Severe Weather

THE CONTRIBUTION OF SURFACE, HORIZONTAL MOISTURE CONVERGENCE TO THE SEVERE CONVECTION OF 10-11 APRIL 1979

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ABSTRACT

The severe weather outbreak of 10-11 April 1979 is examined from the viewpoint of surface conditions, hydrostatic stability and surface moisture convergence. The latter was computed using a 19 x 15 grid with a 95 km gridlength hourly, for 1500-0300 GMT 10-11 April. It was found that surface moisture convergence fields were well correlated in space-time with the development of a surface, sub-synoptic low (SSL) and played a key role in the initia- tion of the severe convection that took place over the Red River Valley. The most severe convection took place in that region where consistently high surface moisture convergence, high hydrostatic instability and high mixing ratio values phased. Finally, some areas where the surface moisture convergence was a poor predictor of severe weather are pointed out and discussed.

1. INTRODUCTION

The parameter moisture convergence, defined to be the convergence of the product of the mixing ratio, q, and the horizontal wind, $\vec{V}$, has been shown in various studies to be helpful in the short term prediction of severe local storms. Hudson (3) showed that well-defined axes of horizontal moisture convergence are generally accompanied by volumes of the fluid undergoing deep cumulus convection. Newman (4), in a case study, showed that "severe weather tends to develop at or closely after the time of greatest horizontal moisture convergence". Also he found the magnitude of the local moisture convergence maximum to increase rapidly prior to severe storm genesis. Tegtmeier (5) found that surface moisture convergence maxima, organized to the east and northeast of a surface, sub-synoptic low (SSL) or dryline wave, were associated with the occurrence of severe thunderstorms and tornado activity. Doswell (6) found similar results using data that had been band-pass filtered for specific wavelengths. McNulty (7) has run tests which suggest that the LFM II boundary layer moisture convergence forecasts can be useful in forecasting local convective outbreaks. Charba (8) has selected moisture convergence as a severe storm predictor for a predictand area to the east. Negri and Vonder Haar (9) derived moisture convergence fields from low level satellite-derived wind fields and surface mixing ratio values. Their results also indicate moisture convergence maxima preceed initial storm formation by as much as 1-3 hours.

This paper will explore the space-time continuity of surface, horizontal moisture convergence for the AVE-SESAME I case, 10-11 April 1979. Figure 1 reveals that there were two swaths of damaging storms during this period. Alberty et al (10) note that the first swath began in northwestern Texas during mid-afternoon and spread over the Red River Valley into eastern Oklahoma by 0400 GMT on the 11th. The second area of severe weather developed in western Texas during the evening of the 10th and moved across north central Texas during the night. It will be shown that the development and timing of the former severe storm swaths can be related to the appearance of a surface pressure perturbation which effectively organized the horizontal moisture convergence field locally thereby enhancing the severe storm environment by releasing potential instability.

2. DATA HANDLING AND COMPUTATIONAL PROCEDURES

Hourly surface data for this case study were obtained from the National Climatic Center (NCC) in Asheville, N.C. The area of concern included the majority of the states of Texas and Oklahoma, the southwest corner of Colorado, eastern New Mexico and southern Kansas. A 19 x 15 grid with a grid interval of approximately 95 km (polar stereographic projection, true at 60°N) covered the area which included sixty stations. A Barnes (11) objective analyses scheme was utilized to interpolate u, v wind components and q values to grid points. Mixing ratios at each station were computed using Teton's empirical formula for vapor pressure:

$$e = 6.108 \exp\left[\frac{aT_d}{b+T_d}\right] \qquad (1)$$

where a = 17.269, b = 237.3 and T_d is the surface dew point in degrees Celcius, together with the relation:

$$q = \frac{.622e}{P-e} \qquad (2)$$

where q is mixing ratio (g kg $^{-1}$), P is the station pressure (mb, found by raising the sea level pressure hypsometrically) and e is the vapor pressure (mb). The Barnes analysis used four iterations with a scan radius of about 381 km. This effectively yields 100% resolution of 650 km wavelength and greater, and $\geq$ 90% resolution for 500 km wavelength and greater. Such fine resolution is available since the average station spacing over the grid area is 180 km.

Horizontal moisture convergence can be expressed as:

$$MC = -\nabla\cdot q\vec{V}_2 = -\vec{V}\cdot\nabla q - q(\nabla\cdot\vec{V}_2) \qquad (3)$$

where ∇ is the two-dimensional del operator. The first term on the right hand side of Equation 1 represents the advection of mixing ratio while the second term in the right side of (1) is the product of the mixing ratio and convergence. Henceforth these terms will be referred to as the advection and convergence terms, respectively. Values of moisture convergence were calculated using the following finite difference equation (4):

$$MC_{i,j} = -\frac{m^2_{i,j}}{2\Delta}\left[q_{i,j}\left(\left(\frac{u}{m}\right)_{i+1,j} - \left(\frac{u}{m}\right)_{i-1,j} + \left(\frac{v}{m}\right)_{i,j+1} - \left(\frac{v}{m}\right)_{i,j-1}\right) + \left(\frac{u}{m}\right)_{i,j} (q_{i+1,j} - q_{i-1,j}) + \left(\frac{v}{m}\right)_{i,j} (q_{i,j+1} - q_{i,j-1})\right] \qquad (4)$$

where Δ is the grid spacing (95.23 km) and m is the image map scale factor for a polar stereographic map projection. It should be noted that the effect of orography, which is relatively insignificant compared to those terms given in Equation 2 has been neglected.

Surface moisture convergence fields were computed hourly from 1500-0300 GMT 10-11 April 1979. These fields together with appropriate surface maps, radar summary and stability analyses form the subject for the rest of this paper.

3. SYNOPTIC CONDITIONS

House (12) views the prediction of severe storms as a two step process. The first step is to determine the stability trend and the second step is to detect or predict the mechanism that will release the instability locally. Towards that end this section will concentrate on the surface weather and stability fields for the period 1500-0300 GMT, 10-11 April in order to sense the stability trend and surface forcing of said field. Then, section four will examine surface moisture convergence from the viewpoint of its being a measure of where the instability will be released.

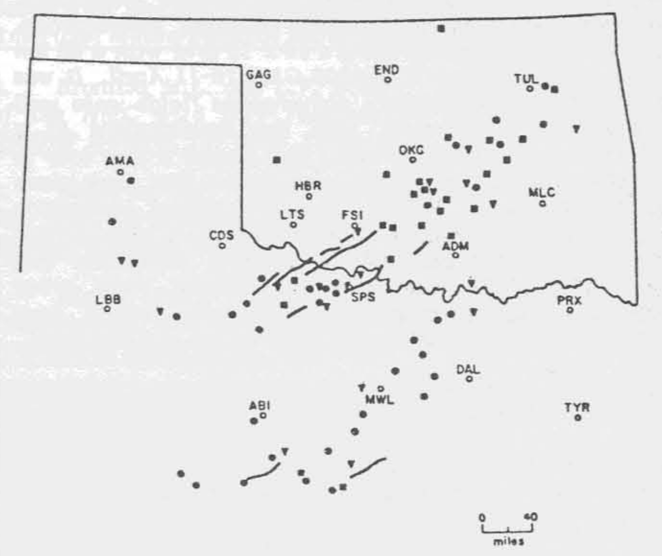


Figure 1. Severe Weather Events During the 12 Hour Period Between 1200 GMT 10 April and 1200 GMT 11 April 1979 in the South-central United States (See Reference 10).

3.a SURFACE WEATHER AND RADAR SUMMARY

The surface weather maps displayed in Figure 2 were analyzed using altimeter settings since more stations report altimeter settings than sea level pressure and also altimeter settings are not affected by local temperature variations. Figure 2a reveals that at 1500 GMT a macroscale low is positioned over central Colorado with a trough extending to the south and east through eastern New Mexico and western Texas. A broad region of predominantly southerly flow is found further to the east over Texas and Oklahoma. The isodrosotherm analysis reveals that a dryline is

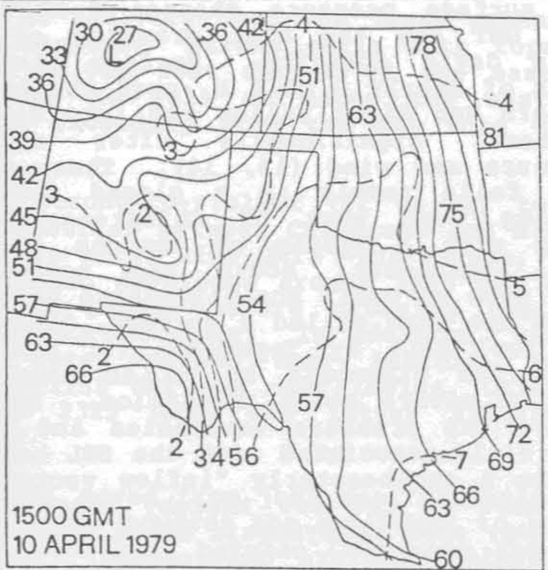


Figure 2a

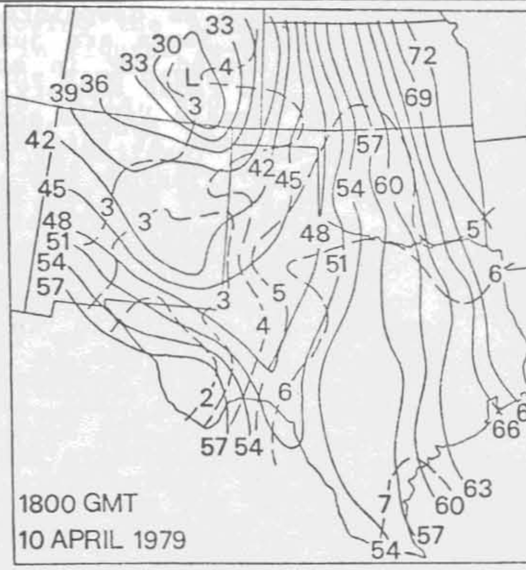


Figure 2b

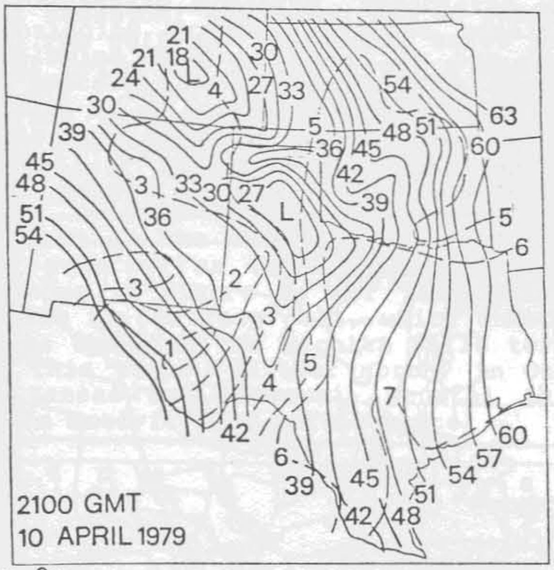


Figure 2c

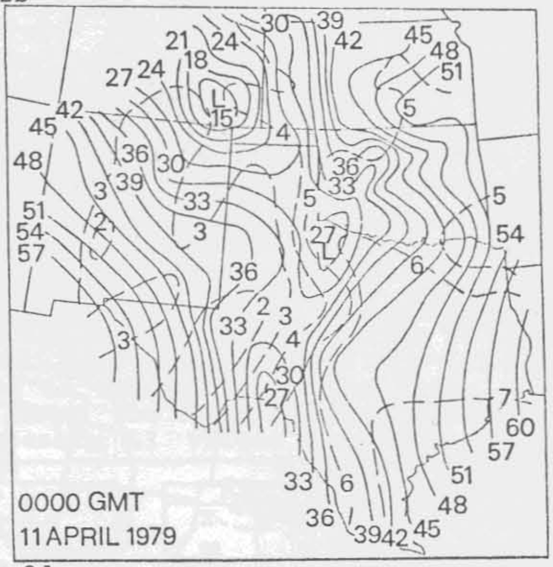


Figure 2d

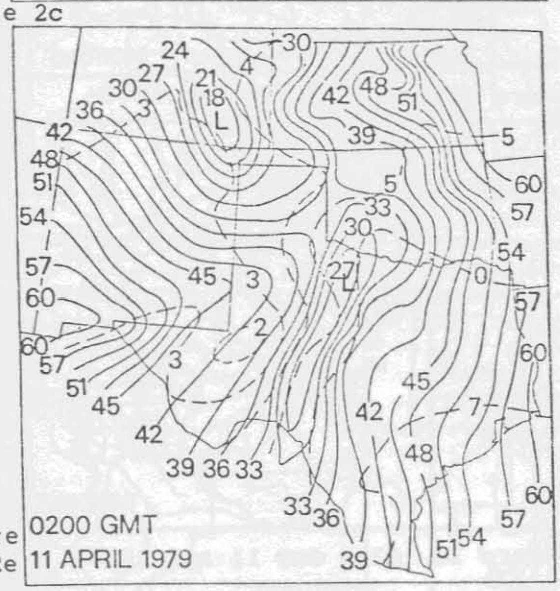


Figure 2e

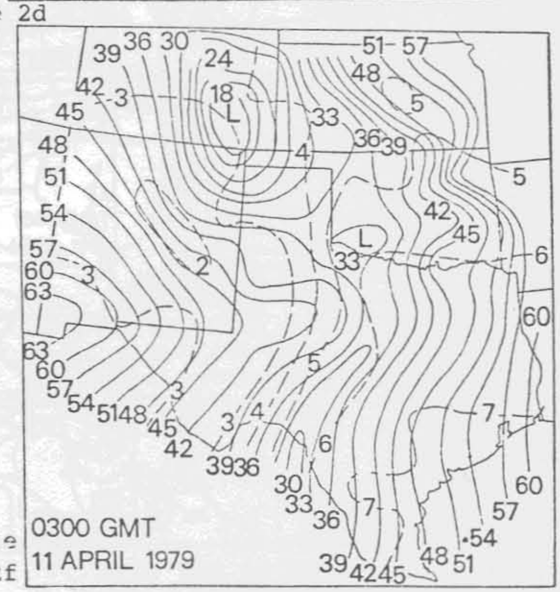


Figure 2f

Figure 2. Altimeter Settings in 0.03 inch Increments (Solid Lines); 45=29.45 inches Hg. Dashed Lines are Surface Dewpoint Temperatures With Increments of 10 Degrees F (5=50F).

forming in western Texas as dewpoints at or above 60F in central Texas are juxtaposed with dewpoints around 20F in south central New Mexico. The radar summary for 1435 GMT (not shown) reveals little activity over Texas and Oklahoma at this time. By 1800 GMT (Figure 2b) we see that the trough in eastern New Mexico and the Texas panhandle has amplified and organized. This zone is becoming an important region of low level convergence as southeasterly momentum of around 20 knots meets southwesterly momentum of nearly 30 knots. This convergence is probably due to surface friction and isallobaric convergence as pressure falls over the last three hours were about 3.7 mb in the southern Texas panhandle. The isodrosotherm analysis reveals that the 60F isodrosotherm has moved north towards the Red River Valley. The dryline has also shifted eastward over this 3 hour period, evidenced by Midland, Texas' decrease in dewpoint from 56F to 38F. Figure 3a, which displays the radar summary for 1735 GMT shows that an east-west line of activity wth a 50,000 foot cell top has grown over the last three hours north of the Dallas-Fort Worth area. Additional weaker activity is found in the southeast corner of Texas near Houston.

The surface pressure changes from 1800-2100 GMT are the most dramatic of the whole day's activity. Surface pressure falls of nearly 7 mb/3 h, over the southwestern Red River Valley and into central Oklahoma, significantly alter surface pressure and wind (13, 14). These pressure falls result in a closed off low forming just west of Childress, Texas along with a system of troughs to the east, northeast, south and northwest. This type of small scale pressure perturbation has been called a surface, subsynoptic low (SSL) by Tegtmeier (5) who has shown its diagnosis to be an important tool in severe storm prediction. Importantly, the pressure tendencies and pressure field associated with the SSL help to create a southeasterly "inflow vector" to the east of the low thereby locally enhancing, over subsynoptic scale regions of the fluid, moisture convergence. Notice, from the isodrosotherm analysis, how the gradient of dew point has increased in the lower Texas panhandle. At 2100 GMT Childress has a dew point of 57F which is juxtaposed with Lubbock, Texas' 17F dewpoint. Moller (15) has related the presence of this SSL to the appearance of tornado corridors which formed later in the day. Figure 3b reveals a literal explo-

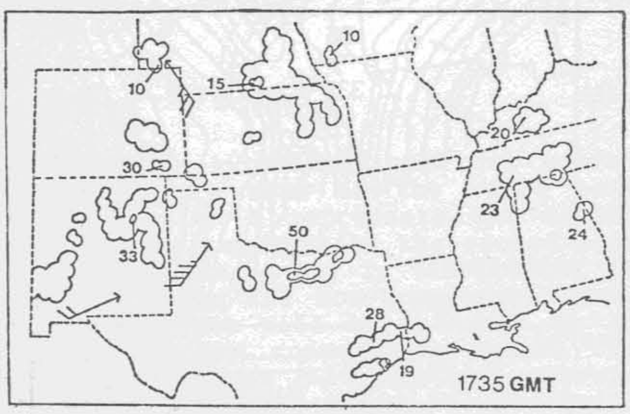


Figure 3a 1735 GMT 10 Apr 1979

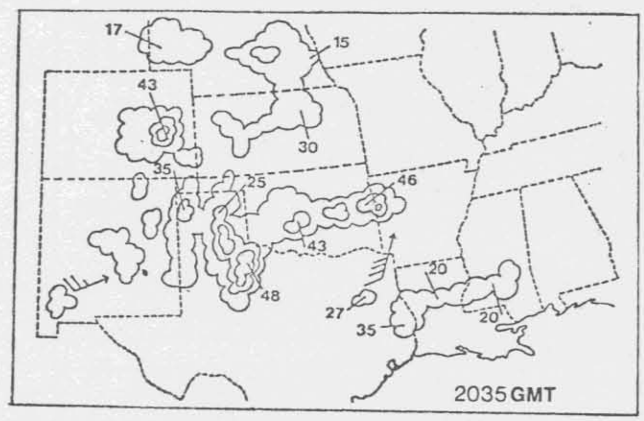


Figure 3b 2035 GMT 10 Apr 1979

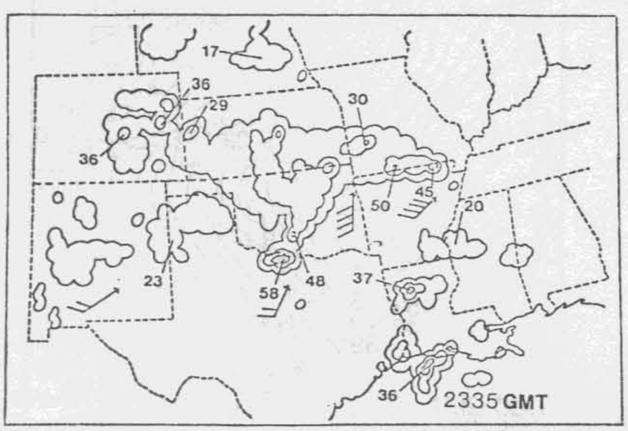


Figure 3c 2335 GMT 10 Apr 1979

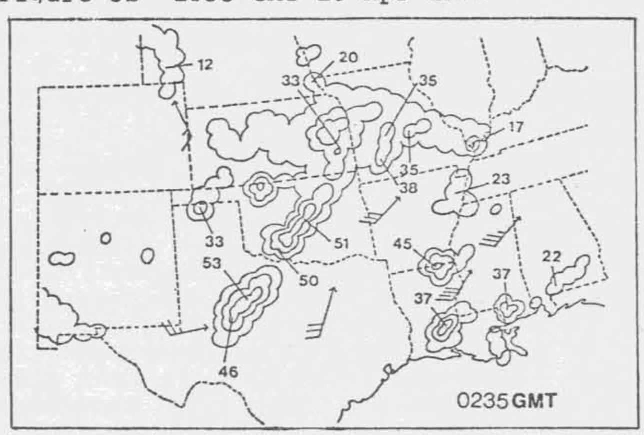


Figure 3d 0235 GMT 11 Apr 1979

Figure 3. National Meteorological Center Radar Summaries.

sion of activity over the Texas panhandle and Oklahoma. Strong cells with tops around 48,000 feet formed to the east of the SSL as well as along the eastward trough extending from the SSL into Oklahoma.

Three strong-to-violent (F2 to F4) tornadoes occurred between Childress and Wichita Falls after 2100 GMT. The Vernon, Texas tornado developed around 2145 GMT killing 11 people before crossing the Red River into Oklahoma. In addition, tornadoes were spawned near Harrold, Texas around 2155 GMT and near Lawton, Oklahoma around 2315 GMT, the latter killing 3 people.

This SSL moved from just west of Childress at 2100 GMT towards the southwest to a position directly between Childress and Wichita Falls by 0000 GMT. To the west, strong westerly momentum, associated with a mesoridging process, created considerable blowing sand and dust in the lower Texas panhandle and southern New Mexico. In Figure 2d we see a "bulge" in the dryline in the vicinity of Abilene, Texas. Tegtmeier (5) notes that often severe weather breaks out to the east-northeast of such dryline "bulges" or waves. Indeed, this is the case for the Red River Valley outbreak as well. The radar summary shown in Figure 3c for 2335 GMT reveals the 58,000 foot cell, which undoubtedly was spawning the Wichita Falls tornado at this time. Further north, in Oklahoma, Kansas and Missouri, general thunderstorm activity was taking place.

Following the subsequent movement of the SSL in Figures 2e-2f, we see that it stays in the same general area, just west of Wichita Falls, and slowly fills. However, further south in the region from San Angelo to Abilene, Texas the trough intensifies and southerly winds back due to pressure falls in this area. By 0200 GMT (Figure 2e) an intense, elongated north-south trough has formed, rekindling severe convection further south. The 0235 GMT radar summary (Figure 3d) gives evidence to this, as a new line of convection with tops near 53,000 feet is shown paralleling this trough. Further north, in Oklahoma, a strong line of convection with tops exceeding 50,000 feet continues. Moller (15) notes that during the period 0200-0300 GMT in the secondary outbreak four tornadoes developed northeast of San Angelo, Texas. Two of the tornadoes had tracks longer than 20 miles and two were over .5 miles wide. By 0300 GMT (see Figure 2f) the mesoridging process noted earlier combined with thunderstorm gust fronts to create strong pressure rises thereby eliminating most signs of this second pressure perturbation.

3.b. STABILITY ANALYSES

Lifted index (LI) analyses for 1500-0300 GMT 10-11 April 1979 are displayed in Figures 4a through 4e. LI values at 1500 GMT reveal that great instability (LI < 0) is found in central and south Texas as well as along the Gulf Coast. Towards the northeast, LI values increase under the

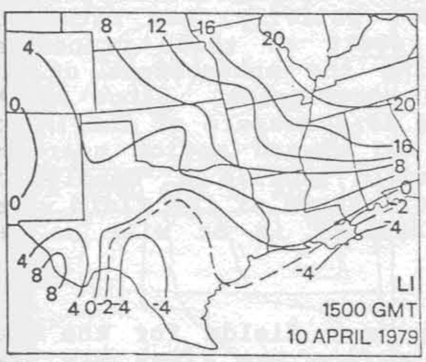


Figure 4a

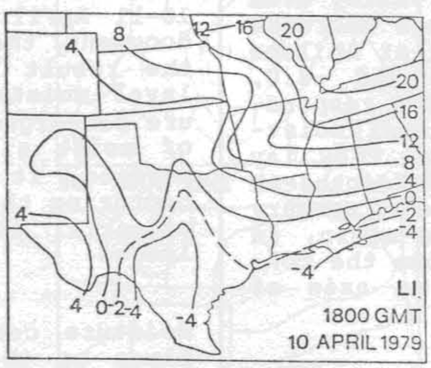


Figure 4b

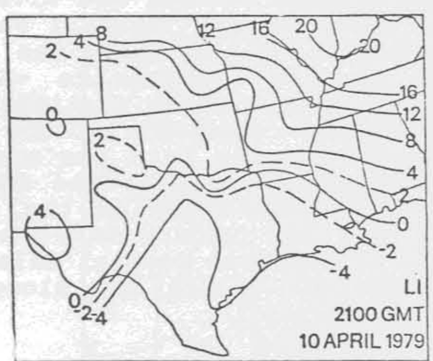


Figure 4c

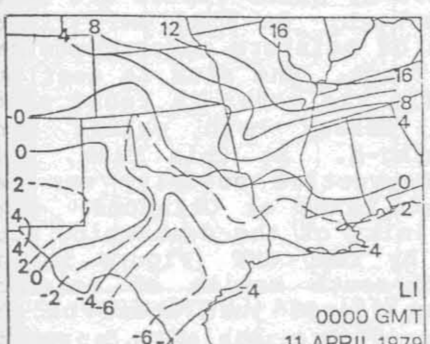


Figure 4d

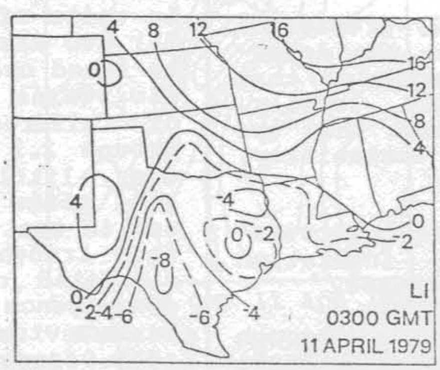


Figure 4e

Lifted Index Analyses

presence of a cool, dry anticyclone centered over the Great Lakes. By 1800 GMT (Figure 4b) two axes of instability form, one in western Texas and the second through central Texas. With the exception of only two stations, most stations in Texas and Oklahoma experienced negative local time tendencies of LI (i.e., instability increased). By 2100 GMT (Figure 4c) the -2 and -4 isopleths have shifted northward toward the Red River Valley. Referring to Figure 3b, it is interesting to note that the convective outbreak at 2035 GMT was not in the most unstable region of the fluid but lay along axes of instability on the northern fringe of the low LI's.

The most significant changes in LI occurs from 2100 to 0000 GMT (Figure 4d) when the -2 isopleth moves northward into western Oklahoma while values of -4 lay just south of the Red River Valley. An examination of individual soundings reveals that decreasing values of LI primarily result from increasing low level moisture and warming associated with the southerly flow in the region, and insolation. The tongue of low instability in southwestern Oklahoma seems to be well correlated with the surface southeasterly inflow vector created by the SSL noted earlier. Thus, it seems that the strongest convection took place in that region where stability was low and low level convergence was enhanced through the formation of a SSL.

From 0000-0300 GMT LI values increase dramatically throughout western Texas. However, in the central Red River Valley area and south central Texas LI values decrease substantially. Notably, the LI at Abilene and Junction decrease to -6.7 and -8.0, respectively. These stations are responding to the resurgence of low level moisture and warming into the area. They lay in close proximity to the second outbreak of convection shown on the radar summary for 0235 GMT (Figure 3d). Once again, in this area and in central Oklahoma the convection has broken out along an axis of low stability.

4. MOISTURE CONVERGENCE

The second step in House's (12) prediction scheme is usually the hardest, the detection or prediction of the mechanism that will release the instability locally. There are a number of mechanisms that the atmosphere uses to release instability, including:

(1) increasing low level parcels' buoyancy through insolation and/or latent heat release,

(2) creating upward motion through the low level convergence associated with a sea breeze,

(3) creating a boundary layer thermal gradient locally which develops an "inland sea breeze" thereby enhancing low level convergence and vertical motion,

(4) inertial-isallobaric convergence generated in low levels in response to upper tropospheric jet streak propagation,

(5) low level convergence development due to the interaction of a cold thunderstorm downdraft with the warm, moist air being entrained into the storm from downstream,

(6) low level convergence development arising from a horizontal variation in the degree to which horizontal momentum is being exchanged vertically (e.g., dryline movement).

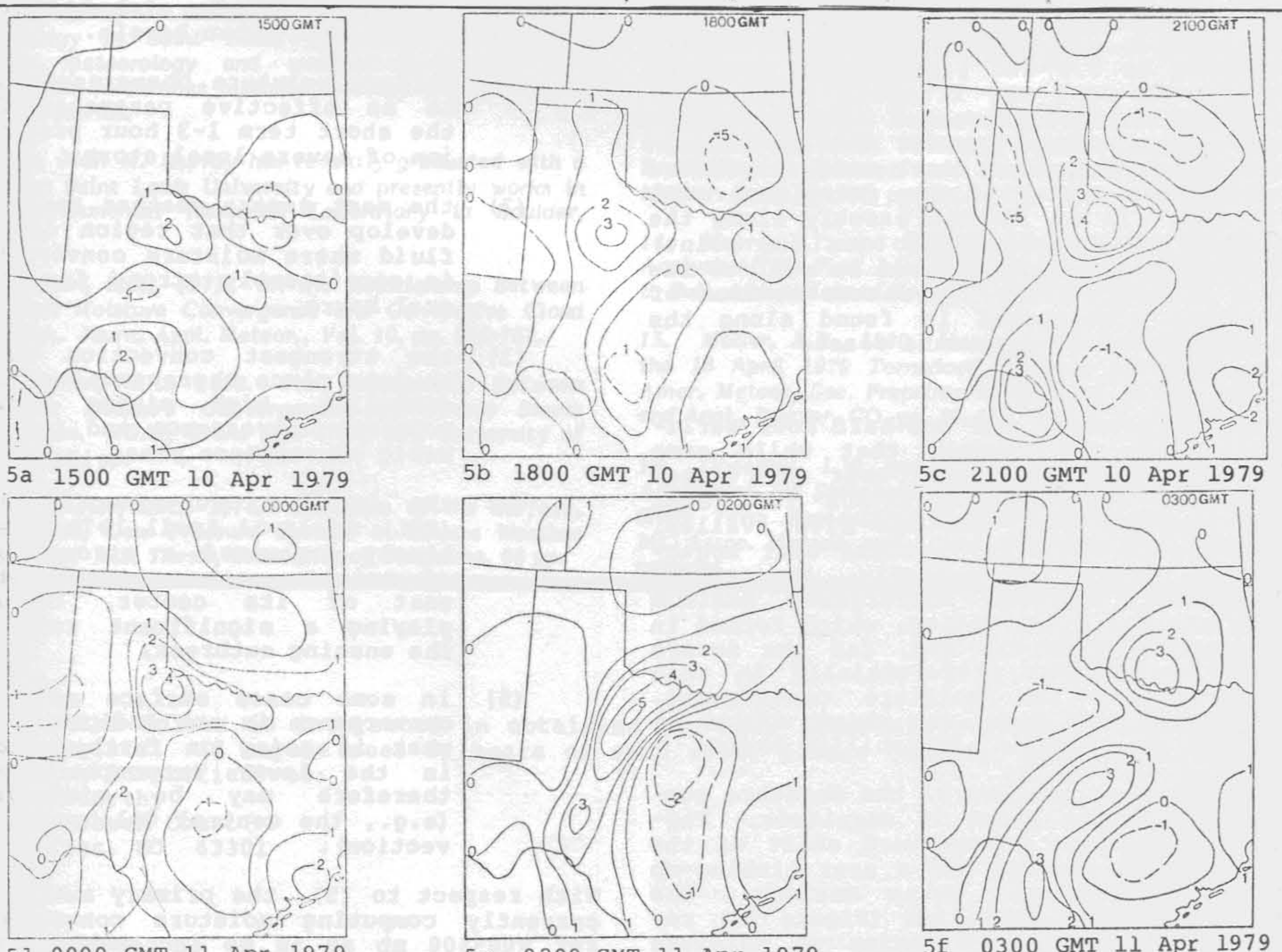
Certainly is is possible for several of these mechanisms to "work together", i.e., the constructive interference of waves which vary over the hydrodynamic spectrum, to enhance the low level convergence field and therefore the subsequent vertical motion. This author has seen considerable evidence in his own research as well as that of Uccellini and Kocin (16) which strongly link the SSL and a low level jet (LLJ), to the propagation dynamics of a strong upper tropospheric jet streak on this SESAME date. However, it is not the aim of this paper to show which of the above mechanisms was responsible for the 10-11 April 1979 activity, but rather to document the result of these processes, the result being the enhancement of low level moisture convergence. Since moisture convergence is a measure of the inflow of moist air and upward motion near the surface, it should provide a "handle" on capturing those regions of the fluid where potential instability is or will be released.

Moisture convergence fields for the same times as the surface map times are presented in Figure 5, where values are given in units of gm/kg-h. At 1500 GMT (Figure 5a) two maxima of moisture convergence can be found over Texas. One area is near Del Rio, Texas while the other is found south of Childress, Texas; both values were around 2.1 gm/kg-h. At this time, however, little convective activity was taking place over Texas or Oklahoma. Both are in the vicinity of the developing surface trough. By 1800 GMT (Figure 5b) an elongated north-south maxima of moisture convergence has formed just ahead of the surface trough (Figure 2b) with a maxima of 3.0 gm/kg-h. Another area of high positive values is found in eastern Texas.

This latter area is split into two centers, one in northeastern Texas with a value of about 1.4 gm/kg-h and one in southeastern Texas with a value near 1.7 gm/kg-h.

The radar summary for 1735 GMT (Figure 3a) reveals that new convective activity has broken out in the vicinity of the latter two areas. The 50,000 foot cell located near the Dallas-Fort Worth area has actually formed between the two northern moisture convergence maxima in the tongue of instability seen in Figure 4b. The southern convective activity has also formed in an area where surface moisture convergence phases with unstable air; however the maximum echo top is only 28,000 feet. Surface conditions alone do not render enough information to help us discern why these two convective regions vary in intensity so greatly.

The most significant feature to watch is the maximum located near the Texas panhandle. It has remained nearly stationary from 1500-1800 GMT but little convection has developed. One reason for this lack of convection would seem to be the relative stability over this area. Figure 4b reveals that lifted indices are around +2 in this area. By 2100 GMT (Figure 5c) this maximum has enlarged and strengthened to a 4.7 gm/kg-h value while moving only slightly east. Extensions of this maximum are found to the northwest and southwest along surface pressure troughs. This maximum is well correlated with the position of the SSL. Indeed, this must be the case since the isallobaric convergence attendent with the SSL formation from 1800-2100 GMT helped to create a concentrated moisture convergence area. The radar summary (Figure 3b) reveals that a 48,000 foot cell has developed in proximity to this moisture convergence maximum. Convection also is found to the northwest along the axis of maximum moisture convergence. Referring to the lifted index analyses for 2100 GMT (Figure 4c) we note that LI values decrease toward the north, thus helping to explain the decrease in maximum echo tops as one proceeds north in the Texas panhandle.



5a 1500 GMT 10 Apr 1979 | 5b 1800 GMT 10 Apr 1979 | 5c 2100 GMT 10 Apr 1979

5d 0000 GMT 11 Apr 1979 | 5e 0200 GMT 11 Apr 1979 | 5f 0300 GMT 11 Apr 1979

Figure 5. Moisture Convergence Values in Grams/Kilogram-Hour in Increments of 1 Unit.

Further south a 3.2 gm/kg-h maximum can be found west of Del Rio, Texas. Less emphasis on the magnitude of this maximum should be given since it is in a data poor region; it is based on only a handful of stations. Nevertheless, the westerly momentum shear is considerable in southern Texas; but in this area mixing ratio values are relatively low, about 9 gm/kg, as opposed to the 13 gm/kg air which lay to the north. Thus, no convection is found here. Additionally, in southeastern Texas moisture convergence values of 2.3 gm/kg-h are found in the vicinity of weak convection in Texas and Louisiana. It is interesting to see that the moderate convection in central Oklahoma is not well correlated with surface moisture convergence since the convergence associated with the SSL dominates the region. Undoubtedly, further aloft (approximately 900-700 mb) moisture convergence must be favorable in this area to intiate and sustain this convection.

Moisture convergence values reach a maximum at 2200 GMT and then decrease by 2300 GMT. At 2200 GMT (not shown) the persistent Red River Valley maximum was 4.9 gm/kg-h while the southwest Texas maxima was 2.4 gm/kg-h. By 2300 GMT these two maxima decrease to 3.9 and 1.8 gm/kg-h, respectively. By 0000 GMT 11 April (Figure 5d) both maxima have increased again. Importantly, the surface map for this time (Figure 2d) reveals that the northern moisture convergence maxima is now coincident with the SSL. It is located exactly along the axis of high mixing ratio (or dew point) while the secondary maximum is well to the west of the dryline. A weaker maximum of moisture convergence is found along the southeast Texas, Louisiana coast.

The radar summary for one-half hour earlier (Figure 3c) reveals that while some modest cells have formed over the Texas/Louisiana coastline, a 58,000 foot cell has exploded over the Red River Valley. However, no activity is found over southwestern Texas. Undoubtedly, the strong persistent moisture convergence maximum over the Red River Valley, which formed in conjunction with the SSL, fed the severe storm environment preferentially in this area. Thus, the moisture convergence, integrated over time, was strong enough to release the potential instability there.

Over the next two hours, the moisture convergence maxima grows in magnitude. Figure 5e displays a southward shift of the northernmost maximum and a near linking-up with the southwest Texas maximum. The surface map for this time (Figure 2e) reveals that these two maxima of moisture convergence lay along an elongated pressure trough. Strong westerly momentum at the surface, associated with the building mesoridge in western Texas meets southeasterly flow, along this pressure trough. This convergence results in the eruption of a northeast-southwest line of convective activity by 0235 GMT through central Oklahoma into Texas as far south as San Angelo (see Figure 3d). There is a significant break in the activity near the Red River Valley. Interestingly, this is reflected in the 0300 GMT moisture convergence field (Figure 5f) which shows two distinct maxima separated by weak positive values.

This latter discontinuous squall line created hailstorms and tornadoes in central Texas and Oklahoma. As noted earlier in section 3.a, numerous reports of hail > 0.75 inches and at least two significant tornadoes accompanied the Texas squall line. Damage was considerably less than the Red River Valley outbreak since these latter storms formed over less populated areas of Texas.

5. CONCLUSIONS

Several conclusions can be stated on the basis of the research shown herein.

(1) surface moisture convergence can be an effective parameter for the short term 1-3 hour prediction of severe local storms,

(2) the most severe weather tends to develop over that region of the fluid where moisture convergence is consistently strong for several hours,

(3) the strongest convection tends to take place where zones of instability, high mixing ratio, moisture convergence and isallobaric convergence phase,

(4) the surface sub-synoptic low (SSL) on 10-11 April 1979 effectively organized a strong zone of moisture convergence to the east of its center, thereby playing a significant role in the ensuing outbreak,

(5) in some cases surface moisture convergence is not indicative of what is going on further aloft in the lower troposphere and therefore may be misleading (e.g., the central Oklahoma convection).

With respect to (5), the primary author is currently computing moisture convergence for 900-500 mb at 50 mb increments using the AVE-SESAME I sounding data. In addition, a vertically integrated moisture convergence parameter will be computed.

These fields will allow a three-dimensional perspective of moisture convergence which may help to overcome the deficiencies of a surface-based perspective.

6. ACKNOWLEDGEMENTS

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REFERENCES AND FOOTNOTES

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