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IMPACT OF WEATHER ON FLIGHT OPERATIONS AT A MAJOR AIRPORT

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INTRODUCTION

Following the crash of a Southern Airways jet at New Hope, Georgia, on April 4, 1977, the Federal Aviation Administration (FAA) recognized the need of timely dissemination of hazardous weather conditions to flight crews (National Transportation Safety Board, 1977). The establishment of the Center Weather Service Unit (CWSU) in each of the Air Route Traffic Control Centers (ARTCC) resulted. These units since have evolved to become an integral part of the ARTCC's operations.

Jointly supported by the FAA and the National Weather Service (NWS), the CWSUs provide weather consultation and advice to managers and staff within the ARTCC. This is accomplished through periodic briefings and the issuance of advisories and short-term forecasts. The idea, of course, is to facilitate the smooth and efficient flow of air traffic through the National Airspace System (NAS).

Planning within the ARTCC is essential to maintaining this smooth and efficient flow of air traffic and necessitates strong dependence on NWS forecasts. When the forecasts are inaccurate, then air traffic delays and stoppages result which, when occurring at major airport complexes, can produce a significant "domino effect" across the country.

The Dallas/Fort Worth International Airport (DFW) is a major complex—rated the second busiest in the world behind Chicago O'Hare International Airport (ORD). This paper will examine the impact that adverse weather conditions, especially those that may not be accurately forecast, can have on DFW operations. Emphasis will be placed on the importance of coordination between the CWSU and ARTCC personnel, and also between the CWSU and the Weather Service Forecast Office (WSFO).

STATEMENT OF THE PROBLEM

Conditions of low ceilings and visibilities severely hamper operations at major airports. At DFW, for example, when the ceiling and visibility lower to around 1000 ft (300 m) and 3 mi (4800 m) respectively, the maximum arrival capacity of 114 aircraft per hour is reduced to approximately 85. This does not significantly restrict the flow of air and ground traffic in and around the airport. However, a further lowering of conditions to 300 ft (90 m) and less than 3 mi (4800 m) reduces this capacity to about 65 aircraft per hour, which can result in some nationwide airborne and ground delays. A continued deterioration of conditions can ultimately stop all operations at the airport and subsequently suspend aircraft releases to DFW at other facilities across the nation.

When adverse conditions are accurately forecast, some adjustments can be made to ease the disruption. However, the impact of an inaccurate forecast is to throw the entire air traffic system into chaos and tend toward operational "gridlock."

One of the greatest challenges facing the aviation forecaster is to accurately predict the onset of Instrument Flight Rule (IFR) conditions (i.e., ceilings below 1000 ft [300 m] and visibilities below 3 mi [4800 m]) so as to give Air Traffic Control (ATC) some time to orderly restrict the flow of air traffic. Equally as challenging is to forecast improvement once the adverse conditions have set in. Such was the challenge on the morning of October 15, 1993.

ANALYSIS

Prior to the issuance of the early morning (0900 UTC) Terminal Forecast (FT) for DFW, both the CWSU meteorologist and the aviation forecaster at the nearby WSFO would have had access to the 0000 UTC upper-air data of October 15. For the purposes of this study, these data were extracted from Eta model output by way of the PC-GRIDDS system (Meier 1993)—a software package that allows viewing of meteorologically significant fields of gridded model output data on a personal computer (PC). The Meteorologist Weather Processor (MWP) has been in operation at CWSUs across the country for some time and has the capability of constructing products similar to those available from PC-GRIDDS.

An analysis of the overall synoptic pattern at 500 mb is shown in Fig. 1. Moderate zonal flow was occurring over much of the southern half of the U.S., with only minor short wave impulses imbedded in the flow.

One such impulse was noted in the thermal field over New Mexico where slightly cooler temperatures were advecting across the area. Additional support for the existence of the impulse was indicated in the relative humidity (RH) field. A strong gradient was positioned over West Texas which separated very dry air over the DFW area from much wetter air situated over far West Texas and New Mexico just ahead of the short wave.

The vertical velocity field at 700 mb was rather nondescript, but did depict a motion couplet moving through Arizona and New Mexico. The couplet was indicative of weak upward motion (2 microbars/sec) ahead of the impulse with sinking motion of similar magnitude trailing it. Despite its weak appearance, the impulse in combination with the strength of the zonal flow, could be expected to produce a significant low-level pressure reduction in the lee of the mountains. This ultimately would drive the return flow.

The 850 mb analysis (Fig. 2) clearly indicated that the return flow was setting up. Deepening low pressure along the eastern foothills of the Rockies was drawing high dew point (12-14 deg C) modified maritime tropical air northward, albeit weakly, across much of South Texas at 0000 UTC on October 15. DFW was in an area of strong dew point gradient. In fact, Fig. 3 shows that the maximum advection of dew point was over DFW and to its west in the vicinity of the strongest flow (7-8 m/s).

Near the surface at the 1000 mb level (Fig. 3), a wave along an old frontal boundary over the central Gulf of Mexico was inducing ridging along the coast of Texas. North and northeast wind, in effect, disrupted the return of moisture northward into Texas. Thus, air over North Texas was drier and somewhat cooler than air over South Texas.

A nice feature of PC-GRIDDS software is its capability to produce user-specified space cross-sections quickly. Virtually any parameter can be depicted in these cross-sections which make them extremely useful in evaluating an evolving fog and stratus episode. For this study, a north-to-south cross-section was constructed oriented along longitude 97 W, from latitude 26 N to 35 N. The intent was to adequately depict the vertical structure of the atmosphere along the axis of greatest expected warm and moist advection.

Fig. 4 shows a cross-section of equivalent potential temperature (θ_e). Most apparent is the sharp contrast in the high θ_e air over South Texas with the drier and potentially cooler air over North Texas. Note also the highest θ_e values were at the surface indicating that the initial surge northward would be in the low-levels.

However, when we compare the θ_e cross-section with one depicting potential temperatures (theta) as shown in Fig. 5, it becomes apparent that the moist air would likely overrun a shallow surface-based cool dome over North Texas. With the high moisture content of the overrunning air, only weak lift would be needed to bring about saturation and subsequent stratus cloud development. The stark contrast in the moisture content of the two air masses would contribute to fog formation. Evaporative mixing might aid the process further.

Thus, atmospheric structure from south to north along the cross-section was conducive to a mixture of stratus and fog formation. One could envision moisture return occurring under an elevated temperature inversion that progressively lowered toward North Texas and the DFW area—the opposite of what would be common along and north of a warm front. Just how this structure would change with time had to be the major concern as forecast time approached.

FORECAST

It is not unusual to see the inversion structure described in the previous section translate northward without change as moisture returns. Often, this translation occurs most rapidly in the 900-850 mb layer. Thus, what evolves is a bulge in the moisture surge (see Fig. 6) where stratus clouds that have formed in the warm air advect northward at a constant level and virtually unimpeded.

The 12-hour Eta model prognosis valid at 1200 UTC on October 15 supported this trend. The flow pattern at 850 mb (Fig. 7) was expected to strengthen (10-15 m/s) as troughing in the lee of the Rockies deepened. This, in turn, would accelerate moisture advection into the DFW area. Dew point temperatures of 10-12 C were forecast to reach as far north as southern sections of Oklahoma.

The warm and moist surge at 850 mb was in contrast to the model's expectation of the surface ridge "holding in" along the Texas Coast. This suggests that overrunning was a distinct possibility. Stratus clouds spreading over North Texas would limit insolation and retard the breakdown of the shallow surface dome of cool air.
A real concern at this time would be to pinpoint the expected axis of significant moisture return. Would this axis extend across DFW? Once again, PC-GRIDDS provided the necessary tools to aid this examination. A time cross-section of both potential temperature and equivalent potential temperature was constructed for DFW (Fig. 8). It was clear from the cross-section that the model expected moisture return to impact DFW at 12 hours. Notice that the "bulge" of rapid moisture return just above the surface is weakly depicted as it approached the area. This

initial return was shortly to be followed by a more extensive surface-based return through 48 hours.

Comparing the expected change in moisture profile to that of temperature, support for overrunning clouds and fog continued. There was a clear depiction of a persistent cool dome at the surface, despite contributions from diurnal processes. This dome of air would be slow to erode during the first 24 hours of the model cycle, thus indicating an expected delay in improving conditions over DFW during the day of October 15.

How did the forecaster handle the situation? After all, forecasting deteriorating conditions on the first day of return flow characteristically is a trouble spot for most forecasters. This particular episode proved to be no different. The initial forecast prepared the previous evening delayed the onset of worsening conditions. The early morning issuance on October 15 and subsequent updates adjusted to the onset problem but were persistently too quick in improving conditions during the day. So, what does this do to operational planning at DFW, and for that matter, across the NAS?

AVIATION IMPACT

To study the effect that low ceilings and visibilities will have on the operations at DFW will require background information about the schedules of airlines that operate at DFW. Some of the major airlines have patterned their flight schedules on a "hub and spoke" method. The "hub and spoke" is a descriptive term for an air carrier route structure that resembles a bicycle wheel. Aircraft depart various locations (outer end of the spokes) throughout the U. S. and the world, and fly into DFW (hub).

The inbound aircraft arrive at approximately the same time. Then passengers make their connections for the remainder of their flight. Use of the "hub and spoke" route structure results in peak arrival and departure periods throughout the day. Such peak periods have made DFW the second busiest airport in the world with over 2200 arrivals and departures daily.

For this event, interest is in how the impending adverse weather will affect arriving aircraft at DFW. There are 10 peak arrival periods each day, often exceeding a rate of 100 aircraft per hour over short periods of time. What may be more important than the number of aircraft arriving in a given hour is the rate at which the aircraft actually arrive at DFW. For example, if 30 aircraft arrive within a 15-minute period, then the rate equals 120 per hour.

The arrival periods at DFW can be categorized into large and small volumes of aircraft for a given period of time. The peak arrival times for large volumes of aircraft occur daily beginning at 1725 UTC (1125 LST), 2310 UTC (1710 LST), and 0025 UTC (1825 LST), with numerous arrival and departure periods in between.

Lowering ceilings and visibilities force a reduction in arrival rate and result in aircraft delays. These are the most common occurrences that translate into weather-factor delays.

Under Visual Flight Rule (VFR) conditions, the maximum allowable arrival rate at DFW is 114 aircraft per hour, or 2 aircraft every minute. Controllers at DFW normally land aircraft on 3 or 4 runways. When ceilings and/or visibilities fall to Instrument Flight Rule (IFR) conditions, runways 13L and 31R can no longer be used due to a conflict with aircraft that may be forced to abort an approach to another runway. The resulting convergence of the traffic patterns effectively reduces the normal VFR rate of 102 aircraft per hour to 66 per hour.

A low arrival rate at DFW during one of the peak arrival periods has a tremendous effect on DFW-bound traffic throughout the Fort Worth ARTCC's airspace and that of neighboring ARTCCs. With various ceiling heights and visibility restrictions, there are corresponding variations in arrival rates ranging from 114 aircraft per hour to less than 66 that DFW Traffic Control (TRACON) can impose on the Fort Worth ARTCC's Traffic Management Unit (TMU).

Unexpected, and therefore unforecast, IFR or low IFR (LIFR) conditions for peak arrival times can result in average airborne delays of 20-40 minutes per aircraft. If the forecast remains persistently inaccurate throughout the day, these delays increase, possibly to as much as 3000-5000 minutes to all aircraft inbound for DFW. At an average cost of $70 per minute to operate an aircraft, these delays translate into as much as $350,000 in additional operating costs in the course of the day. Most of this can be attributed directly to optimistic planning based on an inaccurate forecast.

The CWSU meteorologist interacts almost solely with the TMU. This unit comprises a group of air traffic controllers who regulate the flow of air trafffic into and out of their airspace. The Traffic Manager in Charge (TMIC) and other members of the TMU develop plans for the rerouting or delaying of air traffic.

When conditions at DFW are forecast to deteriorate and aircraft must be delayed, the TMU can restrict the traffic flow and generate an estimate of the magnitude of the delays based on current demand and arrival rate. If the conditions do become restrictive, there are options available to the TMU to reduce the flow of air traffic into the area:

(1) Immediately implement a ground stop at airports within approximately 800 km (500 mi) that have aircraft scheduled to depart for DFW.

(2) Decrease the number of aircraft "in trail" (i.e., decrease the number of aircraft allowed into an approach sector by increasing distances between aircraft as they enter the Center's airspace).

Normal enroute spacing is 8 km (5 mi) between aircraft, but increases to 16-24 km (10-15 mi) when weather conditions deteriorate.

The options listed above are implemented for immediate relief, but are not satisfactory for long-term planning. A national ground stop program is put into effect when adverse weather conditions are expected to persist for 4 hours or longer. It will delay DFW-bound aircraft on the ground for a designated length of time before releasing them. Its goal is to delay aircraft sufficiently to keep the flow of traffic constant through the airspace and into an approach sector but prevent saturation. In other words, it smoothes out the peaks during heavy arrival periods.

The national ground stop program is requested by the TMIC based upon the current forecast, the CWSU meteorologist's advice, and expected traffic demand. This request is forwarded to the Air Traffic Control System Command Center (ATCSCC) in Washington, DC, and is coordinated with traffic management specialists and the National Traffic Management Officer (NTMO). These individuals will seek advice from the ATCSCC advisory meteorologist. The advisory meteorologist will offer his/her recommendation based on the FT and consultation with the CWSU meteorologist about expected weather trends.

A ground delay program is the most cost-effective means to delay arrival of aircraft into an area. Arrival demand must exist, and expected weather conditions must be low enough to force a low arrival rate. Once these criteria are satisfied, then at least 4 hours advance notice is required to effectively implement the program.

On October 15, 1993, the ceilings and visibilities began to lower around 1200 UTC. The acceptance rate was subsequently reduced from 78 aircraft per hour to 66 by 1230 UTC. At that moment, the ARTCC TMIC requested a ground delay program which, as conditions continued to deteriorate, escalated to a national ground stop program. Airborne delays for DFW arrivals totaled 3300 minutes for this event, with most delays occurring during morning hours. These delays alone translated into approximately $230,000 in additional operating costs for the air carriers.

Conditions began to improve after 1930 UTC, and the acceptance rate rose from 66 aircraft per hour to 78. Eventually, all delays were terminated, and the maximum acceptance rate was reestablished.

CONCLUSION AND RECOMMENDATIONS

Timing the onset of deteriorating conditions at DFW no doubt was a difficult forecast problem on the morning of October 15. However, there were clues that supported a rapid worsening of conditions. First, from a synoptic viewpoint, a deepening low pressure system over the Southern Rockies would produce strengthening low level flow, at least in the upper reaches of the boundary layer.

Second, moist air was already poised across South Texas and would not have far to travel to filter into North Texas. Surface wind in the vicinity of the moist air had a definite southerly component.

Third, clear skies and dry air across North Texas produced ideal radiational cooling conditions. An extensive surface-based temperature inversion developed which would trap cool air near the surface. As moisture advected in aloft, the cool dome would serve two purposes—to mix with the approaching moist air and, at the same time, lift it.

Finally, a more detailed after the fact examination using time and space cross-sections clearly revealed the high likelihood of developing low clouds and fog. DFW was situated along the axis of expected high moisture return. High θ_e air was forecast by the Eta model to initially work across DFW by 1200 UTC on October 15. As this occurred, the model continued to hold the surface cool layer in place with a slow, but steady, erosion expected as moisture advection increased. All of these clues help to reinforce a forecast of deteriorating conditions at DFW by 1200 UTC. Once in place, persistence of these conditions was high.

In challenging forecasting situations such as this one, close coordination between the CWSU and the WSFO is essential. While the final details of the forecast rest with the aviation forecaster at the WSFO, input from the CWSU meteorologist should be given special consideration. The old adage of "two heads are better than one" holds true when there are so many factors to consider, some of which are subtle. The CWSU meteorologist has many of the same tools as the WSFO forecaster, yet works in tandem with the ARTCC controllers and experiences first-hand the impact of a particular weather change or forecast adjustment.

To promote this coordination at DFW, the CWSU meteorologist at the Fort Worth ARTCC routinely prepares and transmits to the WSFO aviation forecaster an alphanumeric product entitled "FORT WORTH CWSU AVIATION DISCUSSION" (AFOS product identifier FTWWRKZFW). Through this product, the meteorologist at the CWSU provides a narrative discussion of the main weather concerns of the ARTCC for a particular forecast cycle, as well as a quantitative estimate of the expected aircraft arrival frequency and delays.

Each issuance of FTWWRKZFW furnishes a table of so-called "important numbers" for DFW relating impact and arrival frequency to decreases in ceiling and visibility. For the IFR event of October 15, the coordination product read as follows:

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FTWWRKZFW
TTAA00 KZFW 151610
FORT WORTH CWSU AVIATION DISCUSSION..151610Z

MAIN CONCERN...CIGS/VSBY CONTG TO LWR IN LCL AREA.  SATL
LOOP INDICATES LARGE HOLE OPENING ARND ACT AREA SPRDG NWD.
WOULD LIKE TO HOLD CIGS/VSBY LOW TIL MID AFTN THEN BREAK THE
CLDS.

DFW ARRIVALS/HOUR...66

DFW DELAYS/ACFT...25-30 MIN.

DFW IMPORTANT NUMBERS (TIMING OF ONSET/END VERY IMPORTANT)

  CIG        VSBY      ARRIVAL/HOUR          IMPACT
>1200         >6           102       NO ARTCC PROBLEMS
1000-1200     3-5          84-96     SOME IN-TRAIL DELAYS
300-900       <3           66        NATIONWIDE GROUND/
                                       AIRBORNE DELAYS
<300          <1           0-36      MAJOR NATIOWIDE DELAYS/
                                       GROUND STOPS
TRW                                  VARIABLE DELAYS
ZR,ZL                                MAJOR DELAYS FOR DEICING
WINDSHIFTS -- UP TO 20 MIN GROUND/AIRBORNE DELAYS TO SWITCH
     RUNWAYS
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Operations within the NAS are highly weather dependent. An accurate forecast and, when needed, timely adjustments to the forecast are critical to effective traffic flow management. This includes forecasts of onset as well as improvement of conditions which affect air traffic. Management requires advanced planning which is the key to avoiding unnecessary financial losses to the airline industry, minimizing passenger inconvenience, and maximizing passenger safety. With the stakes so high, it becomes imperative that the NWS, using all of its resources, work to improve its understanding of the impact that its products and services have on the aviation community. The goal of this study has been to promote this understanding.

Additional work needs to be done, however. The NWS should strongly encourage the establishment of a cooperative training program between the WSFOs and CWSUs on a regional or national level. Temporary assignment of WSFO forecasters and/or interns to a CWSU offers first-hand observation of FAA and NWS cooperation. Also, it serves to foster an increased understanding of the importance of the CWSU's mission.

REFERENCES

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National Transportation Safety Board, 1977: *Aircraft Accident Report: Southern Airways, Inc., DC-9-31, N1335U, New Hope, Georgia, April 4, 1977.* NTSB-AAR-78-3, 106 pp.

ACKNOWLEDGEMENTS

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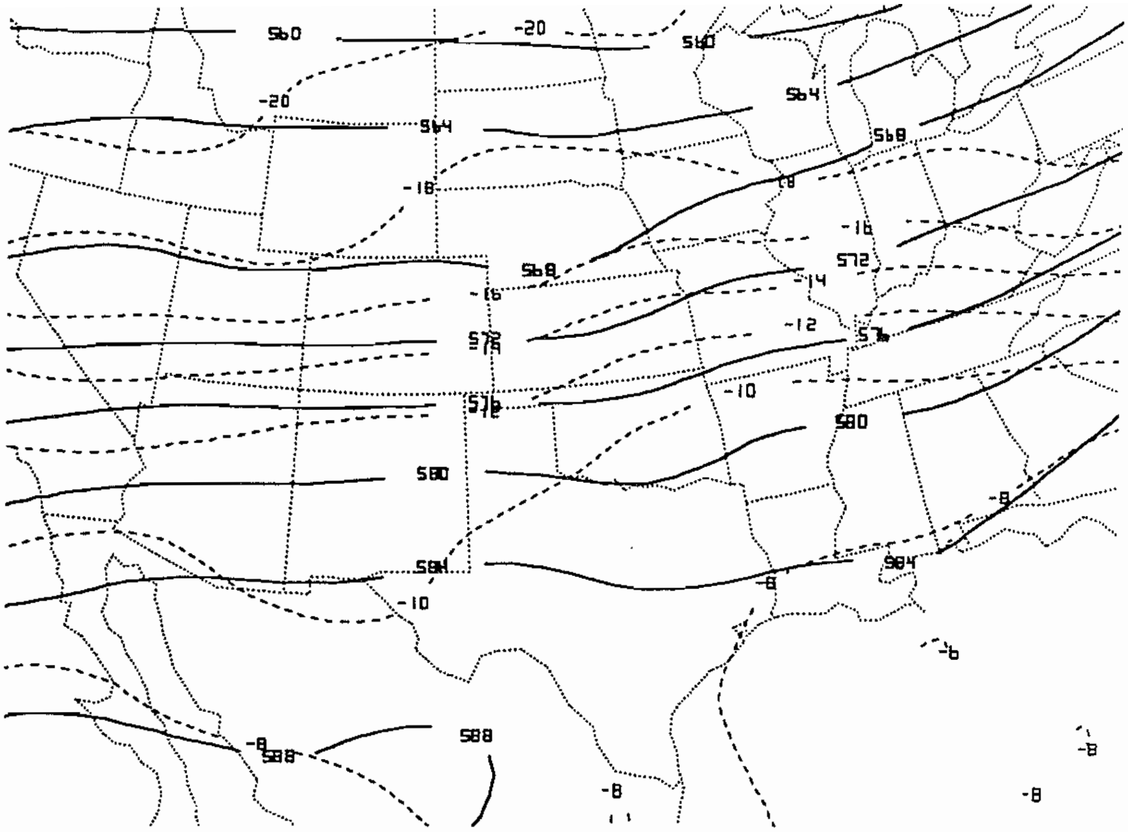


Fig. 1. Analysis of 500 mb height field (dm; solid lines) and temperature field (deg C; dashed lines) for 0000 UTC 15 October 1993.

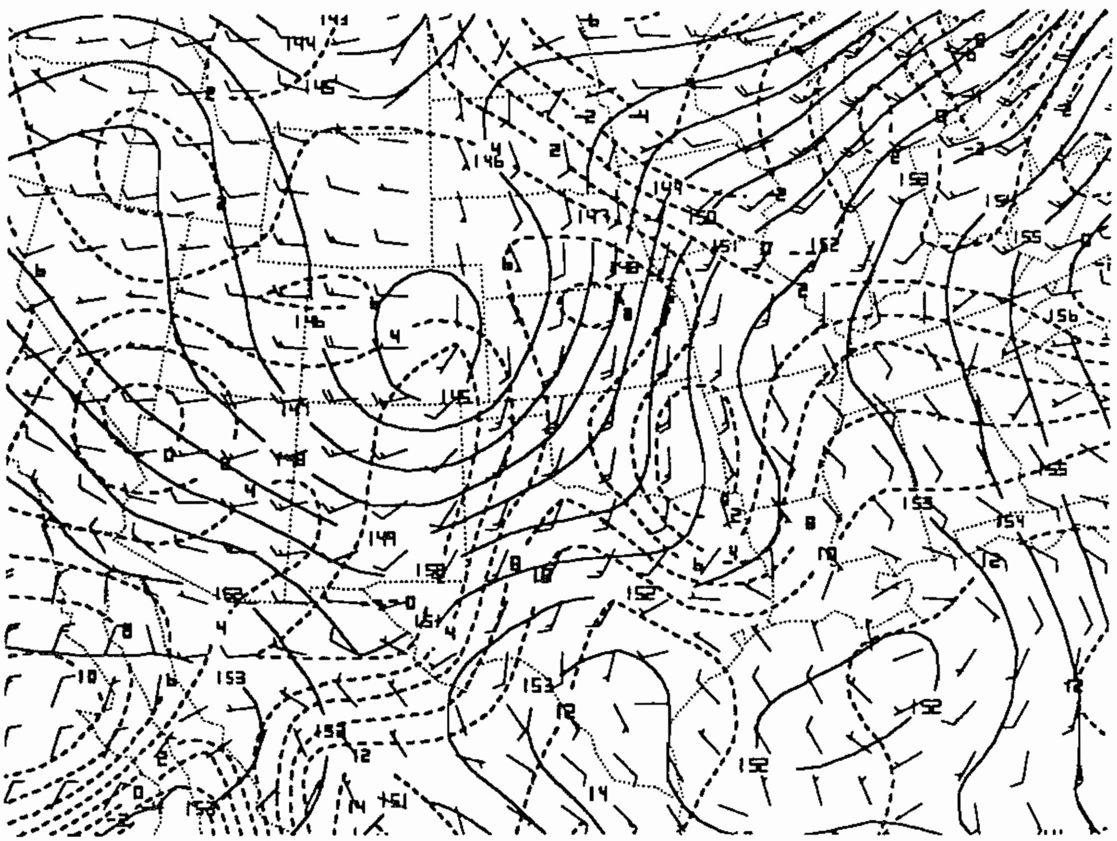


Fig. 2. Analysis of 850 mb height field (dm; solid lines), dew point temperature field (deg C; dashed lines), and wind (kts) for 0000 UTC 15 October 1993.

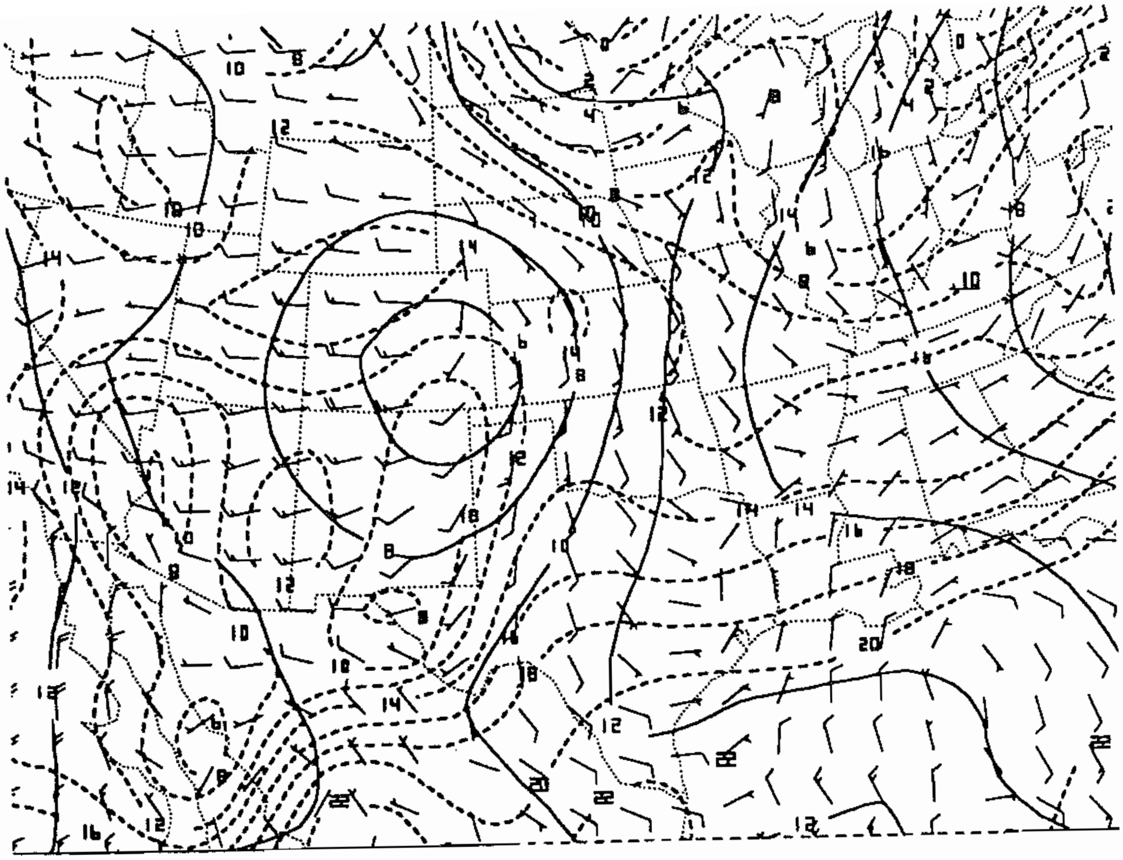


Fig. 3. Analysis of 1000 mb height field (dm; solid lines), dew point temperature field (deg C; dashed lines), and wind (kts) for 0000 UTC 15 October 1993.

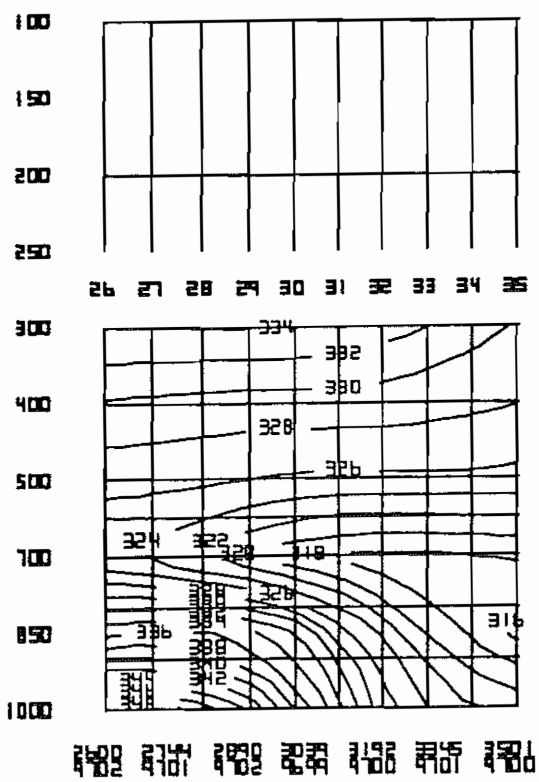


Fig. 4. Space cross-section of equivalent potential temperature (deg K) from near Brownsville, TX (26 N, 97 W) to near Oklahoma City, OK (35 N, 97 W) for 0000 UTC 15 October 1993.

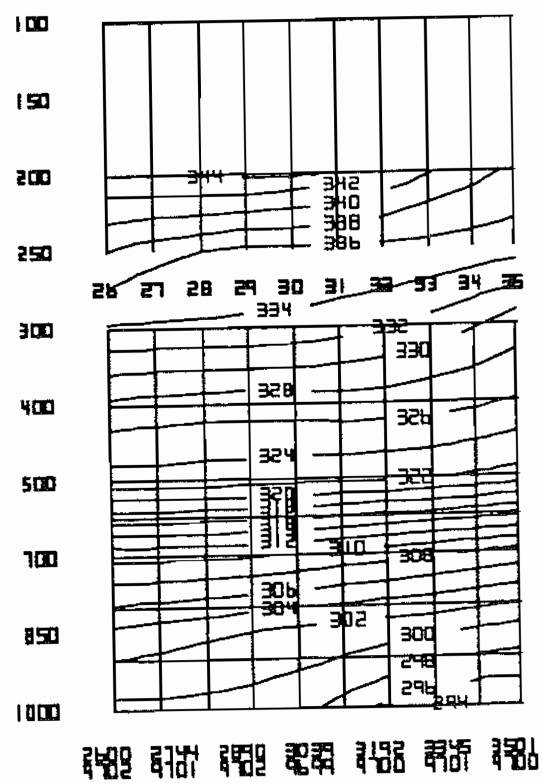


Fig. 5. Space cross-section of potential temperatu (deg K) from near Brownsville, TX (26 N, 97 W) to near Oklahoma City, OK (35 N, 97 W) for 0000 UTC 15 October 1993.

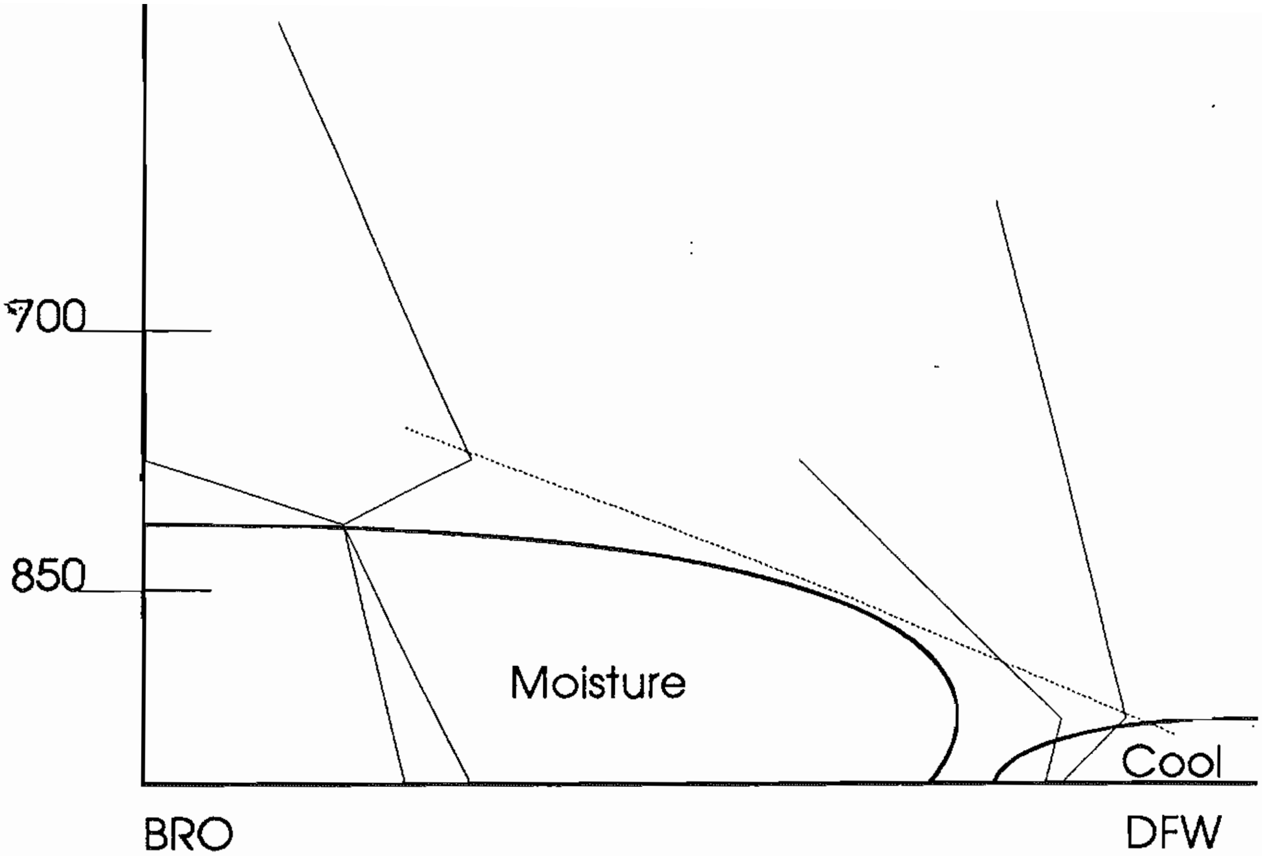


Fig. 6. Cross-sectional schematic of moisture, temperature, and inversion height (dotted line) from Brownsville, TX to DFW near the time of 0000 UTC 15 October 1993.

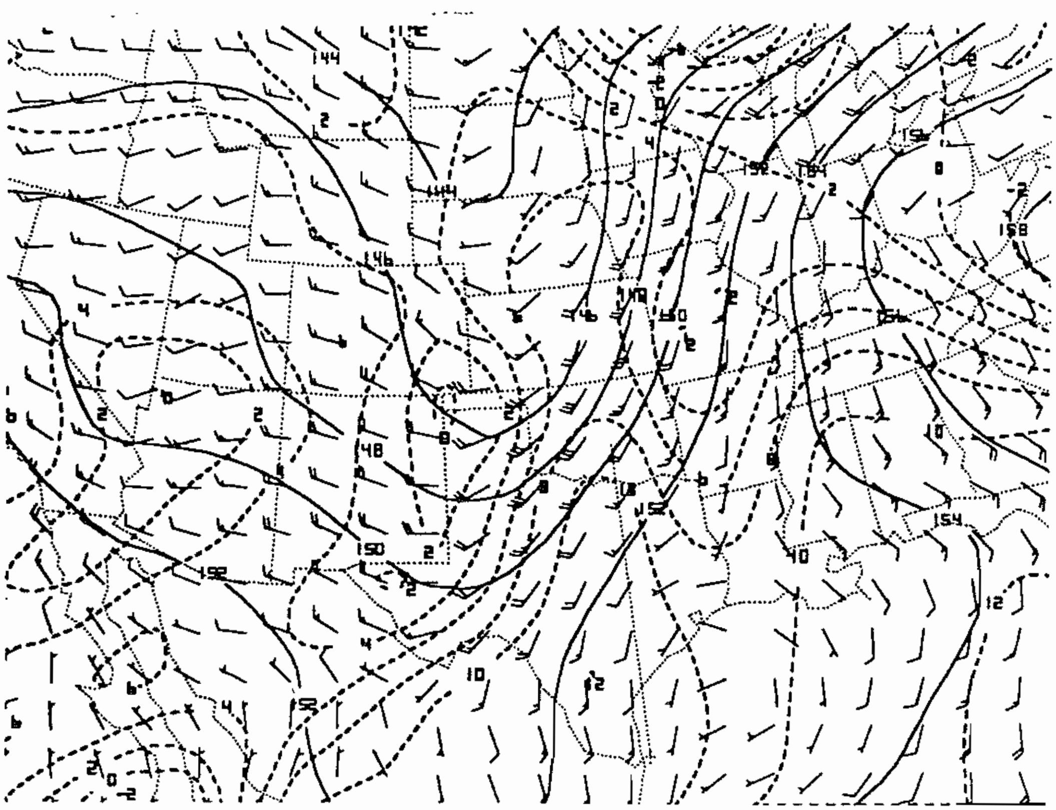
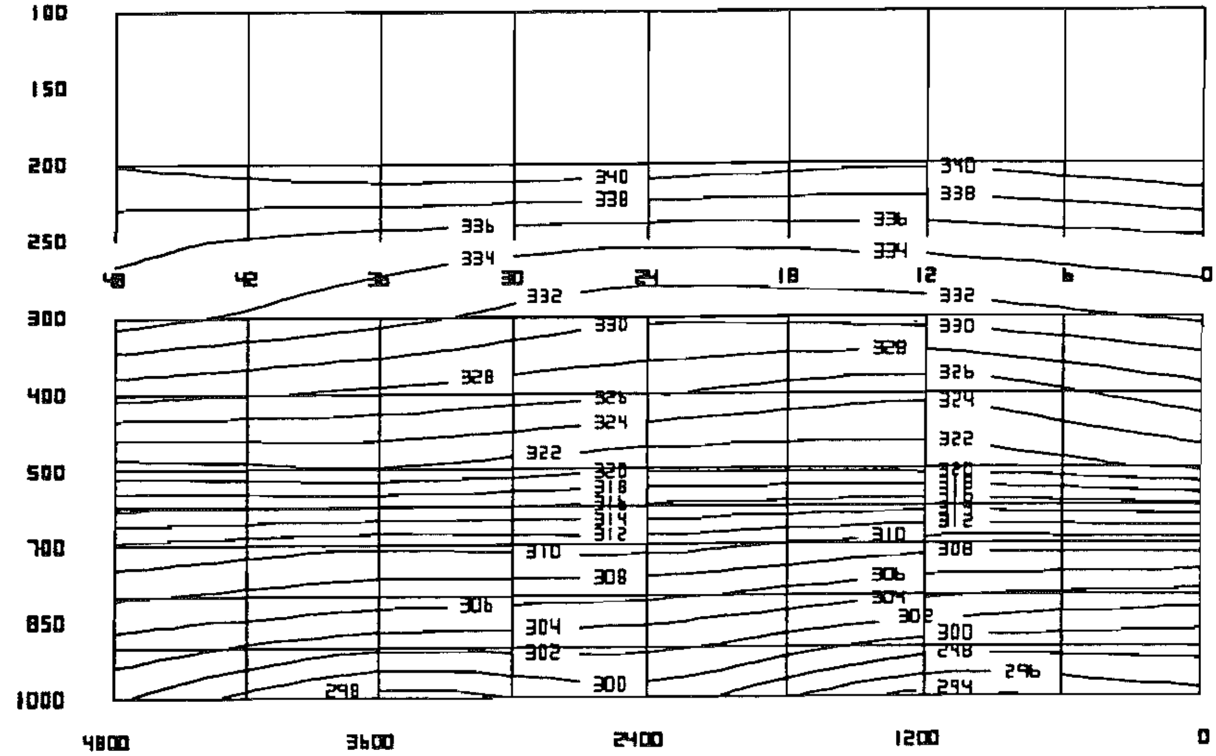
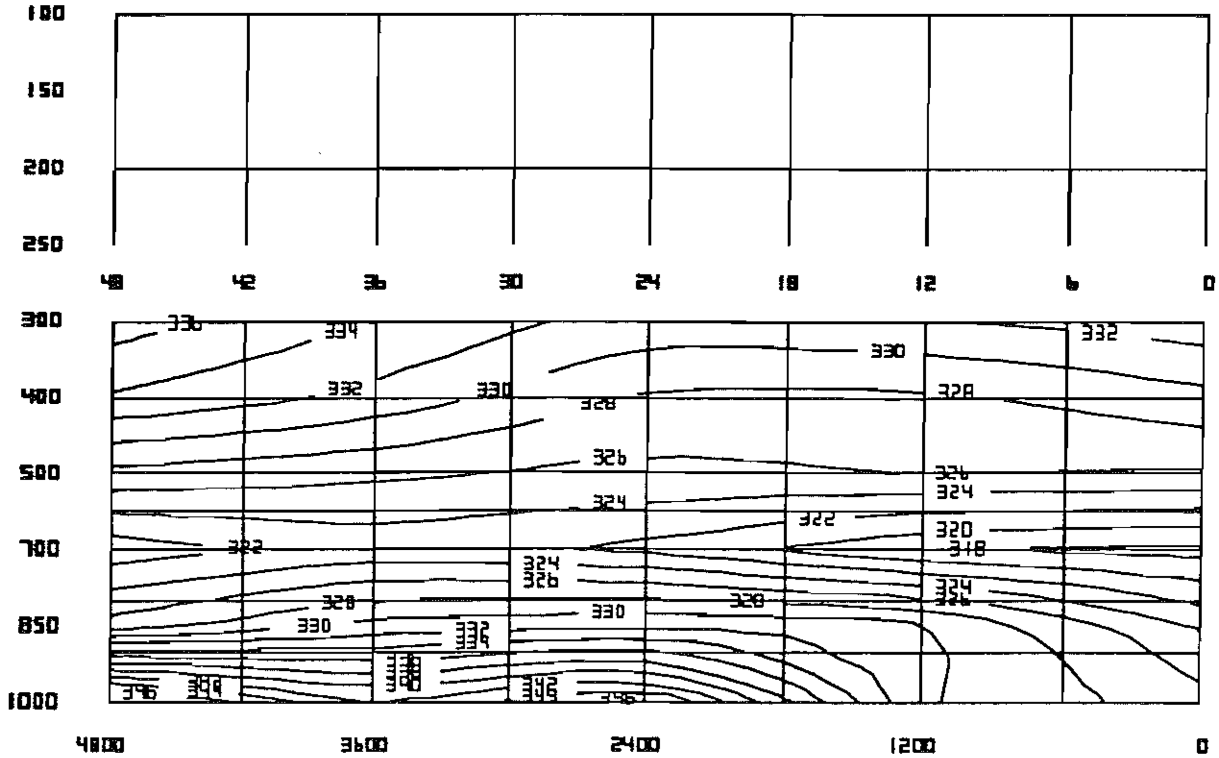


Fig. 7. Forecast of 850 mb height field (dm; solid lines), dew point temperature field (deg C; dashed lines), and wind (kts) valid at 1200 UTC 15 October 1993.



(a)



(b)

Fig. 8. Time cross-section of (a) potential temperature (deg K) and equivalent potential temperature (deg K) at DFW. Time increases right to left at 12-h increments starting at 0000 UTC 15 October 1993.