A Wintertime Mesoscale Cold Front in the Southern Plains

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Abstract

A case study is presented of a wintertime mesoscale cold front that intersects a dryline in the Southern Plains. Evidence is presented that diabatic cooling over snow cover north of the front, and heating and mixing west of the dryline, played important roles in forming a strong surface horizontal temperature gradient. The details of the evolution of the accompanying surface pressure field also are discussed.

1. Introduction

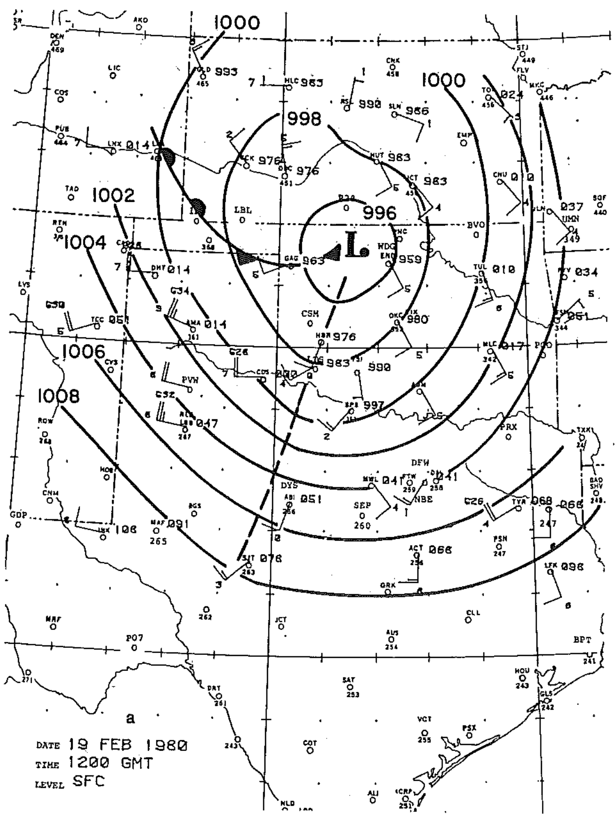
The updated state forecast for Oklahoma issued by the National Weather Service (NWS) in Oklahoma City on Tuesday morning, 19 February 1980, called for "generally fair this afternoon and tonight . . . highs this afternoon . . . lower 60s (16–18°C) southeast to 70s (21–26°C) west." This forecast was a good one for most of the state. However, within a narrow strip from north-central Oklahoma southward beyond Oklahoma City, maximum temperatures for the day were only 5–10°C and there was a low overcast.

Although badly "busted" forecasts are themselves not common events, this forecast was unusual in that it verified poorly only *in a mesoscale area,* one in particular in which there are no mountains or other drastic variations in surface features; furthermore, mesoscale areas of cumulus convection were not present.

The purpose of this paper is to discuss why the forecast was in error, in the hope that by doing so, we may learn more about mesoscale processes in the atmosphere. The following section presents a case study of this event. We then show evidence that diabatic cooling over a region of snow cover in Kansas north of a cold front, and diabatic heating and turbulent mixing over the High Plains west of a dryline, were responsible for the sharp surface temperature gradients found over central Oklahoma. A similar study of a mesoscale cold front in New England has been presented by Sanders (1969).

2. Description of events

A sequence of three-hourly surface maps covering the period from 1200 GMT 19 February to 0300 GMT 20 February is shown in Figs. 1a–f. At 1200 GMT (Fig. 1a), a surface low



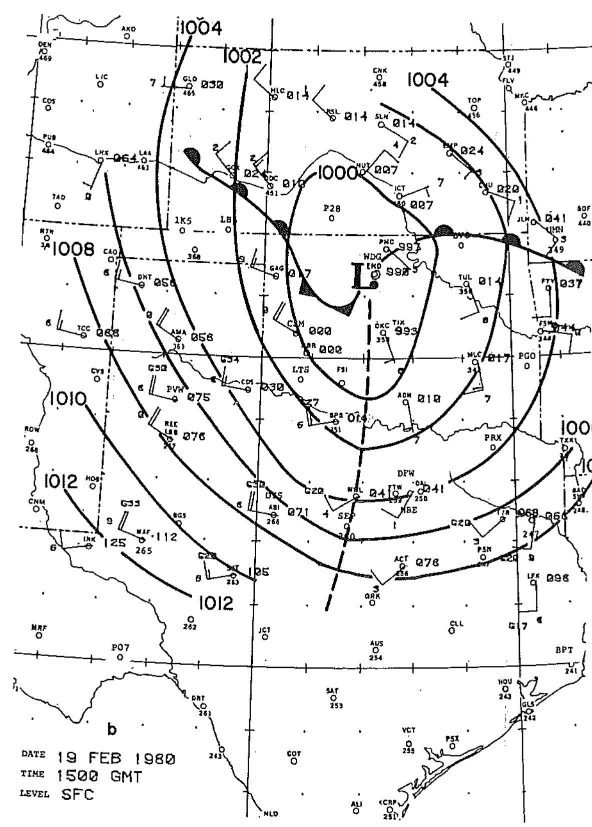


FIG. 1. See caption under continuation of Fig. 1, next page.

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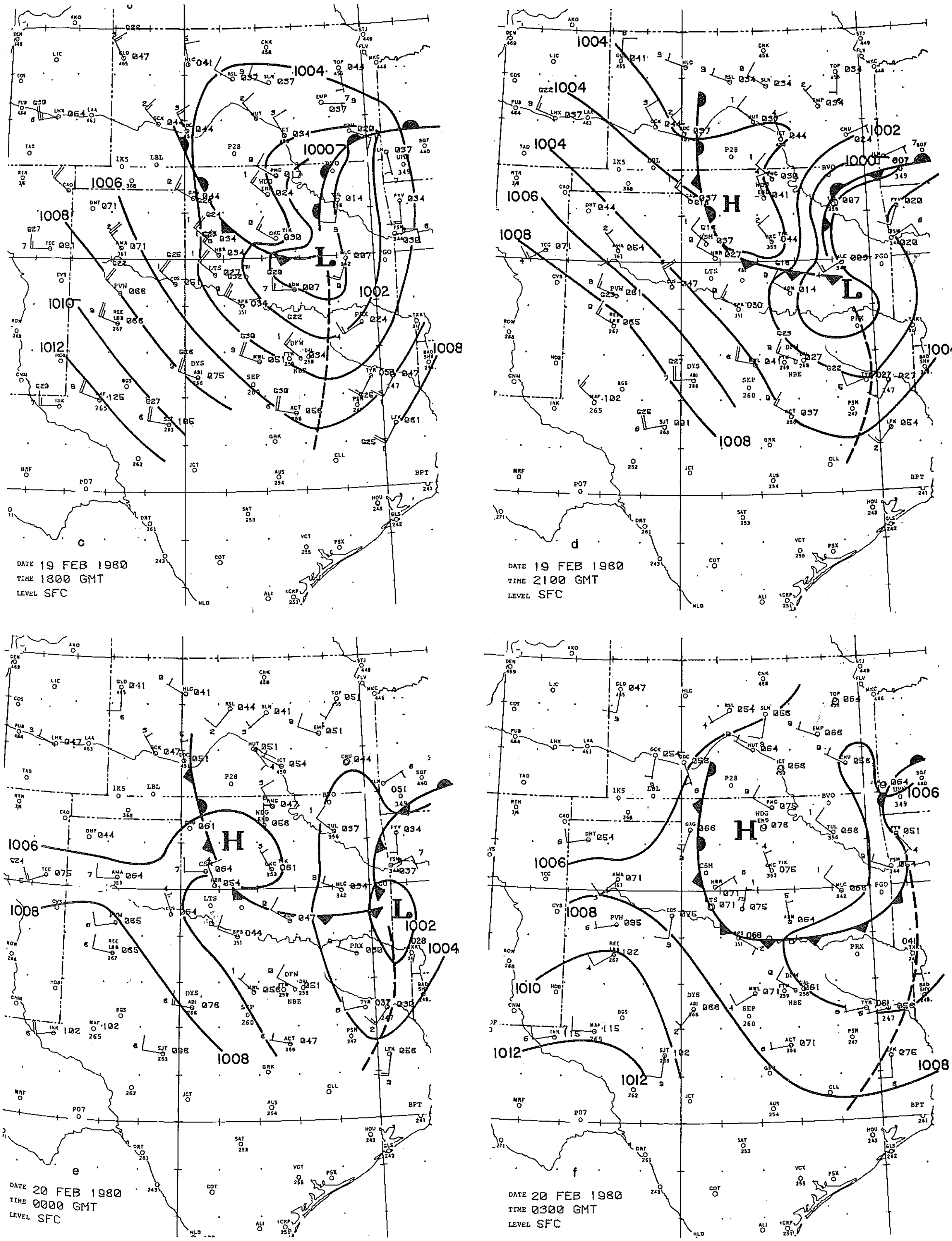


FIG. 1. (cont'd) a) Surface map for 1200 GMT, 19 February 1980; pressure plotted is altimeter setting converted to tenths of millibar, with the 100s and 1000s digits omitted. The wind direction in tens of degrees, with the 100s digit omitted, is plotted at the end of each wind barb. b) Same, but for 1500 GMT. c) Same, but for 1800 GMT. d) Same, but for 2100 GMT. e) Same, but for 0000 GMT, 20 February 1980. f) Same, but for 0300 GMT.

and circulation were located over the northwestern part of Oklahoma. A dryline-like trough and wind-shift line (Schaefer, 1974) extended south-southwestward from the low through west Texas. A front stretched westward from the low into Kansas and Colorado. Surface temperatures were unseasonably high west of the dryline, and near freezing in Kansas north of the low (Fig. 2a). Although the dryline and dryline-front intersection are often preferred areas for severe storm development during the spring (Rhea, 1966; Kessinger and Bluestein, 1979), the morning Stephenville and Oklahoma City soundings indicated that the depth of the moist layer was too shallow and the atmosphere too stable for convective activity (Figs. 3a–b). Documented cases of wintertime activity near the dryline-front intersection (Burgess and Davies-Jones, 1979) are rare.

The flow aloft was mainly from the west-northwest. At 500 mb, at 1200 GMT, a weak vorticity maximum embedded within a region of strong cyclonic shear north of the jet over Texas and Oklahoma was located over the Oklahoma Panhandle (Fig. 4). The satellite discussion from Kansas City issued at 1900 GMT pointed out that no cloud features were discernible in association with this vorticity maximum. The surface low was located in a region of positive differential vorticity advection just downstream from the vorticity maximum aloft, a position which could be accounted for qualitatively on the basis of quasi-geostrophic theory (Holton, 1979).

By 1500 GMT, the low had progressed east-southeastward to a position near Enid (END) in north-central Oklahoma, and the "dryline" had progressed into western Oklahoma and north Texas (Fig. 1b). A warm front had formed in northeastern Oklahoma; the winds in southeastern Kansas had backed in association with frontogenesis. Although the air had warmed substantially behind the dryline in the southwestern part of Texas, it had warmed only slightly in Kansas (*cf.* Figs. 2a and 2b).

Three hours later (Fig. 1c), some new features had appeared as the low continued its movement toward the east-southeast. A well defined narrow wedge of cold air was located over north-central Oklahoma (Fig. 2c). Indications of the formation of a mesoscale ridge along the axis of the cold air and a mesoscale trough in the warm, dry air west of the dryline-front intersection had appeared. In addition, although the low had continued to move in an east-southeasterly direction, the circulation center had now dissociated itself from the low, and was located to the north on the Kansas-Oklahoma border north of Tulsa (TUL). This pattern was not distorted by the reduction to sea-level procedure, because altimeter settings are dependent on a temperature which depends on height only, and the stations east of meridian 100°W in the Southern Plains are all at about the same elevation.

At 2100 GMT, the cold wedge was best defined (Fig. 2d). Temperatures ranged from 30°C at Waco, Texas (ACT) to 3.3°C at Wichita, Kansas (ICT); thus there was a synoptic-scale horizontal temperature gradient of the order of 4–5°C $(100\ \mathrm{km})^{-1}$. Furthermore, a 100 km-wide zone of horizontal temperature gradients of the order of 15°C $(100\ \mathrm{km})^{-1}$ extended as far south as just south of Oklahoma City (OKC).

Both eastern and western Oklahoma had temperatures

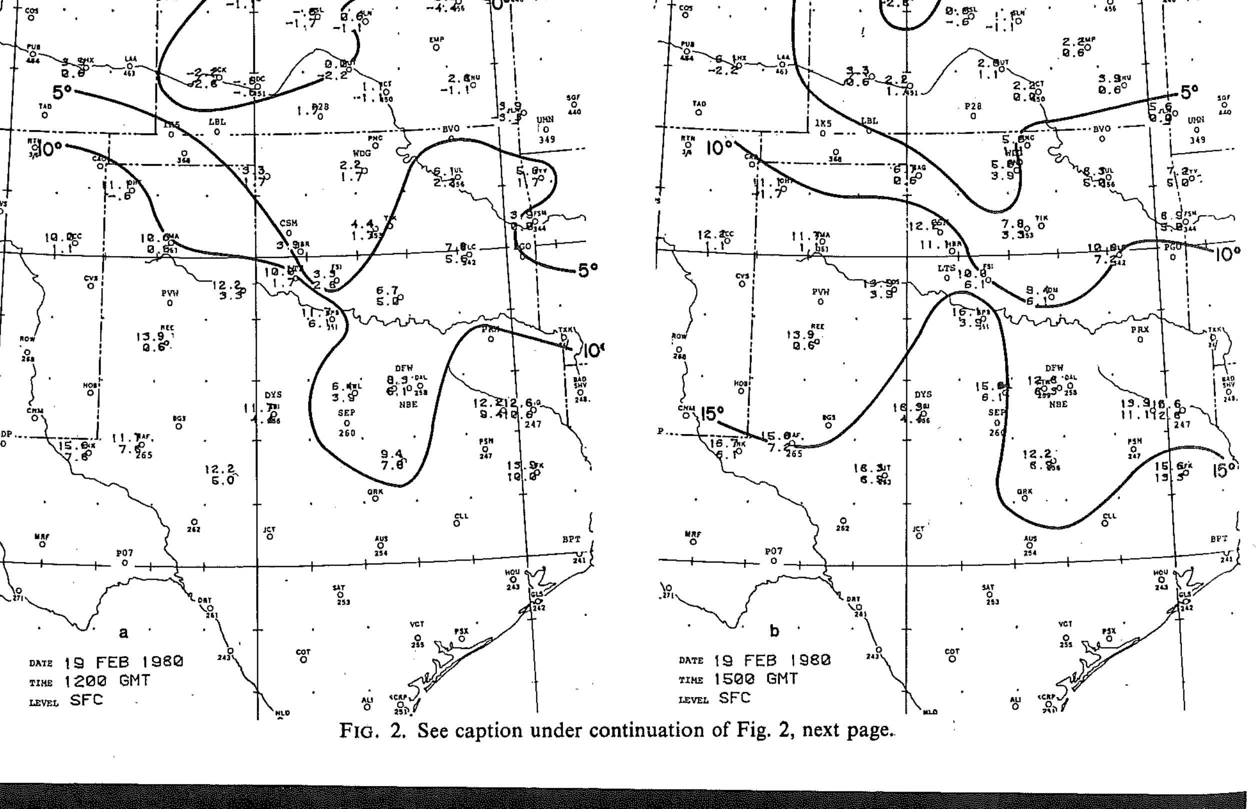


FIG. 2. See caption under continuation of Fig. 2, next page.

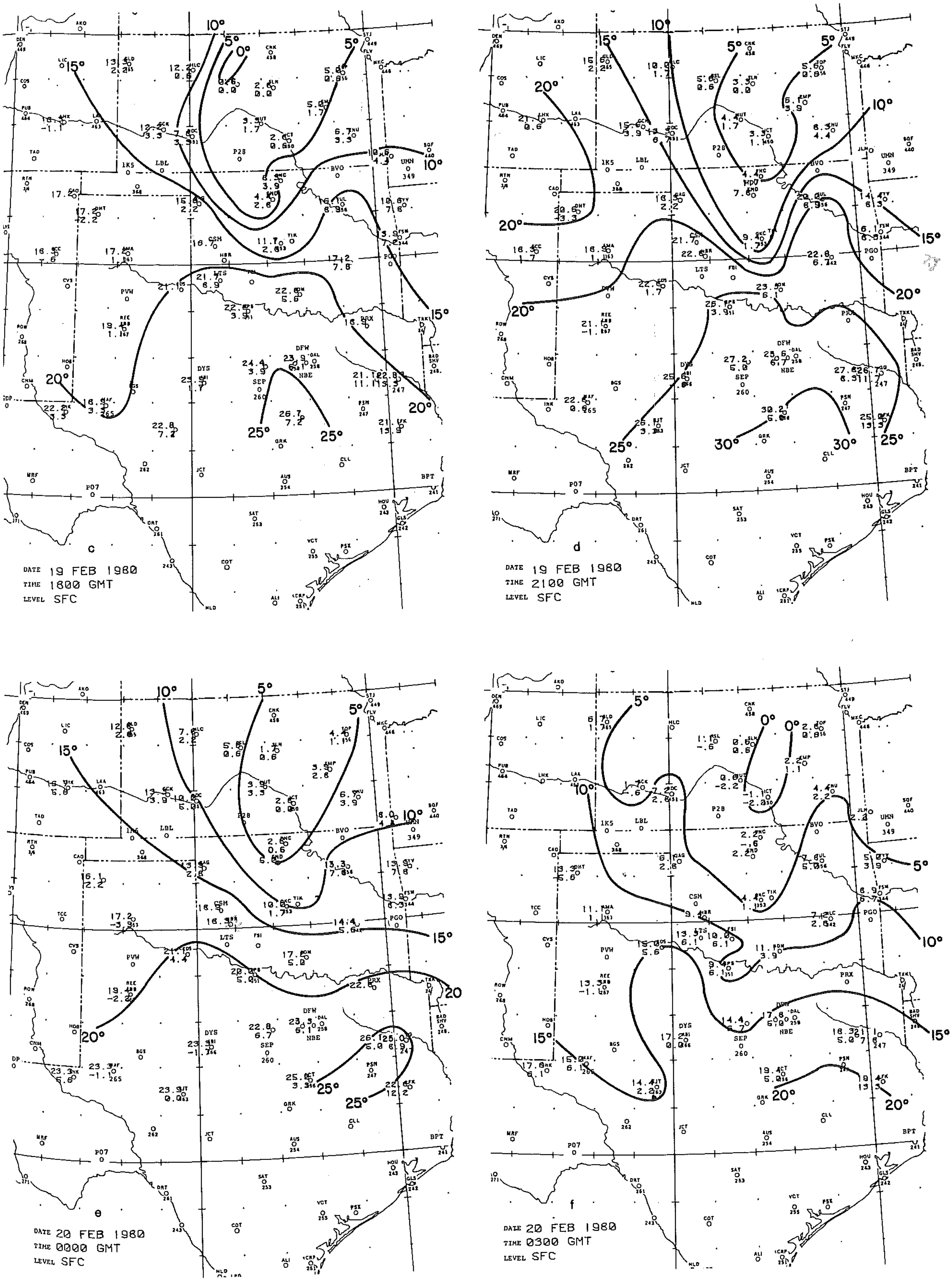
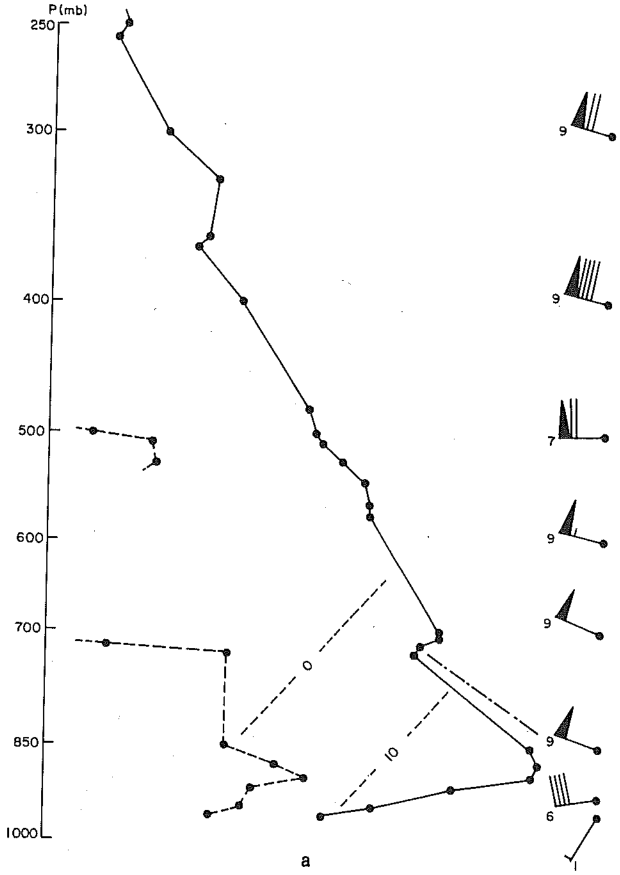


FIG. 2. (cont'd) a) Surface temperature field (solid lines in °C) for 1200 GMT, 19 February 1980; dew point (°C) plotted under temperature. b) Same, but for 1500 GMT. c) Same, but for 1800 GMT. d) Same, but for 2100 GMT. e) Same, but for 0000 GMT, 20 February 1980. f) Same, but for 0300 GMT.



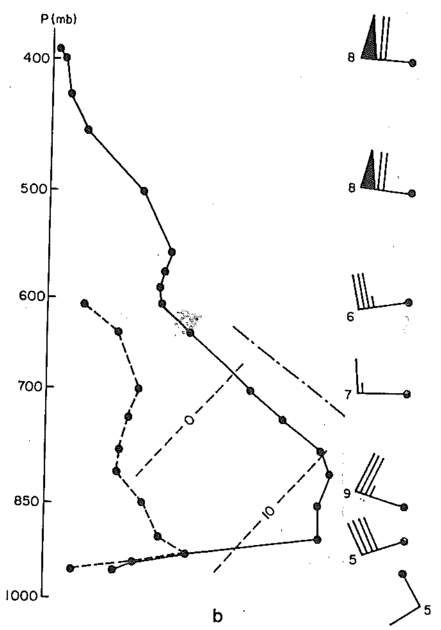


FIG. 3. a) Sounding (skew *T*-log *p* diagram) for Stephenvill Tex. (SEP) at 1200 GMT, 19 February 1980. Solid lines, temper: tures in °C; dashed lines, dew point temperature in °C. The 0° an 10°C isotherms and a dry adiabat (dashed-dotted line) are shown f reference. b) Same, but for Oklahoma City, Okla. (OKC).

around 20°C or higher, while much of central Oklahoma had temperatures below 10°C. A well defined mesoscale high was positioned over the cold air (Fig. 1d). The low was located in southeastern Oklahoma about 100 km or more south of the circulation center, which was located near TUL. The 1832 GMT visual satellite photograph impressively shows the narrow wedge of low clouds protruding southward from Kansas into north-central Oklahoma (Fig. 5).

As the dry air west of the dryline cooled relatively rapidly after sunset (Figs. 2e–f), the temperature gradient weakened. However, the mesoscale high over central and northwest Oklahoma persisted (Fig. 1e). The low had progressed to near the Arkansas-Louisiana border, while the circulation had moved into extreme northeast Oklahoma. A well-defined region of divergence behind the front was apparent at 0300 GMT (Fig. 1f).

3. Discussion

The most intriguing features of this case study are the narrow wedge of cold air, and the mesoscale features in the pressure field accompanying both this cold wedge and the cyclonic circulation located at the dryline-front intersection to the east.

The characteristics of the air masses located behind the dryline, in the "warm" sector, and in the "cold" air mass, are displayed in Figs. 6a, 3a, and 6b. The morning sounding at Stephenville (SEP) is characteristic of the "warm" sector (Fig. 3a): low-level warm advection is indicated by the veei ing of the wind with height below the radiation inversio near 900 mb. The evening SEP sounding is characteristic o the air behind the dryline (Fig. 6a): the lapse rate is nearl dry-adiabatic, and the wind direction and speed are nearl constant from just above the surface to 750 mb. The evenin OKC sounding is characteristic of the "cold" air mass (Fig 6b): cold advection is indicated by the backing of the winc with height below the top of the inversion at 800 mb.

I conjecture that the cool wedge in north-central Oklahoma is due to north-northwesterly flow of air having a history of contact with the cold snow cover in west-central Kansas (Fig. 7). Low clouds, forming while air with dew points above freezing was cooled over the snow cover, further inhibited surface heating from the sun. At 1200 GMT (Fig. 1a), winds between Dodge City (DDC) and Russell (RSL), an area of relatively deep snow cover (Fig. 7), were from the north. It is easily seen from a trajectory analysis using the hourly wind data that air at 2100 GMT at END, located along the cold trough, came from this area at 1200 GMT and earlier. The role of diabatic cooling over snow cover is determined qualitatively by estimating the rate of heat flux from the air to the snow cover. Using the bulk aerodynamic method, the rate of temperature change due to a loss of heat in the lower 20% of the atmosphere is

$$\frac{dT}{dt} = \frac{1}{C_p}\frac{dQ}{dt} \approx \rho\,\frac{C_{Hi}|\mathbf{V}_o|(T_s - T_o)}{1/5(P_o/g)}$$

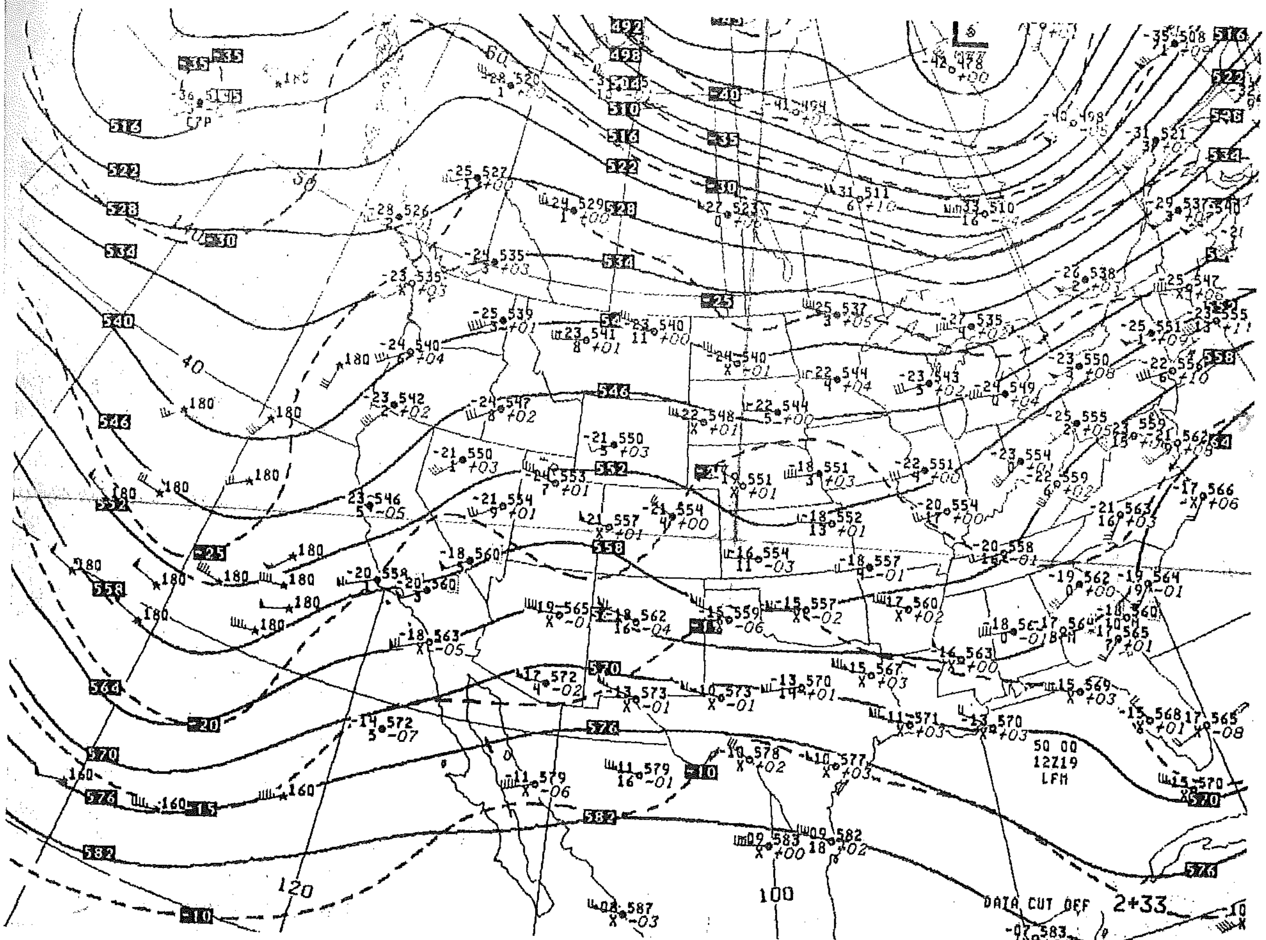


FIG. 4. National Meteorological Center 500 mb analysis for 1200 GMT, 19 February 1980.

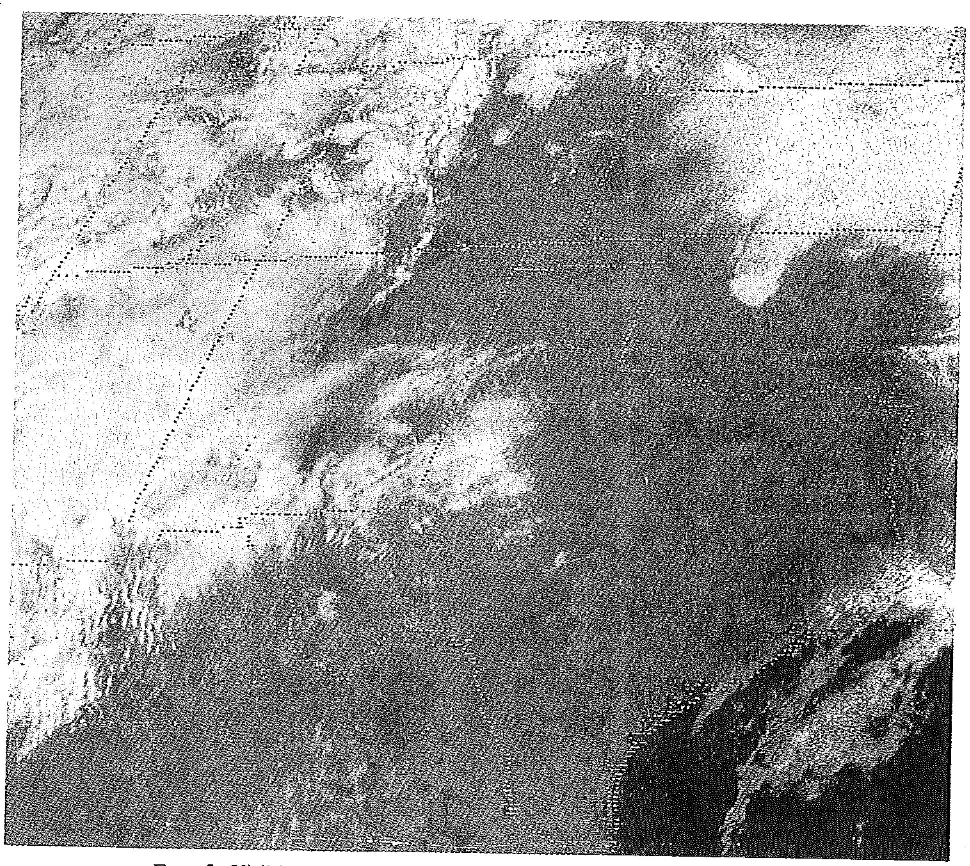


FIG. 5. Visible satellite photograph for 1832 GMT, 19 February 1980.

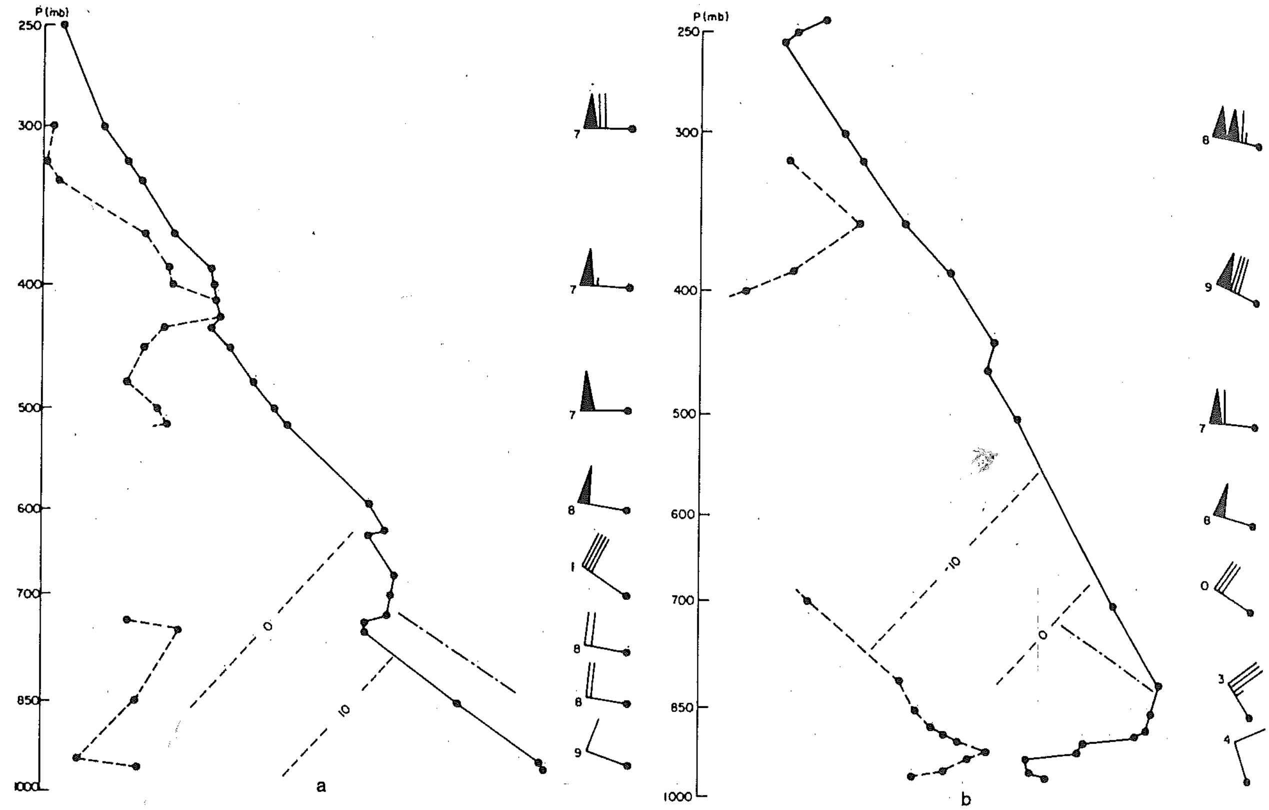


FIG. 6. a) Sounding (skew T-log$p$ diagram) for Stephenville, Tex. (SEP) at 0000 GMT, 20 February 1980. Solid lines, temperature in °C; dashed lines, dew point temperature in °C. The 0° and 10°C isotherms and a dry adiabat (dashed-dotted line) are shown for reference. b) Same, but for Oklahoma City, Okla. (OKC) (−10° and 0°C isotherms shown for reference).

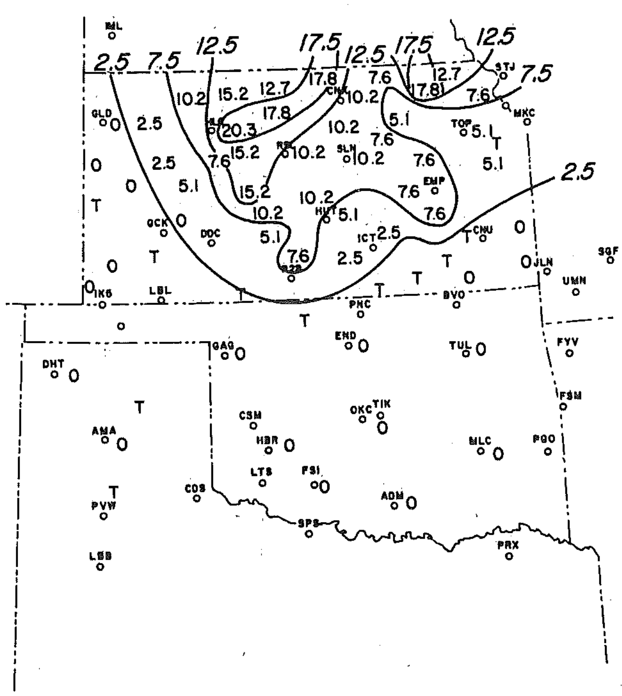


FIG. 7. Snow cover (cm) on 19 February 1980 at 1200 GMT (U.S. Dept. of Commerce, 1980a,b).

where ρ is the air density,

C_{Hi} is the drag coefficient over an icy surface;
$|\mathbf{V}_o|$ is the wind speed at anemometer level;
T_s is the temperature of the icy surface;
T_o is the air temperature at anemometer level;
P_o is the surface pressure; and
g is the acceleration of gravity.

For $|\mathbf{V}_o| \sim 10$ m s^{-1},
$T_s - T_o \sim 10°$C (upstream from the snow-covered area, temperatures were 10°C higher; see Fig. 1c, for example: *cf.* the temperatures of HLC and RSL),
and $C_{Hi} \sim 1.5 \times 10^{-3}$ (Seifert and Langleben, 1972; Langleben, (1972).

The rate of cooling is about 5–10°C day^{-1} (2–4°C in 9 h). If solar radiation raises the surface air temperature about 10°C in 9 h, and if half of the solar radiation gets through cloud cover, then the differential rate of heating between a sunny region and a cloudy region over snow cover should be roughly 7–9°C in 9 h. Indeed, the range of temperatures from the coldest to the warmest region changes from about 18°C at 1200 GMT to 27°C at 2100 GMT, *i.e.*, about 9°C in 9 h.

Air in eastern Oklahoma in the "warm" sector was warmed by warm advection from the south and by insolation; surface air in western Oklahoma was warmed by adiabatic turbulent mixing and by insolation behind the dryline.

Since the mesoscale high is coincident with the cold surface air, it is likely that the high is a hydrostatic consequence of the shallow cold air. For example, at 2100 GMT (Figs. 1d and 2d), the 3 mb altimeter-setting difference between OKC and Ardmore (ADM) could be due to a 10°C difference in mean temperature in a 0.5 km-deep layer. The mesohigh, therefore, may be similar to that found in the outflow of squall lines (Fujita, 1955) (see Fig. 1f).

The dissociation of the circulation and low-pressure area during the afternoon may be a consequence of surface heating, due to turbulent mixing and insolation. It is interesting that the low first became separated from the circulation during the time period when the surface temperature behind the dryline west of the low rose most rapidly. For example, the surface temperature at ADM rose 13.4°C between 1500 and 1800 GMT (Figs. 2b and 2c). In other words, the surface low became displaced toward the warmer surface air. The details of the adjustment process taking place between the wind and temperature field are unknown. On the basis of Rossby adjustment theory, we expect that for small scales of motion such as the ones described in this paper, the pressure field will respond to the wind field (Rossby, 1938). In this case, the low pressure center should have moved northward and become coincident with the circulation center. Since it didn't, it is speculated that turbulent mixing may have played an important role. (Other cases of the dissociation of the surface low from the circulation at the dryline-front intersection have been found in the Southern Plains during the spring, and are currently being studied.)

It would be interesting to test our hypothesis, (*i.e.*, that diabatic cooling, heating, and mixing played important roles) by performing some numerical experiments. We would want, in particular, to see if a model can reproduce the narrow wedge of cold air, the mesohigh, and the trough.

Finally, this case study clearly points out the importance of mesoanalysis and satellite analysis in short-term forecasting.

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announcements *(continued from page 177)*

of the scientific and technological tools and methods available to implement such strategies successfully. The seminar includes specific sessions on Education and Training and Technology Transfer. For further information, please contact: Nancy Giddens, Coordinator, International Seminar, Environmental Research & Technology, Inc., 696 Virginia Road, Concord, Mass. 01742 tel: (617) 369-8910.

12–16 July 1982: The Fourteenth Stanstead Seminar will be held at Bishop's University, Lennoxville, Quebec, Canada, 12–16 July, 1982. The theme of the seminar is "Analysis and Initialization of Atmospheric Observations." Accurate analysis of the complete four-dimensional structure of the atmosphere is essential both for numerical weather prediction and for observational studies. Such atmospheric analyses are generally produced by a combination of objective analysis and initialization. Since objective analysis is approached with primarily the observations in mind, while initialization is highly model oriented, there are often serious inconsistencies between the two. With the FGGE (First GARP (Global Atmospheric Research Program) Global Experiment) data set now universally available, the time seems propitious for a complete discussion of analysis and initialization in the hope of eventually arriving at completely self-consistent procedures.

Several invited papers will review the bases of optimal interpolation, variational procedures, nonlinear normal mode initialization and four-dimensional data assimilation. Other papers will discuss the application of these procedures to the FGGE data set. Please address all correspondence concerning the seminar to: Jacques Derome, Department of Meteorology, McGill University, 805 Sherbrooke Street W., Montreal, Quebec, Canada H3A 2K6 tel: (514) 392-4462. Correspondence concerning the program may also be addressed to either Roger Daley or David Williamson at the National Center for Atmospheric Research, P.O. Box 3000, Boulder, Colo. 80307 tel: (303) 494-5151, ext. 671 or 652.

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