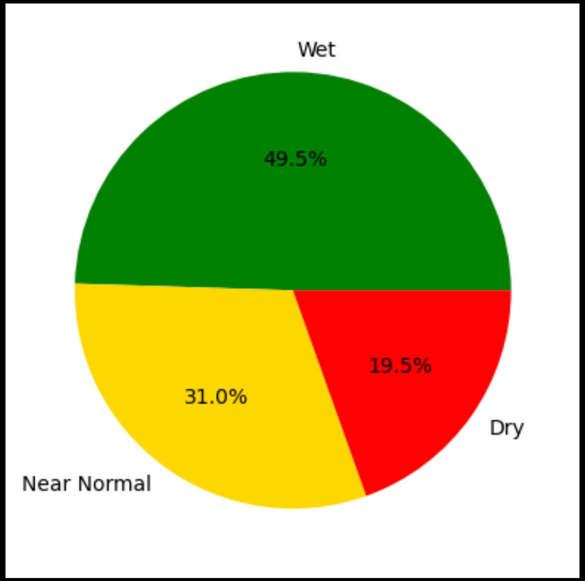
2017 (n = 1343)



2018 (n = 1090)



2019 (n = 1315)

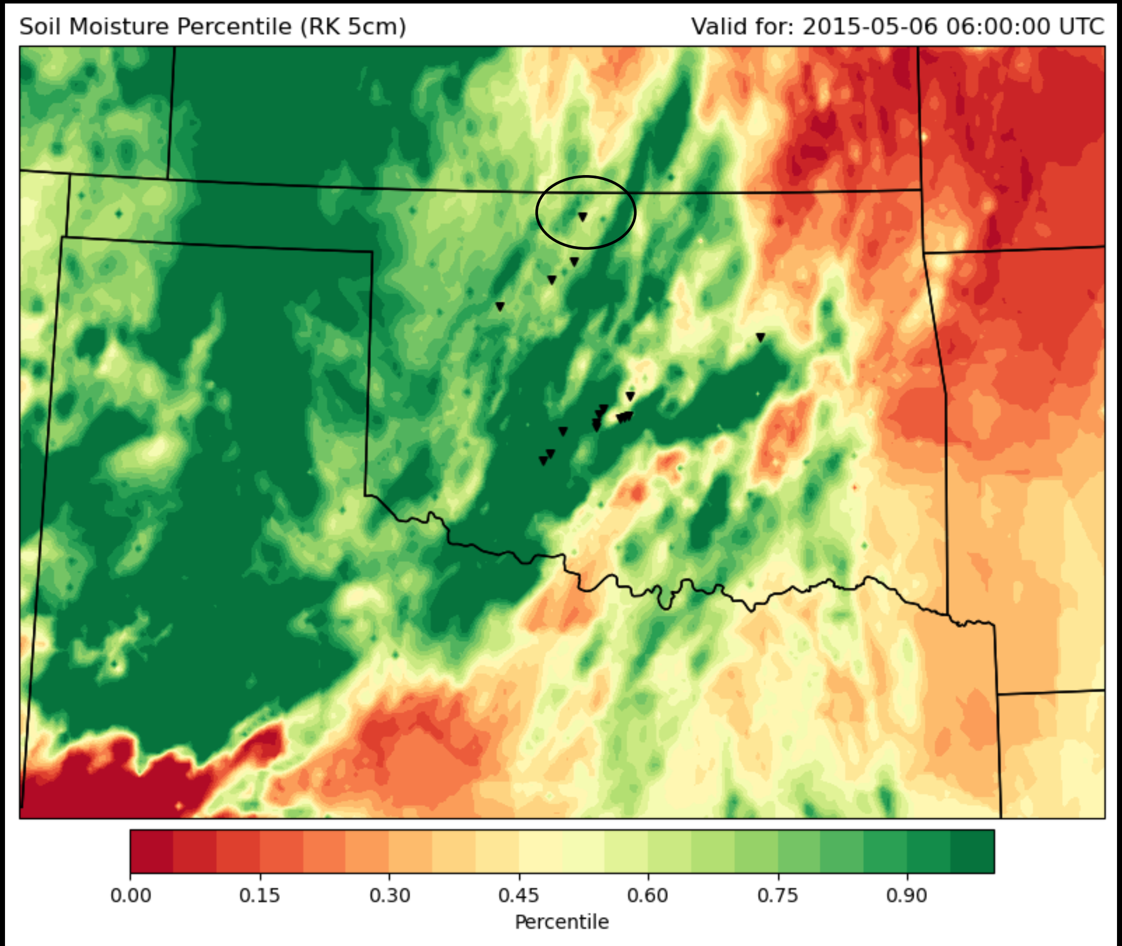


Conclusions from National Dataset (2015-2019)

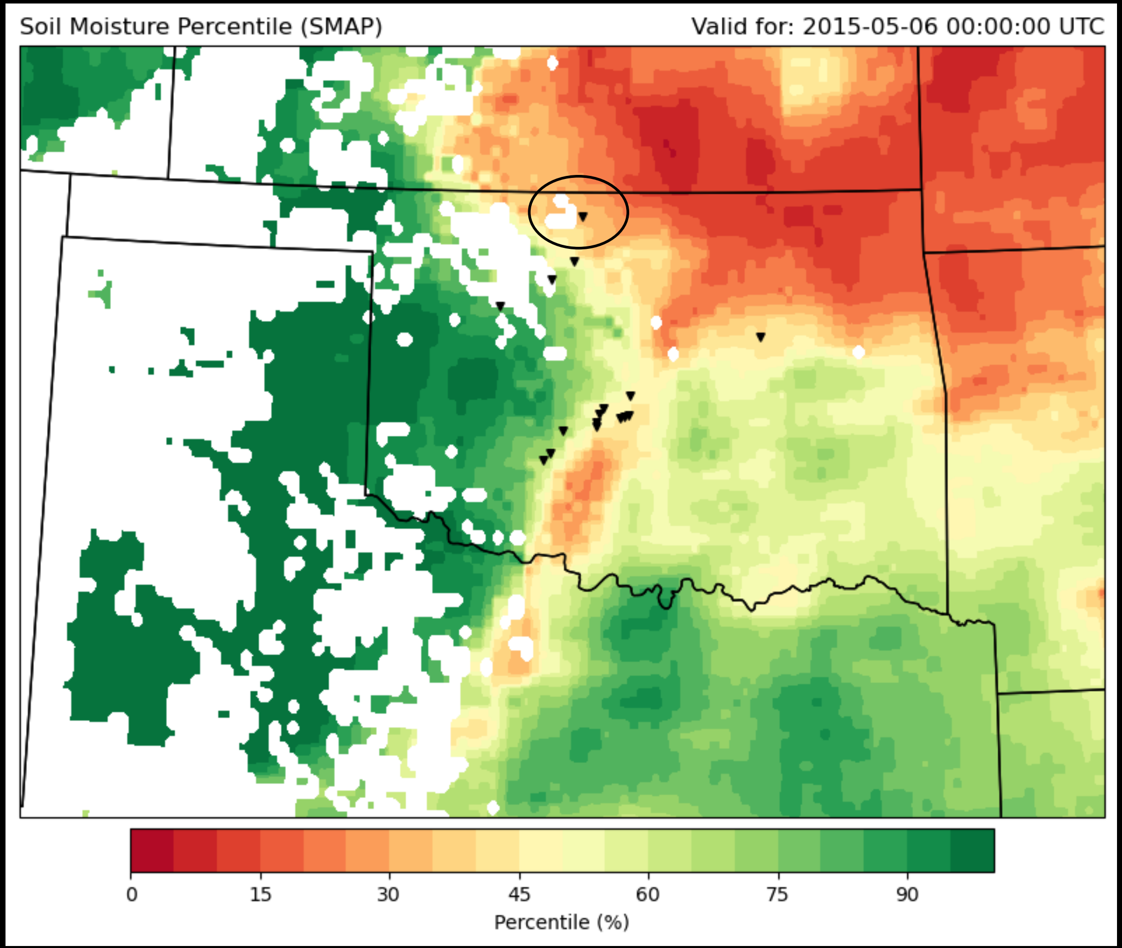
- Tornadoes are more frequent when soil moisture values are higher
- Distribution is somewhat Gaussian, but there is a peak at the highest moisture percentiles
- Some inter-annual variability
- Oklahoma’s trend appears to be similar to national trend

Case Studies: Surface In Situ vs SMAP Level 4

Surface RK

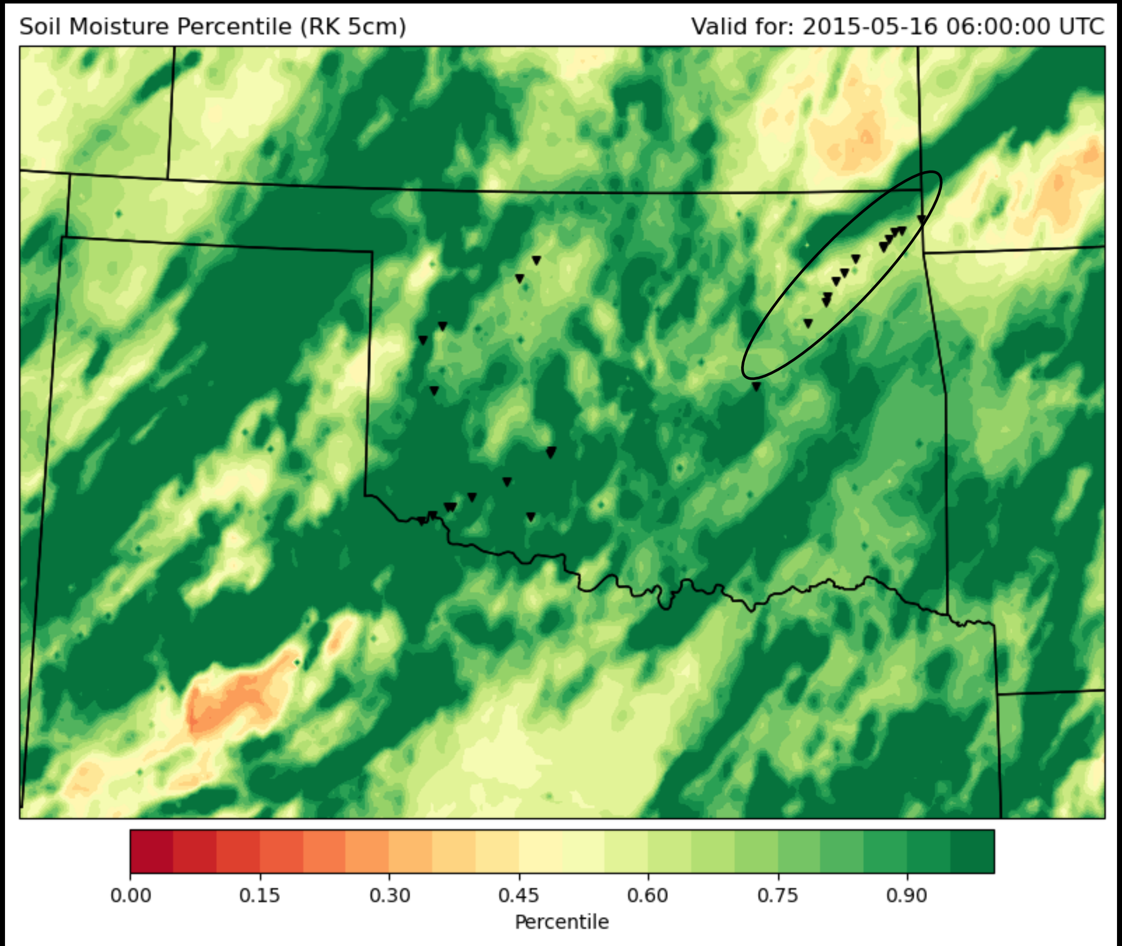


SMAP

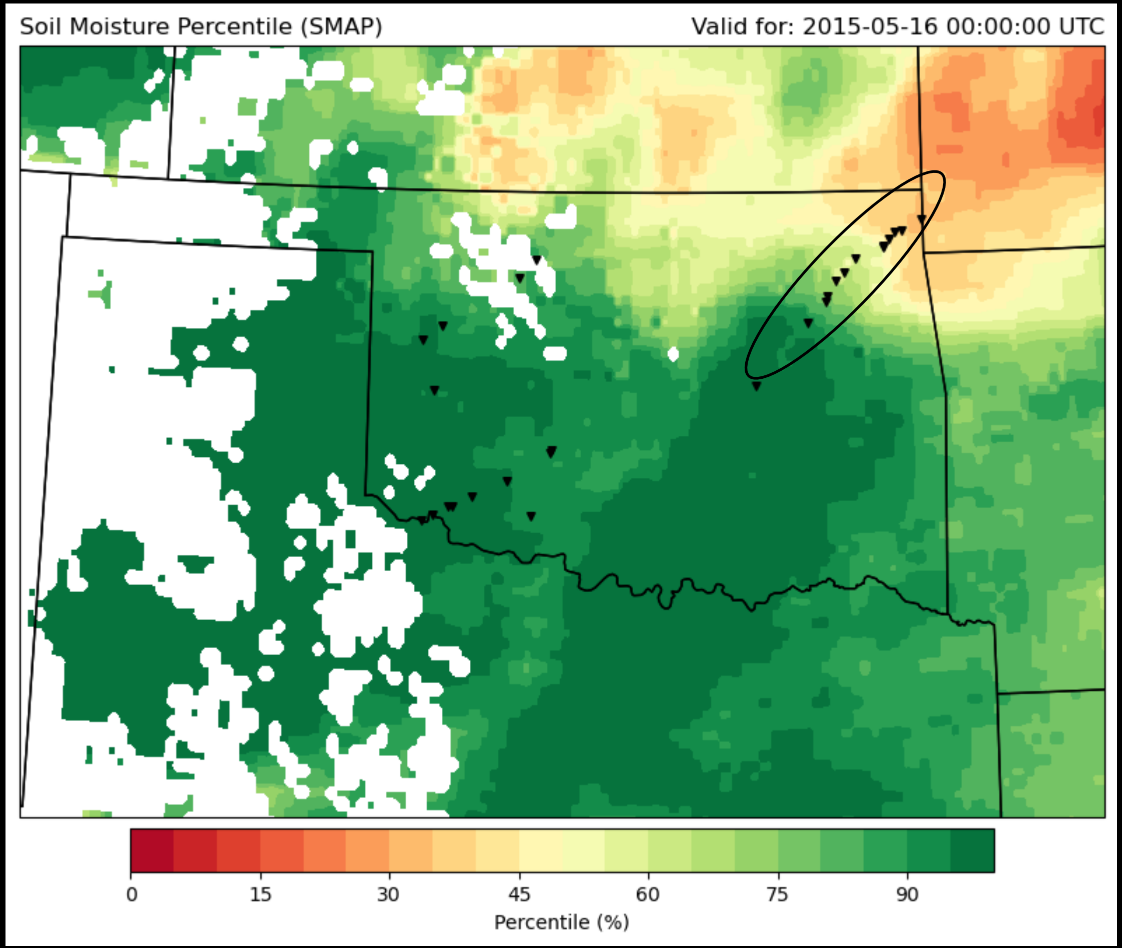


May 6, 2015

Surface RK



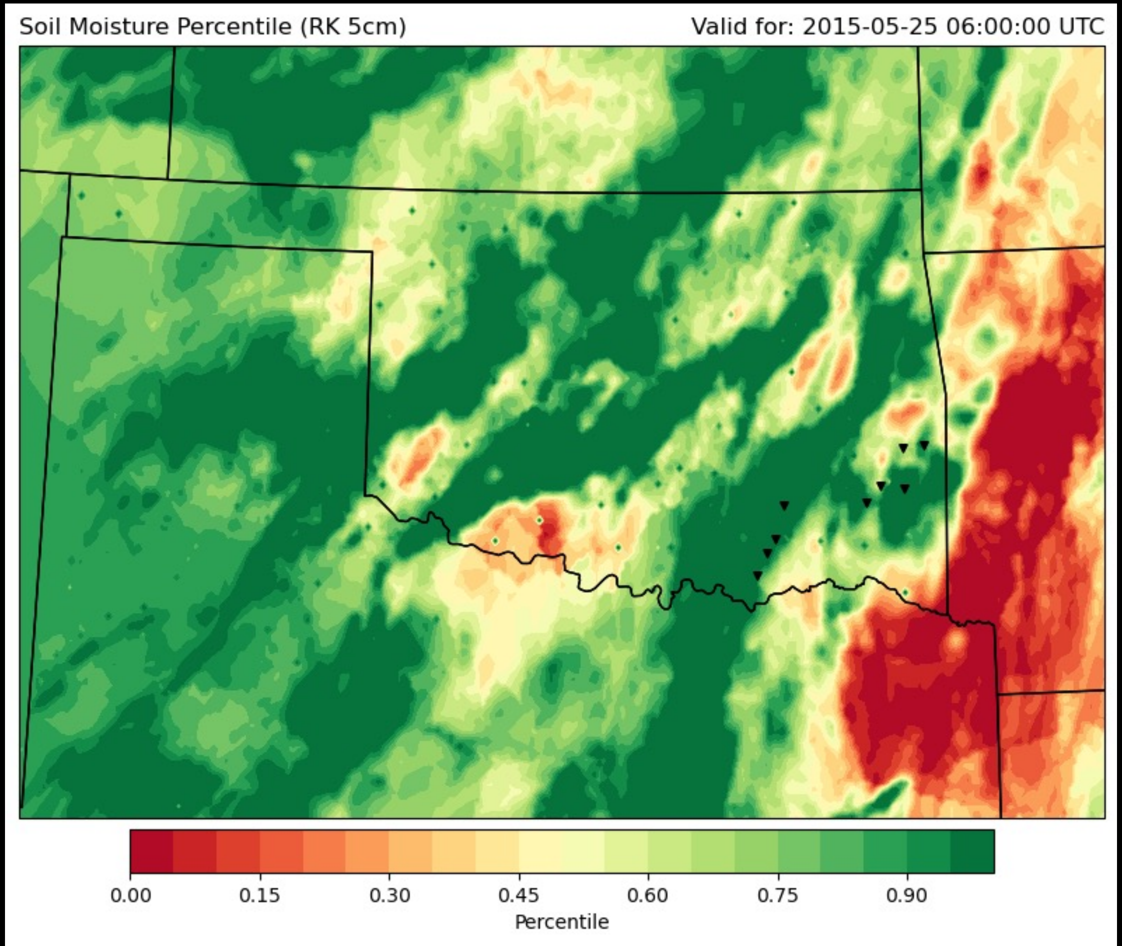
SMAP

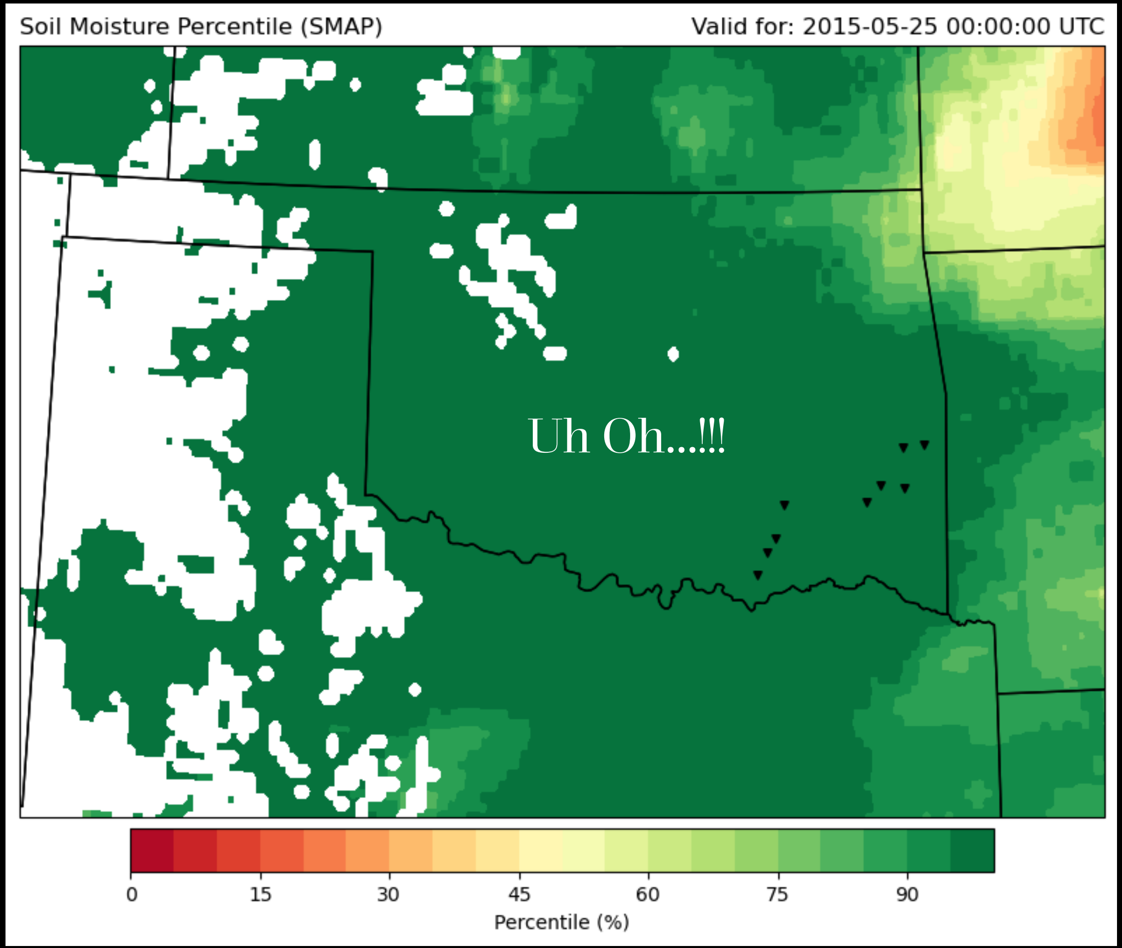


May 16, 2015

Surface RK

SMAP

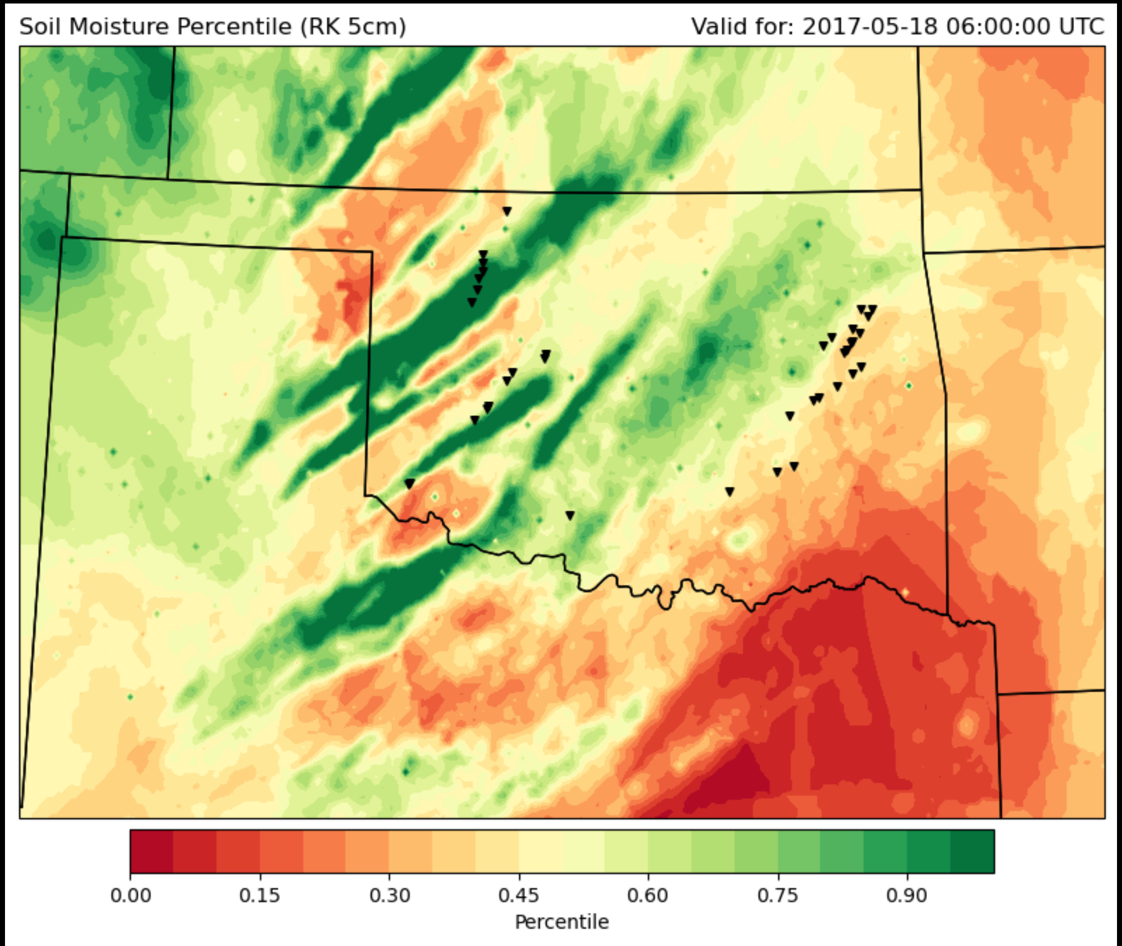


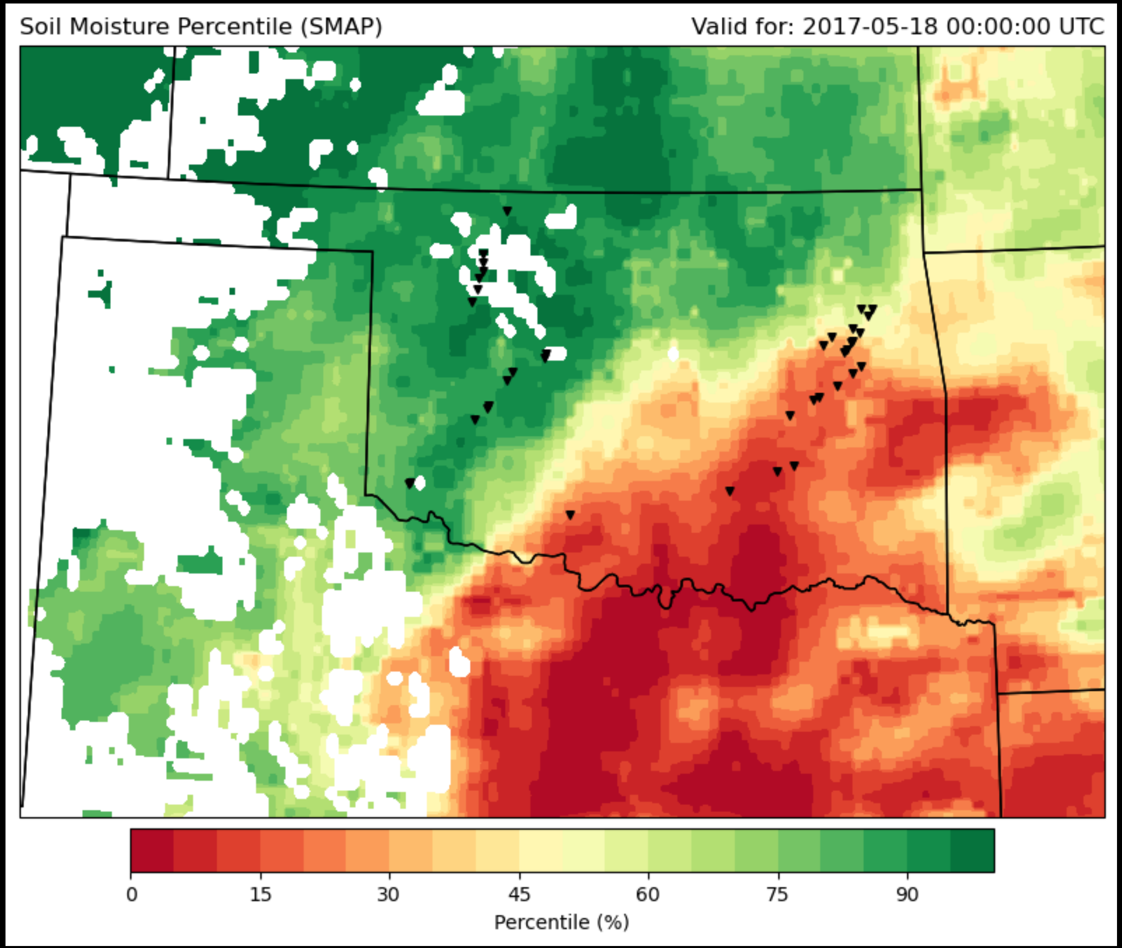


May 25, 2015

Surface RK

SMAP

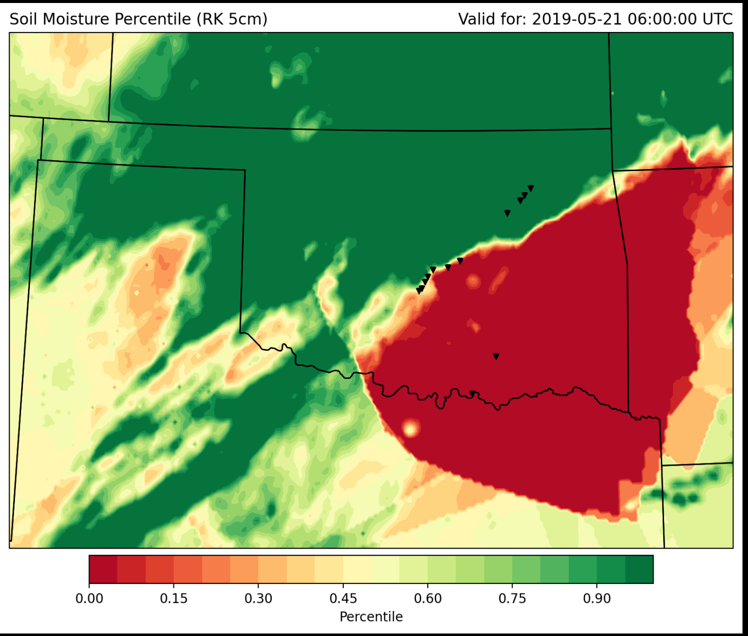




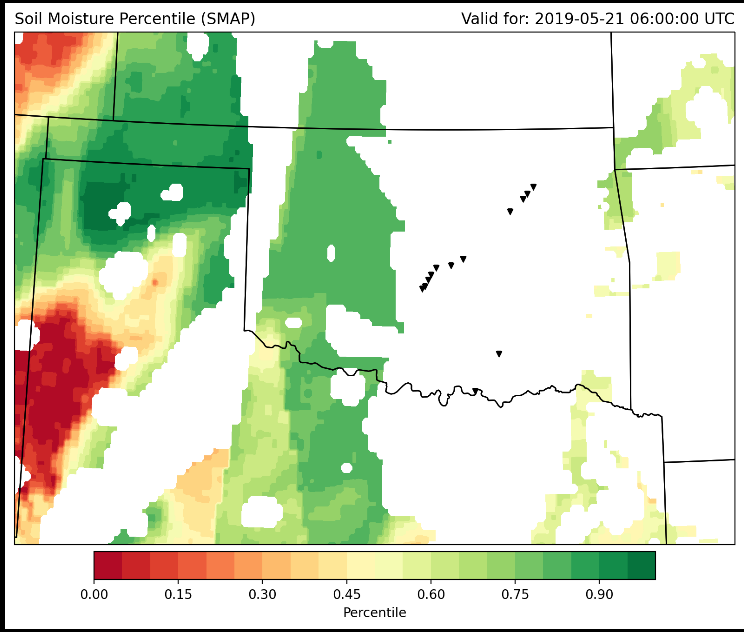
May 18, 2017

Comparison:

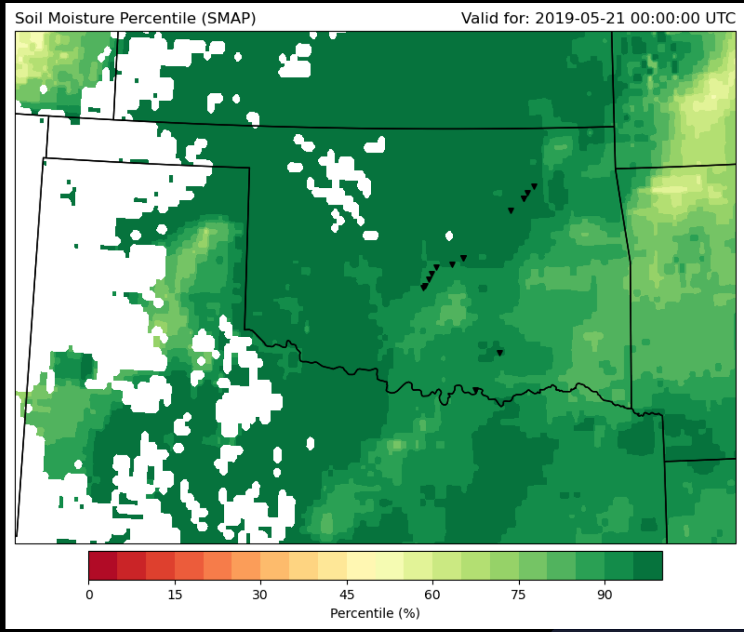
RK



SMAP Level 3



SMAP Level 4



Summary:

- There are differences between the in situ (RK) and SMAP data, sometimes quite noteable
- SMAP L3 data are not available at every location, every day
- Higher resolution data looks to be important for identifying gradients
- Higher resolution SMAP observations would be great!

So what do we need?

- At least daily observations
- Resolution of 10 x 10 km would be great! Smaller even better.
- Accurate observations.

Thank you!

What's next?

- Is there seasonal variation?
- Is there geographic variation?
- Is there a time lag?
- Are soil moisture GRADIENTS important??