LAKE EFFECT SNOW IN THE GREAT PLAINS

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ABSTRACT

Record breaking arctic air over South Dakota in December 1983 interacted with the relatively warm open waters of Lake Oahe to produce lake effect snow in the Pierre area for a period of several days. This paper will examine the rare phenomenon of lake effect snow in the heart of the Great Plains.

1. INTRODUCTION

The historical record breaking cold weather over the Northern Plains during December 1983 provided the basic ingredient for lake effect snows in the heart of the Great Plains. Besides very cold air, the other basic ingredient is a relatively large body of "warm" open water. The Missouri River, with its series of dam-created lakes in the Dakotas and eastern Montana, satisfied this second requirement. The result was several days of lake effect snow observed at Pierre SD during December 1983. This paper will both document these snows and present some possible causes and effects.

2. GEOGRAPHICAL DESCRIPTION

Pierre is located about 6 miles southeast of Oahe Dam on the Missouri River. The dam has created a lake 2 to 5 miles wide extending some 60 to 70 miles upstream. Immediately behind the dam is Lake Oahe 3 to 5 miles wide and stretching east/west about 15 miles. Elevations of the city, Lake Oahe and the airport are 1490, 1610 and 1742 feet, respectively. Land evalation 30 to 40 miles west of Pierre rises to 2200 feet MSL. East and southeast of the airport the land rises to 1800 to 2100 feet MSL. See Figure 1.

3. SYNOPTICS AND WEATHER SITUATION

December 1983 was the coldest December ever recorded in South Dakota. However, the waters of Lake Oahe were open until the last few days of the month. On December 19, the Army Corps of Engineers reported a water temperature of 5°C (41°F). From December 17-24, South Dakota experienced daily average temperatures of -20 to -30°C (-4°F to -22°F). Temperatures at the 850 MB level were -25 to -30°C (-14 to -22°F). Rarely is it so cold so early in the winter season when the lake water temperatures are still above freezing. In addition, prevailing surface winds were northwest to west. These directions allowed the winds to have a long fetch across the part of Lake Oahe just upstream from Pierre. Thus the stage was set for lake effect snows at Pierre SD as the northern plains remained locked in an artic air siege.

The most impressive lake effect snows occurred on December 21 when the Pierre area picked up a new snowfall of 2 to 3 inches. On this day the visibilities ranged from 1/4 to 3 miles. Considerable blowing and drifting snow was also reported due to the northwest to west winds of 15 to 25 MPH with gusts to 35. Incidently, no snow, and few if any clouds were reported by other NWS/FAA stations in South Dakota on December 21st. In addition, observed winds outside of the Pierre area were not as strong. See Table 1 for the listing of the Pierre surface observations as recorded by the FAA Flight Service.

Just after midnight, a surface low pressure trough passed through the Missouri River basin. The winds shifted from the east to southwest. Note that stratocumulus clouds were observed over the river to the west in the 0549Z entry. In general, if the surface winds were from a southwest to west direction, then the best lake effect snow was located northwest of the airport. As the winds veered to the west to northwest direction, the snow bands then moved across the city and airport area. At this time ceilings became obscured, visibilities were reduced, and wind speeds increased. Similar weather conditions were also observed periodically during December 17-24.

Dewpoints on December 21 slowly increased during the day as the lake waters and snowfall added moisture to the air. At 6 PM Pierre's temperature was still -22°C (-8°F), while other locations across the state had dropped into the -25 to -29°C (-13 to -20°F) range. Even overnight lows were significantly higher at Pierre. Obviously there was a tremendous heat transfer from the waters of Lake Oahe to the surrounding air.

The loss of heat energy from Lake Oahe resulted in the lowering the water temperatures. By December 28, the Army Corps of Engineers reported a lake temperature of +1°C (34°F) with ice forming on the shores. Thus the lake effect mechanism was losing one of its main ingredients.

Local weather conditions at Pierre on December 21 are readily indentified in Figure 2. Corresponding satellite photographs from 6 PM to 7 PM graphically show the lake effect snow/cloud mass around Pierre (Figure 3). The downstream extent of the cloud mass was amazing, and was probably due to the driving force of the locally enhanced winds, additional evaporation from open river waters southeast of Pierre, and perhaps some funneling by the river valley contours.

4. BOUNDARY LAYER CONSIDERATIONS AND POSSIBLE PHYSICAL RELATIONS

The extreme contrast between the Lake Oahe water temperatures and the bitter cold arctic air in December 1983 resulted in a unique atmospheric temperature lapse rate. In the first 200 feet above the water surface, the lapse rate was undoubtedly super adiabatic with a tremendous amount of "steam fog" ascending rapidly into the air. Between 200 and 600 feet above the lake surface, the lapse rate was probably adiabatic with the evaporated moisture now changing to the ice crystal state. At 600 feet, the lapse rate was probably moist adiabatic. At this level the ice crystals were in a rapid growth stage, resulting in lake effect clouds and snow. The west to northwest winds then advected this cloud mass downstream to the Pierre airport area where cloud bases were observed to be about 500 feet. A pilot report at 2348Z on the 21st indicated that visibility was obscured between 2200 and 3300 feet MSL (500 and 1600 feet above airport ground level).

If the surface pressure gradient favored a southwest to west wind, the snow band would be shoved north to the Pierre airport. This supported by many observations of a general increase in visibility and rises in cloud ceilings.

If the surface pressure gradient favored a west to northwest flow, then the heaviest snow band would move back into the Pierre area, and this is supported by the general decrease in both visibility and cloud base as Pierre's wind veered to the west to northwest. In addition, velocities tended to increase as the winds veered. A northwest direction would favor a longer stretch over Lake Oahe, where surface friction was weaker. Consequently, northwest winds tended to be stronger than southwest winds. Several other times, during December 17-24, oscillations of wind direction corresponded with changes in visibilities, ceilings, and wind speed. However, the occurrences centered around December were the most dramatic.

5. EFFECTS ON AVIATION WEATHER FORECASTING AND OPERATIONS

This lake effect snow was highly local and only extended downstream along the Missouri River. While the remainder of South Dakota had good flying weather (VFR) on December 21, the local Pierre area was socked in with very poor conditions requiring IFR operations.

Table 2 shows the both the Terminal (FT) and Area Forecasts (FA) issued by the National Weather Service during the late afternoon and evening on December 21. Note the contrast between the Pierre FT and the FA forecast for South Dakota. The FT forecast the lake snow and IFR conditions to continue until 0400Z on the 21st. The FA forecast did not highlight any IFR conditions over South Dakota. This contrast can be expected at times due to the nature of the FT's and FA's. FT's are designed to include locally induced weather. FA's cover much larger areas, and do not refer to localized conditions.

As mentioned before, the Pierre FT expected the lake effect snow to end around 0400Z on the 21st, and possibly start up again at 1400Z on the 22nd. However, the FAA surface observations reveal that the lake effect snow, blowing snow, and gusty winds continued through the nighttime hours. Thus, the adverse weather was not controlled by diurnal variations in heating. Rather, the major forcing function was found in the relationship between the warm open lake waters, bitter cold air, and low level wind flow. Nonetheless, the lake effect snow occurrences may have been slightly enhanced by daytime heating, which would help to destabilize the boundary layer.

6. SUMMARY

The unusual combination of bitter arctic air in December 1983 and the still open waters of Lake Oahe formed the basis for significant lake effect snow at Pierre SD. This kind of snow is rare because climatologically the coldest winter air arrives in January and February when the lake is likely to be frozen over.

During December 17-24 there were several occurrences of poor weather conditions at Pierre. The most vigorous lake effect snows were observed on the 21st. On this day the sky conditions over the remainder of South Dakota were "clear" or "mostly clear". A favorable surface wind field interacted with bitter cold air and the open waters of Lake Oahe to produce frictionally enhanced clouds and 2 to 3 inches of new snow.

Lake effect snows in the heart of the Great Plains are also possible in two other locations; namely, Fort Peck Lake in eastern Montana and Lake Sakakawea in western North Dakota. These lakes, created by dams, may be sufficiently large enough to produce lake effect clouds and/or snows. Of course, the surface wind flow would dictate the snow and cloud mass locations, providing bitter arctic air was present with open waters.

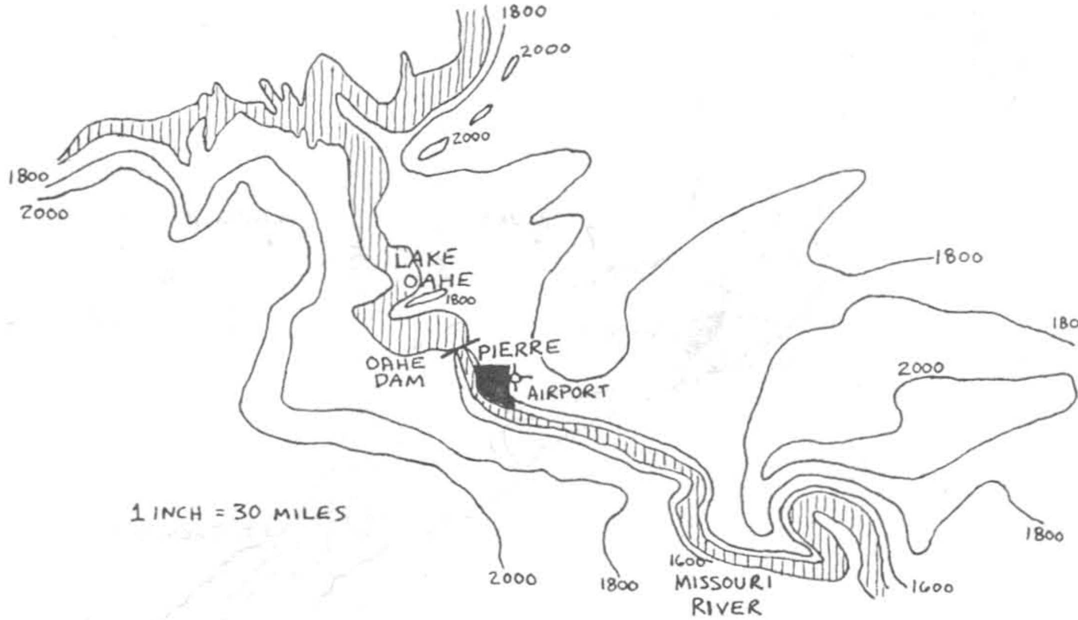

Figure 1. Contour map showing Pierre, the airport, Lake Oahe and the Missouri River.

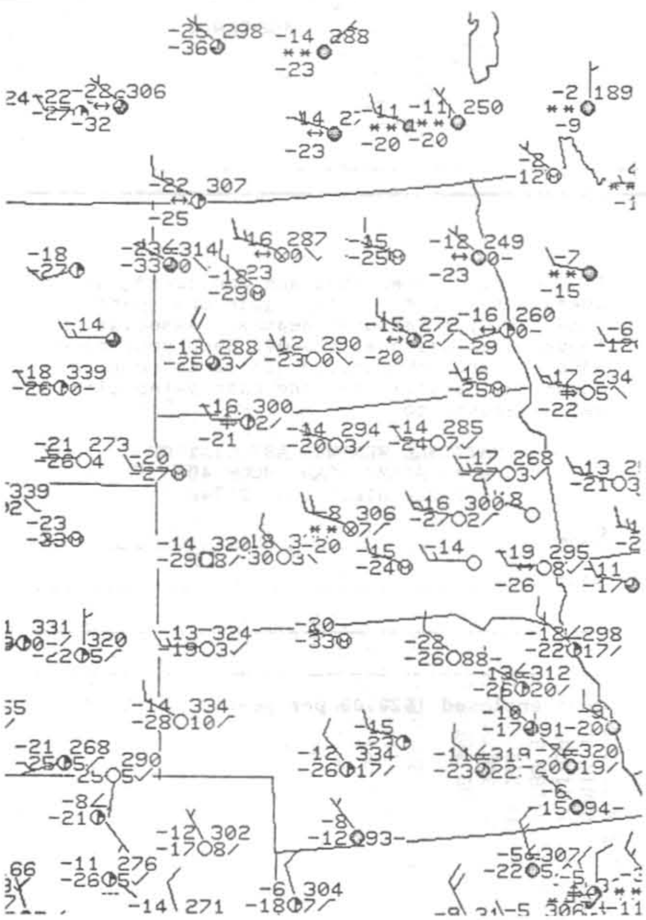

Figure 2a. Surface weather map, 6 PM CST, December 21, 1983.

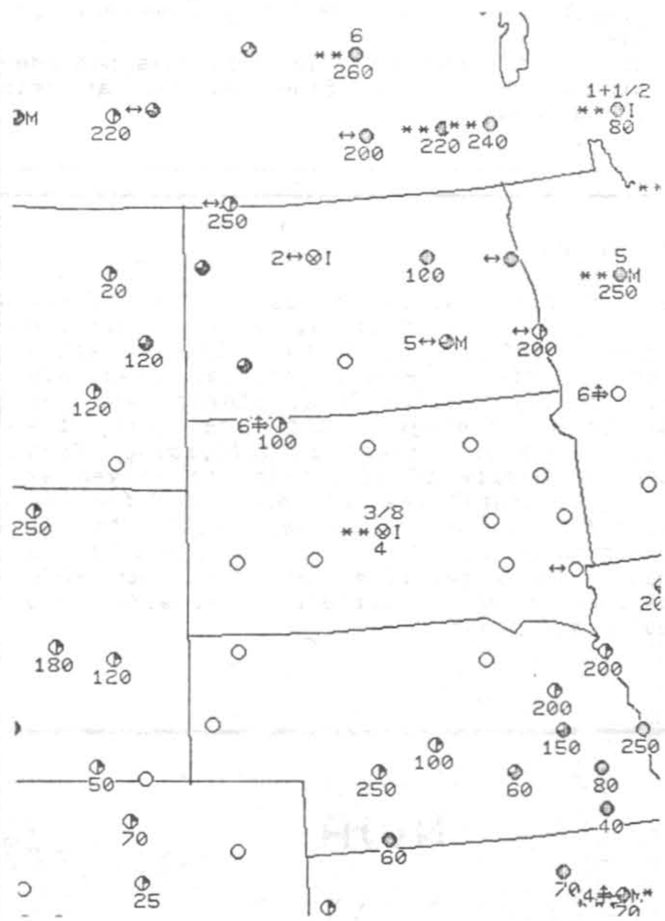

Figure 2b. Weather depiction chart, 6 PM CST, December 21, 1983.

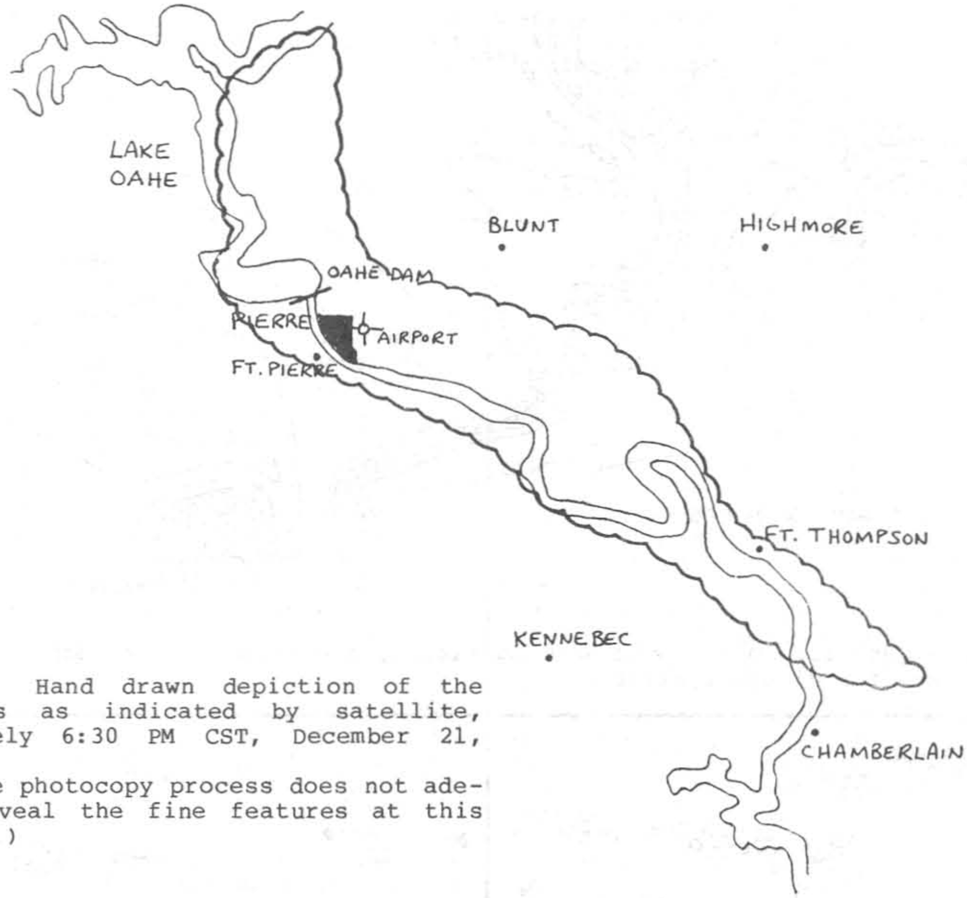

Figure 3. Hand drawn depiction of the cloud mass as indicated by satellite, approximately 6:30 PM CST, December 21, 1983.
(Note: the photocopy process does not adequately reveal the fine features at this cloud mass.)

FOOTNOTES

1. Anton F. Kapela has been a lead forecaster for the National Weather Service Forecast Office at Sioux Falls SD since 1981. His interests include mesoscale meteorology, severe local storms, and jet stream meteorology. After receiving the B.S. and M.S. degrees in meteorology from the University of Wisconsin, he worked as an agricultural weather forecaster for the school's extension system. Prior to his internship in the NWS, he spent three months in Antarctica and the South Pole participating in surface observation and upper air programs.

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FSDSAOPIR
SAUS90 KFSD 230004
 PIR RS 2352 E5 OVC 5BS 425/-11/-21/3315/032/ 10700 92
 PIR RS 2154 -X E5 BKN 1BS 315/-8/-20/3220/030
 PIR SP 2113 -X E5 BKN 1VBS 3120/030/VSBY 1/2 V 11/2 BS4
 PIR RS 2055 -X 5BKN 3/4BS 315/-8/-18/3019/030/VSBY 1/2V1 BS3
 PIR RS COR 1953 W5 X 1/2V BS 312/-8/-18/3123/029/SE40 VSBY1/4V3/4
 PIR RS 1753 W5 X 1/2VBS 312/-8/-18/3123/029/SE40 VSBY1/4V3/4
 PIR RS 1752 -X 8 SCT 1VBS 330/-8/-18/3018G27/034/VSB 1/2 V 11/2
BS3 / 000 84
 PIR SP 1130 -XE8 BKN 1V BS 2824/036/VSBY 1/2V11/2 BS3
 PIR SA 1654 -X12 SCT 4BS 339/-12/-22/2620/036/VSBY N-E2 BS3
 PIR SA 1556 -X12 SCT 4BS 339/-12/-23/2618/036/VSBY N2 BS3
 PIR SP 1518 -X12 SCT 4BS 2618/034/VSBY N2 BS3
 PIR SA 1458 W15 X 1VBS 324/-10/-20/2920/032/VSBY 1/2V11/2/ 214
 PIR SA 1358 W20 X 1/2BS 319/-11/20/3018G26/031
 PIR SA -X 1/2BS 313/-11/-20/3020G29/029/BS6
 PIR SA 1155 W10 X 1/2BS 309/-11/-21/3222G35/028/ 503 90407 89
20012
 PIR RS 1057 -X 1/2BS 307/-10/-20/3223G33/027/BS5
 PIR RS 0954 -X 1BS 308/-9/-18/3122G31/028/BS4
 PIR RS 0856 -X 2BS 311/-9/-19/3021G33/029/BS4/ 400
 PIR SA 0751 -X 21/2BS 311/-9/-18/3018G25/029/BS3
 PIR RS 0550 W15 X 11/2BS 313/-9/-20/2920G28/029/THIN SPOTS INOVC
/ 20800 90407 93 20016 49381
 PIR RS 0456 W13 X 21/2BS 311/-9/-20/-2718G24/028/SE30 THIN SPOTS
INOVC
 PIR RS 0247 -X 1S-BS 306/-9/-22/2918G30/026/BS9/ 000
 PIR RS 0146 W10 X 3/4S-BS 311/-8/-23/3120G30/027/COR HIGH TEMP 93
 PIR SP 0031 W4 X 3/4S-BS 3018G24/026
 PIR SA 2350 W4 X 3/8VS-BS 306/-8/-20/2920G30/026/VSB 1/4 V 1/2
/ 10706 90407 92
 PIR SP 2325 W4 X 3/8VS-BS 2820G30/026/VSBY 1/4 V 1/2
 PIR RS 2258 W4 X 1/2VS-BS 305/-8/-18/2920G29/026/VSBY 1/4 V 3/4 /
UA/OV PIR DURGD 2248 FLUKN/TP PASE/SK 022 OBSCD 033/RM OBSCN
STARTS ON FINAL 31 BTWN OM AND MM..
 PIR RS 2152 W2 X 1/2VS-BS 301/-7/-11/2821/025/VSBY 1/4V3/4
 PIR SP 2124 -X E5 BKN 3/4VS-BS 3218G24/024/VSBY 1/2V1
 PIR SA 2052 W2 X 1/2VS-BS 300/-8/-18/3120G25/024/VSBY 1/4V3/4 107
 PIR SA 1950 W2 X 1/2VS-BS 299/-8/-18/3019G25/024/VSBY 1/4V3/4
 PIR RS 1657 -X E5 OVC 3/4VS-BS 316/-12/-22/3118/030 VSBY 1/2V1
BINOVC N S6
 PIR SP 1619 -XE5 BKN 3S- 3214/030/VSBY S-W 1/2 S5
 PIR RS 1556 W10 X 3/16S-BS 319/-15/-25/2812/030
 PIR RS COR 1453 W5 X 3/16S-BS 311/-15/-26/2713/028/ 208
 PIR RS 1453 W5 X 3/16S-BS 311/-15/-26/2713/028/ 208
 PIR RS 1453 25 X 3/16S-BS 311/-15/-26/2713/028/ 208
 PIR RS 1351 W5 X 1/2S-BS 310/-16/-27/2613/027
 PIR SP 1302 W20 X 1/2S-BS 2811/026
 PIR SA 1155 CLR 8IC 303/-16/-26/2504/025/ 80704 81 90405 20015
 PIR SA 0654 30 SCT 8IC 314/-15/-25/2304/029/SE02ICB10
 PIR SA 0549 80 SCT 250-BKN 3S- 320/-11/-22/0704/031/SC O/RIVER W
/ 50000 94 90405 49487 20012
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Table 1. Observations at Pierre SD

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...
ABR 212222 CLR 3115. 00Z CLR 3110. 07Z 250 SCT. 16Z VFR NO CIG..
ATY 212222 CLR 2810. 00Z CLR. 09Z 250 SCT. 16Z VFR NO CIG..
FSD 212222 250 SCT 5F 3010 CHC -X 3F. 00Z 250 SCT. 16Z VFR NO CIG..
HON 212222 CLR 2810. 00Z CLR. 08Z 250 SCT. 16Z VFR NO CIG..
PIR FT


PIR FT AMD 1 220022 0019Z C4 X 1/2S-BS 2920G30.  02Z C10 OVC 1S- 3012
    OCNL 10 SCT 5S-.  04Z 250 SCT.  14Z CLR 3110 CHC C2 X 1/2S-.
    16Z VFR..
RAP 212222 CLR 3315 CHC -X 3BS. 03Z 250 SCT. 16Z VFR NO CIG..
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MKCFA3W
FAUS6 KCHI 220040
CHIC FA 220040
SGFNT CLDS AND WX VALID UNTIL 221300...OTLK 221300-221900Z.

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ND SD
NO CLDS BLO 120. OCNL VSBYS 3-5BS WITH LCL VSBYS BLO 3IF AFT 09Z.
OTLK...VFR.
.



MKCFA3H
FAUS6 KCHI 220040
CHIH FA 220040
HAZARDS VALID UNTIL 221300
ND SD NE KS MN IA MO LS WI LM IL MI LH IN KY
.
FLT PRCTNS...IFR...NE KS MO LS WI LM MI LH IL IN KY
          ...ICG...KS IA MO LS WI LM MI LH IL IN KY
          ...MTN OBSCN...KY
.
TSTMS IMPLY SVR OR GTR TURBC SVR ICING AND LLWS.
NON MSL HGTS NOTED BY AGL OR CIG
.
THIS FA ISSUANCE INCORPORATES THE FOLLOWING AIRMETS STILL IN
EFFECT...NONE.
....
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Table 2. Area Forecast (FA),

December 22, 1983