

Tornado Forecasting Class Notes - Handout

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Forecasts of surface and upper air maps and various parameters are available from computer models that are run and maintained by the National Weather Service (NWS). These are used by meteorologists to make weather forecasts, including for severe weather. Computer models such as the **NAM** and **RAP** have higher resolution & more detail than the **GFS**; the **HRRR** model has the highest resolution and the most detail. A summary of these models:

- **GFS (Global Forecast System)**: goes out to 16 days, run 4 times per day (12z morning & 00z evening runs are most accurate as they use new sounding observations)
- **NAM (North American Mesoscale)**: goes out to 3.5 days (84 hours), is run 4 times per day
- **RAP (Rapid Refresh)**: goes out to 18 hours (out to 48 hours at 15z/21z/03z/09z), is run hourly.
- **HRRR (High Resolution Rapid Refresh)**: goes out to 18 hours (out to 48 hours at 12z/18z/00z/06z) is run hourly. Has highest resolution detail, best for 1-2 day convective/thunderstorm forecasting.

The **GFS** is used to look ahead longer range (out to 16 days), but it is increasingly unreliable beyond 5-7 days. The early panels can be used as a comparison to the NAM. It is the lowest resolution/least detailed of the models, but is well-established.

The **NAM** is used to look out to 3 days or so, and is more detailed than the GFS. The panels out to 18 or 48 hours can also be used as a comparison to the RAP.

The **RAP** and **HRRR** are short-range models used mostly within 1-2 days of an impending event. The HRRR is updated frequently with available current observations for even more detail.

The **HRRR** with its frequent updating and high resolution is good for convective and thunderstorm forecasting. It has products such as **updraft helicity**, “rotation” tracks on radar forecast panels that suggest where supercell storms may develop. Don’t read these too literally, as they suggest storm mode in general areas, but can vary on specifics from hour to hour.

A good non-NWS model is the **European** model, or **ECMWF**, generated by the **European Center for Medium-Range Weather Forecasts**, going out to 15 days at 12z and 00z. Not available on some sites, it is a respected/useful comparison to the GFS.

Some free sites with computer model forecast graphics:

College of DuPage: weather.cod.edu/forecast (HRRR, RAP, NAM, GFS, & ECMWF)

Pivotal Weather: www.pivotalweather.com/model.php (HRRR, RAP, NAM, GFS, & ECMWF)

TwisterData: www.twisterdata.com (RAP, NAM, & GFS)

UCAR / NCAR weather: weather.rap.ucar.edu/model (RAP, NAM, & GFS)

Storm Prediction Center (SPC) mesoanalysis: www.spc.noaa.gov/exper/mesoanalysis – real-time severe weather fields from 1-hr RAP forecasts updated by surface obs, along with RAP model 2 to 6 hour forecasts of these fields

IMPORTANT NOTE: - Computer models, at best, are only an approximation & estimation of the atmosphere.

- As models go farther out in time, errors can amplify to make large inaccuracies.

- Use computer models only as an “opinion” to be considered and compared with other information & experience.

Reading UTC time on weather maps: Computer models & weather maps use “UTC” or “z” time stamps:

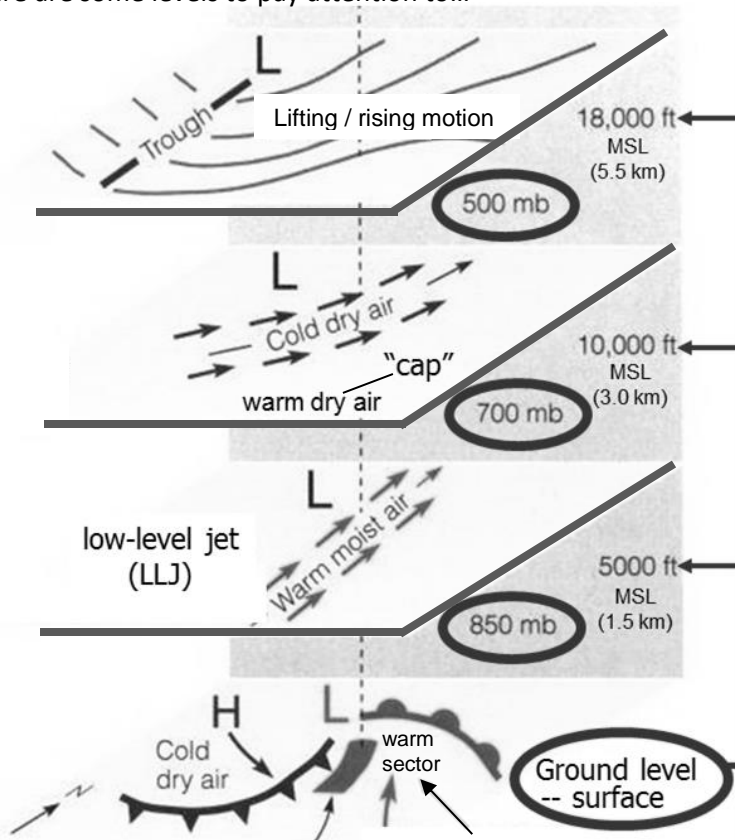
(note: 2100 UTC, 21 UTC, 21z, & 2100z are all different ways of displaying 4:00 pm CDT in Universal Time Coordinated)

1200 UTC =	7:00 a.m. CDT	6:00 a.m. MDT	(6:00 a.m. CST)
1500 UTC =	10:00 a.m. CDT	9:00 a.m. MDT	(9:00 a.m. CST)
1800 UTC =	1:00 p.m. CDT	noon MDT	(noon CST)
2100 UTC =	4:00 p.m. CDT	3:00 p.m. MDT	(3:00 p.m. CST)
0000 UTC =	7:00 p.m. CDT	6:00 p.m. MDT	(6:00 p.m. CST)
0300 UTC =	10:00 p.m. CDT	9:00 p.m. MDT	(9:00 p.m. CST)
0600 UTC =	1:00 a.m. CDT	midnight MDT	(midnight CST)
0900 UTC =	4:00 a.m. CDT	3:00 a.m. MDT	(3:00 a.m. CST)

- **NOTE:** Dates “jump ahead” a day in the evening hours with UTC, starting at 0000 UTC:

4:00 pm CDT on May 17 is 2100 UTC on **May 17**, but 7:00 pm CDT on May 17 is actually **0000 UTC on May 18**.

Upper air maps are slices through the atmosphere at increasing elevations above ground level (the surface map). Here are some levels to pay attention to...



Things to look for regarding severe weather on upper air maps from computer model forecasts:

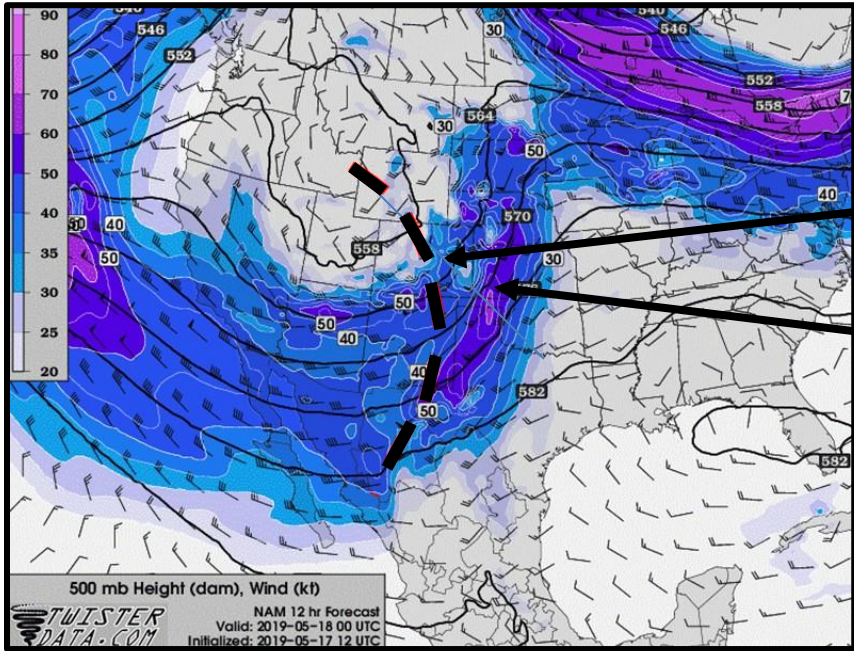
500 mb map (approx. 18,000 ft MSL):
 - use this level to check for wave / trough disturbances aloft that force air upward & can trigger thunderstorms.
 - also check for stronger wind speeds aloft (30-35 knots or greater) that can organize storms into supercells.

700 mb map (approx. 10,000 ft MSL):
 - use this level to check for areas of warm air aloft that can "cap" and inhibit thunderstorm development.

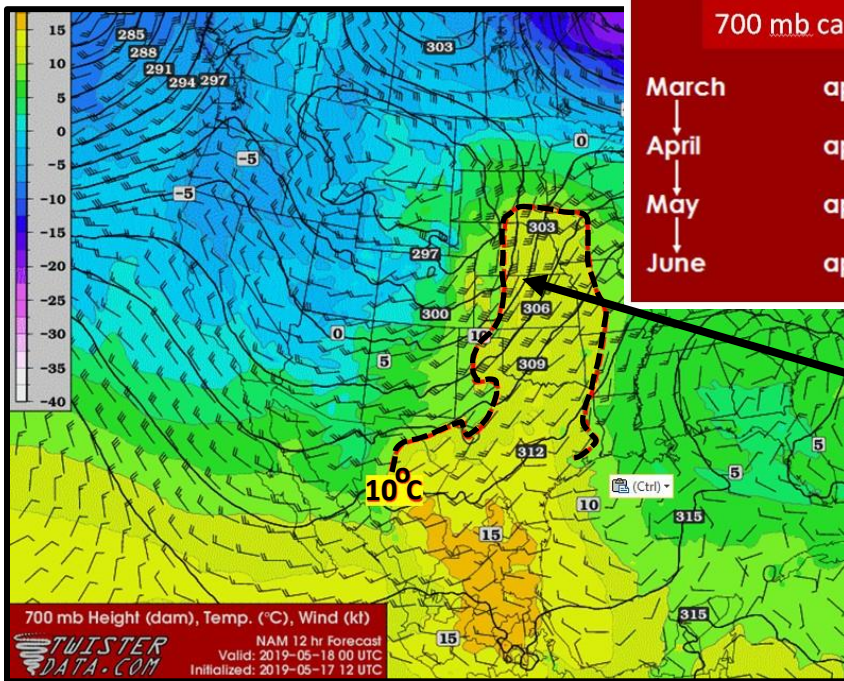
850 mb map (approx. 5,000 ft MSL):
 - use this level to check for stronger winds 1-2 km above ground (the **low-level jet**) that contribute to low-level wind shear & storm-relative helicity [SRH] that can help generate tornadoes.

Surface map (ground level):
 Look for lows, fronts, wind shifts, areas of converging winds, heating, and moisture (dew points in the 50s/60s/70s° F) to locate where organized thunderstorms might form.

Starting at 500 mb (the mid-levels of the atmosphere) and working downward in elevation, let's examine a tornado case & some features important to severe weather using computer model forecasts of upper air maps:



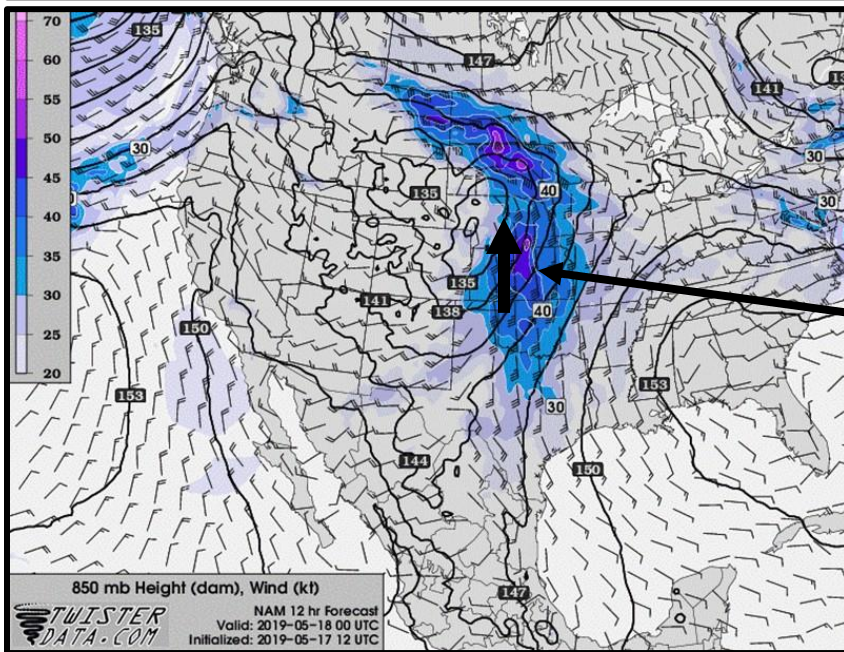
Here is a 12-hour NAM model forecast of winds & flow at **500 mb**, valid at 7 pm CDT on May 17 (0000 UTC on May 18 in UTC time). Notice the strong wave disturbance (thick dashed line) forecast to come out into the central Plains, providing strong lift. Also notice the strong mid-level winds (darker shadings) over the OK panhandle/KS/NE area, supportive for organizing & maintaining supercell storms. If enough low-level moisture from the Gulf of Mexico is in place over the Plains, this looks like a good setting to produce severe weather.



700 mb cap "guide"

March	approx $\geq 5-6^{\circ}\text{C}$
↓	
April	approx $\geq 7-8^{\circ}\text{C}$
↓	
May	approx $\geq 9-11^{\circ}\text{C}$
↓	
June	approx $\geq 12-13^{\circ}\text{C}$

Here is a 12-hour NAM model forecast of winds & temperatures ($^{\circ}\text{C}$) at **700 mb**, valid at 7 pm CDT on May 17. The dashed line I've added encloses a "tongue" of warm temperatures $> 10^{\circ}\text{C}$ forecast aloft at around 10,000 ft MSL. In mid-May, that suggests a "cap" that would inhibit or suppress thunderstorms east of western KS & NE, and over most of OK.



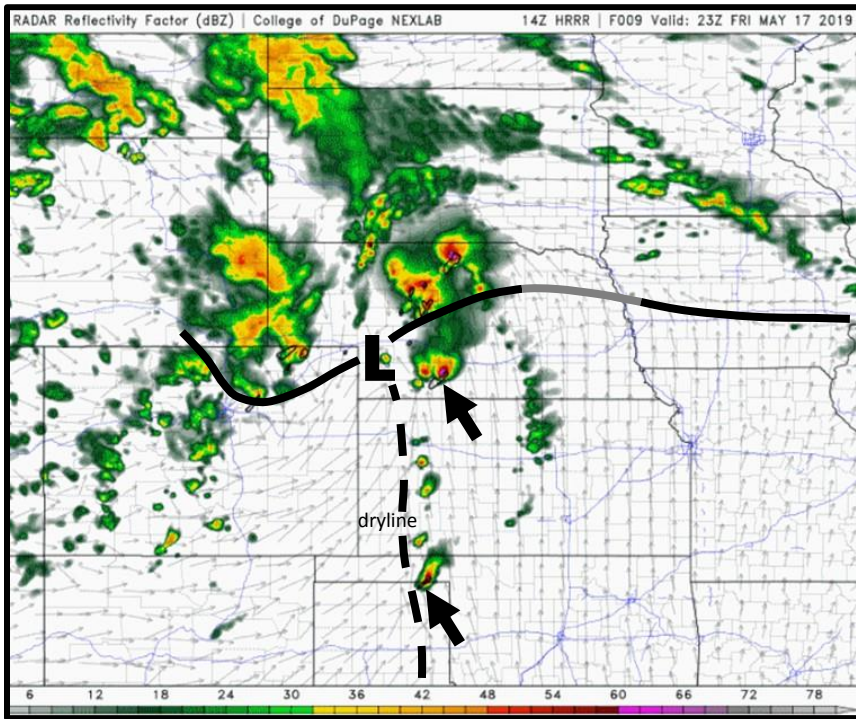
This is a 12-hour NAM model forecast of winds & flow at **850 mb**, valid at 7 pm CDT on May 17. The thick black arrow I've added shows the axis of the **low-level jet** at around 5000 ft MSL where strong low-level winds (darker shadings) are forecast to increase into early evening. This would enhance low-level wind shear that could support low-level rotation in any thunderstorms that form over western KS & NE.

So, the NAM computer model upper air forecasts above suggest that thunderstorms will form over western KS & NE in response to the strong wave at 500 mb moving into the Plains where capping at 700 mb is forecast to be weakest. Strong winds at both 500 mb (mid-levels) and 850 mb (lower levels) also suggest support for rotating supercell storms that could produce tornadoes.

To get more specific, we can look at forecasts of radar reflectivity from both the NAM & RAP models, and also the higher resolution HRRR model to see if those models agree with our assessment above. Will storms, some with rotation, form over western KS & NE?

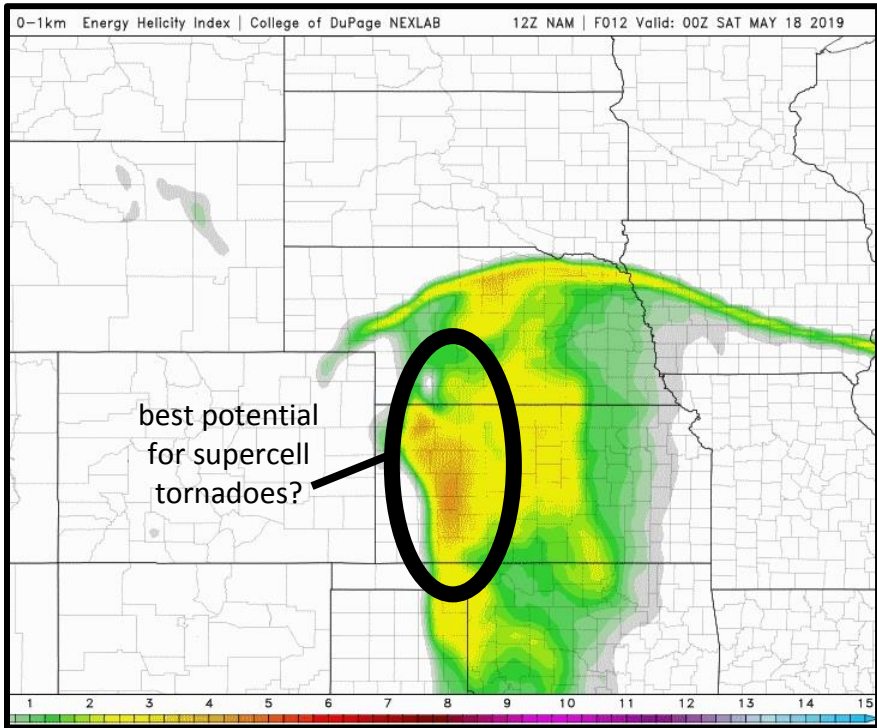
There's not room here to show the NAM radar reflectivity forecast valid at 7 pm CDT on May 17, but it did show a cluster of strong storms forming over southwest NE by 7 pm CDT.

Zooming in on the central U.S., the higher resolution HRRR radar reflectivity forecast (see next page) from mid-morning on May 17th, valid at late afternoon (2300 UTC or 6 pm CDT), agreed with the NAM forecast, showing that strong storms would form over southwest NE by evening. But, unlike the NAM model, it also suggested that a strong storm or two would form over the OK panhandle moving into southwest KS:

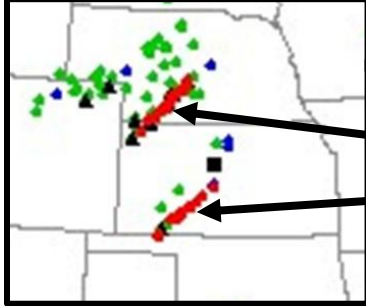


This is a 9-hour HRRR model forecast of composite radar reflectivity valid at 6 pm CDT on May 17. It suggests that rotating storms will form both in southwest NE and the OK Panhandle, possibly moving up into southwest KS (see large black arrows). Looking more closely, the small black "elongated areas" or lines at the south end of these forecast "storms" are the HRRR model indicating tracks of rotation in these cells, suggesting that they would be supercells if they actually do develop. I've also added surface features (a low & fronts) from the HRRR implied by the small gray vector arrows that show surface wind flow forecast by the HRRR model.

To look further at the potential for tornadoes, we'll go back the NAM model zoomed in on the central U.S., looking at a forecast of combinations of instability and low-level wind shear that might support stretching and low-level rotation in storms, suggesting potential for tornadoes when added to the HRRR information above:



Here is a 12-hour NAM model forecast of 0-1 km Energy-Helicity Index (EHI) suggesting where the best combinations of low-level instability & low-level wind shear will be at 7 pm CDT on May 17. The largest EHI values (around 4.0) are circled in black. Notice that those favorable instability/shear combinations are located very near where rotating storms were forecast on the HRRR radar reflectivity forecast above. This in turn suggests that there would be significant tornado potential with any discrete supercells that develop over southwest NE, and also the OK panhandle into southwest KS.



SPC storm reports
May 17, 2019

As it turned out, the model forecasts above did pretty well, supported by our earlier assessment of upper air forecast graphics.

Two long-track tornadic supercells occurred over southwest NE and southwest KS during the late afternoon and evening. The strongest tornadoes were rated EF3.

For supercell tornadoes to develop, what's needed is:

- Thunderstorms must form! - a wave disturbance aloft for lift & rising motion / instability / no capping
- Low-level wind shear – to help generate low-level rotation in storm updrafts
- Deep-layer wind shear - strong winds in mid-levels to support & maintain supercell storms
- Relatively low cloud bases (LCL heights) – to reduce evaporative cooling that could undercut updrafts & interfere with low-level rotation

In the May 17 case we just looked at briefly, the 500 mb forecast showed a strong wave disturbance in mid-levels moving into the Plains, providing lift to initiate thunderstorms, as well as strong mid-level winds to help organize and maintain supercells. The 700 mb temperature forecast suggested that western KS and southwest NE would not be capped, while areas farther east and south would inhibit thunderstorms. And the 850 mb forecast showed a strong low-level jet developing over western KS into southwest NE that would provide low-level wind shear for low-level storm rotation where thunderstorms were expected to form..

The Energy-Helicity index forecast also suggested significant combinations of low-level wind shear and instability where thunderstorms were expected to form over southwest KS and southwest NE. This suggested a good possibility of tornadic supercells in those areas, with tornado potential amplified by the HRRR radar reflectivity forecast suggesting rotating storms over those same areas.

One thing we didn't look at was LCL (lifting condensation level) heights, which were forecast by the NAM model to be fairly low (below 1200 m above ground) over western KS and southwest NE. This would also give added support for supercell tornadoes.

So, it appeared that all the factors in the list above were present on May 17, increasing the potential for supercell tornadoes. The main question was whether tornadic storms might be limited to southwest NE, because the NAM radar reflectivity forecast (not shown) did not indicate storms farther south over Kansas. But the HRRR radar reflectivity forecast did indicate storms moving into southwest KS, and our temperature assessment at 700 mb suggested that capping was relatively weak over western KS, confirming the possibility that storms might form there. And indeed, there were tornadoes in both areas.

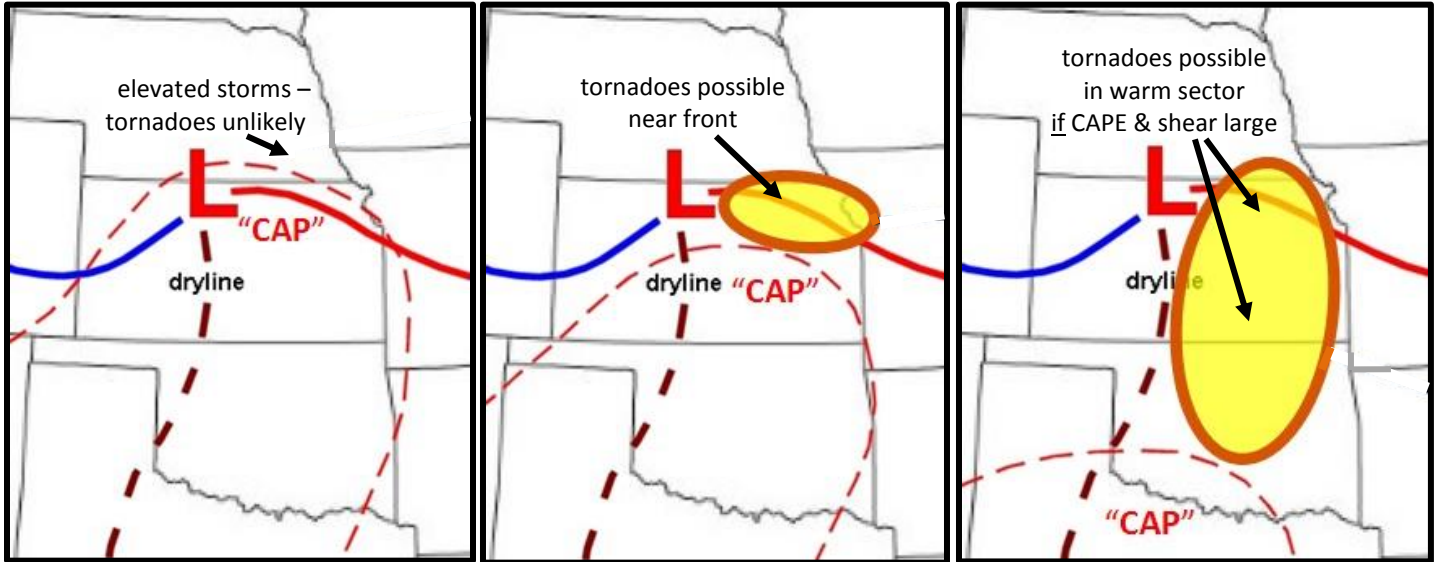
Some additional reference material:

When winds aloft at the 700 mb level are from a southwesterly direction a “cap” of hot, dry air can move out into the Plains, acting like a “lid” to suppress thunderstorm development in some areas. Assessing whether there is a cap and where it might be located is important for thunderstorm forecasting, so here's a rough guide for estimating the cap using **700 mb** temperatures at different times of year:

	Spring		Fall
March	approx $\geq 5-6^{\circ}$ C	August	approx $\geq 12^{\circ}$ C
April	approx $\geq 7-8^{\circ}$ C	September	approx $\geq 9-11^{\circ}$ C
May	approx $\geq 9-11^{\circ}$ C	October	approx $\geq 7-8^{\circ}$ C
June	approx $\geq 12-13^{\circ}$ C	November	approx $\geq 5-6^{\circ}$ C

NOTE: This chart does not work well in the High Plains of eastern NM-CO-WY-MT, far western NE-SD, etc., due to elevation issues. Also, strong surface heating (90's° F or 100's° F) can initiate very high-based storms in otherwise “capped” areas. Such storms from strong daytime heating in areas that appear capped typically dissipate after sunset.

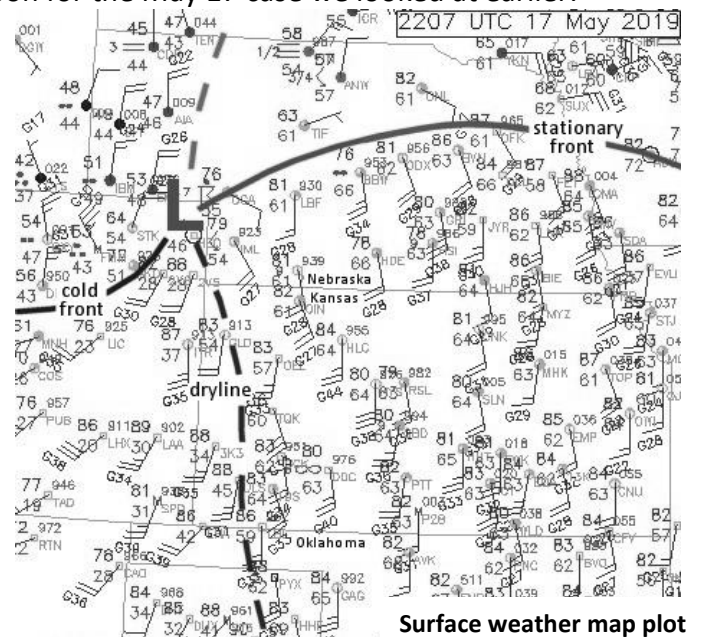
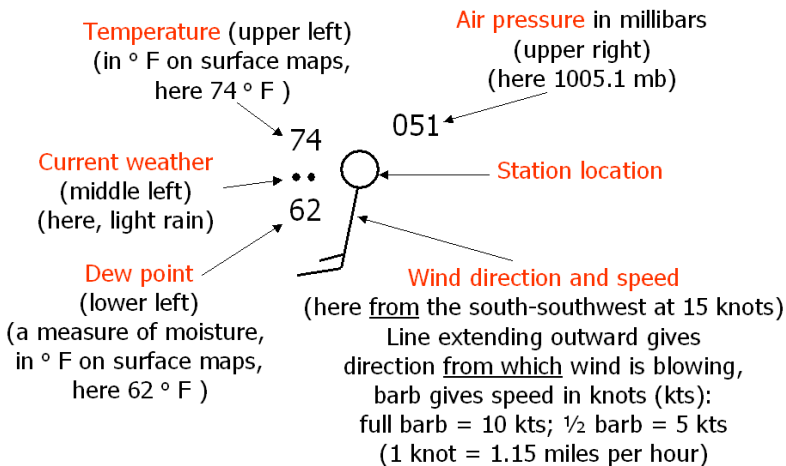
Depending on the location of the cap, tornadic storms may or may not be likely in the warm sector southeast of a surface low:



Monitoring surface maps is important for adjusting forecasts as things evolve during the day. Below is the observed surface map with features analyzed at late afternoon for the May 17 case we looked at earlier:

Surface Maps

Key for surface weather map observation station plots:



Boundaries and wind shifts such as cold fronts/warm fronts/stationary fronts/drylines and storm outflow can help generate thunderstorms through converging winds & lift. These boundaries are located by looking carefully for:

- Sharp temperature changes over a short distance
- Significant changes in moisture (dew point)
- Sharp changes in wind direction

Some sources for real-time weather maps, satellite, and radar:

UCAR / NCAR weather: weather.rap.ucar.edu (surface, satellite, and radar)

College of DuPage weather: weather.cod.edu/analysis (surface maps)

weather.cod.edu/satrad (satellite and radar)

NWS analysed surface maps: www.wpc.ncep.noaa.gov/html/sfctxt.html

SPC mesoanalysis: www.spc.noaa.gov/exper/mesoanalysis (surface, upper air & parameter maps)

A good way to learn is from looking back at archives of maps from past severe weather days. Here are some online sites with archives of weather maps:

Recent data (past few days):

College of DuPage (recent model runs): weather.cod.edu/forecast (model runs from past 1-3 days)

Pivotal Weather (recent model runs): www.pivotalweather.com/model.php (model runs from past 1-3 days)

UCAR weather data (recent data): weather.rap.ucar.edu (last 5 days satellite, radar, & surface)

SPC mesoanalysis (recent data): www.spc.noaa.gov/exper/mesoanalysis/new (maps from past 4 days; choose sector & use “Image Archive & Loops” button)

Data going back several years:

UCAR large weather data archive: www2.mmm.ucar.edu/imagearchive (various maps back to 1996)

SPC large mesoanalysis archive: www.spc.noaa.gov/exper/ma_archive (various maps back to 2005)

SPC weather events large archive: www.spc.noaa.gov/exper/archive/events (various maps back to 2000)

Plymouth State weather archive: vortex.plymouth.edu/myowxp (various maps, some back to 2000)

When forecasting, do what works for you, and have fun with it !

- Jon Davies 2020

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