Analysis of a Wintertime Northeast Flow Case at KSC

Prepared for:
NASA
Kennedy Space Center
Under Contract NAS10-11844

15 April 1993

Prepared By:
Applied Meteorology Unit

ENSCO, Inc. 445 Pineda Court
Melbourne, Florida 32940
(407) 853-8201
(407) 254-4122

Attributes and Acknowledgments:

NASA/KSC POC:

Dr. Frank Merceret, Chief, Applied Meteorology Unit
TM-LLP-2A

Applied Meteorology Unit (AMU)

Michael K. Atchison, Primary Author
Robin Schumann
Greg Taylor
John Warburton
Mark Wheeler
Ann Yersavich

Table of Contents

List of Illustrations

List of Illustrations

(Continued)

List of Tables

1.0 Introduction

Northeasterly flow cases along the east coast of Florida pose many weather problems for launches and landings at the Kennedy Space Center (KSC). Among these problems are low-level stratocumulus ceilings, showers, and cross-wind violations for Space Transportation System (STS) landings. This report documents weather conditions during relatively weak northeasterly flow on 9 December 1992. This case was characterized by relatively stable conditions with a very strong low-level inversion near 850 mb. Because of the low-level hydrostatic stability, several tools could be successfully employed to forecast the movement of cloud bands from the Atlantic Ocean. These tools could also be used for other similar easterly flow cases.

Section 2 describes the surface weather patterns affecting the KSC region surrounding this case. Section 3 presents an analysis of upper-air conditions over Florida and the southeastern United States plus a detailed look at soundings taken from Cape Canaveral Air Force Station (CCAFS). Section 4 presents a detailed analysis of visible satellite imagery near KSC. Section 5 discusses several forecast tools which could help the forecasters in similar atmospheric environments. Section 6 contains a brief summary of this analysis, while Section 7 discusses recommendations made by the Applied Meteorology Unit (AMU). Section 8 contains the acknowledgments and Section 9 a reference.

2.0 Surface Analysis

In the early morning (1200 UTC) of 8 December 1992 a cold front passed through KSC, shifting surface winds from the west to the north. Low stratus moved in just ahead of the front and persisted all day with ceilings at approximately 1000 feet. Temperatures throughout the day remained in the low 60s with dew points in the mid- to upper-50s. Surface winds remained

By 0000 UTC (see Figure 1) on 9 December 1992, the cold front stalled over south Florida with a high pressure ridge from the Ohio Valley controlling the weather over most of the southeastern part of the country. At 0100 UTC on 9 December the low-level cloudiness started to diminish at the Shuttle Landing Facility (SLF) with sky conditions becoming clear between 0300-0700 UTC. During this period winds continued from the north at 5 knots. However, by 1000 UTC (Figure 2) the lower level winds began shifting to the northwest as a weak land breeze (drainage flow) developed. This shift can be seen in the wind direction time series plot for

Tower 511 (Figure 2). At approximately this same time, scattered stratocumulus clouds were moving in from the Atlantic with cloud coverage amounts of 1/10-2/10 below 10,000 feet. Temperatures from 0700 to 1000 UTC decreased from 57°F to 50°F.

By 1200 UTC on 9 December (see Figure 3), the weak cold front had moved further south and was stationary from Key West to the central Bahamas. To the north of the front, a high pressure ridge located from Quebec to Virginia controlled the weather over north and central Florida. Between 1255 and 1455 UTC the surface flow remained from the northwest at 3-5 knots with scattered stratocumulus (2/10 coverage) and high thin cirrus (see Table 1). Temperatures during this period rose from 51 °F at 1200 UTC to 68°F at 1500 UTC. This low level heating broke up an early morning surface inversion and eliminated the weak offshore land breeze. By 1555 UTC, the winds at the SLF (see Table 1) had become east-northeast at 7 knots. As shown in Figure 2 the winds throughout the reminder of the day were from 070°-100° at 7 to 13 knots. Temperatures most of the day were in the lower 70s and dew points in the low to mid 50s (see Table 1).

During the daylight hours on 9 December several bands of stratocumulus clouds advected over the KSC/CCAFS region from Atlantic coastal waters. As shown by the graph of SLF surface observations (Figure 4), cloud coverage below 10,000 feet remained generally at 2/10. However, 3/10-4/10 cloud coverage was reported between 1610 UTC and 1710 UTC and ceiling conditions (greater than or equal to 6/10) were reported between 2014 UTC and 2141 UTC. The increase in clouds during both time periods was associated with stratocumulus cloud bands advecting inland over KSC/CCAFS from the Atlantic. Cloud coverage below 10,000 feet at the SLF remained at 2/10 from 1725 to 1923 UTC. By 2000 UTC cloud coverage was 3/10 but increased to 6/10 (ceiling) by 2014 UTC. A detailed discussion of these bands of stratocumulus clouds and their movement based on satellite imagery is contained in Section 4.

2.1 Summary of Surface Conditions

- A southward moving weak cold front passed through the SLF early on 8 December 1992.
- High pressure behind this front controlled the weather pattern over Florida on 9 December.
- A land breeze existed early on 9 December, but for most of the day a east-northeast flow at 7-13 knots dominated the flow pattern throughout the daylight hours.

- Scattered stratocumulus clouds (generally 2/10 coverage below 10,000 feet were observed at the SLF during most of the day with a ceiling (greater than or equal to 6/10 coverage) between 2014 and 2142 UTC.

Table 1. Shuttle Landing Facility Weather Observations (X68) on 9 December 1992

Time (UTC)	Vis. (nm)	Press. (mb)	Temp. (F)	Dew Pt. (F)	Wind Dir.	Wind Speed (Knots)	Peak Wind (Knots)	Clouds <10k (Tenths)
1255	7	1021.0	51	49	320	5	11	1
1355	8	1021.0	57	53	330	3	10	2
1455	10	1022.0	68	56	300	3	11	2
1555	10	1021.7	71	53	080	7	13	2
1610	10	1021.3	71	52	060	7	12	3
1625	10	1021.3	69	54	080	7	13	3
1640	10	1021.0	69	55	080	7	13	4
1655	10	1020.7	70	53	070	7	14	4
1710	10	1020.3	72	55	100	6	17	3
1725	10	1020.0	71	54	090	8	15	2
1740	10	1020.0	70	54	100	9	18	2
1755	10	1019.6	71	53	090	8	15	2
1810	10	1019.6	70	53	070	8	16	2
1825	10	1019.6	71	54	080	4	14	2
1840	10	1019.0	71	52	070	7	14	2
1855	10	1019.0	70	54	080	5	12	2
1916	10	1018.6	70	52	100	6	12	2
1923	10	1018.6	71	55	100	7	12	2
1955	10	1018.6	70	55	090	6	12	3
2014	10	*	*	*	100	6	11	6
2050	10	1018.6	70	56	100	6	11	7
2055	10	1018.6	70	55	100	6	11	7
2142	10	*	*	*	100	5	11	3
2155	10	1018.6	68	57	100	4	10	3
2255	10	1018.3	63	57	090	3	10	2
2355	10	1018.6	65	56	100	4	10	3

* Indicates data not available.

3.0 Upper-Air Analysis

At 0000 UTC on 9 December 1992, the Meteorological Interactive Data Display System (MIDDS) analyses of 850, 700, and 500 mb (Figures 5-7) upper-air data showed a ridge extending from the Mississippi Valley area into the northern Gulf of Mexico. The flow at these levels over Florida was generally from the west to northwest around 5-10 knots at 850 mb increasing to 30-40 knots at 500 mb. There was some residual moisture at 850 mb, but from 85C mb to 200 mb conditions were quite dry.

By 1200 UTC on 9 December, the ridge (Figures 8-10) had moved east and was located from the Great Lakes to Tennessee then into northern Florida. As shown by the 1246 UTC CCAFS rawinsonde on 9 December (Figure 11), flow at 700 mb was northwest at 15-20 knots and became west at 500 mb around 40 knots. Conditions were also very dry at these levels with dew point depressions of 10°C or greater. In the lower levels there was a 5-6°C surface inversion and a very strong subsidence inversion (5°C) with its base located just below 850 mb. The low level winds (surface to 1000 ft) were northwesterly at 5 knots but shifted to the east-northeast from 1200 to 3500 feet at speeds of 12-17 knots. There was some moisture near the surface and just below the subsidence inversion at cloud base height (around 4000 feet). The winds near cloud base height were from 070°-080° at 8-10 knots.

Between 1200 UTC and 1500 UTC the lower levels of the boundary layer warmed rapidly. As shown by the 1516 UTC CCAFS sounding (Figure 12), the surface inversion had been eroded by low-level heating with temperatures near 20°C. In addition, the 1516 UTC sounding showed that the flow from just above the surface to 4500 feet remained from the east-northeast (060°-080°) at 10-15 knots and that these winds were now able to convectively mix down to the surface.

During the next one and a half hours, no significant changes were noted in the boundary layer over Cape Canaveral. As shown by the 1646 UTC CCAFS sounding (Figure 13), winds from the surface to 4000 feet were from 080°-090° at 10-15 knots. Winds at the subsidence inversion base (around 4500 feet) weakened to 5 knots and became northwesterly above this level. The lapse rate from the surface to 4000 feet was dry adiabatic indicating good low-level mixing. Based on the 1646 UTC sounding, the winds at cloud base were approximately 070° at 10 knots.

Between 1646 UTC and 1820 UTC, there were a few minor changes noted in the lower parl of the atmosphere over the Cape Canaveral region. First, as shown by the 1820 UTC CCAFS sounding (Figure 14), the winds from the surface to approximately 5000 feet had become more easterly. At this time, most levels were indicating winds from 090°-100° at 10-13 knots. In addition, winds had actually decreased slightly near cloud base height (4100 feet as measured al the SLF) and were now from 090° at 8 to 10 knots. Also, the 1820 UTC sounding showed a moist layer from 3800-4200 feet. This is probably indicative of the balloon passing through a cloud at these levels. It must also be noted that prior to this, an aircraft was reporting cloud bases of 3500 feet and tops to 4500 feet. This information combined with the CCAFS sounding data would indicate the thickness of the existing cloud field was approximately 500 to 1000 feet.

3.1 Summary of Upper-Air Conditions

- An upper-level ridge from the Great Lakes to northern Florida provided the Cape Canaveral region with a dry west-northwest flow at levels at or above 850 mb.
- A strong subsidence inversion was present from 850 to 750 mb.
- East-northeast flow at 8-15 knots was present from near the surface to 5000 feet during the daylight hours on 9 December.
- There was a gradual shift in wind direction from east-northeast to east from the surface to 5000 feet during 9 December.
- Cloud base winds at both 1646 and 1820 UTC were estimated to be 070° at 8 knots.

4.0 Satellite Analysis

This section discusses visible satellite imagery collected during 9 December 1992. Figures 15 through 22 show GOES-7 1 km visible satellite images centered over the Cape Canaveral region between 1500 UTC and 2031 UTC. Shown on each image are the location of SLF (X68) and range markers 20 and 40 nm from the SLF. Note there are several sources of errors involved when using satellite images. One of the largest errors is gridding or navigation (i.e., map background plotted over the satellite image). Past studies (Ref. 1) have shown that navigation errors are typically 1-2 nm for GOES-7 images.

Between 1200 UTC and 1500 UTC several low-level convergent bands associated with stratocumulus clouds could be seen just off the east coast of Florida. These bands of clouds were moving toward the coast but dissipating quite rapidly once they encountered the shoreline. The 1501 UTC image (Figure 15) shows three distinct clouds bands extending from Cape Canaveral out 40 nm to the north and east. Cloud band I was located over the Merritt Island area extending off the coast into the Atlantic. This cloud band was dissipating as it encountered the coastline. Cloud Band 2 was more concentrated and was located approximately 15-20 nm to the north and east of the SLF. Cloud band 3 was beginning to develop and was approximately 40 nm to the north and east of the SLF.

By 1601 UTC (Figure 16) cloud band 1 had almost completely dissipated with only a few patchy clouds remaining as it moved over southern Merritt Island. At this time the SLF was reporting 2/10 cloud cover below 10,000 feet. In addition, cloud band 2 had moved to within 10 miles of the SLF and was already showing signs of dissipating. Between 1600 and 1700 UTC cloud band 2 moved close enough to the SLF to increase their cloud cover to 4/10 at 1640 and

1655 UTC (Figure 4). At 1601 UTC, the leading edge of cloud band 3 was approximately 35 nm to the northeast of the SLF and continued to move toward the coast.

At 1701 UTC (Figure 17) cloud band 2 was breaking up over Merritt Island. As cloud band 2 dissipated, the cloud cover at the SLF decreased to 2/10 below 10,000 feet (see Figure 4). At this same time, cloud band 3 continued to move toward the Cape and was now located approximately 25 nm northeast of the SLF. Also at 1701 UTC, there were some developing cumulus over Merritt Island and just west of the Indian River. At 1746 UTC (Figure 18) cloud band 3 was 20 miles to the northeast of the SLF. Also, noted at 1746 UTC was a developing cumulus field over the land to the west of the Indian River. However, these clouds showed no evidence of moving back to the east toward the SLF.

By 1901 UTC (Figure 19) cloud band 3 was now about 12-15 nm to the north and east of the SLF area. Also noted at this time were a few clouds over Merritt Island, with more concentrated clouds west of the Indian River in the western sections of Brevard County. These clouds west of the Indian River were being enhanced by increased convergence and heating over the adjacent land areas to the west of KSC. At 1931 UTC (Figure 20), cloud band 3 had moved to within 10 nm of the SLF.

By 2001 UTC (Figure 21), cloud band 3 was now only 5 miles to the north and east of the SLF. Influence from band 3 was first noted at the SLF with cloud cover increasing to a broken condition at 2014 UTC. By 2031 UTC (Figure 22) the satellite image clearly indicates significant clouds near the SLF. Ceiling conditions continued at the SLF until 2142 UTC.

4.1 Summary of Satellite Analysis

- Three distinct stratocumulus cloud bands affect the SLF between 1500 and 2100 UTC.
- The first 2 bands dissipate as they moved into the KSC area.
- Band 3 holds together and moves into the SLF between 2014 and 2142 UTC.

5.0 Forecasting Tools

This section will focus on how extrapolation of the cloud bands (performed manually or by using the MIDDS tool TRNIMG) could be used to help forecast the movement of the stratocumulus bands over the Atlantic.

5.1 Extrapolation Method

One forecast technique to determine the future location of the individual cloud bands is to estimate cloud movement from previous satellite images and extrapolate this motion into the future. This analysis will concentrate on trying to forecast future movement of cloud band 3. Between 1500 and 1746 UTC, cloud band 3 moved approximately 20 nm in 2 hours and 45 minutes which corresponds to a propagation speed of approximately 8 knots. Advecting cloud band 3 from its 1746 UTC position at a speed of 8 knots would bring it into the X68 area around 2030 UTC. (As shown in Table 1 a ceiling was reported at the SLF at 2014 UTC.) Based on the satellite trends over the previous few hours, this would have been a safe forecast since there was no indication of cloud development in between these bands. In addition, CCAFS soundings indicated the clouds were very thin (less than 1000 feet) and the strong inversion just below 850 mb would preclude the development of any shower activity in the vicinity. Also, there was no indication that the cloud bands were going to accelerate in speed. They had been moving at a constant rate for several hours. In fact, the CCAFS sounding indicated a slight weakening of winds near cloud base height during the afternoon hours and a shift in wind direction more to the east by 1820 UTC. This would suggest even slower movement toward the SLF.

5.2 MIDDS Program "TRNIMG"

Another tool that could be used to forecast the movement of these types of cloud bands is the MIDDS program "TRNIMG". This function translates pixels of any given image at a specified direction and speed of movement. In other words, the user specifies the direction and speed of movement over a given time period and TRNIMG will create a new image using this velocity. This function was originally developed to help forecast the movement of radar echoes but can be applied to any digital image. Please note this function does not take into account any cloud development or dissipation.

The movement of cloud band 3 between 1501 and 1746 UTC was estimated to be 070° at 8 knots. This speed and direction was input into the TRNIMG function for the 1746 UTC image for a 90 minute extrapolation. Figure 23 shows the forecast 1916 UTC image based on the 1746 UTC image. As the forecast image indicates, cloud band 3 was approximately 10 nm to the north and east of the SLF. By interpolating between the 1901 UTC (Figure 19) and 1931 UTC (Figure 20) images, cloud band 3 was about 10 miles from the SLF at 1916 UTC. This is within 3-4 nm of where the TRNIMG forecast band 3 to be located at this time. Thus, the TRNIMG program did provide good guidance regarding the future position of cloud band 3.

5.3 Summary of Forecasting

- Time continuity of visible satellite images between 1501 and 1746 UTC along with sounding data from CCAFS indicates cloud band movement of 070° at 8 knots.

- Extrapolation of cloud movement between 1501 UTC and 1746 UTC suggests band 3 would not reach the SLF until 2030 UTC (clouds actually arrived at 2014 UTC with a ceiling reported at the SLF).
- The MIDDS function "TRNIMG" provided good guidance (within 3-4 nm of actual position) in forecasting movement of cloud band 3 from the 1746 UTC image. (Note that the manual extrapolation method and "TRNIMG" program give similar results since they are both based on the same wind inputs.)

6.0 Summary

On 9 December 1992 the weather over the Cape Canaveral region was controlled by a high pressure ridge located over the mid-Atlantic states giving most of Florida an east to northeasterly low-level wind flow. The key weather feature at KSC on 9 December 1992 was the presence of bands of stratocumulus clouds embedded within this low-level east-northeasterly flow. Between 1500 and 2030 UTC, three distinct cloud bands advected inland over Cape Canaveral from off the Atlantic. Cloud bases were around 4000 feet, just below a very strong subsidence inversion located near 850 mb (around 5000 feet). CCAFS sounding data indicates the cloud thickness at 500-1000 feet. Very little vertical development and no visible moisture (i.e., rain) was evident. The first two cloud bands dissipated quite rapidly as they encountered the coastline. However, between 1600-1700 UTC band 2 did increase the cloud cover below 10,000 feet at the SLF to 3/10-4/10. Then between 1700 and approximately 2000 UTC the cloud cover below 10,000 feet remained at 2/10.

At 1501 UTC cloud band 3 was beginning to take shape approximately 40 nm northeast of the SLF. By 1755 UTC band 3 was about 20 nm northeast of the SLF. Between 1901 and 1931 UTC cloud band 3 moved to within 10 nm northeast of the SLF. By 2014 UTC this cloud band reached the SLF with broken cloud conditions reported below 10,000 feet.

6.1 Conclusions

Two forecast techniques were presented which might be useful in predicting the future location of individual cloud bands. The first technique used an estimation of the cloud band movement from previous satellite images and extrapolated this motion into the future. Between 1501 and 1746 UTC, cloud band 3 moved approximately 20 nm to the west-southwest in 2 hours and 45 minutes which corresponds to a movement of 070° at 8 knots. Advecting cloud band 3 from its 1746 UTC position at 8 knots would bring the cloud band into the SLF area at 2030 UTC. This would have been a good forecast since sky conditions below 10,000 feet at the SLF went broken at 2014 UTC. The second technique used the MIDDS program "TRNIMG" to help forecast the movement of cloud bands. This function translates pixels of any given image at a specified direction and speed. By applying a 90 minute movement of 070° at 8 knots to the 1746 UTC visible image, band 3 was forecast to be approximately 10 miles northeast of the SLF at 1916 UTC. Based on subsequent satellite images, both forecast tools would have provided good guidance on the future position of cloud band 3.

The user must be aware of a few limitations when using these two forecast techniques (the extrapolation method and the "TRNIMG" program):

- Each method assumes clouds at all levels move at the same speed and direction.
- The forecast results are only as good as the input speed and direction estimates.
- Neither method takes into account cloud development or cloud dissipation.

7.0 Discussion and Recommendations

The weather pattern on 9 December 1992 at KSC was characterized by low-level easterly flow with bands of stratocumulus clouds. The primary forecast challenge was to predict the movement of these cloud bands and to determine whether there would be any development between the bands. As discussed in Section 5, two forecast techniques have been successfully applied to forecasting the movement of these cloud bands. These techniques worked well because of several factors:

- This event was characterized by hydrostatically stable conditions with a very strong capping inversion around 5000 feet. This prevented any significant vertical development of the clouds.
- The air mass flowing over the warm Atlantic ocean was not very cold relative to the ocean surface temperatures. Consequently, the low-levels of the atmosphere did not destabilize as the air moved across the ocean trajectory.
- The stratocumulus clouds were organized in well-developed bands perpendicular to the flow. There was also very little development between these bands.

The AMU recommends a study be performed to identify similar easterly flow cases. This would establish a database to develop forecast rules for this type of easterly flow, and also enable a statistical evaluation of the proposed tool's usefulness. The development of these rules would aid SMG and CCFF forecasters and others concerned with short-term, small-scale forecasting.

8.0 Acknowledgments

The AMU would like to thank personnel from both the CCFF and SMG for their careful and constructive review of this report. Also, we would like to thank Computer Sciences Raytheon (CSR) Meteorology Section for providing much of the data that was used in this report. Finally, we appreciate the support given by NASA/KSC in the preparation and review of this report.

9.0 Reference

(1) Pyzalski, Robert, D. A. Santek, J. T. Young, 1988: Automatic Navigation for Meteorological Satellites. Preprints, *Fourth International Conference - Interactive Information and Processing Systems for Meteorology, Oceanography, and Hydrology*, Anaheim, California, American Meteorology Society, J17-J19.

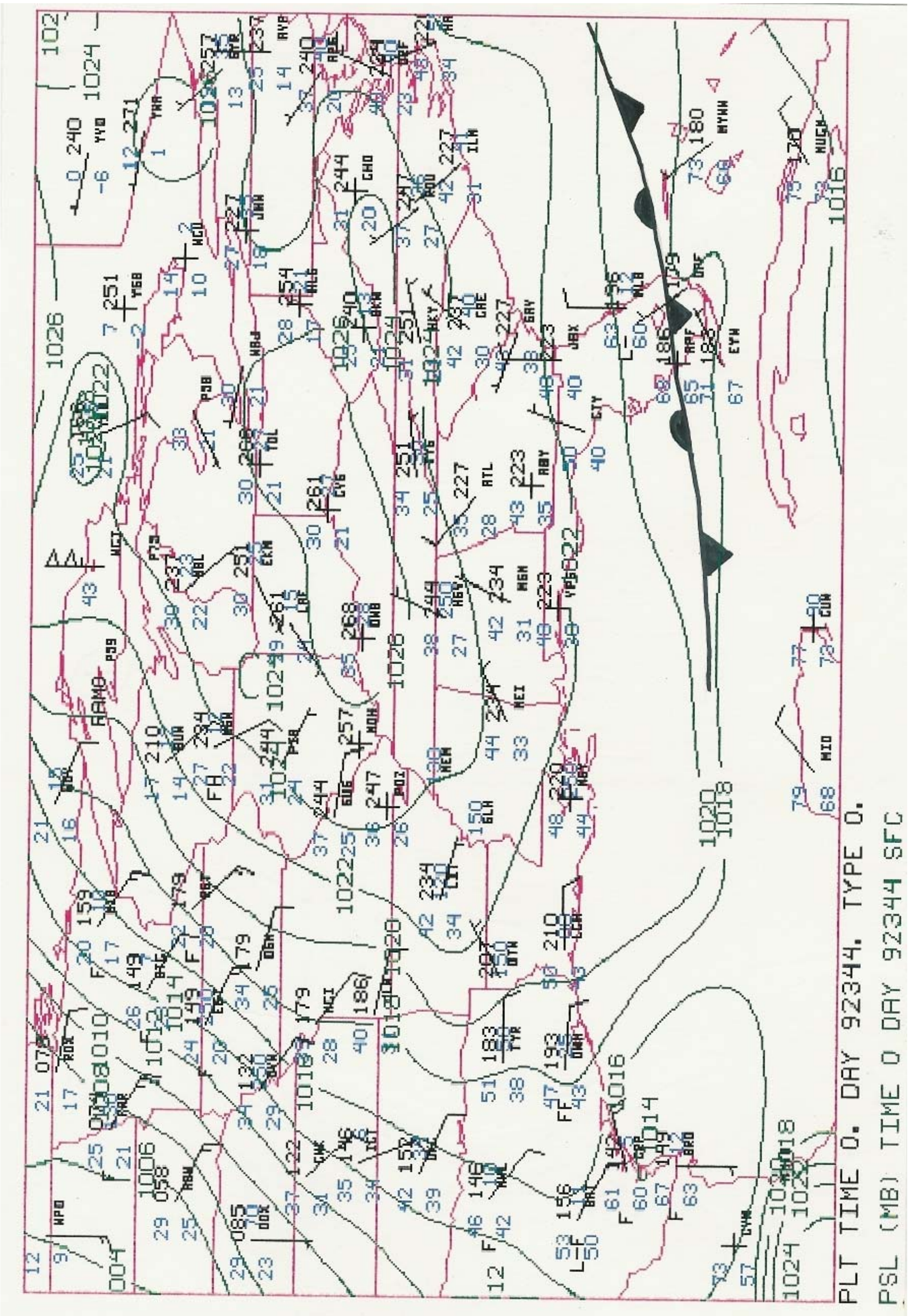


Figure 1. Surface Analysis at 0000 UTC on 9 December 1992.

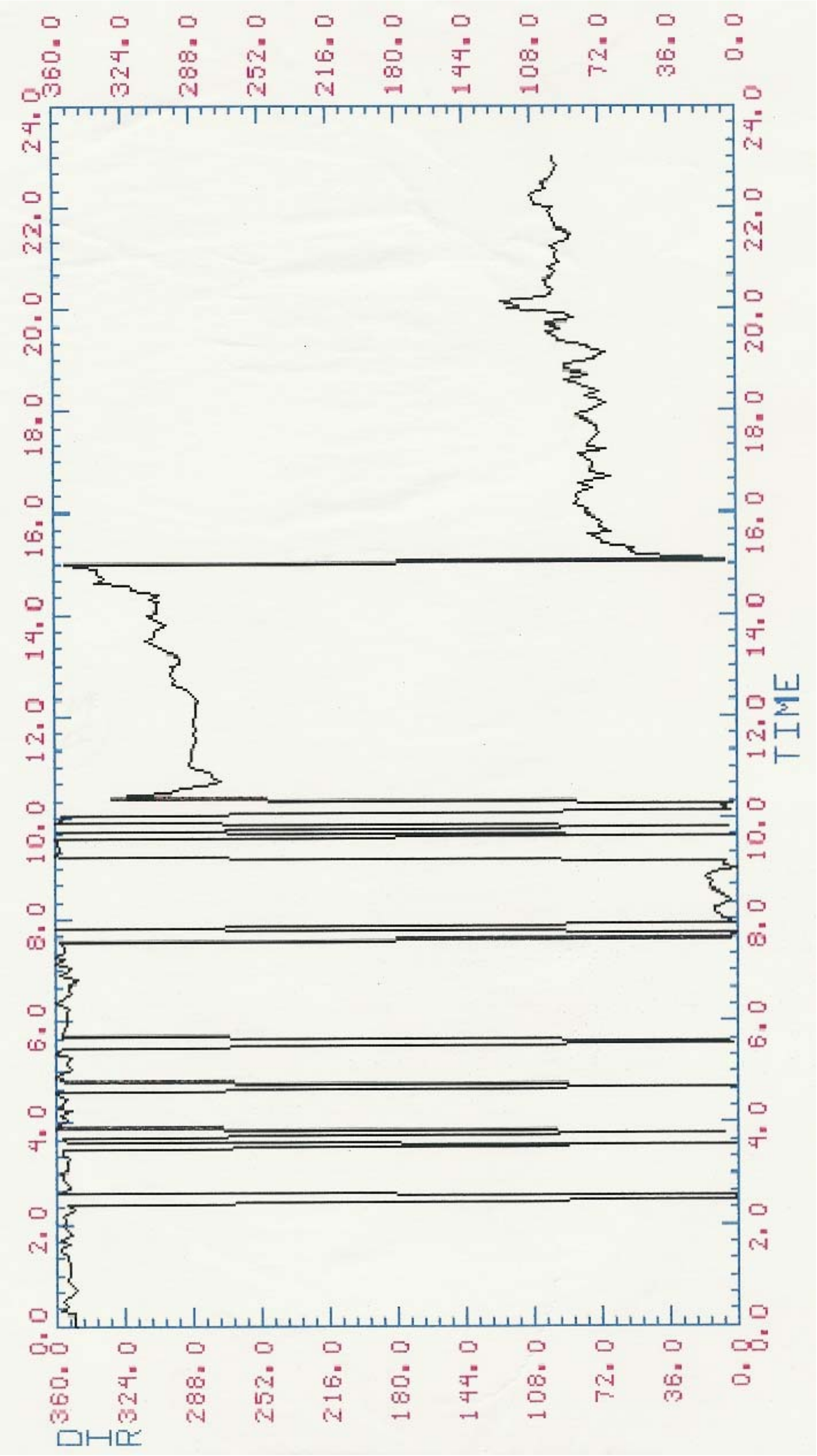


Figure 2a. Time Series of Wind Direction at the 9.1 m (30 ft.) Level at Tower 511 on 9 December 1992.

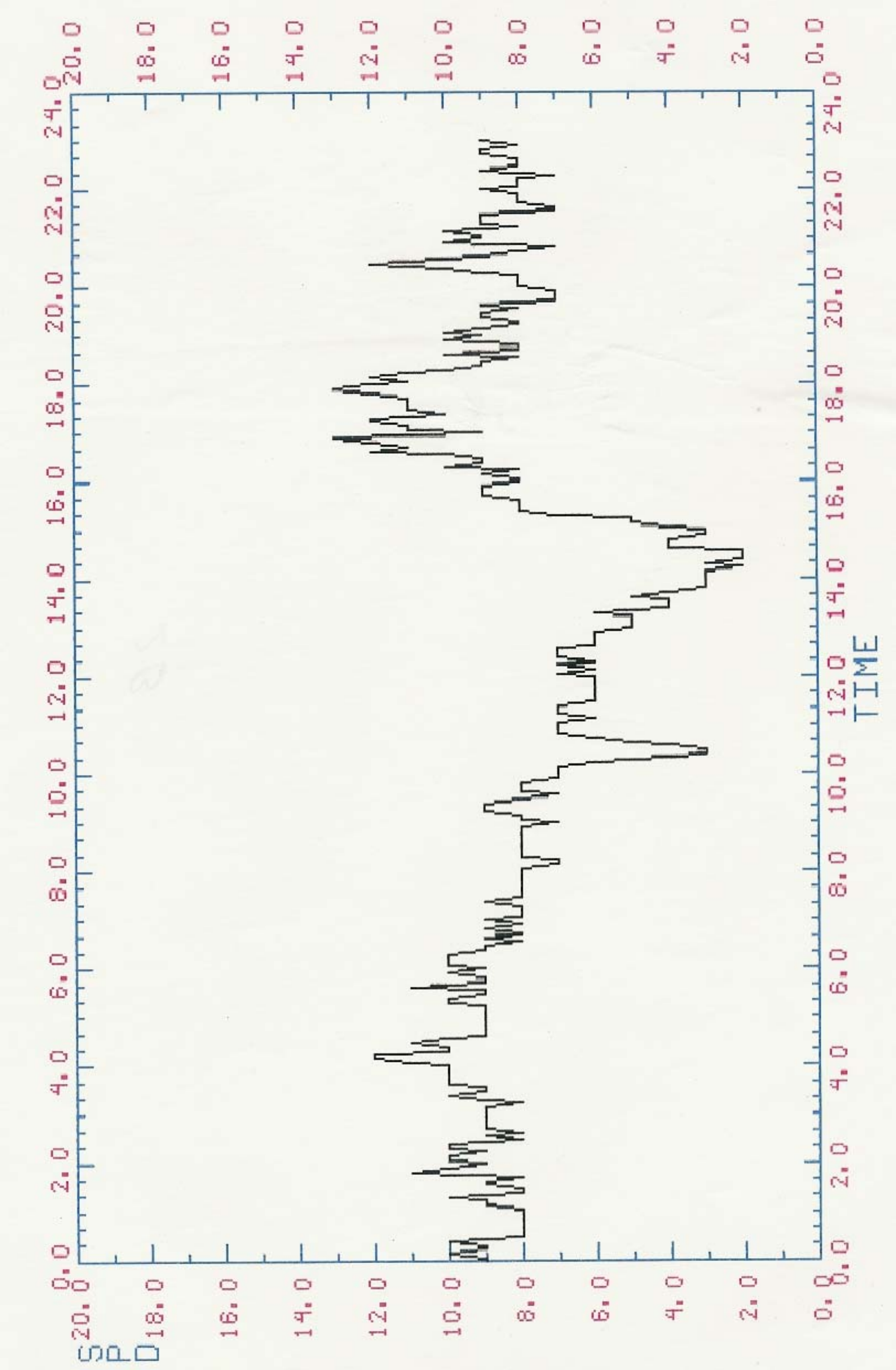


Figure 2b. Time Series of Wind Speed at the 9.1 m (30 ft.) Level at Tower 511 on 9 December 1992.

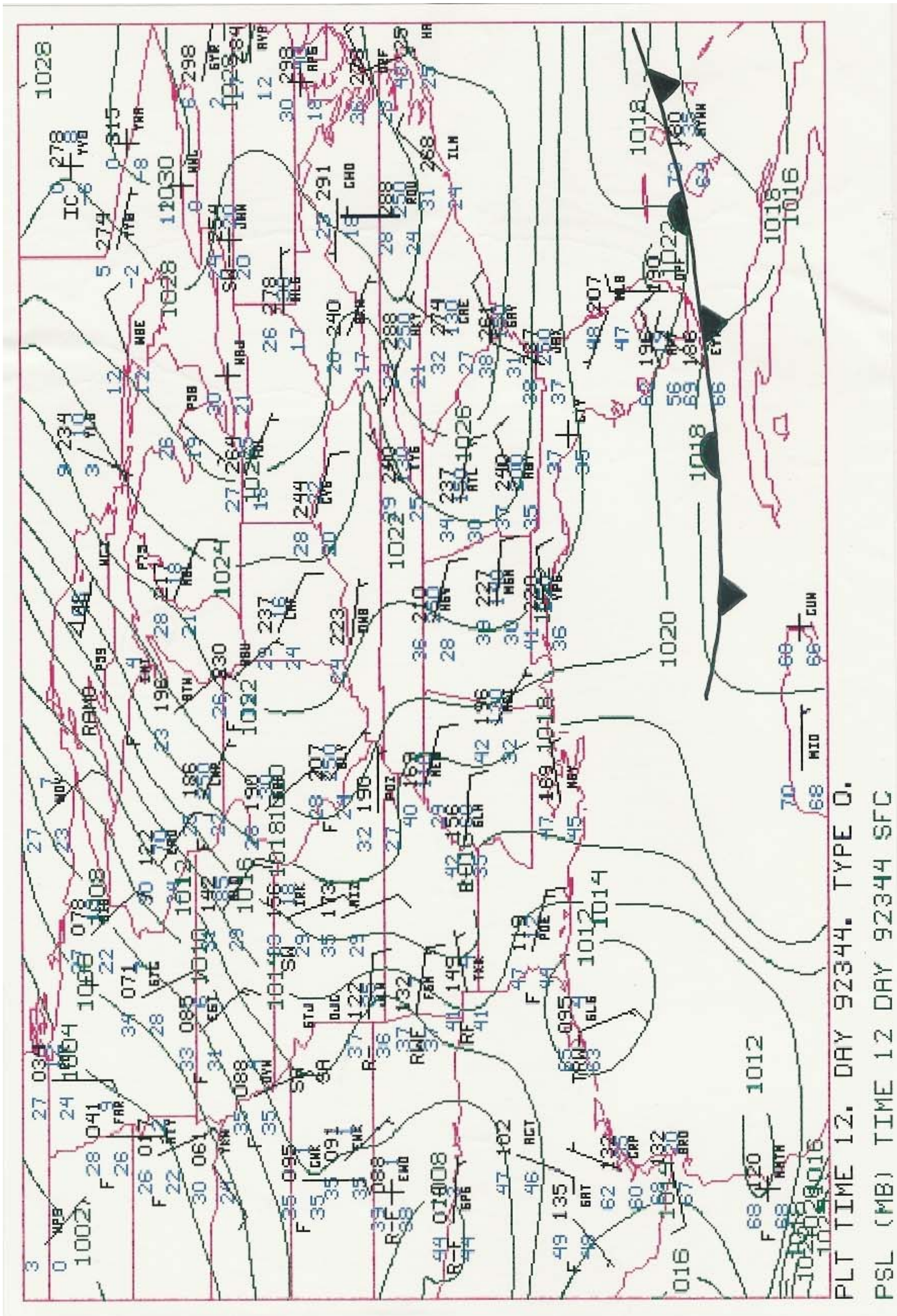


Figure 3. Surface Analysis at 1200 UTC on 9 December 1992.

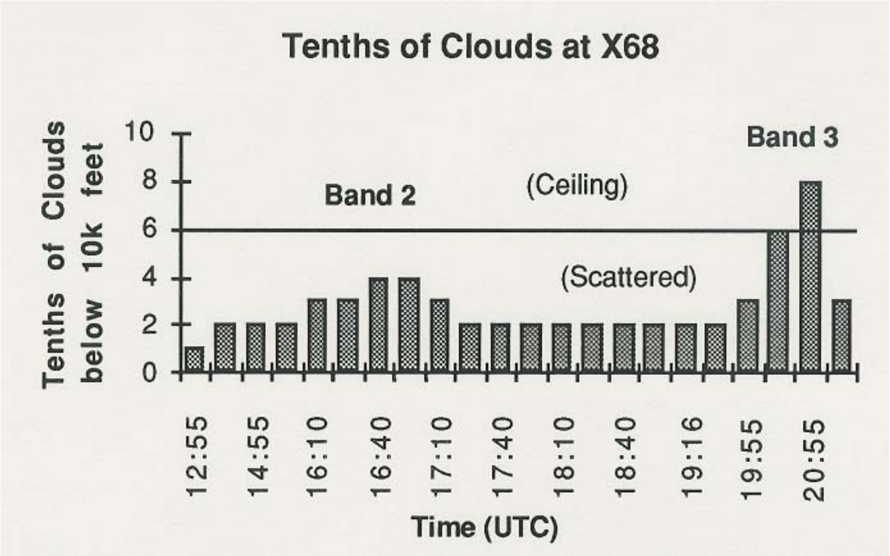


Figure 4. Time Series Graph of Cloud Conditions at the SLF on 9 December 1992.

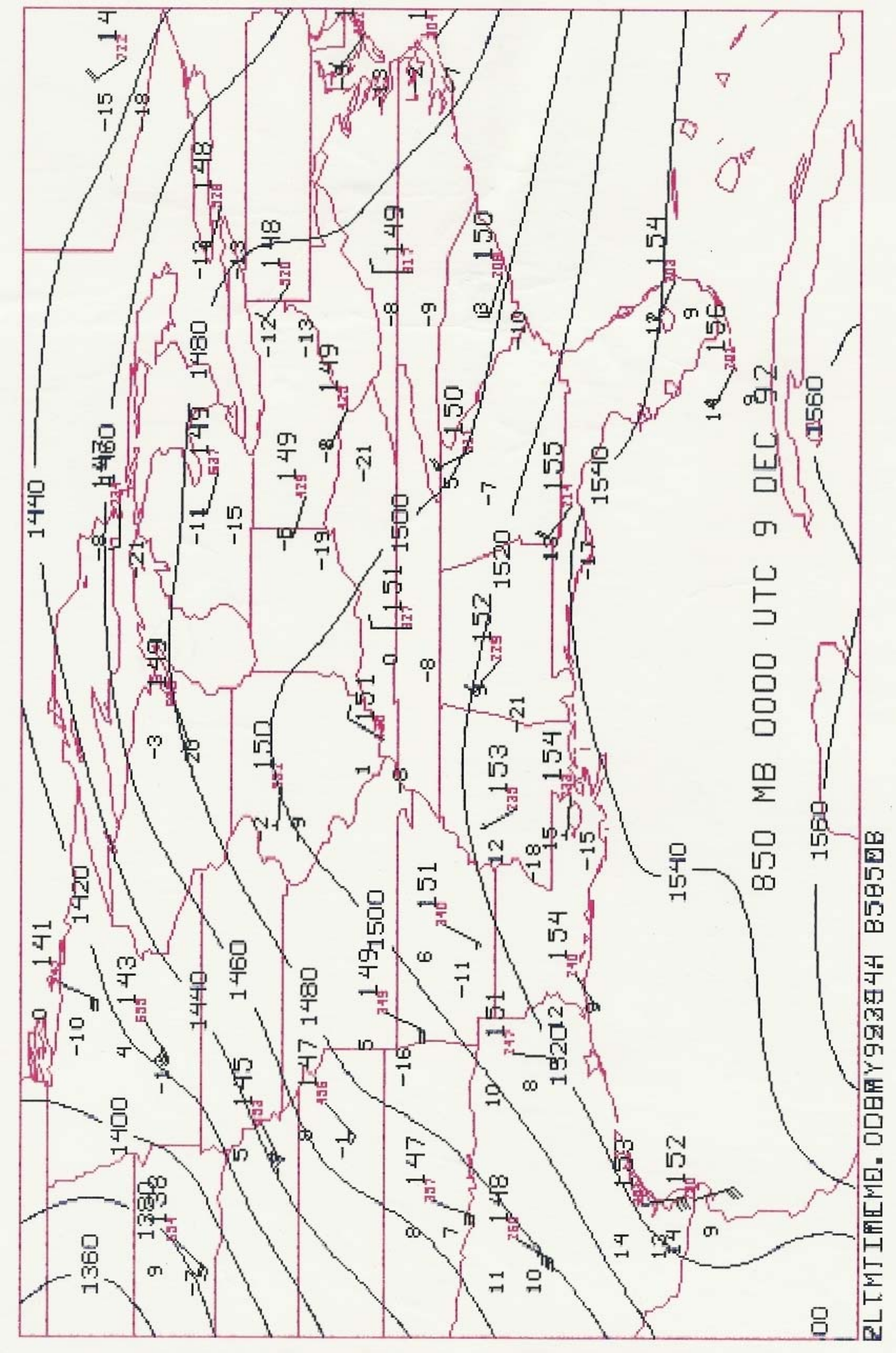


Figure 5. 850 mb Analysis at 0000 UTC on 9 December 1992.

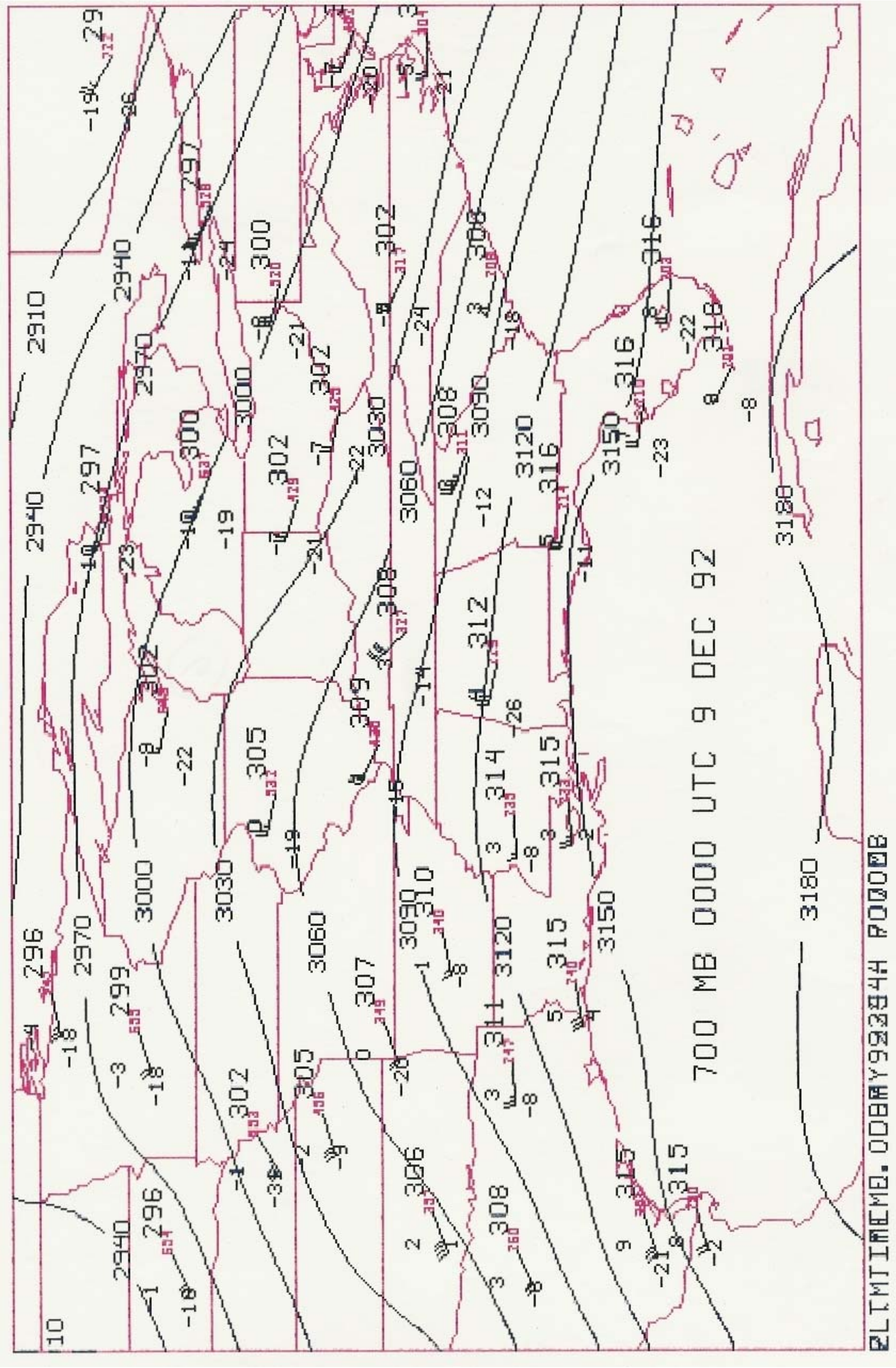


Figure 6. 700 mb Analysis at 0000 UTC on 9 December 1992.

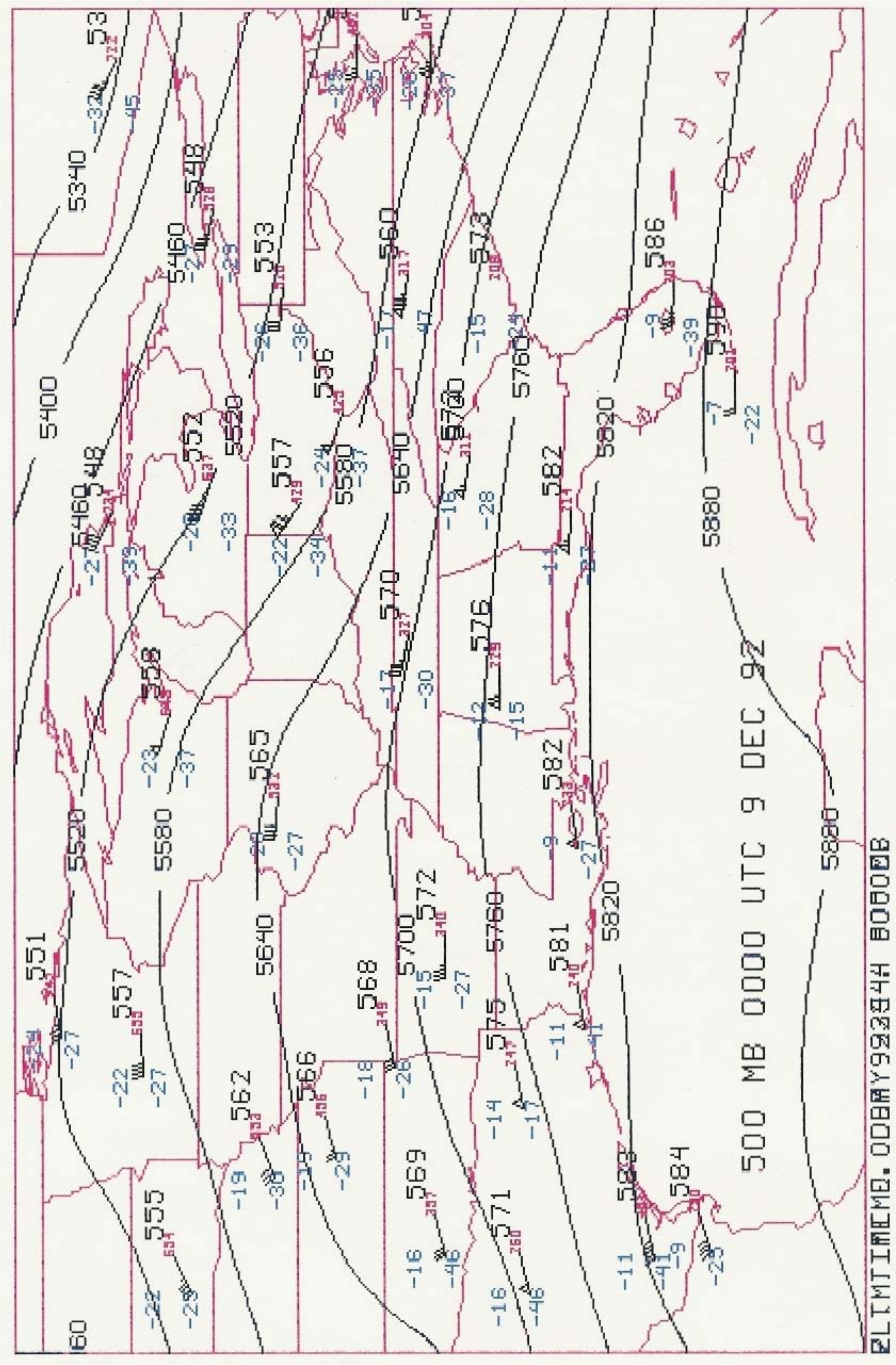


Figure 7. 500 mb Analysis at 0000 UTC on 9 December 1992.

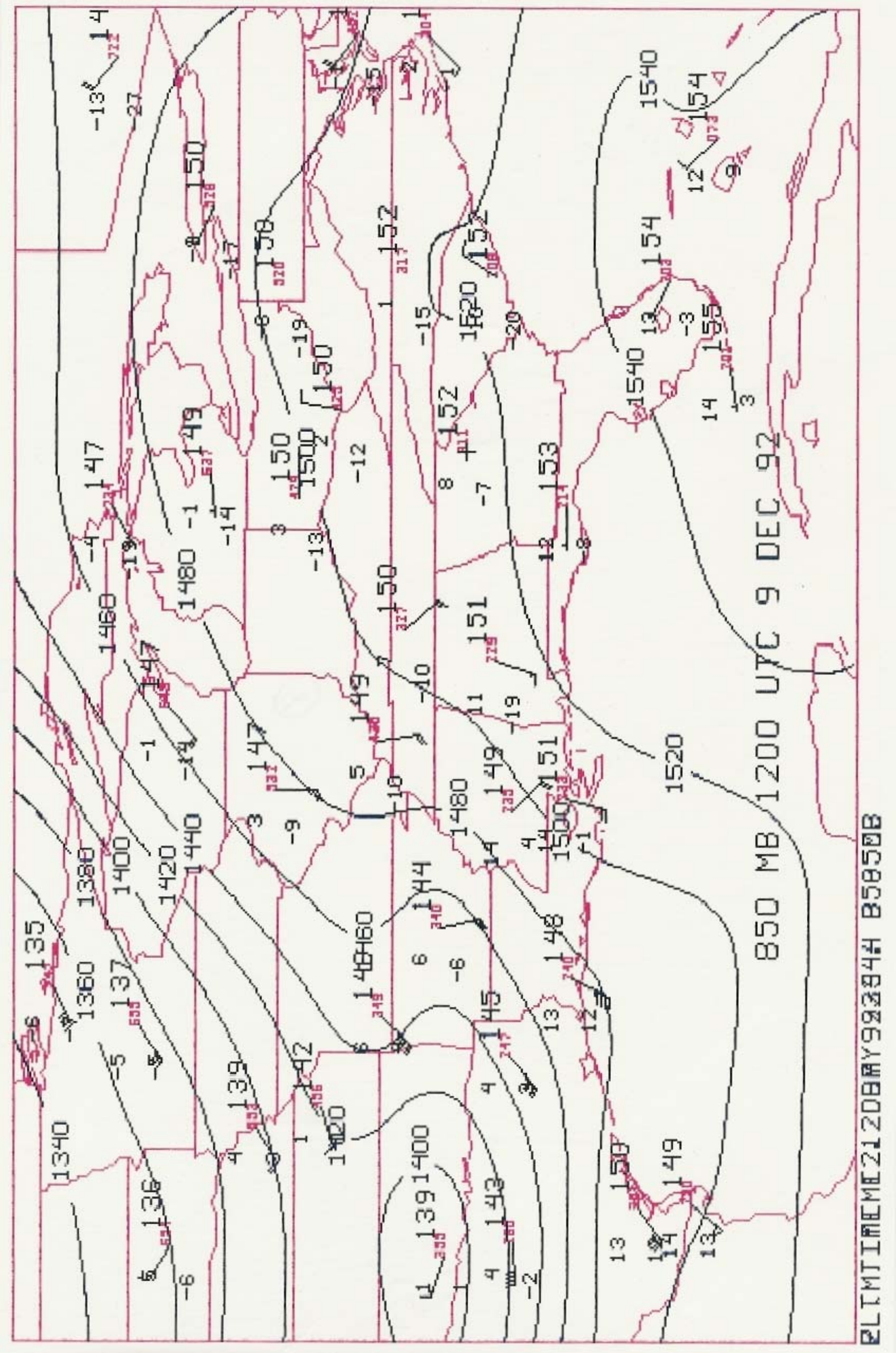


Figure 8. 850 mb Analysis at 1200 UTC on 9 December 1992.

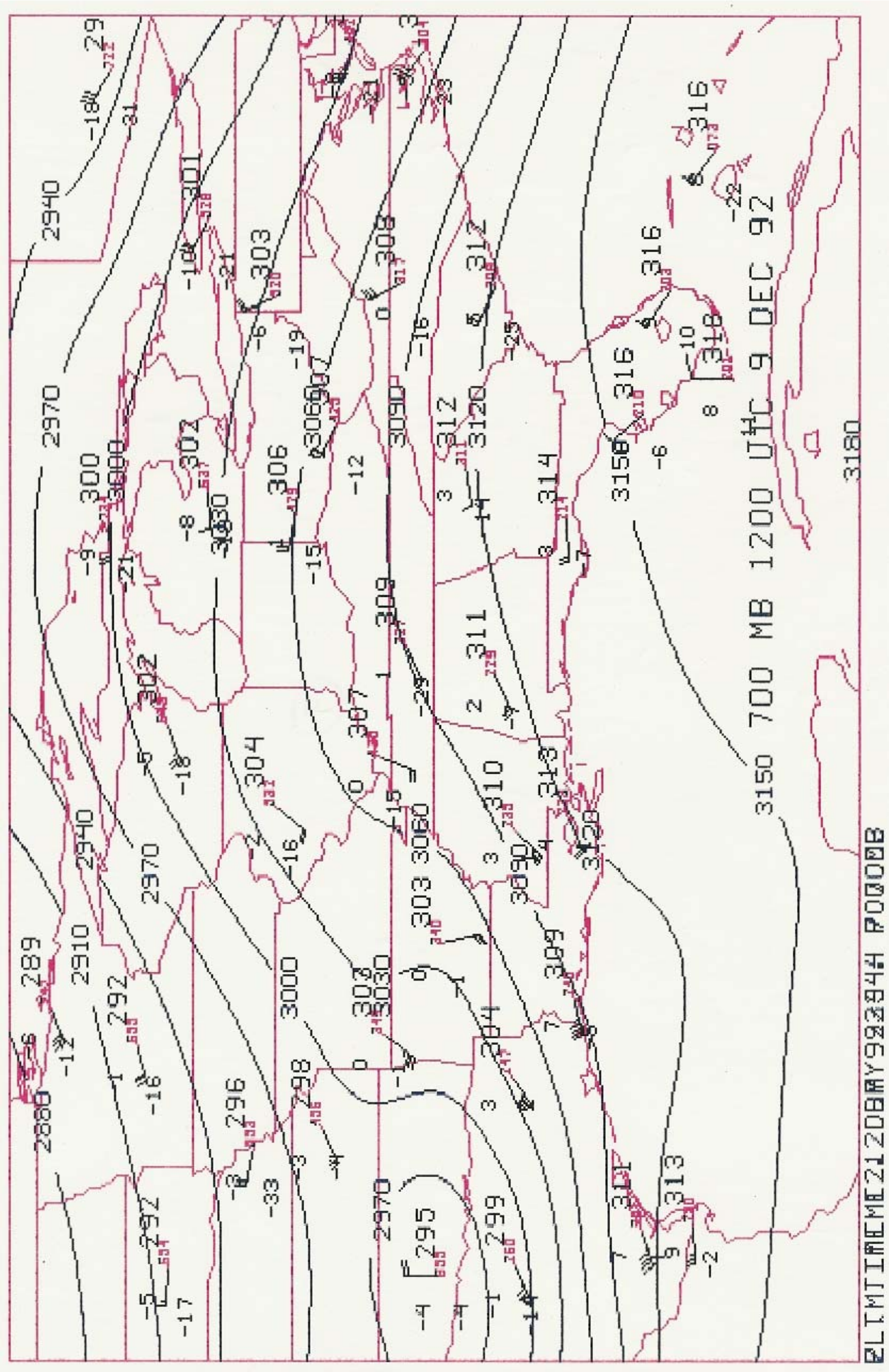


Figure 9. 700 mb Analysis at 1200 UTC on 9 December 1992.

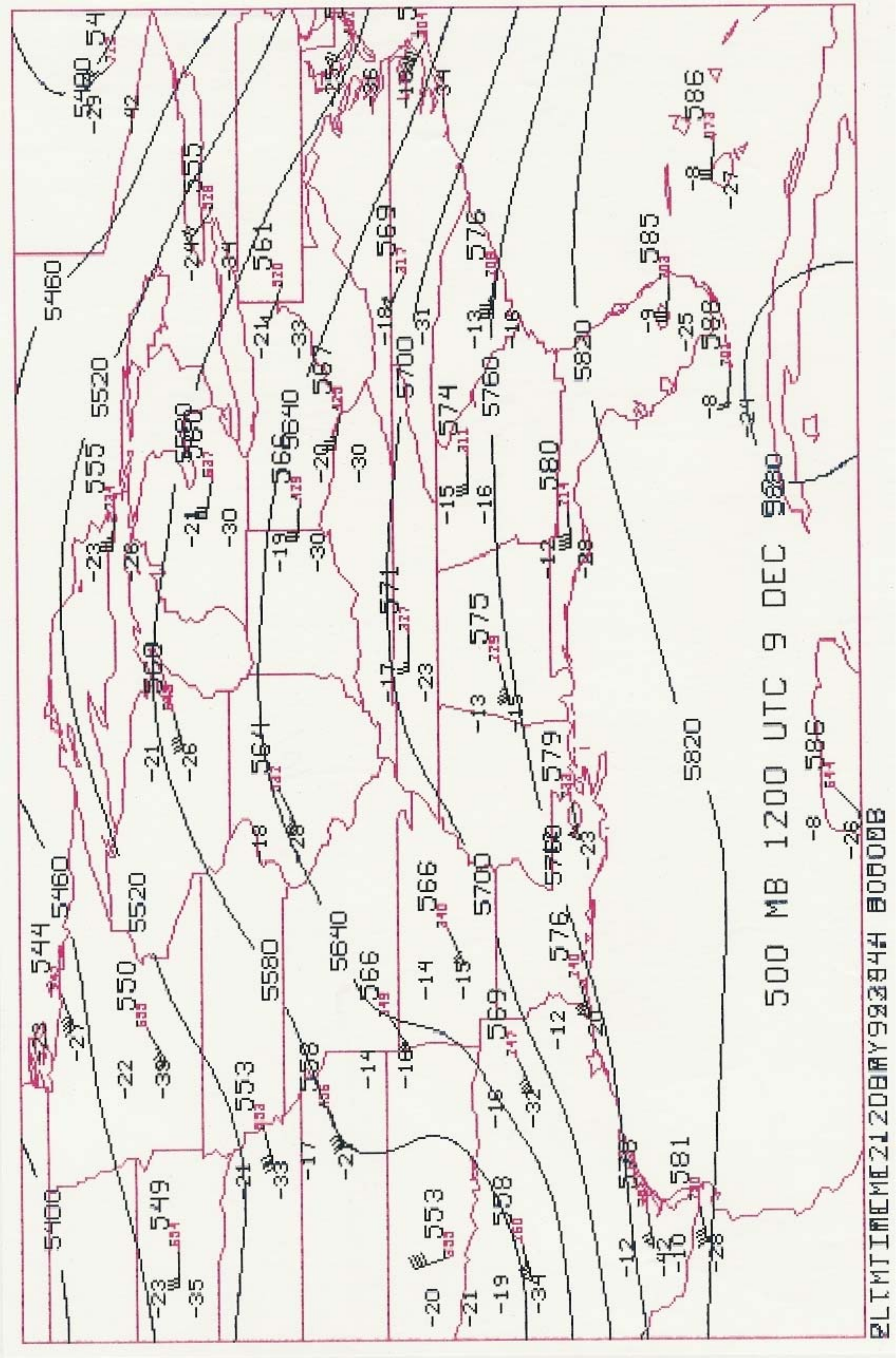


Figure 10. 500 mb Analysis at 1200 UTC on 9 December 1992.

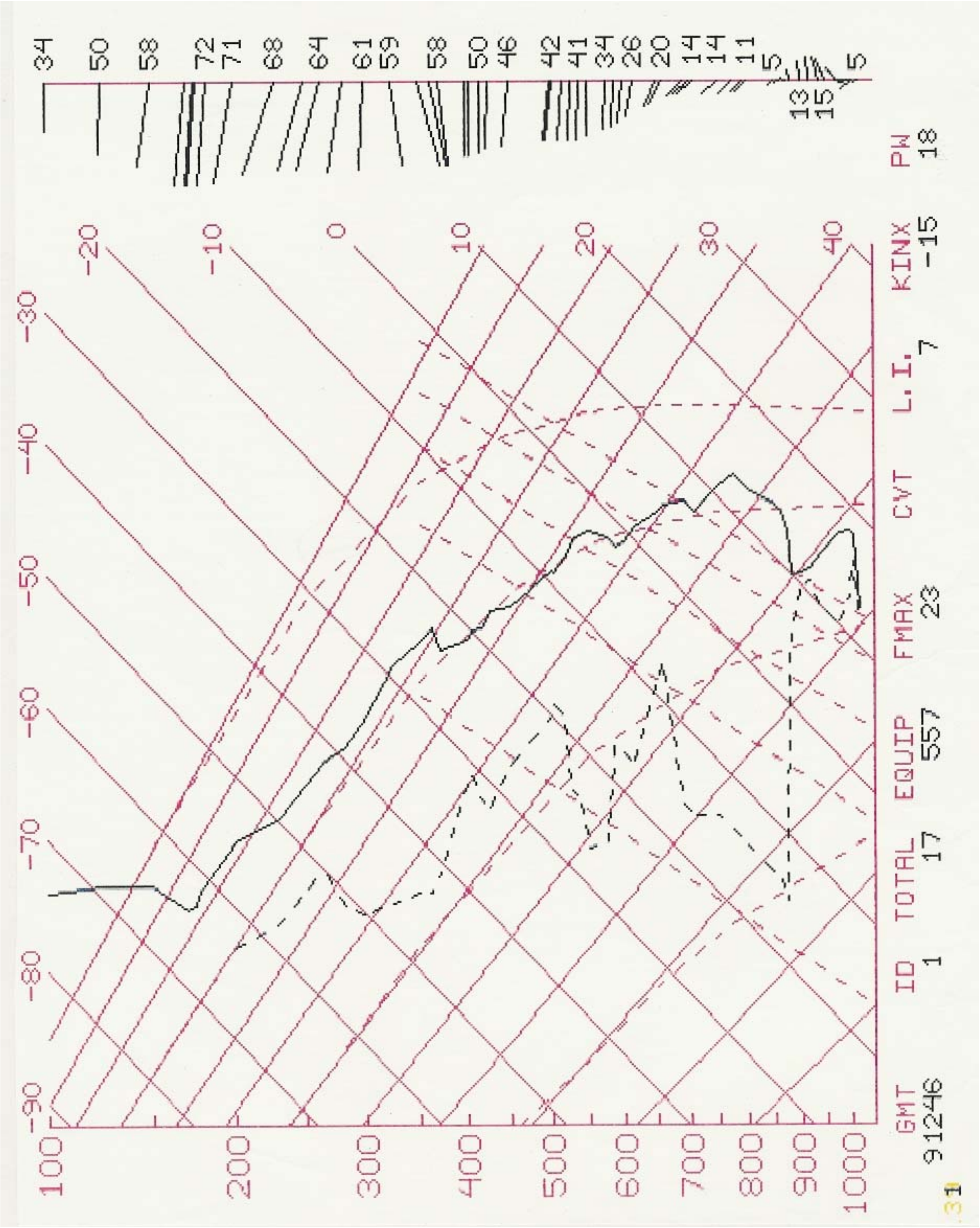


Figure 11. CCAFS Rawinsonde at 1246 UTC on 9 December 1992.

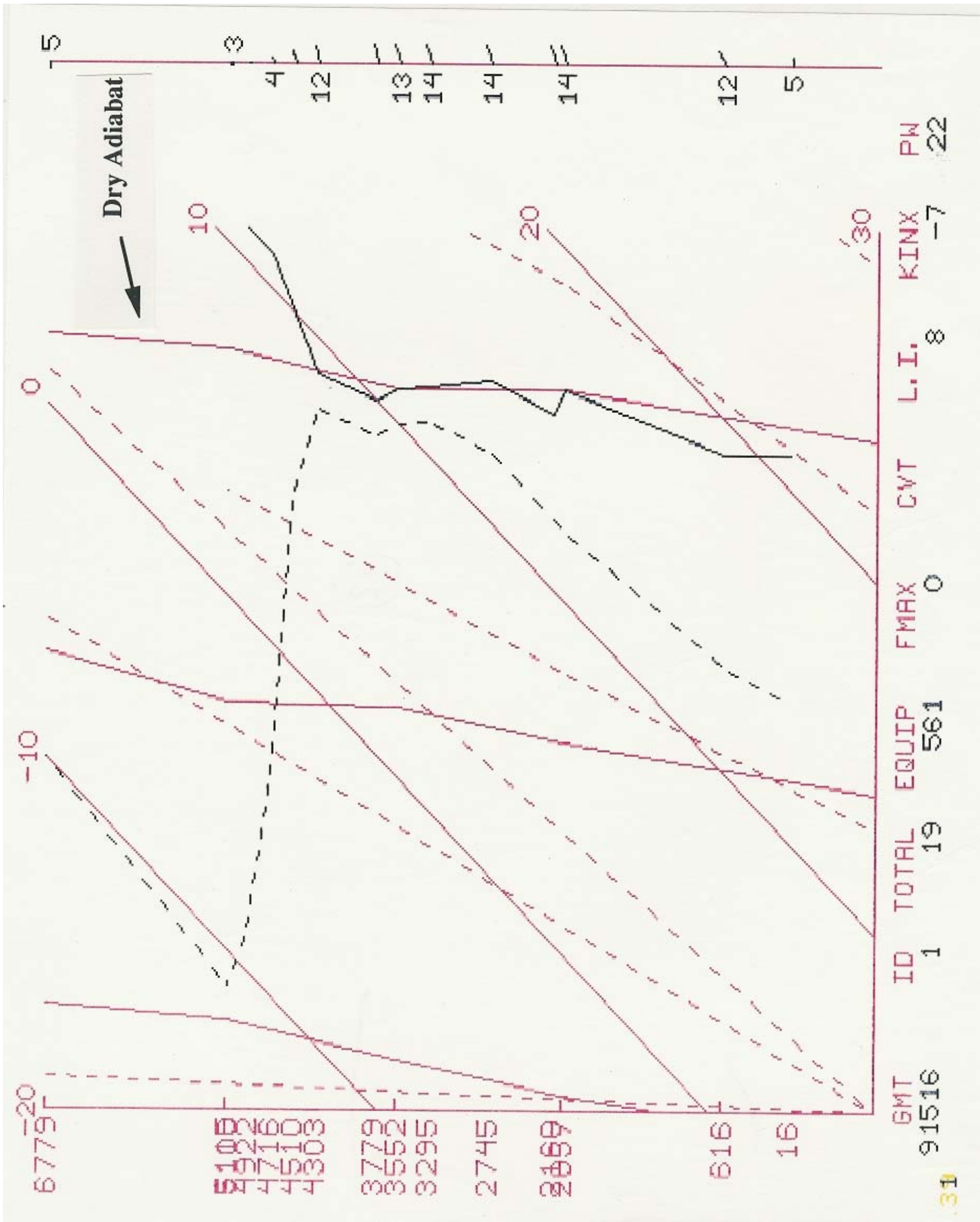


Figure 12. CCAFS Rawinsonde at 1516 UTC on 9 December 1992.

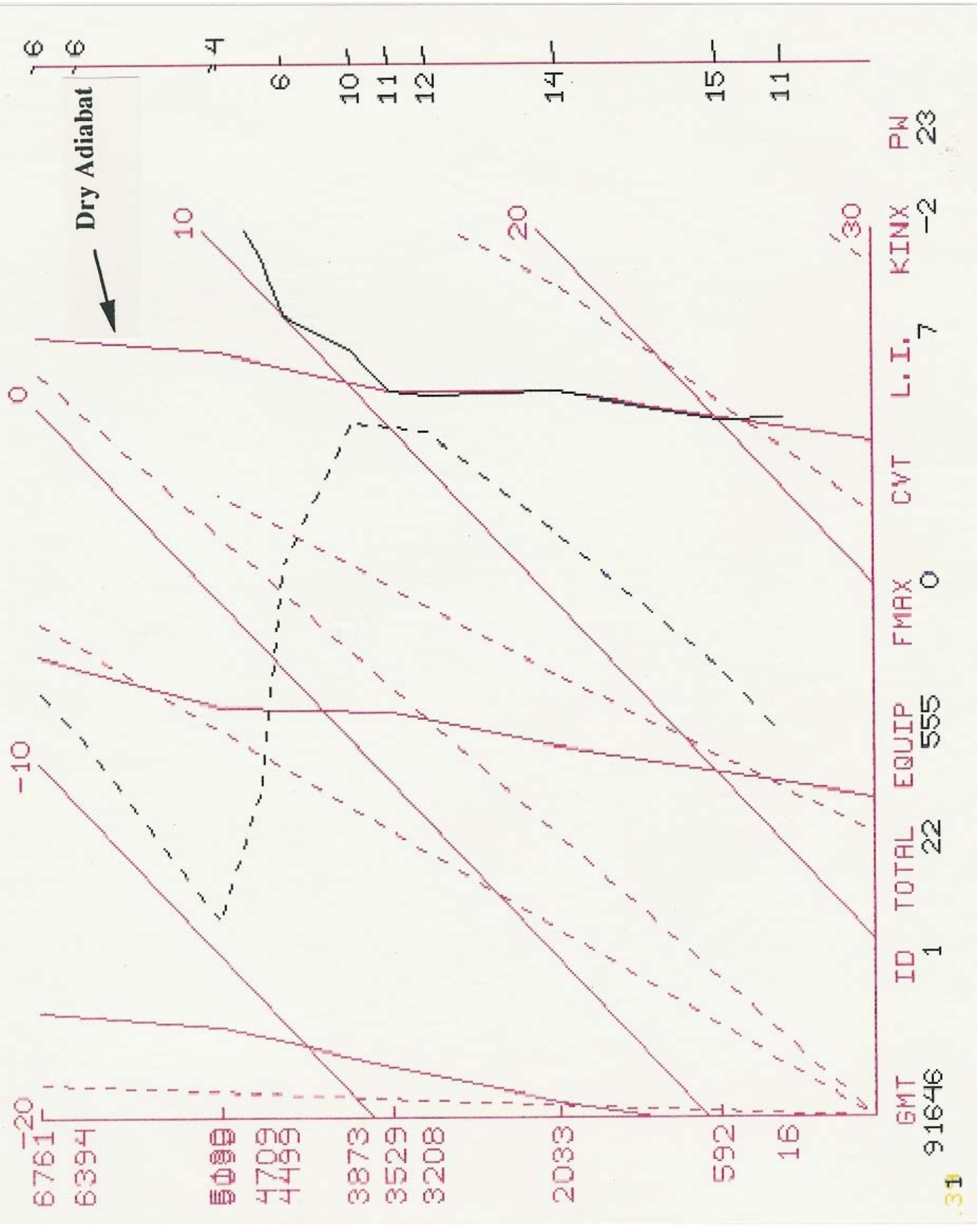


Figure 13. CCAFS Rawinsonde at 1646 UTC on 9 December 1992.

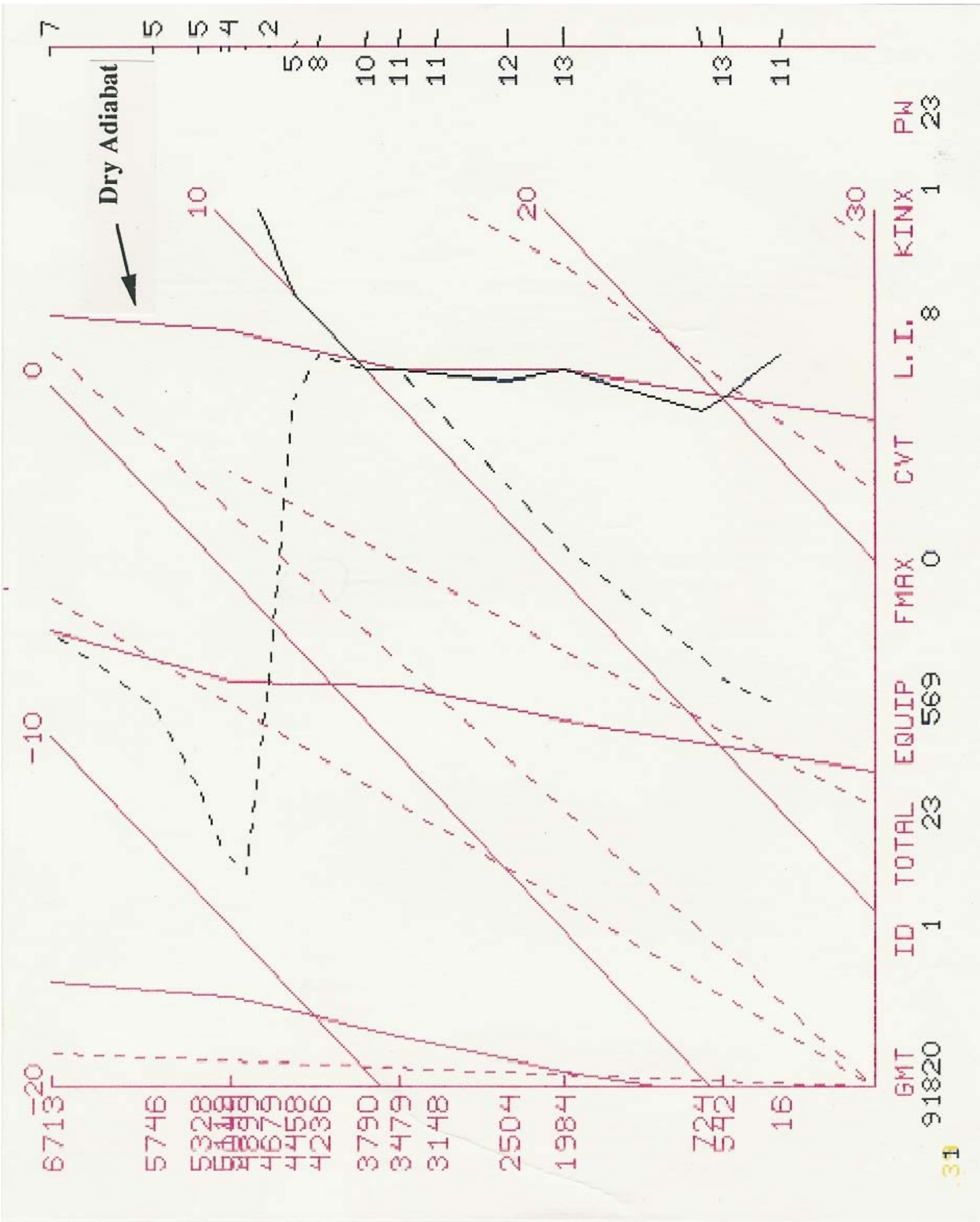


Figure 14. CCAFS Rawinsonde at 1820 UTC on 9 December 1992.

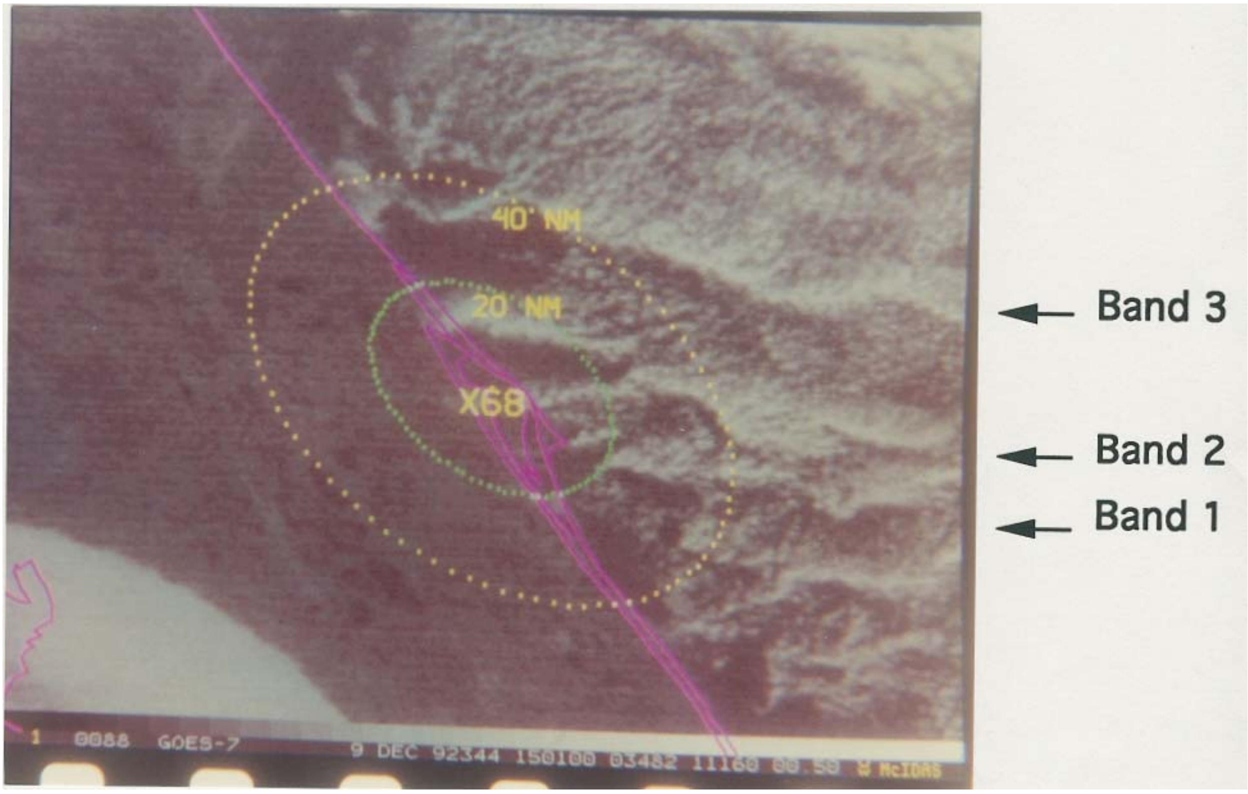


Figure 15. GOES-7 1 km Visible Satellite Image at 1501 UTC on 9 December 1992.

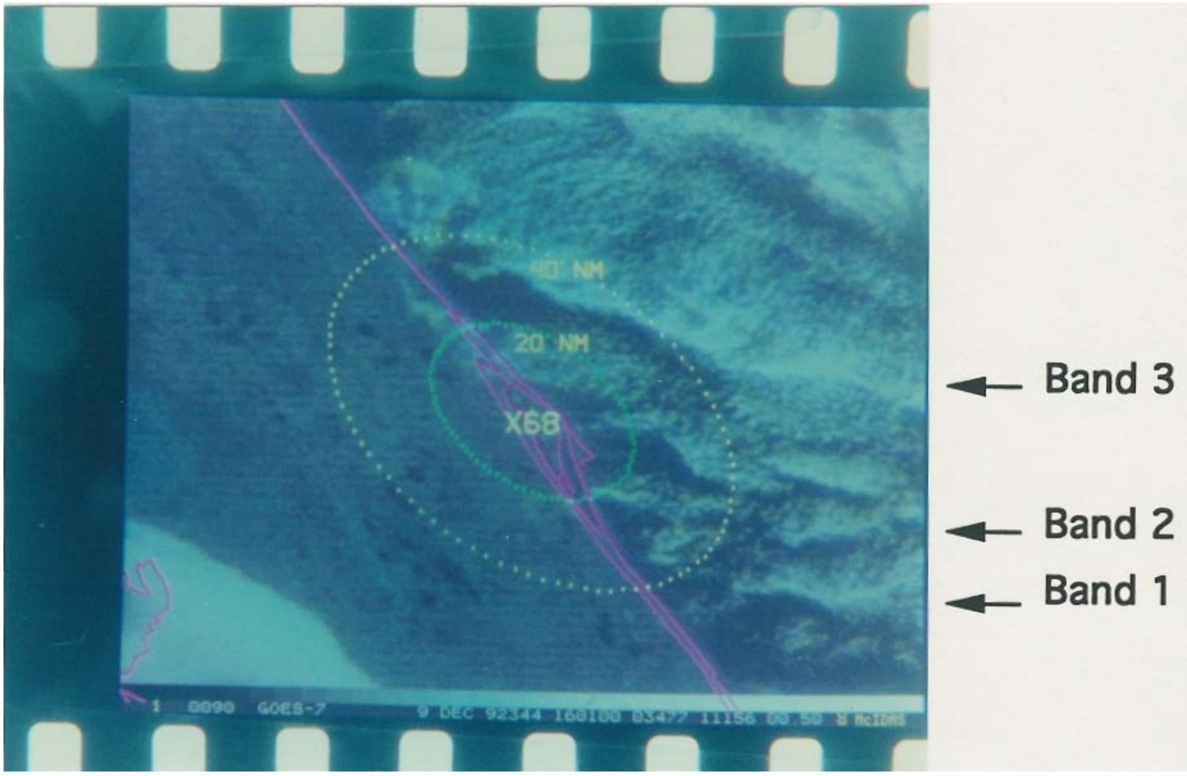


Figure 16. GOES-7 1 km Visible Satellite Image at 1601 UTC on 9 December 1992.

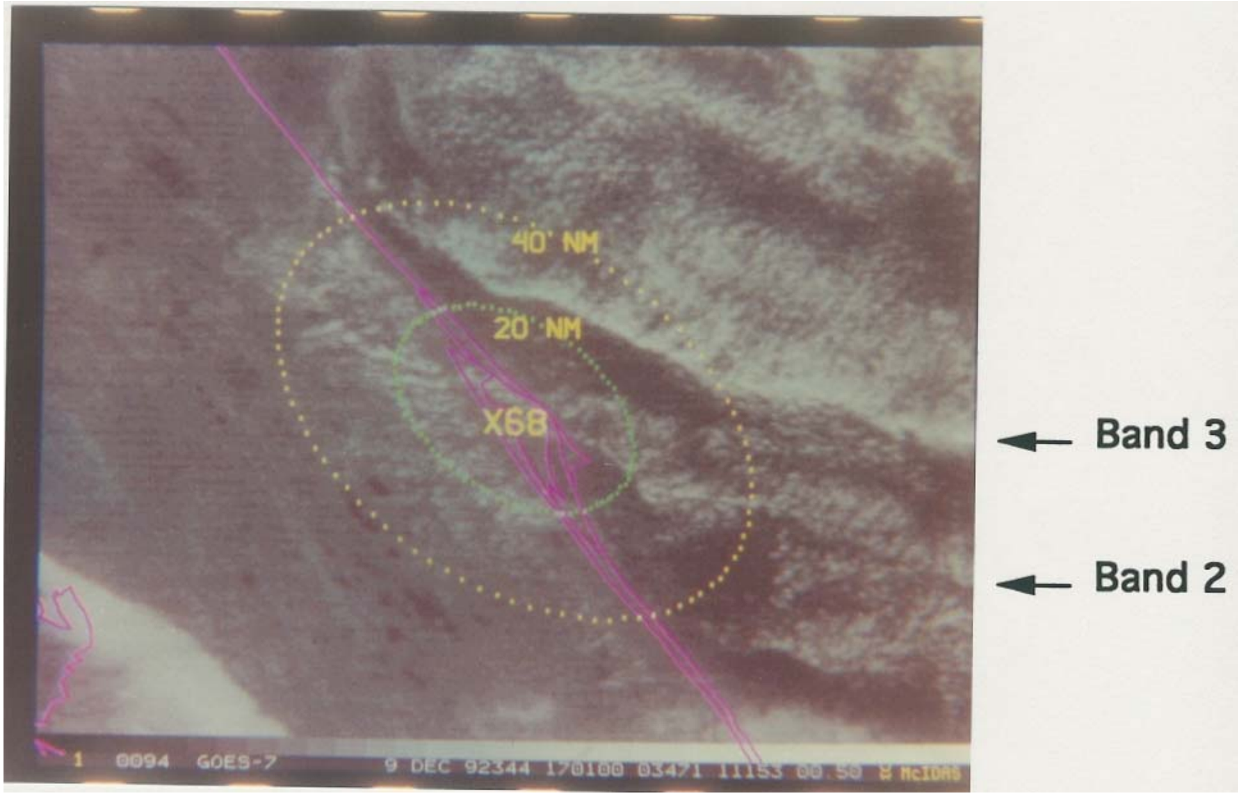


Figure 17. GOES-7 1 km Visible Satellite Image at 1701 UTC on 9 December 1992.

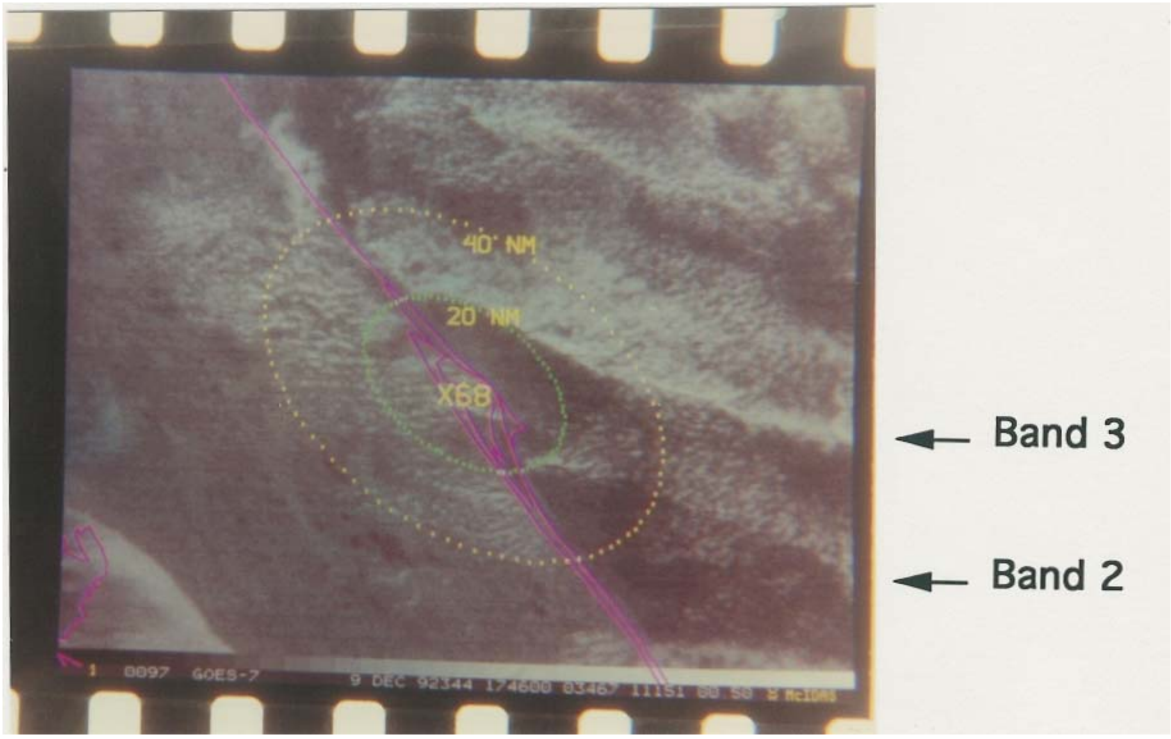
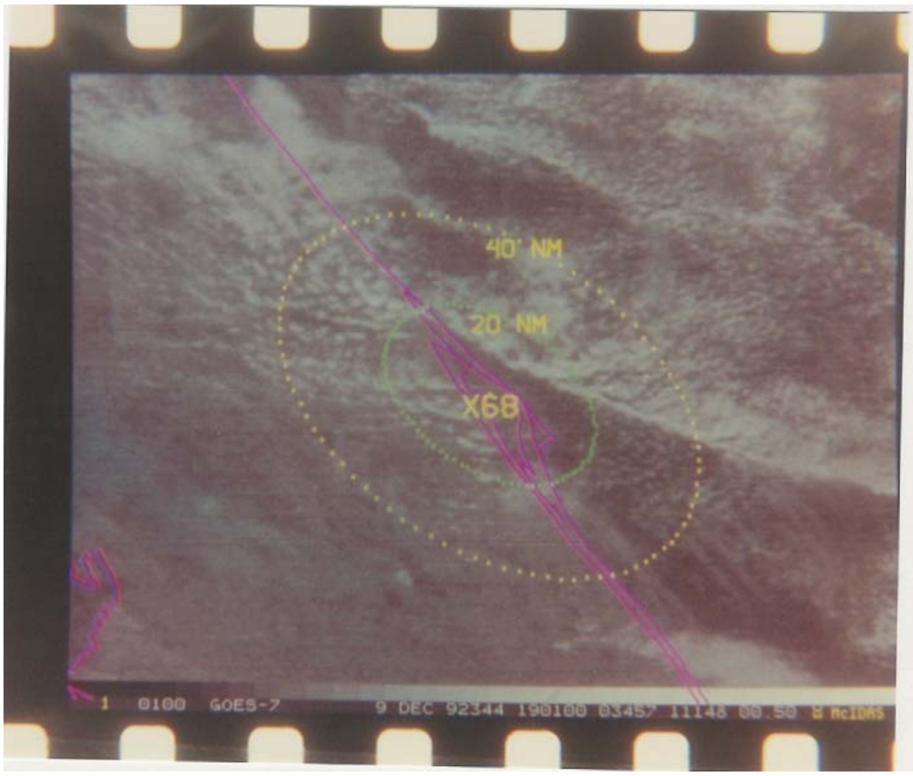


Figure 18. GOES-7 1 km Visible Satellite Image at 1746 UTC on 9 December 1992.



← **Band 3**

Figure 19. GOES-7 1 km Visible Satellite Image at 1901 UTC on 9 December 1992.

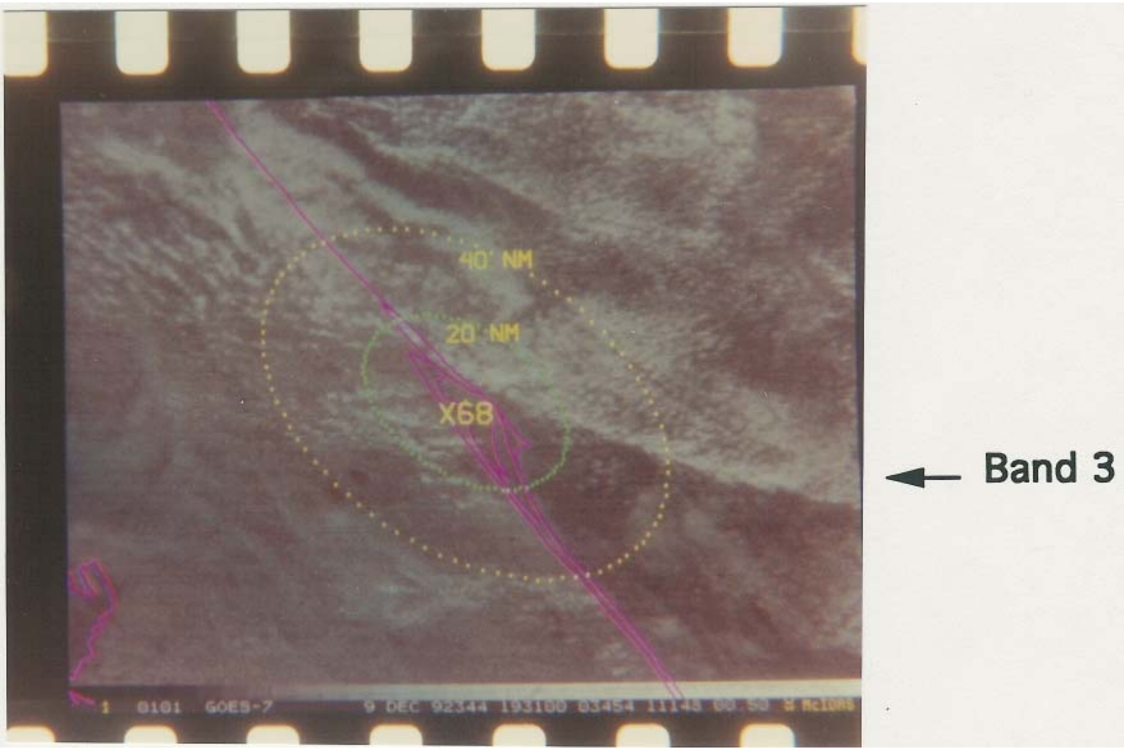


Figure 20. GOES-7 1 km Visible Satellite Image at 1931 UTC on 9 December 1992.

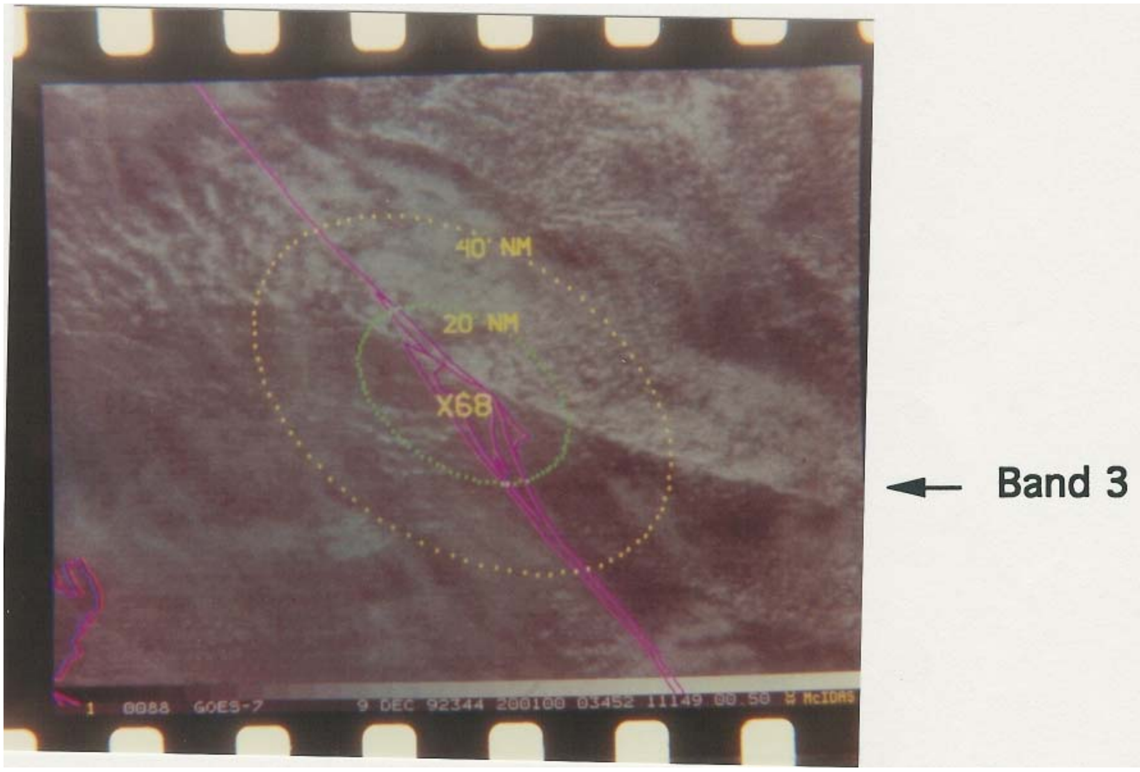


Figure 21. GOES-7 1 km Visible Satellite Image at 2001 UTC on 9 December 1992.

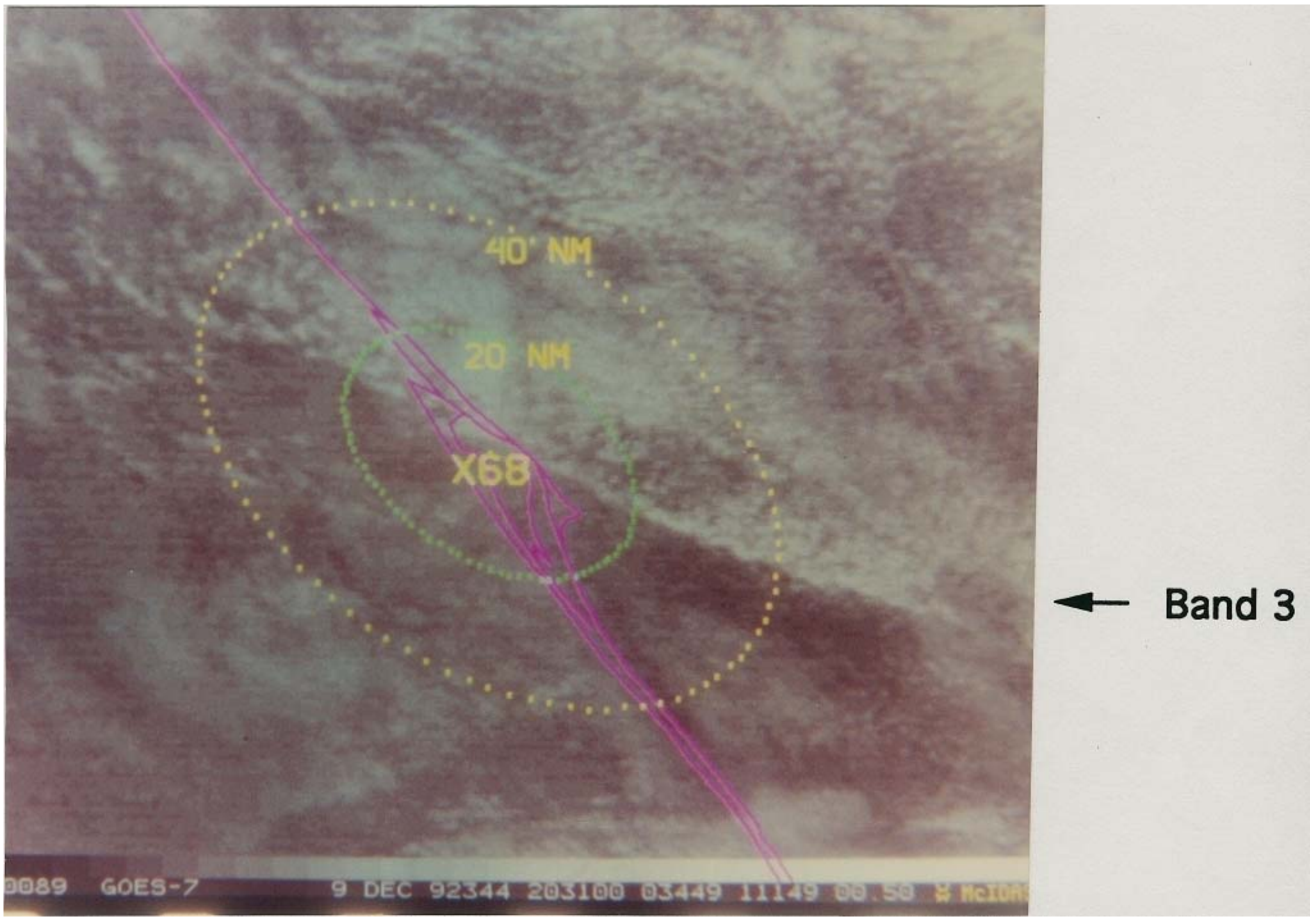


Figure 22. GOES-7 1 km Visible Satellite Image at 2031 UTC on 9 December 1992.

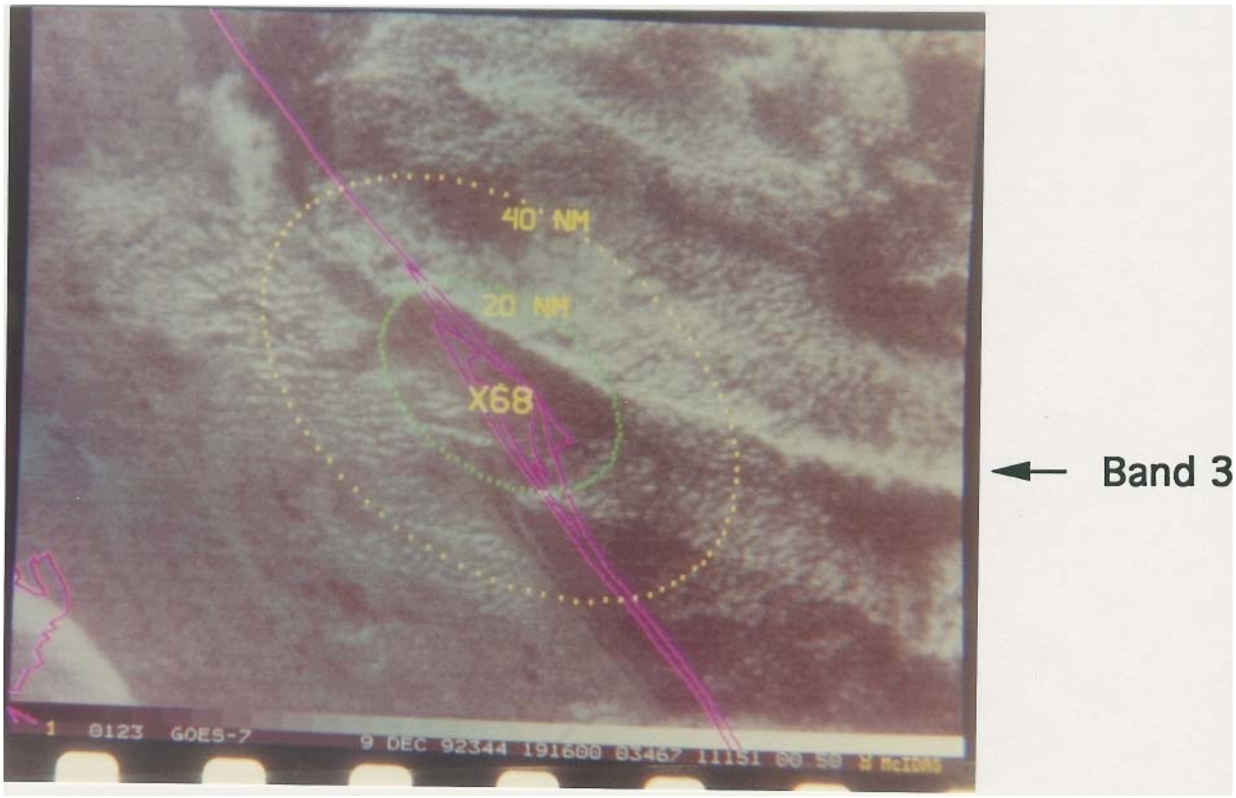


Figure 23. Synthetic Goes-7 1 km Visible Satellite Image for 1916 UTC (translated from the 1746 UTC image).