Frontal Passage and Cold Pool Climatology from Oklahoma Mesonet Surface Observations

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Thesis Defense

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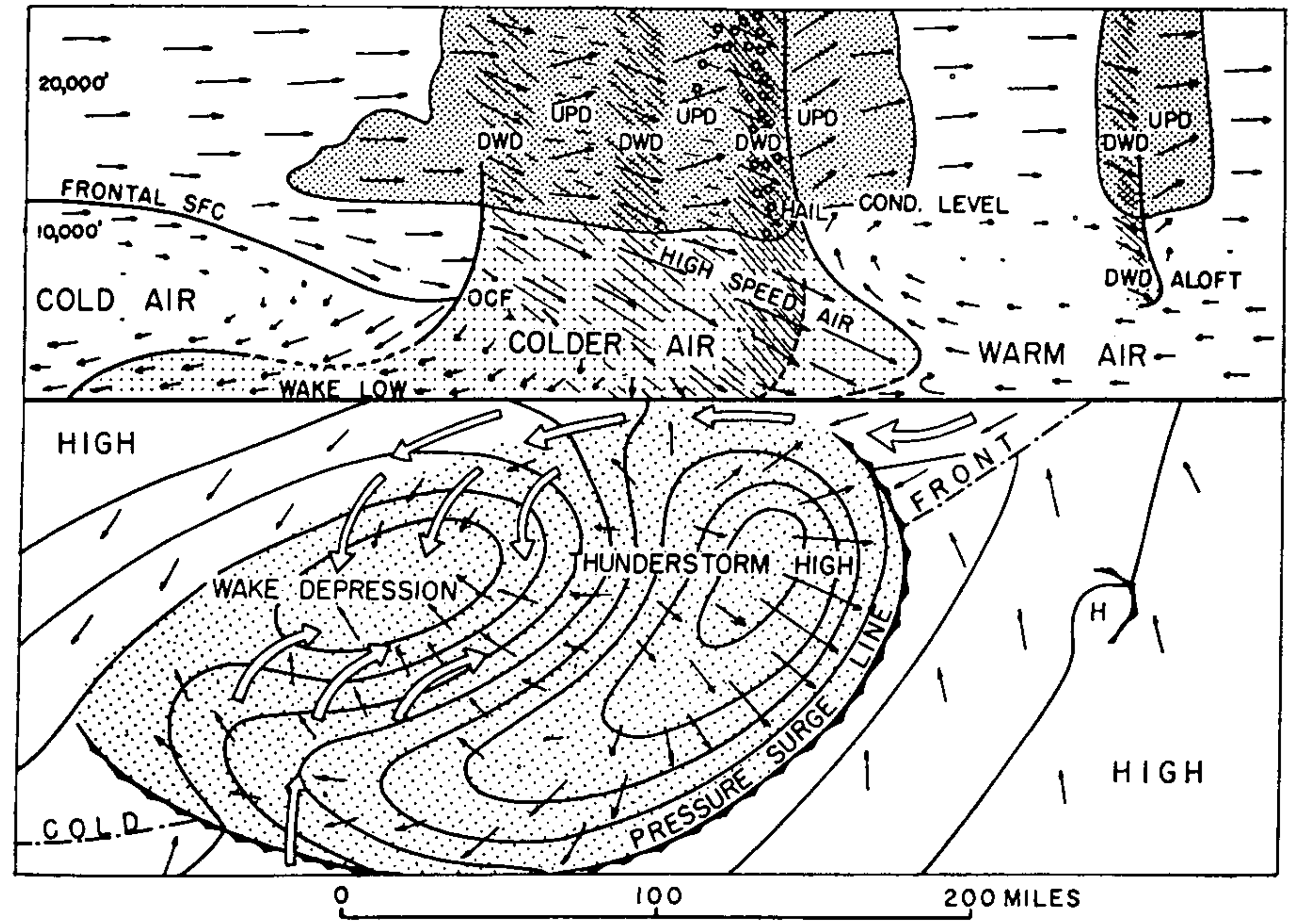
Introduction - Defining Cold Pools

- Newton (1950) found "shallow local cold fronts" in regions of rain-cooled air. These rain-cooled regions can be considered cold pools.
- Fujita (1955) identified a "surge" in pressure marking the front of a squall-line.
- The thunderstorm high (or mesohigh) is a region with strong downdrafts, high pressure, and surface divergence. Generally coincides with the cold pool.
- The wake depression is a low pressure area of convergence behind the main convection.



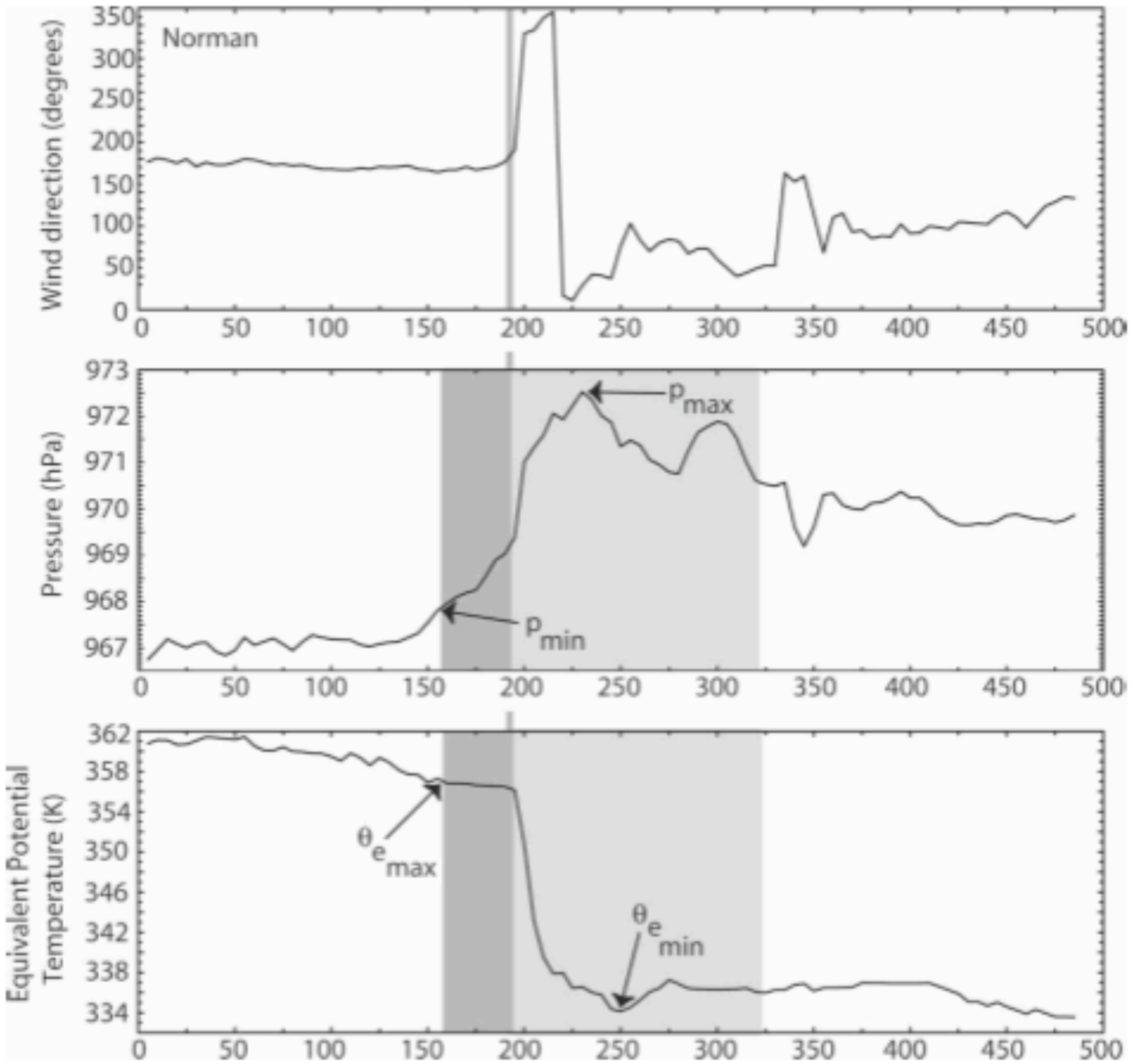
Schematic of a squall-line thunderstorm. (Fujita 1955, Fig. 18)

Introduction - Defining Cold Pools

There is a large variety in cold pool structures and causes, from downdrafts, evaporative precipitation, and radiative causes.

For the purposes of this study, cold pool features will be considered to include:

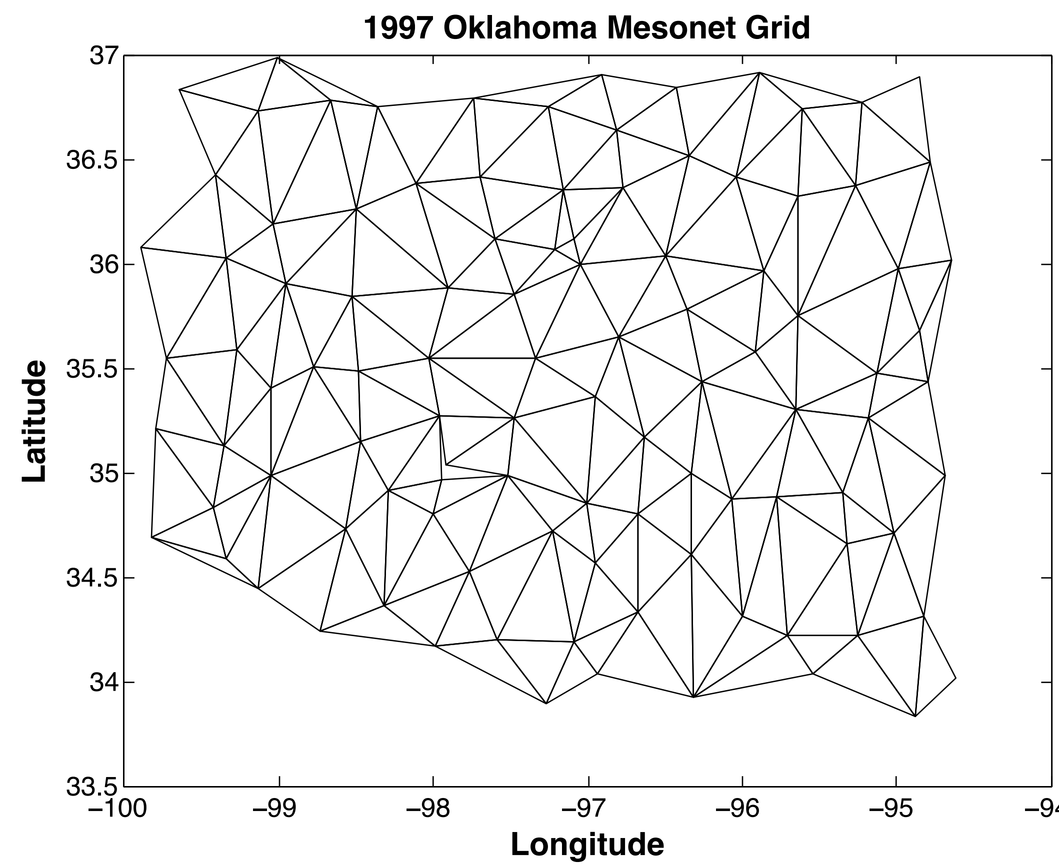
- pressure increase
- temperature drop
- wind shift, divergence



Frontal passage and associated cold pool wind direction, pressure, and equivalent potential temperature for a case in Engerer et al. 2008

Introduction - Oklahoma Mesonet

- Delaunay Triangulation is applied to the Mesonet stations to form a grid.
- Extremely thin, narrow triangles were removed.
- The grid changes each year depending on which stations reach the observation threshold (90%) for the given year.
- 99-104 of the 108 non-panhandle stations are used each of the 15 years.



Mesonet grid for the year 1997.

Methodology - Front Scores (FS)

- To identify a cold pool first the fronts are located to help determine pressure surge lines and outflow boundaries.
- FSs are calculated based on 30 minute pressure increases and temperature decreases.
- Pressure and temperature are adjusted for the diurnal cycle and elevation.
- Diurnal cycle ex: 12z 10 June averages the station values at 12z 8-12 June for the station over the 15 years (up to 75 values averaged).
- The FS is a unitless variable. A 1mb pressure increase is treated the same as 1K temperature decrease.

$$FS_{(t)} = P_{(t,adj)} + T_{(t-30,adj)} - P_{(t-30,adj)} - T_{(t,adj)}$$

Methodology - Frontal Analysis

- Threshold values of FS are set for fronts (3+) and strong fronts (5+).
- A maximum FS above the threshold (highest within 3 hrs in both directions) is considered a front at the station.
- All 3 corners of a Mesonet triangle having a front within 2 hours of each other marks the triangle as undergoing a frontal passage.
- These fronts can be tracked through the Mesonet.

Methodology - Cold Pool Analysis

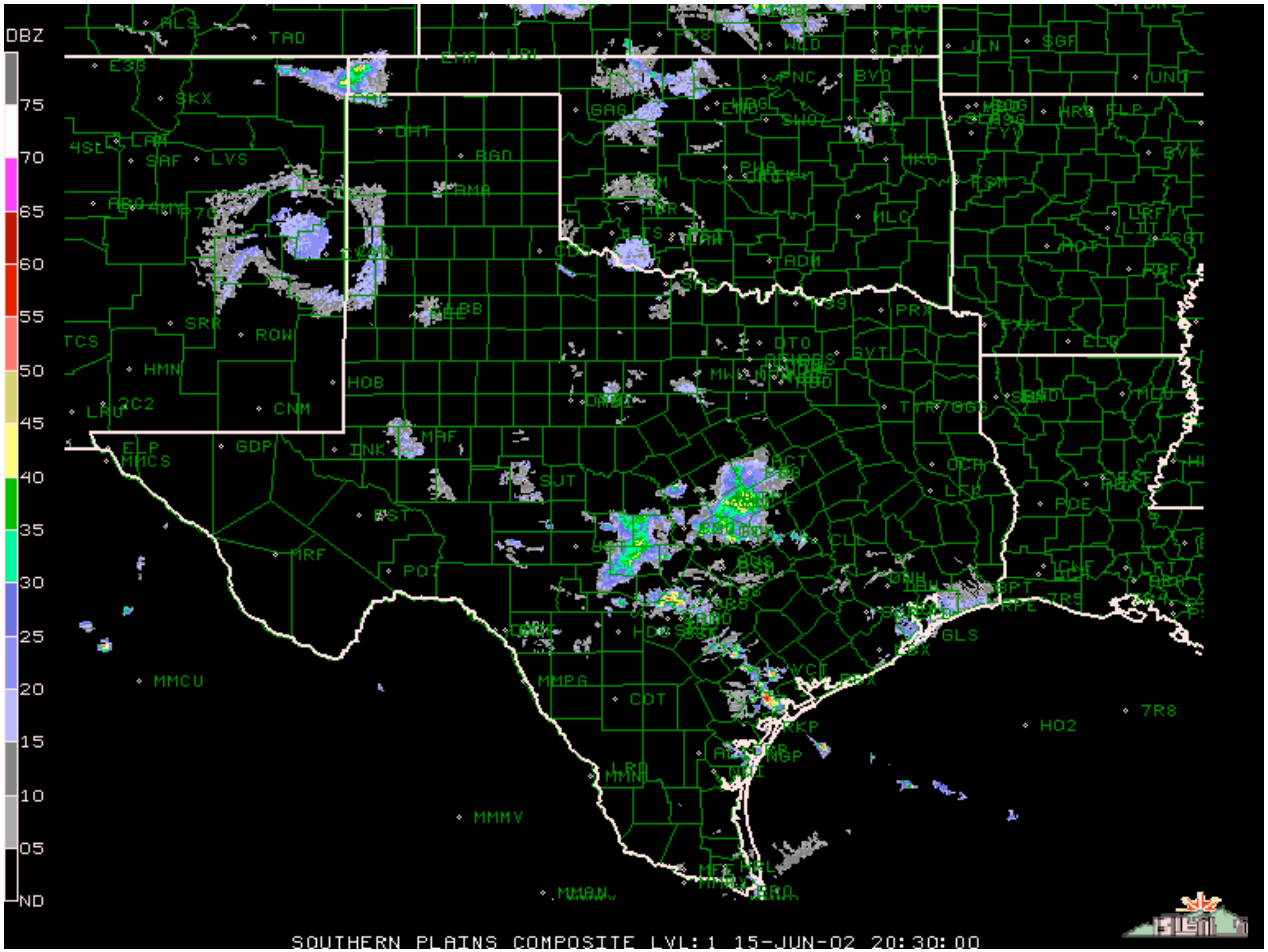
- Divergence for each of the Mesonet triangles was calculated using the methods from Dubois and Spencer 2005, Davies-Jones, 1993.
- A cold pool at a Mesonet triangle is required to have two features:

  I. A frontal passage at the triangle. For study purposes all cold pools have associated fronts while not all fronts have cold pools.

  II. The divergence threshold of $1 \times 10^{-4}\ s^{-1}$ reached within 30 minutes before and 60 minutes after front reaches the middle of the triangle.

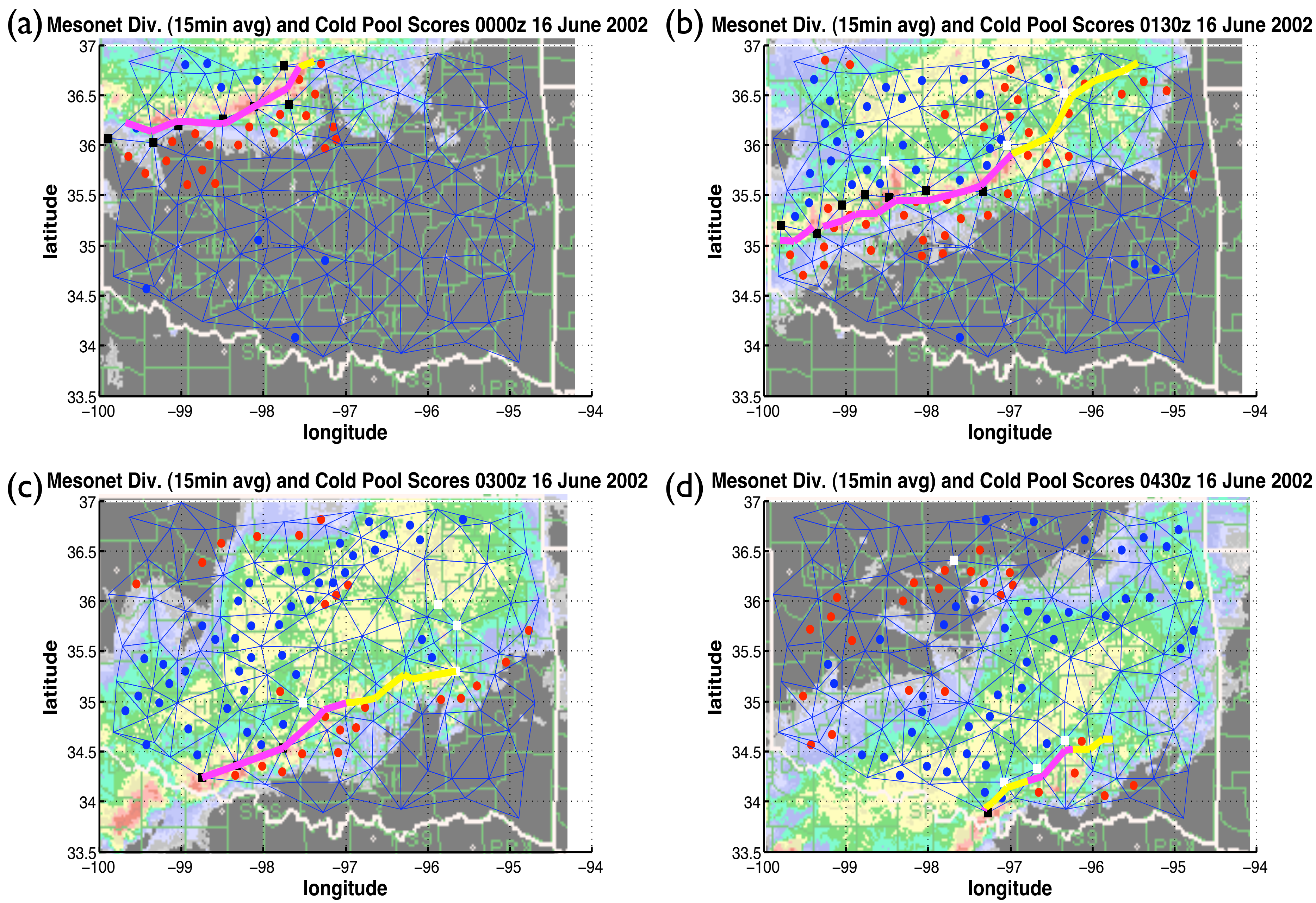
- A cold pool spans from that divergence maximum timestep in both directions until the divergence is half the maximum value.

15-16 June 2002 Case



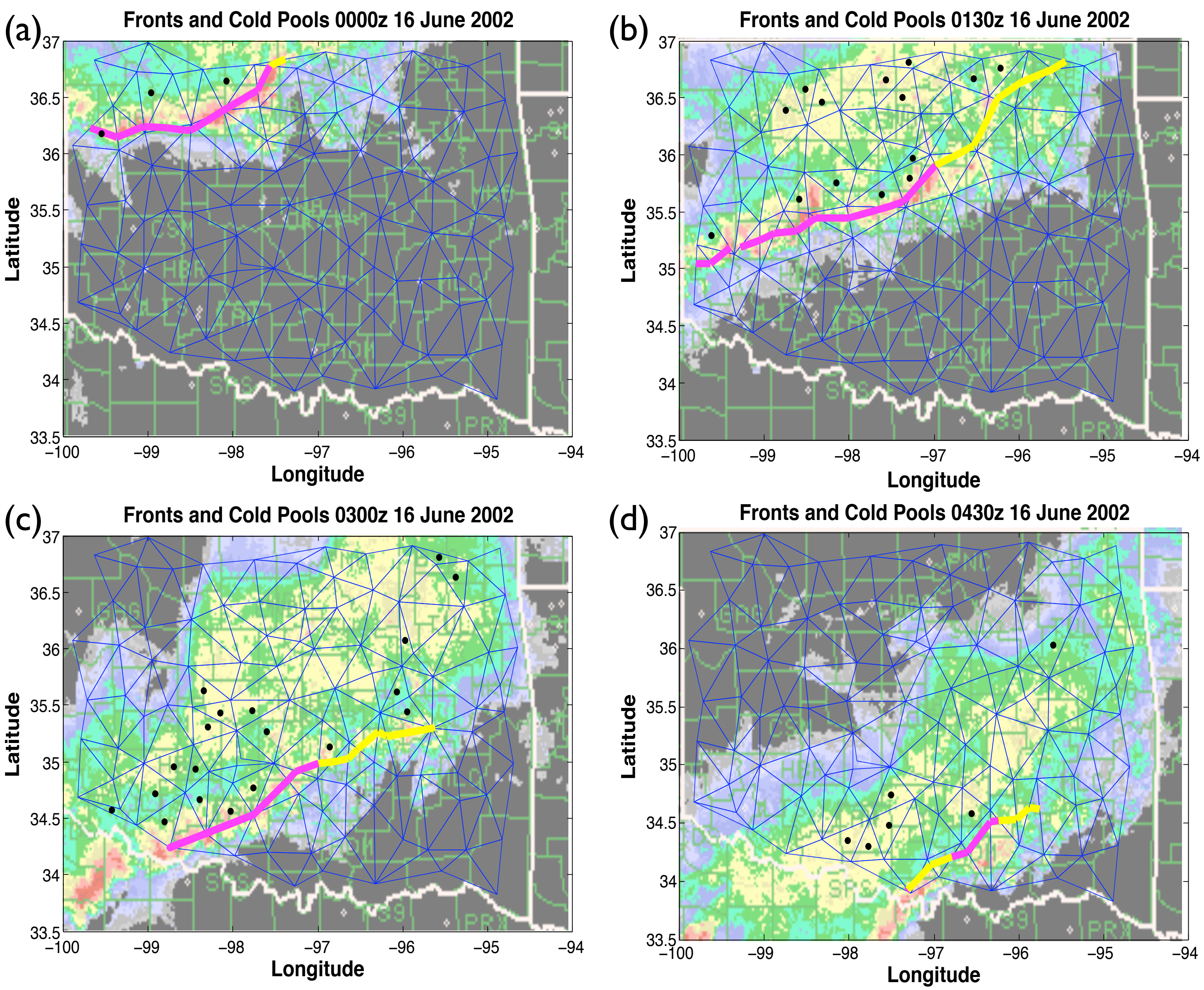
Images from: http://www.mmm.ucar.edu/imagearchive/

15-16 June 2002 Front Analysis

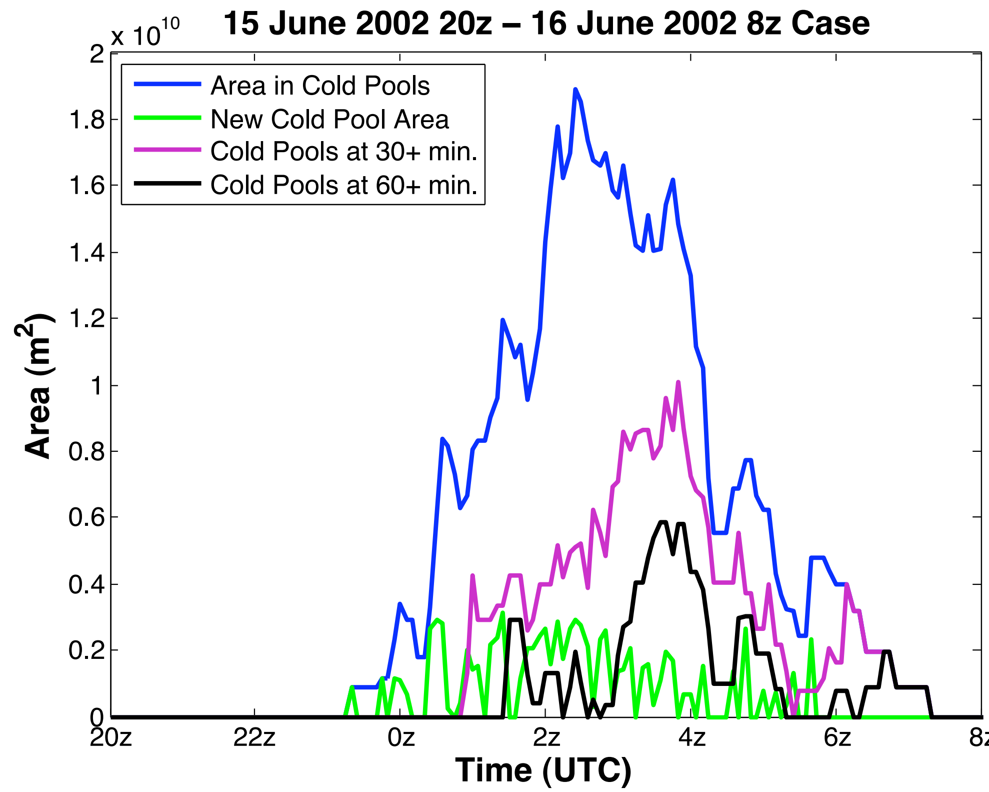


Front analysis for 16 June 2002 (a) 0000z, (b) 0130z, (c) 0300z, and (d) 0430z. Red dots are convergence > $10^{-4}s^{-1}$ while blue dots are divergence >= $10^{-4}s^{-1}$. Yellow lines are fronts where the three corners of the triangle have FSs of 3+ during frontal passage while magenta lines are fronts where the triangle corners have FSs are 5+. White squares are stations where at the current timestep the FS is 3 <= FS < 5; black squares designate stations currently with FSs at 5+. Radar images are from the UCAR image archive.

15-16 June 2002 Cold Pool Analysis

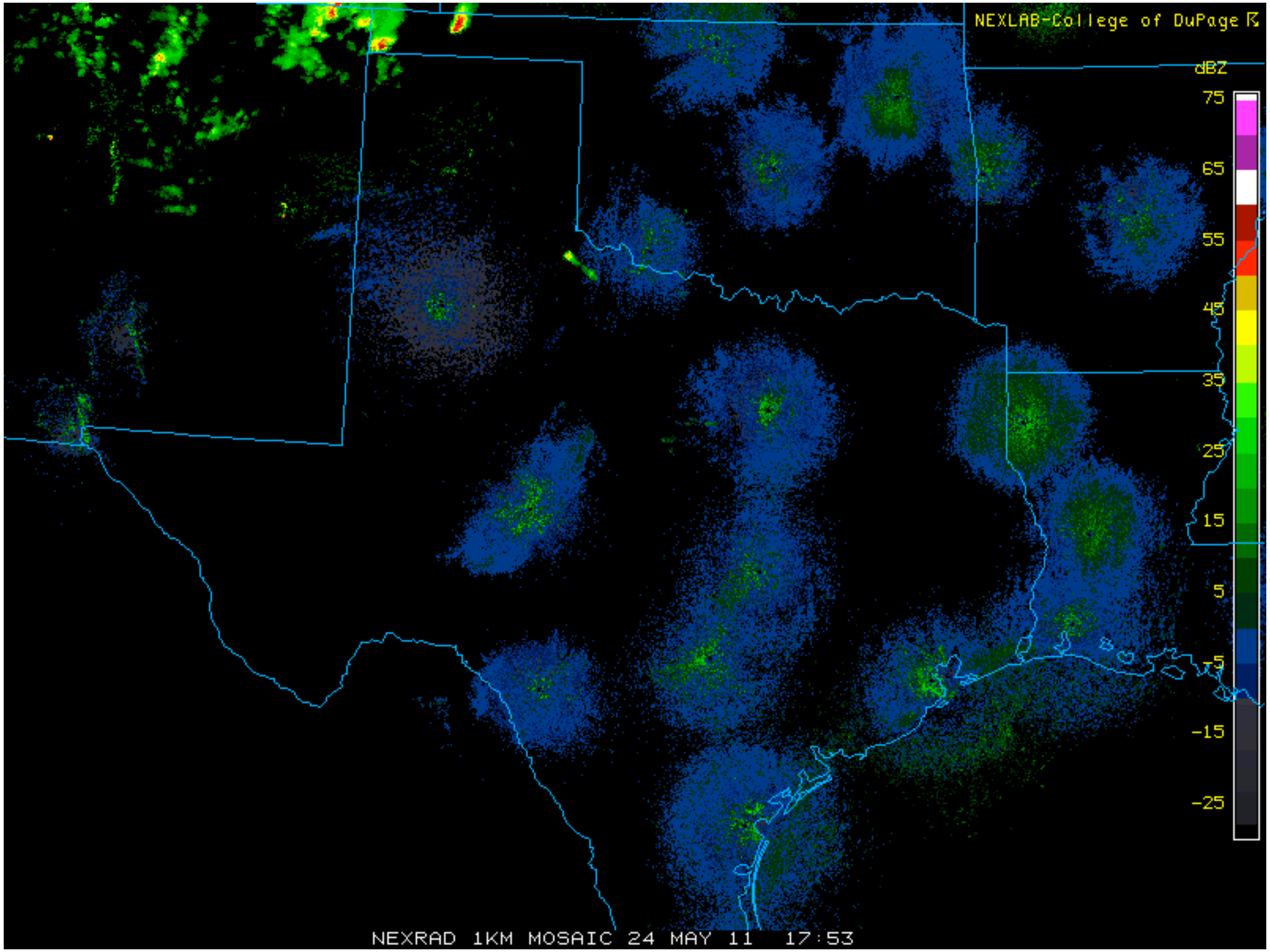


Cold pool analysis for 16 June 2002 (a) 0000z, (b) 0130z, (c) 0300z, and (d) 0430z. Black dots mark triangles that are in cold pools at this time. Fronts are shown for context. Radar images are from the UCAR image archive.



Cold pool areas for the 15-16 June 2002 20z-8z case study. Cold pool areas are shown for total area in cold pools (blue), area that becomes part of a cold pool during the given timestep (green), area that has been in a cold pool at least 30 minutes (purple), and area that has been in a cold pool at least 60 minutes (black).

24-25 May 2011 Case



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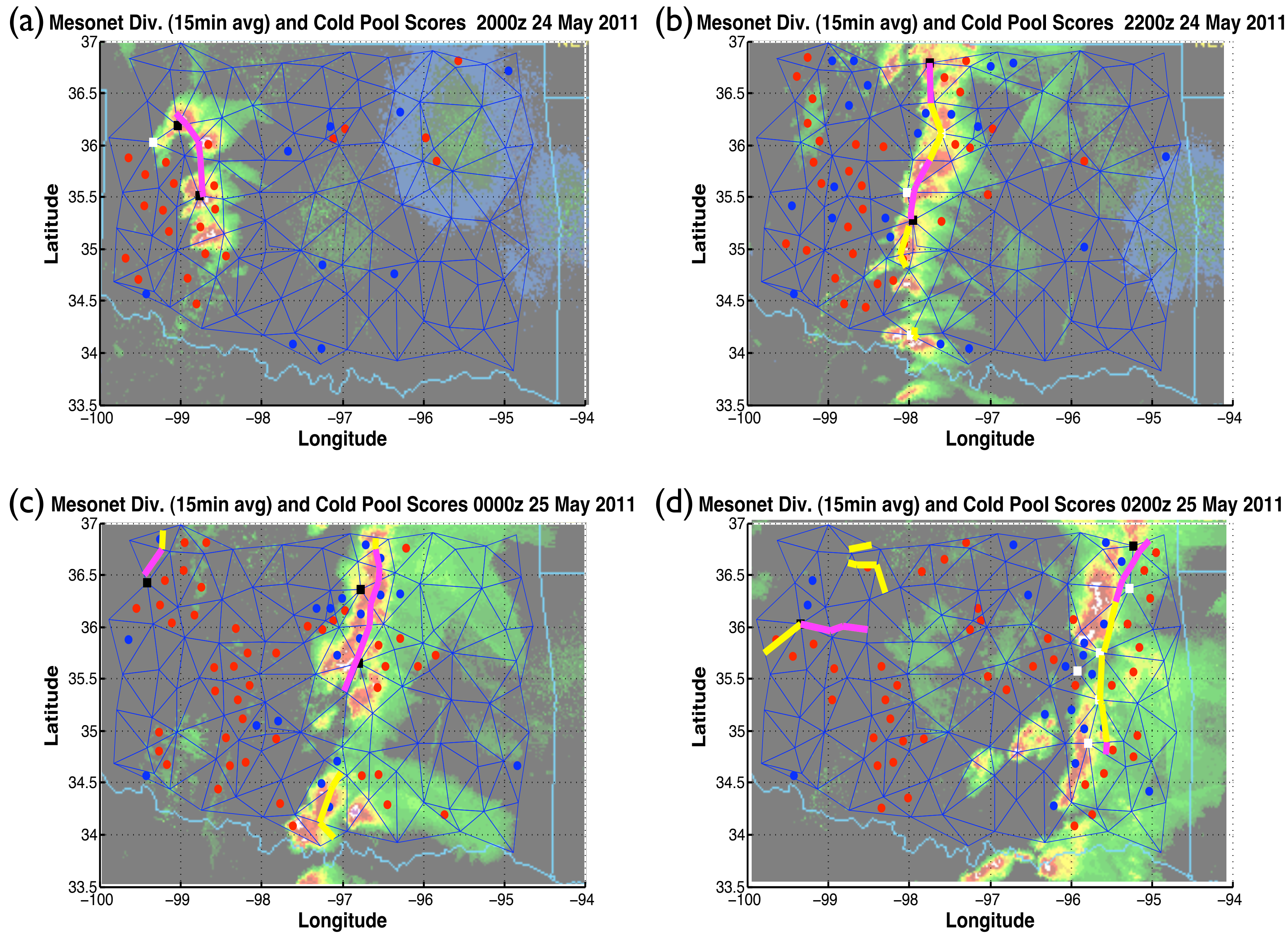
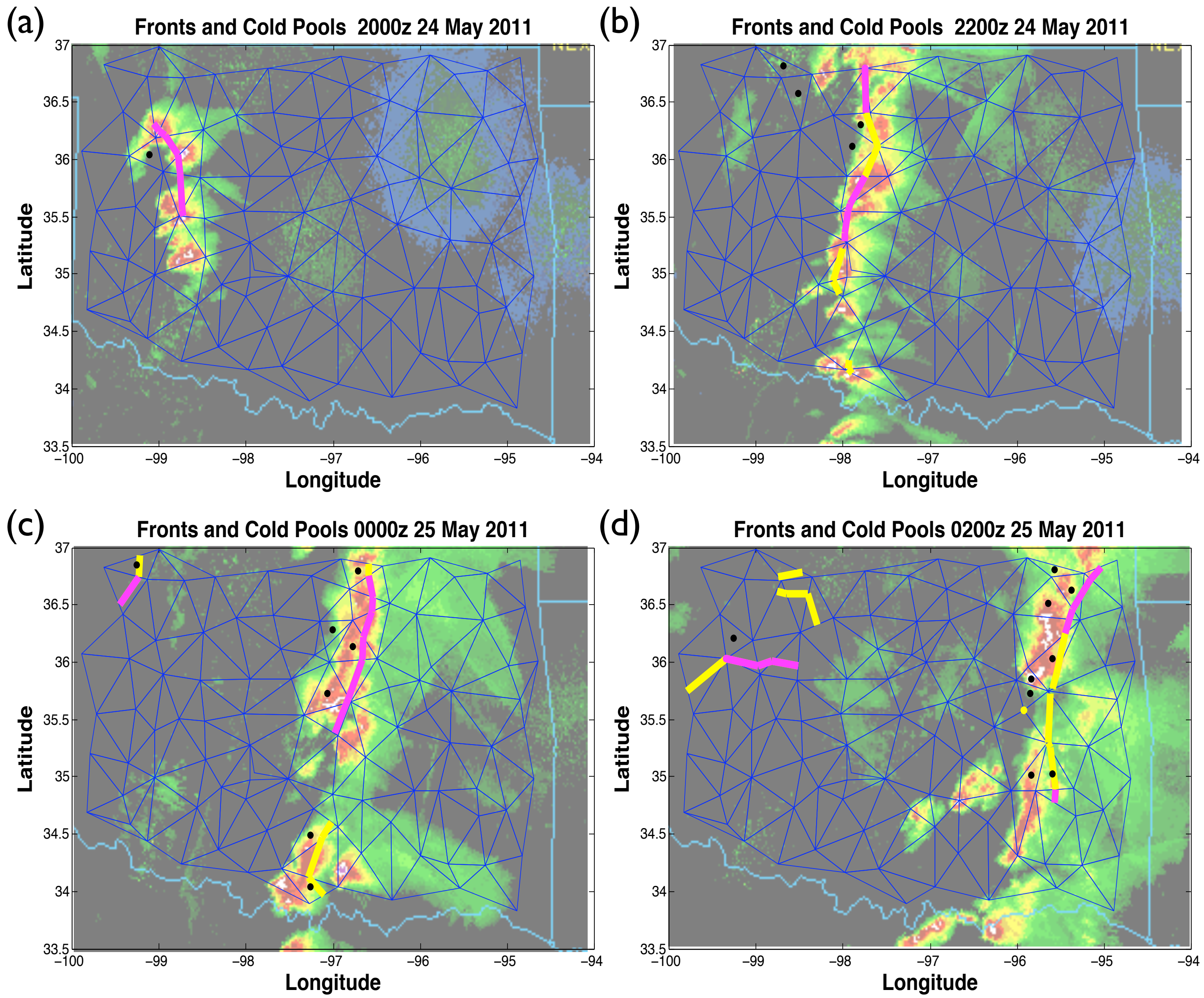
24-25 May 2011 Frontal Analysis

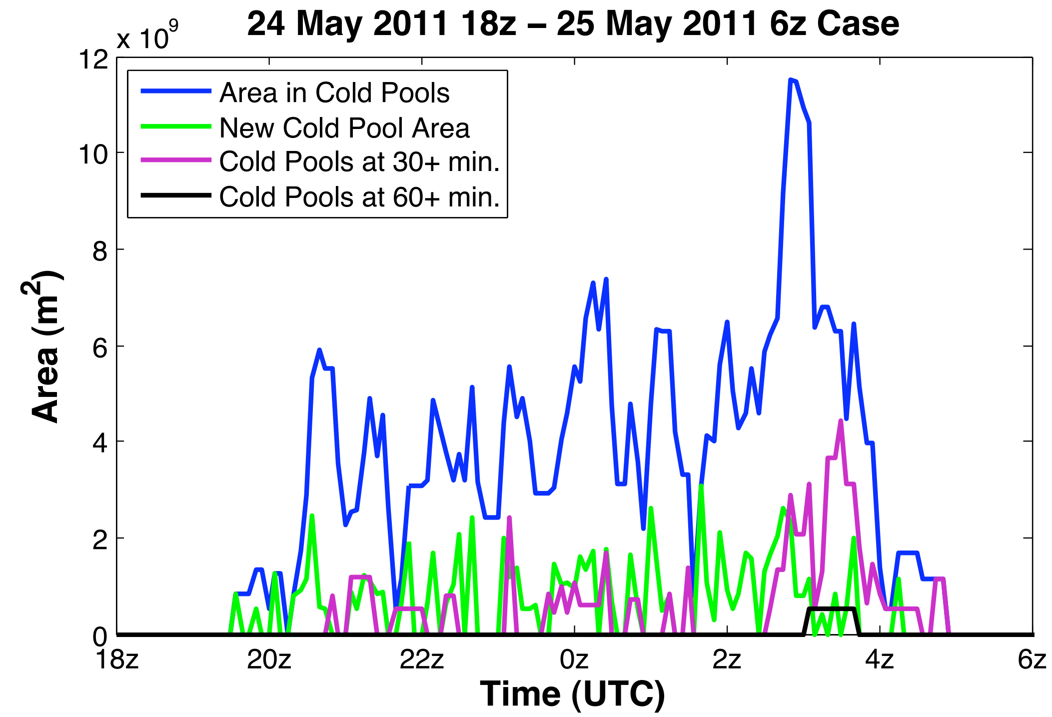


Front analysis for 24-25 June 2011 (a) 2000z, (b) 2200z, (c) 0000z, and (d) 0200z. Red dots are convergence > $10^{-4}s^{-1}$ while blue dots are divergence >= $10^{-4}s^{-1}$. Yellow lines are fronts where the three corners of the triangle have FSs of 3+ during frontal passage while magenta lines are fronts where the triangle corners have FSs are 5+. White squares are stations where at the current timestep the FS is 3 <= FS < 5; black squares designate stations currently with FSs at 5+. Radar images are from the UCAR image archive.

24-25 June 2011 Cold Pool Analysis



Cold pool analysis for 24-25 June 2011 (a) 2000z, (b) 2200z, (c) 0000z, and (d) 0200z. Black dots mark triangles that are in cold pools at this time. Fronts are shown for context. Radar images are from the UCAR image archive.



Cold pool areas for the 15-16 June 2002 20z-8z case study. Cold pool areas are shown for total area in cold pools (blue), area that becomes part of a cold pool during the given timestep (green), area that has been in a cold pool at least 30 minutes (purple), and area that has been in a cold pool at least 60 minutes (black).

Front and Cold Pool Climatology

- Variable changes (T, P, q_v, h/cp)
- Convergence/Divergence
- Seasonal Pattern
- Diurnal Pattern
- Geographic Pattern

Variable Changes

- Variable changes are based on the 30 minutes before frontal passage up to 2 hrs after frontal passage at station.
- ΔP is maximum pressure increase in that 2.5 hr range (after front - before front).
- ΔT is maximum pressure decrease in that range (before front - after front).
- Δq_v and $\Delta h/c_p$ use the same timesteps as ΔT to determine decreases.
- Summer has lowest variable changes except temperature, winter has largest variable changes except Δq_v.

Table 6.1. Average ΔT, ΔP, Δq_v, and Δh/cp for all frontal passage (FS3+ / FS5+).

Season	ΔT (K)	ΔP (mb)	Δq_v (g/kg)	Δh/cp (K)
Spring (MAM)	-5.8/-7.7	2.8/3.6	-1.5/-2.9	-9.2/-14.8
Summer (JJA)	-6.1/-7.7	2.0/2.5	-0.6/-1.0	-7.1/-10.2
Fall (SON)	-6.2/-8.4	2.4/3.1	-1.5/-2.8	-9.6/-15.3
Winter (DJF)	-6.6/-10.2	2.9/4.4	-1.2/-2.7	-9.5/-17.1
Annual	-6.1/-8.1	2.5/3.2	-1.1/-2.1	-8.7/-13.4

Table 6.2. Average ΔT, ΔP, Δq_v, and Δh/cp during frontal passages which yield cold pools (FS3+ / FS5+).

Season	ΔT (K)	ΔP (mb)	Δq_v (g/kg)	Δh/cp (K)
Spring (MAM)	-5.8/-7.5	2.9/3.5	-1.7/-2.8	-10.1/-14.6
Summer (JJA)	-6.2/-7.7	2.0/2.5	-0.8/-1.0	-8.1/-10.3
Fall (SON)	-6.3/-8.3	2.6/3.1	-1.6/-2.5	-10.3/-14.6
Winter (DJF)	-7.1/-10.3	3.5/4.5	-1.5/-2.8	-10.9/-17.1
Annual	-6.2/-8.0	2.6/3.1	-1.3/-2.0	-9.5/-13.0

- Stronger fronts have larger variable changes.
- Cold pool presence is more influential for weaker fronts than strong fronts.

Variable Changes

Table 6.3. Correlations between ΔT, ΔP, Δq_v, and Δh/cp for all frontal passages (FS3+ / FS5+).

Season	ΔT,ΔP	ΔT,Δq_v	ΔT,Δh/cp	ΔP,Δq_v	ΔP,Δh/cp	Δq_v,Δh/cp
Spring (MAM)	-0.32/-0.44	0.36/0.31	0.61/0.61	-0.20/-0.15	-0.24/-0.28	0.94/0.94
Summer (JJA)	-0.15/-0.06	-0.01/-0.11	0.33/0.19	-0.13/-0.14	-0.17/-0.15	0.92/0.95
Fall (SON)	-0.23/-0.17	0.42/0.41	0.65/0.65	-0.32/-0.22	-0.33/-0.24	0.95/0.96
Winter (DJF)	-0.41/-0.38	0.54/0.47	0.80/0.77	-0.14/+0.17	-0.28/-0.03	0.92/0.93
Annual	-0.28/-0.32	0.28/0.22	0.58/0.53	-0.20/-0.17	-0.25/-0.25	0.93/0.94

Table 6.4. Correlations between ΔT, ΔP, Δq_v, and Δh/cp for frontal passages which yield cold pools (FS3+ / FS5+).

Season	ΔT, ΔP	ΔT, Δq_v	ΔT, Δh/cp	ΔP, Δq_v	ΔP, Δh/cp	Δq_v, Δh/cp
Spring (MAM)	-0.32/-0.46	0.38/0.31	0.65/0.61	-0.19/-0.18	-0.27/-0.31	0.95/0.94
Summer (JJA)	-0.13/-0.04	-0.02/-0.12	0.33/0.19	-0.12/-0.13	-0.18/-0.15	0.93/0.95
Fall (SON)	-0.22/-0.18	0.40/0.41	0.67/0.65	-0.29/-0.25	-0.34/-0.28	0.95/0.96
Winter (DJF)	-0.44/-0.43	0.55/0.46	0.83/0.77	-0.07/+0.15	-0.26/-0.08	0.92/0.92
Annual	-0.27/-0.32	0.25/0.19	0.57/0.51	-0.20/-0.19	-0.26/-0.28	0.93/0.94

- Temperature correlations are much lower in summer, especially for strong fronts, highest in winter.
- Pressure correlations with Δq_v and $\Delta h/c_p$ are lower in summer and winter than spring and fall.
- Δq_v and $\Delta h/c_p$ have the highest correlation, suggests Δq_v has stronger influence than ΔT on $\Delta h/c_p$.
- Summer ΔT and Δq_v and winter ΔP and Δq_v correlations are opposite in sign.
- Cold pool presence has little effect on correlations.

Convergence/Divergence

- Convergence ahead of front and divergence behind front.
- Summer divergence is much stronger behind fronts, even without cold pool presence, than in other seasons.
- Convergence strength ahead of cold pools is not significantly different from convergence strength of all frontal passages.

Table 6.5. Divergence values at the beginning, middle, and end of all triangle frontal passages experienced by Mesonet triangles from 1997-2011 by season (FS3+ / FS5+) in s^{-1}.

Season	Beg. Div.	Mid. Div.	End. Div.
Spring (MAM)	$-1.40E^{-4}/-2.00E^{-4}$	$-1.55E^{-5}/-2.55E^{-5}$	$6.50E^{-5}/8.08E^{-5}$
Summer (JJA)	$-1.32E^{-4}/-1.72E^{-4}$	$1.87E^{-5}/2.47E^{-5}$	$1.24E^{-4}/1.61E^{-4}$
Fall (SON)	$-1.37E^{-4}/-2.02E^{-4}$	$-3.12E^{-5}/-5.30E^{-5}$	$5.75E^{-5}/8.03E^{-5}$
Winter (DJF)	$-1.09E^{-4}/-1.75E^{-4}$	$-3.52E^{-5}/-6.36E^{-5}$	$2.30E^{-5}/2.94E^{-5}$
Annual	$-1.32E^{-4}/-1.87E^{-4}$	$-1.10E^{-5}/-1.83E^{-5}$	$7.50E^{-5}/1.01E^{-4}$

Table 6.6. Divergence values at the beginning, middle, and end of triangle frontal passages yielding cold pools experienced by Mesonet triangles from 1997-2011 by season (FS3+ / FS5+) in s^{-1}.

Season	Beg. Div.	Mid. Div.	End. Div.
Spring (MAM)	$-1.35E^{-4}/-1.86E^{-4}$	$3.47E^{-5}/2.77E^{-5}$	$1.26E^{-4}/1.36E^{-4}$
Summer (JJA)	$-1.29E^{-4}/-1.70E^{-4}$	$4.69E^{-5}/4.63E^{-5}$	$1.62E^{-4}/1.89E^{-4}$
Fall (SON)	$-1.35E^{-4}/-1.98E^{-4}$	$2.11E^{-5}/1.90E^{-6}$	$1.27E^{-4}/1.45E^{-4}$
Winter (DJF)	$-9.82E^{-5}/-1.62E^{-4}$	$2.51E^{-5}/4.22E^{-5}$	$9.58E^{-5}/9.66E^{-5}$
Annual	$-1.29E^{-4}/-1.78E^{-4}$	$3.68E^{-5}/3.02E^{-5}$	$1.38E^{-4}/1.58E^{-4}$

Seasonal Distribution

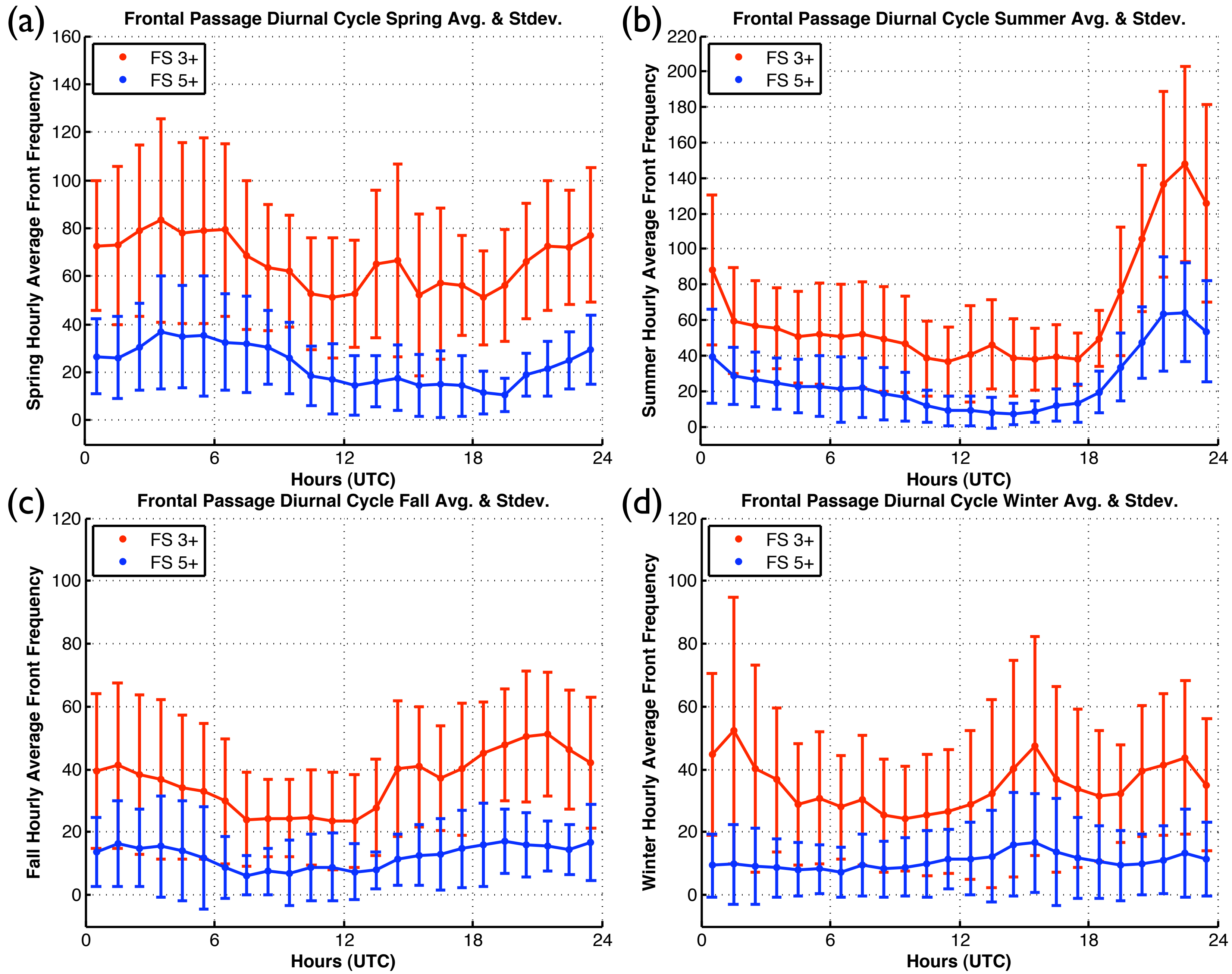
Table 6.7. Number of frontal passages and cold pools experienced by Mesonet triangles from 1997-2011 by season (FS3+ / FS5+).

Season	# Fronts	# Cold Pools	% Fronts w/ Cold Pools
Spring (MAM)	23,811/8,329	13,820/5,397	58%/65%
Summer (JJA)	22,785/9,014	18,083/7,855	79%/87%
Fall (SON)	13,009/4,442	6,645/2,620	51%/59%
Winter (DJF)	12,539/3,843	4,329/1,530	35%/40%
Annual	72,144/25,628	42,877/17,402	59%/68%

- Spring has the highest # of fronts.
- Summer has the most cold pools.
- Summer has the highest percentage of fronts that result in cold pools.
- Strong fronts are more likely to lead to cold pools.

Diurnal Distribution

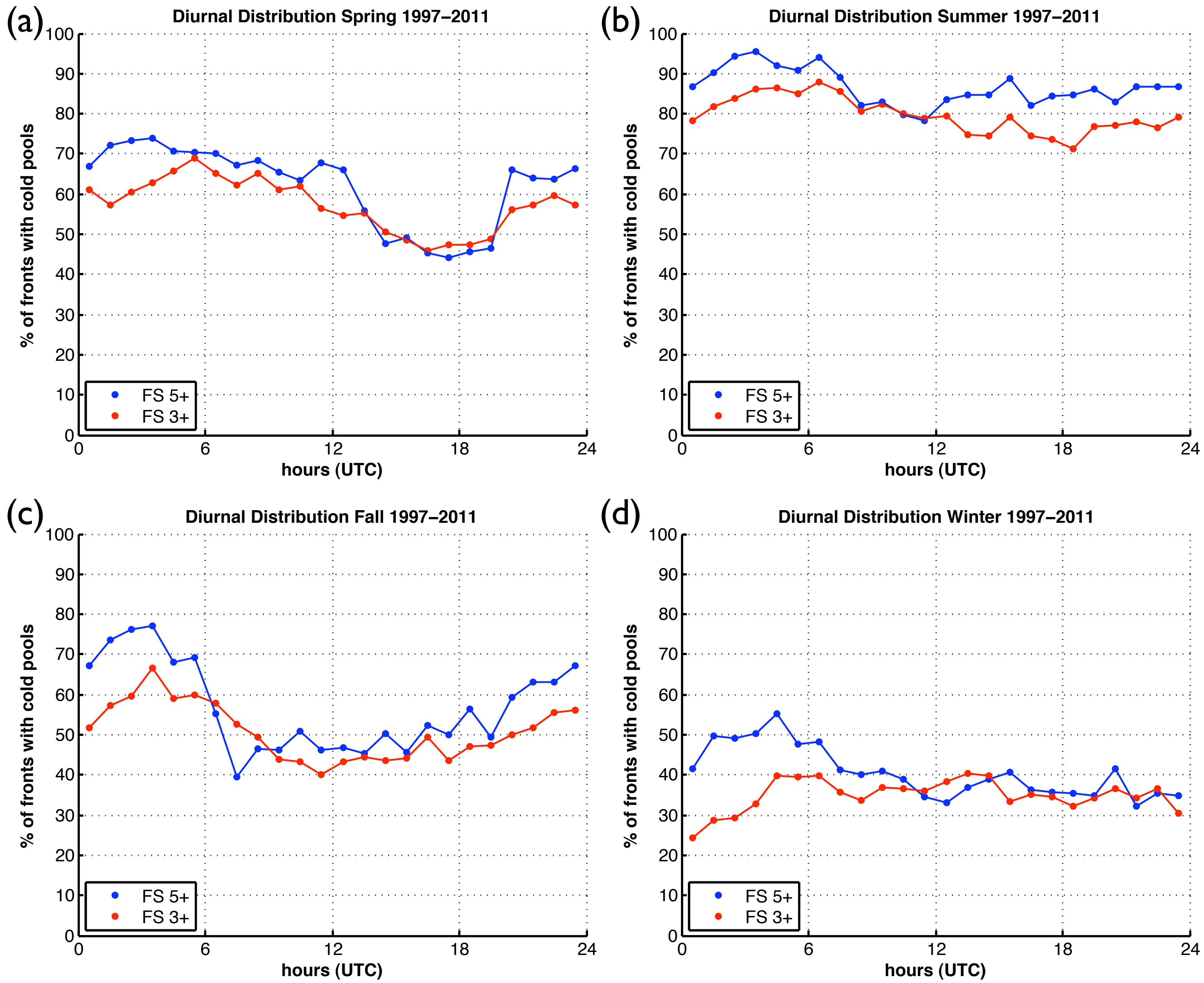
- Summer frontal passage frequency peaks in late afternoon - early evening.
- Spring, fall, and winter have less of a diurnal cycle.
- Cold pool diurnal distribution (not shown) roughly the same pattern.
- Without diurnal temperature adjustment a much larger spike forms in late afternoon - early evening.



Average and stdev. of fronts (FS3+, red) and strong fronts (FS5+,blue) for (a) spring, (b) summer, (c) fall, and (d) winter.

Diurnal Distribution

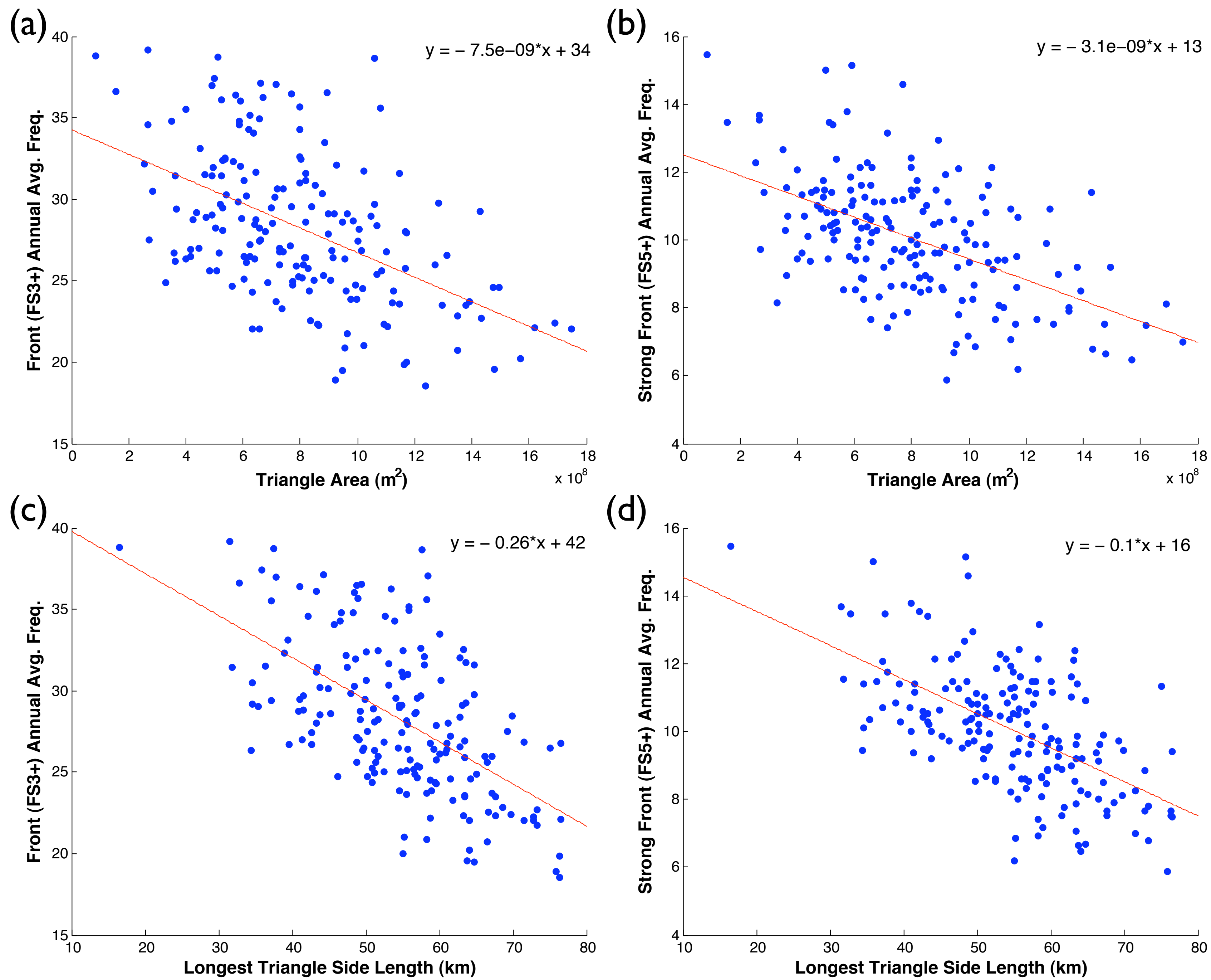
- Stronger fronts are more likely to result in cold pools.
- Summer fronts are more likely to result in cold pools, winter least likely.
- There's a slight preference for fronts from 0-6z to develop cold pools.



Percentage of fronts (FS3+, red) and strong fronts (FS5+,blue) that result in cold pools for (a) spring, (b) summer, (c) fall, and (d) winter.

Geographic Distribution

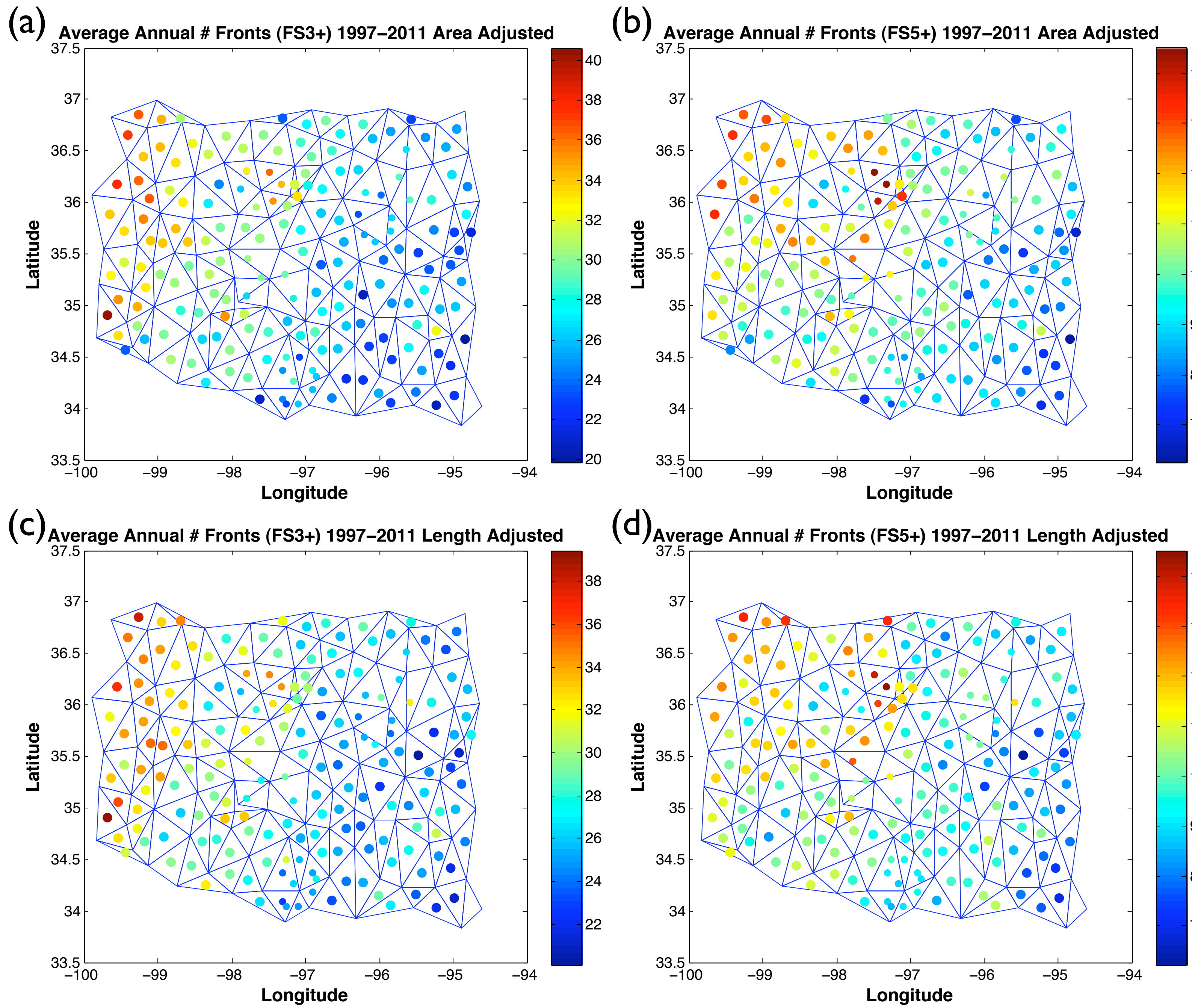
- Smaller triangles have more fronts on average than larger triangles.
- Longer side length triangles have fewer fronts on average.
- Likely a result of small scale systems not reaching all three triangle stations and the 2hr time limit to reach all three triangle stations.



Scatterplots of triangle (a) front frequency and area, (b) strong front frequency and area, (c) front frequency and max. side length, and (d) strong front frequency and max. side length.

Geographic Distribution

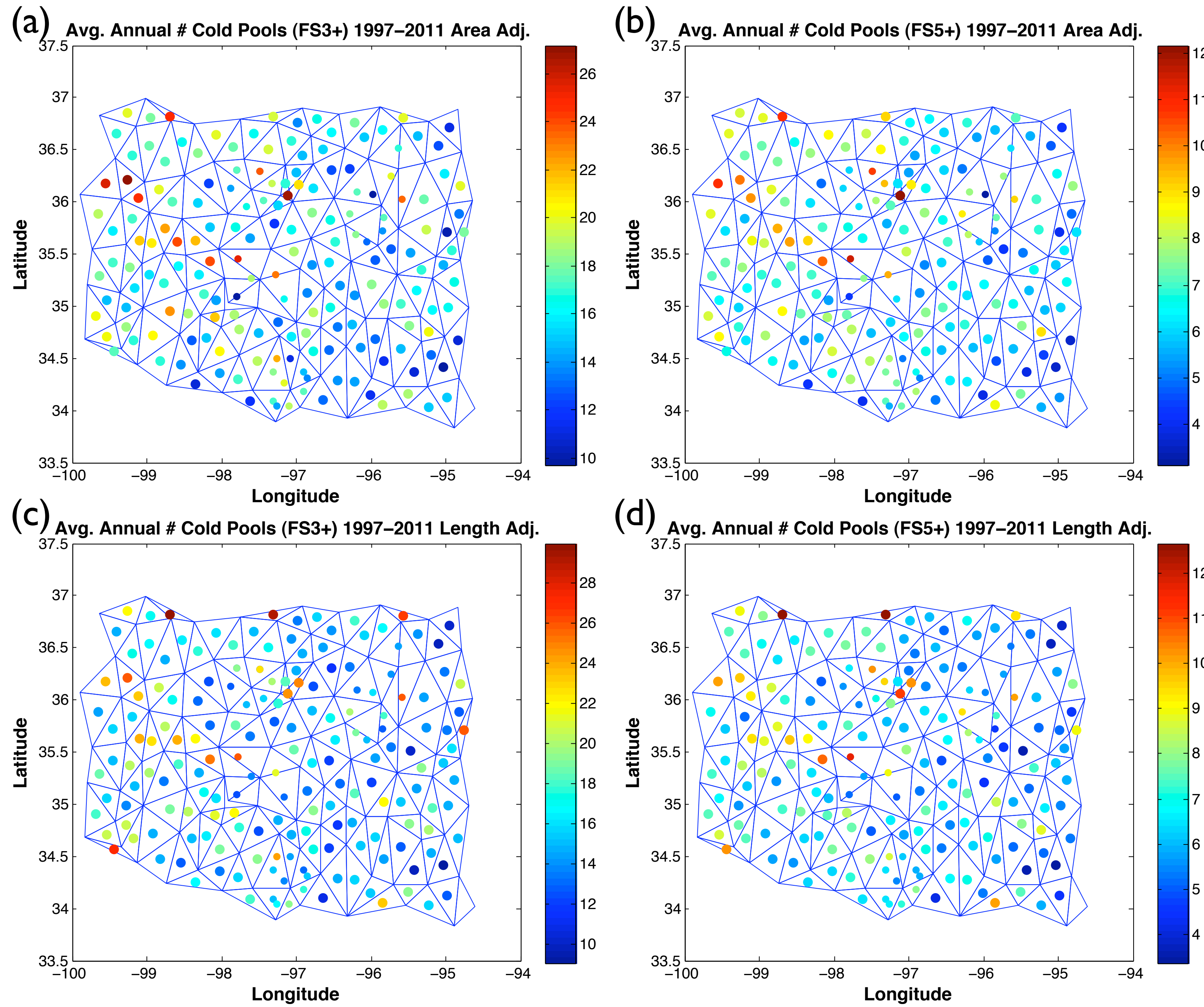
- Smaller and western triangles have more frequent frontal passages.
- Larger and eastern triangles have less frequent frontal passages.
- West to east pattern matches up well with dryline position climatology (Hoch and Markowski, 2005).



Frontal passage geographical distribution for fronts (a,c) and strong fronts (b,d) for area adjusted (a,b) and length adjusted (c,d) census values. Size of dots represent # of years triangle centroid was in that location. Grid is the 1997 triangles, some stations change location or disappear over time.

Geographic Distribution

- West to east gradient less well-defined for cold pools.
- Anomalies are much more significant (higher distribution of difference between mean scores).
- Area adjustment fits better than length adjustment.



Cold pool geographical distribution for fronts (a,c) and strong fronts (b,d) for area adjusted (a,b) and length adjusted (c,d) census values. Size of dots represent # of years triangle centroid was in that location. Grid is the 1997 triangles, some stations change location or disappear over time.

Conclusions

- Fronts and cold pools can be tracked across the Oklahoma Mesonet relying on surface temperature, pressure, and divergence.
- Generally, summer had lower changes in variables (T, P, q_v, h/cp) and lower correlations than the other seasons with few exceptions.
- Divergence is stronger and occurs earlier in summer frontal passages than other seasons.
- A larger percentage of summer fronts had cold pools; winter was lowest.
- The diurnal cycle peaks in the early evening hours in the summer, at night for the other seasons.
- Geographically, fronts and cold pools are more likely to occur in western regions of Oklahoma.
- Area and side length influence the frequency of front and cold pool events.

Future Work

- Incorporate more variables, tune the model to better identify types of cold pools (synoptic, convective).
- Increase resolution to better capture small cold pool events and cold pool areas.
- Comparison to model simulations; what would this method applied to model output yield for cold pool size?
- Estimate rain evaporation; can be considered using frameworks like Fujita 1959.
- Expand to 3-D data. Case studies can use data from the Midlatitude Continental Convective Clouds Experiment (MC3E).

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