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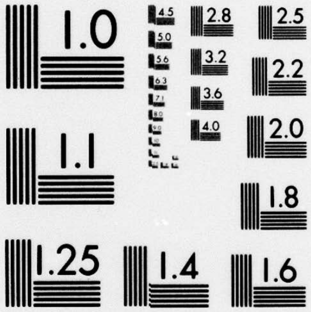
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Moisture Advection and the Sangster Chart

Carl A. Johnson

3d Weather Wing
Offutt AFB, Nebraska 68113

1 8 JUN 1979

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This technical note discusses clouds, precipitation and upper low movements as they were observed to occur with certain type boundary layer moisture advection patterns. Moisture advection was calculated using Sangster chart winds and surface mixing ratios.

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PREFACE

Moisture is one of the two most important parameters which influence weather events that affect our daily lives. A logical consequence is that the forecaster must know the current moisture content and be able to measure changes to that value if accurate forecasts are to be produced. It has been my long standing belief that the energy released by low level moisture patterns actually influences the intensity and to a degree, the movement of developing storm systems. Unfortunately, no forecaster aid has been developed to provide forecasters with the necessary information.

This study was made to serve two purposes. First, I wanted to determine if a computer driven product could be practically produced and transmitted to weather forecasters and second, to illustrate potential uses of the product once it was determined that it could be made available.

Computer produced moisture fields and surface data for the same time periods were supplied for this study through the kind cooperation of Dr. Wayne Sangster of the Central Region Office of the National Weather Service. The moisture fields were combined with surface geostrophic winds available on the ASUS 10 KMKC teletype bulletins to determine approximate moisture advection rates. These were compared to horizontal weather depiction analyses, radar analyses, and the 500mb analyses to illustrate the product effectiveness. While no esoteric statistical analyses were performed, circumstantial evidence strongly suggests that this product would be a powerful forecasting tool for short range forecasting.

Since the ingredients of the product are currently produced for the CONUS by the National Weather Service and could be computed easily by AFGWC for global application, this product appears to be worthy of further study and implementation.

Acknowledgements

The author wishes to express his most sincere thanks to the men and women who worked harder in preparing this report than he did.

Thanks to Ms Diana LeBoeuf for typing this report many times over.

Thanks to Sgt Dave Nelson whose steady hand and limitless patience helped construct the majority of the graphics.

A special thanks to A1C Arnold Patillo who gained a new insight into the numerical order of the universe by typing more than 25,000 numbers on computer punch cards.

A special thanks to my friend and co-worker, CMSgt Eugene M. Weber, who generously contributed graphics he made for his own, yet unpublished, tech note on East Coast snowstorms.

Thanks to Major H. A. King III, who commands a special task force against verbosity, and attacked by verbal overages with reckless abandon. And a special thanks to him for helping interpret some of the results, and generously allowing me the time to do the work.

Last, but not least, thanks to Dr. Wayne E. Sangster. His gracious hospitality and open invitation to unselfishly share his data and assistance literally made this study possible.

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CHAPTER 1 - INTRODUCTION

GENERAL

Reams of literature have been written on the topic of moisture and its influence on our weather. Petterssen relates that weather and climate are, in fact, determined by moisture and temperature regimes.(1) The past experiences of this forecaster contains several unhappy examples of incorrectly "guessing" the track that moisture-laden air would follow; each resulting in an incorrect cloud or precipitation forecast. Consequently, it was felt that forecasters would be well served by a product which could give timely advice concerning the source, amount, and trajectory of moisture available to affect his or her domain. Hence, this study was generated. The goal was simple; to observe whether or not the Surface Geostrophic Wind and Vorticity Chart could be used in conjunction with fields of analyzed surface moisture to provide an accurate picture of moisture advection and corresponding changes in the weather. Both the wind and moisture products used in the study are routinely prepared on computers by the National Weather Service in Kansas City MO. Each product covers the entire United States, but currently the moisture (mixing ratio) chart is not available to AWS forecasters and, only the portion of Surface Geostrophic Winds and Vorticity Chart covering the Midwest is transmitted over teletype circuits. This product is the ASUS 10 KMKC bulletin and is made available every three hours. The terms Sangster chart or Sangster winds will be used in reference to ASUS 10 data and surface geostrophic winds in this report.

NATURE OF THE STUDY

Sangster winds and surface mixing ratios were used to compute <u>approximate</u> rates of moisture advection. It is important that the word <u>approximate</u> be emphasized. This is done for two reasons. First, there is no guarantee that the Sangster winds represent the true gradient level winds. In fact, it has been shown that over sloping terrain in the Great Plains, Sangster winds precede boundary layer winds by approximately 9 hours,(2) by the nature of the equations,(3) this time differential would dissappear over uniform terrain. However, even over uniform terrain, the fact that the geostrophic approximations are based on surface data must be considered a reason for departure between the Sangster winds and those that actually occur in the boundary layer. A second reason is the seemingly questionable assumption made by this author, that surface moisture is linked in an inviolate continuum with the Sangster winds, which, are approximations of winds above the surface.(4) With these objections in mind, the study is presented in a qualitative sense. That is, even though moisture advection is quantified in units of gm/kg-hr, it should not be construed as absolute, or even percentages of absolute advection without further study. Even knowing this, it is felt that the real benefit arises from timely updating of moisture trajectories and knowledge (in a relative sense) of how stations are located with respect to centers and axes of positive and negative moisture advection.

Another weakness is the fact that offshore, Sangster winds and moisture are extrapolated from values observed onshore. This causes at least some inaccuracy in those portions of United States where ample moisture exists in close proximity to areas of extreme dryness. The Southwestern U.S. falls in this category. The problem in the southwest is further complicated by the fact that Mexican data are frequently missing, and data along the California coast are nonexistent. As a consequence, little correlation was observed between weather events and the moisture advection areas in that area.

Finally, the case studies were generally presented without regard to the synoptic situation, realizing, of course, that this is somewhat artificial. This was done primarily for brevity with the idea that fewer words would get the same idea across.

Moisture Advection Computations

This section is provided only as a reference for future study. The equation used for horizontal moisture advection, A, is given by:

$$A = -\overline{V} \circ \nabla_2 w$$

$$= -u \frac{\partial w}{\partial x} - v \frac{\partial w}{\partial y} \; ; \; \text{gm/kg-hr}$$

where $\overline{V}$ = Sangster wind velocity

w = Surface mixing ratio

and u, v = The zonal and meridional components of the Sangster wind, respectively.

In preparing the data for computer analysis, it was necessary to rotate V from the earth's coordinate system to grid coordinates. This was accomplished by the simple rotation equation:

$$\hat{u} = v \sin \theta + u \cos \theta$$

$$\hat{V} = v \cos \theta - u \sin \theta$$

where θ = the angular departure from the map reference point; i.e. 90°N, 110°W

$$= -\text{Arctan}\,(i - 7.5)/(39-j)$$

and i, j are the east-west, north-south grid coordinates, respectively.

The mixing ratio chart, calcualted at the NWS central region, is of the same scale as the Sangster chart, however, the grid is offset ½ grid point west and ½ grid point south of the wind grid. Consequently, when the two charts are overlayed, each grided wind forms the center of a square, whose verticies are values of mixing ratio, see Fig 1-1.

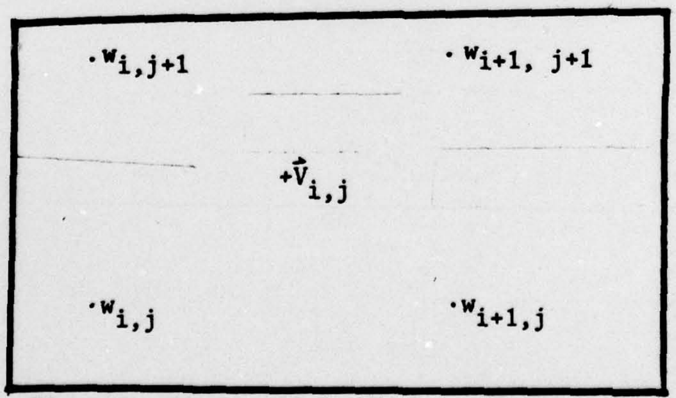


Fig 1-1. Mixing Ratio Grid (w) Compared to Velocity grid $(\hat{V})$.

Consequently, an averaging process was done such that:

$$\frac{\Delta w}{\Delta x} = (w_{i+1,j} - w_{i,j} + w_{i+1,j} - w_{i,j})/2\Delta x$$

Where Δx = grid distance in nautical miles.

While this averaging would tend to smooth out mixing ratio gradients, it was the most expedient in terms of programming ease. Another, perhaps better method, would have been to check each wind for positive or negative $\hat{u}$ and $\hat{j}$ components and then calculate the gradients from the upwind moisture grids. At any rate, our method did yield adequate results. Examples of the entire Sangster chart and the mixing ratio chart are shown in Figures 1-2 and 1-3, respectively.

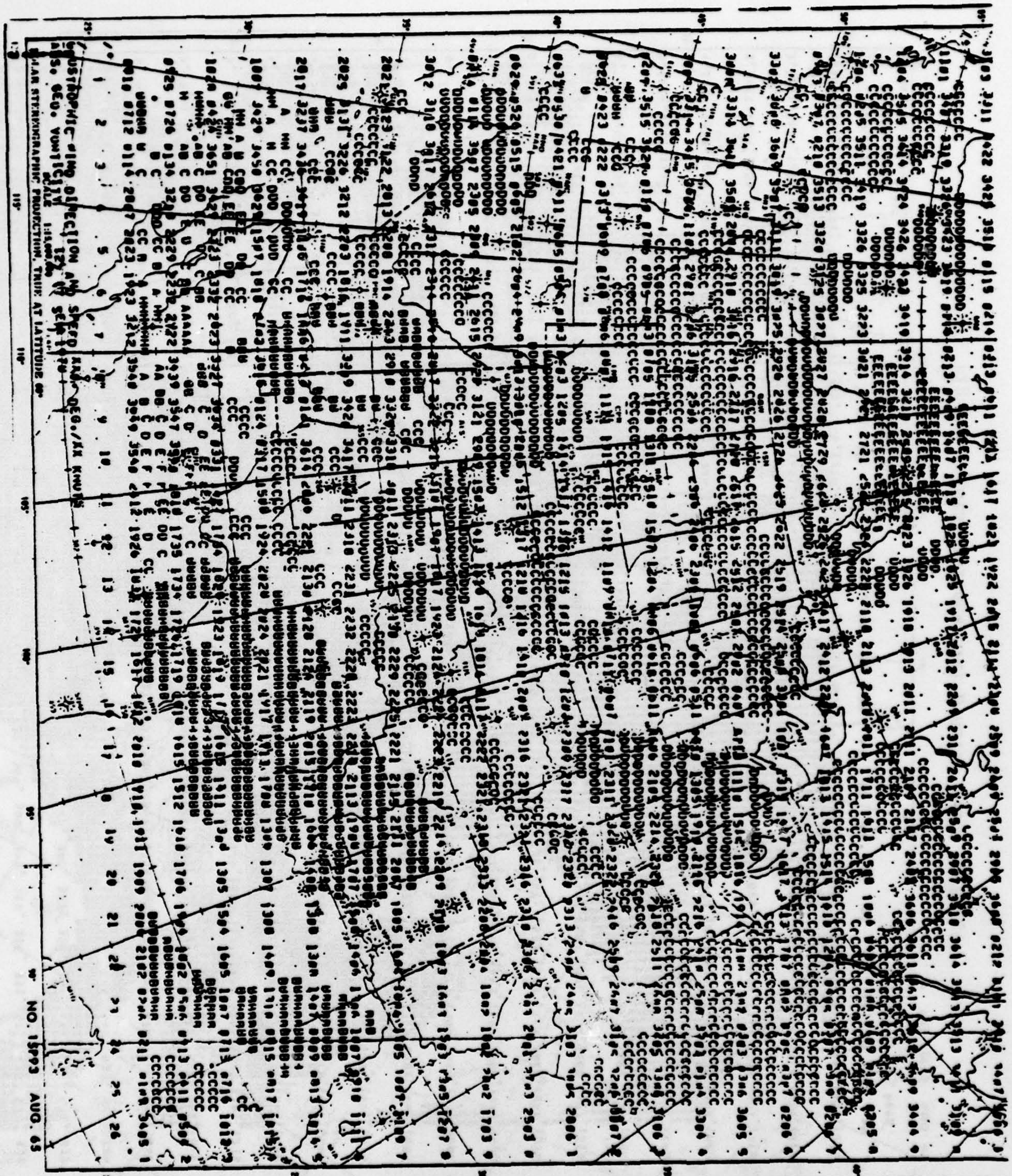


Fig 1-2. Total Surface Geostrophic Wind and Vorticity Chart Coverage.

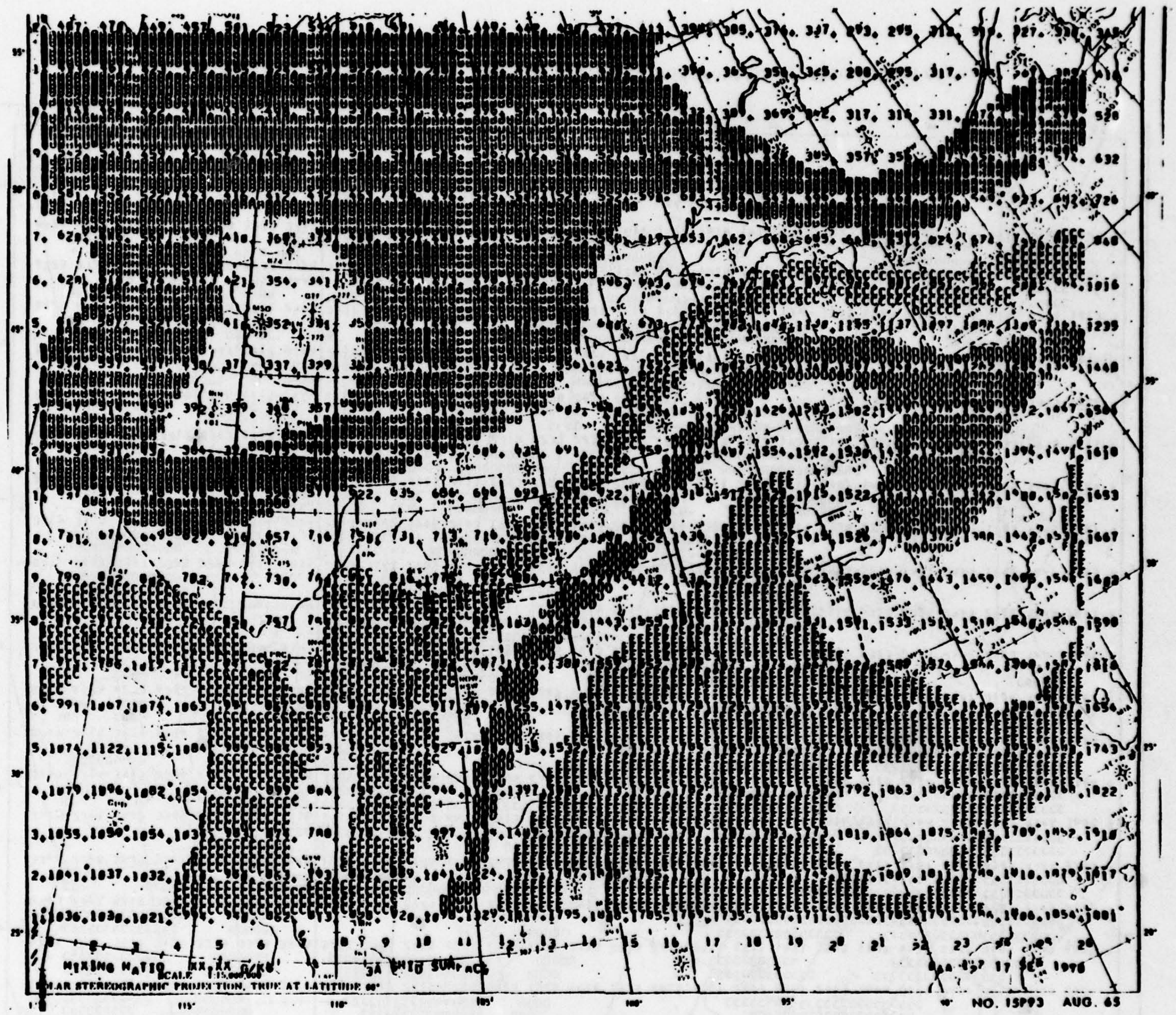


Fig 1-3. Total Surface Mixing Ratio Chart Coverage.

CHAPTER 2 - GENERAL

THE MOISTURE ADVECTION PRODUCT

The term moisture advection simply refers to the amount of moisture passing by a specified location in a given amount of time. It is a function of the moisture distribution and wind velocity. Consequently, moisture will move (advect) towards or away from a station most quickly when the winds are blowing rapidly through a strong moisture gradient. Positive moisture advection means the winds are blowing from moist air towards dryer air, while negative advection indicates the opposite is occurring. Neutral advection occurs when the winds are calm, or blowing parallel to a moisture gradient. Figure 2-1 depicts a uniform moisture gradient superimposed over cyclonic circulation. Point A is experiencing positive moisture advection while point C is experiencing negative moisture advection. Points B and D are experiencing little, or no (neutral) moisture advection.

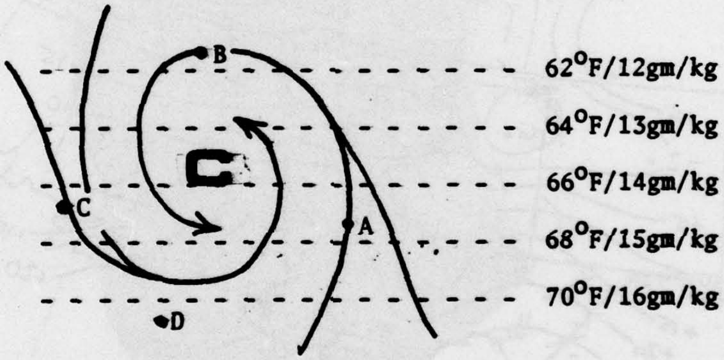


Fig 2-1. Cyclonic Flow in a Uniform Moisture Gradient. Points A and C experience positive and negative moisture advection, respectively. Points B and D have neutral advection. Moisture is expressed both as dew point temperature and mixing ratio (1000mb).

This simple illustration indicates that it might be possible to manually superimpose dew point temperature over the Sangster winds and qualitatively determine moisture advection. In fact, this was done as a pilot project to determine if this study should be initiated. This procedure does reveal areas of moisture advection (and drying) and can easily be done at locations where the Sangster Chart is received. The easiest method is to reproduce the Sangster Chart overlay with select station circles enscribed on it. Dew points can then be plotted directly on the overlay, analyzed for isodrosotherms, and then superimposed on the streamlined Sangster wind field. Moisture advection areas show up quite clearly. Figure 2-2 demonstrates this process. The shaded area is where positive moisture advection is occurring. This procedure is unfortunately time consuming and subject to some analysis error, but it will have to do until such time that moisture advection data are computerized.

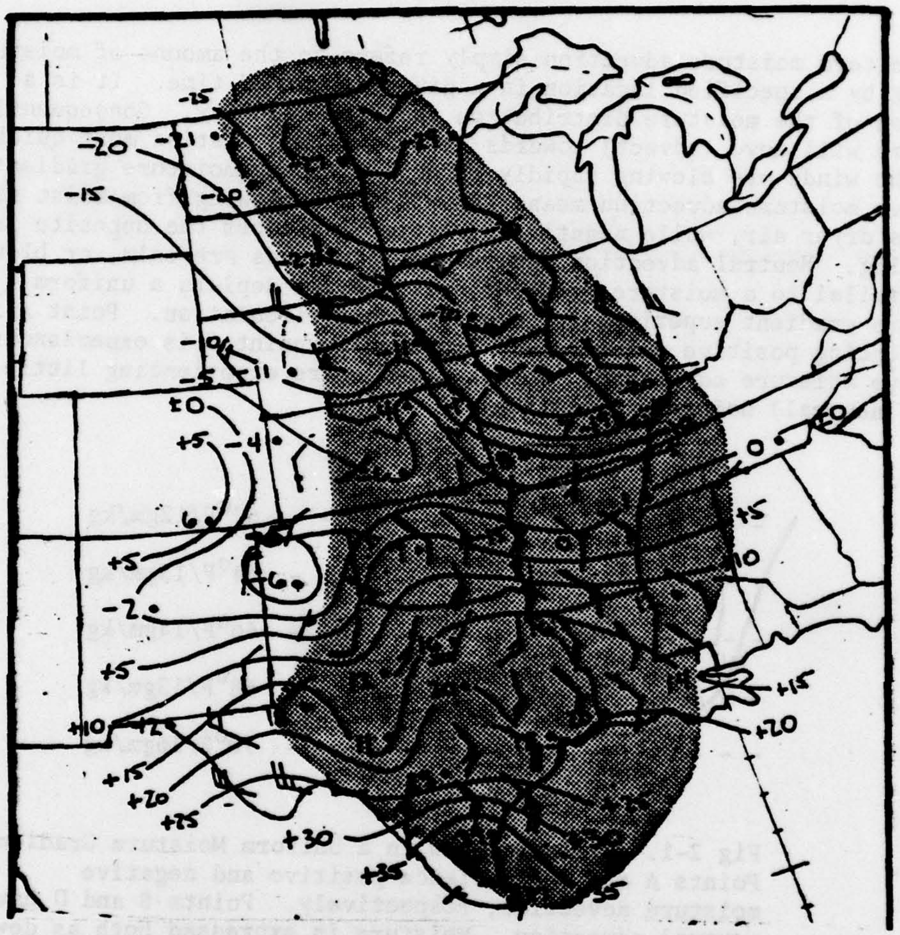
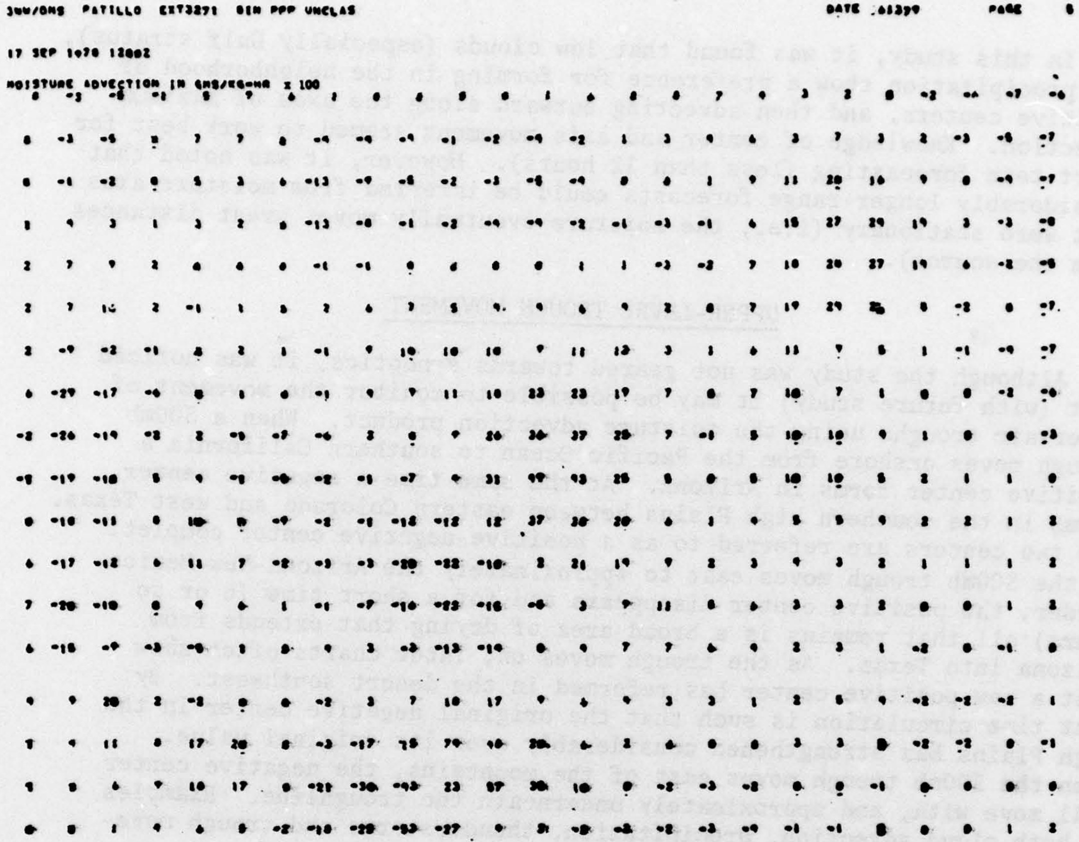


Fig 2-2. Manually Prepared Moisture Advection Chart. Surface dew points overlaying Sangster winds show positive and negative advection areas.

MOISTURE FIELDS

Figure 2-3 shows the raw computerized moisture advection chart. Units are in hundredths of a gm/kg-hr. Analysis consists of isopleths of moisture advection, advection centers and positive moisture axes. Isopleths are labeled in increments of +.10 gm/kg-hr, but have been multiplied by 100 so as to display whole units. Positive and negative advection centers are labeled ⊕ and ⊖ respectively and the center value underlined, and placed as close to the center location as possible. Positive moisture advection axes are shown as a heavy black line and represent lines along which maximum moisture advection is occurring. Figure 2-4 is the final analysis and corresponds to the computer chart shown in Figure 2-3.



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17 SEP 1978 1200Z

MOISTURE ADVECTION IN GMS/KG-HR  X 100
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Fig 2-3. Raw Moisture Advection Product. 17 Sep 78, 1200Z

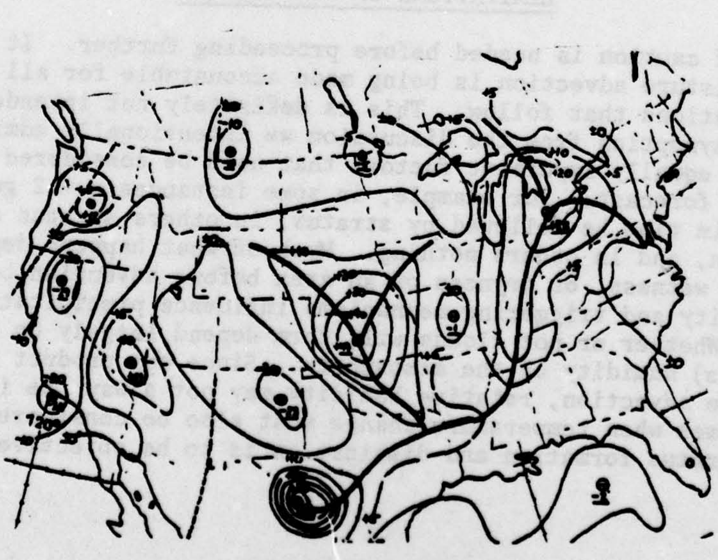

Fig 2-4. Finalized Moisture Advection Product. 17 Sep 78, 1200Z

In this study, it was found that low clouds (especially Gulf stratus), and precipitation show a preference for forming in the neighborhood of positive centers, and then advecting outward along the axes of maximum advection. Knowledge of center and axis movement seemed to work best for short-term forecasting (less than 12 hours). However, it was noted that considerably longer-range forecasts could be inferred from moisture axes that were stationary (i.e., the moisture eventually moves great distances from the source).

UPPER-LEVEL TROUGH MOVEMENT

Although the study was not geared towards synoptics, it was noticed that (with future study) it may be possible to monitor the movement of upper-air troughs using the moisture advection product. When a 500mb trough moves onshore from the Pacific Ocean to southern California a positive center forms in Arizona. At the same time a negative center forms in the southern high Plains between eastern Colorado and west Texas. The two centers are referred to as a positive-negative center couplet. As the 500mb trough moves east to approximately the Arizona-New Mexico border, the positive center disappears and for a short time (6 or so hours) all that remains is a broad area of drying that extends from Arizona into Texas. As the trough moves on, later charts often show that a new positive center has reformed in the desert southwest. By that time circulation is such that the original negative center in the high Plains has strengthened considerably over its original value. When the 500mb trough moves east of the mountains, the negative center will move with, and approximately underneath the troughline. Examples of both cloud advection, precipitation, thunderstorms and trough movement are shown in Chapter 3.

LIMITATIONS OF THE PRODUCT

A word of caution is needed before proceeding further. It may seem as though moisture advection is being made accountable for all the weather situations that follow. This is definitely not intended. By eliminating synoptics from the discussion we intentionally admit the existance of equally important factors that need be considered prior to issuing a forecast. For example, in some instances a +.2 gm/kg-hr (+20) center may, in time be followed by stratus, in others stratus and precipitation, and in others nothing. Much of what happens depends on the relative wetness, or dryness of an area before advection begins. Also, stability and triggering mechanisms influence precipitation potential. Whether or not clouds will form depend largely on the relative (not absolute) humidity of the atmosphere. Since our product measures only moisture advection, relative humidity may not always be inferable. There are times when temperature change must also be considered if the timing of stratus formation and dissipation is to be objectively estimated.

First, Gulf stratus will usually form more slowly than indicated by the moisture advection chart because of the warm southerly flow associated with the onset of a Gulf stratus. Even though moisture is being added to the atmosphere, warming is also taking place, hence the temperature - dew point spread closes more slowly. In other words, the relative humidity does not increase as rapidly as would be indicated by holding the temperature constant and increasing the mixing ratio in accordance to the moisture advection chart figures. The result is that it takes longer to form a lifting condensation level that is suitably low for stratus formation. The opposite situation develops behind cold fronts. In this case, even though drying is evident on the moisture advection chart, the air is being cooled. Unless this cooling is taken into account clearing may be forecast, but wide areas of post-frontal clouds may actually exist. Temperature advection may be estimated, or numerically computed using observed thermal fields. This was not done in our study. In short, factors other than moisture advection will have to be considered using other products. The moisture advection product best shows where the maximum potential, for a given weather event, exists.

CHAPTER 3 - CASE STUDIES

Example 1 - 17 Sept 1978

DISCUSSION

For this case only two moisture advection charts were prepared. They are based on 17/09Z and 17/12Z Sangster data. While this is not sufficient to establish reliable continuity, several uses for the moisture advection charts are suggested. Included in this discussion are Gulf stratus formation in Texas, thunderstorm formation in the Great Plains, dissipation of upper Mississippi Valley precipitation and a brief glimpse at the relationship between a 500mb trough position and corresponding positive moisture advection areas and drying areas.

TEXAS GULF STRATUS

This first Gulf stratus advection case takes place in southern Texas. Note in Figure 3-1 that a positive center is located in the Texas Big Bend country. An axis extends from the center into northeastern Texas, and then splits into two separate branches; one continuing northeast and the second recurving northward into the Great Plains. At the approximate time of the moisture advection chart, patches of stratus were forming over San Antonio at 07Z and in the vicinity of Tyler by 10Z (see Figures 3-2 and 3-3). At 13Z (Figure 3-4) stratus has filled in along the moisture advection axis and extended in a banana-shaped arc from Old Mexico to northeast Texas. By 16Z (Figure 3-5) the stratus had dissipated in the southwest portions but extended eastward along the moisture advection axis to near Monroe LA. By 19Z (not shown) all stratus dissipated.

GREAT PLAINS THUNDERSTORM FORMATION

In the early morning hours, light showers and thundershowers were forming in eastern Colorado and the panhandle of Nebraska (see Figure 3-6).

The showers are forming along the western boundary of the rather strong positive moisture advection areas centered in Kansas and Nebraska. Since thunderstorms were present, it would seem reasonable to assume that the area of precipitation would increase considerably as it moved into the region of strong moisture advection. Subsequent precipitation analyses confirm the assumption (see Figures 3-7 through 3-10). Note that on the next moisture advection chart, 12Z (Figure 3-11), the Nebraska center had diminished, but the total area of positive moisture advection had expanded into North Dakota. It is interesting that the northern-most extension of the thunderstorm activity in North Dakota closely aligns with the zero advection isoline. Also

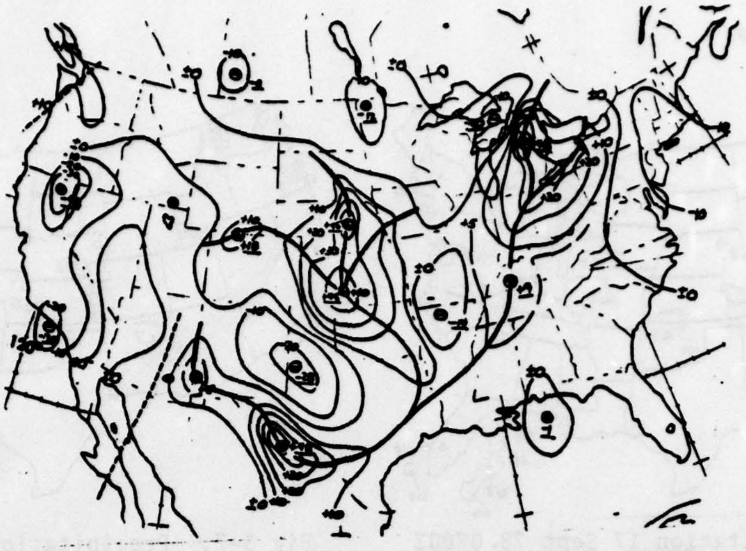

Fig 3-1. Moisture Advection 17 Sept 78, 0900Z

Fig 3-2. CIG ≤ 3000 ft. 17 Sept 78, 0700Z

Fig 3-3. CIG ≤ 3000 ft. 17 Sept 78, 1000Z

Fig 3-4. CIG ≤ 3000 ft. 17 Sept 78, 1300Z

Fig 3-5. CIG ≤ 3000 ft. 17 Sept 78, 1600Z

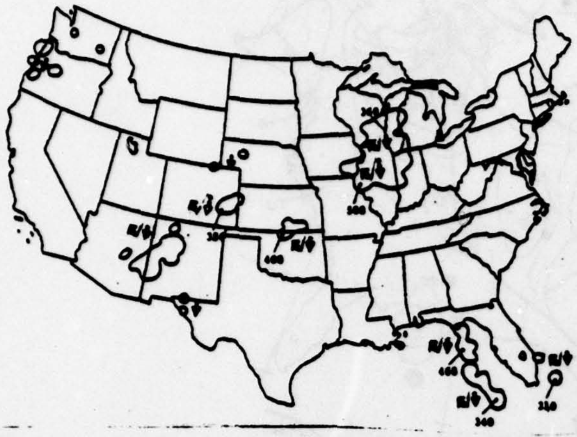

Fig 3-6. Precipitation 17 Sept 78, 0700Z

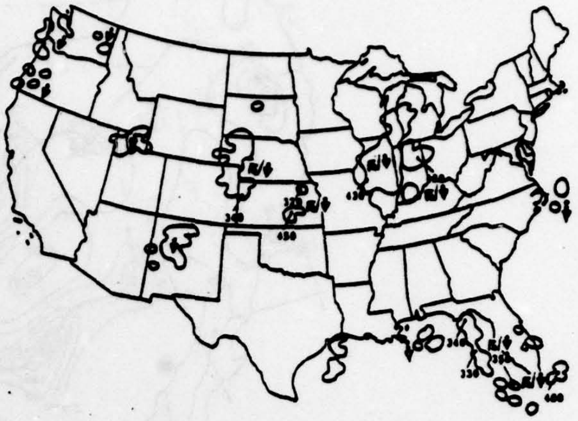

Fig 3-7. Precipitation 17 Sept 78, 1000Z

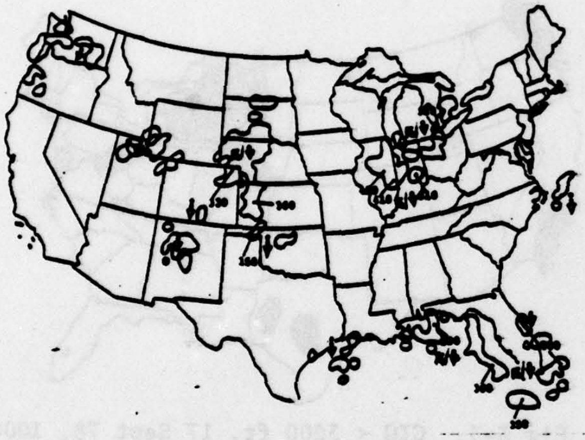

Fig 3-8. Precipitation 17 Sept 78, 1100Z

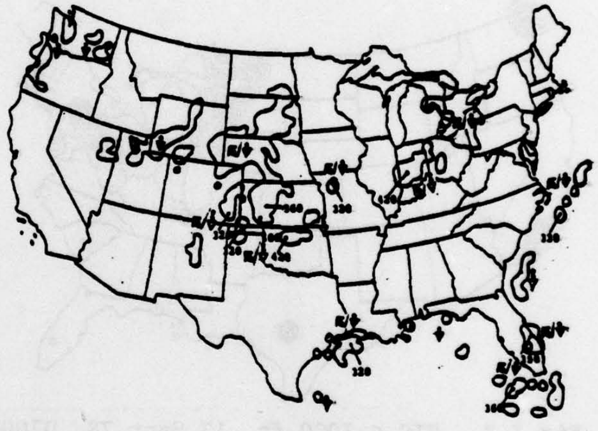

Fig 3-9. Precipitation 17 Sept 78, 1400Z

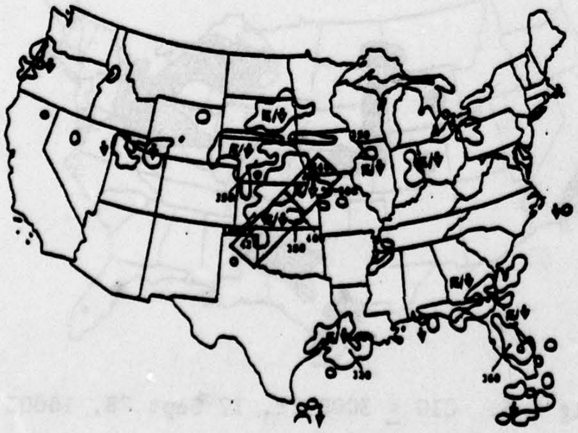

Fig 3-10. Precipitation 17 Sept 78, 1700Z

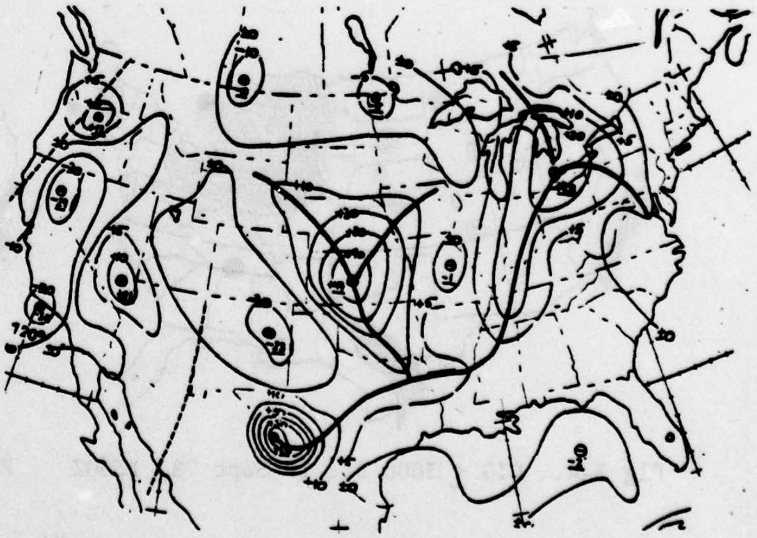

Fig 3-11. Moisture Advection 17 Sept 78, 1200Z

note the maximum axis that extends northeast, through Iowa. Although later advection charts are not available, it appears as though the maximum advection center in Kansas moved northeast along the Iowa axis causing heavy precipitation in that state. Reconstructing events shows the heaviest precipitation moved through southern Iowa (see Figures 3-12 through 3-15). Figure 3-16 shows the 12Z positive center and axis locations superimposed over the day's precipitation totals. The next day (Sept 18th) dawned with the positive moisture advection center located in Michigan (see Example 2).

DISSIPATION OF UPPER MISSISSIPPI VALLEY PRECIPITATION

Another large area of precipitation was present in the upper Mississippi Valley (Figures 3-6 through 3-10). Note the weakening of the northern portion of the positive moisture advection area between 09Z and 12Z in Michigan. Also note that the southern portions of the area (southern Indiana and Kentucky) did not weaken, but remained approximately the same. Figures 3-7 through 3-9 show a distinct decrease in precipitation area and intensity through Michigan, but the portion of the band through southern Indiana remained fairly intense through 1435Z (Figure 3-9). The entire precipitation area had diminished considerably by 1735Z which was suggested by the overall decrease in intensity of the positive moisture advection areas between 09Z and 12Z (from +.48 to +.28 gm/kg-hr; a decrease of .20 gm/kg-hr).

500mb TROUGH POSITION AND POSITIVE-NEGATIVE ADVECTION CENTER COUPLET; SOUTHWESTERN UNITED STATES

One challenging issue facing forecasters today is being able to accurately place a 500mb trough position between the 12-hourly analyses. If the trough's motion is uniform, extrapolation is possible. However, weather is frequently at its worst when trough motion is not uniform. For example, troughs that are stationary in the southwestern United States often produce major weather events when they suddenly move into the Great Plains. Prognostic charts covering these situations may be susceptible to problems resulting from locked-in-error(5), or possibly analysis errors.(6)

Hopefully, in time, we may learn to properly use moisture advection centers to accurately place upper-level trough locations at 3-hour intervals. This example illustrates what is thought to often happen as a 500mb trough moves onshore from California. For convenience, the 17/0900Z interpolated trough positions are included in Figure 3-1. Note the Arizona trough is preceded by a +.05 gm/kg-hr center (shown as +5) on the Arizona-New Mexico border, and a -.20 gm/kg-hr (-20) center located on the Texas panhandle. This feature has been named a positive-negative center couplet, and was observed to form in advance of upper troughs moving into the Southwest from the Pacific Ocean. Note the

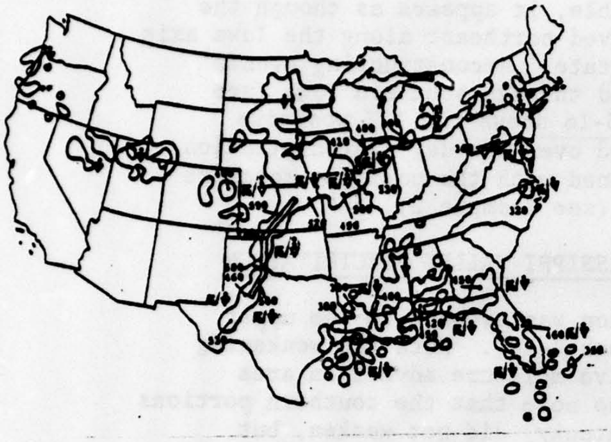

Fig 3-12. Precipitation 17 Sept 78, 2100Z

Fig 3-13. Precipitation 17 Sept 78, 1900Z

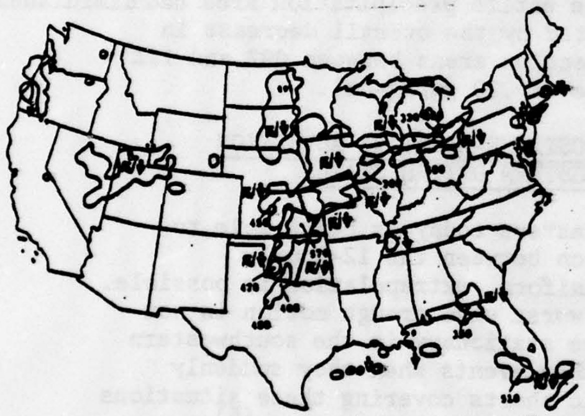

Fig 3-14. Precipitation 18 Sept 78, 0100Z

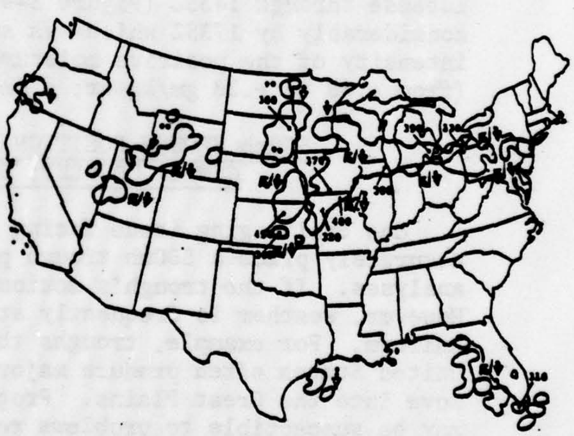

Fig 3-15. Precipitation 18 Sept 78, 0400Z

PRECIPITATION AREAS AND AMOUNTS

Fig 3-16. Precipitation Amounts 17/12Z-18/12Z. Dark lines are moisture advection axes, large dots are positive moisture advection centers.

second 500mb trough in the Pacific Northwest. Figure 3-11 shows the 17/1200Z positions of the aforementioned troughs. The important feature to note is the eastward movement of the southern 500mb trough to the Arizona-New Mexico border. At this time the positive center of the moisture advection couplet dissipated leaving a broad area of drying from Arizona to Texas. This was found to happen in all instances where 500mb troughs were observed to cross over into New Mexico from Arizona. A second feature is the positive center forming near Las Vegas. This is thought to be forming ahead of the Pacific Northwest trough which is digging rapidly southward. It will be shown in the next example.

Example 2 - 18 Sept 1978

DISCUSSION

Again, only two moisture advection charts are available. They are based on 18/06Z and 18/09Z Sangster data. Included in the discussion is the second Texas Gulf stratus episode, a precipitation event in Wyoming and Montana and another look at the southwest 500mb trough position with respect to centers of moist advection and drying. Several other significant features of interest exist on the maps, but are left for the reader's inspection. Two such areas are the large low ceiling and precipitation area in the upper Midwest, and the light rain occurring in southern Oregon.

TEXAS GULF STRATUS

As on the September 17th case, a positive moisture advection axis extends northeast from Mexico to northeast Texas (Figure 3-17). Also, as with the previous day, the stratus first formed at San Antonio and subsequently filled in (northeastward and southwestward) along the maximum axis (see figures 3-18 through 3-21). Unlike the previous day, the advecting stratus band also followed a secondary moisture advection axis that branched from the main axis near Longview, Texas and curved northwest into Oklahoma. No explanation for this departure can be offered except that on the 17th, considerable midcloudiness was present over central Oklahoma. On the 18th no middle-level cloudiness existed. It's possible that mid-cloud ceilings inhibited cooling which, in turn, retarded the formation of strong boundary layer winds that are often important in Gulf stratus advection(7). At any rate, it is noted that ceilings were generally lowest through east Texas, northern Louisiana, and southern Arkansas. This corresponds well to the 06Z maximum center located in east Texas (Figure 3-17). This center clearly existed prior to stratus formation.

WYOMING AND MONTANA PRECIPITATION EVENT

This is an interesting case because of the mountainous location in which it took place. When this project began, we had no idea that our method of calculating moisture advection would "hold water" in, or west of the Rockies. Consequently, this case was quite encouraging. At 18/06Z (Figure 3-17) a positive advection area was centered near Billings, Montana. Two separate axes converged on this center; one coming from Oregon and the other from Wyoming. The axes merged at the center and then continued eastward in a single arc, into North Dakota. The progress of the precipitation shield from Wyoming into Montana and North Dakota is shown in Figures 3-22 through 3-24. Note that this progress corresponds closely to the 06Z axis location. Moreover, by 13Z, the heaviest rain (moderate) was falling at Billings, directly under

Fig 3-17. Moisture Advection, 18 Sept 78, 0600Z

Fig 3-18. Cigs ≤ 3000 ft, 18 Sept 78, 0100Z

Fig 3-19. Cigs ≤ 3000 ft, 18 Sept 78, 0700Z

Fig 3-20. Cigs ≤ 3000 ft, 18 Sept 78, 1300Z

Fig 3-21. Cigs ≤ 3000 ft, 18 Sept 78, 1600Z

Fig 3-22. Precipitation, 18 Sept 78, 0100Z

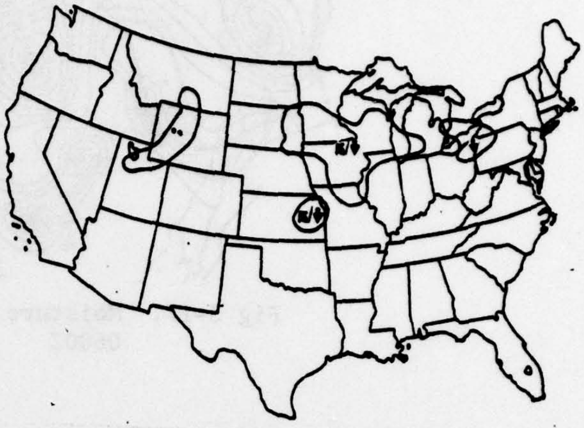

Fig 3-23. Precipitation, 18 Sept 78, 0700Z

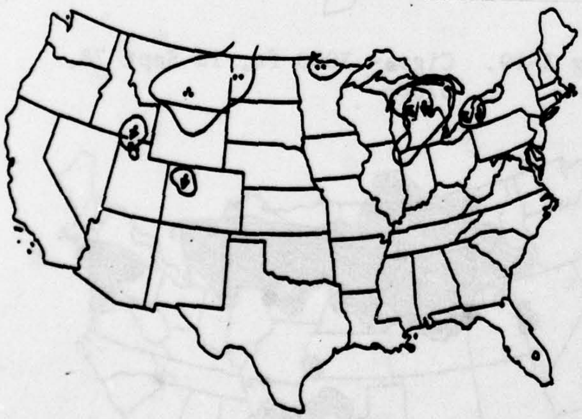

Fig 3-24. Precipitation, 18 Sept 78, 1600Z

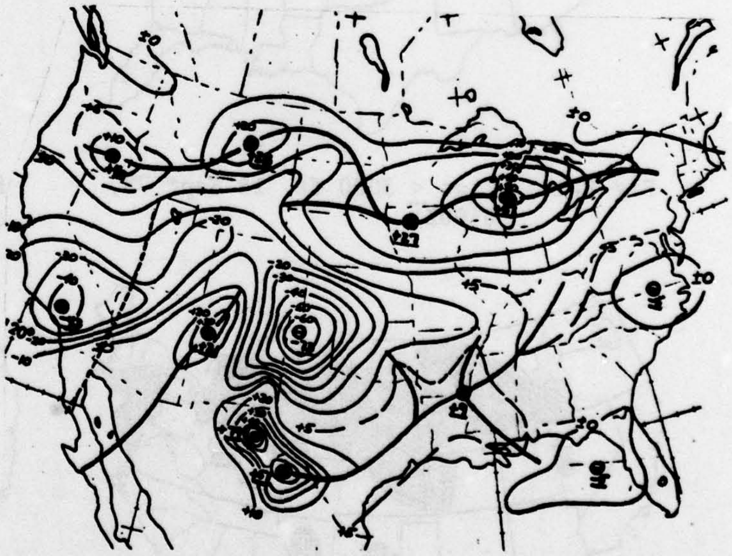

Fig 3-25. Moisture Advection, 18 Sept 78, 0900Z

the center of positive moisture advection, In fact, Billings and Miles City, Montana received 1.66 and 1.08 inches of rain, respectively. Note that the positive center remained stationary between these two cities between 06Z and 09Z (Figures 3-16 and 3-25). The most precipitation anywhere else in the 3-state area was .39 inch at Lewiston, Montana.

500MB TROUGH POSITION IN THE SOUTHWEST U.S. IN RELATION TO POSITIVE AND NEGATIVE ADVECTION AREAS

By the 18th, a deep 500mb low had moved into position just west of the Great Salt Lake. The interpolated 18/06Z and 18/09Z trough positions are shown in Figures 3-16 and 3-25, respectively. The intensity of the trough was much stronger than the day before; likewise, so was the positive-negative advection center couplet. The positive center value in Arizona is +.54 (+54) gm/kg-hr and the negative center in northern Texas is -.70 (-70) gm/kg-hr. Both values are quite strong compared to others we observed in those parts of the country. Unfortunately, no continuity exists beyond 18/09Z. Observing the couplet is all that can be done.

EXAMPLE 3: 11-13 JANUARY 1977

DISCUSSION

The 11th of January marked the beginning stages of one of the more extensive stratus episodes of 1977. On this day, the stratus was confined to central Texas. However, during the next two days, the stratus moved northward into Canada.

TEXAS GULF STRATUS, 11 JANUARY 1977

The moist advection analyses begins with the 06Z data set (Figure 3-26). A weak positive center is located in north-central Texas. An axis of positive moisture advection extends from the Gulf of Mexico into the northern Plains. Stratus began forming about the time of this chart (there was none shown on the 01Z weather depiction chart). However, by 07Z (Figure 3-27) Victoria, Texas reported low ceilings (almost precisely the location where the axis crossed the Gulf coast). Figures 3-28 and 3-29 are important in that you will notice the centers of positive moisture advection remain in Texas and so does the stratus (see Figures 3-30 through 3-32). The moisture centers began moving north on 12 January when the stratus began its northward progression into the Great Plains (see below).

GULF STRATUS INCURSION INTO THE NORTHERN PLAINS, 12 JANUARY 1977

Rather than a separate instance, this is actually a continuation of the 11 January episode. We pick back up on the moisture advection chart series at 12/00Z (Figure 3-3). The stratus was oriented southwest-northeast from Old Mexico to northeast Texas (similar to examples 1 and 2, see Figure 3-34). It seems conceivable that forecasters in the northern Plains would have felt quite comfortable in forecasting fair skies the next morning. However, this was not to be the case. By 06Z the positive moisture advection center moved westward, beyond San Angelo (Figure 3-35) and had two axes, one extending into New Mexico, and the second into Oklahoma. By 12Z (Figure 3-36), the center shifted even further west and was now located near the Big Bend area. By now, a major axis connected the Texas center to a newly formed center in Oklahoma. The axis then extended northward into Nebraska. Weather depiction charts show the results of this shift (see Figures 3-37 through 3-39). As might have been anticipated, the stratus thickened and lowered in west Texas. Note that stratus even invaded eastern New Mexico as suggested by the 06Z and 12Z moisture advection charts. By 16Z (Figure 3-39) the stratus was moving rapidly northward and now reached central Kansas. Continuing with the trend, the 18Z moisture chart (Figure 3-40) clearly indicated that the stratus should continue to advect northward along the axis. The northern extent of the axis, and the continued northward movement of the positive advection center, suggest that the stratus would advect into the Dakotas. Additionally,

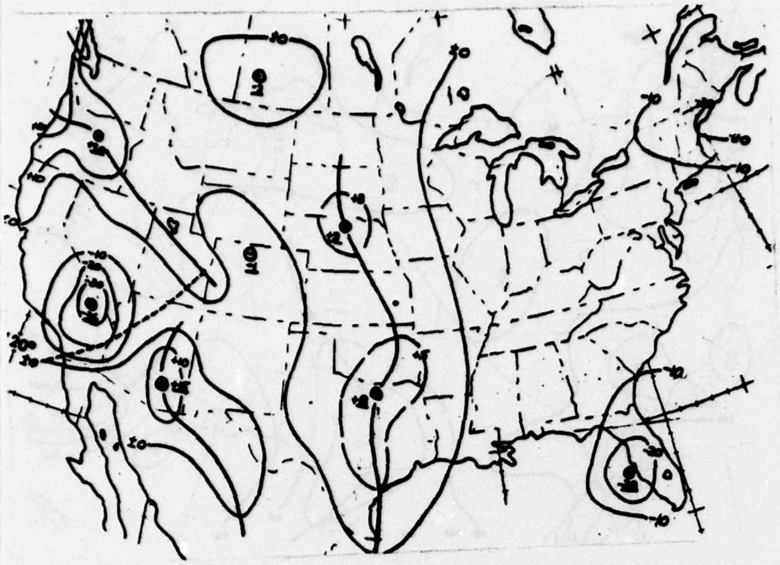

Fig 3-26. Moisture Advection, 11 Jan 77, 0600Z

Fig 3-27. CIG ≤ 3000 ft, 11 Jan 77, 0700Z

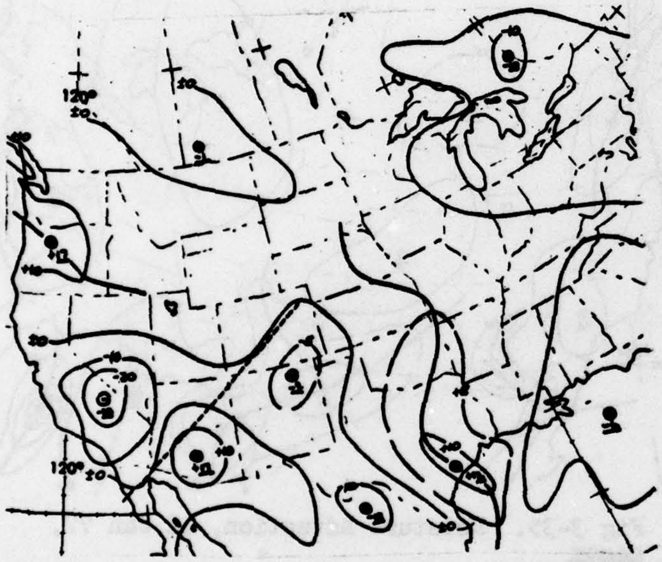

Fig 3-28. Moisture Advection, 11 Jan 77, 1200Z

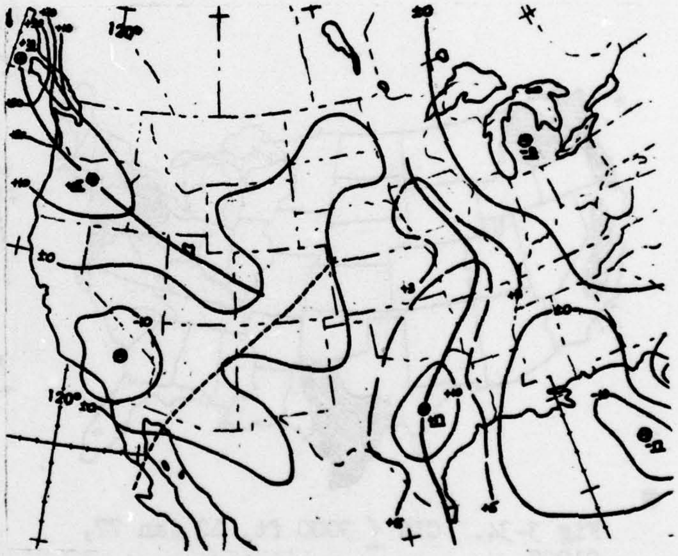

Fig 3-29. Moisture Advection, 11 Jan 77, 1800Z

Fig 3-30. CIG ≤ 3000 ft, 11 Jan 77, 1300Z

Fig 3-31. CIG ≤ 3000 ft, 11 Jan 77, 1900Z

Fig 3-32. CIG ≤ 3000 ft, 11 Jan 77, 2200Z

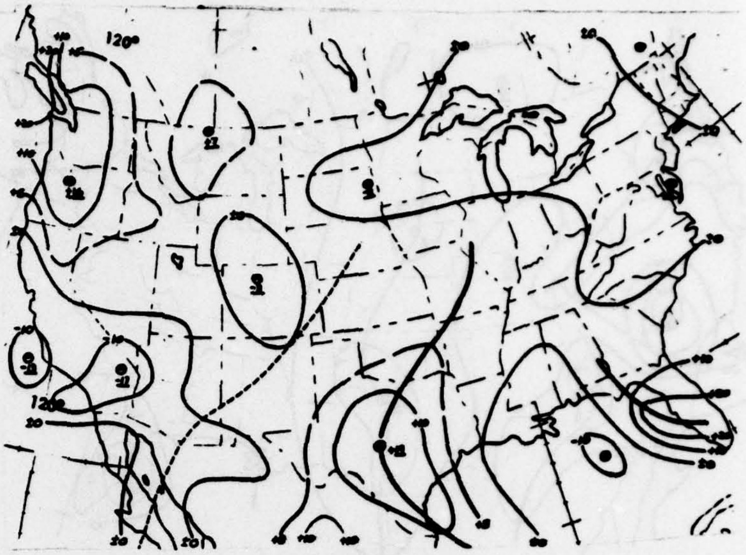

Fig 3-33. Moisture Advection, 12 Jan 77, 0000Z

Fig 3-34. CIG ≤ 3000 ft, 12 Jan 77, 0100Z

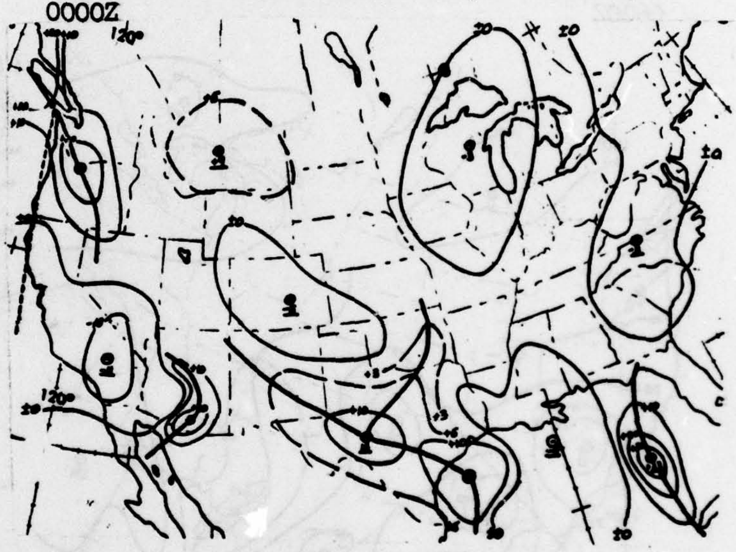

Fig 3-35. Moisture Advection, 12 Jan 77, 0600Z

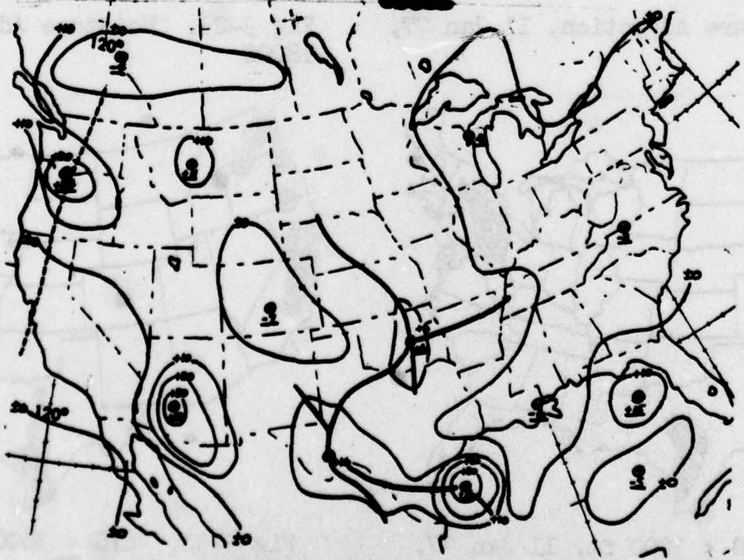

Fig 3-36. Moisture Advection, 12 Jan 77, 1200Z

Fig 3-37. CIG ≤ 3000 ft, 12 Jan 77, 0700Z

Fig 3-38. CIG ≤ 3000 ft, 12 Jan 77, 1000Z

Fig 3-39. CIG ≤ 3000 ft, 12 Jan 77, 1600Z

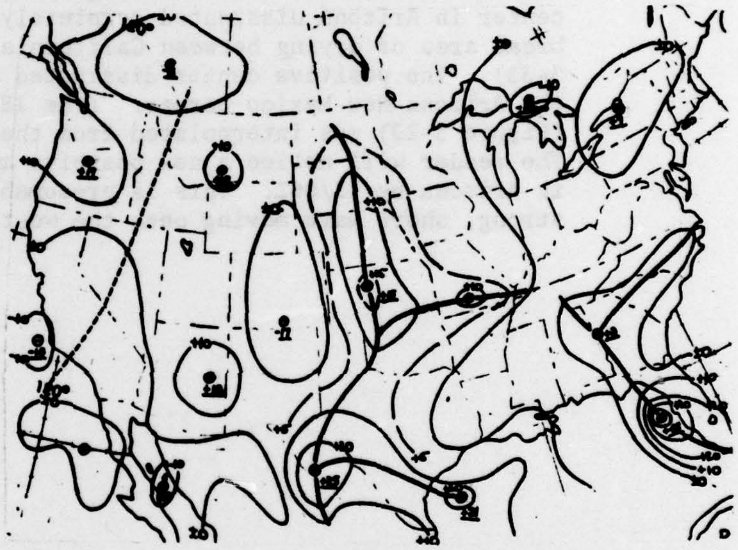

Fig 3-40. Moisture Advection, 12 Jan 77, 1800Z

Fig 3-41. CIG ≤ 3000 ft, 13 Jan 77, 0100Z

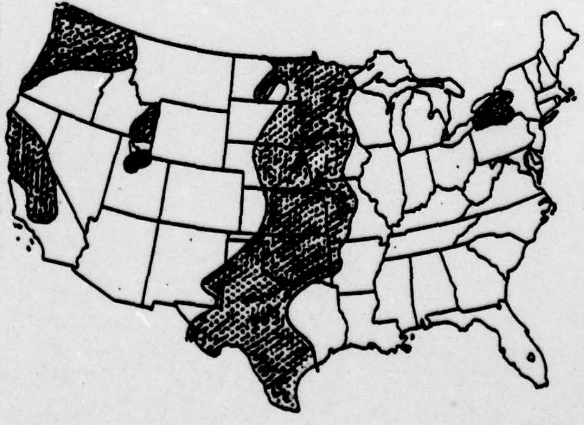

Fig 3-42. CIG ≤ 3000 ft, 13 Jan 77, 0700Z

the weak axis at 12Z (and at 18Z) (Figures 3-28 and 3-29) extended eastward from the Oklahoma center, and indicated that the stratus would spread eastward into Iowa, Missouri and northern Arkansas. Figures 3-41 and 3-42 illustrate this northward and eastward progression. Finally, note that in the Northern Plains, the eastern boundary of the stratus correspond closely to the zero advection line position. This position was established by 12Z.

FORMATION AND DISSIPATION OF A POSITIVE-NEGATIVE CENTER COUPLET, 11 JAN 1977

At 11/1200Z a weak short wave trough extended from eastern Colorado through Four Corners and into Baja California (see Figure 3-28). In response to the trough, a weak couplet formed, with a +.17 gm/kg-hr (+17) center in Arizona, and a weak -.09 gm/kg-hr (-9) center in eastern New Mexico. As the trough progressed south and east, the positive center in Arizona dissipated completely by 12/0000Z, leaving only a broad area of drying between California and Texas (see Figures 3-29 and 3-33). The positive center dissipated when the upper trough crossed the Arizona-New Mexico border. (The 1800Z 500mb trough position (Figure 3-29) was interpolated from the 11/12Z and 12/00Z analyses.) The reader will notice a new positive moisture advection center forming in Arizona by 12/06Z. This is presumably in response to a new, rather strong, short wave moving onto the west coast (see Figures 3-35 and 3-36).

EXAMPLE 4: 23-26 JANUARY 1978

DISCUSSION

This example involves the most extensive excursion into synoptics. It covers events that led up to, and existed during the Ohio Valley blizzard of 25 and 26 January 1978. The storm was particularly violent and set all-time low pressure records along the center's path(7). Governor James A. Rhodes, of Ohio, called the storm "the greatest disaster in Ohio's history" as 150,000 people were left stranded in near zero cold without heat or electricity(8). In all, over 50 storm-related deaths were reported in 19 states.

The event begins at 23/1200Z when the strong upper-level disturbance that caused the blizzard was deepening over the southwestern United States. The time span between 23/1200Z and 26/1800Z encompasses many of the same items that have already been discussed: Gulf stratus, the formation and dissipation of positive-negative center couplet, and precipitation areas. In addition, we will associate the upper trough's position (east of the Rockies) with negative moisture center movement, and observe the tremendous moisture advection gradients that were created by the great storm's circulation.

23/1200Z THROUGH 25/1200Z JANUARY 1978

Figure 3-43 shows the 23/12Z 500mb position. Compare the digging trough in the Western U.S. with the location of the positive-negative advection center couplet. The positive center is in Arizona and the negative center is located in northern Old Mexico (Figure 3-44). For ease of reference, the 500mb trough has been placed on all moisture advection charts (dashed line).

East of the Rockies, a complex series of positive moisture advection centers were present (Figure 3-44). The positive centers in the southern United States were to remain nearly stationary for 24 hours (until 24/12Z) and served to supply abundant moisture for the storm yet to come.

At 23/12Z, the weather over the country (see Figures 3-45 and 3-46) consisted of light to moderate snow in the central Rockies, a large area of Gulf stratus in the central United States and light snow showers along the Great Lakes. Rain was falling along with the Gulf stratus in Louisiana and east Texas. This correlated closely with the +9 positive center located in the area (compare Figures 3-44 and 3-46).

During the next 24 hours, the Western U.S. 500mb trough deepened, dug and remained over the desert southwest (see Figures 3-47 and 3-48). In response to this development, the Western U.S. positive-negative center couplet moved south into Mexico. The Southeastern U.S. positive centers remained nearly stationary (see Figures 3-49 through 3-52).

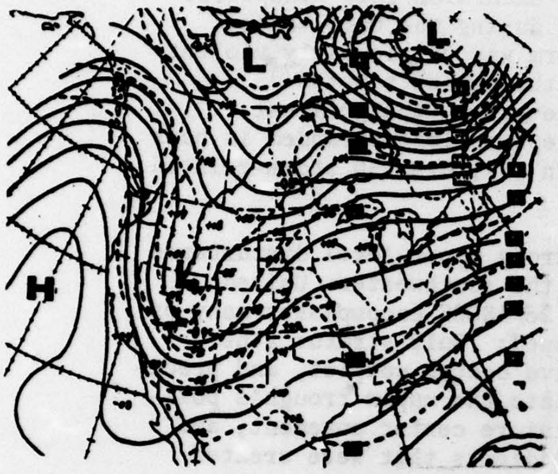

Fig 3-43. **500mb Analysis, 23 Jan 78, 1200Z**

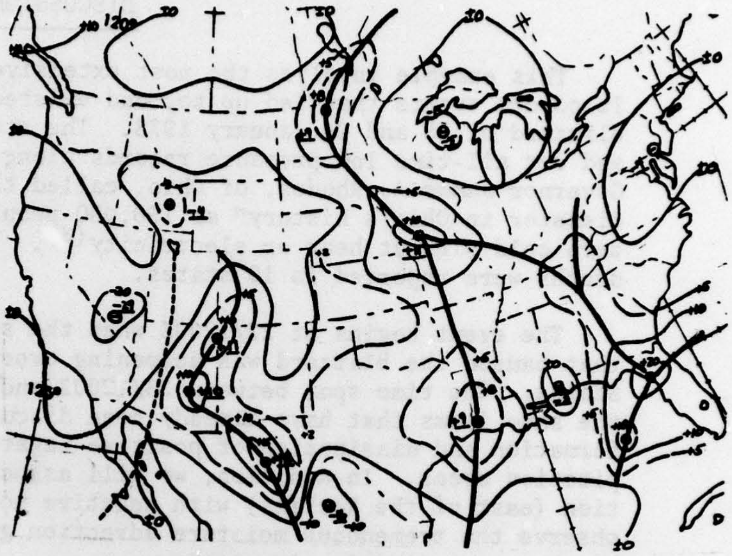

Fig 3-44. **Moisture Advection, 23 Jan 78, 1200Z**

Fig 3-45. **CIG ≤ 3000 ft, 23 Jan 78, 1200Z**

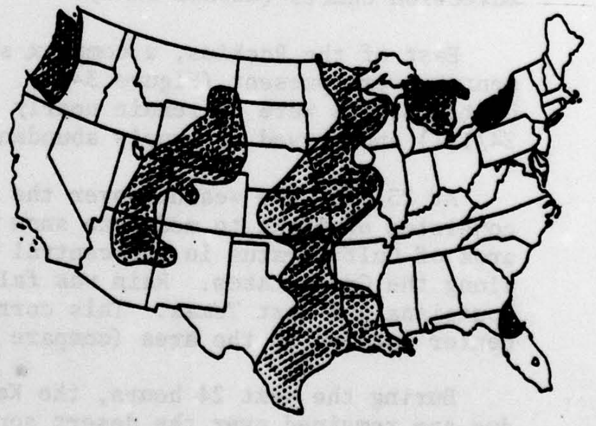

Fig 3-46. **CIG ≤ 3000 ft, 23 Jan 78, 1800Z**

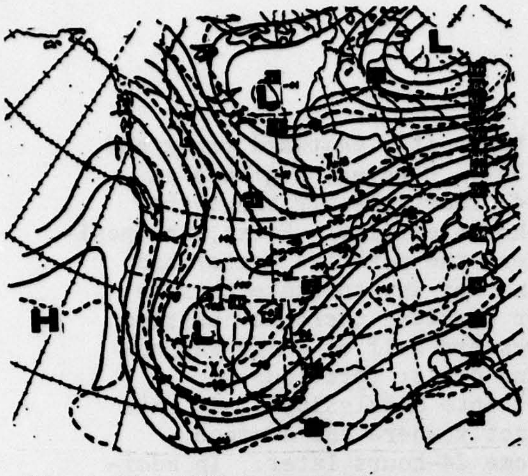

Fig 3-47. 500mb Analysis, 24 Jan 78, 0000Z

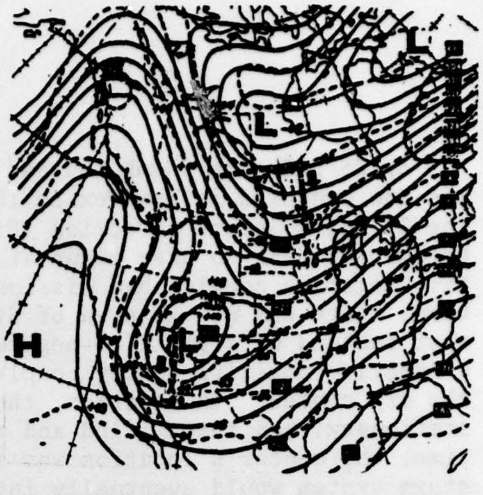

Fig 3-48. 500mb Analysis, 24 Jan 78, 1200Z

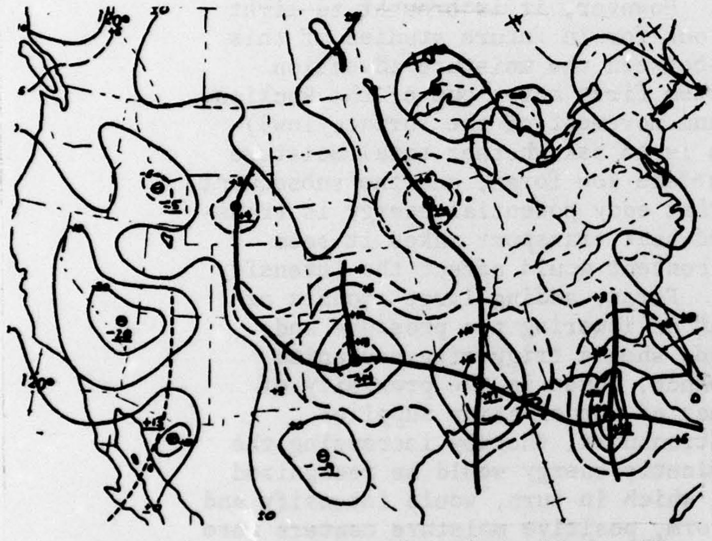

Fig 3-49. Moisture Advection, 23 Jan 78, 1800Z

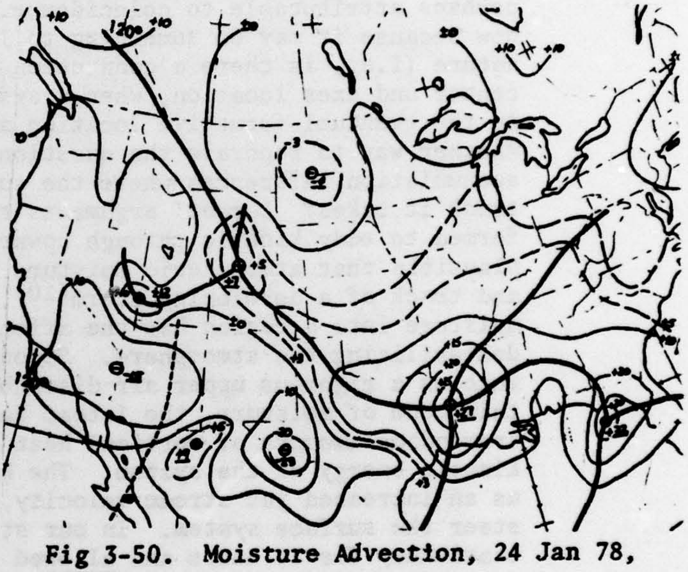

Fig 3-50. Moisture Advection, 24 Jan 78, 0000Z

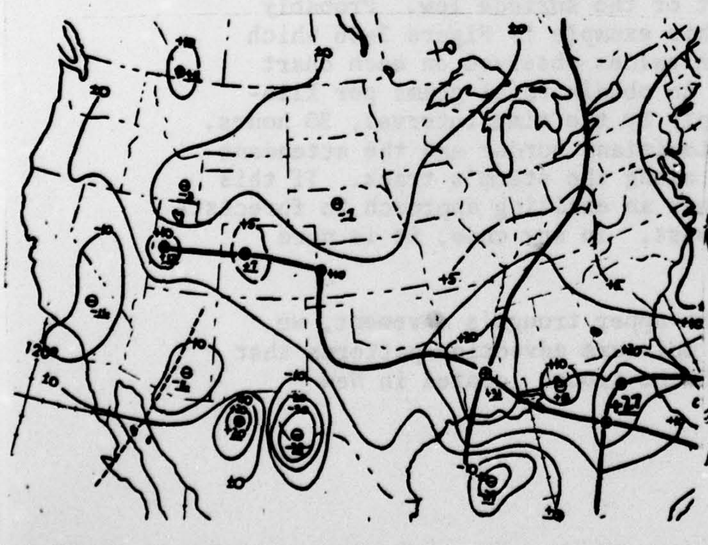

Fig 3-51. Moisture Advection, 24 Jan 78, 0600Z

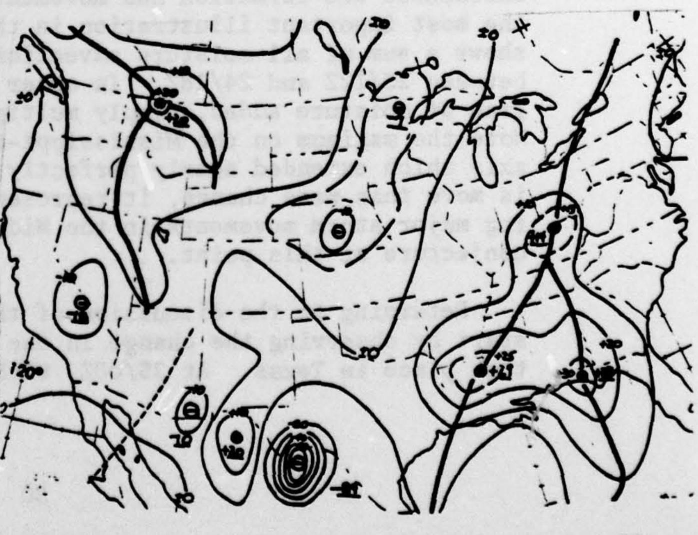

Fig 3-52. Moisture Advection, 24 Jan 78, 1200Z

By 25/00Z, the 500mb low had finally begun it's eastward track and was now centered in New Mexico (Figure 3-53). However, a glance at the 24/18Z moisture advection (Figure 3-54) chart clearly shows the trough movement to have begun at least 6-hours earlier. First, the positive-negative couplet had dissipated. Where the positive center had been, there was now an area of drying. Another way to state this is that instead of a positive-negative center couplet, there now existed a negative-positive center couplet, the western half of which was now the dry center. In addition, the Louisiana center (previously stationary) had intensified and moved east into Mississippi. At this time, the center's location was almost exactly where the surface storm system would eventually intensify some 24-hours later. In addition, the axis that extended northward into the Ohio Valley was very close to the surface storm's track (see Figure 3-55). This fact is perhaps attributable to coincidence. However, it is brought to light now because it may be something to look for in future studies of this nature (i.e., is there a connection between the moisture advection center and axes location, when a system first moves out of the Rockies, to the eventual formative location and movement of the surface low?) Another way to rephrase the question is to ask whether total moisture accumulation influences where the surface low forms, and the subsequent track it takes? Lorenz' arguments that eddy potential energy is transformed to eddy kinetic through upward heat transport makes it seem plausible that atmospheric moisture content would affect the intensity and track of a developing storm(10). First, adding large amounts of moisture into a region has the affect of lowering the pressure and destabilizing the atmosphere. Second, when a triggering mechanism such as a rigorous upper air disturbance, moves in the proximity of this zone of moisture, the latent heat of condensation supplies tremendous amounts of vertical heat transport, thereby increasing the kinetic energy of the system. The kinetic energy would be recognized as an increased jet stream velocity, which in turn, would intensify and steer the surface system. In our storm, positive moisture centers were stationary for 24 hours and allowed large amount of moisture to flow into the Gulf Coast states and Ohio Valley. This feature apparently influenced the formation and movement of the surface low. Probably the most important illustration in this example is Figure 3-56 which shows a sum of all moisture advection values observed on each chart between 23/12Z and 24/18Z. In order to obtain total grams per kilogram of moisture added, simply multiply by the time interval, 30 hours. Note the maximum on the Mississippi-Louisiana border and the attendant axis which extended nearly perfectly along the storm's track. If this is more than mere change, it represents an exciting approach to forecasting major storm movements in the Midwest. In any case, it is pure conjecture at this point.

Returning to the discussion of the upper trough's movement, we start by observing the change in the moisture advection patterns that took place in Texas. At 25/00Z, with the trough located in New

Mexico, weak positive moisture advection still remained in west Texas (Figure 3-57). However, by 25/0600Z, the trough had moved out of the mountains and onto the plains of Texas (Figure 3-58). Note that the trough now took up a position in the southern-most negative moisture advection area.

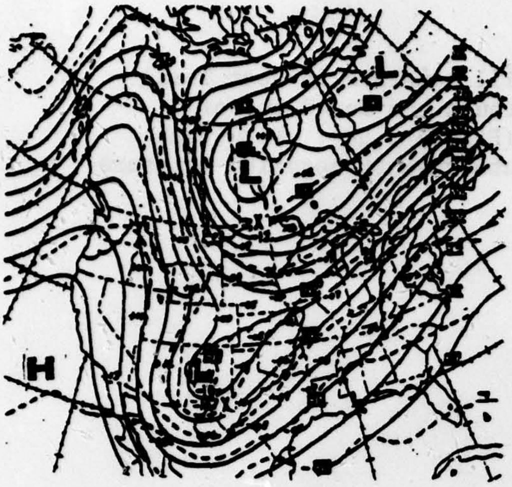

Fig 3-53. 500mb Analysis, 25 Jan 78, 0000Z

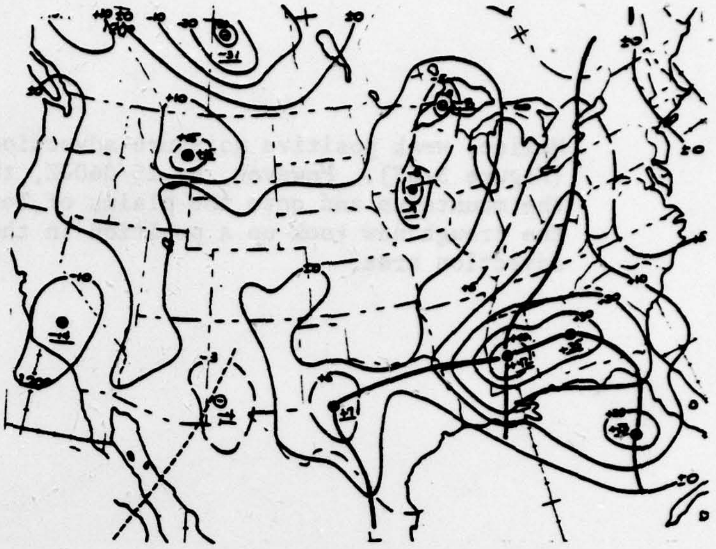

Fig 3-54. Moisture Advection, 24 Jan 78, 1800Z

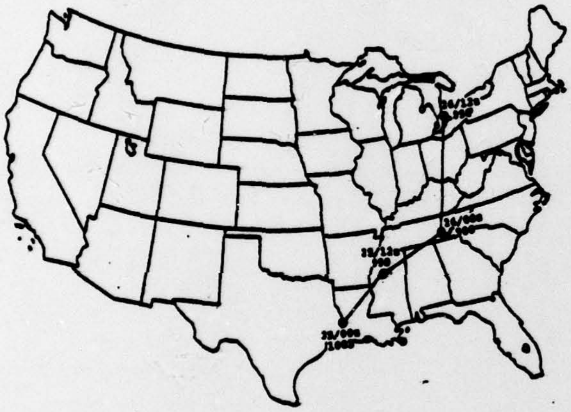

Fig 3-55. Storm's Track, 25/00Z - 26/12Z

Fig 3-56. Moisture Accumulations 23/12Z - 24/18Z. Storm Track Superimposed

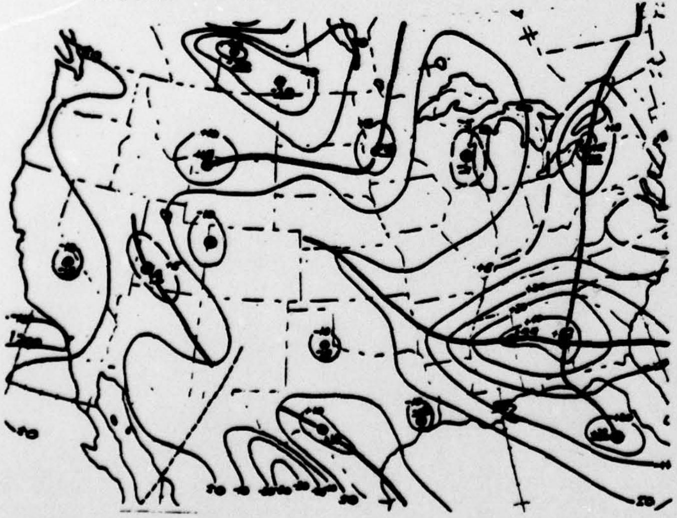

Fig 3-57. Moisture Advection, 25 Jan 78, 0000Z

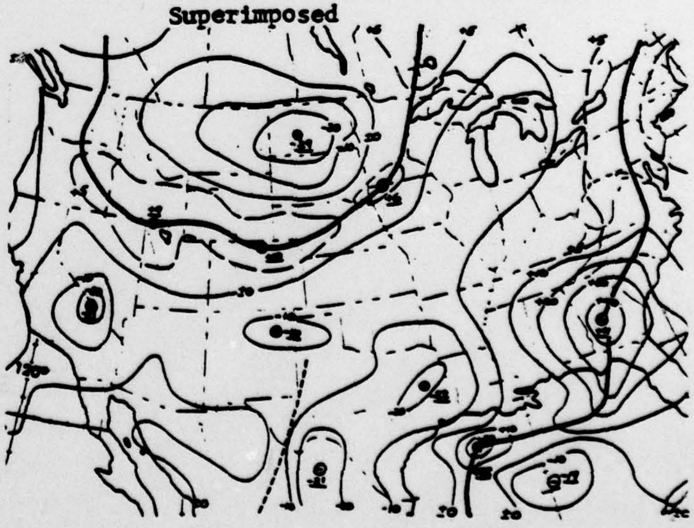

Fig 3-58. Moisture Advection, 25 Jan 78, 0600Z

Fig 3-59. 500mb Analysis, 25 Jan 78, 1200Z

Fig 3-60. 500mb Analysis, 26 Jan 78, 0000Z

Fig 3-61. 500mb Analysis, 26 Jan 78, 1200Z

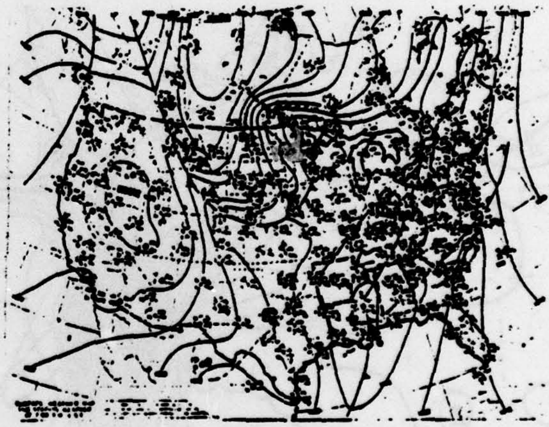

Fig 3-62. Surface Analysis, 25 Jan 78, 1200Z

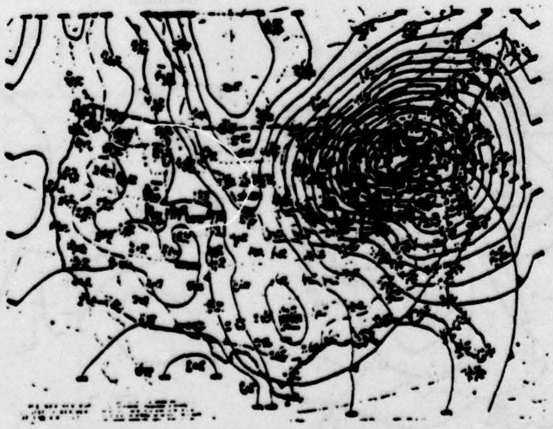

Fig 3-63. Surface Analysis, 26 Jan 78, 1200Z

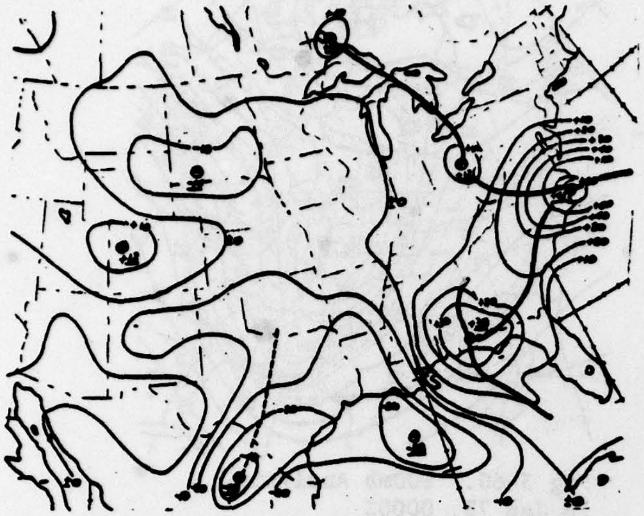

Fig 3-64. Moisture Advection, 25 Jan 78, 1200Z

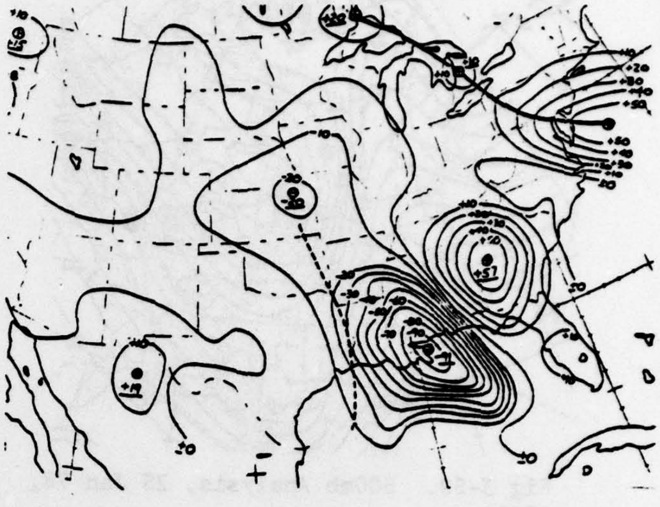

Fig 3-65. Moisture Advection, 25 Jan 78, 1800Z

Fig 3-66. Moisture Advection, 26 Jan 78, 0000Z

Fig 3-67. Moisture Advection, 26 Jan 78, 0600Z

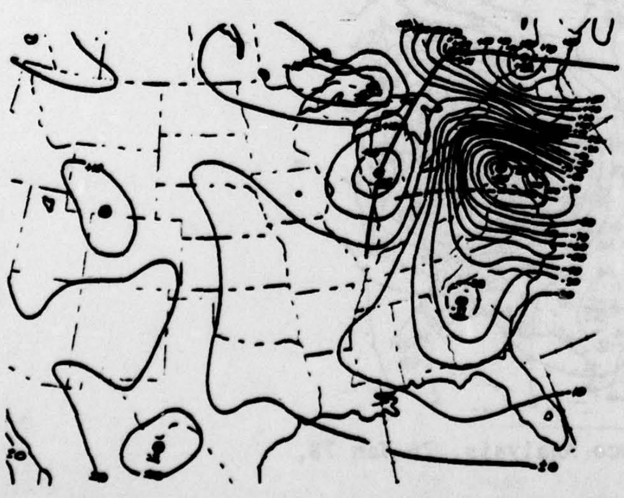

Fig 3-68. Moisture Advection, 26 Jan 78, 1200Z

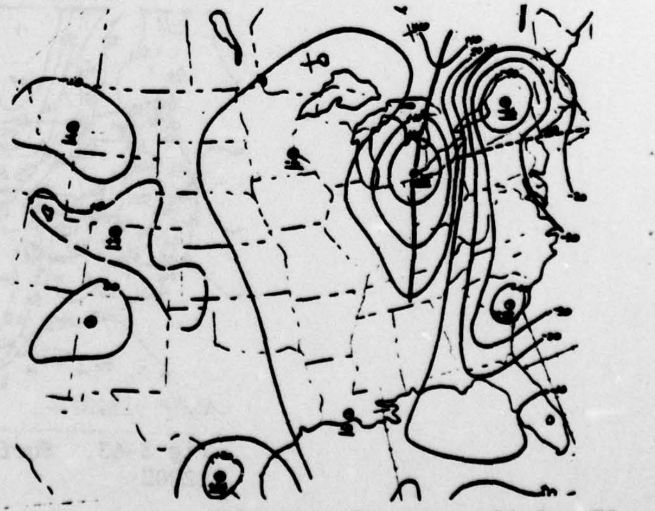

Fig 3-69. Moisture Advection, 26 Jan 78, 1800Z

It was located right of the zero advection line, but left of the negative center. The trough stayed in this position with respect to the negative advection throughout the history of the storm. What remains to be said about this example can easily be followed in the illustrations. Figures 3-59 through 3-61 depict the 500mb analyses for 25/12Z, 26/00Z and 26/12Z, respectively. Figure 3-62 shows the Daily Weather Map (DWM) series surface analysis for 25/12Z (6-hours prior to the rapid intensification of the storm), and Figure 3-63 shows the 26/12Z DWM surface analysis (taken near the height of the blizzard). Figure 3-64 through 3-69 are moisture analyses which show the extraordinarily high values of moisture advection (both positive and negative) attained during the storm. Note, this series of moisture advection charts show the actual circulation of the storm probably began in earnest around 25/18Z (Figure 3-65).

It was then that the drying area congealed into a single center, and more than doubled in intensity over the last chart (from - .38 gm/kg-hr to -.91 gm/kg-hr). Also, the positive center had nearly doubled in intensity (+.38 gm/kg-hr). This resulted from increased cyclonic circulation.

Another interesting feature that was taking place around this time is the shift that occurred in the storm's moisture source regions. Up till 25/1200Z the moisture had mostly streamed in from the Gulf of Mexico. From 25/12Z on, the Atlantic Ocean become the prime source. Actually, the Gulf source dried up as the storm's cold front moved through the area and produced north winds over the Gulf of Mexico. The Atlantic then conveniently took over the duties of supplying the storm's moisture; as neatly as if it were pre-planned.

So ends this example. By 26/18Z, the moisture advection chart (Figure 3-69) shows that the storm's circulation had waned and the heaviest of the precipitation had passed. The breadth of the storm can be best understood by observing the 26/09Z cloud and precipitation areas (Figures 3-70 and 3-71, respectively); the intensity can be seen from Rickenbacker AFB, Ohio's observations (Table 3-1).

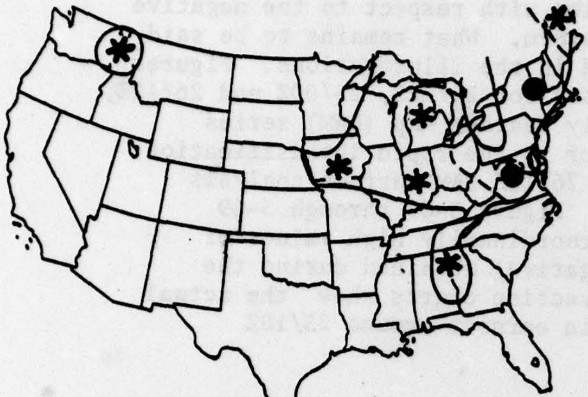

Fig 3-70. Precipitation, 26 Jan 78, 0900Z

Fig 3-71. CIG ≤ 3000 ft, 26 Jan 78, 0900Z

TABLE 3-1
RICKENBACKER AFB OH OBSERVATIONS
26 JANUARY 1978

Time	Sky Cond	Vis	Weather	Temp (°F)	Wind
26/00Z	3 OVC	1	R-F	37	0809
01Z	3 OVC	1 3/8	R-F	37	0808
02Z	2 BKN 20 OVC	1 1/2	R-F	37	0808
03Z	1 OVC	1 1/2	R-F	37	0710
04Z	1 BKN 3 OCV	1 1/2	R-F	38	0611
05Z	1X	3/8	RF	39	0706
06Z	1X	3/8	RF	38	0210
07Z	-X5 BKN 10 OVC	2	R-F	35	2827G34
08Z	0X	1/4	SBS	31	2531G40
09Z	0X	1/8	SBS	19	2544G56
10Z	0X	1/8	SBS	13	2434G37
11Z	0X	0	S+BS	12	2442G61
12Z	0X	1/8	SBS	10	2440G56
13Z	0X	0	SBS	8	2440G53
14Z	0X	0	SBS	7	2446G54
15Z	0X	0	SBS	6	2338G52
16Z	0X	0	SBS	6	2338G51
17Z	0X	0	SBS	6	2340G50
18Z	0X	0	SBS	7	2334G46
19Z	0X	0	SBS	8	2230G42
20Z	0X	0	SBS	9	2330G42
21Z	0X	0	SBS	10	2334G44
22Z	0X	0	SBS	11	2332G42
23Z	0X	1/8	S-BS	11	2335G47

CHAPTER 4

CONCLUSION

This study was intended to point out the utility of an automated moisture advection chart based on Sangster winds. It was shown that stratus outbreaks in the Midwest often form in the vicinity of positive moisture advection centers and then spread outward along positive moisture axes. This knowledge should prove valuable to personnel issuing short-term aviation forecasts in the southern and central United States.

The study suggests that heaviest precipitation tends to form in the vicinity of positive moisture advection centers and moves along the positive moisture advection axes. This information would doubtless be useful for short-term modification of numerical weather guidance in general weather and hydrologic forecasts.

Hopefully, upper trough movement can be inferred from the moisture advection patterns based on Sangster winds. An upper trough over the Southwest United States will cause a positive-negative moisture advection center to form. The positive center will be located in Arizona, or (just south) in Mexico, and the corresponding negative center will form just east of the Rockies somewhere between Colorado and northern Mexico. As the 500mb trough progresses eastward across the Arizona-New Mexico border, the positive center of the couplet will disappear leaving behind a large area of drying in the Southwestern United States and Texas. When the trough moves beyond the mountains, our example showed that it was located above the negative moisture advection area, between the zero advection line and the negative center (i.e., in the left hemisphere of the negative advection area). This information should help forecasters (especially those in the lee of the Rockies) time major weather events which are typically caused by deep troughs that spawn in the Desert Southwest. Among those events are major snowstorms, severe thunderstorms and heavy precipitation.

Also, in the blizzard example, we began a count of moisture accumulation at the time the upper trough first entered the Desert Southwest until the moisture advection chart showed movement eastward. It was demonstrated that maximum moisture accumulated near the Louisiana-Mississippi border and extended northward into the Ohio Valley. Twenty-four hours later, the storm formed, and tracked, respectively in almost perfect accord with the center and axis of maximum moisture accumulation. If this is not coincidental, it is felt that a knowledge of moisture advection and accumulation may help us greatly in our ability to forecast the movements of storms which draw upon great bodies of water such as the Gulf of Mexico and Atlantic Ocean for a source of moisture and energy.

In view of the advantages that forecasters stand to gain from automating moisture advection from Sangster winds and mixing ratio fields, it is felt that additional studies should be performed. They are:

a. An objective method for forecasting the onset of stratus ceilings. The simplest method might be to correlate current temperature-dewpoint spreads and moisture advection rates to ceiling formation times. Keeping the regression equations limited to 3-dimensions would promote ease of use at base weather stations since results could be easily graphed. However, if three variables aren't adequate, additional entries to the regression equations could be time of day, month of year, local climatology, initial temperature, pressure and other items that lower the lifting condensation level and favor stratus formation.

b. Further monitoring 500mb trough movement using moisture advection analyses and the rules stated in this report. The 500mb troughs that dig and deepen in the Southwestern United States should be watched closely to see if they are accompanied by nearly stationary moisture advection centers and axes east of the continental divide. If they are, moisture accumulation charts should be constructed, beginning at the time the upper trough first digs into the Southwest until such time the moisture advection positive-negative center couplet dissipates (i.e., the upper trough moves east of the Arizona-New Mexico border). The ability of the moisture advection product to predict movement of storms that are moisture-laiden shouldn't require a great number of examples, particularly if the storm's path is irregular as was the example in this report. Caution should be exercised, however, when trying to prog "dry" storms. It is felt that other factors will dominate storm movements when abundant moisture sources are not available.

c. Summer precipitation should be watched closely to see how far in advance positive moisture advection centers forewarn of thunderstorm activity. Nocturnal thunderstorms in the Great Plains should be of special interest.

d. Whenever practical each of the above items should be compared to existing forecast tools such as the LFM, MOS, FOUS bulletins and other progs to check for advantages or disadvantages.

The author hopes this report will provide a foundation for the continuing study of moisture advection product. It is a product that he feels holds many potential benefits for the operational forecaster.

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