NOAA Technical Memorandum
NWS WR-268

Prediction of Heavy Snow Events in the Snake River Plain Using Pattern Recognition and Regression Techniques

Thomas Andretta and William Wojcik
National Weather Service Office
Pocatello, Idaho

October 2003

ABSTRACT

This study examines the heavy snow climatology of the Snake River Plain of eastern Idaho. Heavy snow is defined as 6 inches or more of snowfall in a 24 hour period. This climatology is based on synoptic patterns collected from National Weather Service (NWS) climate observing stations available from the National Climatic Data Center (NCDC) archives covering the historical period from 1949 to 1997. Identification of two synoptic-scale patterns conducive to heavy snow are examined for the region of study. The manuscript uses analog and multiple linear regression techniques to derive equations to estimate mean snowfall amounts for the Snake River Plain which includes these subregions: Upper Snake River Plain, Lower Snake River Plain, and eastern Magic Valley. Based on the patterns, the snowfall equations are expanded as a function of longitude, latitude, and elevation. Finally, a heavy snow event that occurred on 15 April 2002 is selected to test the accuracy of the regression equations.

1. Introduction

Forecasting heavy snow in the valleys of the western United States remains one of the most rewarding challenges for operational meteorologists. While there is an abundance of research on forecasting spatial distributions of snow in the eastern and central United States, the use of circulation patterns and other synoptic indicators in the Northwest United States remains problematic (Terry 1992). However, magic charts (Chaston 1989) describing overlapping regions of strong vertical motion and cold 700 mb temperatures, Q vector convergence of deep layer relative humidity (Mathewson 2000), and favorable upper-level jet streak locations (Blank 1989) were tools developed by some forecasters to predict spatial distributions of heavy snow. Richmond (1992) examined the synoptic signatures conducive to heavy snowfall in Missoula, MT based on a 10 storm climatology. A similar technique was employed by Tardy (2002) for forecasting heavy snow amounts in the Sierra, Nevada region. In this study, both analog charts and regression techniques will be used as climatological indicators to predict heavy snow in the Snake River Plain of eastern Idaho.

a. Topography

Fig. 1a shows a map of the Northwest United States with the region of study (red inset region). City identifiers and points of reference in Idaho and surrounding states highlighted in this study are indicated in Figs. 1b and 1d. Contrasting with the width of the Snake River Plain (~ 100 km) (all heights MSL), the elevation of the plain rises gently in a leftward curving arc in a southwest to northeast orientation from roughly 1200 m in the eastern Magic Valley to 1600 m in the Upper Snake River Plain. The arc terminates in the shape of a fish hook at the Upper Snake River Plain (Figs. 1c, 1d). West of the “fish hook”, the central mountain valleys drain onto an expansive desert (Arco Desert) which varies in elevation from 1500 to 1900 m. The Snake River Plain is bounded by raised topography to the south and east ranging in elevation between 1700 and 2000 m.

b. Climatology and Methods

From a climatological standpoint, the periodic topographic intersection of channeled northwest flow from the central mountain valleys and downslope low-level northeast flow in the Upper Snake River Plain with upslope low-level southwesterly winds in the Lower Snake River Plain is conducive to localized boundary layer convergence, leading to short duration snow events (~ 6 to 10 hrs) during the late fall and winter months (Andretta and Hazen 1998; Andretta 2003). On the other hand, major low pressure systems contribute to more longer-lived (~ 12 to 24 hrs) snowstorms over the valleys of eastern Idaho when cold frontal passages and Pacific cyclogenesis peak harmonically (Andretta 1999). This study examines the synoptic patterns that produce heavy snow (defined as 6 inches or more of snow in a 24 hour period) and derives equations to predict the mean snowfall amounts for the Snake River Plain using synoptic pattern matches and multiple linear regression techniques. These methodologies are applied to a heavy snow event that occurred on 15 April 2002.

c. Case Study

The 15 April 2002 snowstorm is selected in this study for several reasons. It ranks as the 8th greatest 24 hour snowfall ever recorded at the Pocatello WSO Airport and the 3rd greatest April snowfall ever measured for the station. In addition, the snowfall was also very persistent (~ 9 to 12 hrs) over a large area with accumulations over the entire Snake River Plain of at least 6 inches, peaking at 10 to 16 inches (~ 30% of the annual total snowfall normals) at some locations in the Upper Snake River Plain. From a forecasting perspective, the model grids performed very poorly in the prediction of snowfall amounts in the Snake River Plain. The high resolution MESO ETA model run cycles initialized at 0000 UTC and 1200 UTC 15 April 2002 underestimated the rapid deepening of the surface low over northern Utah by 5 to 7 mb in the late morning hours of the event and did not indicate the cold air advection in the lowest 1500 ft in the forecast soundings.

2. Methodology

Table 1 lists the 19 National Weather Service (NWS) climate stations including their geographical locations used in this study. A Visual Basic program collected the NWS climate record snowfall amounts (historical records from 1899 to 2001 for all stations) and extracted only those snow events (1949 to 1997) that amounted to 6 inches or more. Tables 2a and 2b list these 28 heavy snow events with the individual station snow amounts and the average snow amount per episode. Note that the event date is given as the reporting date of the observation and may actually be the day after the heavy snow event occurred. A further examination indicated that the heavy snow was clustered around NWS stations in similar geographical regions. The NWS historical synoptic records (1899 to 1994) on a CD-ROM entitled, Global Historical Fields, were examined to study the weather patterns that produced the heavy snow accumulations on those dates. These synoptic fields were based on radiosonde data for 0000 UTC and 1200 UTC and included: mean sea-level pressure (mb), 700 mb height (m) and temperature (deg C), 500 mb height (m) and temperature (deg C), and 300 mb height (m) and temperature (deg C). Unfortunately, other parameters like wind, vertical velocity, relative humidity, and stability were not available on the CD-ROM for this study. Historical records used in this study covered the period from 1949 to 1997. Finally, a regression formula was run on 16 of the 28 events to check for specific correlated synoptic fields that could produce the heavy snow spatial distributions.

3. Precipitation and Snowfall Climatology

a. Precipitation Climatology

As Figs. 1c and 1d indicate, the average annual precipitation totals (based on 1971 to 2000 NCDC normals) are correlated with terrain height. The Snake River Plain receives approximately 8 to 12 inches of precipitation per year with higher amounts in the mountains surrounding the valley walls (Sagendorf 1996; Andretta 1999). The figures indicate that locally higher valley amounts (~ 12 to 14 inches per year) are situated between Richfield (RIC) and Carey (CAR), near Massacre Rocks State Park (MAS), and near Rexburg Ricks College (RXE) in the eastern part of the Upper Snake River Plain.

b. Snowfall Climatology

Based on the NCDC monthly normals and period of record for each station, the snowfall climatology of the Snake River Plain is characterized by maxima during December and January with a second weaker maximum in February or March for all the NWS stations. Occurrences of snowfall in the plain between June and September are very rare. Annual snowfall totals vary from 15 to 25 inches in the eastern Magic Valley to 20 to 35 inches in the Lower Snake Plain, with a local maximum of 40 inches at Pocatello WSO Airport (PIH). A sharp gradient in total annual snowfall is evident in the Upper Snake River Plain with 35 inches at Idaho Falls FAA Airport (IDA) increasing with elevation to 57 inches at Rexburg Ricks College.

4. Analog Signatures

Fig. 2 displays an example of one synoptic pattern from 1200 UTC 01 December 1982 that produced 6 to 10 inches of snow in the Snake River Plain. An intense surface low (~ 984 mb) (Fig. 2a) was located just east of Salt Lake City, UT with the 500 mb and 300 mb trough axes (Figs. 2c, 2d) negatively tilted back across western Idaho and Oregon. Moreover, Fig. 2b shows a closed 700 mb low center situated over eastern Idaho. This pattern was associated with cold air advection snows in eastern Idaho. By contrast, Fig. 3 illustrates a warm air overrunning pattern from 0000 UTC 29 December 1992 that produced 6 to 10 inches of snow in the region of study. The deep surface low (~ 988 mb) in Fig. 3a was positioned offshore along the coast of Washington and Oregon. The isobaric kink extending eastward from the low center suggested that the warm front was oriented across eastern Idaho with the Snake Plain in the warm sector of the storm. The 700 mb trough in Fig. 3b was situated off the Washington coast. The mid and upper-level trough patterns (Figs. 3c, 3d) were stacked up near the surface low position with southwest flow aloft over eastern Idaho. Table 2a and Table 2b summarize the snow events that were associated with these two synoptic patterns. The key indicators for the pattern types are listed below:

a. Type COLD Pattern (18 cases)

1) Closed surface low (~ 985 to 1000 mb) over northeast Nevada, northern Utah, southwest Wyoming, or west-central Colorado
2) Surface cold front over central and southern Utah (Snake River Plain in cold sector)

3) 700 mb (~ 0 to -6 deg C) (usually) closed low center over eastern Idaho
4) 500 mb negatively or neutrally tilted phased trough (~ -25 to -35 deg C) over western Idaho and Oregon
5) 300 mb negatively or neutrally tilted phased trough over western Idaho and Oregon

b. Type WARM Pattern (10 cases)

1) Closed surface low (~ 990 to 1005 mb) off the coast of Washington and Oregon (low may be elongated and extending inland)
2) Surface warm front over eastern Idaho (Snake River Plain in warm sector)
3) 700 mb (~ -10 to -15 deg C) (usually) closed low center off coast of Washington and Oregon
4) 500 mb neutrally or positively tilted phased trough axis near 700 mb trough position
5) 300 mb neutrally or positively tilted phased trough axis near 700 mb trough position

c. Type Frequency

As indicated in Tables 2a and 2b, the Type COLD pattern occurred most (18 / 28 = 64%) of the time. Since the heavy snow climatology covered the period from 1949 to 1997, an operational meteorologist could expect the Type COLD pattern, 18 cases / 48 years = 1 event every 2.7 years and the Type WARM pattern, 10 cases / 48 years = 1 event every 4.8 years. Thus, both patterns occurred 28 times / 48 years or 1 pattern every 1.7 years. The frequency of the COLD / WARM events for the three subregions were: Upper Snake River Plain (13 / 7), Lower Snake River Plain (16 / 9), and eastern Magic Valley (11 / 8).

5. Multiple Linear Regression Technique

Using a multiple variable linear regression algorithm, it was possible to correlate certain synoptic fields that were prerequisites for heavy snow events in the Snake River Plain. Events from 1949 to 1962 were excluded from this study because of fragmentary radiosonde data and related synoptic fields. Accordingly, applying forward regression techniques to 16 out of the 28 cases, the following linear regression model was deduced (Wilks 1995):

a. General Equations

Type COLD and WARM patterns (16 cases):
M ~ 7.36 + 0.03 MSLP (X) - 0.07 T H7 (BOI) + 0.04 T H7 (RKS) - 0.01 H H5 (Y) (1)

Type COLD pattern (10 cases):
M ~ 10.58 + 0.12 MSLP (X) + 0.69 T H7 (BOI) - 0.49 T H7 (RKS) - 0.07 H H5 (Y) (2)

Type WARM pattern (6 cases):
M ~ 13.60 + 0.04 MSLP (X) + 0.05 T H7 (BOI) + 0.49 T H7 (RKS) + 0.04 H H5 (Y) (3)

where:
M = Mean Snow Amount (inches)
MSLP = Mean sea-level pressure (mb)
T = Temperature (degrees Centigrade)
H = Height (m)
H7 = 700 mb level
H5 = 500 mb level
X = [SLC (Salt Lake City, UT) - LLJ (Challis, ID)] +
[EKO (Elko, NV) - WEY (West Yellowstone, WY)]
Y = [BOI (Boise, ID) - RKS (Rock Springs, WY)]

Please see Fig. 1b for the locations of the key stations used in these regression equations.

b. Regional Equations

Grouping the 16 cases into the regions of study (for both Type WARM and COLD patterns) yielded these equations:

For the Upper Snake River Plain (8 cases):
M ~ 6.52 + 0.04 MSLP (X) - 0.18 T H7 (BOI) + 0.02 T H7 (RKS) + 0.01 H H5 (Y) (4)

For the Lower Snake River Plain (9 cases):
M ~ 7.16 + 0.03 MSLP (X) - 0.17 T H7 (BOI) + 0.12 T H7 (RKS) + 0.01 H H5 (Y) (5)

For the eastern Magic Valley (including the Lower Snake River Plain) (9 cases):
M ~ 8.34 + 0.06 MSLP (X) - 0.16 T H7 (BOI) + 0.18 T H7 (RKS) + 0.01 H H5 (Y) (6)

where:
M = Mean Snow Amount (inches)
MSLP = Mean sea-level pressure (mb)
T = Temperature (degrees Centigrade)
H = Height (m)
H7 = 700 mb level
H5 = 500 mb level
X = [SLC (Salt Lake City, UT) - LLJ (Challis, ID)] +
[EKO (Elko, NV) - WEY (West Yellowstone, WY)]
Y = [BOI (Boise, ID) - RKS (Rock Springs, WY)]

Please see Fig. 1b for the locations of the key stations used in these regression equations.

c. Station Equations

A further examination of the heavy snow amounts for the Type COLD and Type WARM patterns yielded these equations for the individual NWS climate stations as a function of longitude, latitude, and elevation:

For the Type COLD case (36 cases):
S(L1, L2, Z) ~ 151.43 - 55.62 cos(L1 + 180) - 173.01 sin(L2) - 0.001 Z +
0.04 MSLP (X) - 0.04 T H7 (BOI) + 0.02 T H7 (RKS) - 0.03 H H5 (Y) (7)

For the Type WARM case (22 cases):
S(L1, L2, Z) ~ -73.92 + 101.54 cos(L1 + 180) + 68.07 sin(L2) - 0.001 Z -
0.10 MSLP (X) - 0.52 T H7 (BOI) + 0.49 T H7 (RKS) + 0.03 H H5 (Y) (8)

where:
S = Snow Amount (inches)
L1 = Longitude (decimal degrees) of NWS station
L2 = Latitude (decimal degrees) of NWS station
Z = Elevation (feet MSL) of NWS station
MSLP = Mean sea-level pressure (mb)
T = Temperature (degrees Centigrade)
H = Height (m)
H7 = 700 mb level
H5 = 500 mb level
X = [SLC (Salt Lake City, UT) - LLJ (Challis, ID)] +

[EKO (Elko, NV) - WEY (West Yellowstone, WY)]
Y = [BOI (Boise, ID) - RKS (Rock Springs, WY)]

Please see Fig. 1b for the locations of the key stations used in these regression equations.

d. Statistical Correlation

Please see Table 3 for a summary of the correlated variables used in the regression output. Table 4 lists the pertinent output variables for each of the regression equations including degrees of freedom, correlation coefficient, and standard deviation for the predictand snow amounts (Wilks 1995). One noteworthy fact evident in Table 4 is that while the overall correlation score was weak ($r = 0.23$) for the variables in all 16 cases, the best correlation occurred in equations (2) and (3) for each of the pattern types ($r > 0.70$). Excluding (5), when the pattern types were resolved by geographical region and NWS station location, the correlation coefficients were moderate to strong ($r > 0.50$).

6. Case Study: 15 April 2002

a. Synoptic Analysis

The FNL (final) model data is a product of the Global Data Assimilation System (GDAS), which uses the Global spectral Medium Range Forecast model (MRF) to assimilate multiple sources of measured data and forecast meteorology. The FNL model data used in this study was collected from the National Oceanic and Atmospheric Administration (NOAA) Idaho National Engineering and Environmental Laboratory (INEEL) daily repository. As Fig. 4a indicates, an intense 990 mb surface low developed near Salt Lake City, UT (SLC) at 1800 UTC 15 April 2002. The 700 mb pattern was deep with the low pressure center over the Snake Plain with temperatures in the -10 to +6 deg C band from Boise, ID (BOI) to Rock Springs, WY (RKS) (Fig. 4b). The upper-level charts (Figs. 4c, 4d) show the 500 and 300 mb troughs aligned over eastern Washington and eastern Oregon during the afternoon hours. These factors suggested the synoptic evolution of a Type COLD pattern heavy snow event for the Snake River Plain.

b. Mesoscale Analysis

Both the Boise, ID (BOI) (Fig. 5a) and Salt Lake City, UT (SLC) (Fig. 5b) observed soundings for 1200 UTC 15 April 2002 indicated a deep layer of moisture from 600 to 300 mb. At 1800 UTC, the regional (Fig. 6a) and mesonet (Fig. 6b) charts indicated a warm front extending from a 986 mb surface low over northern Utah with temperatures of 70 to 75 deg F near SLC; temperatures north of the frontal boundary were between 30 and 38 deg F over the Lower Snake River Plain. A 998 mb surface low was located over central Idaho with a tight isobaric gradient and southwest flow in the Snake River Plain. The surface observations indicated snow falling at the Pocatello WSO Airport (PIH) and Idaho Falls FAA Airport (IDA) as the warm air from northern Utah was advected northward and climbed over the colder air in place over eastern Idaho. The NOAA Air Resources Laboratory/Field Research Division (ARL/FRD) mesonet profiler (located about 10 km northwest of Big Southern Butte (BIG); elevation ~ 5200 ft MSL) showed temperature decreasing with height from the surface to 1200 ft AGL (Fig. 6c). The KSFX WSR-88D composite reflectivity chart (Fig. 6d) indicated a large field of 20 to 35 dBZ over the Snake River Plain with localized 40 to 45 dBZ returns just north of the radar tower and extending to PIH.

By 2100 UTC, the 985 mb surface low over SLC had extended northeast to near RKS with widespread snow at most observation stations in the Snake River Plain (Figs. 7a, 7b). The ARL/FRD profiler in Fig. 7c indicated a cooling of 4 to 5 deg F from the surface up to 1000 ft AGL from 1800 to 2100 UTC. A rapid decrease of temperatures with height above 1700 ft AGL was evident, possibly indicative of the 700 mb trough passage (Fig. 4b) and eastern Idaho located in the cold sector of the deepening surface low. There was little change to the radar echo morphology and intensity (Fig. 7d).

Later that afternoon, at 0000 UTC 16 April 2002, the surface low center (985 mb) had moved very slowly to near RKS as snowfall persisted in the Snake River Plain (Figs. 8a, 8b). The NOAA ARL/FRD mesonet profiler indicated a temperature lapse rate of -9 deg F / 3500 ft with marked cooling above 2500 ft AGL versus 3 hours earlier (Fig. 8c). Cyclogenesis persisted over western Wyoming border but the radar echoes had weakened over the Snake Plain as dry air advection developed in the eastern Magic Valley (Figs. 8b, 8d). The steady snow caused by the synoptic-scale forcing tapered off by 0400 UTC 16 April 2002.

c. Cross Sectional Analysis

The BUFKIT (Mahoney et al 1998) hourly data from the ETA model provided supplementary information regarding the heavy snowfall that occurred in the Snake River Plain. Figs. 9a and 9b illustrate the 24 hour time cross sections for vertical velocity (solid lines) and relative humidity (shaded regions) above 85% starting at 1200 UTC 15 April 2002 for IDA and PIH, respectively. There was a deep layer of moisture from the surface to about 600 mb in both time series. Note the +15 to +20 ubar sec -1 vertical motion fields centered between 600 and 500 mb from 1700 UTC 15 April 2002 to 0300 UTC 16 April 2002 in both instances.

d. Regression Analysis

The regression equations were used to estimate mean snowfall amounts for the different regions of the Snake River Plain. Accordingly, substituting the various parameters from the 1800 UTC 15 April 2002 FNL forecast (Figs. 4a, 4b, and 4c) and applying (2), (4), (5), (6), and (7) yielded the following results:

MSLP (X) = -9.0 mb
T H7 (BOI) = -10.0 deg C
T H7 (RKS) = +6.0 deg C
H H5 (Y) = -150 m

For the Type COLD pattern:
M ~ 10.58 + 0.12 MSLP (X) + 0.69 T H7 (BOI) - 0.49 T H7 (RKS) - 0.07 H H5 (Y) (2)
M ~ 10.58 - 1.08 - 6.90 - 2.94 + 10.50 ~ 10.2 inches

For the Upper Snake River Plain:
M ~ 6.52 + 0.04 MSLP (X) - 0.18 T H7 (BOI) + 0.02 T H7 (RKS) + 0.01 H H5 (Y) (4)
M ~ 6.52 - 0.36 + 1.80 + 0.12 - 1.50 ~ 6.6 inches

For the Lower Snake River Plain:
M ~ 7.16 + 0.03 MSLP (X) - 0.17 T H7 (BOI) + 0.12 T H7 (RKS) + 0.01 H H5 (Y) (5)
M ~ 7.16 - 0.27 + 1.70 + 0.72 - 1.50 ~ 7.8 inches

For the eastern Magic Valley (including the Lower Snake River Plain)
M ~ 8.34 + 0.06 MSLP (X) - 0.16 T H7 (BOI) + 0.18 T H7 (RKS) + 0.01 H H5 (Y) (6)
M ~ 8.34 - 0.54 + 1.60 + 1.08 - 1.50 ~ 9.0 inches

For the Type COLD pattern:

S(L1, L2, Z) ~ 151.43 - 55.62 cos(L1 + 180) - 173.01 sin(L2) - 0.001 Z +
0.04 MSLP (X) - 0.04 T H7 (BOI) + 0.02 T H7 (RKS) - 0.03 H H5 (Y) (7)

Idaho Falls FAA Airport:

S ~ 151.43 - 20.87 - 118.68 - 4.74 - 0.36 + 0.40 + 0.12 + 4.50 ~ 11.8 inches (7)

Pocatello WSO Airport:
S ~ 151.43 - 21.16 - 117.00 - 4.45 - 0.36 + 0.40 + 0.12 + 4.50 ~ 13.5 inches (7)

Burley FAA Airport:
S ~ 151.43 - 22.15 - 116.48 - 4.16 - 0.36 + 0.40 + 0.12 + 4.50 ~ 13.3 inches (7)

The forecast amounts generated from the regression equations agreed favorably with the observations. The mean snowfall over the Snake River Plain for the event was ~ 12.0 inches, closely matching the results in (2). Weather spotters recorded 10 to 16 inches of snow in the Upper Snake River Plain with 8 to 12 inches in the eastern Magic Valley and Lower Snake River Plain. However, approximately 1 to 3 inches of these snowfall totals were associated with a non-synoptic scale low-level convergence zone that formed in the Snake River Plain in the late night hours on 15 April 2002 (Andretta 2003). Note that the snowfall amounts obtained from the station equation in (7) superceded the regional equation estimates.

7. Future Considerations

The authors plan to develop a computer application to assist operational forecasters in predicting heavy snowfall for the Snake River Plain. The regression equations will be applied to high resolutions of the MESO ETA or MM5 model with output generated in a time step dependent tabular format. The output tables may be used to supplement traditional numerical (e.g., FWC, MAV, MET, and MEX) forecast guidance. Hopefully, subsequent winters will afford an opportunity to test the veracity of the WARM regression equations with a case study.

8. Conclusions

The heavy snowfall climatology of the Snake River Plain was explored focusing on analog pattern matches and regression forecasting techniques to derive equations for heavy snow episodes in the Upper Snake River Plain, Lower Snake River Plain, and eastern Magic Valley. This climatology was based on 19 NWS climate stations based on historical records from 1949 to 1997. Two synoptic-scale patterns were identified, Type COLD and Type WARM, which were critical to the development of heavy snowfall in the Snake River Plain.

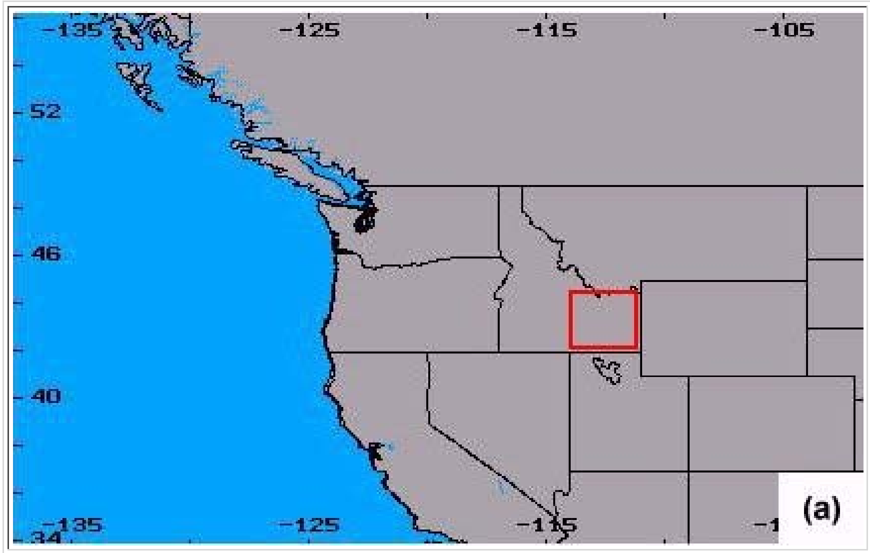
A regression model was developed for the entire Snake River Plain based on 16 out of 28 heavy snow events featuring three sets of snowfall regression equations. The correlation coefficient for all 16 cases was weak ($r = 0.23$). However, the regression equations dependent on pattern type were derived with strong positive correlation coefficients ($r > 0.70$). A second set of equations independent of pattern type were developed for the Upper Snake River Plain, Lower Snake River Plain, and eastern Magic Valley. These equations yielded weak to moderate correlation. A third set of regression equations based on pattern type was derived as a function of longitude, latitude, and elevation for individual NWS stations. These equations yielded moderate to strong correlation ($r > 0.50$). Finally, the techniques were applied to the heavy snow episode on 15 April 2002 with favorable agreement between the regression forecasts and the observations of snowfall.

9. Acknowledgments

The authors would like to thank MIC James Meyer and SOO Dean Hazen for proofreading this paper and proving helpful comments on the scientific content. A sincere appreciation to the NOAA ARL/FRD and INEEL for providing the model and profiler data used in this study.

Figures

Figure: fig1ab.html



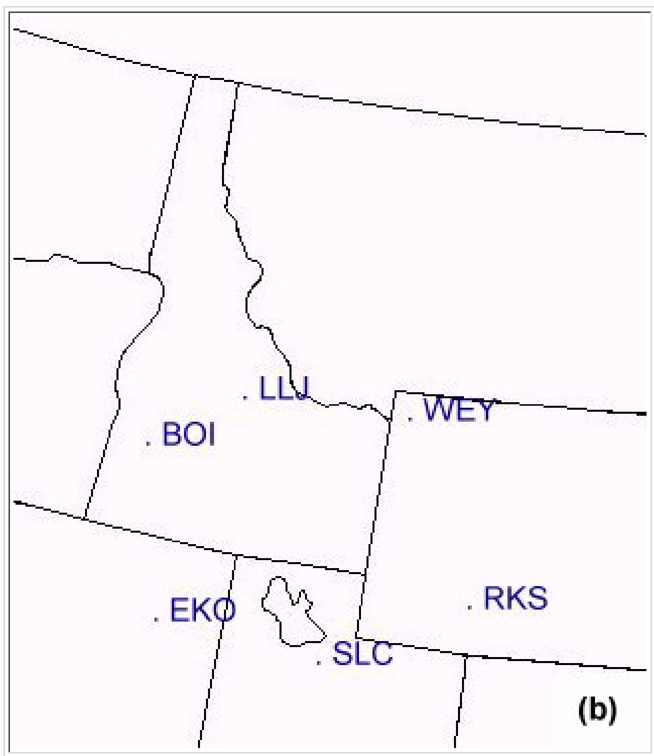


Figure 1: (a) Map of Northwest United States with eastern Idaho (red rectangle)
(b) Map of Idaho with city identifiers and points of reference

Figure: fig1cd.html

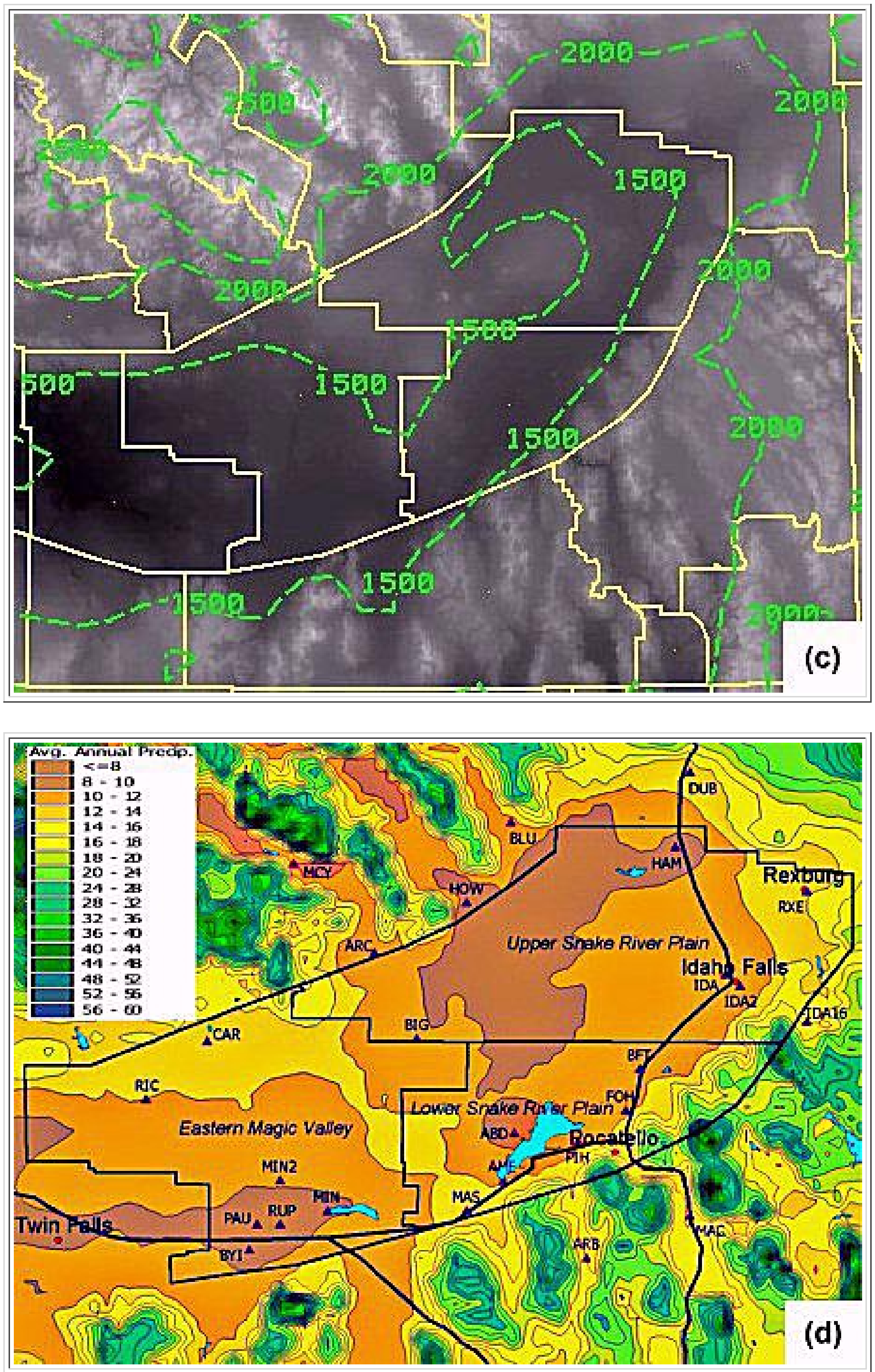


Figure 1: (c) Map of eastern Idaho with regions of study and terrain elevation (m)
(d) Map of eastern Idaho with station identifiers and annual precipitation (in)

Figure: fig2.html

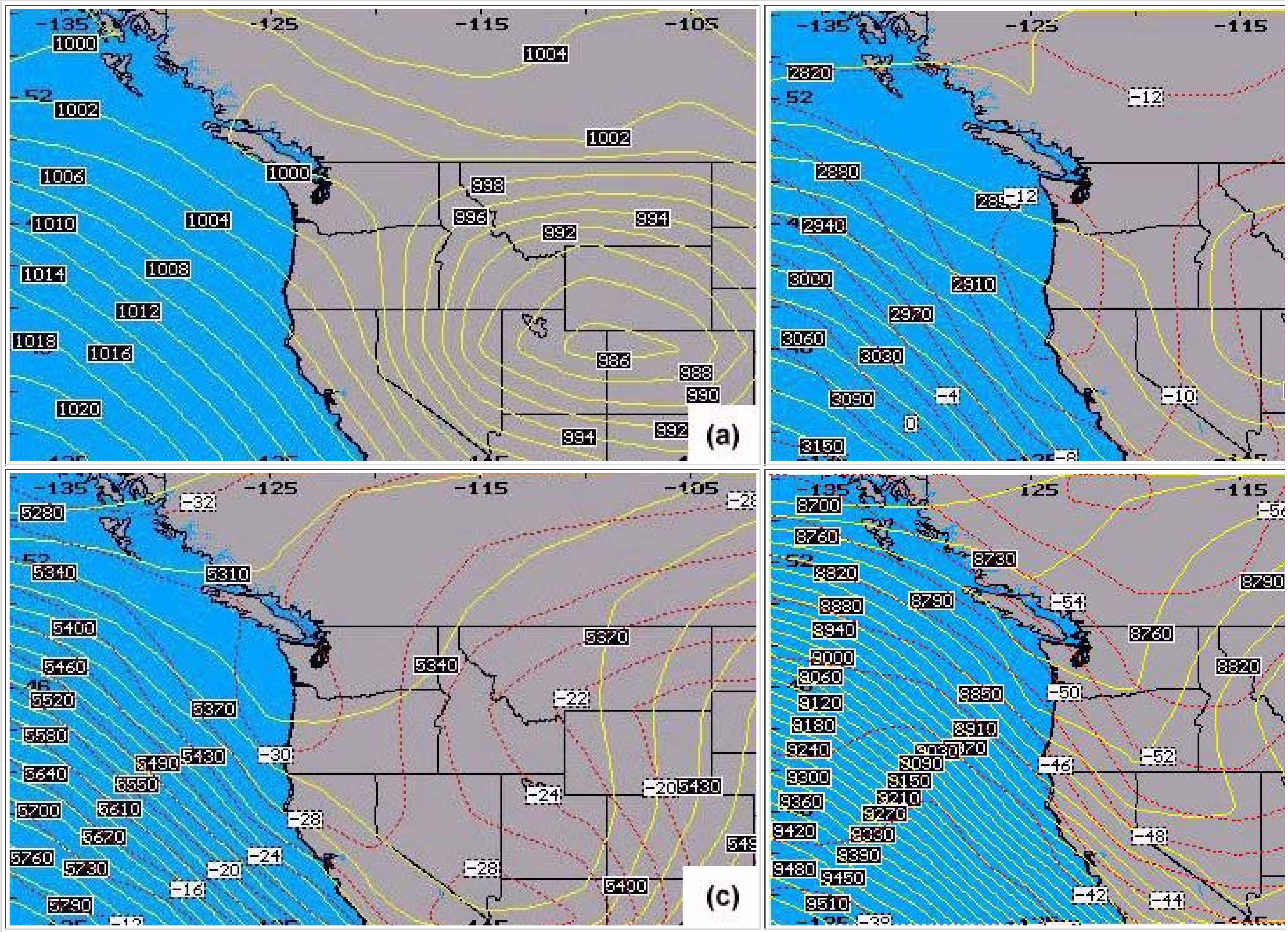


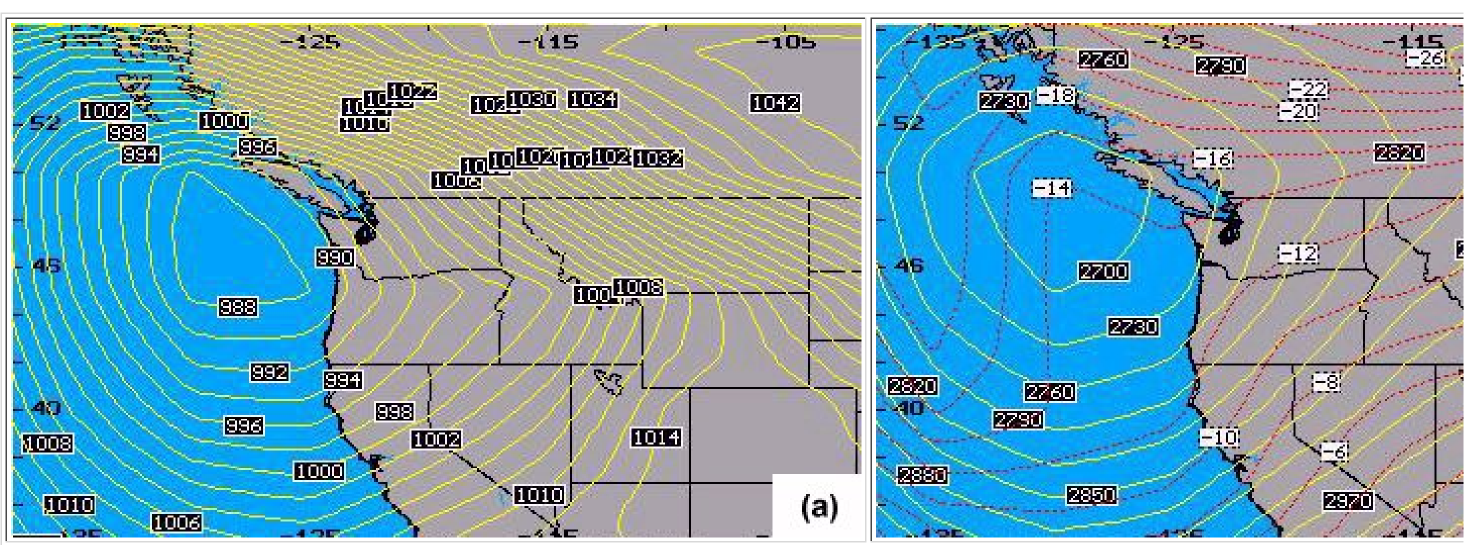
Figure 2: (a) Observed mean sea-level pressure (mb) for 1200 UTC 01 December 1982

(b) Observed 700 mb height (m) and temperature (deg C) for 1200 UTC 01 December 1982

(c) Observed 500 mb height (m) and temperature (deg C) for 1200 UTC 01 December 1982

(d) Observed 300 mb height (m) and temperature (deg C) for 1200 UTC 01 December 1982

Figure: fig3.html



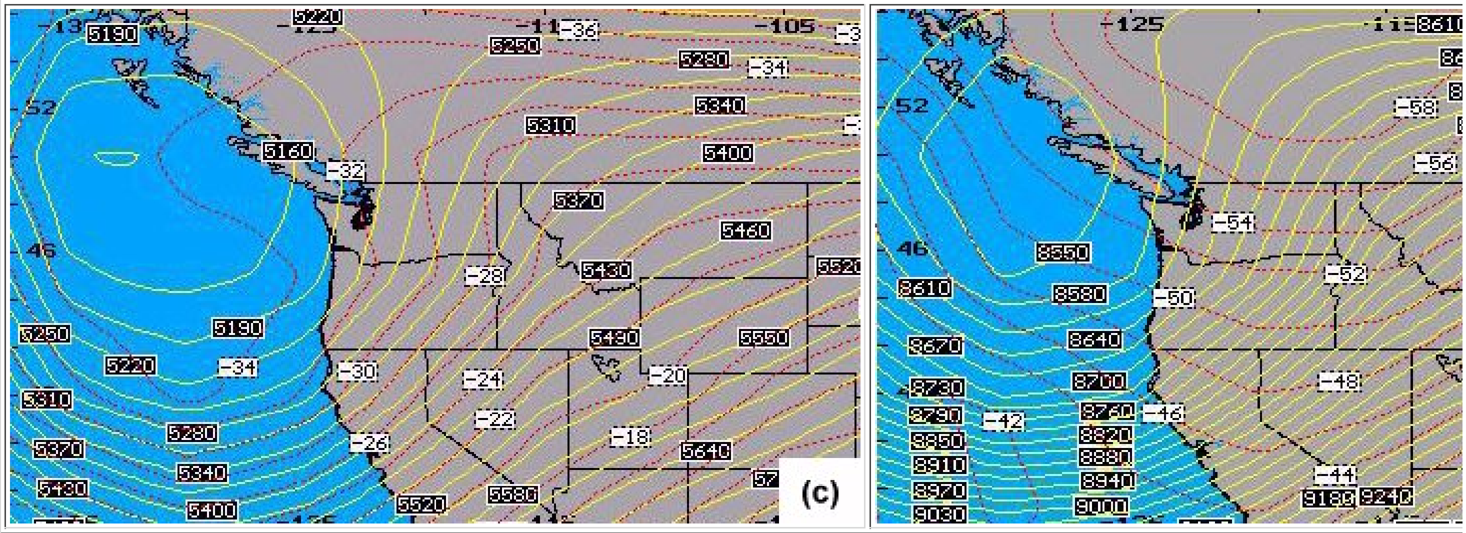


Figure 3: (a) Observed mean sea-level pressure (mb) for 0000 UTC 29 December 1992

(b) Observed 700 mb height (m) and temperature (deg C) for 0000 UTC 29 December 1992

(c) Observed 500 mb height (m) and temperature (deg C) for 0000 UTC 29 December 1992

(d) Observed 300 mb height (m) and temperature (deg C) for 0000 UTC 29 December 1992

Figure: fig4a.html

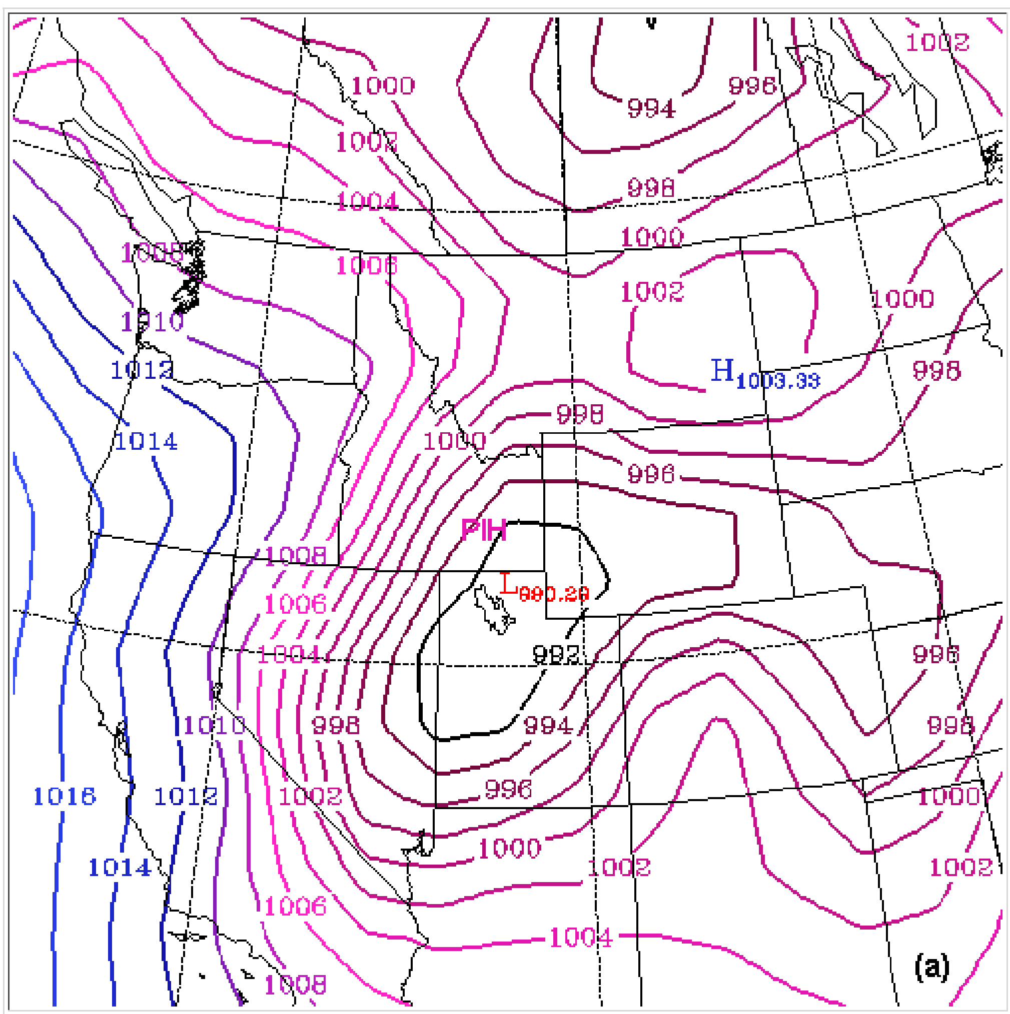


Figure 4: (a) FNL Archive mean sea-level pressure (mb) for 1800 UTC 15 April 2002

Figure: fig4b.html

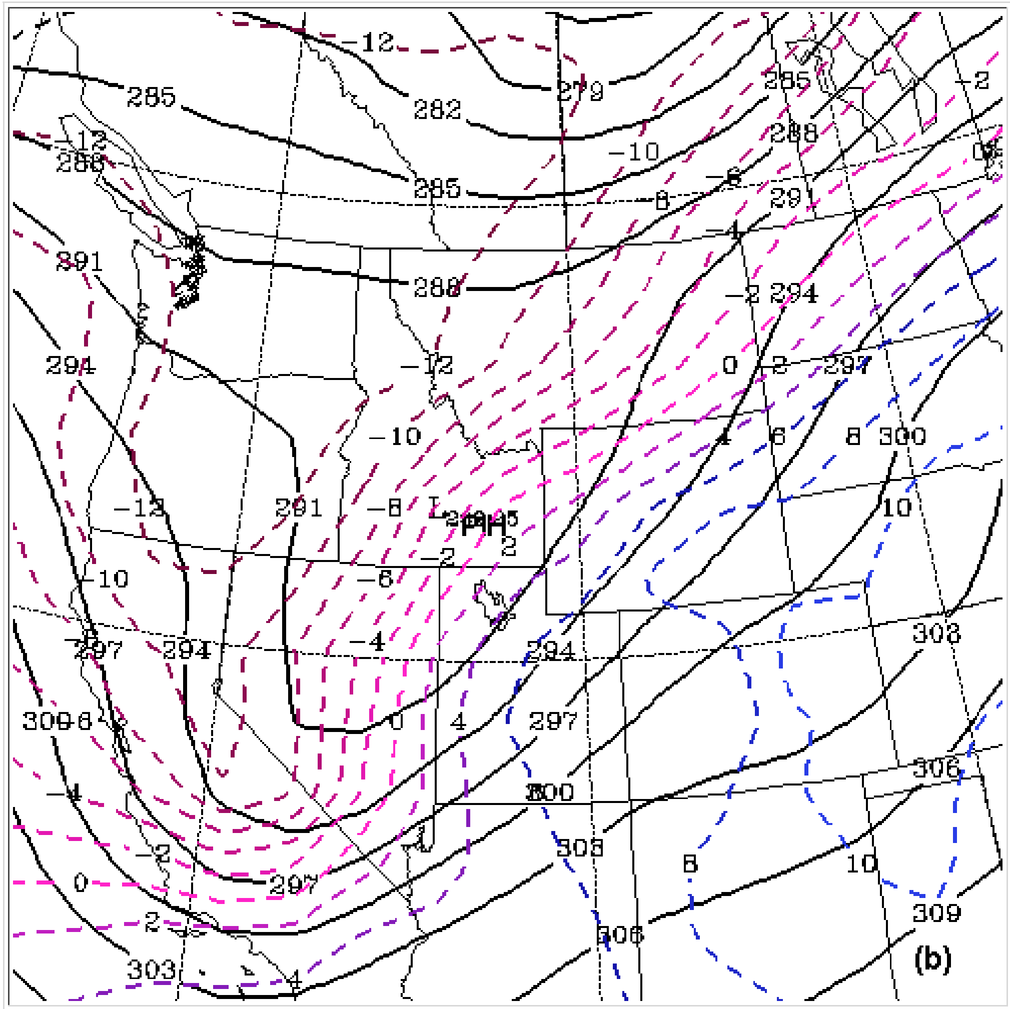


Figure 4: (b) FNL Archive 700 mb height (dm) and temperature (deg C) for 1800 UTC 15 April 2002

Figure: fig4c.html

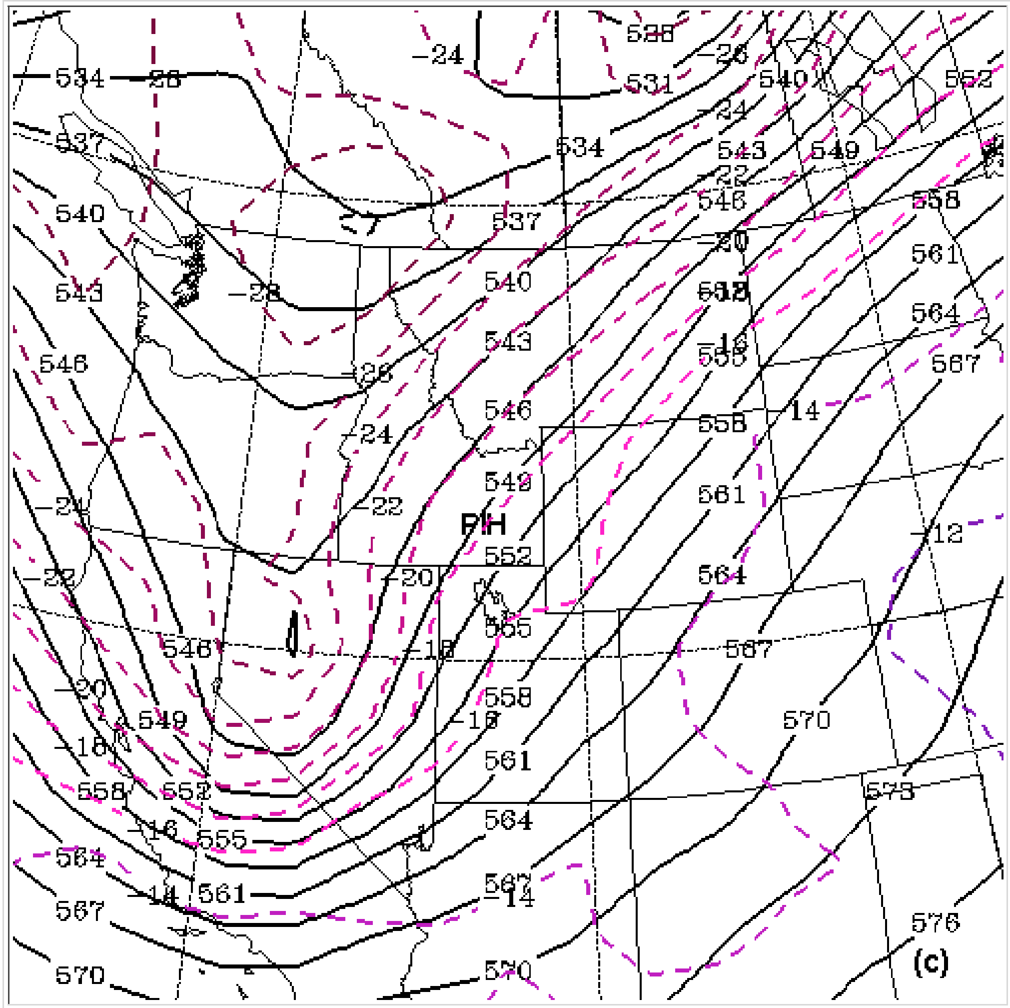


Figure 4: (c) FNL Archive 500 mb height (dm) and temperature (deg C) for 1800 UTC 15 April 2002

Figure: fig4d.html

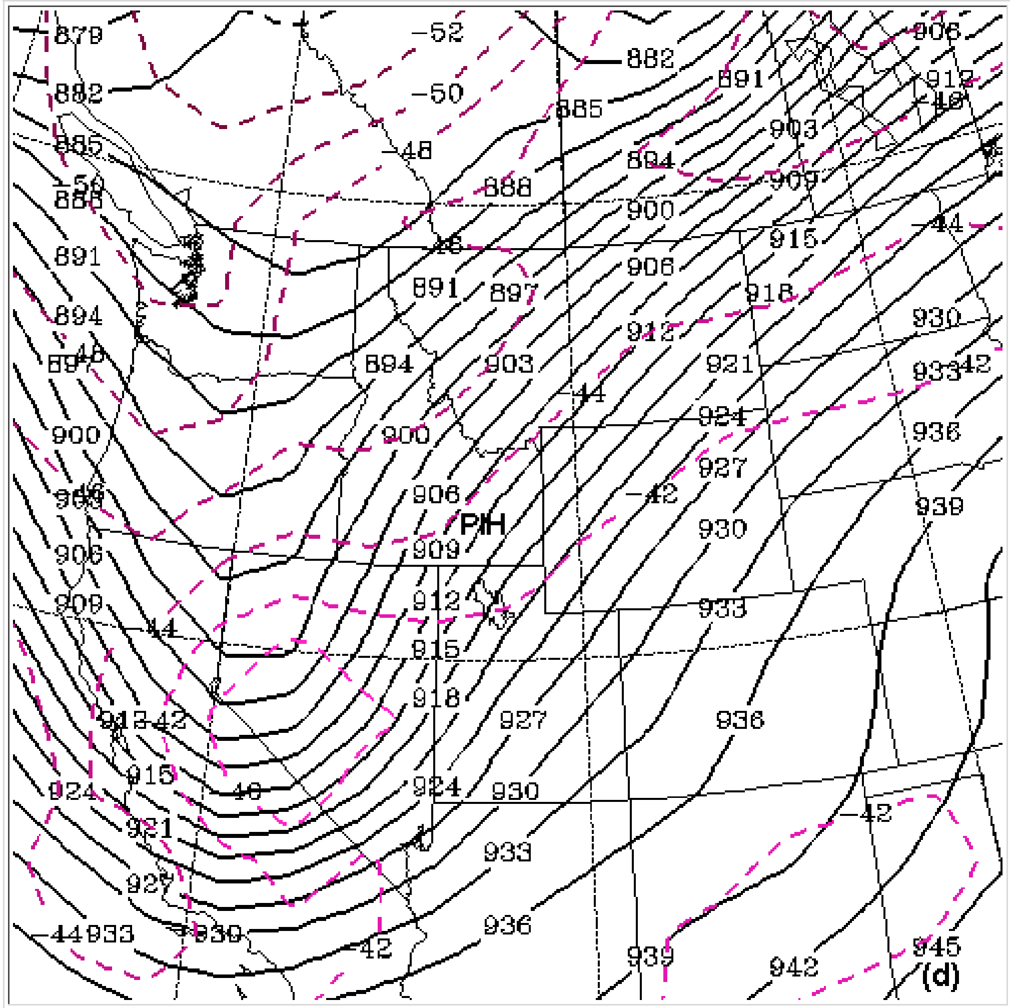


Figure 4: (d) FNL Archive 300 mb height (dm) and temperature (deg C) for 1800 UTC 15 April 2002

Figure: fig5a.html

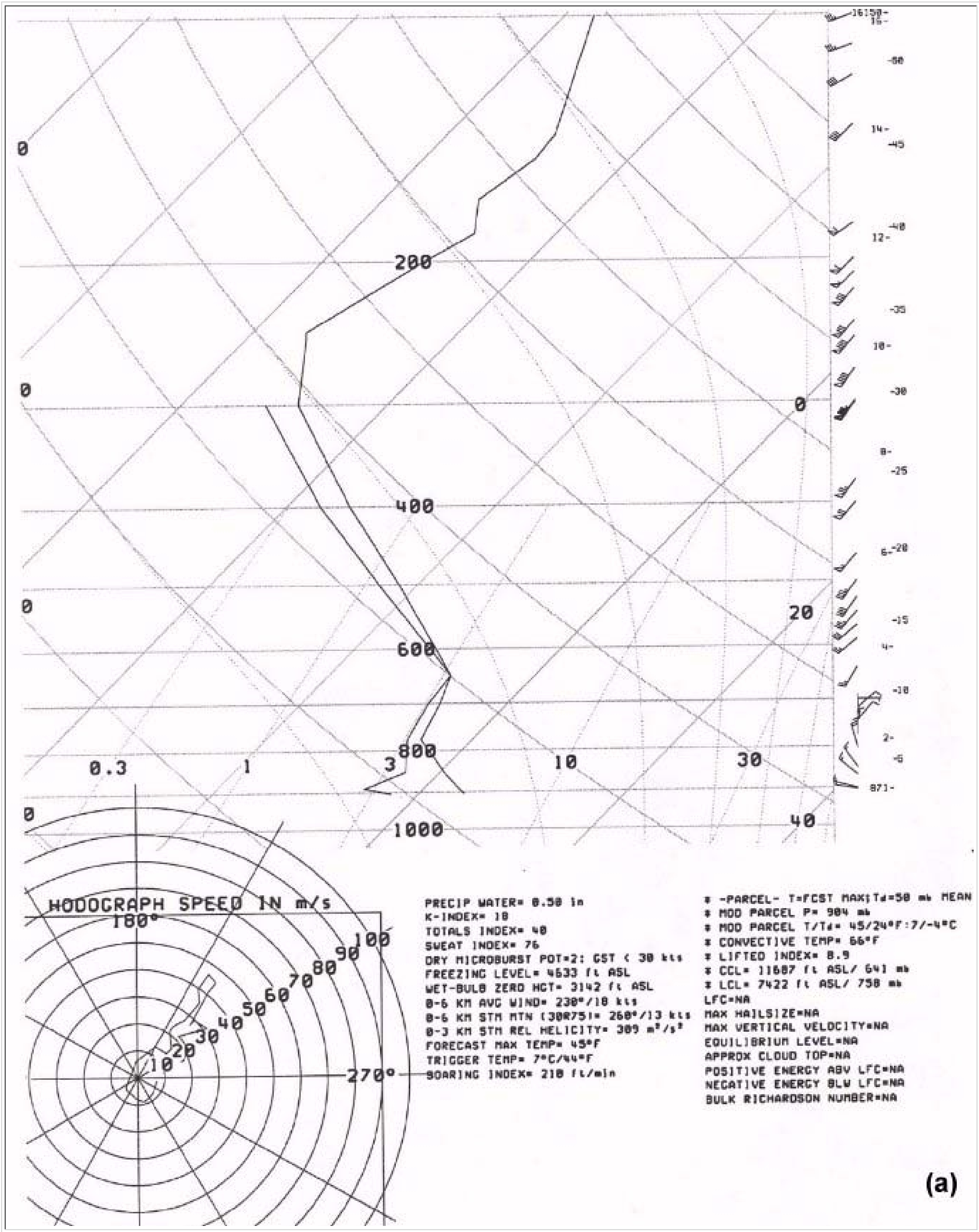


Figure 5: (a) Observed Sounding for Boise, Idaho at 1200 UTC 15 April 2002

Figure: fig6a.html

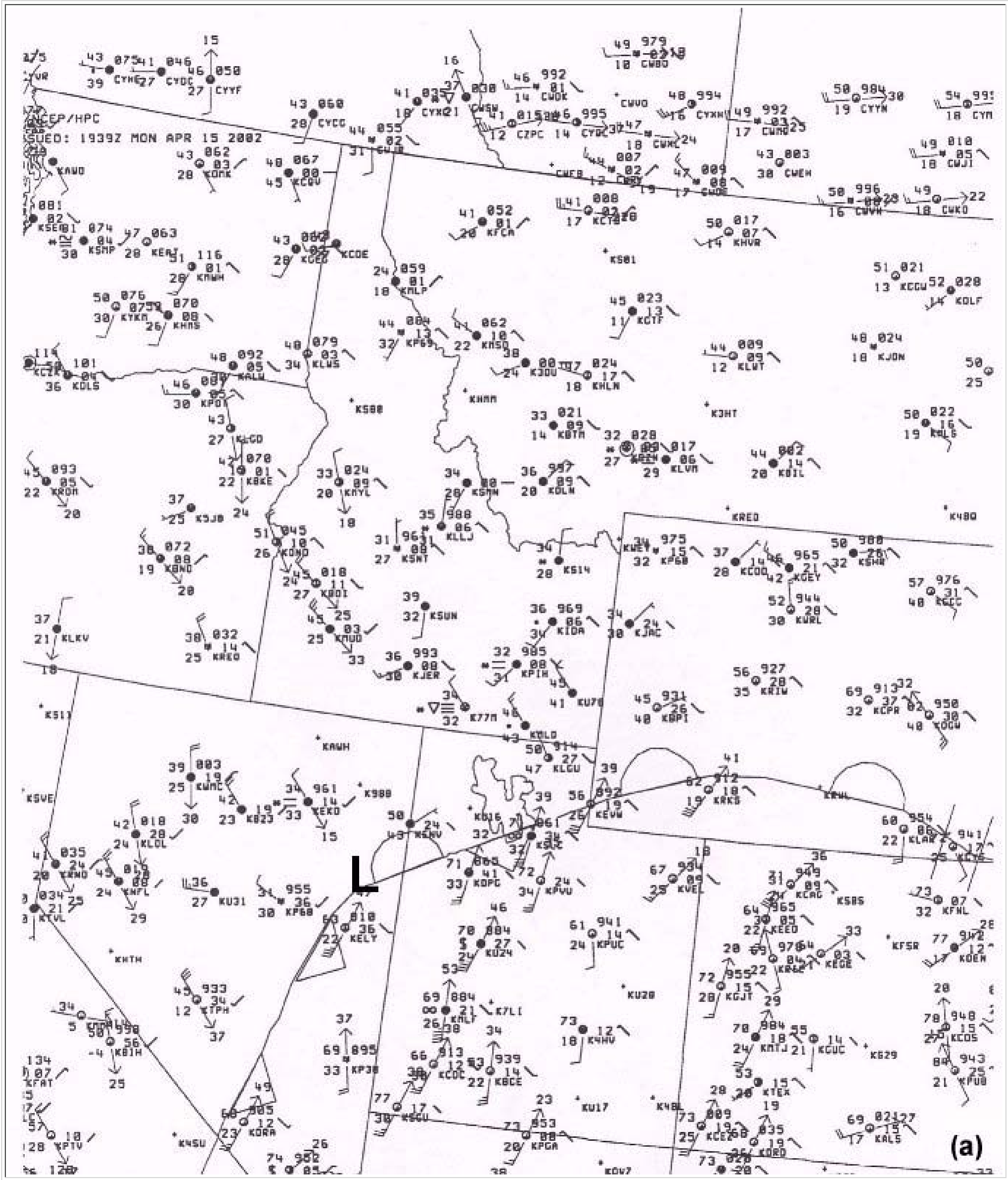


Figure 6: (a) NWS Regional Observations and Surface Fronts at 1800 UTC 15 April 2002

Figure: fig6c.html

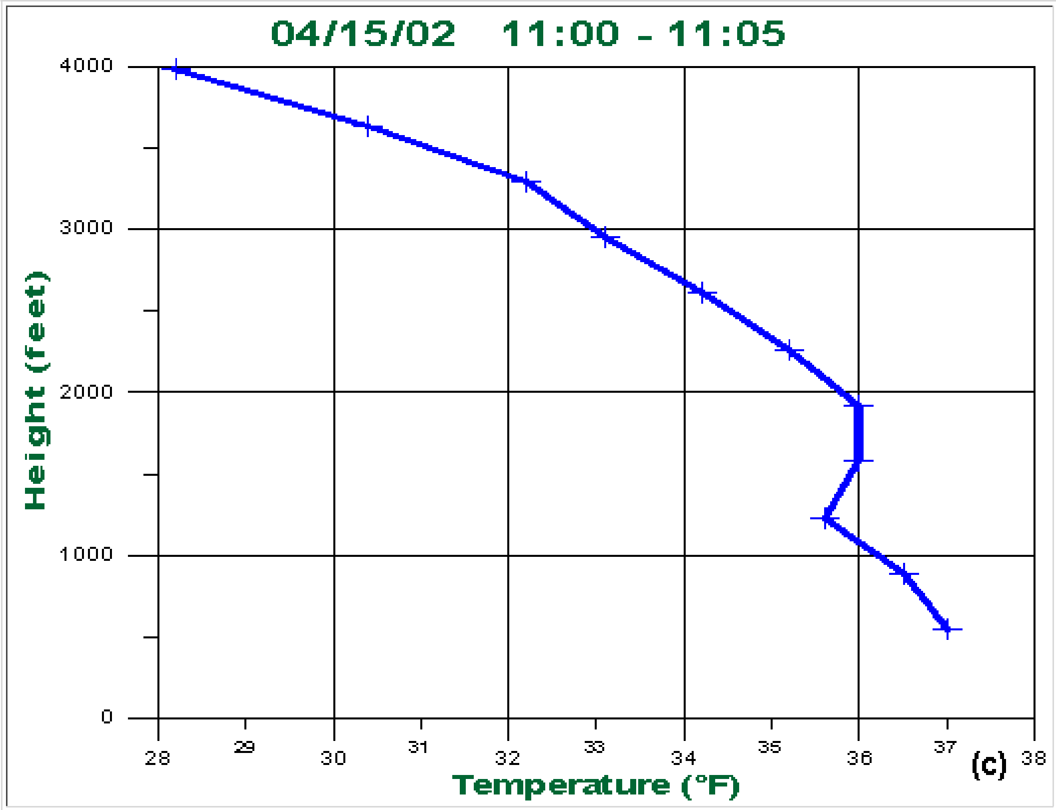


Figure 6: (c) ARL/FRD Temperature Profiler (deg F) from 1800 to 1805 UTC 15 April 2002

Figure: fig6d.html

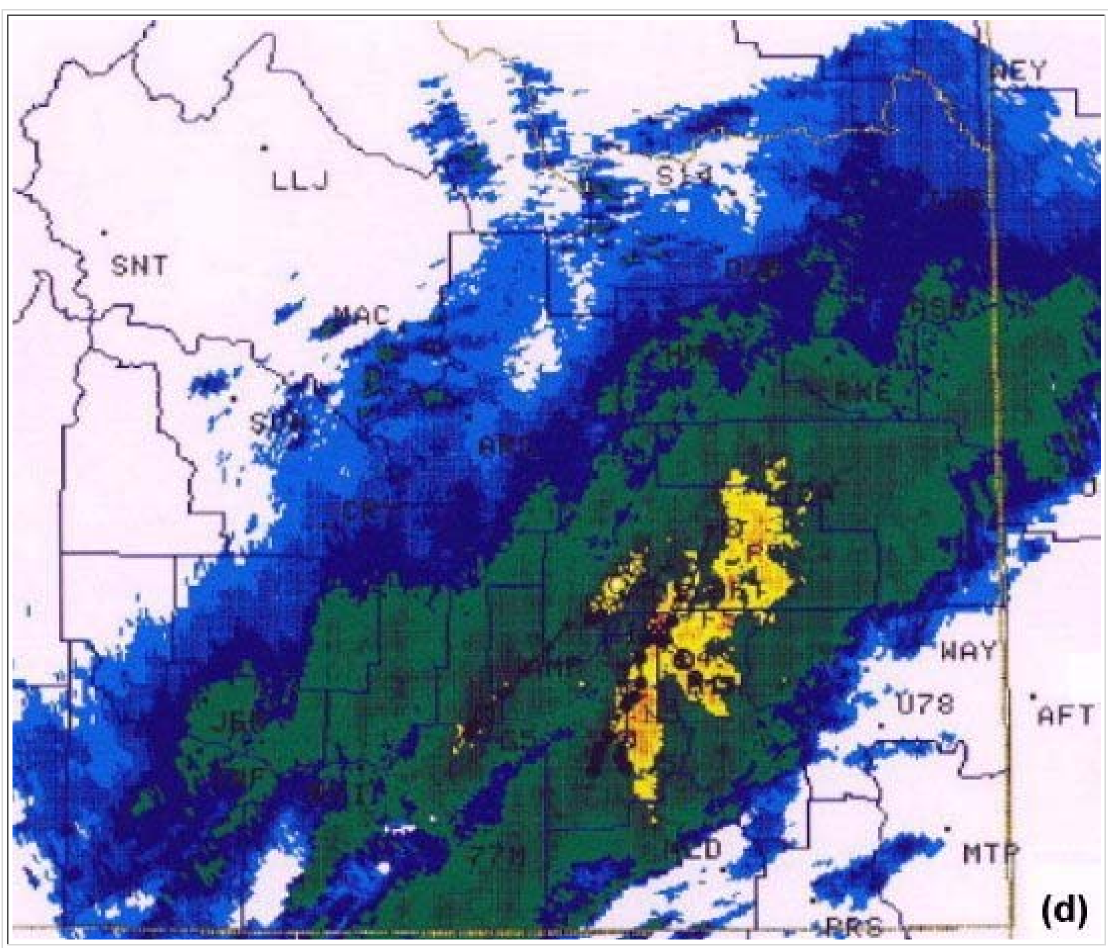


Figure 6: (d) KSFX WSR-88D Composite Reflectivity (dBZ) at 1800 UTC 15 April 2002

Figure: fig7a.html

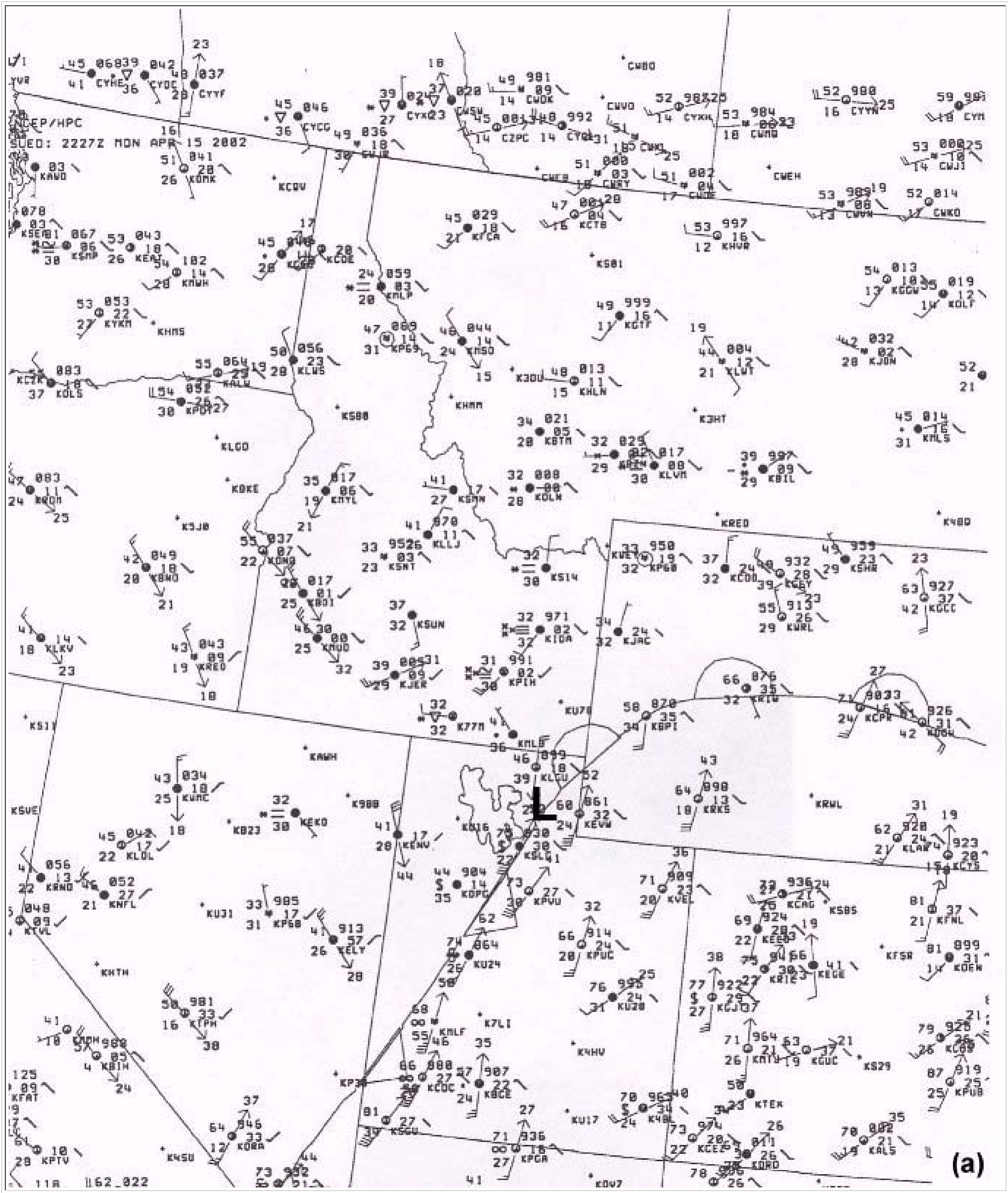


Figure 7: (a) NWS Regional Observations and Surface Fronts at 2100 UTC 15 April 2002

Figure: fig7d.html

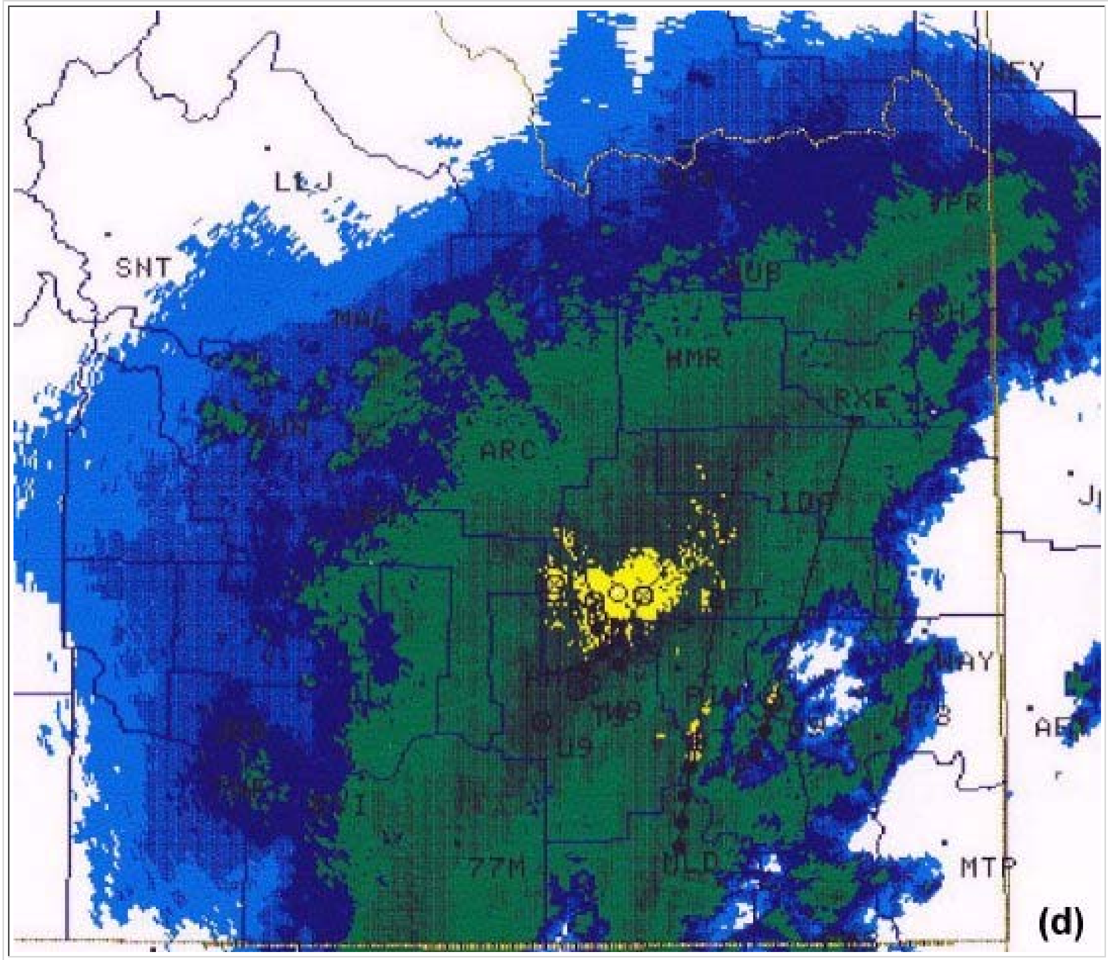


Figure 7: (d) KSFX WSR-88D Composite Reflectivity (dBZ) at 2101 UTC 15 April 2002

Figure: fig8a.html

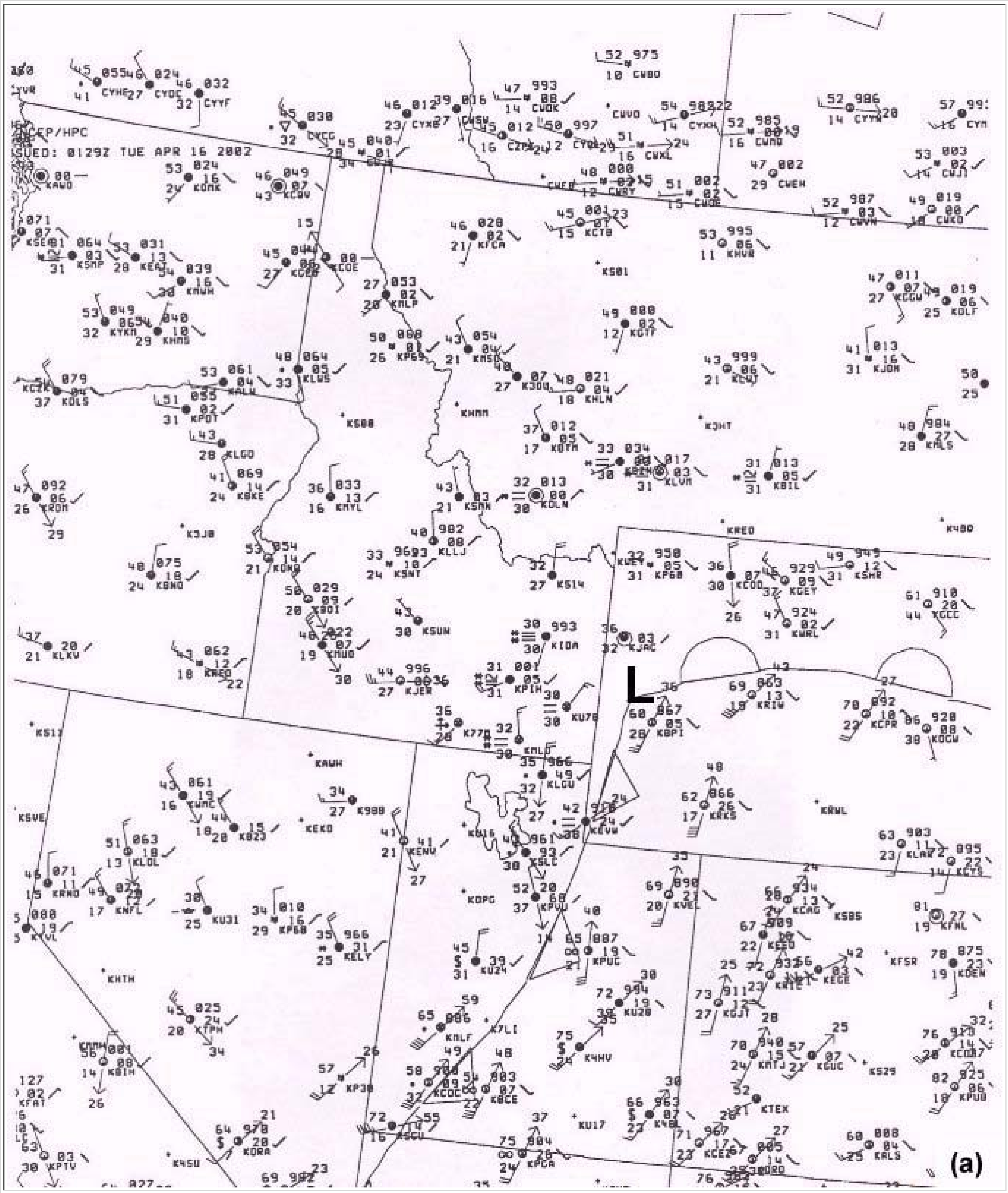


Figure 8: (a) NWS Regional Observations and Surface Fronts at 0000 UTC 16 April 2002

Figure: fig8b.html

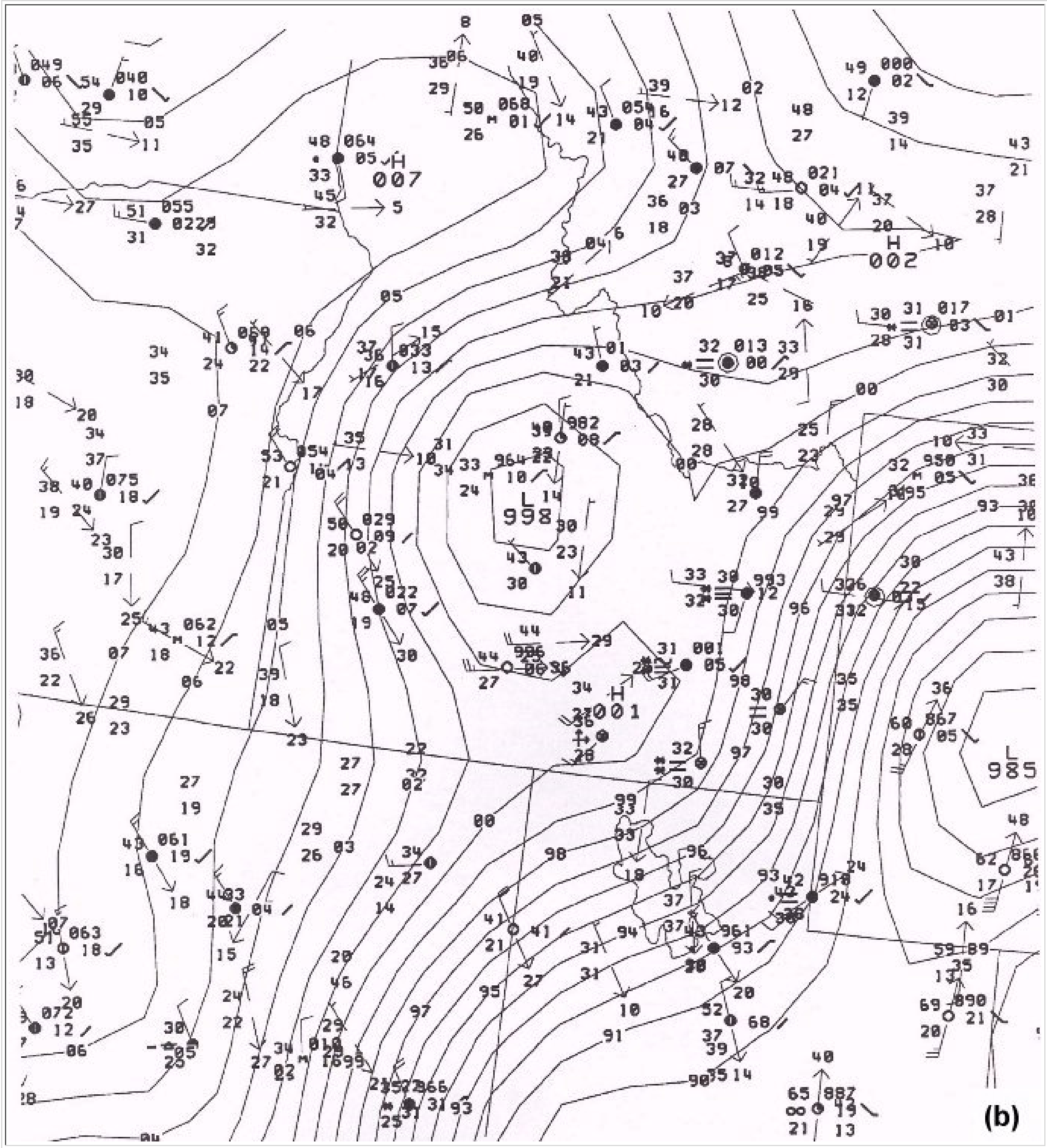


Figure 8: (b) NWS and ARL/FRD Mesonet Observations at 0000 UTC 16 April 2002

Figure: fig8c.html

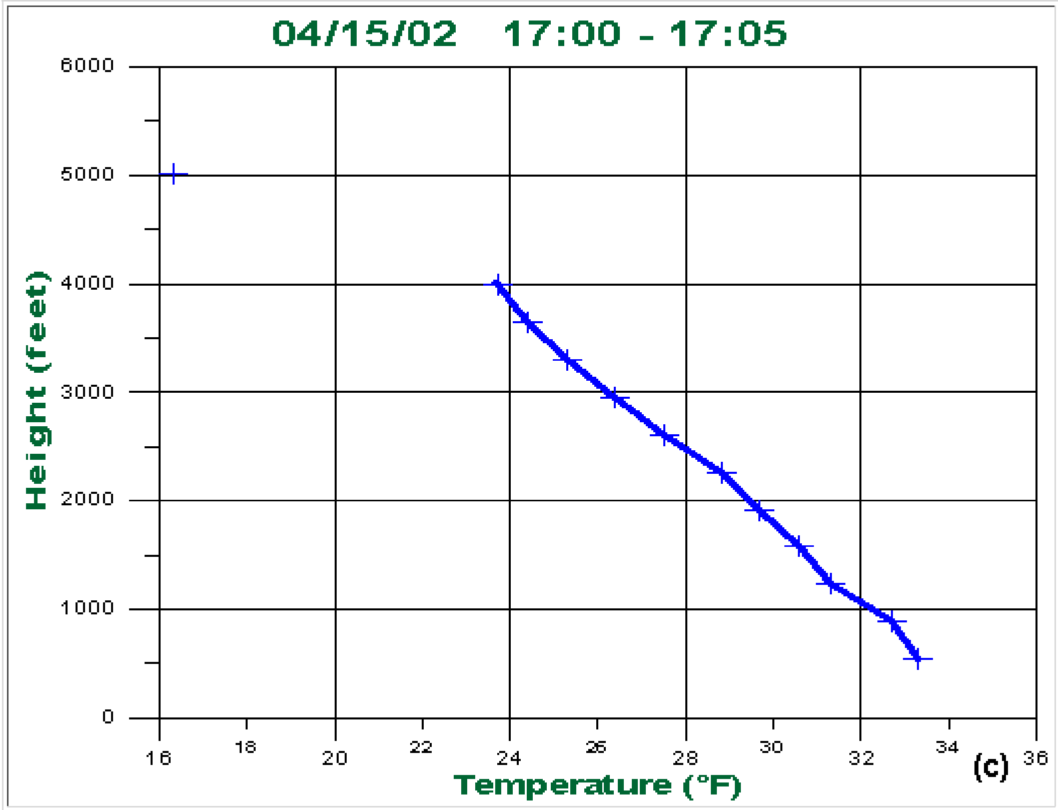


Figure 8: (c) ARL/FRD Temperature Profiler (deg F) from 0000 to 0005 UTC 16 April 2002

Figure: fig9a.html

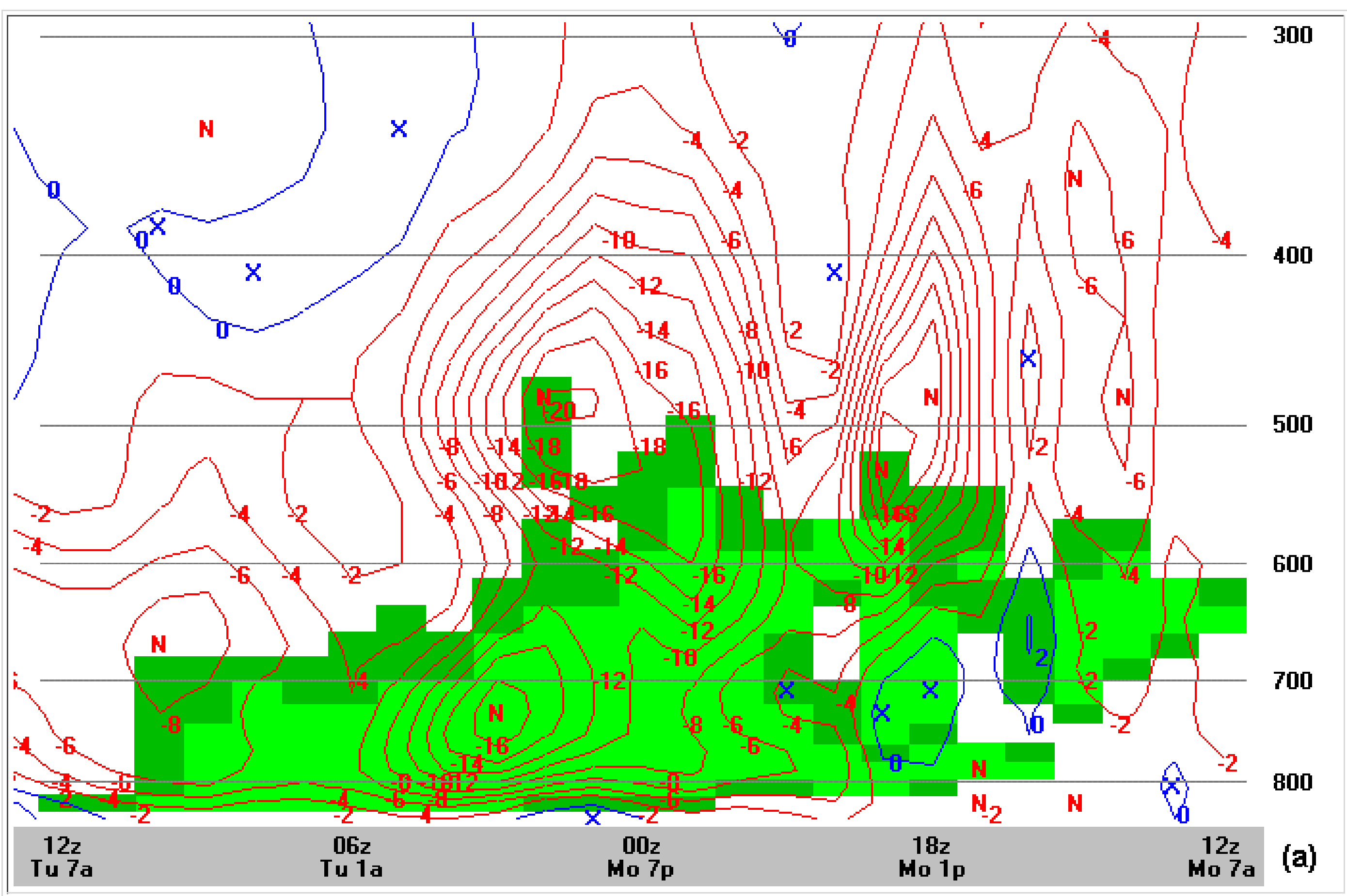


Figure 9: (a) ETA BUFKIT IDA Time-Height Cross Section for 1200 UTC 15 April 2002

Figure: table1.html

Table 1: Station Identifiers, NWS Station Names, and Geographical Locations

Station Identifier	NWS Station Name	Longitude (deg)	Latitude (deg)	Elevation (ft)
ABD	Aberdeen Experimental Station	-112.50	42.57	4400
AMF	American Falls 1 SW	-112.52	42.47	4320
ARB	Arbon 2 NW	-112.34	42.30	5170
BFT	Blackfoot 2 SSW	-112.23	43.11	4500
BYI	Burley FAA Airport	-113.46	42.32	4160
FOH	Fort Hall Indian Agency	-112.26	43.02	4500
HAM	Hamer 4 NW	-112.15	43.59	4800
IDA16	Idaho Falls 16 SE	-111.47	43.21	5720
IDA2	Idaho Falls 2 ESE	-112.01	43.29	4770
IDA	Idaho Falls FAA Airport	-112.04	43.31	4740
MAC	McCammon	-112.12	42.39	4770
MAS	Massacre Rocks State Park	-113.00	42.40	4230
MIN	Minidoka Dam	-113.30	42.40	4210
MIN2	Minidoka 10 WNW	-113.40	42.47	4290
PAU	Paul 1 ENE	-113.45	42.37	4210
PIH	Pocatello WSO Airport	-112.36	42.55	4450
RIC	Richfield	-114.09	43.04	4310
RUP	Rupert 3 WSW	-113.40	42.37	4200
RXE	Rexburg Ricks College	-111.47	43.49	4920

Figure: table2a.html

Table 2a: Dates of Heavy Snow Events and Related Snow Amounts (1949 - 1970)

Event Date	NWS Stations (Snow Amount (Inches))	Average Snow Amount (Inches)	Pattern Type
01-15-1949	ABD (6.0), AMF (8.0), BFT (6.0)	6.7	COLD
02-11-1949	ABD (8.0), BFT (6.0), IDA (9.6)	7.9	COLD
01-17-1950	AMF (9.5), MIN (8.0), PAU (7.0) PIH (7.8)	8.1	WARM
01-18-1950	ABD (7.5), AMF (10.0), BFT (6.0) FOH (8.0), RUP (8.5)	8.0	WARM
12-24-1951	ABD (6.0), AMF (8.0), MIN (6.0) PAU (12.0), RUP (9.0)	8.2	COLD
02-22-1955	IDA2 (6.0), IDA (6.0), MAC (13.0)	8.3	COLD
05-15-1955	HAM (10.0), IDA2 (11.5), IDA (8.0)	9.8	COLD
11-14-1955	IDA16 (7.0), MAC (6.5), RIC (7.0)	6.8	COLD
01-20-1962	BYI (6.0), IDA16 (8.5), MAC (7.0) MIN (7.0), PIH (6.0)	6.9	COLD
03-02-1962	AMF (8.0), IDA16 (12.0), MIN (11.0) PAU (8.0), RUP (10.0)	9.8	WARM
12-21-1963	AMF (8.0), BFT (9.0), IDA (6.2)	7.7	COLD
03-12-1967	BYI (6.0), MIN (6.5), PAU (6.0)	6.2	WARM
01-27-1968	ARB (12.0), BYI (12.0), MIN (8.0) MIN2 (10.0), PAU (10.0)	10.4	COLD
12-19-1968	ARB (8.0), MIN (7.0), RIC (6.0)	7.0	COLD

Figure: table2b.html

Table 2b: Dates of Heavy Snow Events and Related Snow Amounts (1971 - 1997)

Event Date	NWS Stations (Snow Amount (Inches))	Average Snow Amount (Inches)	Pattern Type
01-12-1971	FOH (6.0), HAM (6.0), IDA16 (9.5)	7.2	WARM
04-26-1976	ABD (7.0), BFT (8.0), FOH (7.0) MAS (7.5), PIH (7.4)	7.4	COLD
11-22-1977	ABD (9.0), MIN (10.0), PAU (6.0) RIC (12.0)	9.3	WARM
12-01-1982	AMF (10.0), BFT (8.3), MIN (7.2) PIH (9.5)	8.8	COLD
12-04-1983	AMF (12.0), IDA2 (10.0), IDA (6.2) RXE (8.0)	9.1	WARM
01-21-1985	IDA2 (6.0), MIN (6.0), PAU (6.2) RUP (7.0)	6.3	COLD
03-02-1985	ABD (6.5), ARB (8.0), BYI (8.4) FOH (6.0), IDA2 (6.0), PIH (8.2)	7.2	COLD
12-23-1988	ARB (6.0), IDA16 (12.0), RIC (6.0)	8.0	COLD
12-25-1988	BFT (7.0), IDA16 (6.0), PIH (10.8)	7.9	COLD
12-29-1992	BFT (8.0), BYI (10.2), IDA2 (6.0) MAS (6.0), PIH (7.4)	7.5	WARM
12-30-1992	FOH (6.0), MIN (8.0), PAU (8.0) RXE (7.0)	7.3	WARM
01-11-1993	AMF (8.0), IDA2 (6.0), IDA (8.0) MAC (6.0), MAS (7.0), PIH (6.6) RUP (6.0)	6.8	COLD
01-25-1997	AMF (7.0), BYI (6.0), MAC (9.0) MAS (6.0)	7.0	WARM
10-24-1997	ABD (6.0), IDA2 (6.0), PIH (7.6)	6.5	COLD

Figure: table3.html

Table 3: Correlation Variables for Multiple Linear Regression Analysis

Event Date	SLPD1	SLPD2	SLPS	TMPS1	TMPS2	HGTS1	HGTS2	HGTD	Pattern Type
12-21-1963	-7.70	-2.10	-9.80	-11.55	-10.15	5489.10	5502.69	-13.59	COLD
03-12-1967	-2.50	-15.00	-17.50	-9.00	-6.30	5456.44	5519.45	-63.01	WARM
01-27-1968	-4.50	-19.50	-24.00	-12.10	-8.55	5362.04	5445.54	-83.50	COLD
12-19-1968	-6.20	-12.80	-19.00	-16.10	-14.70	5328.89	5371.44	-42.55	COLD
01-12-1971	4.70	-12.50	-7.80	-9.70	-6.75	5384.25	5466.35	-82.10	WARM
04-26-1976	-11.70	3.70	-8.00	-10.10	-6.00	5454.25	5484.25	-30.00	COLD
11-22-1977	5.60	-2.70	2.90	-6.35	-7.40	5505.09	5538.50	-33.41	WARM
12-01-1982	-8.00	0.00	-8.00	-7.95	-4.90	5342.85	5355.44	12.60	COLD
12-04-1983	-9.50	2.50	-7.00	-10.70	-7.70	5401.04	5403.44	-2.40	WARM
01-21-1985	-6.30	-14.40	-20.70	-6.65	-8.05	5577.08	5567.69	9.40	COLD
03-02-1985	-13.70	-10.70	-24.40	-9.10	-5.25	5422.79	5462.50	-39.71	COLD
12-25-1988	-9.10	-7.40	-16.50	-15.40	-11.85	5339.94	5378.79	-38.85	COLD
12-29-1992	14.50	-4.50	10.00	-7.55	-6.00	5451.20	5514.19	-62.99	WARM
01-11-1993	-13.20	-6.00	-19.20	-13.70	-6.80	5344.19	5421.98	-77.80	COLD
01-25-1997	8.00	-10.00	-2.00	-9.00	-13.00	5500.00	5483.50	16.50	WARM
10-24-1997	-8.00	2.00	-6.00	-7.50	-6.00	5525.00	5520.00	5.00	COLD

Code: MSLP :: SLPD1 (SLC - LLJ), SLPD2 (EKO - WEY), SLPS = (SLPD1 + SLPD2): mb
700 mb Temperature :: TMPS1 (BOI), TMPS2 (RKS): deg C
500 mb Height :: HGTS1 (BOI), HGTS2 (RKS), HGTD = (HGTS1 - HGTS2): m

Figure: table4.html

Table 4: Output Variables for Multiple Linear Regression Equations

Equation	Degress of freedom (df)	Pearson Correlation Coefficient (r)	Standard Deviation (s) (inches)
1	15	0.23	1.35
2	9	0.73	1.13
3	5	0.80	1.63
4	7	0.57	0.99
5	8	0.29	0.92
6	8	0.65	1.12
7	35	0.65	1.45
8	21	0.56	2.08

REFERENCES

Andretta, T. A., 2003: Climatology of the Snake River Plain Convergence Zone. Ntl. Wea. Digest, in print.

Andretta, T. A., 1999: Harmonic Analysis of Precipitation Data in Eastern Idaho. Ntl. Wea. Digest, 23:1-2, 31-40.

Andretta, T. A. and D. S. Hazen, 1998: Doppler Radar Analysis of a Snake River Plain Convergence Event. Wea. Forecasting, 13, 482-491.

Blank, J., 1989: A Heavy Snow Event Associated with Jet Streak Interaction. Western Region Technical Attachment No. 89-36.

Chaston, P. R., 1989: The Magic Chart for Forecasting Snow Amounts. Ntl. Wea. Digest, 14:1, 20-22.

Holcomb, J. W., 1981: Forecasting Heavy Snow at Wenatchee, Washington. NOAA Technical Memorandum NWS WR-172.

Mahoney, E. A. and T. A. Niziol, 1998: BUFKIT: A Software Application Toolkit for Predicting Lake Effect Snow. Preprints, 13th Intl. Conf. On Interactive Info. and Processing Sys. (IIPS) for Meteorology, Oceanography, and Hydrology, Amer. Meteor. Soc., Long Beach, CA.

Mathewson, T. O. and V. J. Nouhan, 2002: Synoptic Regimes Associated with Heavy Snow Events across the County Warning Forecast Area of NWSO Goodland, Kansas. Central Region Applied Research Paper No. 20-02.

Richmond, M., 1992: Forecasting Heavy Snow Events in Missoula, Montana. NOAA Technical Memorandum NWS WR-217.

Sagendorf, J. F., 1996: Precipitation Frequency and Intensity at the Idaho National Engineering Laboratory. NOAA Technical Memorandum ERL ARL-215.

Tardy, A., 2002: Significant Snow in the Sierra Nevada from Maritime Polar Origins. Western Region Technical Attachment No. 02-04.

Terry, B., 1992: NMC Heavy Snow QPFs. Western Region Technical Attachment No. 92-32.

Wilks, D. S., 1995: Statistical Methods in the Atmospheric Sciences: An Introduction (International Geophysics, Vol 59), Academic Press, 467 pp.