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METEOROLOGICAL AND OZONE CHARACTERISTICS IN THE HOUSTON AREA FROM AUGUST 23THROUGH SEPTEMBER 1, 2000

FINAL REPORT
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TABLE OF CONTENTS

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LIST OF FIGURES

LIST OF FIGURES (Continued)

Figure **Page**

LIST OF FIGURES (Continued)

LIST OF FIGURES (Continued)

Figure **Page**

LIST OF FIGURES (Continued)

LIST OF FIGURES (Continued)

<u>**Figure**</u> <u>**Page**</u>

LIST OF FIGURES (Continued)

LIST OF FIGURES (Concluded)

1. INTRODUCTION

This report describes the meteorological processes that influenced the spatial and temporal characteristics of ozone for August 15 through September 15, 2000 in the Houston area. This characterization was designed to support the evaluation of photochemical models. The meteorological processes include transport, recirculation, and horizontal dispersion of pollution by wind, variations in sunlight due to clouds, and the vertical mixing and dilution of pollution within the atmospheric boundary layer. The variability of these processes, which affects the variability in pollution, is governed by the diurnal heating and cooling cycle, the movement of large-scale high- and low-pressure systems, and local and regional topography.

In general, high ozone concentrations occur in the Houston area when an aloft ridge of high pressure encompasses the Houston area. Aloft ridges cause sinking in the mid- to low-levels of the atmosphere. As the air sinks, it adiabatically warms, which forms a temperature inversion and stabilizes and dries the atmosphere. This process limits the vertical mixing of boundary layer air and limits cloud production (which increases ozone photochemistry). On the other hand, aloft low-pressure systems are associated with rising air, no inversion, clouds or rain, strong vertical mixing, and low ozone concentrations. Subtle variations in the location and strength of the high and low-pressure systems have a strong influence on the local stability of the atmosphere, which can have a dramatic influence on cloud cover and the vertical dispersion of pollution and, thus, a dramatic influence on ozone concentrations.

Besides influencing the stability and cloud cover, aloft pressure systems also influence the strengths and locations of surface high- and low-pressure systems. In turn, the large-scale pressure patterns interact with local mechanisms to produce the observed local flows in the Houston area. The local mechanisms are generally driven by the diurnally changing temperature contrast between the land, Galveston Bay, and the Gulf of Mexico. In the Houston area, the large-scale summertime boundary layer flow is typically a sea breeze from the southeast. This flow is driven by circulation around a surface high that typically persists over the eastern Gulf of Mexico and Western Atlantic (the Bermuda High). However, with an upstream ridge or a broad high influencing the weather in Texas, the influence of the Bermuda High on local winds is often reduced. Under these conditions, the boundary layer southeasterly winds are lighter than normal and can even turn light northerly at night and in the early morning hours. This pattern can create rotation in the winds and flow reversals for a few hours during the morning and midday period as the land breeze transitions to the Bay or Gulf breeze. This pattern fosters stagnation, reduced transport distances, and, under some circumstances, recirculation—all of which lead to pollutant build up.

These general meteorological processes are associated with high ozone concentrations in the Houston area. The day-by-day characterization that follows shows that slight variations in the meteorological processes described above can have a dramatic affect on the spatial and temporal characteristics of high ozone concentrations. It is these variations in meteorological processes that should be captured in modeling efforts if they are to properly replicate the physical system that led to the observed temporal and spatial characteristics of ozone concentrations in the Houston area from August 15 to September 15, 2000. The meteorological processes or conditions that are particularly important include

- The timing, spatial extent, and strength of convective cloud cover.
- The large-scale pressure pattern.
- The existence, timing, strength, direction, and spatial extent of the land breeze, Bay breeze, and Gulf breeze.
- The evolution of the mixed layer, including the rate of growth of the convective boundary layer (CBL), the ultimate height of the CBL, and other changes in the CBL (i.e., if and when the CBL is undercut by the Bay marine layer and/or the Gulf marine layer).

The basic understanding regarding the phenomena that influence ozone concentrations in the Houston area is based on previous work by a large number of researchers, including the following: Paul Roberts et al., 1995[1] (and summarized in Haney et al., 1995[2]); work by various TNRCC staff members including Pete Breitenbach, Fernando Mercado, and Bethany Georgoulias and summarized by Breitenbach (2001)[3]; work by John Nielsen-Gammon (for example, his April 2002 presentation[4] and information on the Texas A&M University web site, http://www.met.tamu.edu/temp/); and information on the TexAQS-2000 web site (http://www.utexas.edu/research/ceer/texaqs/). Much of this work has been focused on a "conceptual model" of the meteorological phenomena that influence high ozone concentrations in the Houston area. A conceptual model is a description, both in text and graphical images, of the important phenomena (meteorological and chemical) that influence high ozone concentrations in an area.

This report presents the data and information we used to characterize the meteorological processes (Section 2), a summary of the most important meteorological characteristics on each day of the study period (Section 3), and details of those characteristics on each day (Section 4). Appendix A contains a day-by-day visual summary of the air quality and meteorological characteristics of the August 15 through September 15, 2000 period that were used to support the analysis presented in Sections 3 and 4. Appendix B contains weather maps for the same period.

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[1] Roberts P.T., Lindsey C.G., Dye T.S., Main H.H., Korc M.E., Ray S.E., Arthur M., and Schoell B.M. (1995) Gulf of Mexico Air Quality Study. Volume 2: data analysis appendices A-M. Draft final report prepared for U.S. Department of the Interior, MMS, Gulf of Mexico OCS Region, New Orleans, LA and Systems Applications International, San Rafael, CA by Sonoma Technology, Inc., Santa Rosa, CA, STI-92091-1512-DV (SYSAPP-95/013d, OCS Study, MMS 94-0046), March.

[2] Haney J., Douglas S.G., Lok N., Roberts P.T., Lindsey C.G., Main H.H., Dye T.S., Korc M.E., Ray S.E., Arthur M., and Schoell B.M. (1995) Gulf of Mexico Air Quality Study. Volume 1: summary of data analysis and modeling. Final report prepared for U.S. Department of the Interior, MMS, Gulf of Mexico OCS Region, New Orleans, LA by Systems Applications International, San Rafael, CA, SYSAPP-95/013d, OCS Study, MMS 94-0046, August.

[3] Breitenbach, P. (2001) Meteorological model for Houston/Galveston ozone events. Presented at the TNRCC Interim Science Meeting, August 7, 2001.

[4] Nielsen-Gammon, J.W., (2002) MM5 modeling of August 2000 episode and conceptual model of wind flow patterns. Presented at TNRCC Interim Science Coordinating Committee/Texas Environmental Research Consortium Meeting and Workshop, April 4-5, 2002.

2. DATA AND INFORMATION USED TO CHARACTERIZE METEOROLOGICAL PROCESSES

In order to characterize the meteorology and ozone concentrations for August 15 through September 15, we analyzed selected available data and organized them into the following topics.

Large-Scale Aloft Weather: The height of the 500-mb constant-pressure level and winds at 500 mb as depicted on the National Weather Service Daily Weather Maps were used to characterize the aloft large-scale weather patterns that existed at 0600 CST on each day. Locations and strengths of ridges, troughs, and circulation patterns were noted, along with their probable influence on mixing and cloud cover in the Houston area. Selected weather maps are shown in Section 4 and Appendix B contains weather maps for the entire period.

Large-Scale Surface Weather: The large-scale surface pressure pattern and regional winds as depicted on the National Weather Service Daily Weather Maps were used to characterize the large-scale surface flows that existed at 0600 CST on each day. General locations of surface highs and lows were noted, along with their probable influence on local flows in the Houston area.

Local Flows: The diurnal and spatial changes in the local flow patterns were characterized by reviewing hourly spatial plots of surface wind data collected at all Continuous Air Monitoring Station (CAMS) sites within the Houston area and hourly radar profiler wind and reflectivity data collected at Ellington Field. The existence, timing, and strength of synoptic winds, the land breeze, the Bay breeze, and the Gulf breeze were noted, along with their relationship to the vertical mixing at Ellington Field, the large-scale pressure pattern, and cloud cover.

The Ellington Field profiler data were obtained from the Texas Natural Resource Conservation Commission (TNRCC). We performed a brief quality check of this data, which included removing data that were contaminated by birds. We also received Ellington Field profiler data that were quality controlled by the Environmental Technology Lab (ETL). Since the quality-controlled data sets were similar, we chose to use the data from TNRCC since the data were in CST time and reported semi-hourly, as opposed to the ETL data, which were in UTC time and reported every hour.

Cloud Cover: Quarter-hourly visible satellite images of southeast Texas were reviewed to characterize the spatial and temporal variations in cloud cover and its probable impact on photochemistry. The existence and movement of clouds associated with large-scale systems, convective activity, the land breeze front, the Bay breeze front, and the Gulf breeze front were noted.

Vertical Mixing: The hourly height of the daytime surface-based mixed layer was estimated from the Ellington Field radar profiler reflectivity data for August 25-28, 30, and 31, and September 1. Reflectivity data were not of sufficient quality to estimate mixing height on August 23, 24, and 29. The mixing height data were used to determine the characteristics of the daytime mixed layer including the period of CBL growth, the maximum height of the CBL, the time of maximum height of the CBL, and any undercutting of the CBL by the Bay and/or Gulf boundary layers.

Ozone Patterns: Spatial and temporal ozone patterns were analyzed by reviewing hourly spatial plots of ozone data collected at CAMS sites in the Houston and Galveston Bay area. The ozone plots were reviewed in conjunction with the meteorological data discussed above.

Additional meteorology and air quality metrics were calculated and reviewed and are discussed in Appendix A.

3. SUMMARY OF IMPORTANT CHARACTERISTICS FOR EACH DAY

This section summarizes the most important meteorological and ozone characteristics for each day from August 15 through September 15, 2000. More details and figures illustrating the various processes are included in Section 4 and in Appendix A.

August 15–Ozone concentrations were not high on this day due to continuous onshore southeasterly flow. The peak ozone concentration was 87 ppb at Conroe at 1500 CST.

August 16–Ozone concentrations were moderate on this day. The peak ozone concentration occurred east of Houston and the Ship Channel at Baytown (111 ppb at 1400 CST). The location of the peak ozone is consistent with persistent west winds.

August 17–Ozone concentrations were high on this day due to a 135^o rotation in the winds from westerly in the morning to southeasterly in the afternoon and stable atmospheric conditions associated with a small aloft anticyclone.

August 18–Ozone concentrations were lower than on August 17, primarily due to continuous onshore winds that drove the high ozone concentrations well north of Houston to Conroe (130 ppb at 1700 CST)**.**

August 19–Ozone concentrations were higher than on August 18 (146 ppb maximum) primarily due to some recirculation defined by a 135^o rotation in the winds from westerly in the morning to southeasterly in the afternoon.

August 20–Ozone concentrations were not as high (113 ppb maximum) as on August 19 even though there was a 135^o rotation in the winds from westerly in the morning to southeasterly in the afternoon. It is possible that the monitoring network did not observe the highest ozone levels northeast of Houston between Baytown and Conroe.

August 21–Widespread high ozone concentrations resulted from sunny skies after brief morning cloudiness and recirculation of both downtown and Ship Channel emissions as winds shifted from northwest in the morning to southeast in the afternoon.

August 22–Ozone concentrations were not high on this day because there was only a 45^o rotation in the winds from northeast in the morning to east in the afternoon.

August 23–Ozone concentrations were not high due to significant morning cloud cover, no surface stagnation, and only a 45^o rotation in the winds from northeast in the morning to east in the afternoon.

August 24–Ozone concentrations were higher than on August 23 but were still relatively low due to widespread convective activity that began about 1300 CST. This activity appears to have been related to a pressure disturbance and not the Bay or Gulf breeze front.

August 25–Ozone concentrations were high on this day and were associated with land/Bay/Gulf breeze circulation, relatively low mixing heights, few clouds, and a polluted Bay breeze that undercut the convective boundary layer and penetrated well into central Houston before being overrun by the Gulf breeze.

August 26–Ozone concentrations were high on this day in northeast Baytown in the late morning and late in the day at Conroe. This day was different from August 25 in that morning flow was from the west, afternoon flow was from the southeast, and there was only a very brief weak Bay breeze. It is probable that the monitoring network failed to observe the majority of the polluted air as it moved between Baytown and Conroe, northeast of the monitoring network.

August 27–Ozone concentrations were low primarily due to high mixing heights and very early onset of the Gulf breeze driven by large-scale southerly flow.

August 28–Ozone concentrations were moderate on this day. Winds were similar to those on August 27, with very early onset of the Gulf breeze driven by large-scale southerly flow; however, mixing heights were much lower than on August 27, which could explain the higher ozone concentrations on August 28.

August 29–Ozone concentrations were moderate to high on this day even though there was no land/Bay/Gulf breeze cycle. The flow and ozone patterns were very similar to those on August 26, with morning flow from the west, afternoon flow from the southeast, and no Bay breeze. As on August 26, it is probable that the monitoring network failed to observe the majority of the dirty air as it moved between Baytown and Conroe, northeast of the monitoring network.

August 30–Ozone concentrations were very high on this day due to low mixing heights, no clouds, and recirculation defined by a moderate northwest land breeze and a period of stagnation, followed a weak southeast Bay breeze.

August 31–High ozone concentrations existed throughout the Houston area, with very high ozone concentrations in the Ship Channel. The high concentrations were associated with confined vertical mixing, probable carryover from August 30, and light west to northwest winds. There was no land/Bay/Gulf breeze circulation.

September 1–High ozone concentrations were confined to the Baytown area. The high concentrations in Baytown were associated with west and southwest flow throughout the day.

September 2–Ozone concentrations were moderately high (125 ppb maximum) due to sunny skies and limited recirculation. The recirculation was caused by light-to-moderate westerly and northwesterly winds until mid-afternoon, followed by a light southeasterly Bay breeze.

September 3–High ozone concentrations were confined to Baytown and La Porte due to persistent west/southwest winds.

September 4–High ozone concentrations were confined to Texas City and Galveston due to morning west and northwest winds, followed by afternoon northeast and east winds. In addition, it is possible that the high ozone concentrations at Galveston were, in part, related to smoke that was transported from a fire located between Houston and Lake Charles, Louisiana.

September 5–High ozone concentrations occurred at Galveston (133 ppb) and at Clute (185 ppb) due to clear skies and persistent north and northeast winds. Ozone concentrations in the Houston and Ship Channel areas were much lower.

September 6–High ozone concentrations were confined to southwest of Houston due to persistent northeast to east winds.

September 7–Low ozone concentrations were associated with moderate northeasterly flow and an upper-level low-pressure system over the area.

September 8–Low ozone concentrations were associated with northeasterly winds, an upper-level low-pressure system, and cloudy skies.

September 9–Moderate ozone concentrations (104 ppb maximum) were associated with light and variable morning winds followed by a light afternoon Gulf breeze, and partly cloudy skies associated with a low-level disturbance just offshore of Galveston.

September 10–Low ozone concentrations (83 ppb maximum) were associated with onshore flow the entire day and an upper-level low-pressure system.

September 11–Very low ozone concentrations occurred due to convective activity, clouds, and onshore flow the entire day.

September 12–Moderate ozone concentrations occurred on this day and were confined to just north of Houston due to onshore winds. The moderate ozone concentrations did not reach Conroe because afternoon convective activity cleaned the air by 1400 CST.

September 13–Very low ozone concentrations occurred due to extensive convective activity, clouds, and rain.

September 14–Ozone concentrations were moderate despite light east winds because there were high clouds over the area.

September 15–Moderate ozone concentrations were evenly distributed in the Houston area even though winds were northerly the entire day.

4. DETAILS OF IMPORTANT CHARACTERISTICS

This section presents the important meteorological and ozone characteristics observed from August 15 through September 15, 2000. More extensive analysis was performed for the modeling days August 23 through September 1, 2000; these days are discussed first.

4.1 AUGUST 23, 2000

Large-Scale Aloft: An aloft high-pressure system existed over the Southeast and centered over Mississippi (see **Figure 4-1**). Only the edge of the system was over the Houston area. Therefore, subsidence over Houston was probably weak or did not exist. The lack of subsidence allowed for much convective activity.

Large-Scale Surface: A surface high-pressure system was centered over the Carolinas (see **Figure 4-2**), which drove large scale southeasterly winds; however, a weak trough embedded within the high-pressure system parallel to the coastline provided confluence of flows along the trough-line, which probably enhanced afternoon convective activity.

Local flows: There was a land/Bay/Gulf breeze cycle on this day. However, there was no stagnation period during transitions between flows, and the winds only shifted by 45° between 0000 and 1700 CST.

The important characteristics of the surface winds are as follows.

- Winds were light southeasterly from 0000 to about 0300 CST.
- There was a northeast land breeze from 0400 to about 1200 CST (see **Figure 4-3**).
- There was an easterly Bay breeze along the west shore of Galveston Bay and the Houston area from about 1200 to 1700 CST (see **Figure 4-4**).
- The Bay breeze shifted to a Gulf breeze at 1700, which continued for the rest of the day.

The important characteristics of the aloft winds at Ellington Field (see **Figure 4-5**) are as follows.

- There was a southeasterly Gulf breeze between 0130 and 0430 CST from the surface to about 3000 m agl.
- Winds were northeasterly at about 0430 CST in the lowest 100 m and southerly above 100 m agl. The depth of the northerly winds increased steadily to about 1000 m about 1100 CST, while southeasterly winds continued aloft. By 1100 CST, the southeasterly and easterly winds extended from the surface to aloft layers. No data were available after 1330 CST.

Cloud Cover: Clouds and convective activity were significant by about 0900 CST over south central Houston and over the entire area by about 1030 CST (see **Figure 4-6**). The clouds were probably associated with the surface trough and not the Bay or Gulf breeze front. By 1200 CST, there were only high, thin clouds over the greater Houston area.

Vertical Mixing: No mixing height data were available for this day.

Ozone Pattern: Ozone concentrations on this day were the lowest of the period. The peak concentration was 101 ppb at CAMS 53 (Bayland Park) at 1600 CST. Ozone concentrations generally rose and fell together throughout the Houston and Ship Channel areas, except there was a weak ozone "wave" that moved from east to west from the La Porte and Channelview areas through downtown, to west of Houston. The east-to-west movement of the high ozone concentrations is consistent with the long period of an easterly Bay breeze observed from 1200 to 1700 CST. The relatively low ozone concentrations throughout the area were probably due to the morning cloud cover.

4.2 AUGUST 24, 2000

Large-Scale Aloft: The aloft high-pressure system moved over Colorado (see **Figure 4-7**), and like August 23, only the edge of the system was over the Houston area. Thus, as on August 23, subsidence over Houston was probably weak. The lack of subsidence allowed for convective activity.

Large-Scale Surface: A surface high-pressure system was centered over Alabama and Georgia (see **Figure 4-8**) with strength diminished from August 23, but it continued to drive the southeasterly flow in the Houston area.

Local Surface Flows: There was a land/Bay/Gulf breeze cycle on this day. However, unlike August 23, the offshore flow was north and northwest across most of the area (as opposed to northeast). Therefore, when the easterly Bay breeze began, there was more rotation in the winds than on August 23, which would be more conducive to higher ozone concentrations. The important characteristics of the surface winds are as follows.

- There was a north and northwest land breeze from about 0300 CST through about 1200 CST (see **Figure 4-9**).
- The northwest breeze shifted to the southeast in the Ship Channel at 1200 CST.
- There was an easterly Bay breeze across the domain from 1400 through 1800 CST (see **Figure 4-10**).
- The Bay breeze then shifted to a Gulf breeze at 1800 CST, which continued for the rest of the day.

The important characteristics of the aloft winds at Ellington Field (see **Figure 4-11**) are as follows.

- No wind data were available until 1430 CST, at which time strong easterly winds from the surface to about 1000 m agl were observed. The winds shifted to southeasterly below about 500 m agl by 1700 CST and shifted to easterly from about 500 m agl to 1500 m agl. The southeasterly and east winds continued through the rest of the day.

Cloud Cover: Clouds and convective activity were significant over the area by about 1330 CST and lasted through dusk (see **Figure 4-12**). The convective activity was probably the reason for ozone concentrations peaking early in the day and dropping in the early afternoon.

Vertical Mixing: No mixing height data were available for this day.

Ozone Pattern: Ozone concentrations on this day were the second lowest of the period. The peak concentration was 111 ppb at CAMS 608 (La Porte) at 1100 CST (see Figure 4-9), a much earlier peak than on August 23. Unlike most other days during this period, there was no ozone "wave" that moved across the area. Other sites with high ozone concentrations included sites southwest of downtown Houston (CAMS 53: 88 ppb at 1200 CST), and sites north of downtown Houston (CAMS 8: 83 ppb at 1200 CST). By 1400 CST, as the Bay breeze moved across the area and widespread convective activity was underway, ozone concentrations dropped below 70 ppb at all sites (see Figure 4-10).

4.3 AUGUST 25, 2000

Large-Scale Aloft: The aloft high-pressure system was similar to that on August 24, but centered over northeastern New Mexico (see **Figure 4-13**); thus, as on August 24, subsidence over Houston was probably weak.

Large-Scale Surface: The large surface high over the southeastern U.S. weakened and there was a small surface high-pressure system over Houston (see **Figure 4-14**). Therefore, the synoptic onshore flow that existed on the two preceding days was gone, which allowed local forcing to dominate the winds in Houston.

Local flows: There was a land/Bay/Gulf breeze cycle on this day. However, unlike on August 24, the offshore flow was northeast across most of the area (as opposed to northwest) and the land breeze lasted for a shorter time.

The important characteristics of the surface winds are as follows.

- There was a northeast land breeze from about 0500 CST through about 1000 CST (see **Figure 4-15**), except for an easterly Bay breeze at La Porte by 0900 CST.
- The land breeze shifted to easterly and southeasterly area-wide at 1100 CST (see **Figure 4-16**).
- The wind then shifted to a southeast Gulf breeze area-wide at about 1400 CST (see **Figure 4-17**), which continued for the rest of the day, slowly shifting to south by 1900 CST.

The important characteristics of the aloft winds at Ellington Field (see **Figure 4-18**) are as follows.

- Winds were light southerly from the surface to about 1000 m agl from midnight to 0530 CST.
- The land breeze observed in the surface data was about 500 m deep at 0600 CST and grew to about 1000 m deep by 1000 CST.
- There was an easterly Bay breeze from 1230 CST trough 1630 CST.
- There was a Gulf breeze from about 1700 CST through midnight below about 900 m agl.

Cloud Cover: Clouds and convective activity were not significant on this day. The convective activity that did exist was associated with the Bay breeze front (see **Figure 4-19**), which began to appear on the western edge of Galveston Bay at 0800 CST, and the Gulf breeze, which began to appear on the Gulf Coast at 0800 CST. Clouds associated with the Gulf breeze reached central Houston at about 1300 CST (see **Figure 4-20**).

Vertical Mixing: The growth of the CBL lasted until about 1130 CST at Ellington Field, when it reached its maximum height of the day of 1700 m agl (see **Figure 4-21**). At about 1200 CST, mixing heights began to lower, which coincided with the onset of the easterly Bay breeze that probably undercut the CBL (see Figure 4-16).

Ozone Pattern: Ozone concentrations reached 194 ppb at CAMS 401 (Crawford in central Houston). Several other sites were high as well, including sites in Baytown and La Porte early in the day and in northeast Houston late in the afternoon. Data indicate that the morning northeast winds were light enough that much of the emissions from the ship channel remained in the Ship Channel area and the bulk of the emissions did not travel much south of La Porte. As the wind shifted east in the La Porte area from 0900 to 1000 CST, the ozone concentration rapidly rose to 104 ppb at CAMS 35, but at CAMS 608, just south of CAMS 35, ozone concentrations remained in the 70s ppb. This suggests that pollutants carried offshore from Baytown impacted northern La Porte during the onset of the easterly Bay breeze. As the easterly Bay breeze filled into the Houston area at 1100 CST (see Figure 4-16), and shifted southeast by 1400 CST (see Figure 4-17), the highest ozone concentrations moved from the Ship Channel area, through downtown, to northeast Houston. The coincident timing of the Bay breeze and high ozone concentrations across the area suggest that the high ozone concentrations were associated with the Bay air mass, which undercut the convective boundary layer as the Bay breeze moved from the southeast to the northwest. A summary of the important ozone observations that showed an east to west/northwest “wave” of ozone include the following:

- At 1100 CST, ozone concentrations at CAMS 35 and CAMS 607 (Baytown) were 132 ppb and 129 ppb, respectively (see Figure 4-16).
- At 1300 CST, the ozone concentration at CAMS 407 in central Houston was 194 ppb, whereas ozone concentrations in the Ship Channel dropped to 70-to-90 ppb.
- By 1400 CST, ozone concentrations in west Houston increased (CAMS 408 was 177 ppb) and sites in central Houston remained high while ozone concentrations at sites east continued to decrease (see Figure 4-17).

- By 1600, CST sites in northeast Houston had high ozone concentrations (CAMS 26 was 157 ppb) while sites in central and east Houston had low concentrations (see **Figure 4-22**).
- The high ozone concentrations never reached Conroe, probably because the high ozone concentrations passed to the southwest and west of Conroe.

4.4 AUGUST 26, 2000

Large-Scale Aloft: An aloft high-pressure system was centered over northeastern New Mexico and had expanded over all of Texas (see **Figure 4-23**) from the preceding day, which increased the likelihood of subsidence over Houston. A weak anticyclonic circulation was also evident over the Houston area, which would also result in subsidence over Houston.

Large-Scale Surface: The small surface high-pressure system over Houston had weakened (see **Figure 4-24**) from the day before, but no large scale forcing existed, thus allowing local flows to again dominate.

Local flows: There was not a typical land/Bay/Gulf breeze cycle on this day. The flow was generally from the west to northwest during the morning hours, as opposed to northeast as on August 25. There was only a very weak Bay breeze that did not penetrate beyond the ship channel before the Gulf breeze overtook the Bay breeze by about 1130 CST. This pattern kept high ozone concentrations confined to Baytown, CAMS 610 (north of Baytown), northeast Houston, and Conroe.

The important characteristics of the surface winds are as follows.

- Winds were light and variable until 0700 CST.
- Winds were light from the west and northwest from 0700 through 0900 CST (see **Figure 4-25**).
- Winds were southwesterly from 0900 to 1000 CST, shifting southeasterly by 1100 CST (see **Figure 4-26**) and lasting until the evening.

The important characteristics of the aloft winds at Ellington Field (see **Figure 4-27**) are as follows.

- Winds were light southerly from the surface to about 900 m agl from midnight to 0530 CST.
- There was a land breeze from the surface to about 300 m from 0600 CST to about 0900 CST, at which time winds became light and variable.
- Winds were light easterly from 1100 to 1400 CST from the surface to about 500 m agl. At 1400 CST, the winds shifted to southeasterly below about 800 m agl and continued throughout the day.

Cloud Cover: Clouds were not significant on this day and were similar to August 25 with one exception: convective activity associated with the Bay breeze front did not penetrate west beyond La Porte (see **Figure 4-28**), at which point the Bay breeze was overtaken by the Gulf breeze. Whereas, on August 25, clouds associated with the Bay breeze front penetrated through central Houston.

Vertical Mixing: The growth of the CBL lasted until about 1300 CST at Ellington Field, when it reached its maximum height of the day of 2300 m agl (see Figure 4-21). The CBL was about 600 m higher than on August 25. After 1300 CST, the mixed layer decreased, presumably due to undercutting by the Gulf breeze. The higher CBL height on this day compared to August 25 was probably related to the later arrival of marine air at Ellington Field on August 26 than on August 25.

Ozone Pattern: High ozone concentrations on this day were confined to Baytown, northeast Houston, and Conroe. The area of high ozone concentration is consistent with the westerly morning flow, the lack of a significant easterly Bay breeze, and southeasterly flow in the afternoon. The locations of peak ozone concentrations were different than on August 25, in that on August 25 the easterly Bay breeze penetrated well into central Houston, pushing high ozone concentrations to central and northwest Houston. On August 26, the morning westerly flow (see Figure 4-25) probably drove the bulk of morning emissions from Houston and the La Porte area into Galveston Bay. At 0900 CST, when the flow turned southwest, the high ozone concentrations were transported toward Baytown. By 1100 CST, as the winds shifted southeast, the ozone concentration reached 119 ppb at CAMS 610, north of Baytown while ozone concentrations at La Porte and Baytown remained below about 75 ppb (see Figure 4-26). By 1300 CST the southeasterly Gulf breeze carried the high ozone concentrations north of Houston to CAMS 8 (102 ppb at 1300 CST (see **Figure 4-29**) and 116 ppb at 1500 CST), while sites in the Ship Channel, southwest Houston, and northwest Houston had low-to-moderate concentrations. By 1600 CST, the high ozone concentrations arrived at Conroe and ozone concentrations reached 140 ppb at 1700 CST (see **Figure 4-30**). Given the flow pattern on this day, it is likely that the highest ozone concentrations in the mid-afternoon were northeast of Houston between Conroe and Baytown, where no monitors existed.

4.5 AUGUST 27, 2000

Large-Scale Aloft: The strength of the aloft high-pressure system was similar to that on August 26 and continued to encompass Texas (see **Figure 4-31**), which implies subsidence over Houston.

Large-Scale Surface: An approaching surface low-pressure system centered over Kansas (see **Figure 4-32**) had begun to drive a south-southwesterly flow over the Houston region, which counteracted the easterly Bay breeze forcing. This southwest flow can be seen on the visible satellite images (see **Figure 4-33**).

Local flows: There was a land/Gulf breeze flow on this day, with only a weak Bay breeze in the La Porte area. The winds were generally southwest during the overnight hours, driven by the synoptic pressure gradient. In the hours around dawn, the winds shifted west and northwest. By about 0800 CST, the winds shifted back to southwest and remained southwest to southeast for the remainder of the day, becoming relatively strong by 1300 CST.

The important characteristics of the surface winds are as follows.

- Winds were southwesterly until 0400 CST.
- Winds were light westerly and northwesterly from 0500 through 0700 CST (see **Figure 4-34**).
- Winds were southwesterly to southeasterly from 0800 CST through the rest of the day (see **Figure 4-35**).

At Ellington Field, (see **Figure 4-36**) there were moderate southwesterly to southeasterly winds from the surface to about 1200 to 2000+ m agl throughout the day. However, between 0700 and 1300 CST winds were light below about 200 to 500 m agl.

Cloud Cover: Clouds and convective activity were not significant on this day. However, there were scattered clouds associated with the Gulf breeze that are observed near Galveston at 0800 CST and over central Houston by 1100 CST.

Vertical Mixing: The CBL grew rapidly on this day until about 1400 CST at Ellington Field, when it reached its maximum height of the day of 2900 m agl (see Figure 4-21). After 1400 CST the mixed layer height decreased, which coincided with the onset of the strong Gulf breeze. The mixed layer height continued to decrease through the day.

Ozone Pattern: The relatively high mixing heights on this day, combined with the persistent southerly flow caused relatively low ozone concentrations at all sites. The highest ozone concentration occurred at CAMS 8 (80 ppb at 1400 CST, see **Figure 4-37**) and Conroe (87 ppb at 1700 CST, see **Figure 4-38**).

4.6 AUGUST 28, 2000

Large-Scale Aloft: The aloft high-pressure system was centered over Arkansas and had expanded further south into the Gulf of Mexico (see **Figure 4-39**) from August 27. This expansion caused increased subsidence over the area compared to August 27.

Large-Scale Surface: The surface low-pressure system located over the Dakotas and the associated stationary front from Nebraska through Missouri continued to combine with the surface high-pressure system centered over the Florida panhandle (see **Figure 4-40**) to drive a south-southwesterly flow over the Houston area.

Local flows: The winds on this day were very similar to those on August 27, except that the winds were light and variable around dawn as opposed to west and northwest as on August 27. For most of the day, the winds were from the southeast to southwest, forced by the large-scale surface pattern.

The important characteristics of the surface winds are as follows.

- Winds were southwesterly from 0000 through 0300 CST (see **Figure 4-41**).
- Winds were light and variable from about 0400 to 0700 CST.

- Winds were southwesterly from 0800 through 1100 CST (see **Figure 4-42**).
- Winds were southerly and southeasterly from 1100 to 1300 CST, becoming strong southeasterly by 1300 CST (see **Figure 4-43**).

At Ellington Field (see **Figure 4-44**) the aloft winds were very similar to the winds on August 27, but were stronger. There were moderate to strong southwest to southeast winds from the surface to about 2000 plus m agl throughout the day. The lightest southerly winds occurred between 0700 and 1400 CST below 200 to 500 m agl.

Cloud Cover: Clouds and convective activity were not significant on this day (see **Figure 4-45**) and were very similar to those on August 27. Scattered clouds associated with the Gulf breeze were near Galveston at 0800 CST and over North Houston by 1200 CST.

Vertical Mixing: Although the mixed layer was deeper during the mid-morning hours compared to August 27, the ultimate height of the mixed layer was restricted to about 1850 m agl (see Figure 4-21), about 1000 m lower than on August 27. In addition, it remained between 1850 and 1700 m agl between 1100 and 1500 CST before slowly decreasing through the remainder of the day. The steady height of the mixed layer during this period indicates that the mixed layer was probably the marine layer that was only slightly modified by heating from the land.

Ozone Pattern: The only high ozone concentrations on this day occurred at Conroe. Ozone concentrations were 107 ppb at 1600 CST and 112 ppb at 1700 CST (see **Figure 4-46**). All other sites in the Houston area had ozone concentrations below 80 ppb. The low ozone concentrations at all sites except Conroe were presumably due to the persistent and relatively strong onshore flow. The higher ozone concentrations at Conroe compared to August 27 may be due to the lower mixing heights on August 28.

4.7 AUGUST 29, 2000

Large-Scale Aloft: The aloft high-pressure system centered over Oklahoma continued to encompass Texas (see **Figure 4-47**). In addition, there was a small anticyclonic circulation over eastern Texas.

Large-Scale Surface: A small surface high was located over the Houston area (see **Figure 4-48**), probably caused by the sinking motion associated with the anticyclonic circulation over eastern Texas. Rotation around the surface high drove offshore flow east of Houston and onshore flow in Houston.

Local flows: The winds on this day were somewhat similar to those on August 26, with westerly flow during the morning hours and a southeast Gulf breeze during the afternoon hours, with only 1 hour of easterly Bay breeze at La Porte. This pattern confined the highest ozone concentrations to Baytown, northeast Houston, and Conroe.

The important characteristics of the surface winds are as follows.

- Winds were from the southwest and west from 0000 through 0300 CST (see **Figure 4-49**).
- Winds were light and variable and northwesterly from 0400 through 0700 CST (see **Figure 4-50**).
- Winds were westerly from 0700 through 1200 CST (see **Figure 4-51**).
- There was a weak Bay breeze at 1300 CST at La Porte and light and variable winds elsewhere.
- Winds were southeasterly from 1400 to 1700 CST (see **Figure 4-52**), and shifted to southerly by 1800 CST (see **Figure 4-53**).

The important characteristics of the aloft winds at Ellington Field (see **Figure 4-54**) are as follows.

- Winds were missing prior to 0800 CST.
- Winds were light westerly between 0830 and 1200 CST between the surface and about 1000 m agl.
- Winds were light and variable and light northeasterly between 1230 and 1400 CST between the surface and 1000 m agl.
- Winds were moderate southeasterly shifting to southwesterly from 1430 CST below about 800 m agl through the remainder of the day. They gradually increased in strength throughout the day.

Cloud Cover: Clouds and convective activity were minimal on this day (see **Figure 4-55**), were associated with the onshore flow, and were confined to central Houston and west of Houston. The relatively clear skies to the east of Houston allowed for maximum solar radiation.

Vertical Mixing: No mixing height data were available for this day.

Ozone Pattern: The high ozone concentrations on this day were confined to Baytown, northeast Houston, and Conroe. As on August 26, the area of high ozone concentrations is consistent with the westerly morning flow, the lack of a significant easterly Bay breeze, and southeasterly flow in the afternoon. During the morning hours, the westerly winds carried Houston and La Porte area emissions to Baytown and over Galveston Bay. By 1100 CST, ozone concentrations in Baytown (CAMS 607) were 110 ppb, while all other sites were below 80 ppb. By 1300, CAMS 607 remained the outstanding site (129 ppb). Ozone concentrations at most other sites remained in the 60-to-80 ppb range. By 1500 CST, an hour after the southeast Gulf breeze began, sites east and south of Houston were in the 50 to 70 ppb range, sites in the Channel View and north downtown area were in the 80 to 100 ppb range, and the high ozone concentrations were well east of Houston, as observed at CAMS 610 (146 ppb, see Figure 4-52). At 1700 CST, high ozone concentrations were probably located between Baytown and Conroe; ozone concentrations in the Baytown area, including CAMS 610, had dropped to about 40 to 70 ppb, while the ozone concentration at Conroe was 99 ppb. However, by 1800 CST, the high ozone concentrations arrived at Conroe and ozone concentrations spiked to 134 ppb (see Figure 4-48).

4.8 AUGUST 30, 2000

Large-Scale Aloft: An aloft high-pressure system remained centered over Oklahoma (see **Figure 4-56**), but had begun to weaken. However, an anticyclonic circulation pattern over Houston had expanded west. This anticyclonic circulation probably caused subsidence, which explains the clear skies and reduced vertical mixing over Houston on this day.

Large-Scale Surface: A weak surface high-pressure system that was centered over Houston along with low pressure in the eastern Gulf of Mexico and Atlantic coastline combined to create a weak northwest to southeast pressure gradient (see **Figure 4-57**), which caused offshore flow in Houston.

Local flows: The flow on this day was dominated by offshore (west and northwest winds) until midday, followed by a weak Bay and Gulf breeze late in the day. The offshore flow on this day was stronger than on all preceding days, which explains why this day had high ozone concentrations in the Galveston and Texas City areas.

The important characteristics of the surface winds are as follows.

- Winds were northwesterly from 0000 through 1300 CST (see **Figures 58 and 59**).
- Winds were from the east and southeast at Galveston and Texas City, and were light and variable elsewhere at 1400 CST.
- There was a weak Bay breeze at 1500 CST at La Porte and Baytown, a Gulf breeze at Galveston and Texas City, and light and variable winds elsewhere (see **Figure 4-60**).
- Winds were light southeasterly throughout the area from 1600 to 1700 CST (see **Figure 4-61**) and shifted southerly by 1800 CST.

The important characteristics of the aloft winds at Ellington Field (see **Figure 4-62**) are as follows.

- Winds were moderate from the southwest from midnight to 0500 CST below about 500 m agl. At about 0530 CST, the winds shifted to the west. Between 0830 and 1300 CST the winds were from the northwest, decreased in speed, and increased in depth to about 1000 m agl.
- Winds were light and variable and northeasterly from 1330 through 1630 CST.
- At 1730 CST, there was a southeasterly Gulf breeze below about 600 m agl. The Gulf breeze slowly swung through the southwest and was west by midnight.

Cloud Cover: Clouds were non-existent on this day (see **Figure 4-63**) due to subsidence, dry offshore flow, and only a very weak Bay and Gulf breeze.

Vertical Mixing: Mixing heights were very confined on this day (see Figure 4-21), with no apparent Bay or Gulf breeze undercutting, and very slow CBL growth. By 1100 CST, the CBL was only about 500 m agl, more than one-half the height of the next lowest day for August 23 through August 29, at this time. By 1500 CST, the CBL was 1550 m agl and by 1700 CST, it reached its maximum height of the day of 2000 m agl. Although the maximum height of the

CBL was about 300 m higher than on the lowest day (August 25), the peak mixing height occurred five hours later in the day. The low mixing heights on this day probably played a large role in the high ozone concentrations.

Ozone Pattern: Ozone concentrations on this day were very high, with several sites reporting concentrations above 150 ppb. High ozone concentrations occurred on the Gulf Coast in Texas City and Galveston, in southeast Houston, and in the Ship Channel. The area of high ozone concentrations and the magnitude of the concentrations are consistent with the northwest winds, lack of cloud cover, and very confined vertical mixing. The morning northwest flow carried Houston and Ship Channel emissions into Galveston Bay probably as far south as the Gulf Coast. At 1200 CST, most of the sites were still reporting low ozone concentrations, except Texas City where the ozone concentration was 90 ppb. At 1300 CST, winds turned northeast at Texas City, and ozone concentrations increased to 136 ppb, presumably as material offshore in the Gulf was carried back onshore. At the same time, ozone concentrations began to rise at La Porte. By 1500 CST, ozone concentrations were still high in Texas City even though the wind had shifted to southeast (see Figure 4-60). This suggests that the high ozone concentrations went slightly offshore in the Gulf during the morning hours, before returning to Texas City and Galveston in the weak onshore flow. In southeast Houston and in the Ship Channel, from 1400 to 1700 CST (see Figure 4-61), ozone concentrations were high (up to 199 ppb at La Porte). The high concentrations over this period were probably due to the confined mixing and light offshore winds from 1200 to 1400 CST, followed by light southeasterly return flow from Galveston Bay. By 1800 CST, ozone concentrations were much lower, presumably due to titration and a lack of sunlight, rather than from the intrusion of clean marine air or vertical ventilation.

4.9 AUGUST 31, 2000

Large-Scale Aloft: The aloft high-pressure pattern was very similar that on August 30 with anticyclonic circulation over Houston (see **Figure 4-64**). This circulation probably caused subsidence, which explains the clear skies over Houston on this day.

Large-Scale Surface: The surface pressure gradients were weak in the Houston area (see **Figure 4-65**). However, there was a weak low-pressure trough running north to south over Louisiana. The trough was too weak and too far east to create cloud cover in the Houston area; however, it did drive light westerly winds in the Houston area.

Local flows: The flow on this day was similar to that on August 30. It was dominated by offshore (west and northwest winds) until midday, followed by a weak Gulf breeze in the mid-afternoon. Unlike conditions on August 30, there was no well-defined Bay breeze.

The important characteristics of the surface winds are as follows.

- Winds were light westerly from 0000 to 0700 CST (see **Figure 4-66**)
- Winds were light northwesterly from 0800 to 1200 CST (see **Figure 4-67**)
- Winds were light and variable from 1300 to 1400 CST (see **Figure 4-68**)

- Winds were light southerly and shifted to a southeast Gulf breeze from 1500 to 2100 CST (see **Figure 4-69**).

The important characteristics of the aloft winds at Ellington Field (see **Figure 4-70**) are as follows.

- Winds were westerly below about 600 m agl and continued from the preceding evening until about 0600 CST. Between 0600 and 1100 CST the winds gradually swung to the northwest, decreased in speed, and increased in depth to about 1000 m agl.
- Winds were light and variable and easterly between 1200 and 1630 CST below about 600 m agl.
- There was a southwesterly Gulf breeze below about 800 m agl from 1700 CST through midnight.
- From 1330 to 1700 CST, the winds became light and variable with some northeasterly wind.
- At 1730 CST, there was a southeasterly Gulf breeze below about 600 m agl. The Gulf breeze slowly swung to the southwest.

Cloud Cover: There were no clouds on this day due to the combination of the extended period of dry offshore flow and the anticyclonic rotation aloft that generated sinking motion.

Vertical Mixing: The anticyclonic rotation on this day suppressed the CBL growth during the morning hours. The CBL growth was slightly faster than on August 30 (Figure 4-21). In addition, during the afternoon hours, the CBL grew much faster than on August 30.

Ozone Pattern: High ozone concentrations on this day were widespread, but they were not as high as on August 30. Several sites reported ozone concentrations above 120 ppb and the highest concentrations occurred between 1500 and 1600 CST (see Figure 4-69). The highest concentration was 168 ppb at CAMS 35 in the La Porte area. High ozone concentrations occurred throughout Houston, in the Ship Channel, and on the Gulf Coast in Texas City. The area-wide high ozone concentrations on this day were probably partially related to very light westerly winds overnight, which would allow for carryover of emissions from the day before. On most other days, overnight winds were strong enough to move “yesterday’s” emissions out of the region, so that the material would not contribute to “today’s” ozone. In addition, the afternoon Gulf breeze occurred late in the day and was very weak. It appeared to have contained material that moved offshore during the morning; thus, the Gulf breeze did not clean out the south side of Houston on this day. Finally, there were no clouds on this day, so photochemistry was not inhibited in any particular area.

4.10 SEPTEMBER 1, 2000

Large-Scale Aloft: The 500-mb height pattern was very similar to that on August 31. A small anticyclonic circulation was still in place over Houston (see **Figure 4-71**). This anticyclonic circulation probably caused subsidence, which explains the clear skies and reduced vertical mixing over Houston on this day.

Large-Scale Surface: The north-to-south surface trough that was located over central Louisiana on August 31 had moved over Lake Charles, Louisiana (see **Figure 4-72**). This surface low provided an area of surface convergence that generated afternoon convective activity just east of Houston. In addition, the combination of higher pressure to the west of Houston, and the low to the east, drove westerly winds overnight and throughout the day until 1700 CST.

Local flows: The local flows on this day were dominated by the low-pressure system over Lake Charles, Louisiana, and convective activity that moved through the area late in the day. There was no land breeze, Bay breeze, or Gulf breeze on this day. The winds were light and from the west to southwest throughout the area from midnight to 1600 CST (see **Figure 4-73**). At about 1700 CST, the winds abruptly shifted to the northeast (see **Figure 4-74**). The northeast winds were probably associated with the outflow from convective activity that developed just northeast of Houston at about 1600 CST (see **Figure 4-75**).

The important characteristics of the aloft winds at Ellington Field (see **Figure 4-76**) are as follows.

- Winds were moderately westerly below about 1000 m agl, continued from the preceding evening, and lasted until about 1000 CST. At 1030 CST, the winds decreased in strength, swung to the southwest in the lowest 500 m, and continued from the west from about 500 to 1500 m agl until 1700 CST.
- Wind data are missing from 1700 to 1930 CST.

Cloud Cover: There were no clouds in the area until 1700 CST; therefore, clouds did not inhibit the production of ozone in the area. The lack of clouds in Houston was probably related to subsidence associated with the aloft anticyclonic flow.

Vertical Mixing: The growth of the mixed layer was slow on this day and was slower than on August 31 (see Figure 4-21). By 1200 CST, the mixing heights were about 800 m agl and reached a maximum height of about 2350 m agl at 1500 CST. The mixing heights on this day were very similar to those on August 30, the day with the highest ozone concentrations.

Ozone Pattern: The ozone pattern was dominated by the continuous west to southwest winds. The only high ozone concentrations occurred in the Baytown area, probably associated with the combination of both Houston and Ship Channel emissions as the wind transported material from west to east. At 1200 CST, ozone concentrations were below 100 ppb at all sites (see **Figure 4-77**). However, at 1300 CST ozone concentrations were high in the Baytown area. Ozone concentrations were 163 ppb at CAMS 611, 124 ppb at CAMS 607, and 124 ppb at CAMS 610 (see **Figure 4-78**). All other sites had ozone concentrations below 100 ppb at this time. The high concentrations at CAMS 611 were probably caused by transport of material by the southwest winds blowing from the La Porte to Baytown. By 1400 CST, the ozone concentrations dropped at CAMS 611, while rising at CAMS 610 just northeast of Baytown. The rise in concentrations at CAMS 610 is associated with continued southwest transport of material from La Porte, through CAMS 611 in Baytown, to CAMS 610. After 1500 CST, ozone concentrations began to fall. At 1700 CST, when winds shifted to the northeast, ozone concentrations at all sites were below about 80 ppb (Figure 4-74), indicating that the northeast winds were clean and probably associated with convective outflow.

4.11 AUGUST 15 THROUGH AUGUST 22, 2000

August 15, 2000

Large-Scale Aloft: There was an aloft ridge centered over the Texas Panhandle that extended over central Texas, but the strength of the ridge did not encompass Houston (**Figure 4-79**). Therefore, the aloft weather pattern was probably not conducive to high ozone concentrations.

Large-Scale Surface and Local Flows: There was a surface high-pressure system centered over Atlanta, Georgia and a surface low over Eastern Colorado (**Figure 4-80).** This pressure pattern resulted in continuous onshore southeasterly flow the entire day in the Houston area.

Ozone Pattern: The ozone pattern reflected continuous southeast winds. The highest ozone concentration was 87 ppb at Conroe at 1500 CST (**Figure 4-81**) and low ozone concentrations were observed in the greater Houston area.

August 16, 2000

Large-Scale Aloft: The aloft high-pressure system had expanded from August 15 to encompass Houston. In addition, there was a small anticyclonic circulation over Houston, which allowed for clear skies in the Houston area (**Figure 4-82**). These conditions contributed to high ozone concentrations.

Large-Scale Surface and Local Flows: There was a surface high over eastern Texas and Louisiana with a weak west to east pressure gradient over Houston (**Figure 4-83**). This pressure gradient drove light westerly winds throughout the day.

Ozone Pattern: The ozone pattern reflected the continuous westerly winds. The highest ozone concentration occurred east of Houston and the Ship Channel at Baytown (111 ppb at 1400 CST, **Figure 4-84**). By 1500 CST the area of high ozone concentration moved farther east to CAMS 610. There were low ozone concentrations elsewhere in the greater Houston area.

August 17, 2000

Large-Scale Aloft: The aloft high-pressure system was slightly weaker than that on August 16, but there was still a small anticyclonic circulation over Houston (**Figure 4-85**). Anti-cyclonic circulations are associated with subsiding air, which creates conditions conducive to high ozone concentrations.

Large-Scale Surface and Local Flows: There was a surface high over Houston and Lake Charles, Louisiana. There were weak synoptic pressure gradients, which allowed local flows to dominate. In the morning there were westerly winds until about 1100 CST. By about 1300 CST the winds shifted to a southeasterly Bay breeze (see **Figure 4-86**, for example).

Ozone Pattern: There appear to have been two separate air masses of high ozone on this day. One air mass of high ozone moved east of the Ship Channel in the morning westerly winds and then northwest to Conroe in the afternoon southeasterly winds. The other air mass of high ozone was observed just west of central Houston and passed through Aldine (CAMS 8) north of Houston where at 1500 CST ozone concentrations reached 150 ppb (Figure 4-86).

August 18, 2000

Large-Scale Aloft: The aloft high-pressure system continued to dominate the weather over Houston, but the small anticyclonic circulation over Houston observed on the day before was no longer over Houston (**Figure 4-87**).

Large-Scale Surface and Local Flows: There was a surface high over Lake Charles, Louisiana, and a weak pressure gradient over Houston. The weak synoptic pressure gradient allowed the Gulf breeze to dominate the winds in the greater Houston area. In the early morning hours, winds were calm before becoming light southeast at 0700 CST. By 1200 CST the winds shifted more to the south and continued from the south through the evening (**Figure 4-88**).

Ozone Pattern: Continuous southerly winds from the early morning hours through the evening drove the high ozone concentrations well north Houston to Conroe (130 ppb at 1700 CST) (**Figure 4-89**) with much lower ozone concentrations at all other sites.

August 19, 2000

Large-Scale Aloft: There was an aloft high-pressure system over Texas and a small anticyclonic circulation over Houston (**Figure 4-90**).

Large-Scale Surface and Local Flows: A weak surface pressure gradient continued over Houston which allowed locally forced flows to dominate the winds in the greater Houston area. In the early morning hours winds were light west and northwest (**Figure 4-91**) before becoming southwest from about 0800 CST to 1200 CST (**Figure 4-92**). By 1300 CST the winds shifted to a southeast Bay breeze, slowly swinging to the south through the afternoon and evening due to the onset of the Gulf breeze (**Figure 4-93**).

Ozone Pattern: As on August 17, 2000, there appear to have been two separate air masses of high ozone on this day. One air mass of high ozone moved east of the Ship Channel in the morning westerly winds (146 ppb at CAMS 610 at 1100 CST) (Figure 4-92) and then northwest to Conroe in the afternoon southeasterly winds (124 ppb at 1800 CST). The other air mass of high ozone was just northeast of downtown and passed through Aldine (CAMS 8) north of Houston, where at 1600 CST ozone concentrations reached 122 ppb (Figure 4-93). It is possible that the monitoring network did not observe the highest ozone levels northeast of Houston between Baytown and Conroe.

August 20, 2000

Large-Scale Aloft: As on August 19, there was an aloft high-pressure system over Texas and a small anticyclonic circulation over Houston (**Figure 4-94**).

Large-Scale Surface and Local Flows: Weak surface pressure gradients continued to allow local flows to dominate (**Figure 4-95**). The flow pattern on this day is very similar to that on

August 19. There were light moderate westerly winds between 0800 and 1200 CST (**Figure 4-96**) and southeasterly winds between 1300 CST and throughout the evening.

Ozone Pattern: Like August 19, 2000, there appear to have been two separate air masses of high ozone on this day; however, the ozone concentrations in the air masses are lower than on the preceding day. One air mass of high ozone again moved east of the Ship Channel in the morning westerly winds (118 ppb at CAMS 610 at 1400 CST) (**Figure 4-97**) and then northwest to Conroe in the afternoon southeasterly winds (89 ppb at 1800 CST). The other air mass of high ozone was just northeast of central Houston and passed through Aldine (CAMS 8) north of Houston, where at 1600 CST ozone concentrations reached 89 ppb. Similar to August 19, it is possible that the monitoring network did not observe the highest ozone levels northeast of Houston between Baytown and Conroe.

August 21, 2000

Large-Scale Aloft: The aloft high-pressure system continued to dominate the weather over Houston, but the small anticyclonic circulation observed on August 20 was no longer over Houston (**Figure 4-98**).

Large-Scale Surface and Local Flows: A weak surface pressure gradient continued over Houston which allowed locally forced flows to dominate the winds in the greater Houston area. However, unlike conditions on the preceding day, there was an almost 180-degree turning of the winds in the late morning hours and subsequent recirculation. Between 0700 CST and 1000 CST winds were light northwesterly (see **Figure 4-99** for example). Between about 1100 CST and though the evening winds were light to moderate southeasterly (**Figure 4-100** for example).

Ozone Pattern: Sunny skies, after brief morning cloudiness, combined with the recirculation of both downtown and Ship Channel emissions, allowed widespread high ozone concentrations that moved from the Ship Channel area through central Houston and to the west of central Houston. The southeast-to-west "wave" of ozone included

- High ozone concentrations at La Porte and Baytown at 1200 CST (Figure 4-100), which dropped at 1300 CST as the southeasterly winds carried the air mass to the west (**Figure 4-101**).

- High ozone concentrations at several sites at 1300 CST near downtown Houston including 159 ppb at the Houston Regional Office (CAMS 81) and 153 at CAMS 407 (Figure 4-101).

- High ozone concentrations at several sites at 1400 CST extending from north of downtown Houston at CAMS 8 through east of downtown at CAMS 408 to southwest of downtown at CAMS 53 (**Figure 4-102**); ozone at sites to the southeast fell.

- High ozone concentrations farther southwest, west, and northwest of downtown as the afternoon progressed.

August 22, 2000

Large-Scale Aloft: The aloft high-pressure system continued to dominate the weather over Houston and was very similar to that of the day before (**Figure 4-103**).

Large-Scale Surface and Local Flows: Despite an apparent weak surface pressure gradient over Houston, winds on this day did not exhibit flow reversal or strong turning of the winds that was typical for days when local forcing dominated. Morning winds were northeasterly (see **Figure 4-104,** for example), only turning about 45 degrees to the east by about 1300 CST (see **Figure 4-105,** for example) and to the southeast at 1600 CST.

Ozone Pattern: The persistent wind direction on this day kept ozone concentrations moderate, and the highest concentrations occurred to the west and northwest of Houston. The highest concentration was only 107 ppb at Aldine north of Houston at 1600 CST.

4.12 SEPTEMBER 2, 2000, THROUGH SEPTEMBER 15, 2000

September 2, 2000

Large-Scale Aloft: There was an aloft high-pressure system over Texas that encompassed Houston (**Figure 4-106**), which aided in producing sunny skies throughout the day.

Large-Scale Surface and Local Flows: There were light-to-moderate westerly and northwesterly winds until about 1400 CST, at which time the winds shifted to a light southeast Bay breeze near La Porte and Baytown (**Figure 4-107**) and to a southerly Gulf breeze throughout the domain by 1700 CST. The persistence of the northwest and westerly flow is surprising given the weak surface pressure gradients in the Houston area.

Ozone Pattern: Although there was flow reversal on this day, it seems that the speed and duration of the west/northwest winds carried the bulk of the morning ozone precursors too far southeast to return to the Houston or Ship Channel areas before evening. Ozone concentrations reached 125 ppb at Deer Park (CAMS 35) at 1500 CST (Figure 4-107), the peak ozone observation of the day.

September 3, 2000

Large-Scale Aloft: The aloft high-pressure system retrograded to the west, and the dynamics associated with the system were probably not over Houston. Despite this fact, it seems that dry aloft air from the northeast kept skies cloud-free until the evening.

Large-Scale Surface and Local Flows: There was a surface high-pressure system located over central Texas and a low-pressure system centered over Mobile, Alabama. This pressure pattern drove light west-to-southwest winds the entire day.

Ozone Pattern: Despite the persistent west/southwest winds, ozone concentrations still reached 127 ppb at Baytown CAMS 611 at 1600 CST (**Figure 4-108**).

September 4, 2000

Large-Scale Aloft: The aloft high-pressure system was centered over the Texas Panhandle and had expanded east to encompass Houston, which contributed to high ozone concentrations.

Large-Scale Surface and Local Flows: There was a surface high-pressure system located over central Texas and lower pressure to the east of Houston, and pressure gradients were weak. Surface winds smoothly rotated 360 degrees on this day.

- During the predawn hours winds were from the southwest and west
- By 0600 CST winds were from the northwest
- By 1100 CST winds were from the north
- By 1300 CST winds were from the northeast
- By 1500 CST winds were from the east
- By 1700 CST winds were from the southeast
- By 2000 CST winds were from the south
- By 2100 CST winds were from the southwest

Ozone Pattern: The morning west and northwest winds, followed by afternoon northeast and east winds, drove the highest ozone concentrations to Texas City and Galveston. The peak ozone concentration was 145 ppb at 1200 CST at Galveston Airport (**Figure 4-109**). It is possible that the high ozone concentrations at Galveston were, in part, related to smoke that was transported from a fire located between Houston and Lake Charles, Louisiana (see **Figure 4-110**). Ozone concentrations in the Houston and Ship Channel areas were much lower.

September 5, 2000

Large-Scale Aloft: The aloft high-pressure system remained centered over the Texas Panhandle and intensified from September 4 (**Figure 4-111**).

Large-Scale Surface and Local Flows: There was a strong continental high over the east and southeast United States and a low centered over Corpus Christi (**Figure 4-112**). This pressure pattern drove north and northeast winds over the Houston area the entire day. Extensive amounts of smoke were transported into the Gulf of Mexico from fires between Houston and Lake Charles, Louisiana. It is possible that smoke may have contributed to the peak ozone in Houston on this day.

Ozone Pattern: The persistent north and northeast winds sent Houston and Ship Channel emissions to the Gulf Coast, thus causing peak ozone concentrations to occur at Galveston (133 ppb at 1200 CST, **Figure 4-113**) and at Clute (185 ppb at 1400 CST). Ozone concentrations in the Houston and Ship Channel areas were much lower.

September 6, 2000

Large-Scale Aloft: The aloft high-pressure system was still centered over the Texas Panhandle but weakened from the preceding day (**Figure 4-114**).

Large-Scale Surface and Local Flows: The strong continental high continued to persist over the east and southeast United States with low pressure over the Gulf of Mexico (**Figure 4-115**). This pressure pattern drove northeast and east winds over the Houston area until about 1500 CST, at which time the winds turned southeast.

Ozone Pattern: The persistent northeast-to-east winds sent Houston and Ship Channel emissions to the west and southwest, thus causing peak ozone concentrations to occur at Croquet (156 ppb at 1300 CST) and at Bayland Park (122 ppb at 1300 CST) (**Figure 4-116**). Ozone concentrations in the Houston, Ship Channel, and Gulf Coast areas were much lower.

September 7 through September 15, 2000

Large-Scale Aloft: The aloft high-pressure ridge that brought poor air quality to the region for several days before finally retrograded west and was replaced by a weak upper-level low that moved into Texas from the Gulf of Mexico (see **Figure 4-117**). The upper-level low persisted over Houston from September 6 through September 10. Upper-level low-pressure systems are not conducive to ozone formation because they enhance vertical mixing and promote cloud cover. From September 10 through September 15, there was no clear high- or low-pressure system over the area. From September 7 through September 15, 2000, ozone concentrations were mostly low, and the maximum ozone concentration was only 104 ppb on September 9.

Large-Scale Surface, Local Flows, and Ozone:

September 7: The continental high drove moderate northeasterly flow in the region. The persistent winds, combined with the upper-level low, resulted in a maximum ozone concentration of 73 ppb at Clute and Bayland Park to the southwest of Houston.

September 8: The continental high continued to drive moderate northeasterly flow in the region. The persistent winds, combined with the upper-level low and cloudy skies, resulted in a maximum ozone concentration of 69 ppb at Croquet to the southwest of Houston.

September 9: The continental high weakened, which allowed light and variable morning winds followed by a light afternoon Gulf breeze. Despite the light flow, partly cloudy skies associated with a low-level disturbance just offshore of Galveston and the lack of a strong high-pressure ridge, the ozone concentration only reached 104 ppb, which occurred at North Wayside near central Houston.

September 10: Clockwise rotation around the continental high into a low over the Plains and Texas Panhandle created a light but almost continuous onshore flow in the Houston area. The onshore flow combined with a low-pressure system aloft allowed maximum ozone concentrations to reach 83 ppb. The maximum concentrations occurred well downwind of Houston at Conroe.

September 11: Similar to conditions on September 10, clockwise rotation around the continental high into a low over the Plains enhanced the Gulf breeze in the Houston area. With no strong aloft ridge over Houston, the Gulf breeze front produced extensive convective activity in the Houston area by about 12:00 CST. The clouds and vertical mixing associated with the convective activity kept maximum ozone concentrations to only 54 ppb.

September 12: Onshore winds and afternoon convective activity continued to dominate the weather in the Houston area. The surface low-pressure system moved over western Texas while high pressure persisted over the southeast. This allowed the Gulf breeze to blow all day, keeping emissions somewhat dispersed. Despite the Gulf breeze, ozone concentrations reached 100 ppb at Aldine, north of Houston at 1200 CST. Ozone levels rapidly fell after 1200 CST due to the onset of convective activity.

September 13: An upper-level low-pressure system resulted in extensive convective activity, clouds, and rain. These weather conditions kept ozone concentrations very low. The maximum ozone concentration on this day was only 36 ppb.

September 14: The upper-level low-pressure moved southwest over Mexico, and a ridge began to build into Texas from the Northwest. The ridge was still too far west to produce dynamics over Houston that were conducive to high ozone concentrations. At the surface, high pressure to the northwest of Houston and lower pressure in the Gulf of Mexico produced an offshore pressure gradient. This gradient counteracted the Gulf breeze to produce a day of variable flow although the flow was most often out of the east. Despite the light winds, high clouds associated with convective activity along the Gulf Coast kept ozone concentrations to a maximum of 100 ppb, which occurred near Missouri City to the southwest of Houston.

September 15: A strong surface high, centered on the Plains, combined with low pressure in the Gulf of Mexico to create an offshore synoptic pressure gradient. The offshore pressure gradient resulted in light northerly and northeasterly winds throughout the day. Although the winds were from the north, the high ozone concentrations were rather evenly distributed throughout the greater Houston area. In addition, the maximum ozone concentration (94 ppb) of the day occurred at Aldine to the north of Houston at 1600 CST.

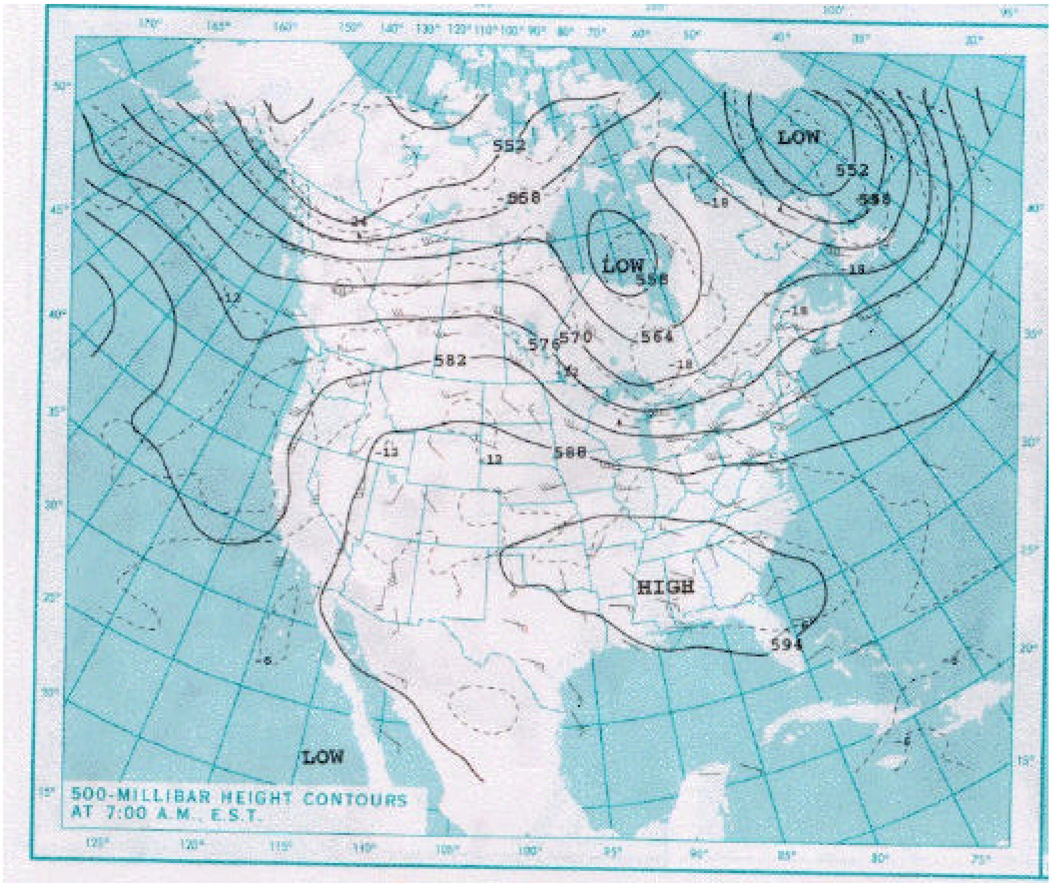


Figure 4-1. Contours of the height of the 500-mb surface pressure for August 23, 2000, at 0600 CST.

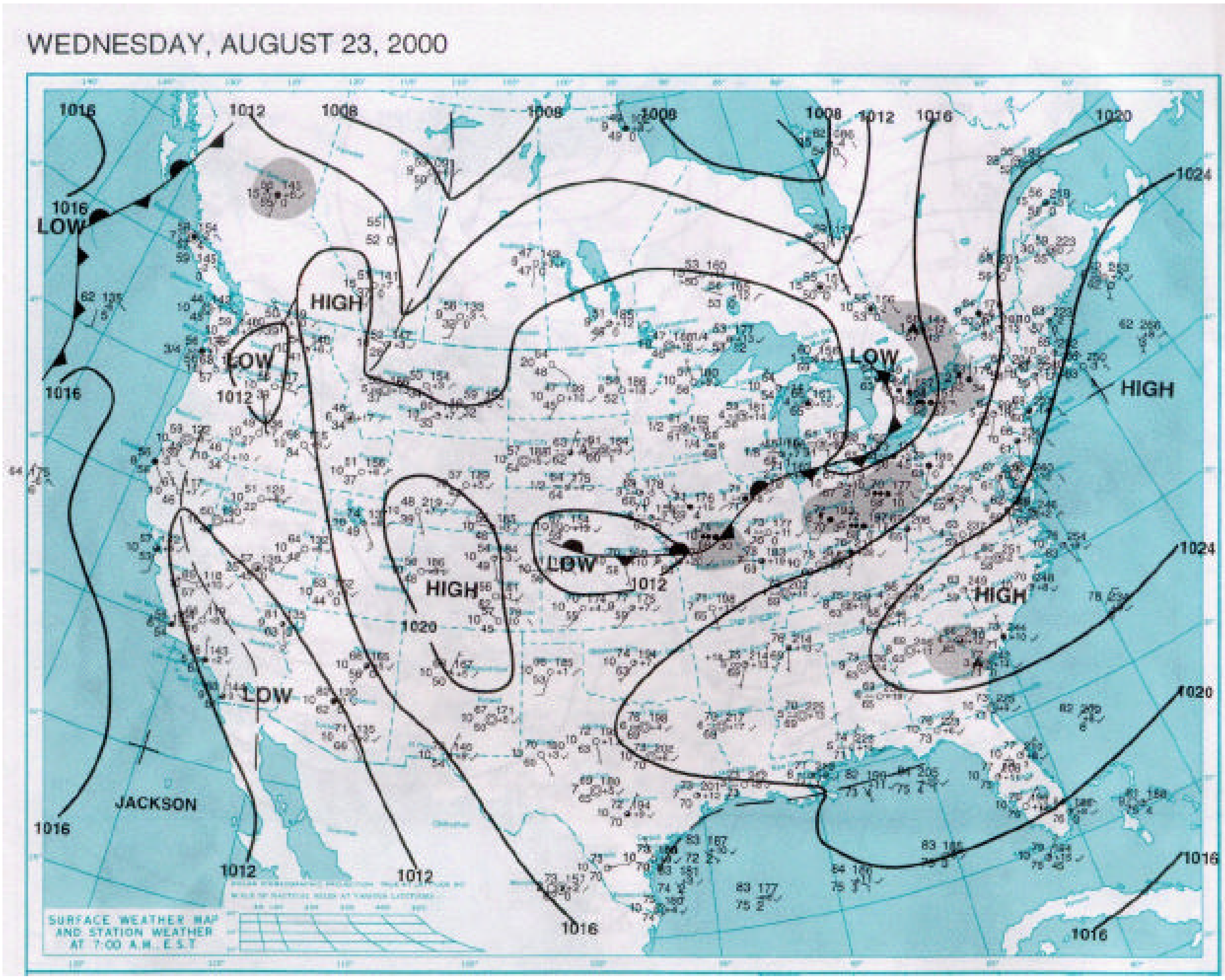


Figure 4-2. Surface analysis chart showing the winds, contours of surface pressure, and other weather conditions on August 23, 2000, at 0600 CST.

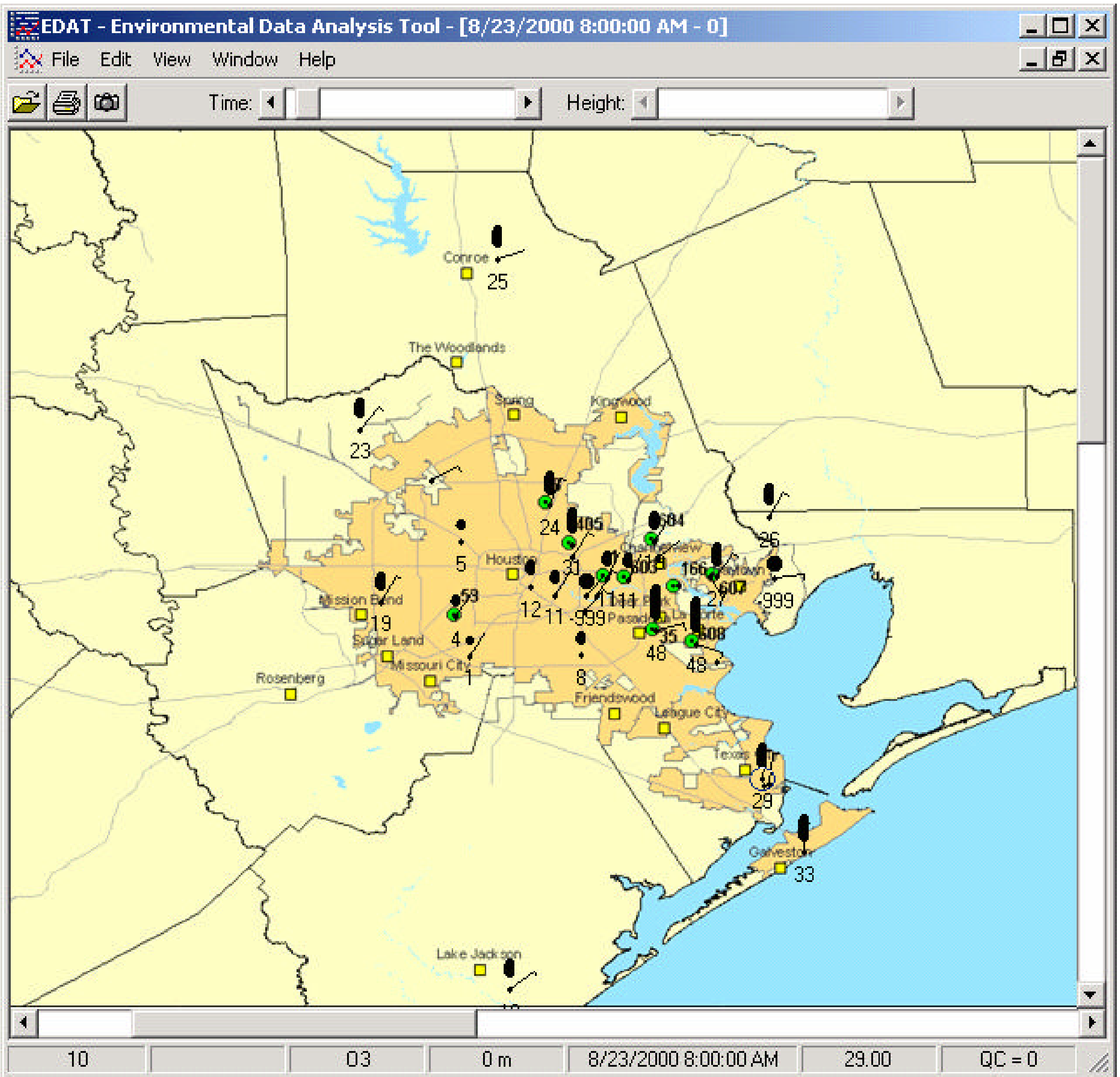


Figure 4-3. Spatial plot of hourly surface winds and ozone concentrations at CAMS sites on August 23, 2000, at 0800 CST. For winds, one-half of a flag = 2.5 m/sec and one flag = 5 m/sec. The wind blows from the end of the flagstaff, toward the monitoring site. For ozone, the plain text below each site shows the concentration in parts per billion, and the bar above each site shows the concentration by bar size. Note that missing data are reported as -999. The CAMS numbers of selected sites are also shown.

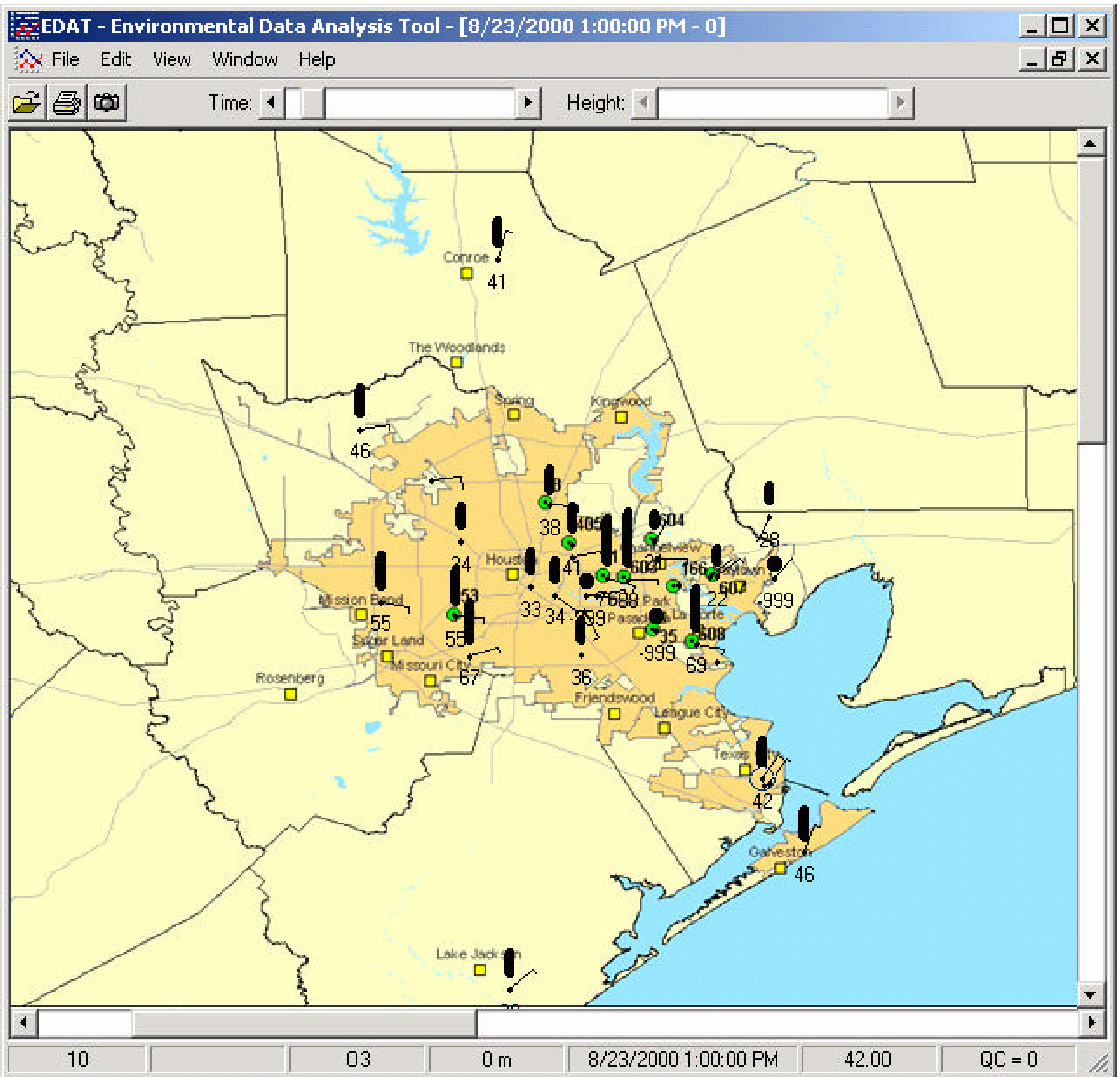


Figure 4-4. Spatial plot of hourly surface winds and ozone concentrations at CAMS sites on August 23, 2000, at 1300 CST. For winds, one-half of a flag = 2.5 m/sec and one flag = 5 m/sec. The wind blows from the end of the flagstaff, toward the monitoring site. For ozone, the plain text below each site shows the concentration in parts per billion, and the bar above each site shows the concentration by bar size. Note that missing data are reported as -999. The CAMS numbers of selected sites are also shown.

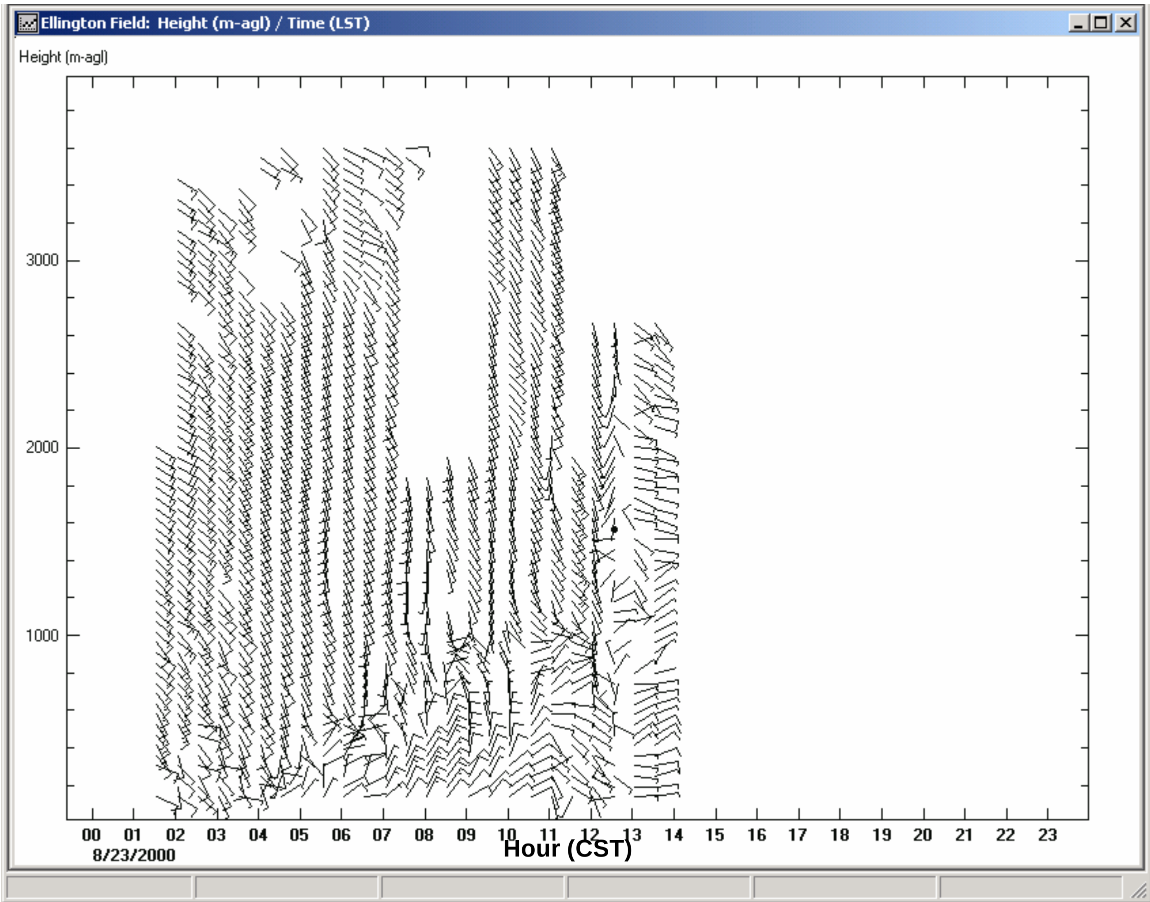


Figure 4-5. Time-height cross-section of radar profiler winds collected at Ellington Field on August 23, 2000.

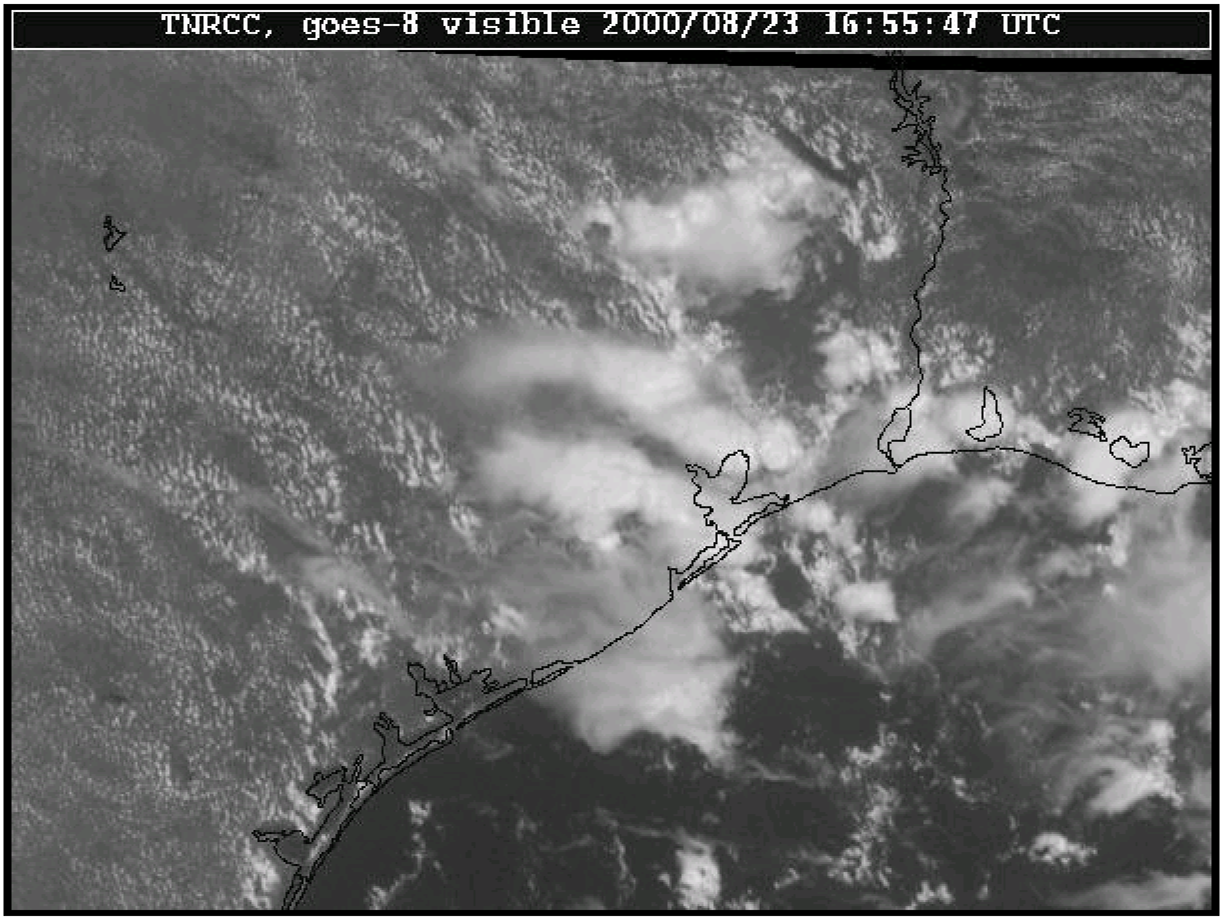


Figure 4-6. Visible satellite image for August 23, 2000, at 1055 CST (1655 UTC).

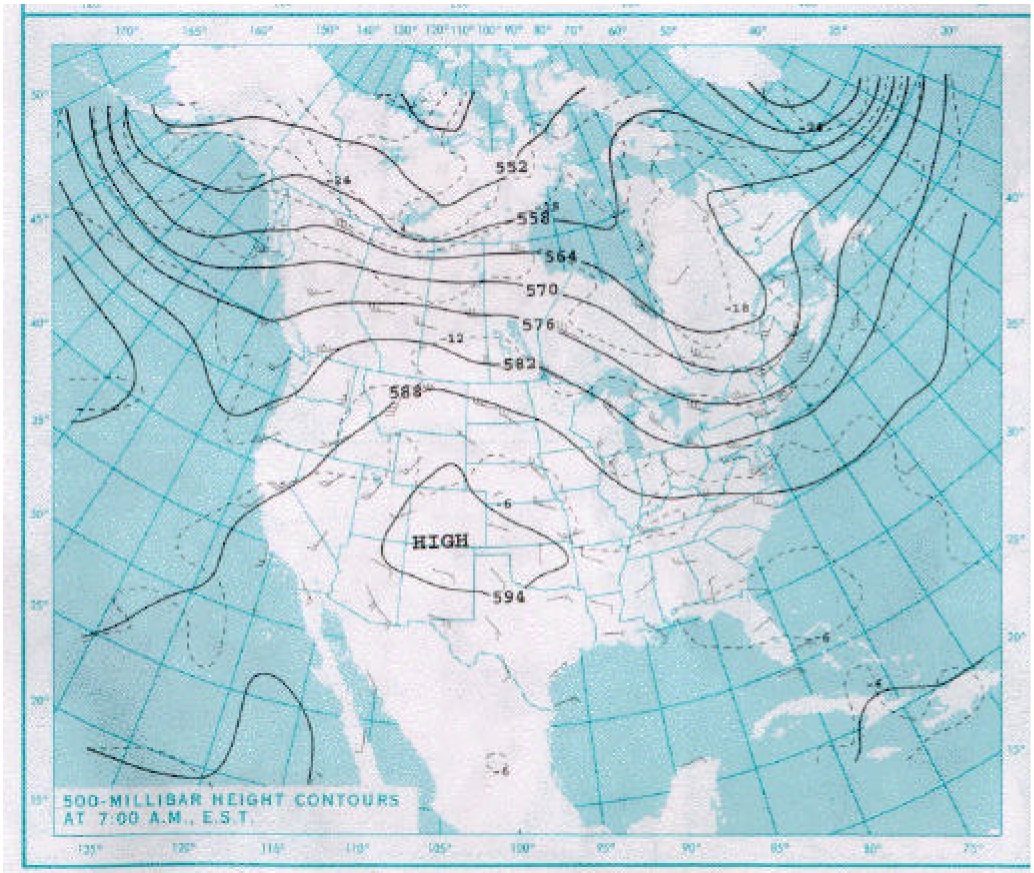


Figure 4-7. Contours of the height of the 500-mb surface pressure for August 24, 2000, at 0600 CST.

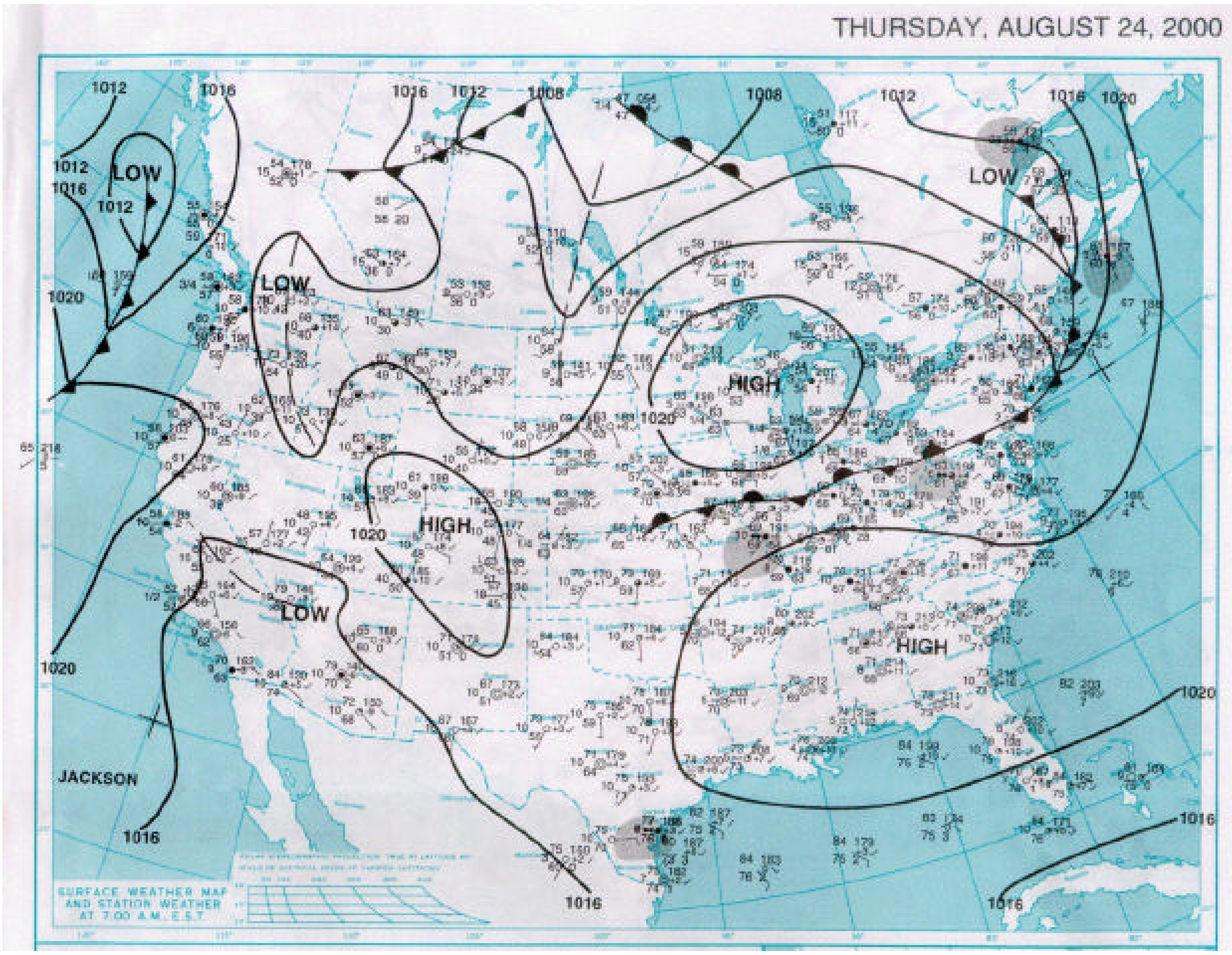


Figure 4-8. Surface analysis chart showing the winds, contours of surface pressure, and other weather conditions on August 24, 2000, at 0600 CST.

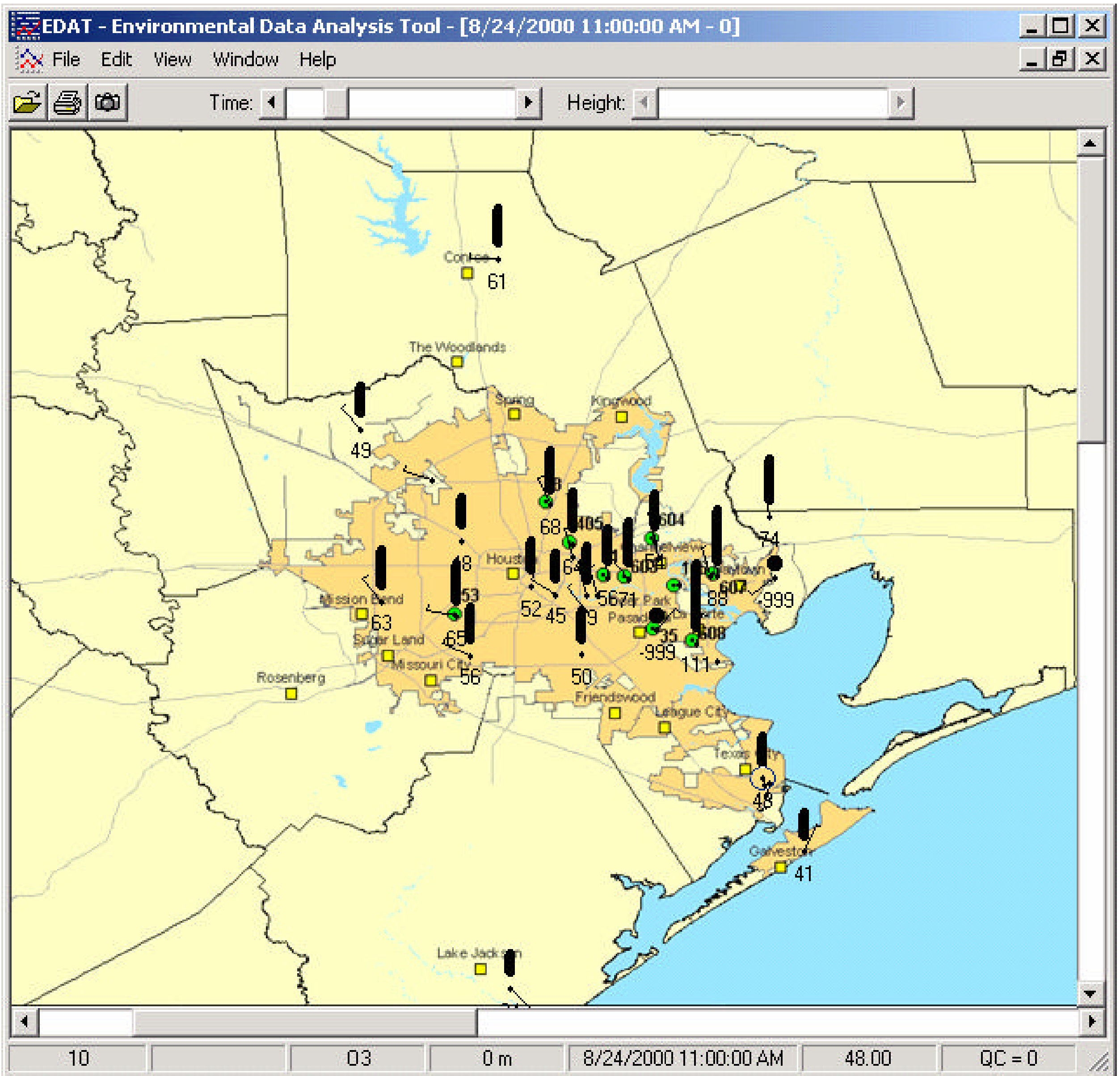


Figure 4-9. Spatial plot of hourly surface winds and ozone concentrations at CAMS sites on August 24, 2000, at 1100 CST. For winds, one-half of a flag = 2.5 m/sec and one flag = 5 m/sec. The wind blows from the end of the flagstaff, toward the monitoring site. For ozone, the plain text below each site shows the concentration in parts per billion, and the bar above each site shows the concentration by bar size. Note that missing data are reported as -999. The CAMS numbers of selected sites are also shown.

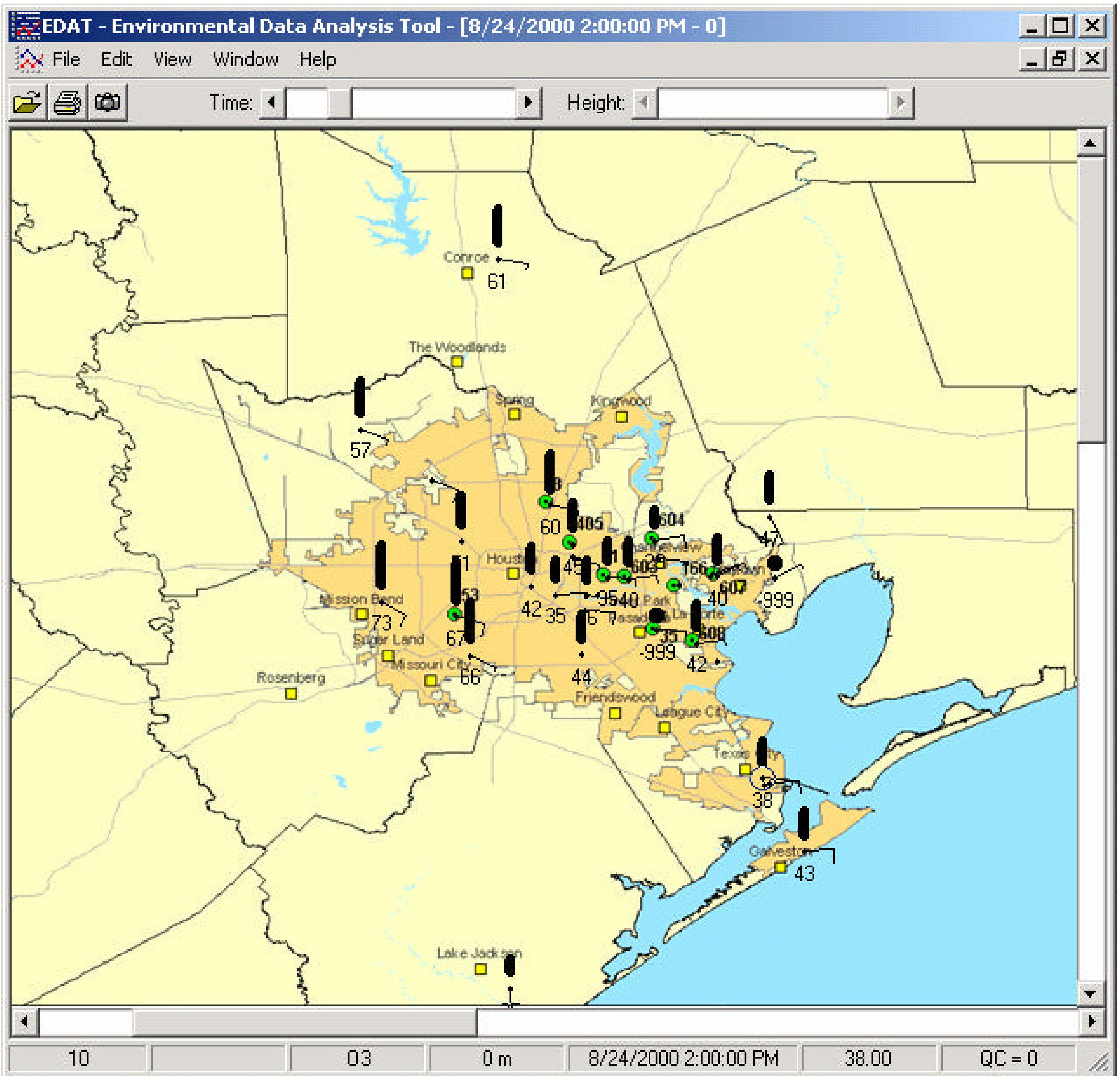


Figure 4-10. Spatial plot of hourly surface winds and ozone concentrations at CAMS sites on August 24, 2000, at 1400 CST. For winds, one-half of a flag = 2.5 m/sec and one flag = 5 m/sec. The wind blows from the end of the flagstaff, toward the monitoring site. For ozone, the plain text below each site shows the concentration in parts per billion, and the bar above each site shows the concentration by bar size. Note that missing data are reported as -999. The CAMS numbers of selected sites are also shown.

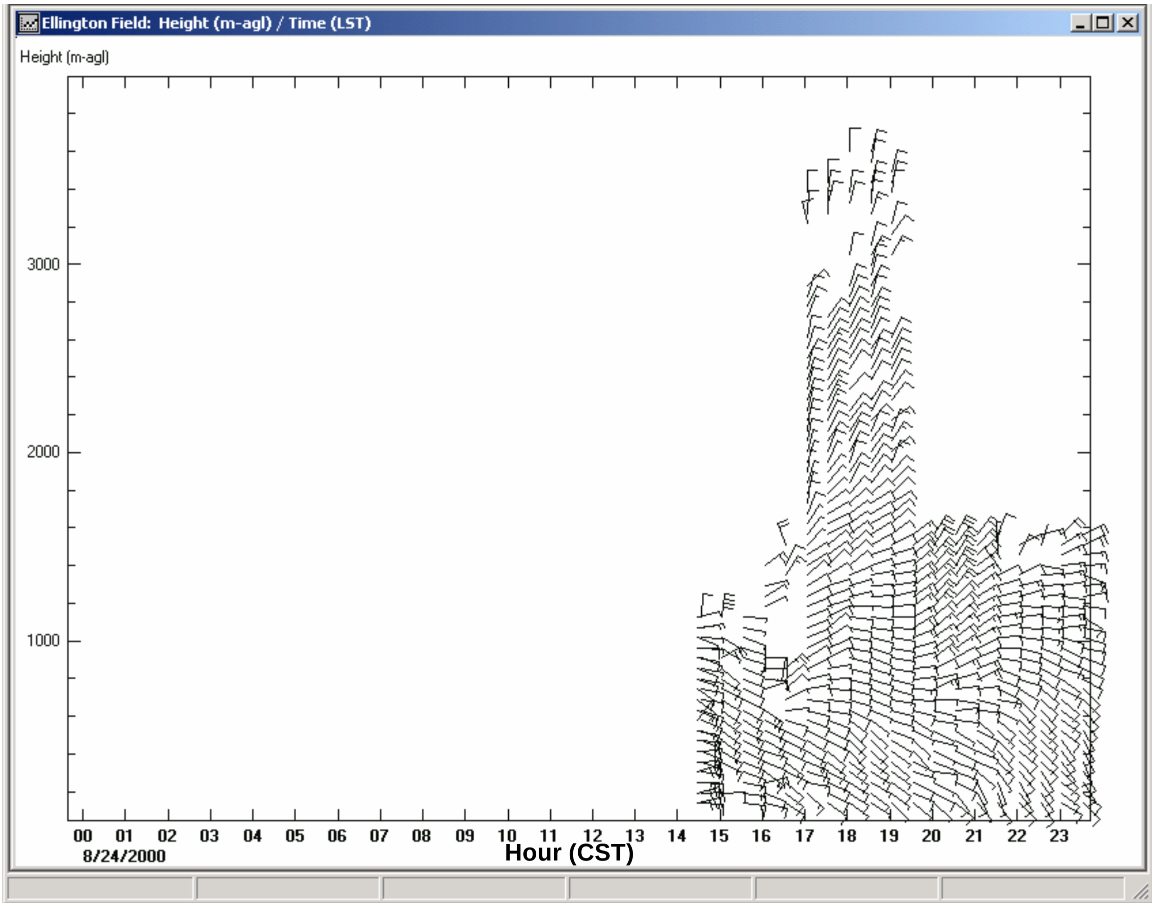


Figure 4-11. Time-height cross-section of radar profiler winds collected at Ellington Field on August 24, 2000.

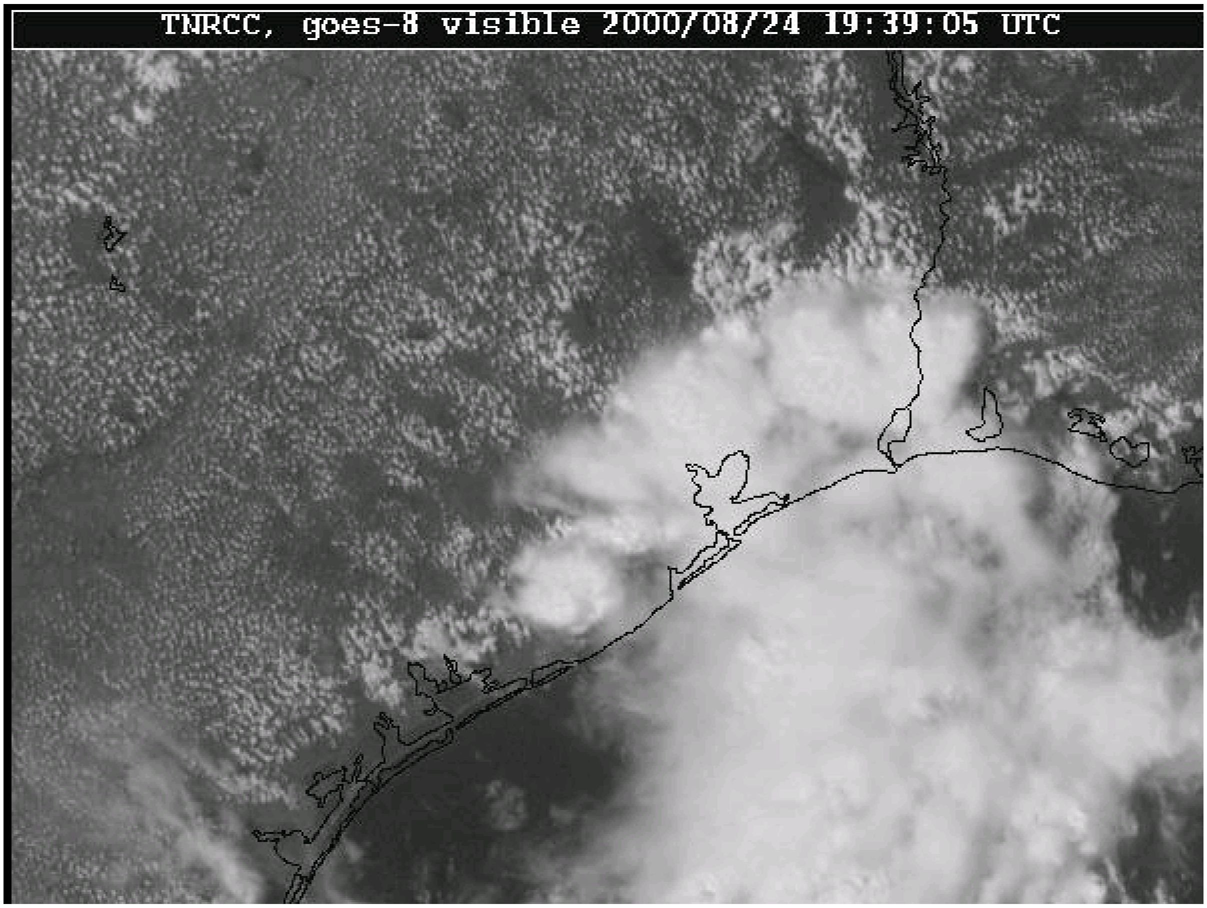


Figure 4-12. Visible satellite image for August 24, 2000, at 1335 CST (1935 UTC).

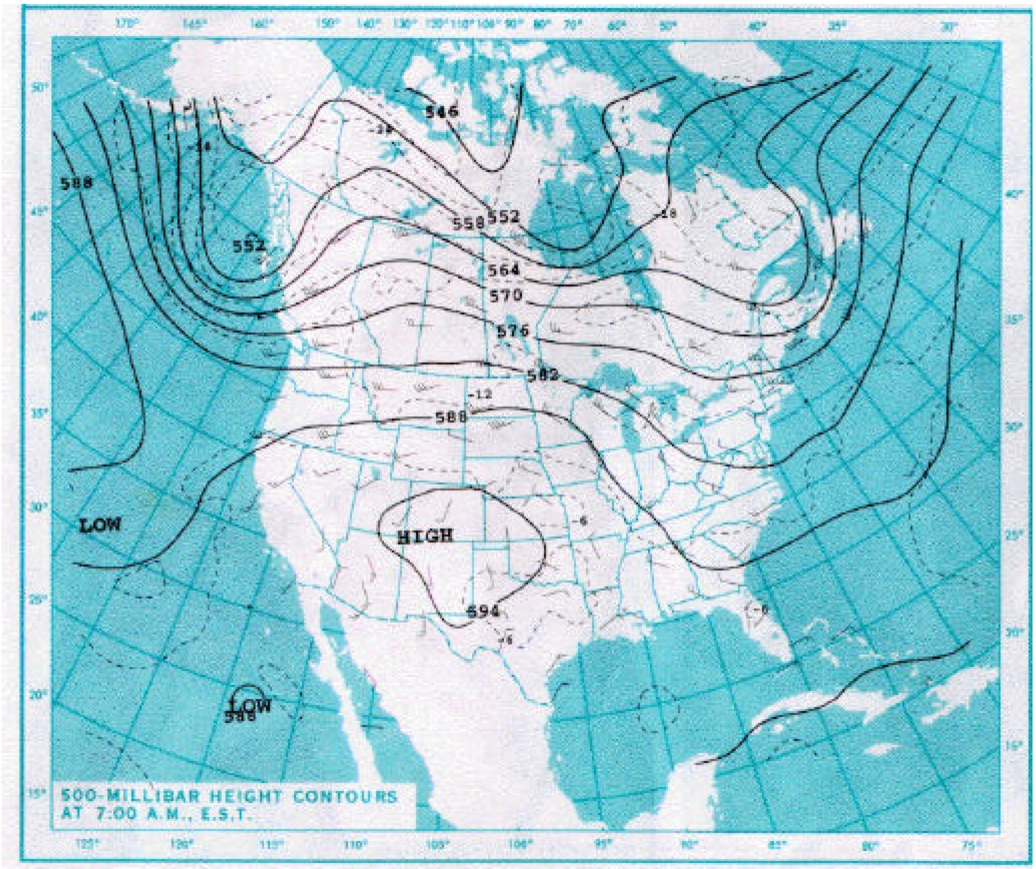


Figure 4-13. Contours of the height of the 500-mb surface pressure for August 25, 2000, at 0600 CST.

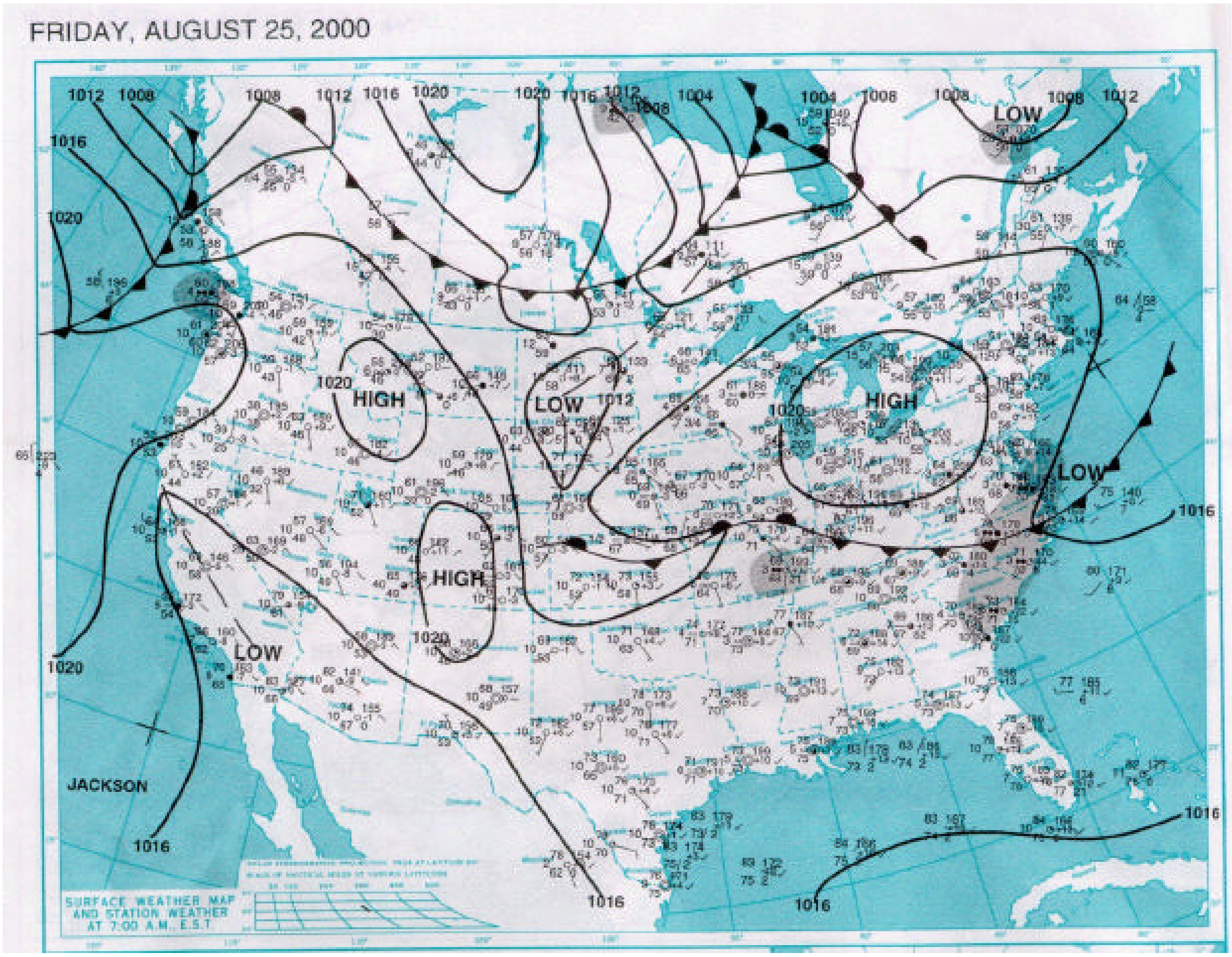


Figure 4-14. Surface analysis chart showing the winds, contours of surface pressure, and other weather conditions on August 25, 2000, at 0600 CST.

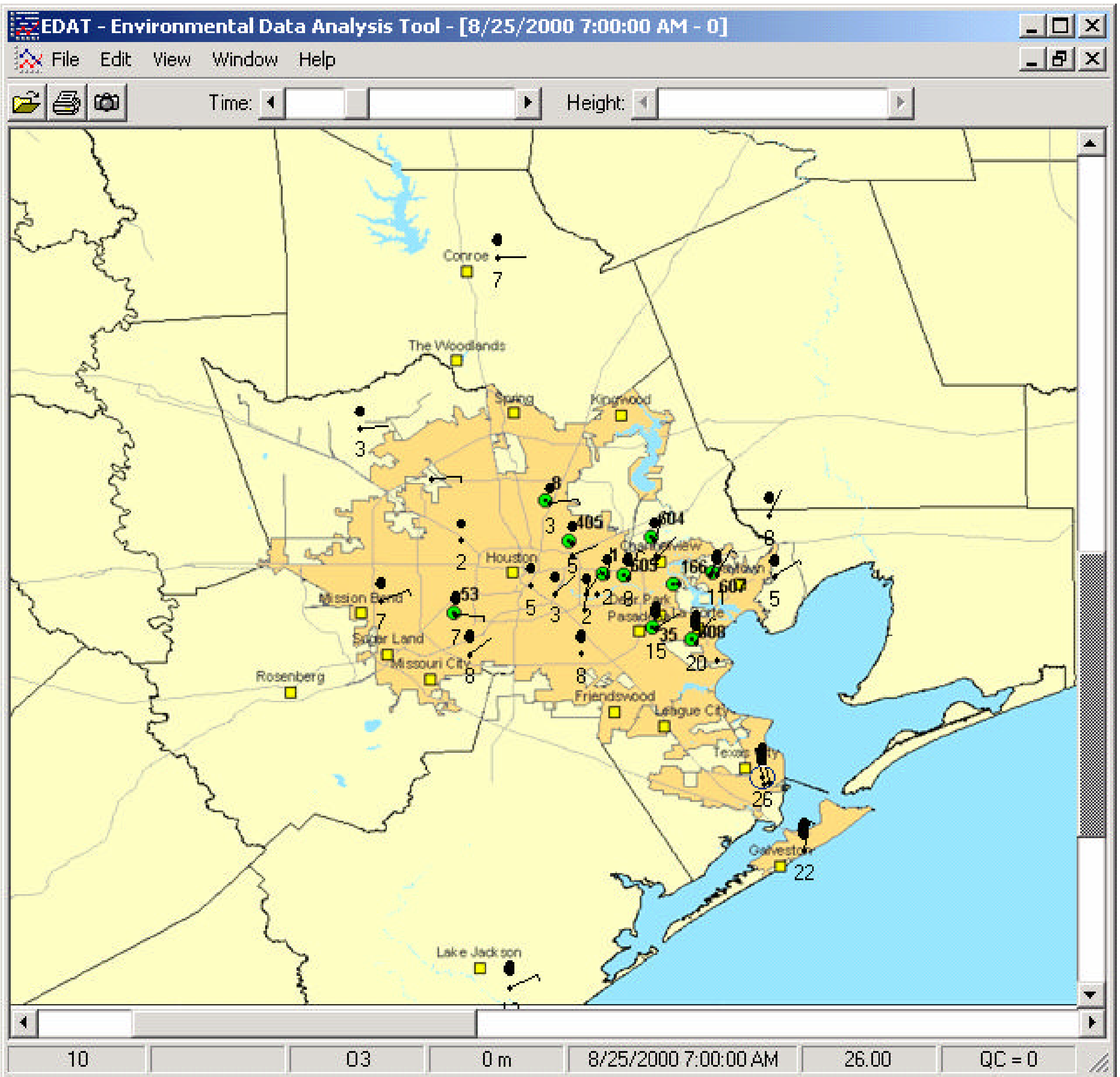


Figure 4-15. Spatial plot of hourly surface winds and ozone concentrations at CAMS sites on August 25, 2000, at 0700 CST. For winds, one-half of a flag = 2.5 m/sec and one flag = 5 m/sec. The wind blows from the end of the flagstaff, toward the monitoring site. For ozone, the plain text below each site shows the concentration in parts per billion, and the bar above each site shows the concentration by bar size. The CAMS numbers of selected sites are also shown.

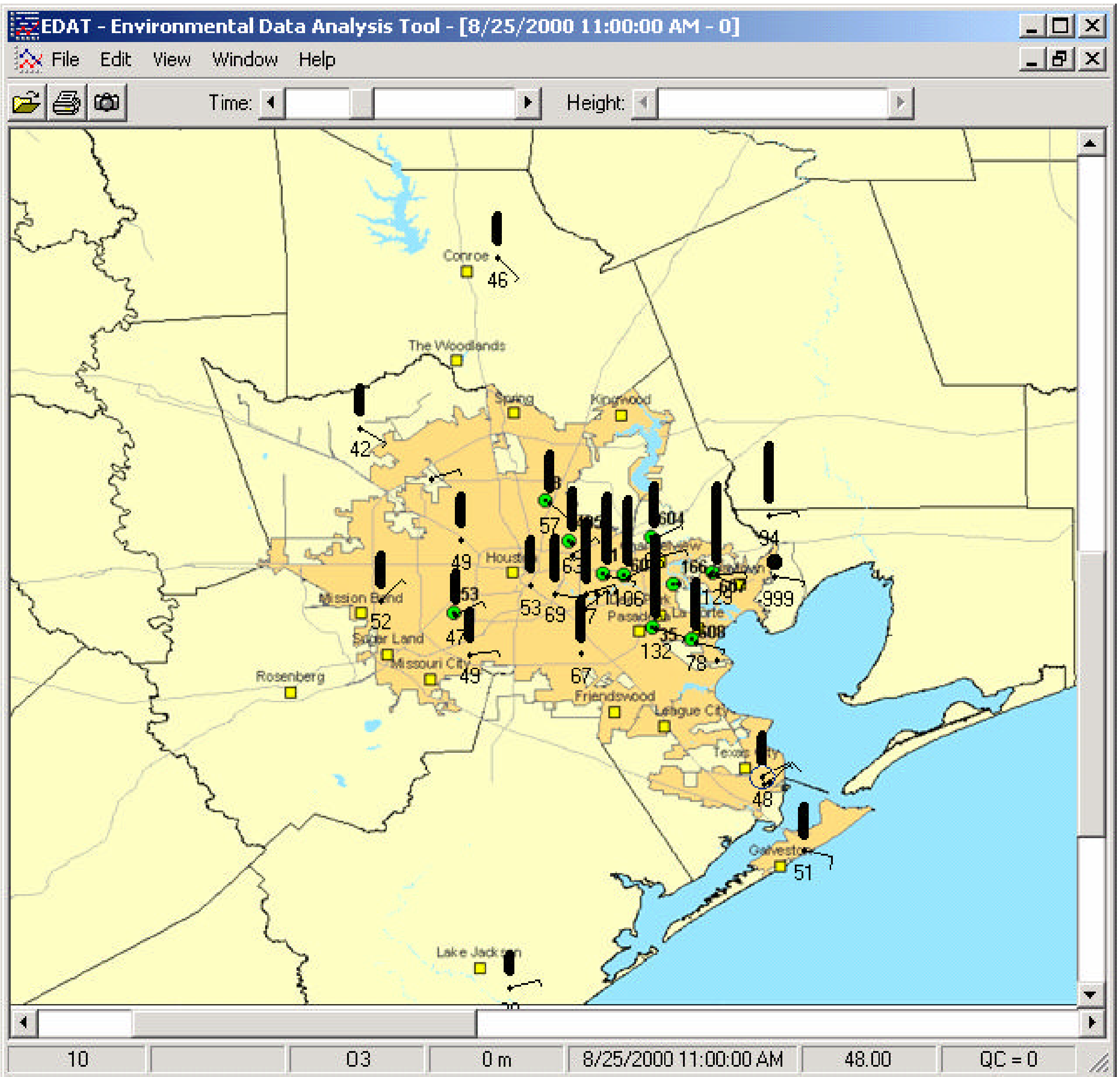


Figure 4-16. Spatial plot of hourly surface winds and ozone concentrations at CAMS sites on August 25, 2000, at 1100 CST. For winds, one-half of a flag = 2.5 m/sec and one flag = 5 m/sec. The wind blows from the end of the flagstaff, toward the monitoring site. For ozone, the plain text below each site shows the concentration in parts per billion, and the bar above each site shows the concentration by bar size. Note that missing data are reported as -999. The CAMS numbers of selected sites are also shown.

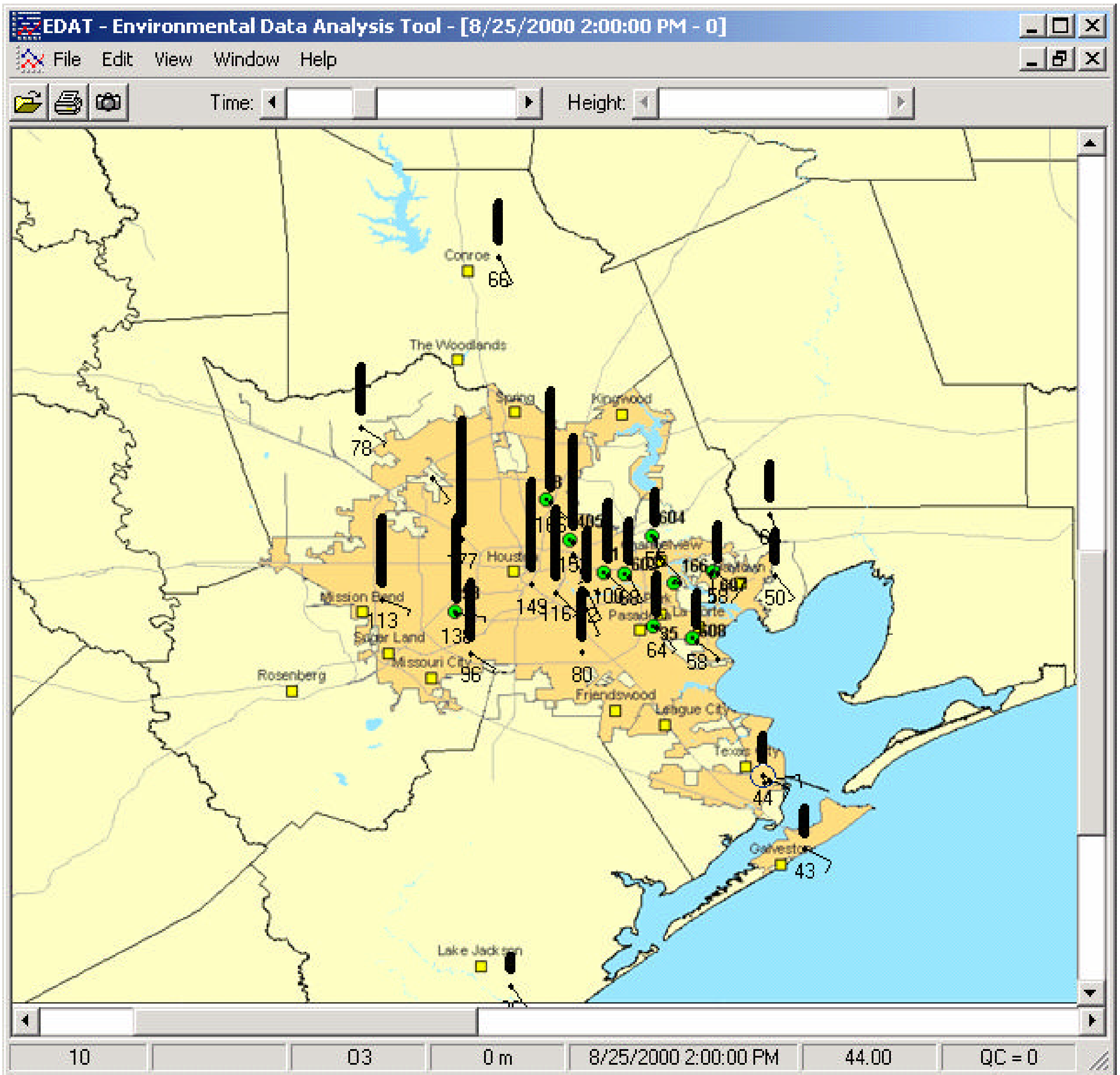


Figure 4-17. Spatial plot of hourly surface winds and ozone concentrations at CAMS sites on August 25, 2000, at 1400 CST. For winds, one-half of a flag = 2.5 m/sec and one flag = 5 m/sec. The wind blows from the end of the flagstaff, toward the monitoring site. For ozone, the plain text below each site shows the concentration in parts per billion, and the bar above each site shows the concentration by bar size. The CAMS numbers of selected sites are also shown.

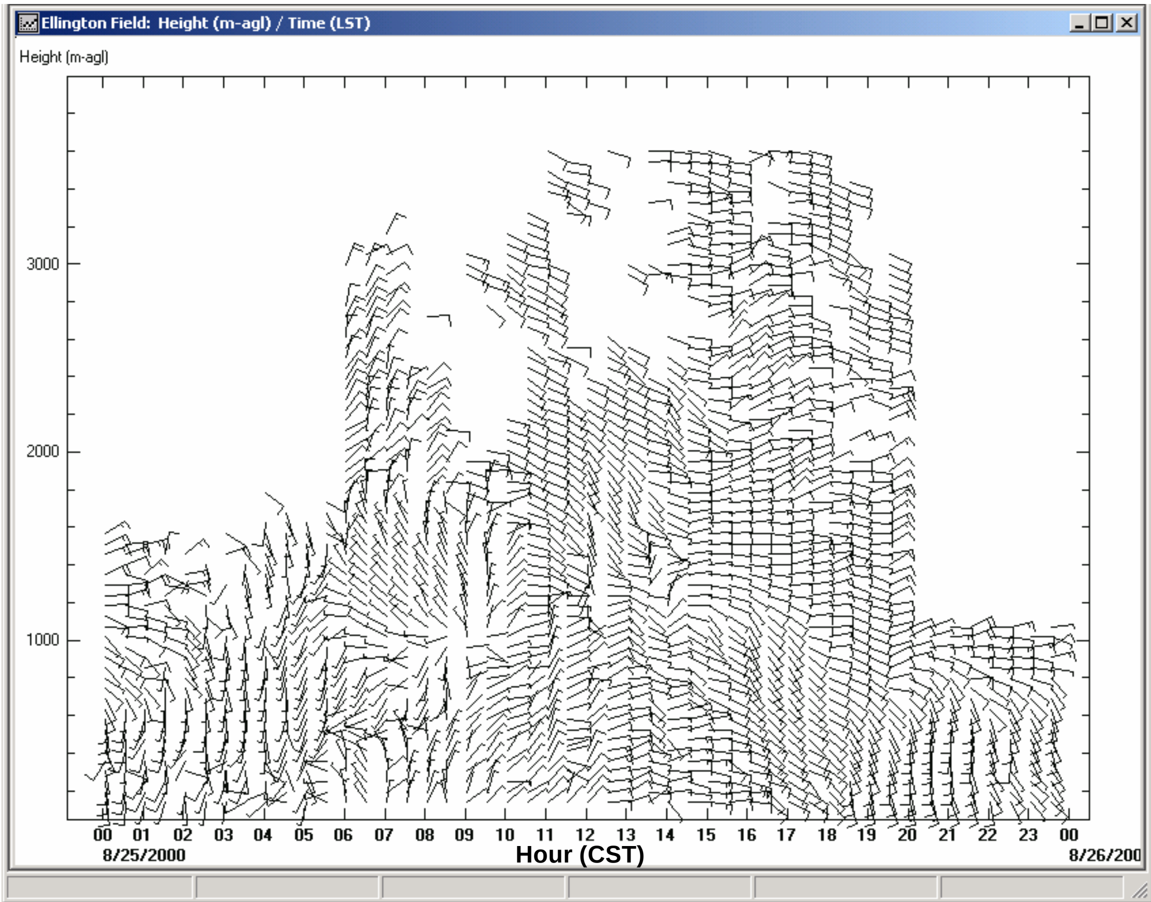


Figure 4-18. Time-height cross-section of radar profiler winds collected at Ellington Field on August 25, 2000.

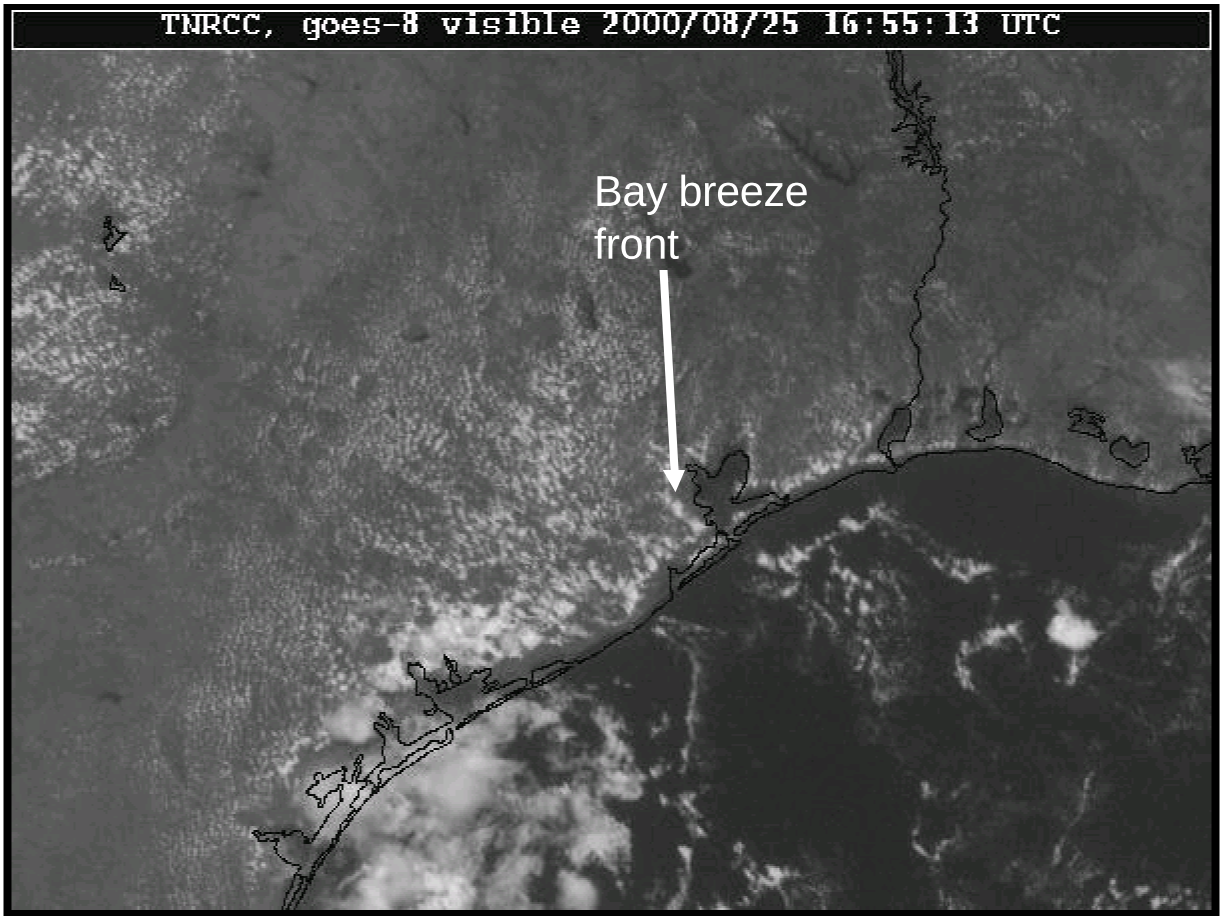


Figure 4-19. Visible satellite image for August 25, 2000, at 1055 CST (1655 UTC).

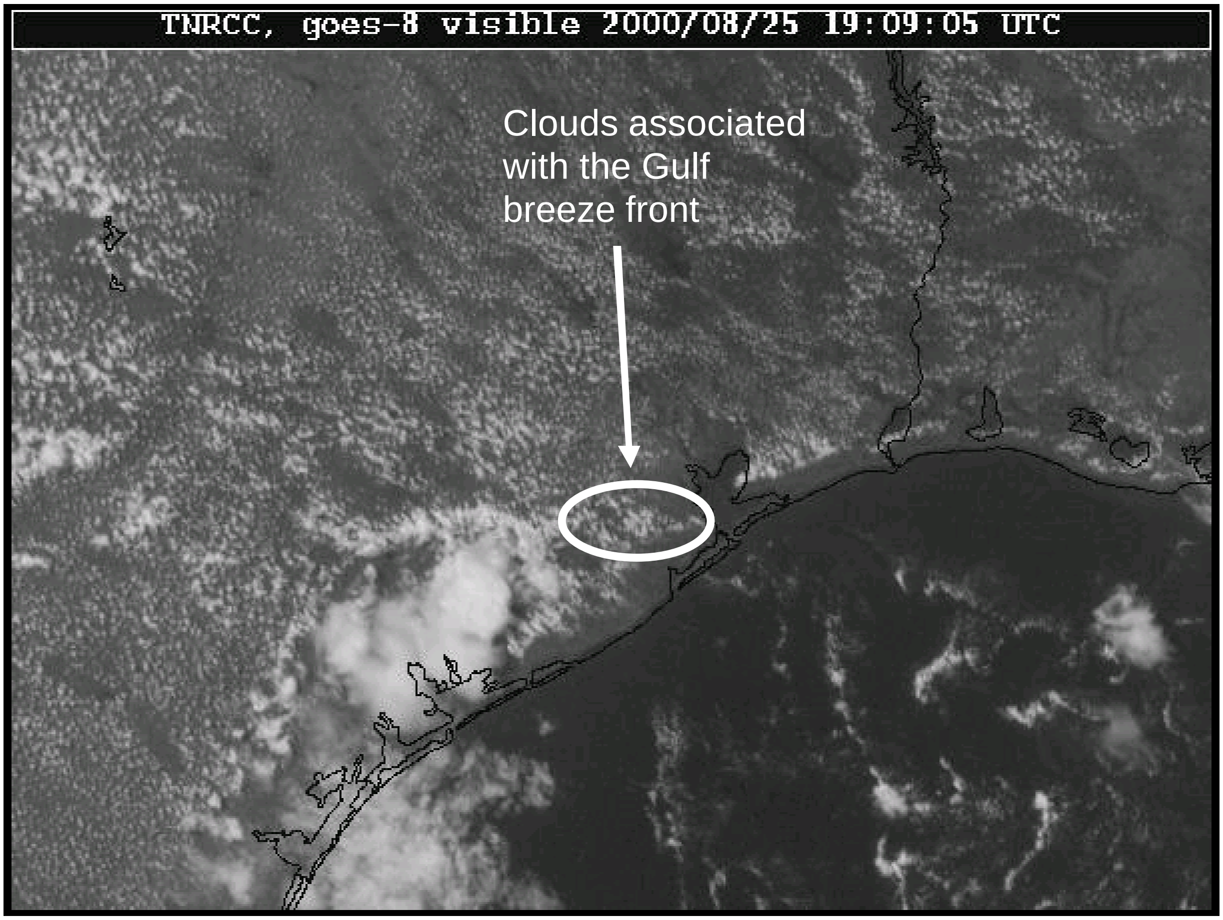


Figure 4-20. Visible satellite image for August 25, 2000, at 1309 CST (1909 UTC).

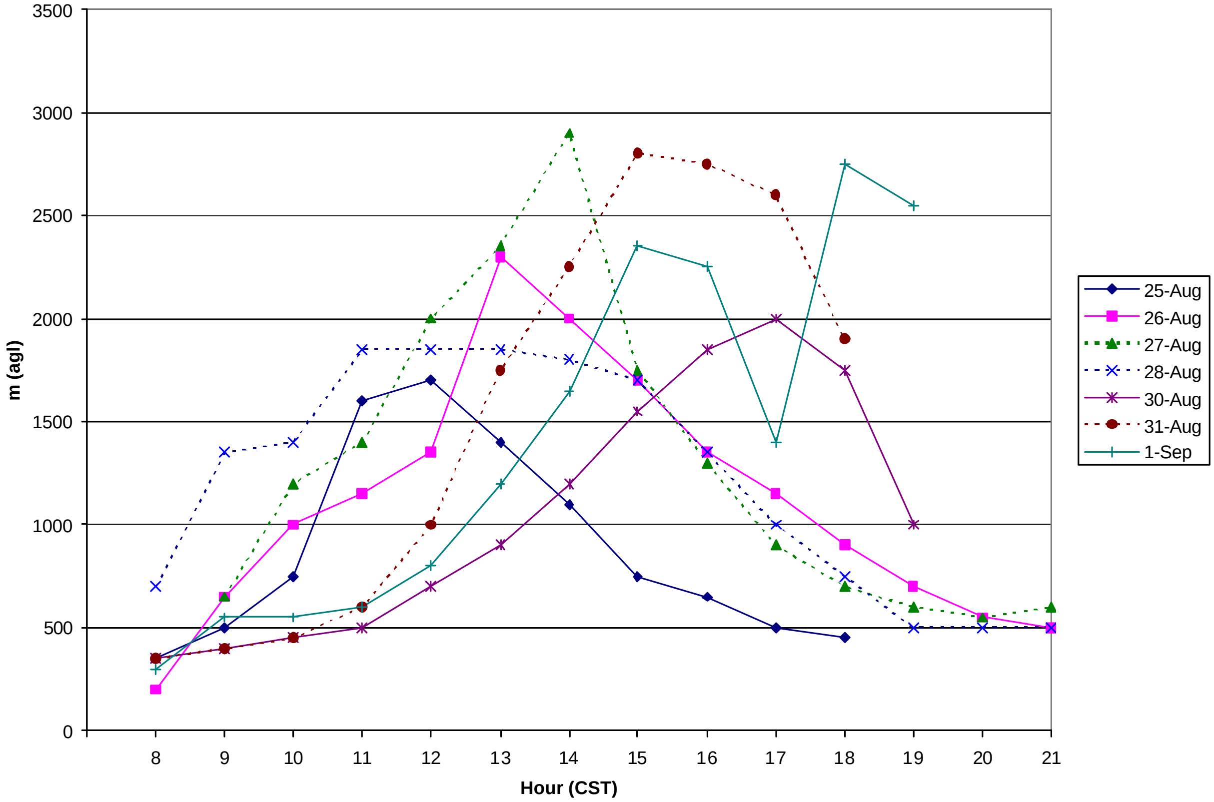


Figure 4-21. Hourly mixing heights that were estimated from radar profiler reflectivity data (C_n^2) on August 25- 28, 30, 31, and September 1, 2000.

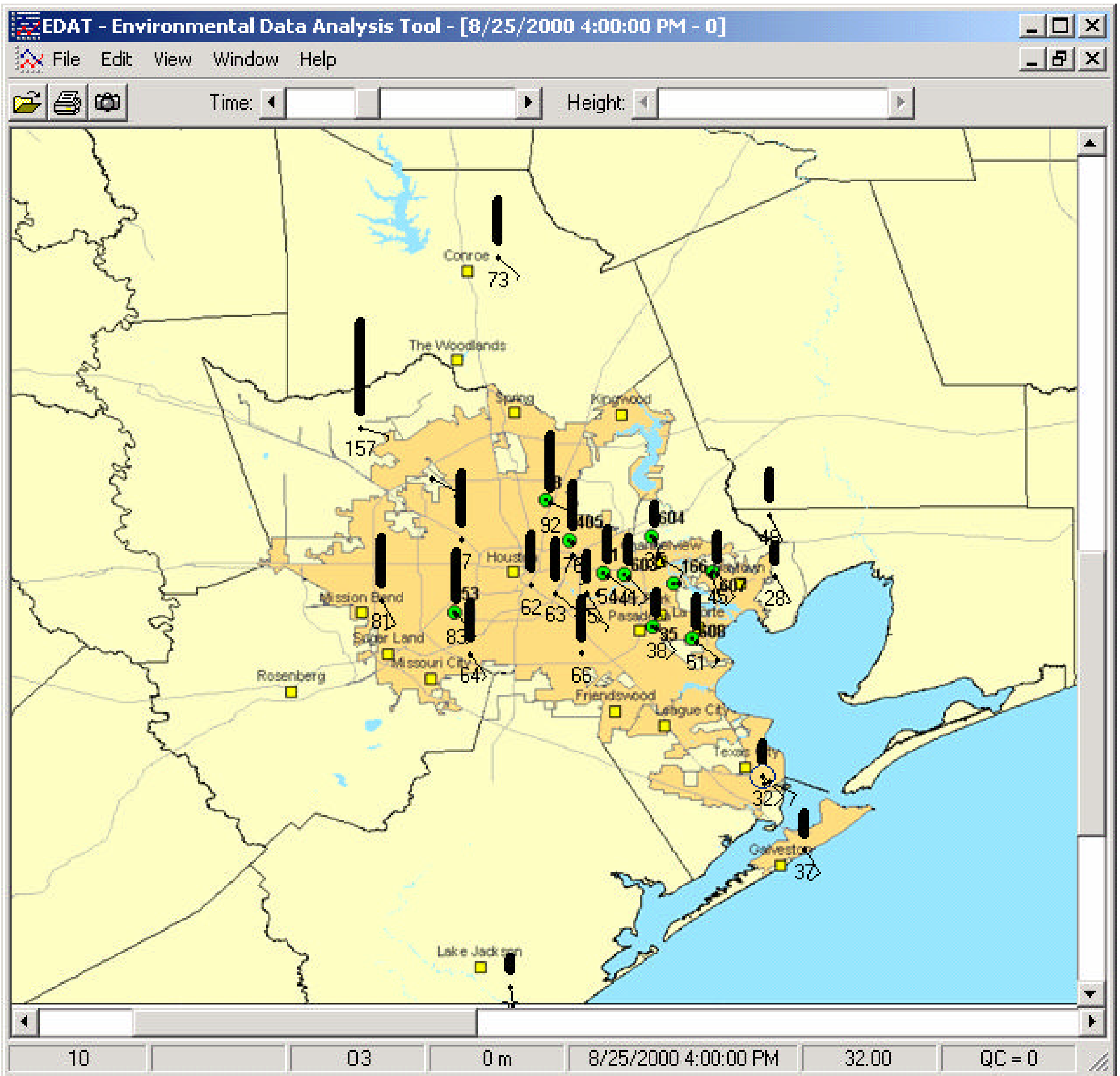


Figure 4-22. Spatial plot of hourly surface winds and ozone concentrations at CAMS sites on August 25, 2000, at 1600 CST. For winds, one-half of a flag = 2.5 m/sec and one flag = 5 m/sec. The wind blows from the end of the flagstaff, toward the monitoring site. For ozone, the plain text below each site shows the concentration in parts per billion, and the bar above each site shows the concentration by bar size. The CAMS numbers of selected sites are also shown.

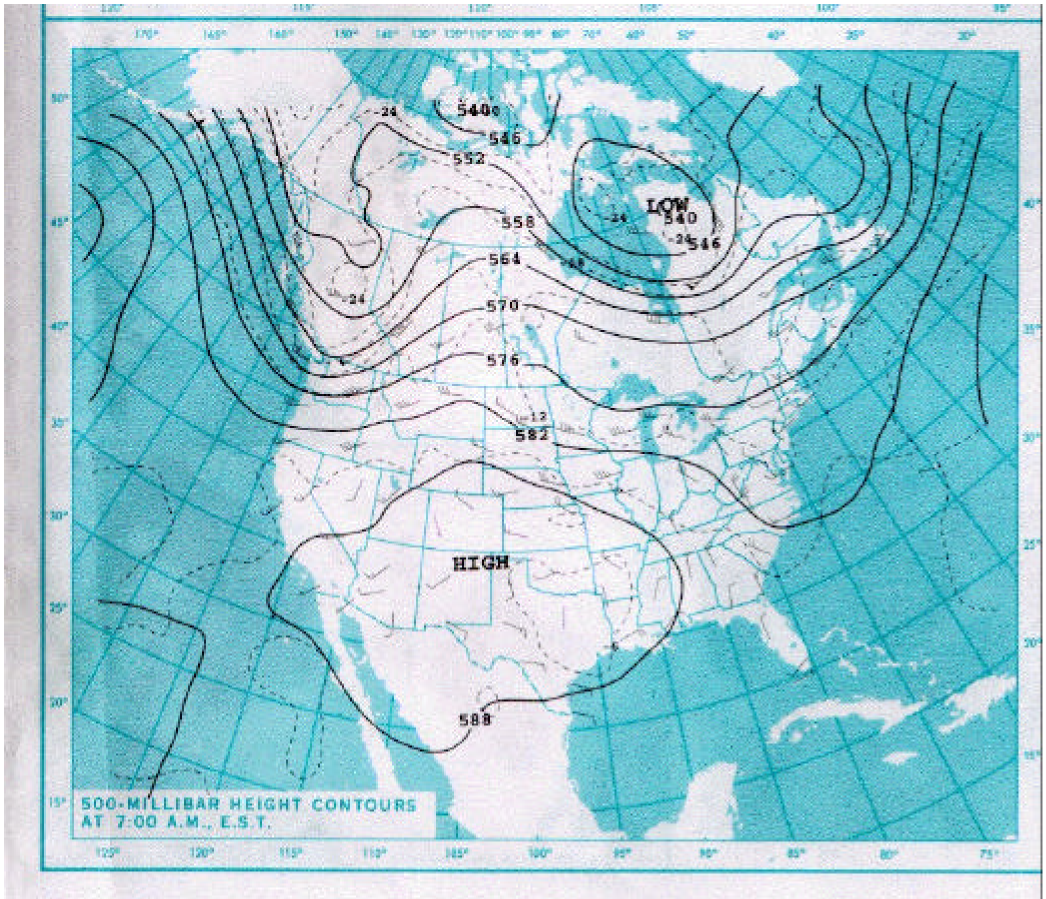


Figure 4-23. Contours of the height of the 500-mb surface pressure for August 26, 2000, at 0600 CST.

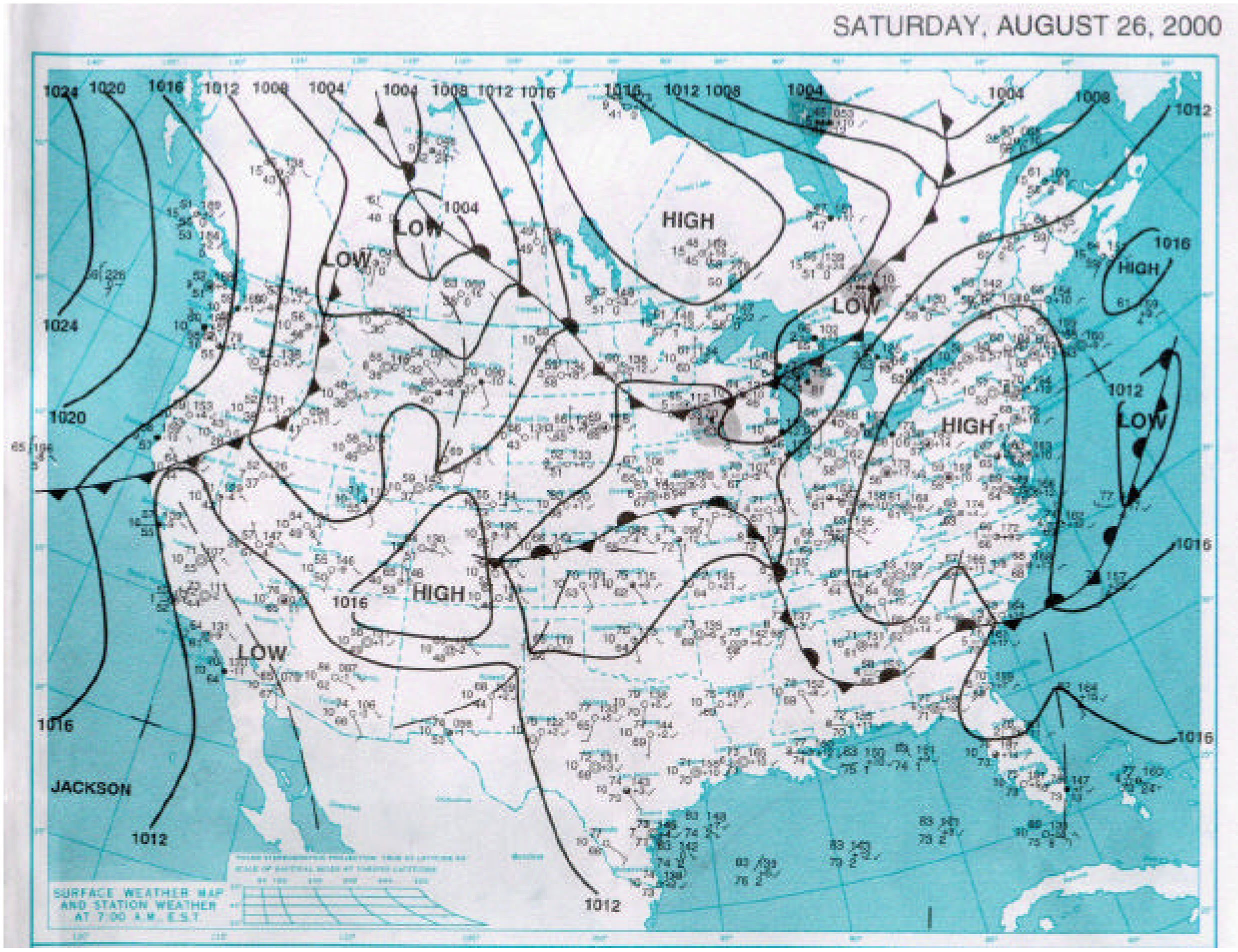


Figure 4-24. Surface analysis chart showing the winds, contours of surface pressure, and other weather conditions on August 26, 2000, at 0600 CST.

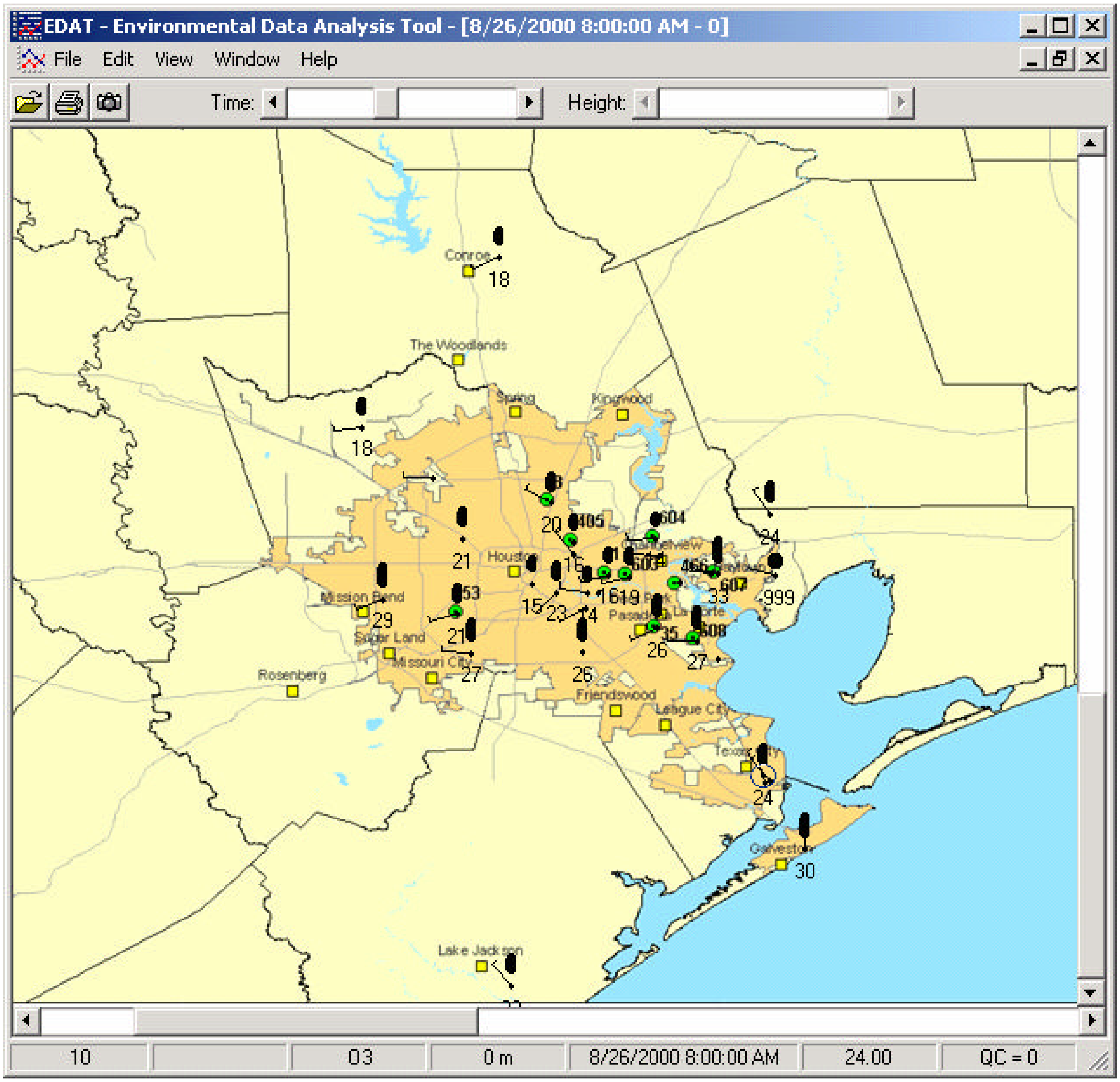


Figure 4-25. Spatial plot of hourly surface winds and ozone concentrations at CAMS sites on August 26, 2000, at 0800 CST. For winds, one-half of a flag = 2.5 m/sec and one flag = 5 m/sec. The wind blows from the end of the flagstaff, toward the monitoring site. For ozone, the plain text below each site shows the concentration in parts per billion, and the bar above each site shows the concentration by bar size. Note that missing data are reported as -999. The CAMS numbers of selected sites are also shown.

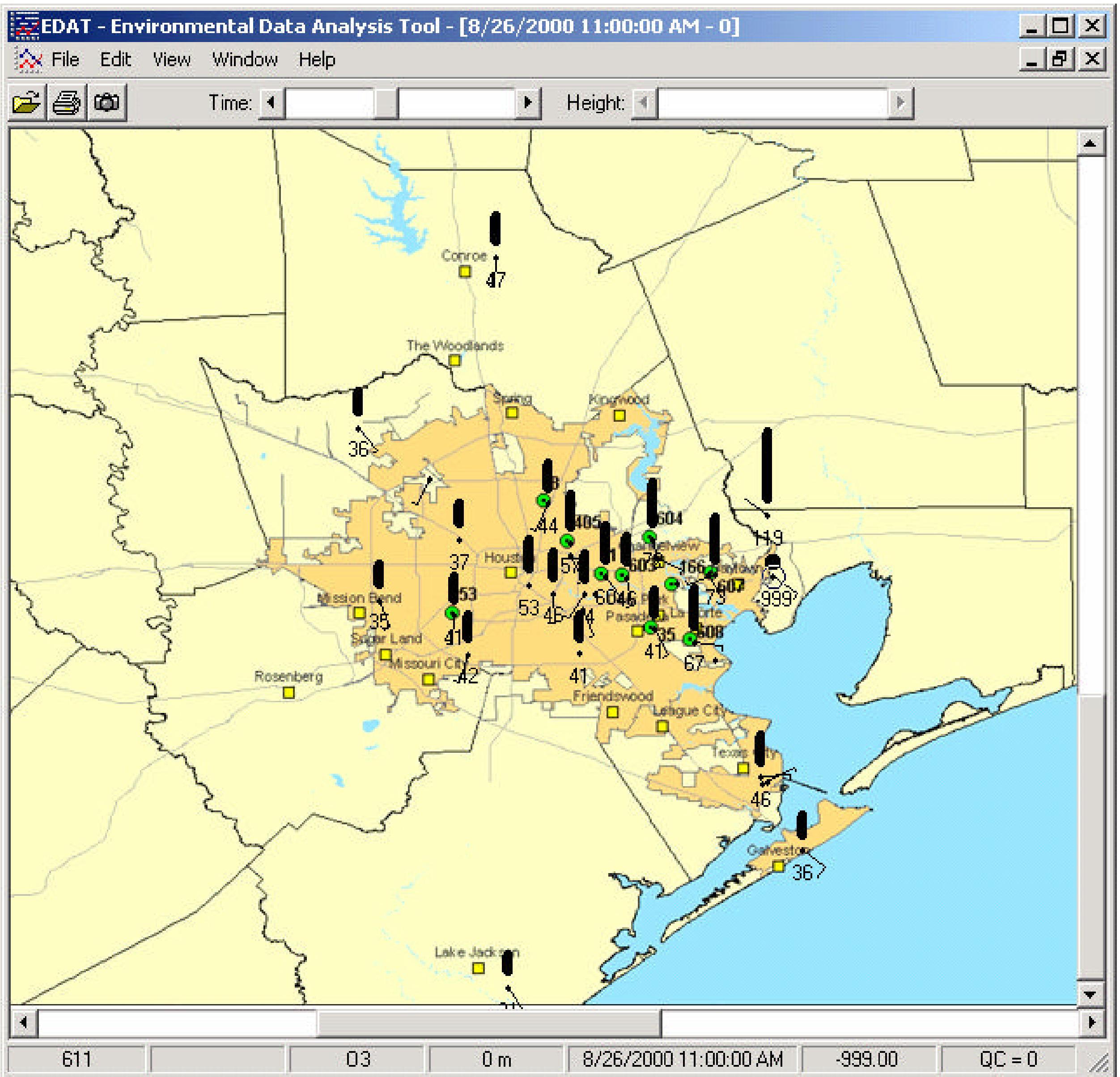


Figure 4-26. Spatial plot of hourly surface winds and ozone concentrations at CAMS sites on August 26, 2000, at 1100 CST. For winds, one-half of a flag = 2.5 m/sec and one flag = 5 m/sec. The wind blows from the end of the flagstaff, toward the monitoring site. For ozone, the plain text below each site shows the concentration in parts per billion, and the bar above each site shows the concentration by bar size. Note that missing data are reported as -999. The CAMS numbers of selected sites are also shown.

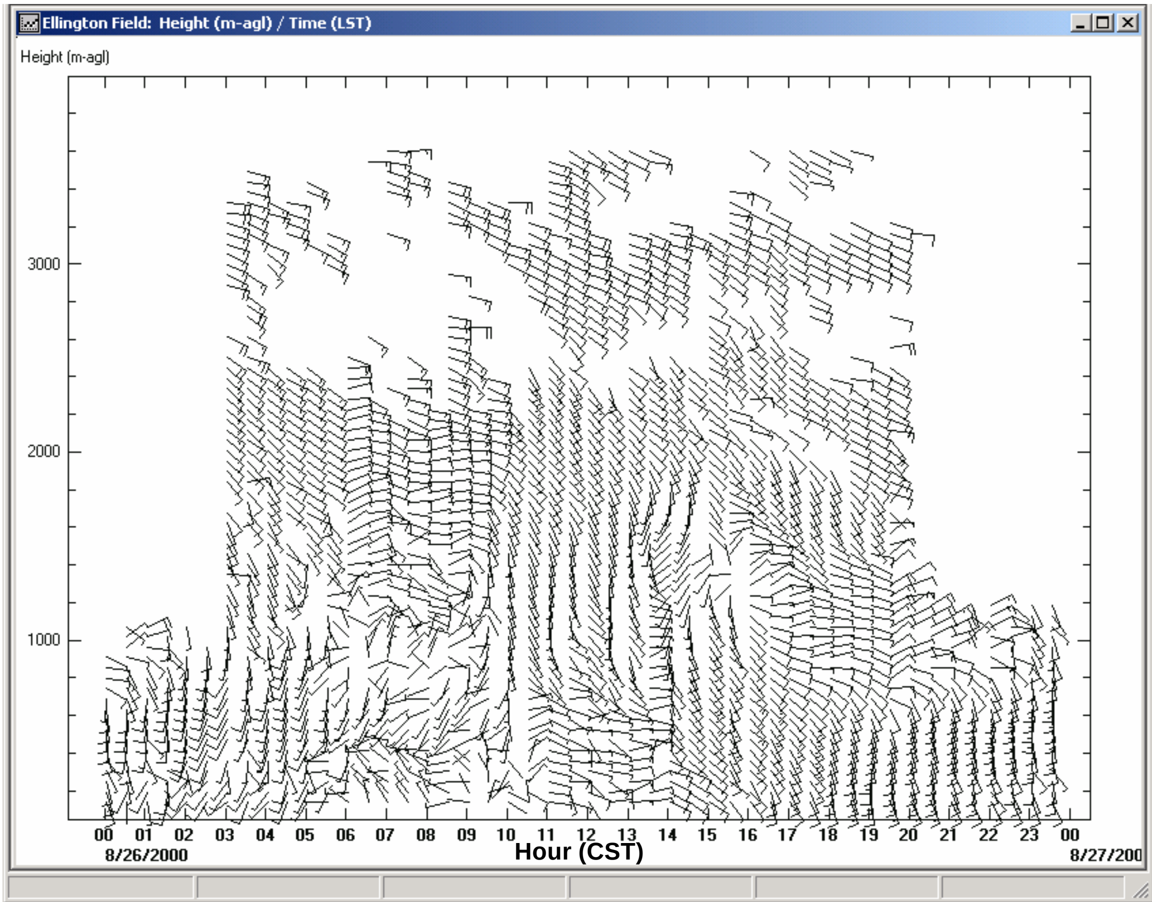


Figure 4-27. Time-height cross-section of radar profiler winds collected at Ellington Field on August 26, 2000.

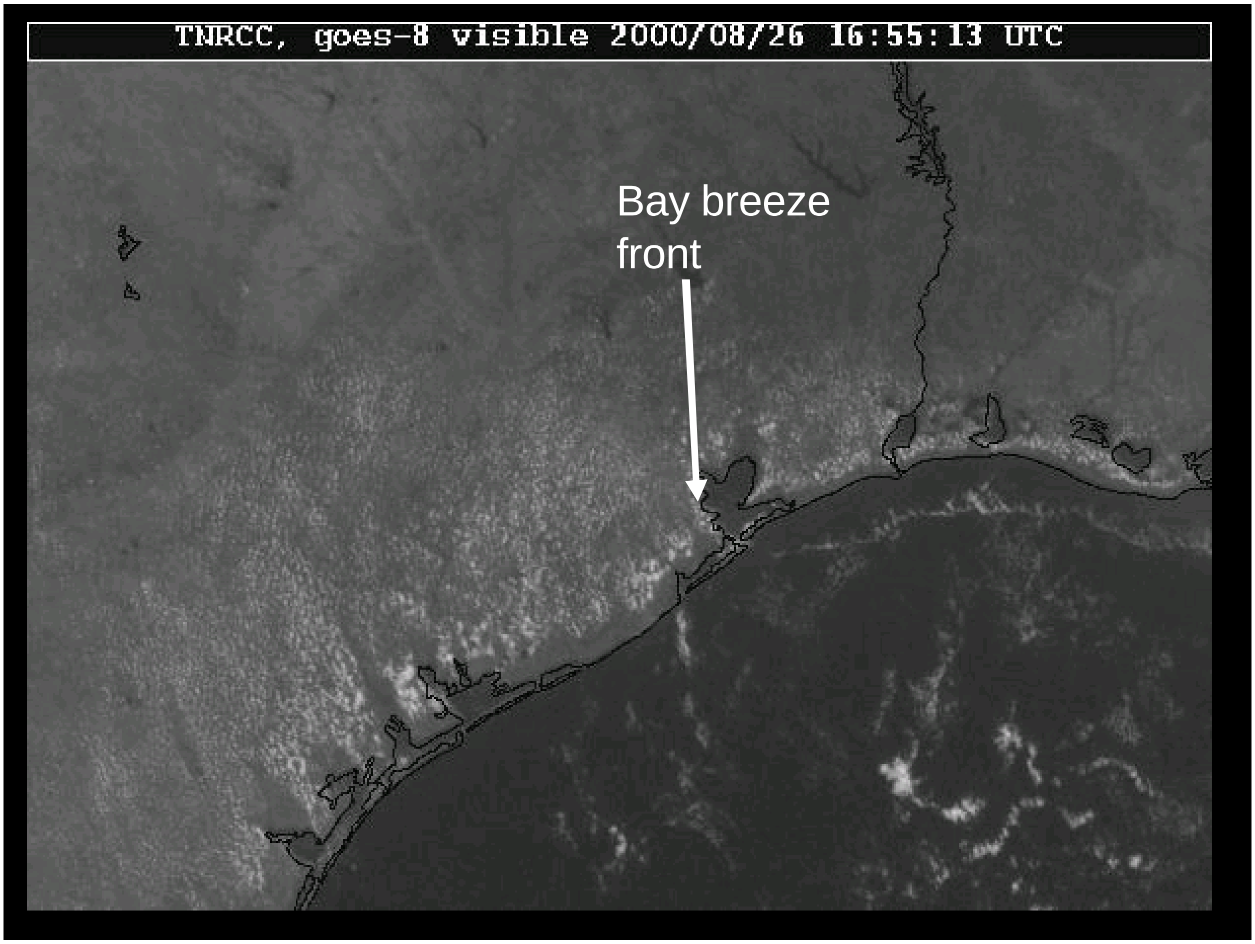


Figure 4-28. Visible satellite image for August 26, 2000, at 1055 CST (1655 UTC).

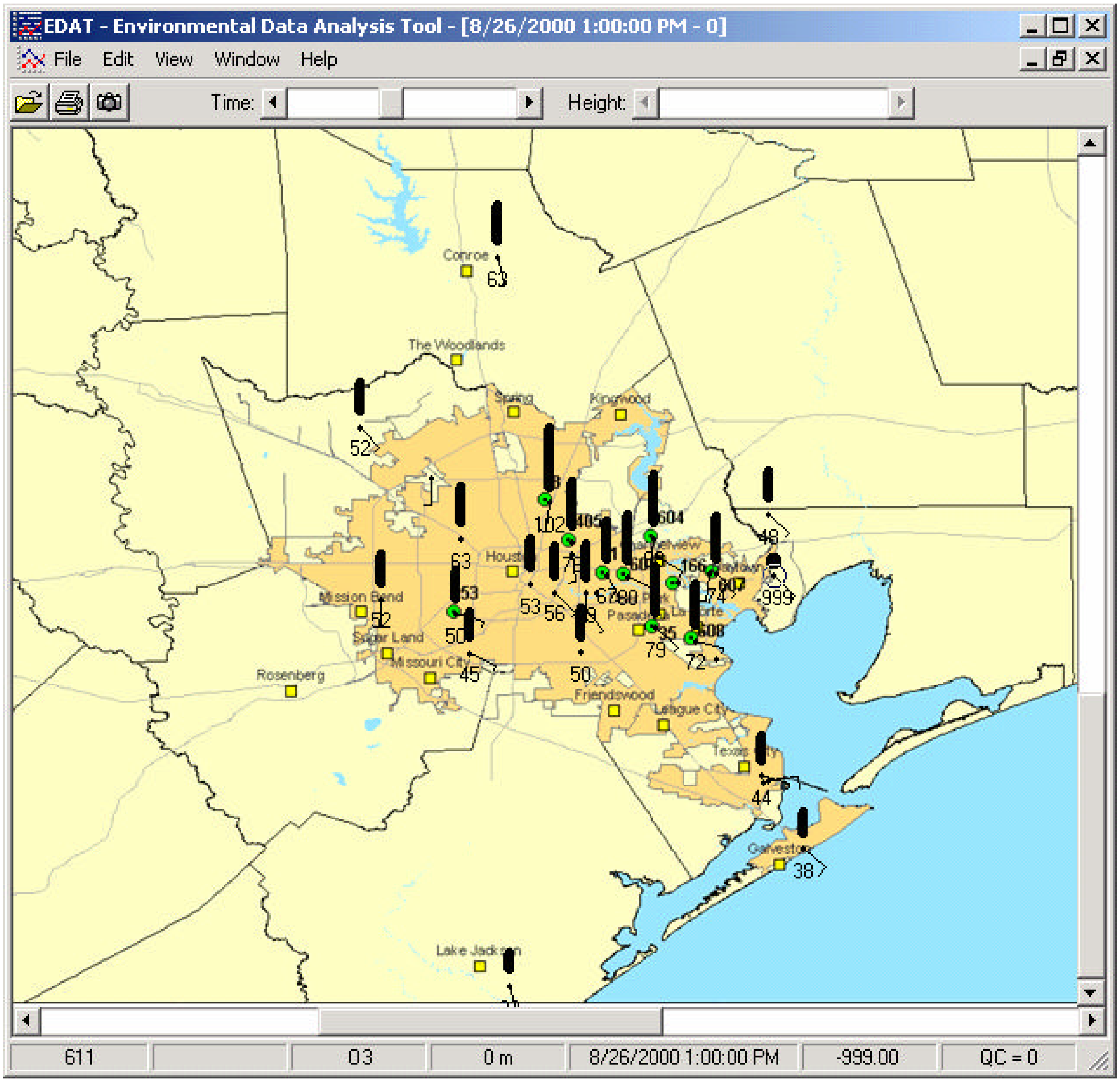


Figure 4-29. Spatial plot of hourly surface winds and ozone concentrations at CAMS sites on August 26, 2000, at 1300 CST. For winds, one-half of a flag = 2.5 m/sec and one flag = 5 m/sec. The wind blows from the end of the flagstaff, toward the monitoring site. For ozone, the plain text below each site shows the concentration in parts per billion, and the bar above each site shows the concentration by bar size. Note that missing data are reported as -999. The CAMS numbers of selected sites are also shown.

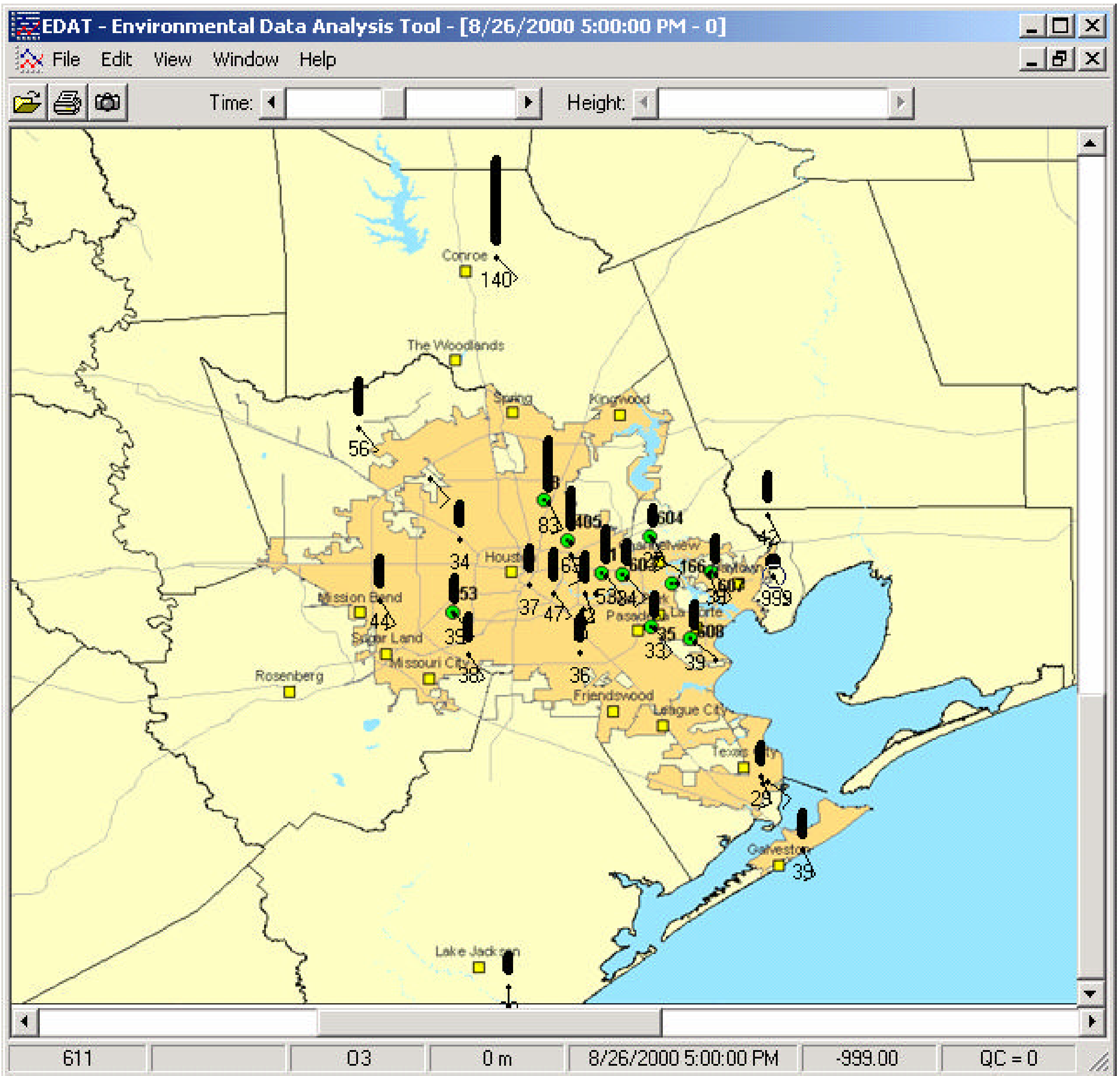


Figure 4-30. Spatial plot of hourly surface winds and ozone concentrations at CAMS sites on August 26, 2000, at 1700 CST. For winds, one-half of a flag = 2.5 m/sec and one flag = 5 m/sec. The wind blows from the end of the flagstaff, toward the monitoring site. For ozone, the plain text below each site shows the concentration in parts per billion, and the bar above each site shows the concentration by bar size. Note that missing data are reported as -999. The CAMS numbers of selected sites are also shown.

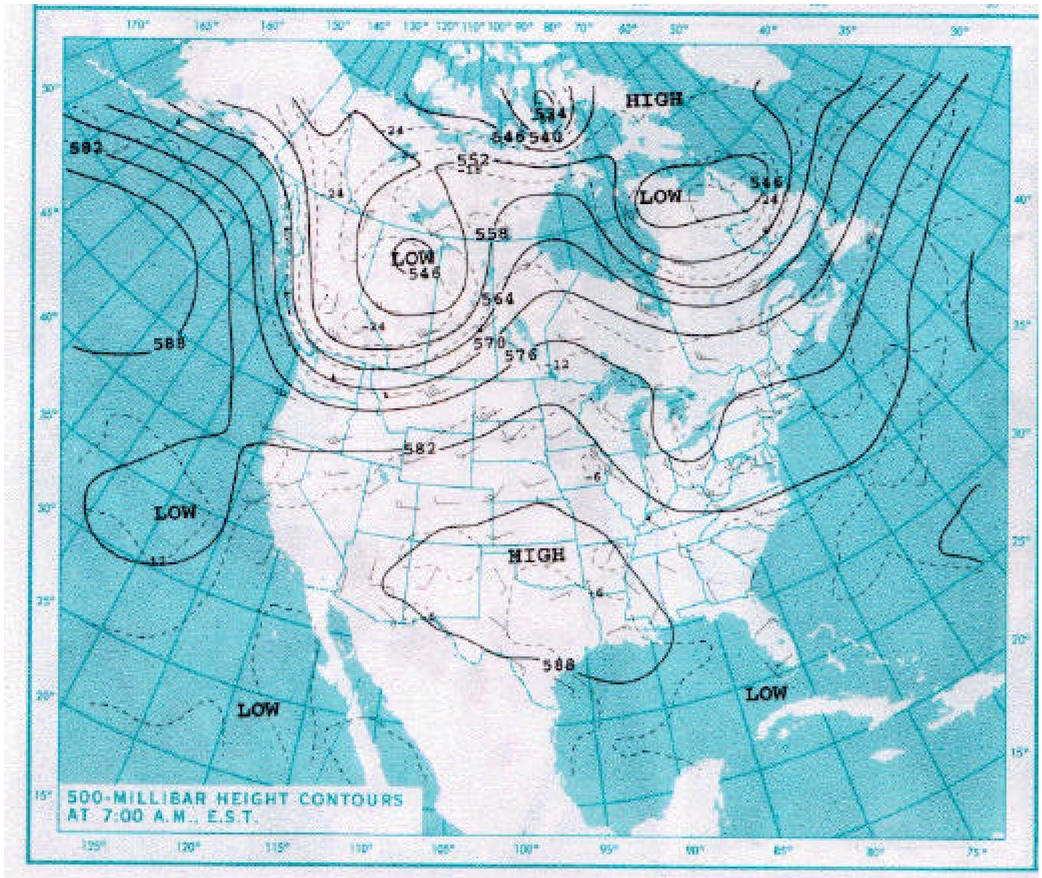


Figure 4-31. Contours of the height of the 500-mb surface pressure for August 27, 2000, at 0600 CST.

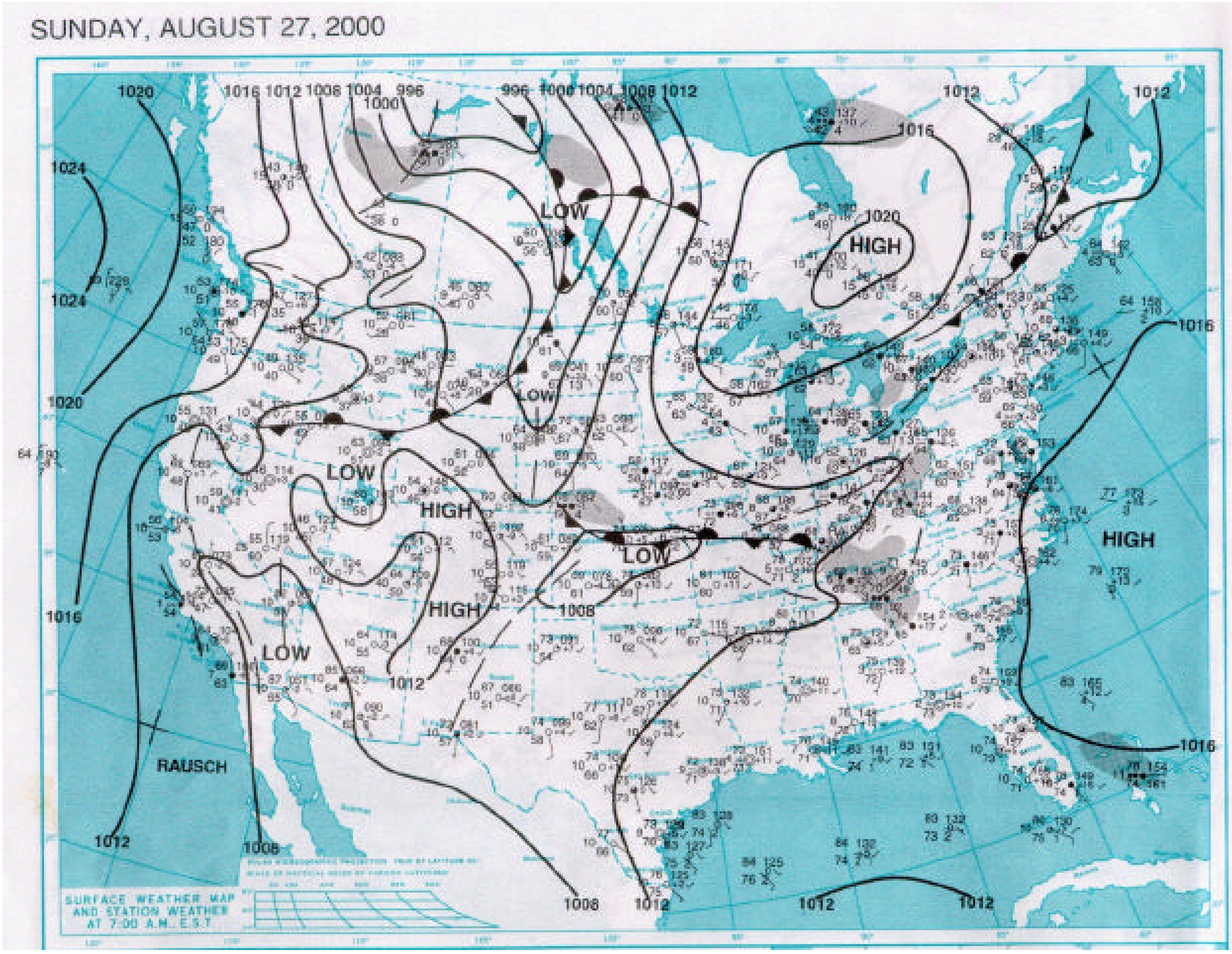


Figure 4-32. Surface analysis chart showing the winds, contours of surface pressure, and other weather conditions on August 27, 2000, at 0600 CST.

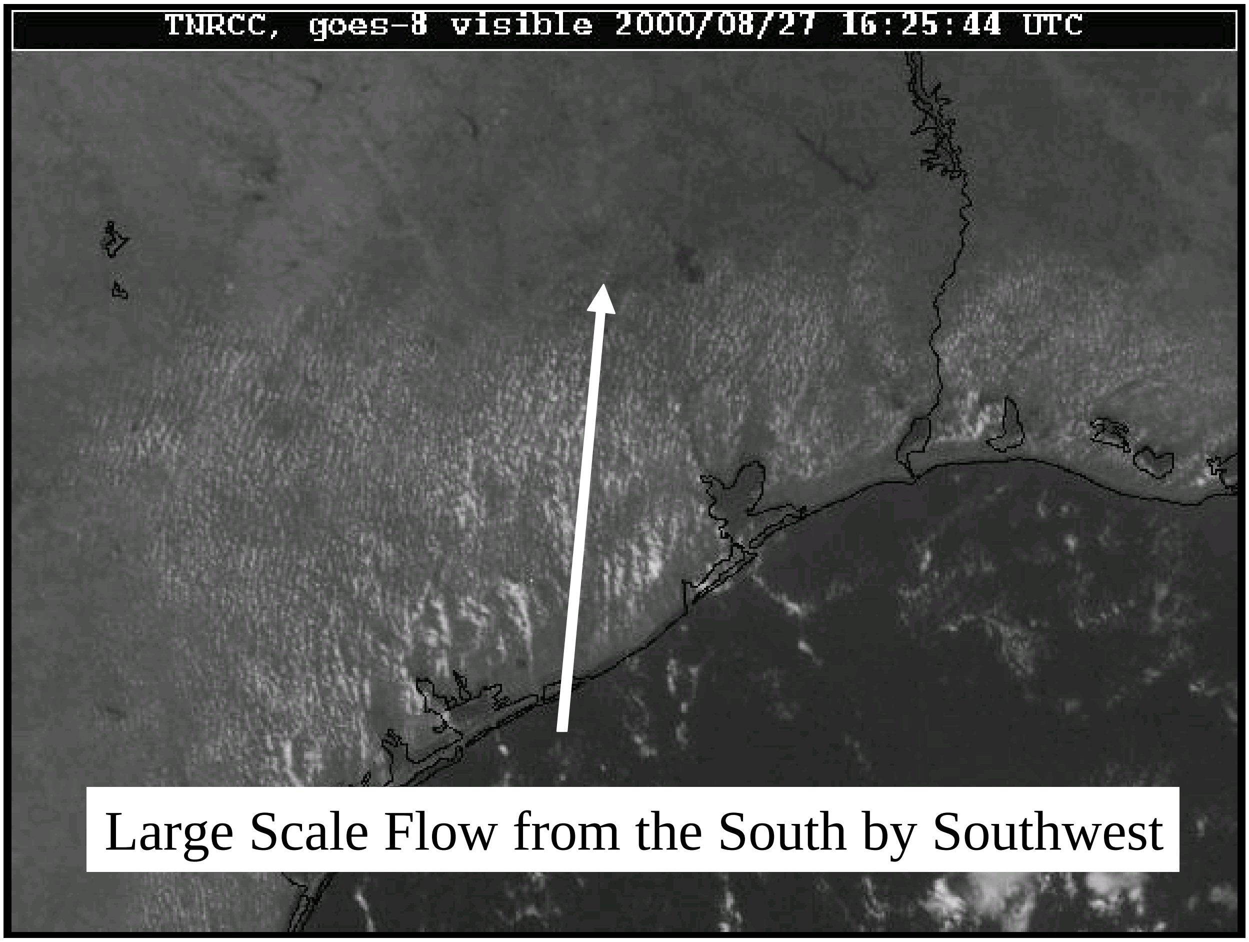


Figure 4-33. Visible satellite image for August 27, 2000, at 1025 CST (1625 UTC).

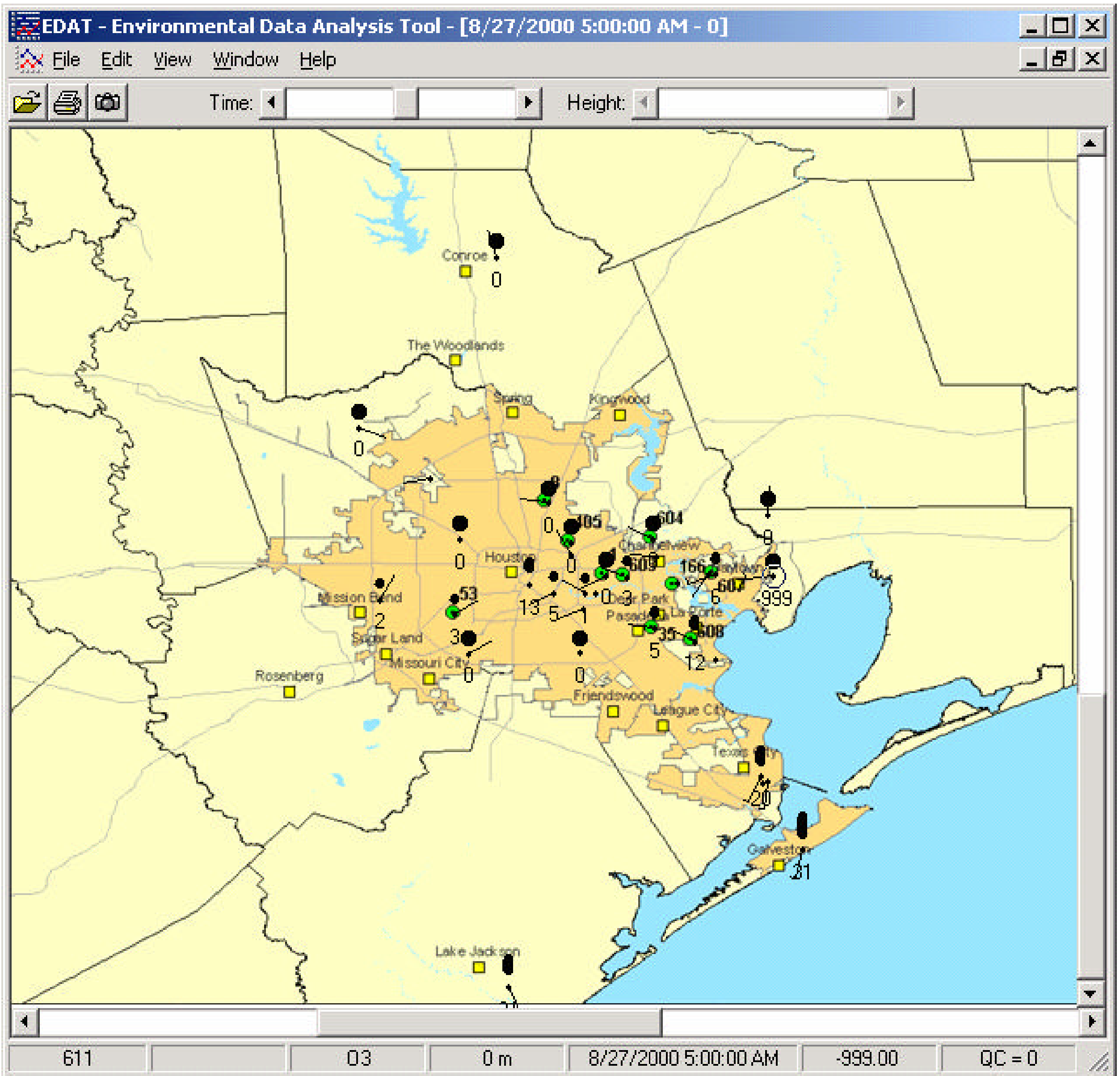


Figure 4-34. Spatial plot of hourly surface winds and ozone concentrations at CAMS sites on August 27, 2000, at 0500 CST. For winds, one-half of a flag = 2.5 m/sec and one flag = 5 m/sec. The wind blows from the end of the flagstaff, toward the monitoring site. For ozone, the plain text below each site shows the concentration in parts per billion, and the bar above each site shows the concentration by bar size. Note that missing data are reported as -999. The CAMS numbers of selected sites are also shown.

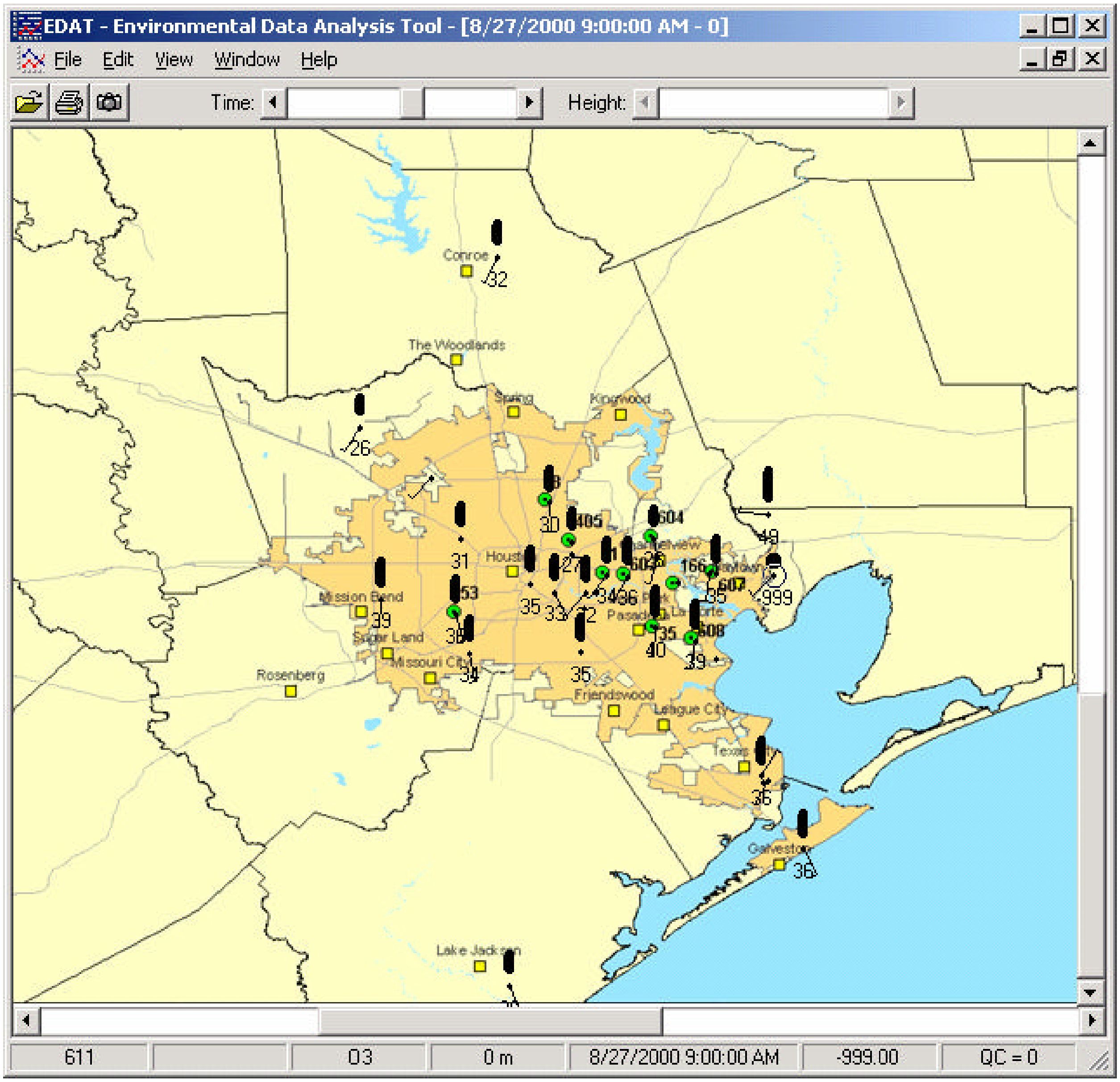


Figure 4-35. Spatial plot of hourly surface winds and ozone concentrations at CAMS sites on August 27, 2000, at 0900 CST. For winds, one-half of a flag = 2.5 m/sec and one flag = 5 m/sec. The wind blows from the end of the flagstaff, toward the monitoring site. For ozone, the plain text below each site shows the concentration in parts per billion, and the bar above each site shows the concentration by bar size. Note that missing data are reported as -999. The CAMS numbers of selected sites are also shown.

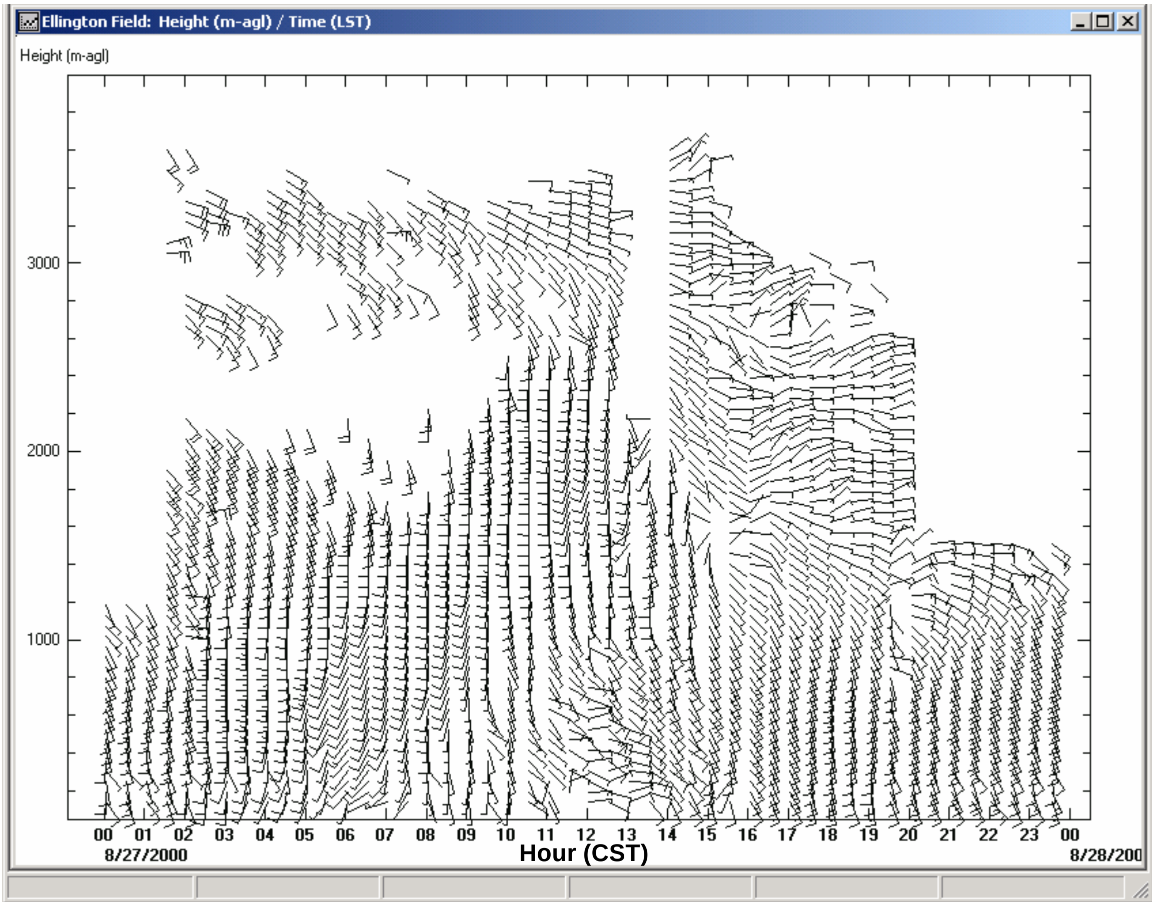


Figure 4-36. Time-height cross-section of radar profiler winds collected at Ellington Field on August 27, 2000.

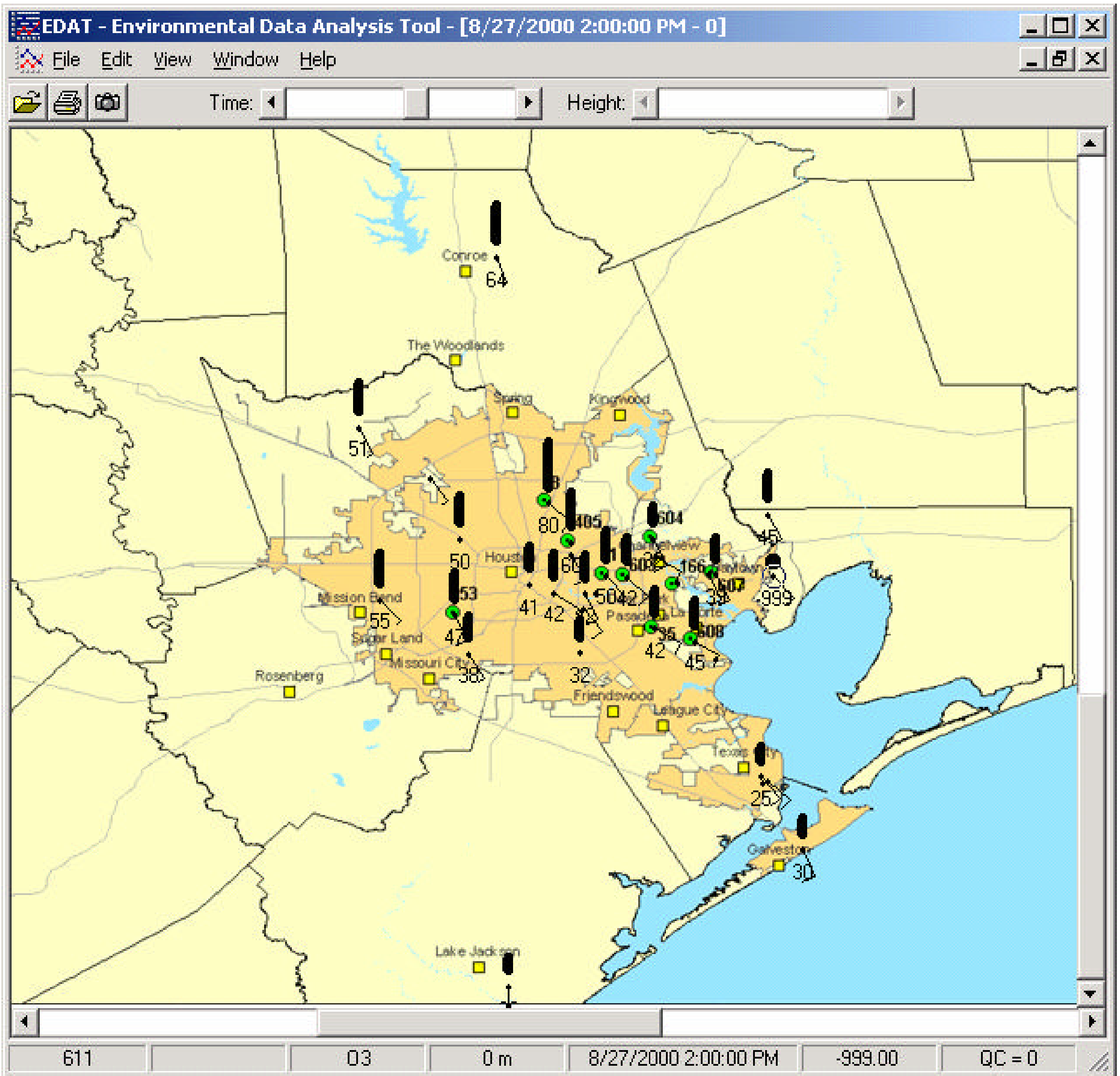


Figure 4-37. Spatial plot of hourly surface winds and ozone concentrations at CAMS sites on August 27, 2000, at 1400 CST. For winds, one-half of a flag = 2.5 m/sec and one flag = 5 m/sec. The wind blows from the end of the flagstaff, toward the monitoring site. For ozone, the plain text below each site shows the concentration in parts per billion, and the bar above each site shows the concentration by bar size. Note that missing data are reported as -999. The CAMS numbers of selected sites are also shown.

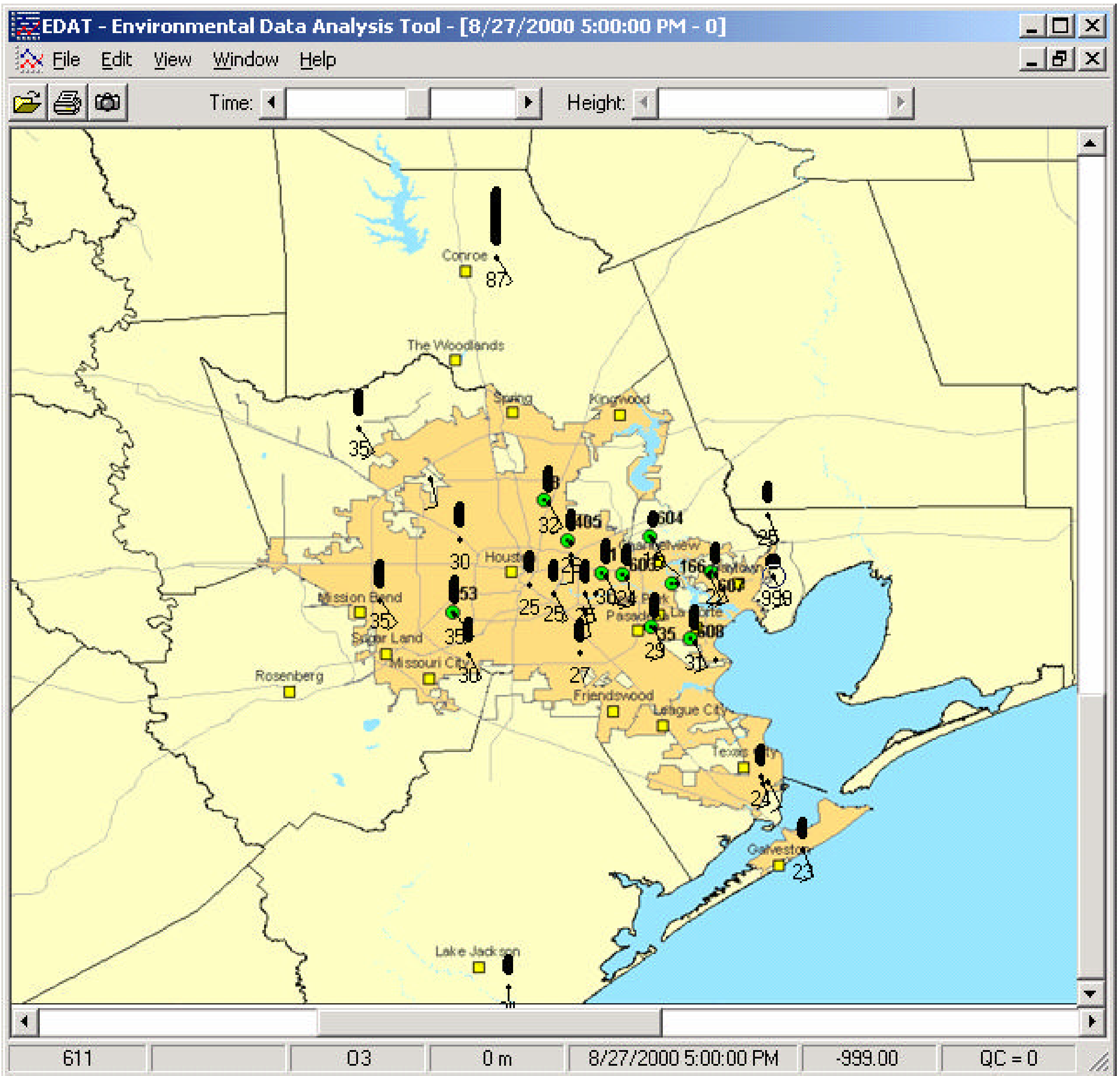


Figure 4-38. Spatial plot of hourly surface winds and ozone concentrations at CAMS sites on August 27, 2000, at 1700 CST. For winds, one-half of a flag = 2.5 m/sec and one flag = 5 m/sec. The wind blows from the end of the flagstaff, toward the monitoring site. For ozone, the plain text below each site shows the concentration in parts per billion, and the bar above each site shows the concentration by bar size. Note that missing data are reported as -999. The CAMS numbers of selected sites are also shown.

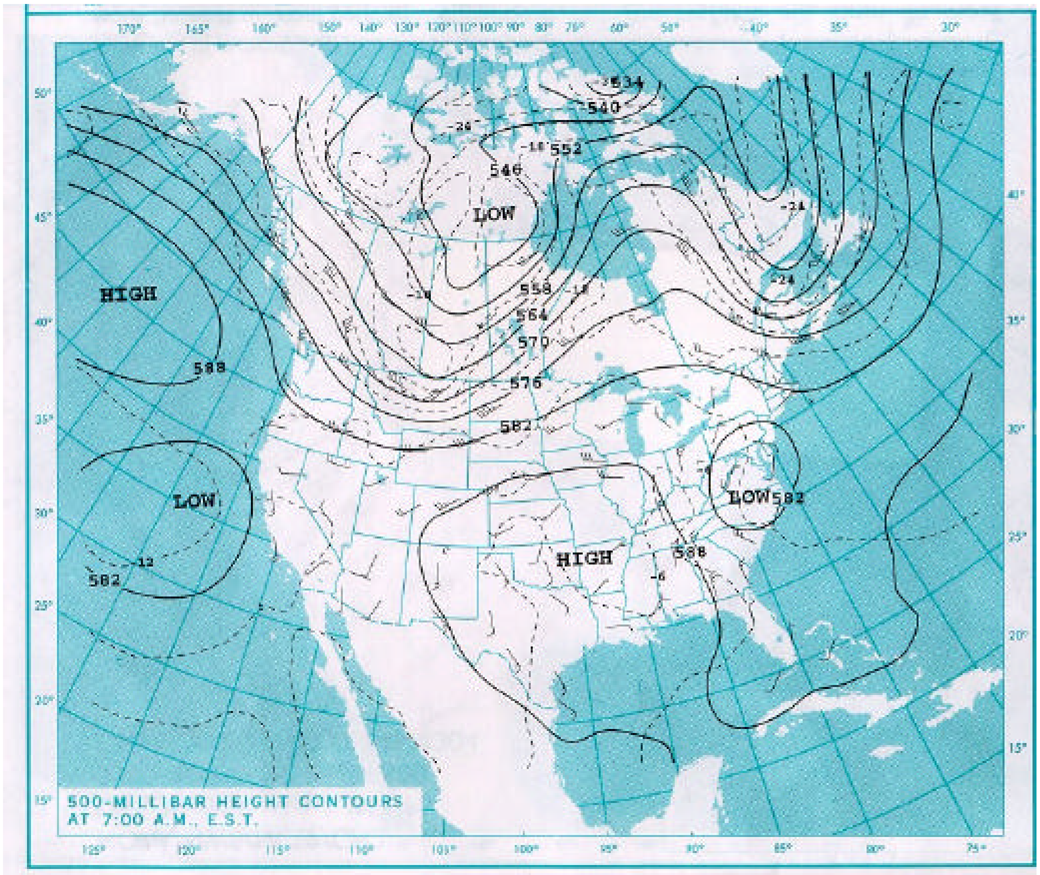


Figure 4-39. Contours of the height of the 500-mb surface pressure for August 28, 2000, at 0600 CST.

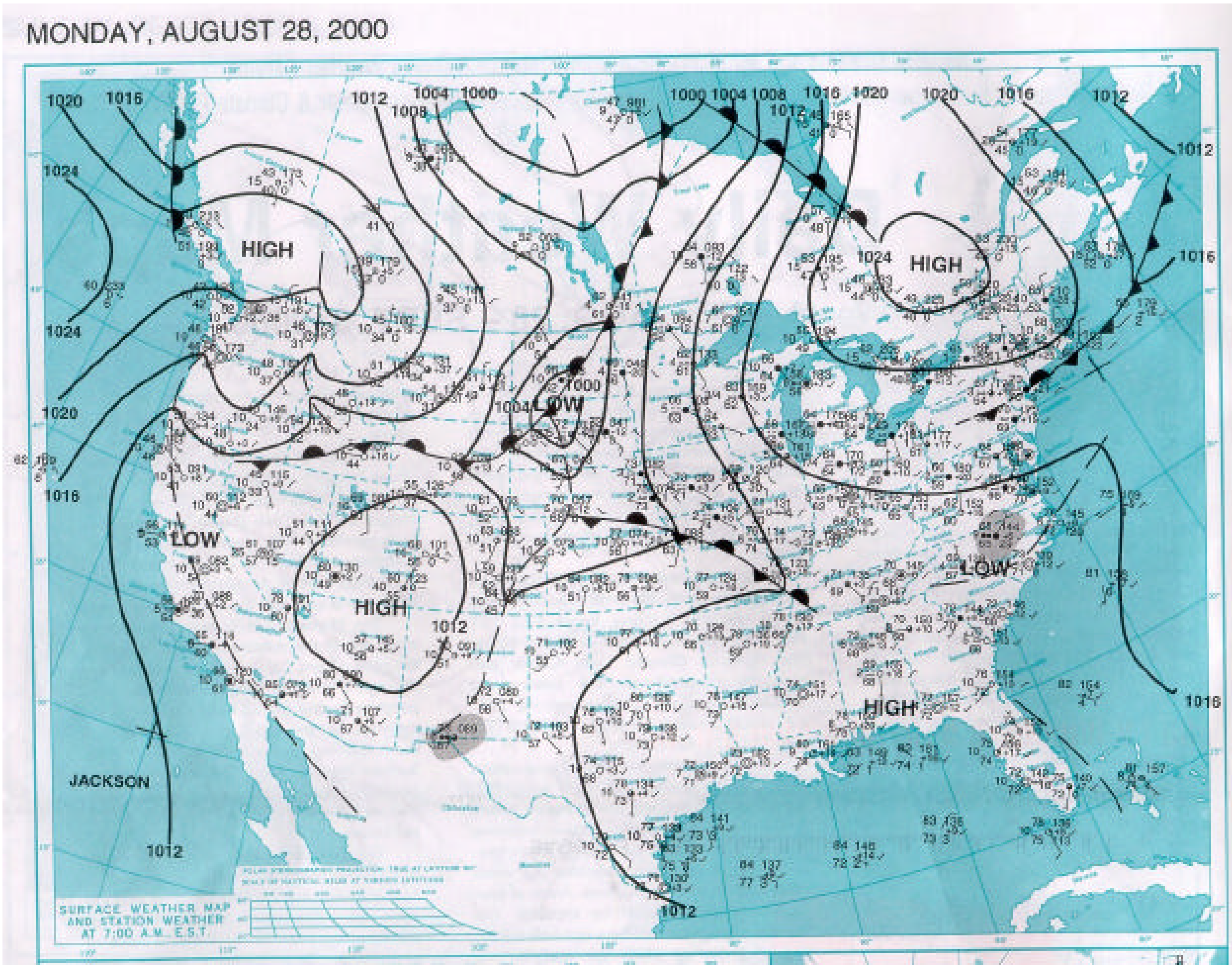


Figure 4-40. Surface analysis chart showing the winds, contours of surface pressure, and other weather conditions on August 28, 2000, at 0600 CST.

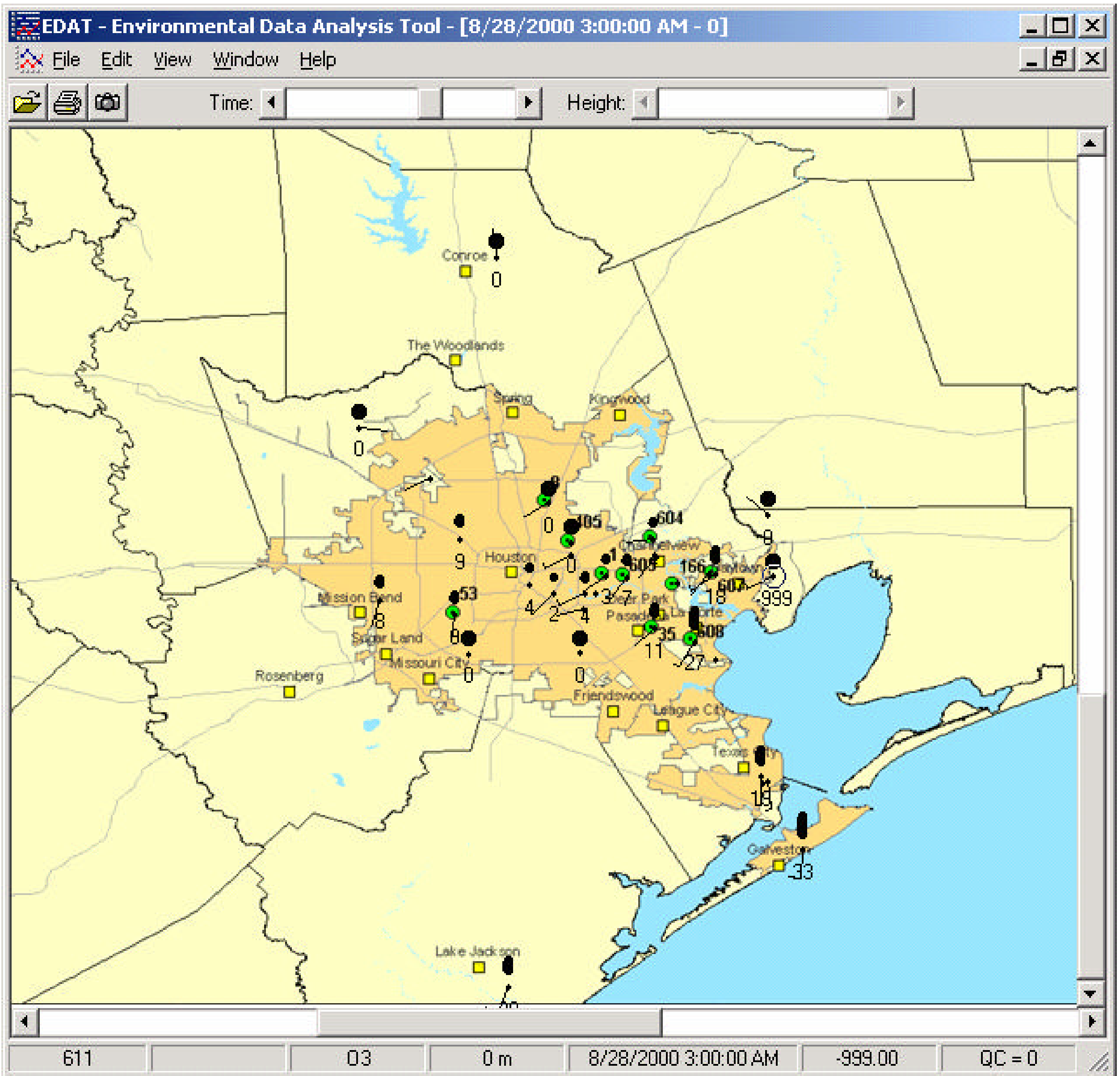


Figure 4-41. Spatial plot of hourly surface winds and ozone concentrations at CAMS sites on August 28, 2000, at 0300 CST. For winds, one-half of a flag = 2.5 m/sec and one flag = 5 m/sec. The wind blows from the end of the flagstaff, toward the monitoring site. For ozone, the plain text below each site shows the concentration in parts per billion, and the bar above each site shows the concentration by bar size. Note that missing data are reported as -999. The CAMS numbers of selected sites are also shown.

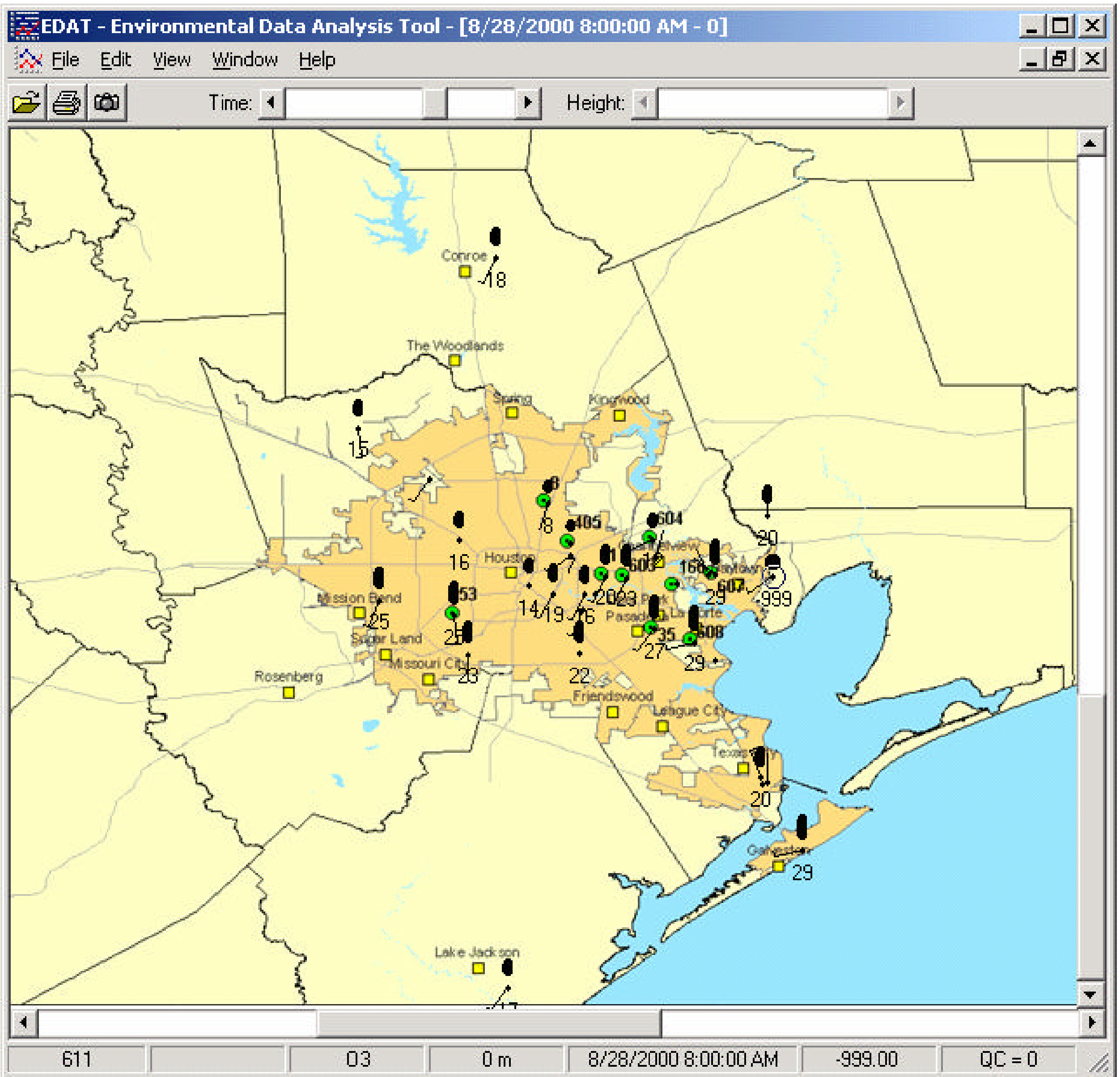


Figure 4-42. Spatial plot of hourly surface winds and ozone concentrations at CAMS sites on August 28, 2000, at 0800 CST. For winds, one-half of a flag = 2.5 m/sec and one flag = 5 m/sec. The wind blows from the end of the flagstaff, toward the monitoring site. For ozone, the plain text below each site shows the concentration in parts per billion, and the bar above each site shows the concentration by bar size. Note that missing data are reported as -999. The CAMS numbers of selected sites are also shown.

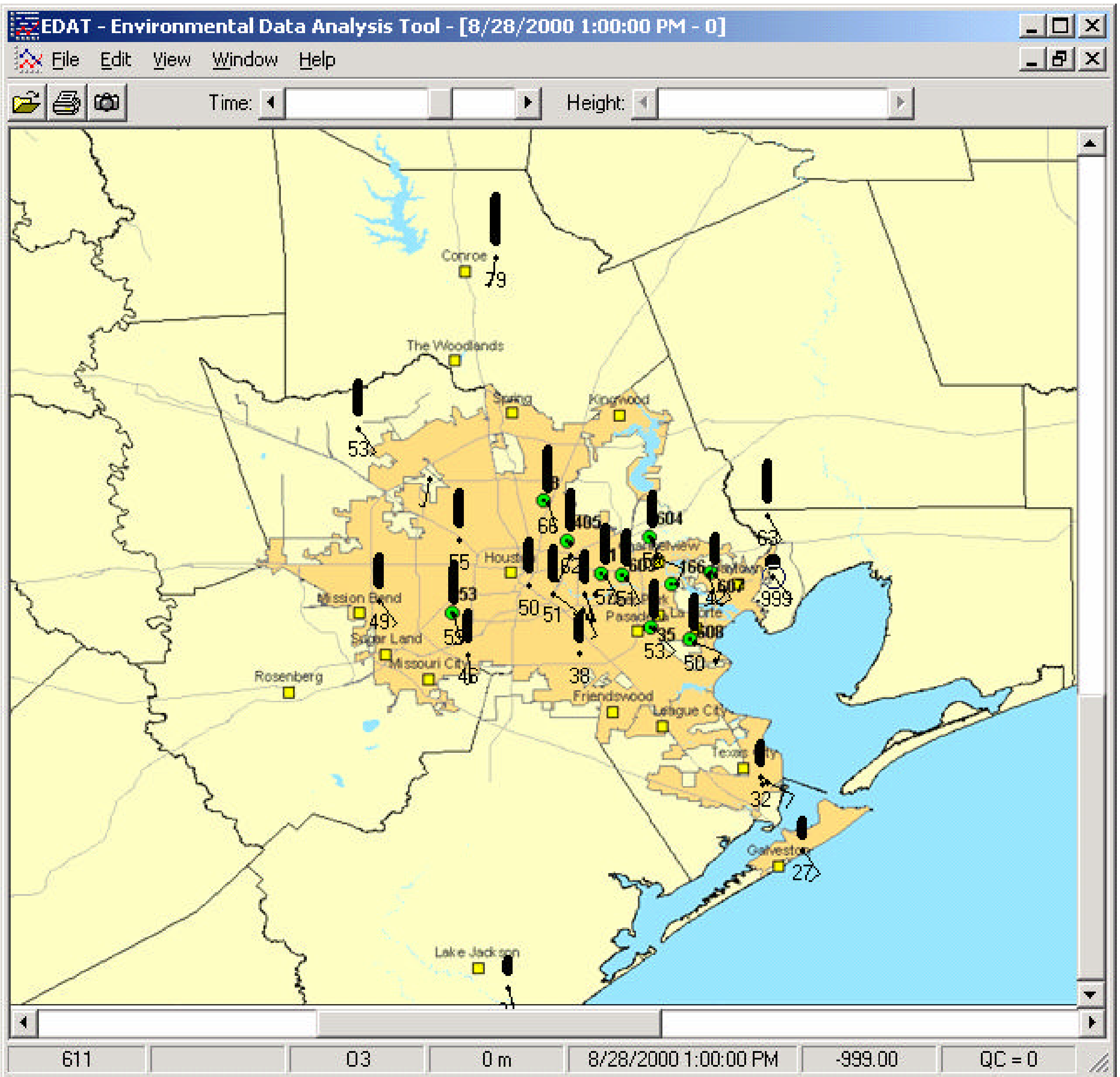


Figure 4-43. Spatial plot of hourly surface winds and ozone concentrations at CAMS sites on August 28, 2000, at 1300 CST. For winds, one-half of a flag = 2.5 m/sec and one flag = 5 m/sec. The wind blows from the end of the flagstaff, toward the monitoring site. For ozone, the plain text below each site shows the concentration in parts per billion, and the bar above each site shows the concentration by bar size. Note that missing data are reported as -999. The CAMS numbers of selected sites are also shown.

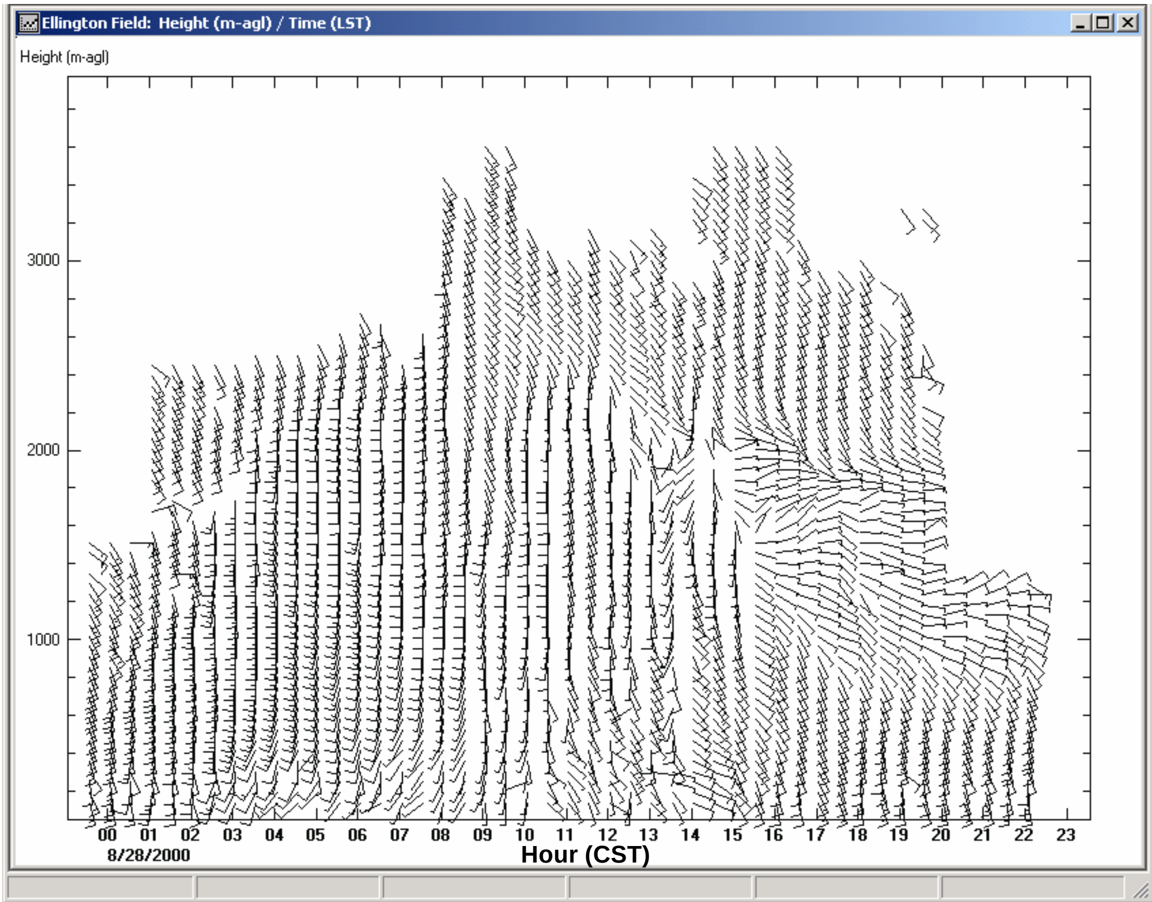


Figure 4-44. Time-height cross-section of radar profiler winds collected at Ellington Field on August 28, 2000.

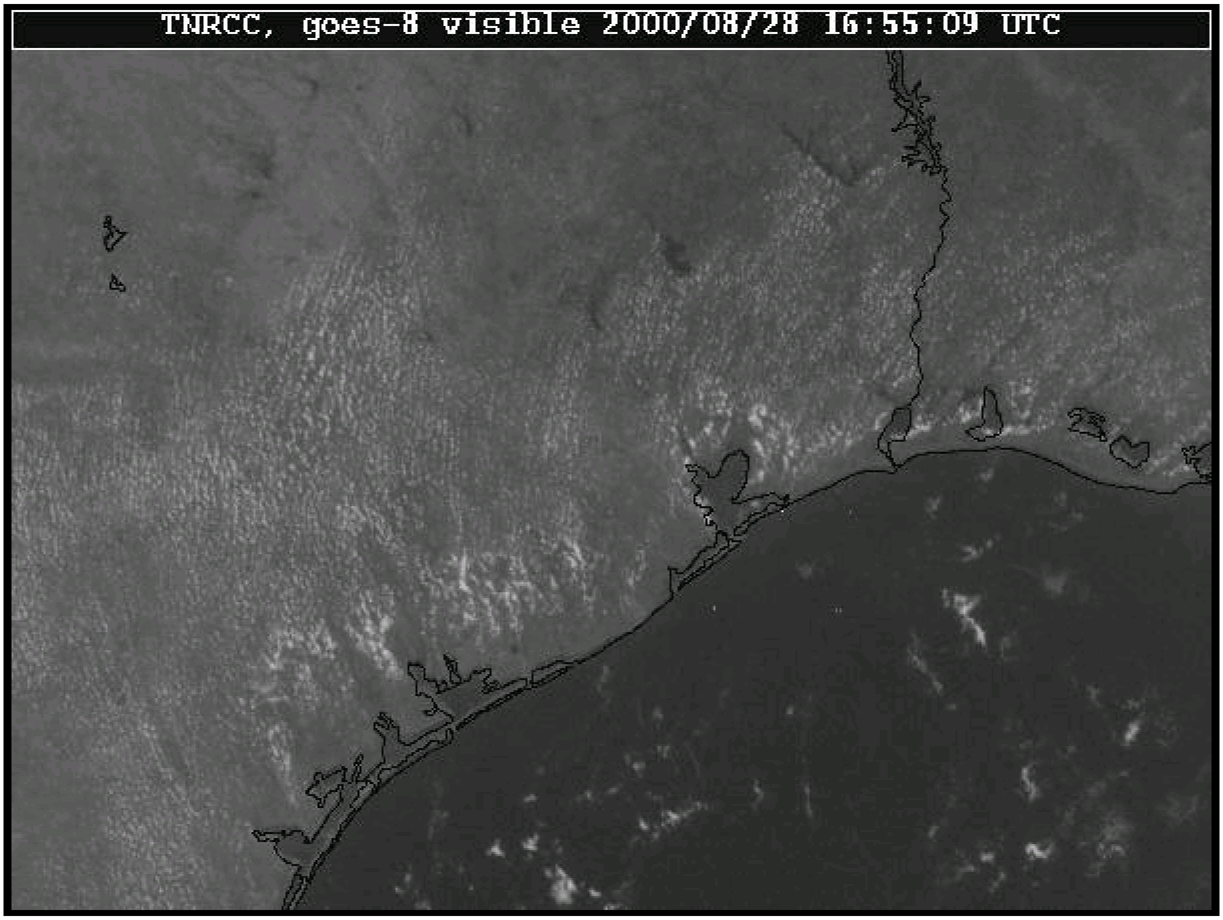


Figure 4-45. Visible satellite image for August 28, 2000, at 1055 CST (1655 UTC).

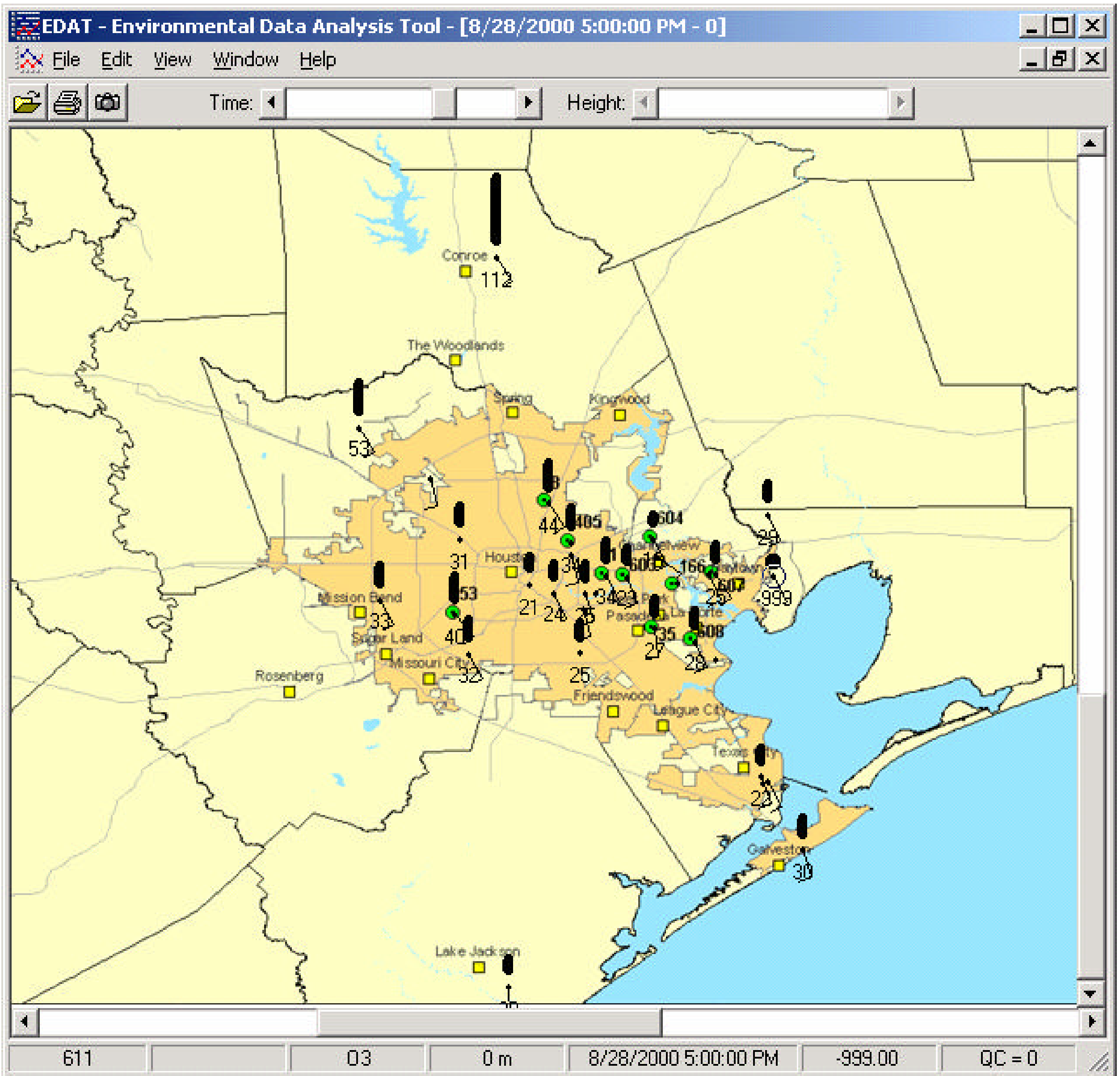


Figure 4-46. Spatial plot of hourly surface winds and ozone concentrations at CAMS sites on August 28, 2000, at 1700 CST. For winds, one-half of a flag = 2.5 m/sec and one flag = 5 m/sec. The wind blows from the end of the flagstaff, toward the monitoring site. For ozone, the plain text below each site shows the concentration in parts per billion, and the bar above each site shows the concentration by bar size. Note that missing data are reported as -999. The CAMS numbers of selected sites are also shown.

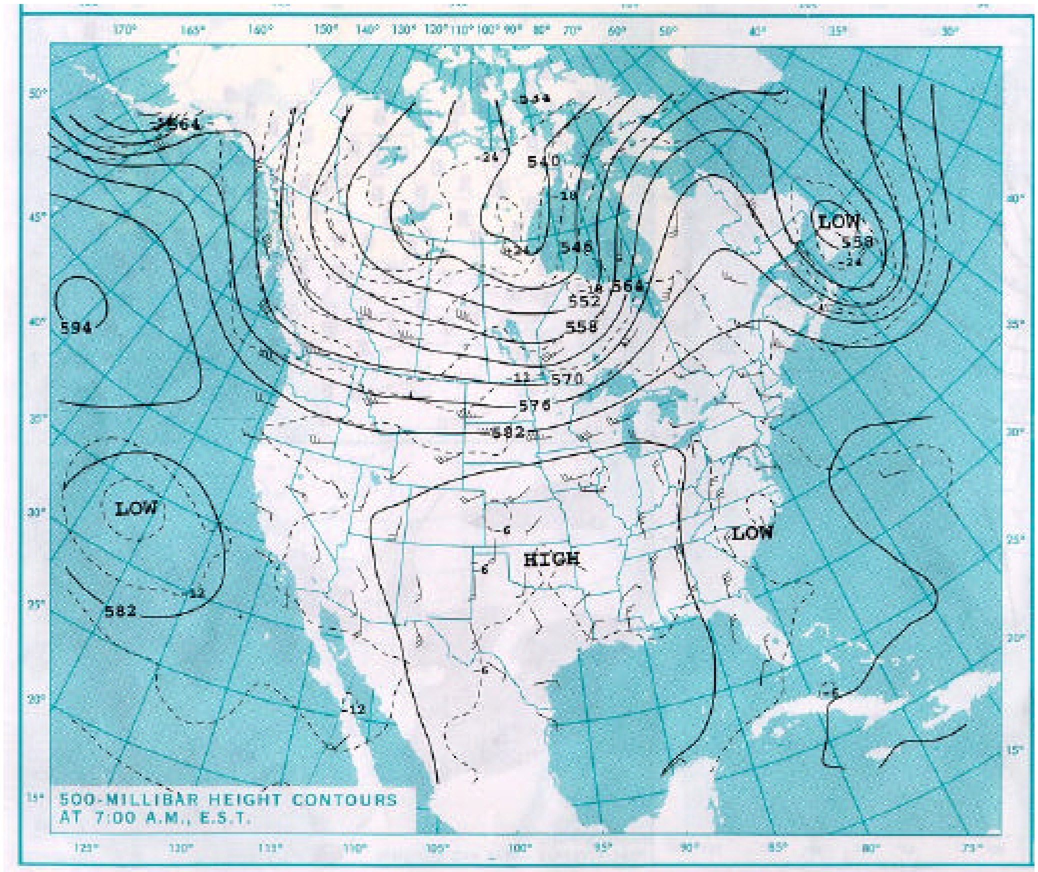


Figure 4-47. Contours of the height of the 500-mb surface pressure for August 29, 2000, at 0600 CST.

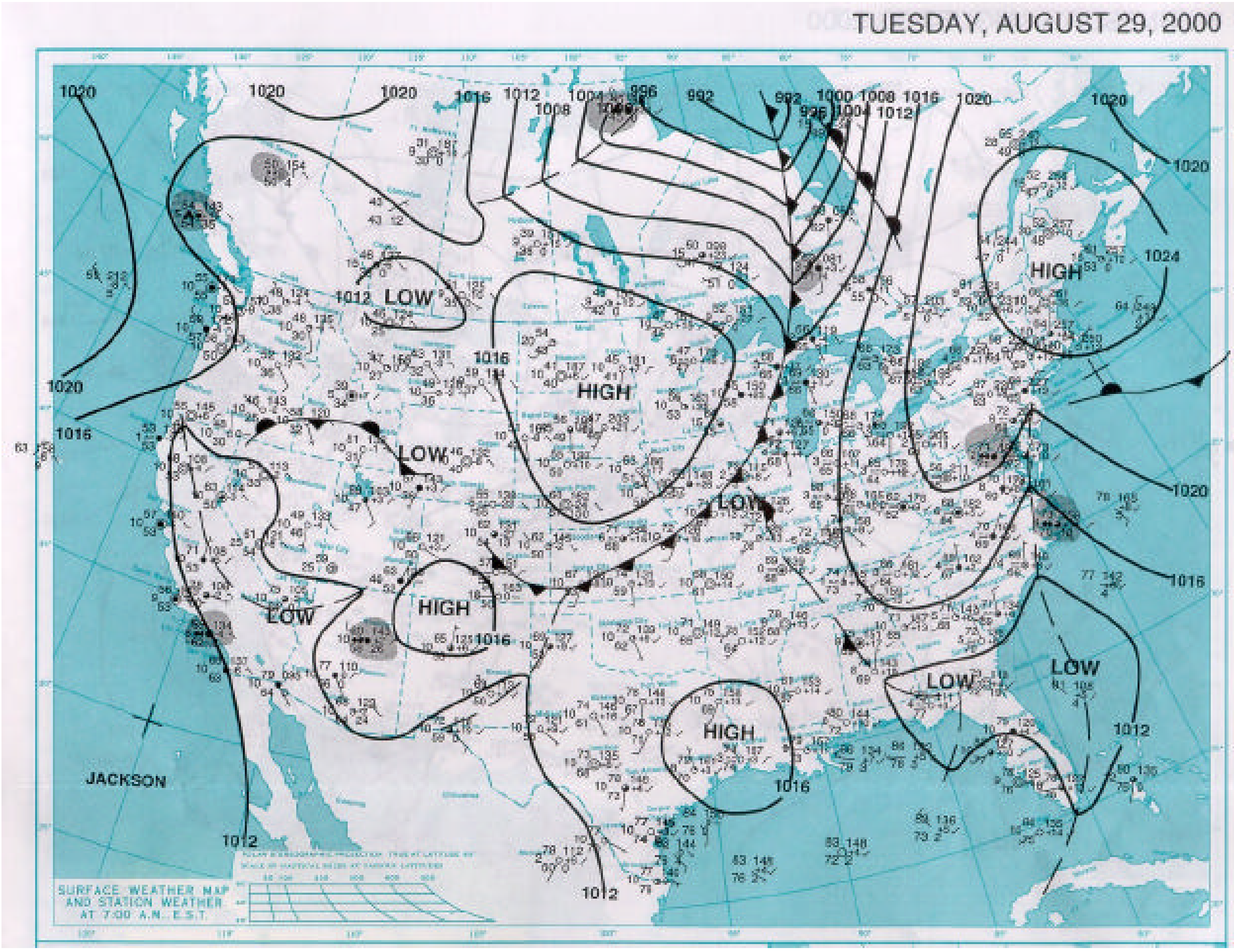


Figure 4-48. Surface analysis chart showing the winds, contours of surface pressure, and other weather conditions on August 29, 2000, at 0600 CST.

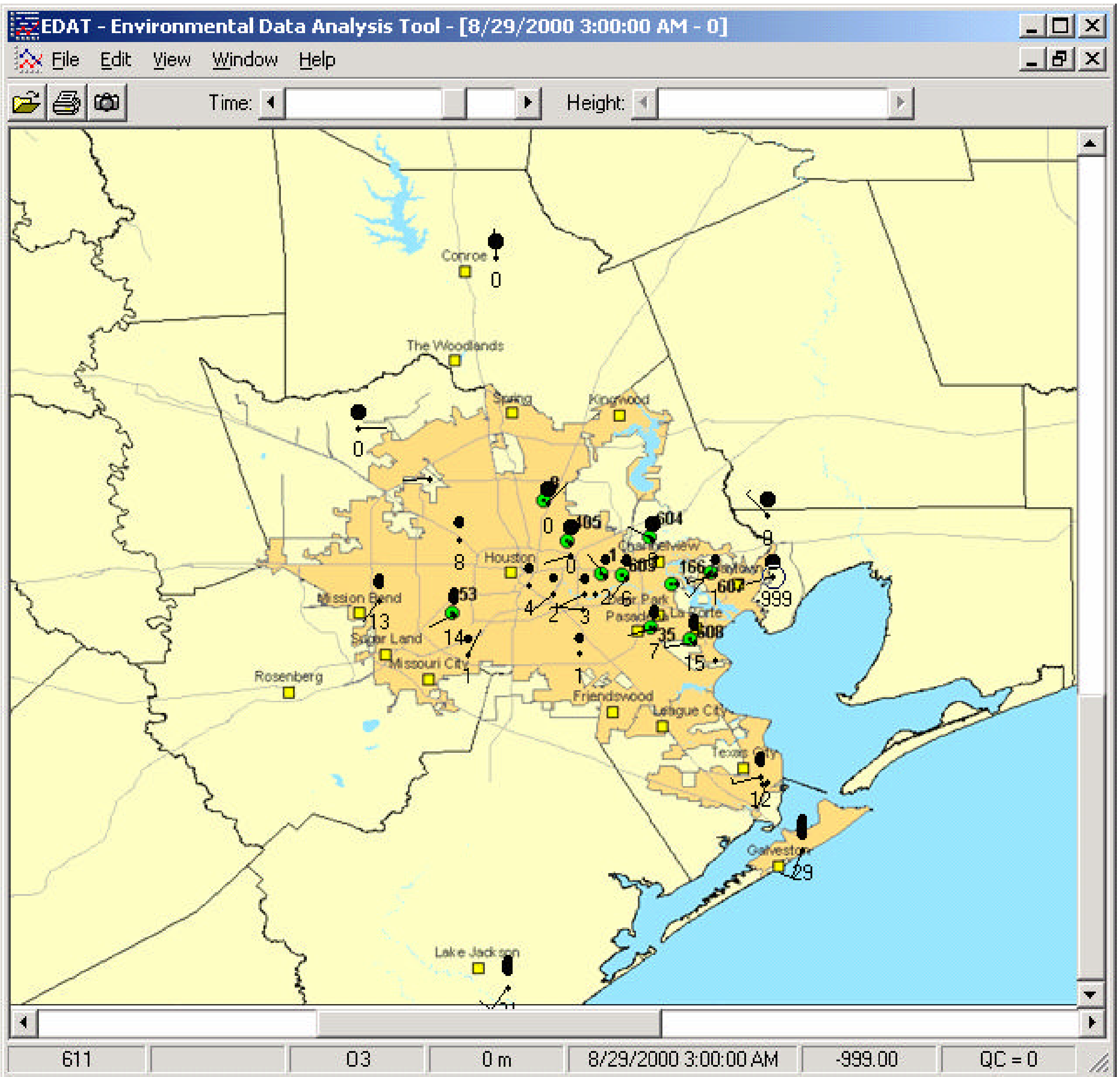


Figure 4-49. Spatial plot of hourly surface winds and ozone concentrations at CAMS sites on August 29, 2000, at 0300 CST. For winds, one-half of a flag = 2.5 m/sec and one flag = 5 m/sec. The wind blows from the end of the flagstaff, toward the monitoring site. For ozone, the plain text below each site shows the concentration in parts per billion, and the bar above each site shows the concentration by bar size. Note that missing data are reported as -999. The CAMS numbers of selected sites are also shown.

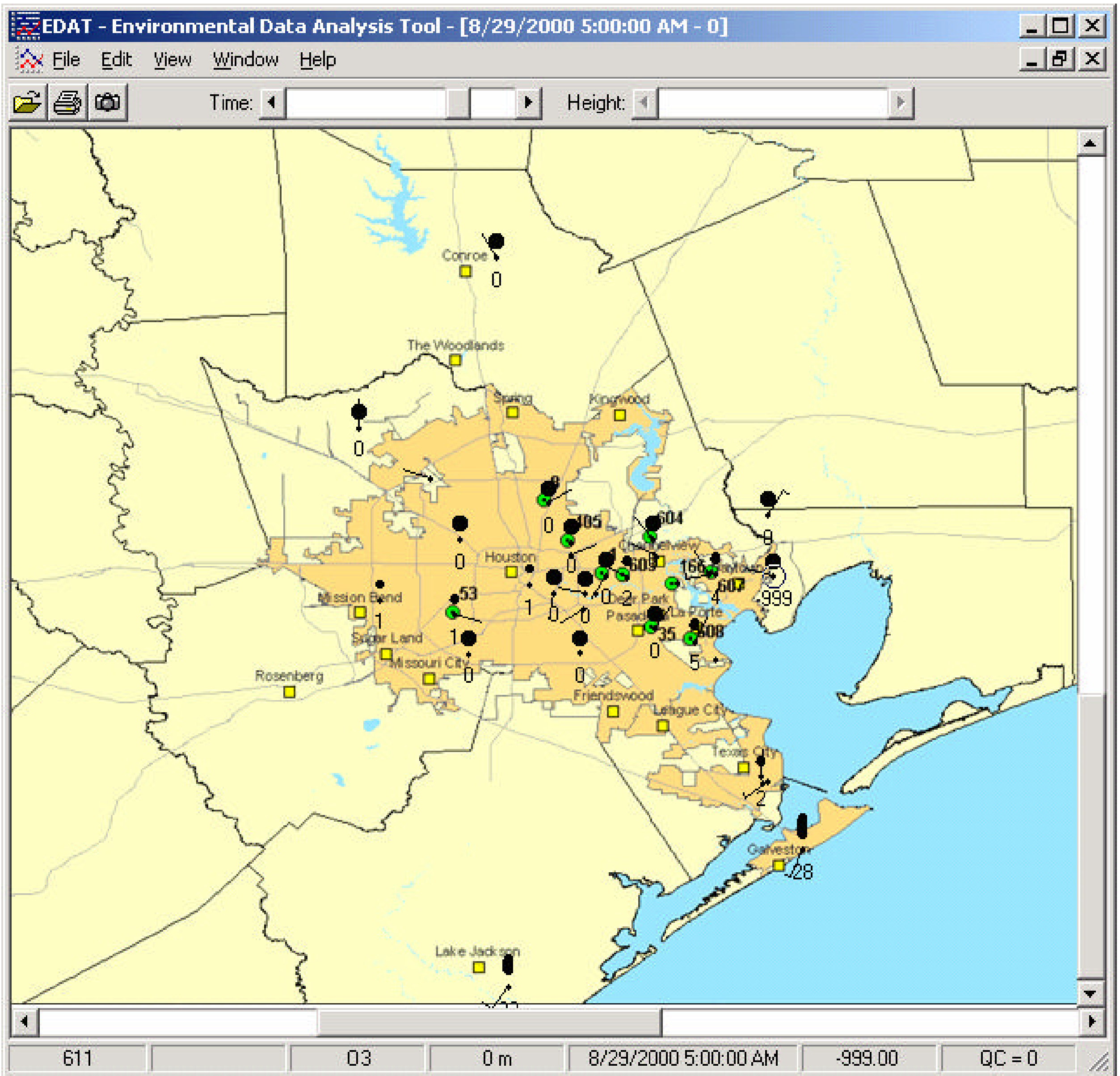


Figure 4-50. Spatial plot of hourly surface winds and ozone concentrations at CAMS sites on August 29, 2000, at 0500 CST. For winds, one-half of a flag = 2.5 m/sec and one flag = 5 m/sec. The wind blows from the end of the flagstaff, toward the monitoring site. For ozone, the plain text below each site shows the concentration in parts per billion, and the bar above each site shows the concentration by bar size. Note that missing data are reported as -999. The CAMS numbers of selected sites are also shown.

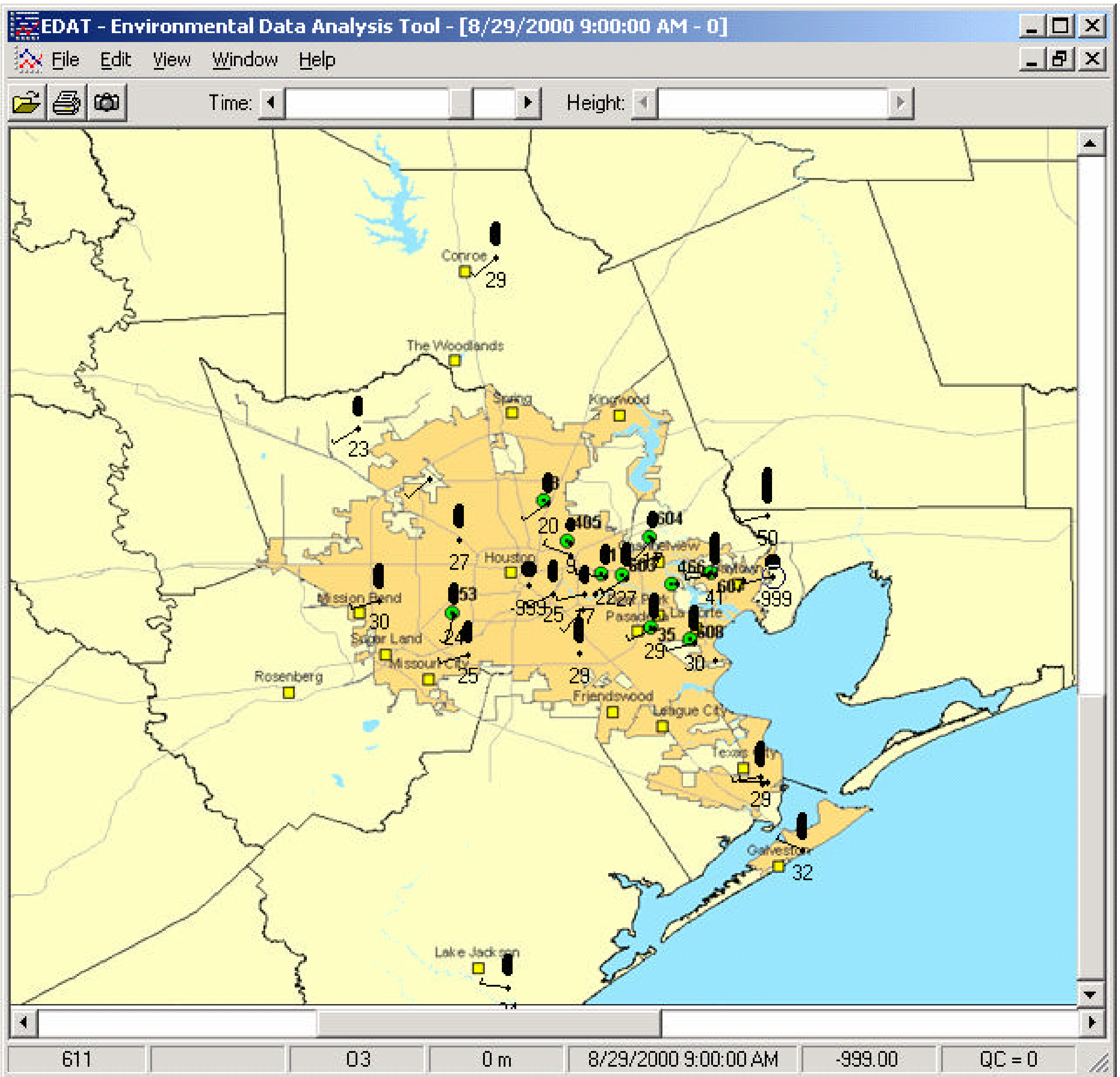


Figure 4-51. Spatial plot of hourly surface winds and ozone concentrations at CAMS sites on August 29, 2000, at 0900 CST. For winds, one-half of a flag = 2.5 m/sec and one flag = 5 m/sec. The wind blows from the end of the flagstaff, toward the monitoring site. For ozone, the plain text below each site shows the concentration in parts per billion, and the bar above each site shows the concentration by bar size. Note that missing data are reported as -999. The CAMS numbers of selected sites are also shown.

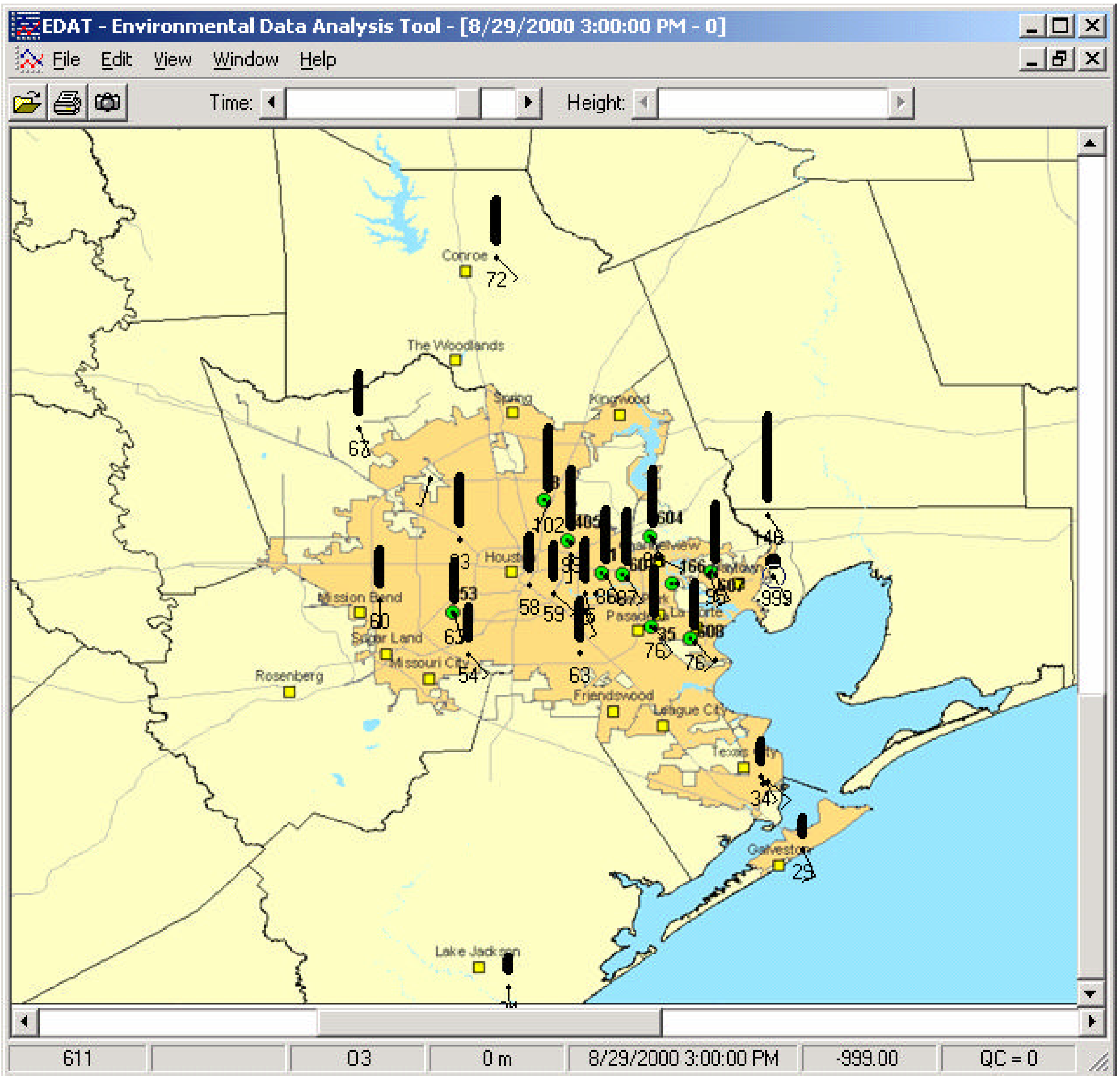


Figure 4-52. Spatial plot of hourly surface winds and ozone concentrations at CAMS sites on August 29, 2000, at 1500 CST. For winds, one-half of a flag = 2.5 m/sec and one flag = 5 m/sec. The wind blows from the end of the flagstaff, toward the monitoring site. For ozone, the plain text below each site shows the concentration in parts per billion, and the bar above each site shows the concentration by bar size. Note that missing data are reported as -999. The CAMS numbers of selected sites are also shown.

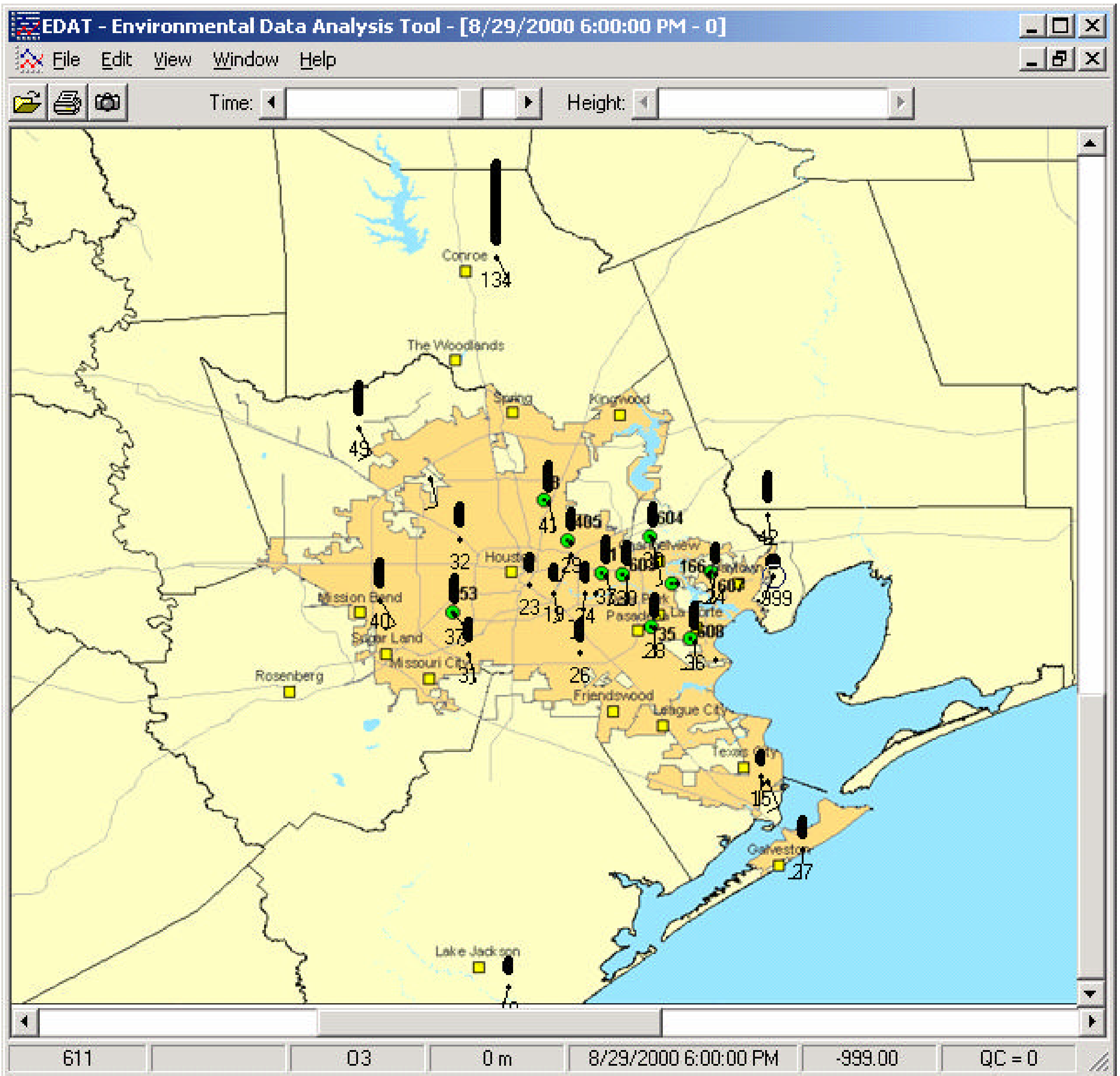


Figure 4-53. Spatial plot of hourly surface winds and ozone concentrations at CAMS sites on August 29, 2000, at 1800 CST. For winds, one-half of a flag = 2.5 m/sec and one flag = 5 m/sec. The wind blows from the end of the flagstaff, toward the monitoring site. For ozone, the plain text below each site shows the concentration in parts per billion, and the bar above each site shows the concentration by bar size. Note that missing data are reported as -999. The CAMS numbers of selected sites are also shown.

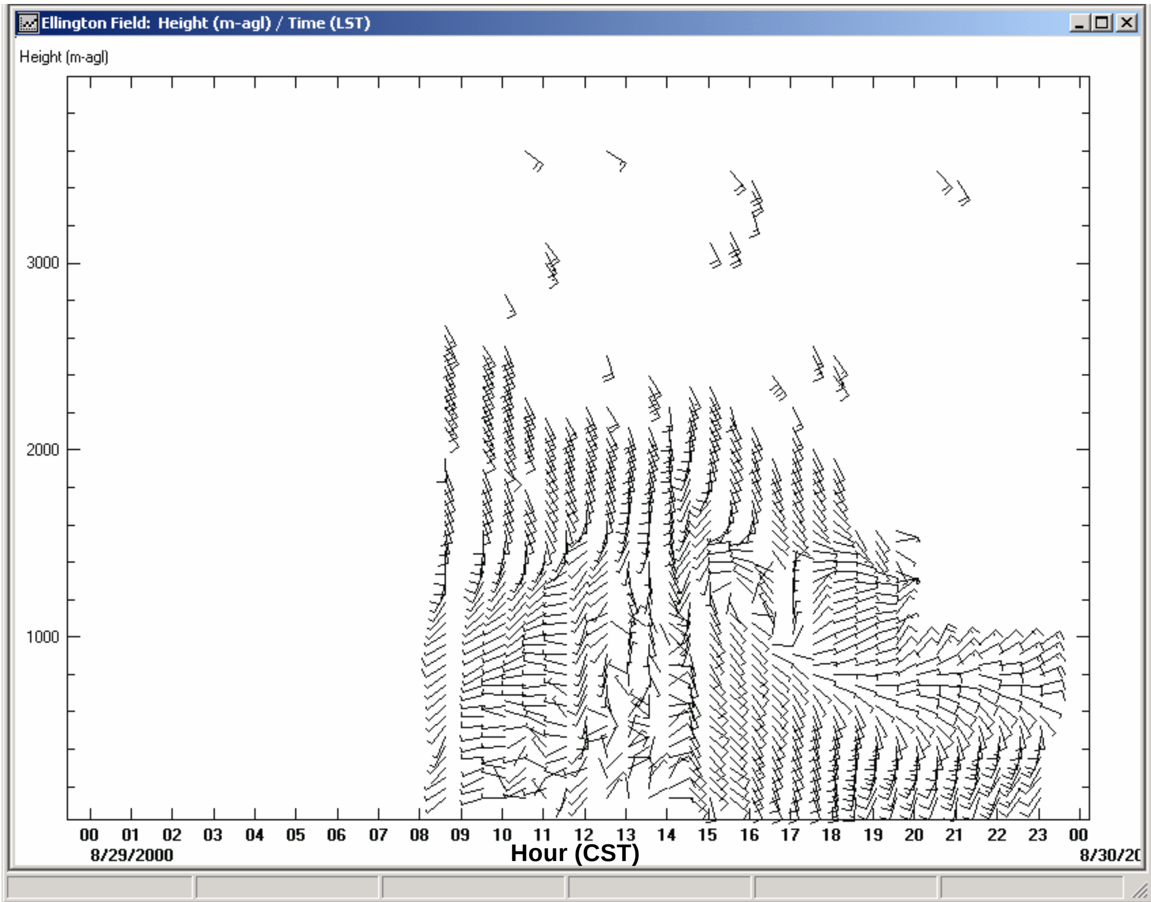


Figure 4-54. Time-height cross-section of radar profiler winds collected at Ellington Field on August 29, 2000.

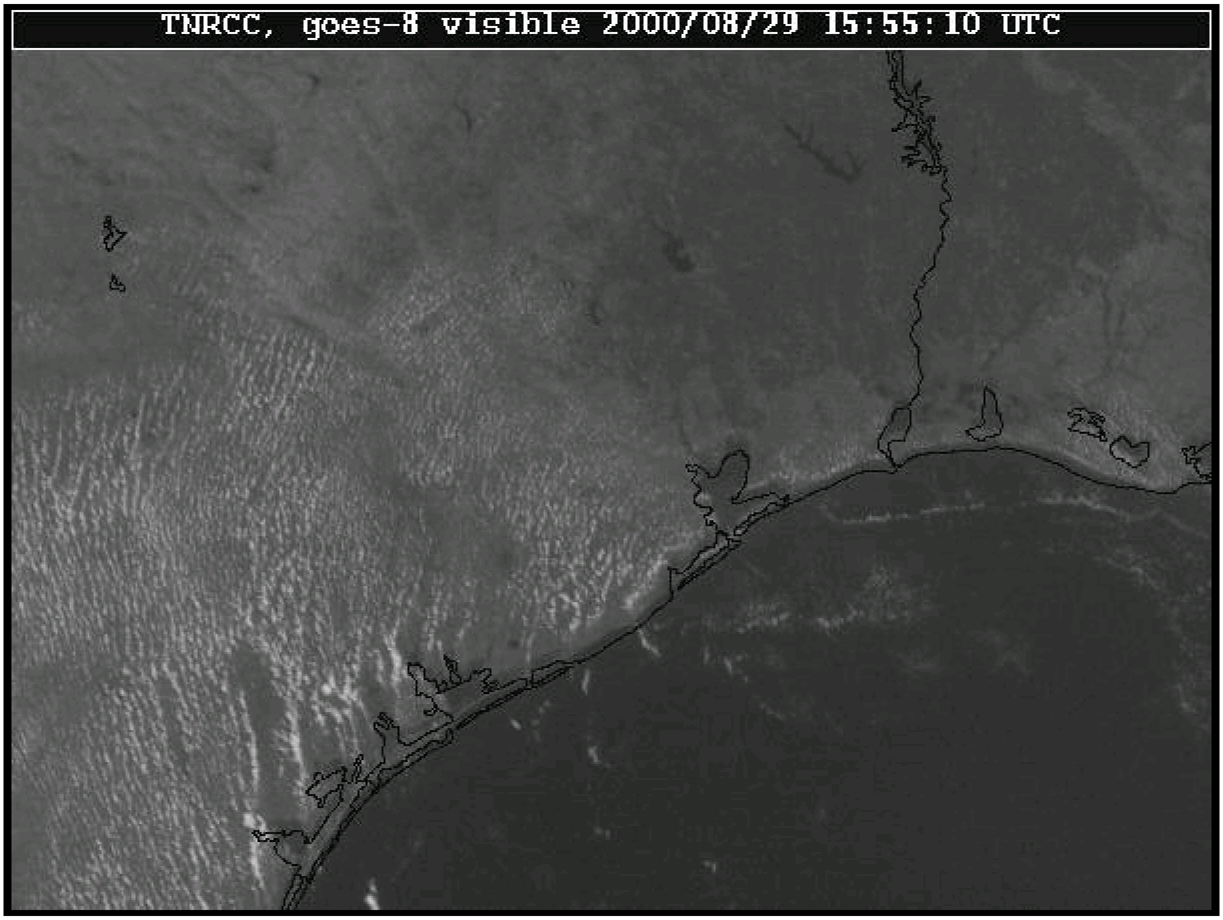


Figure 4-55. Visible satellite image for August 29, 2000, at 0955 CST (1555 UTC).

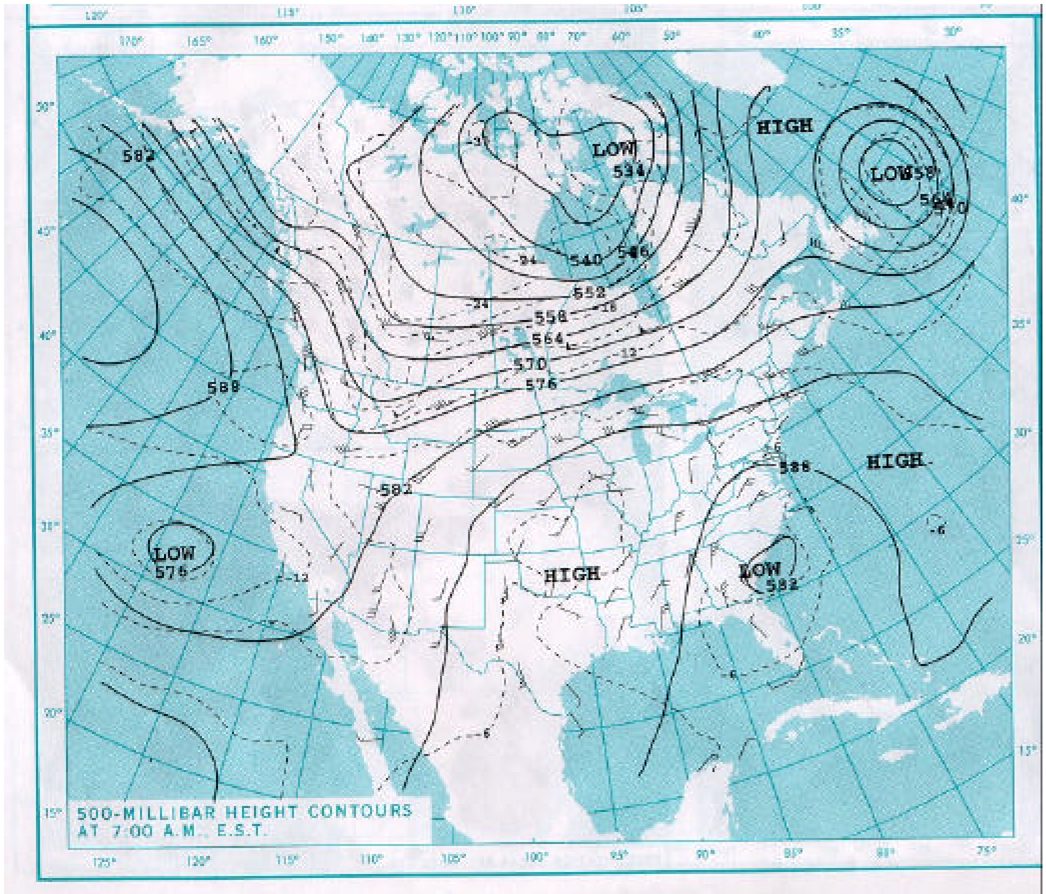


Figure 4-56. Contours of the height of the 500-mb surface pressure for August 30, 2000, at 0600 CST.

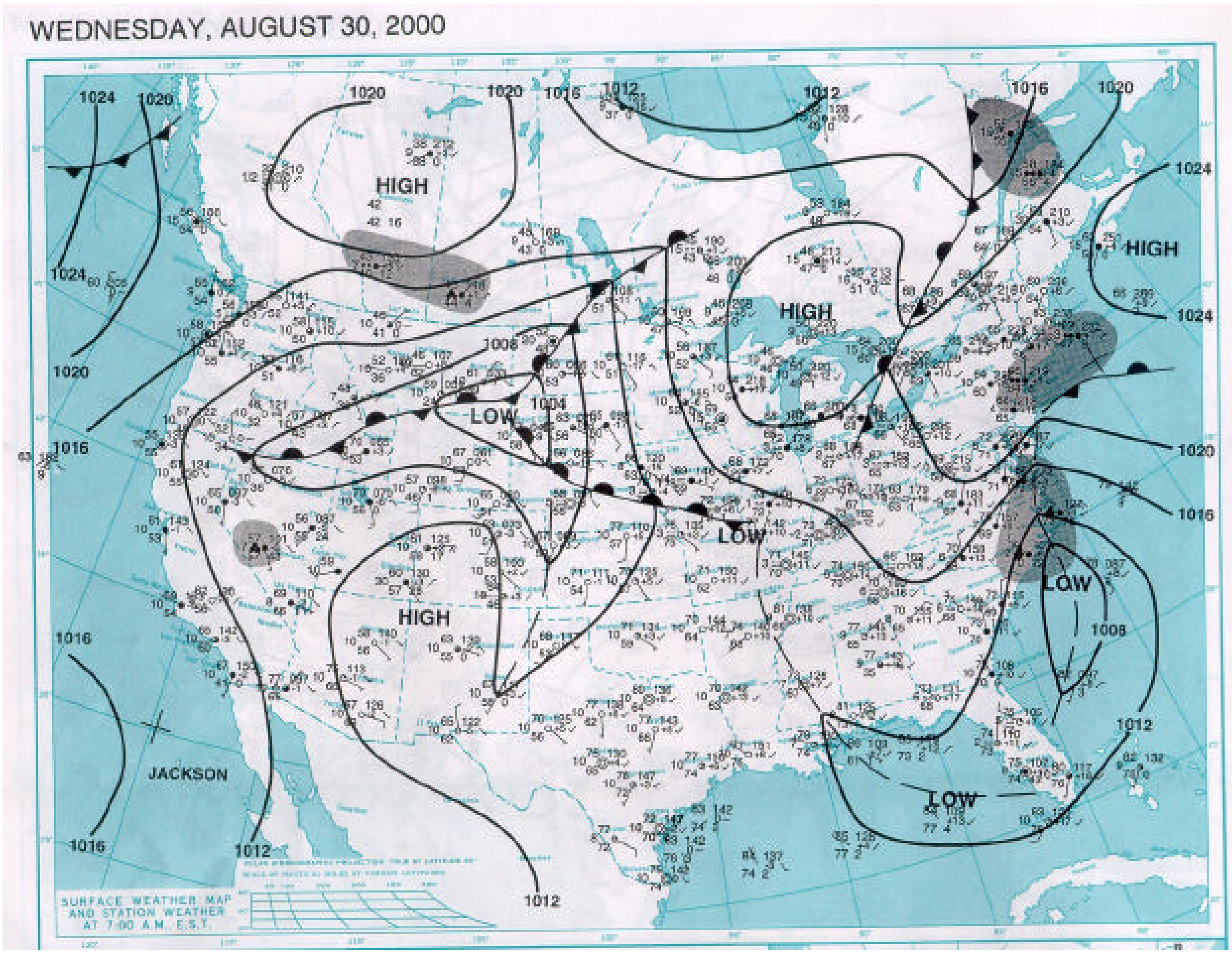


Figure 4-57. Surface analysis chart showing the winds, contours of surface pressure, and other weather conditions on August 30, 2000, at 0600 CST.

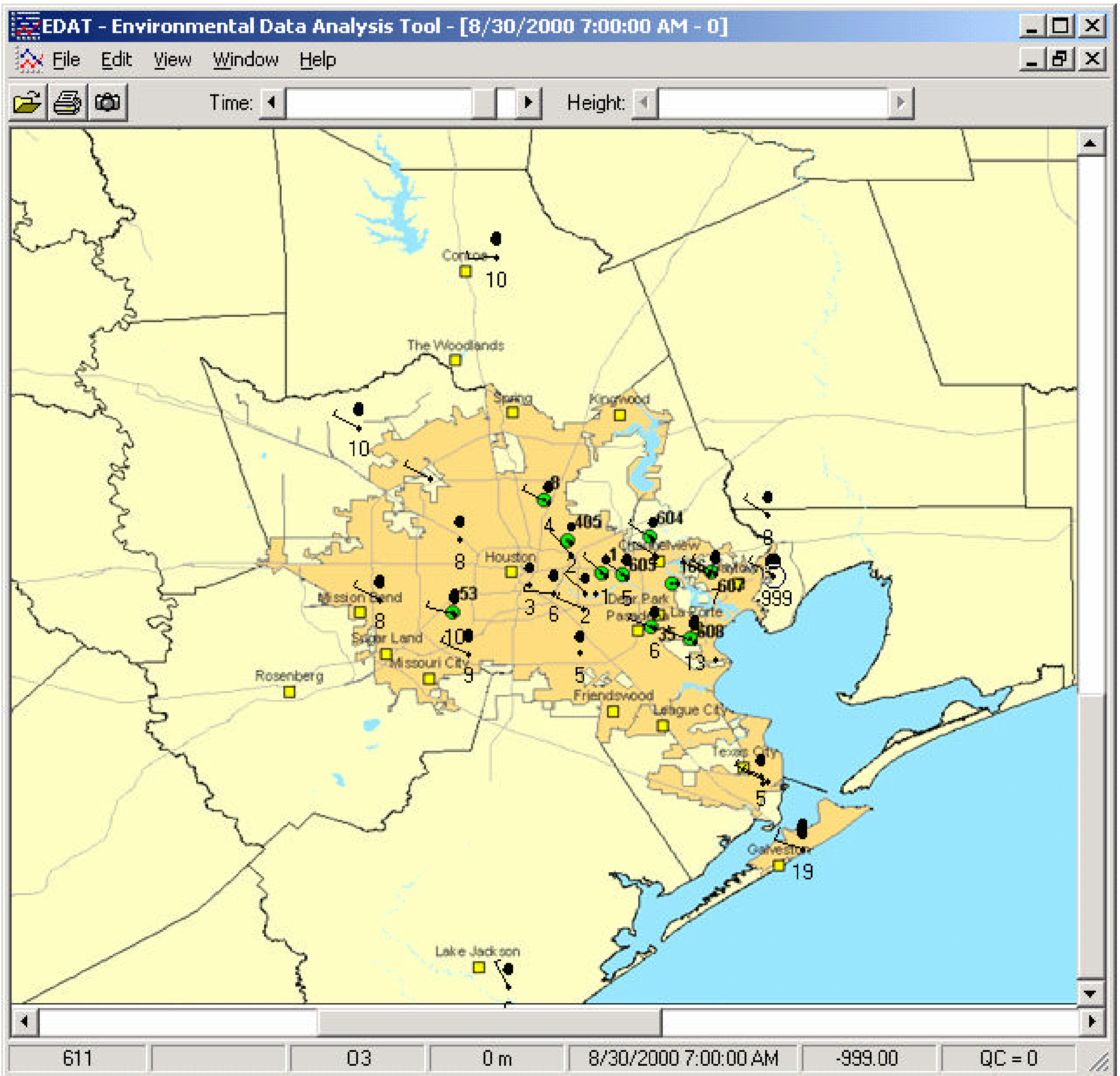


Figure 4-58. Spatial plot of hourly surface winds and ozone concentrations at CAMS sites on August 30, 2000, at 0700 CST. For winds, one-half of a flag = 2.5 m/sec and one flag = 5 m/sec. The wind blows from the end of the flagstaff, toward the monitoring site. For ozone, the plain text below each site shows the concentration in parts per billion, and the bar above each site shows the concentration by bar size. Note that missing data are reported as -999. The CAMS numbers of selected sites are also shown.

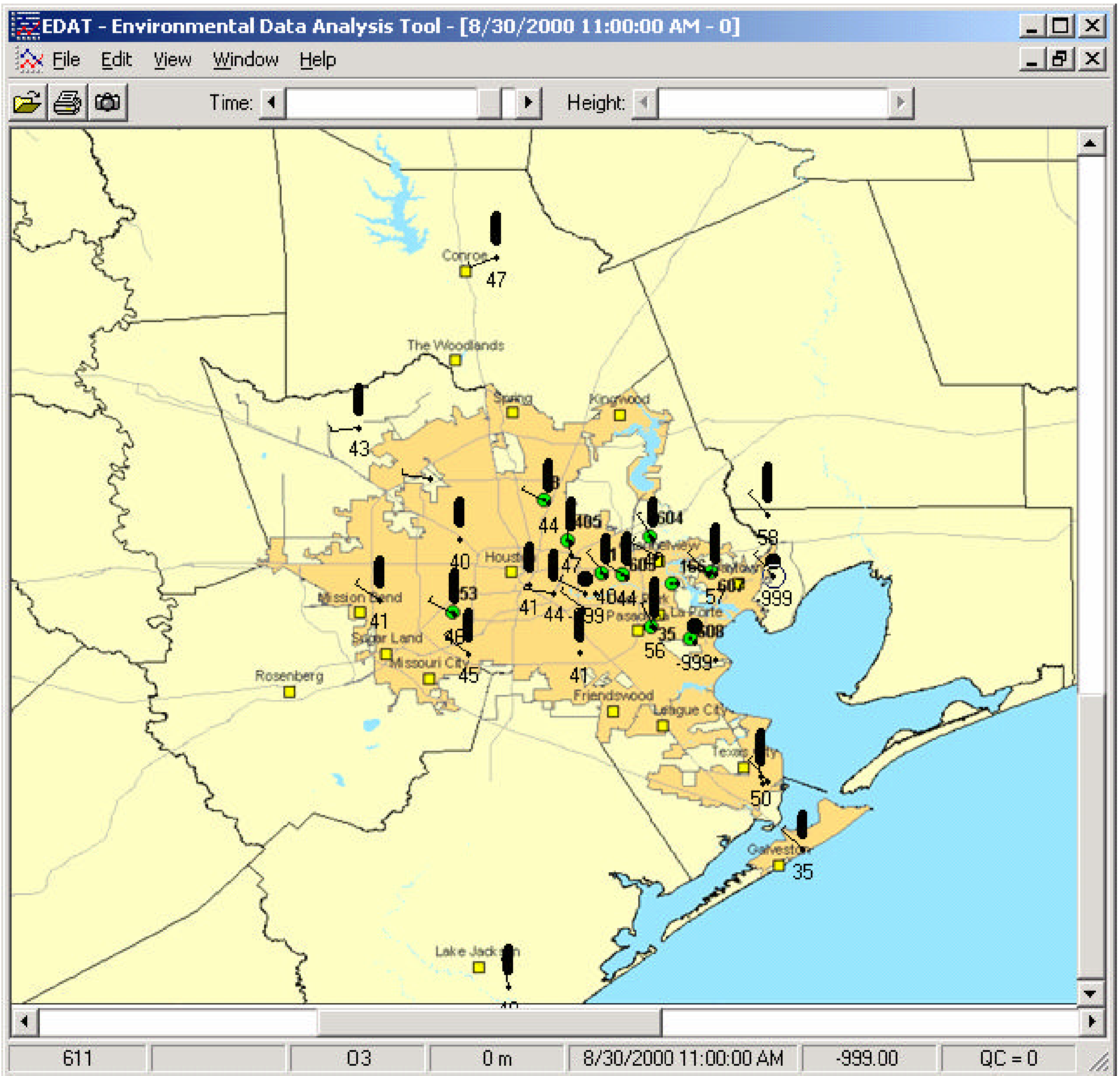


Figure 4-59. Spatial plot of hourly surface winds and ozone concentrations at CAMS sites on August 30, 2000, at 1100 CST. For winds, one-half of a flag = 2.5 m/sec and one flag = 5 m/sec. The wind blows from the end of the flagstaff, toward the monitoring site. For ozone, the plain text below each site shows the concentration in parts per billion, and the bar above each site shows the concentration by bar size. Note that missing data are reported as -999. The CAMS numbers of selected sites are also shown.

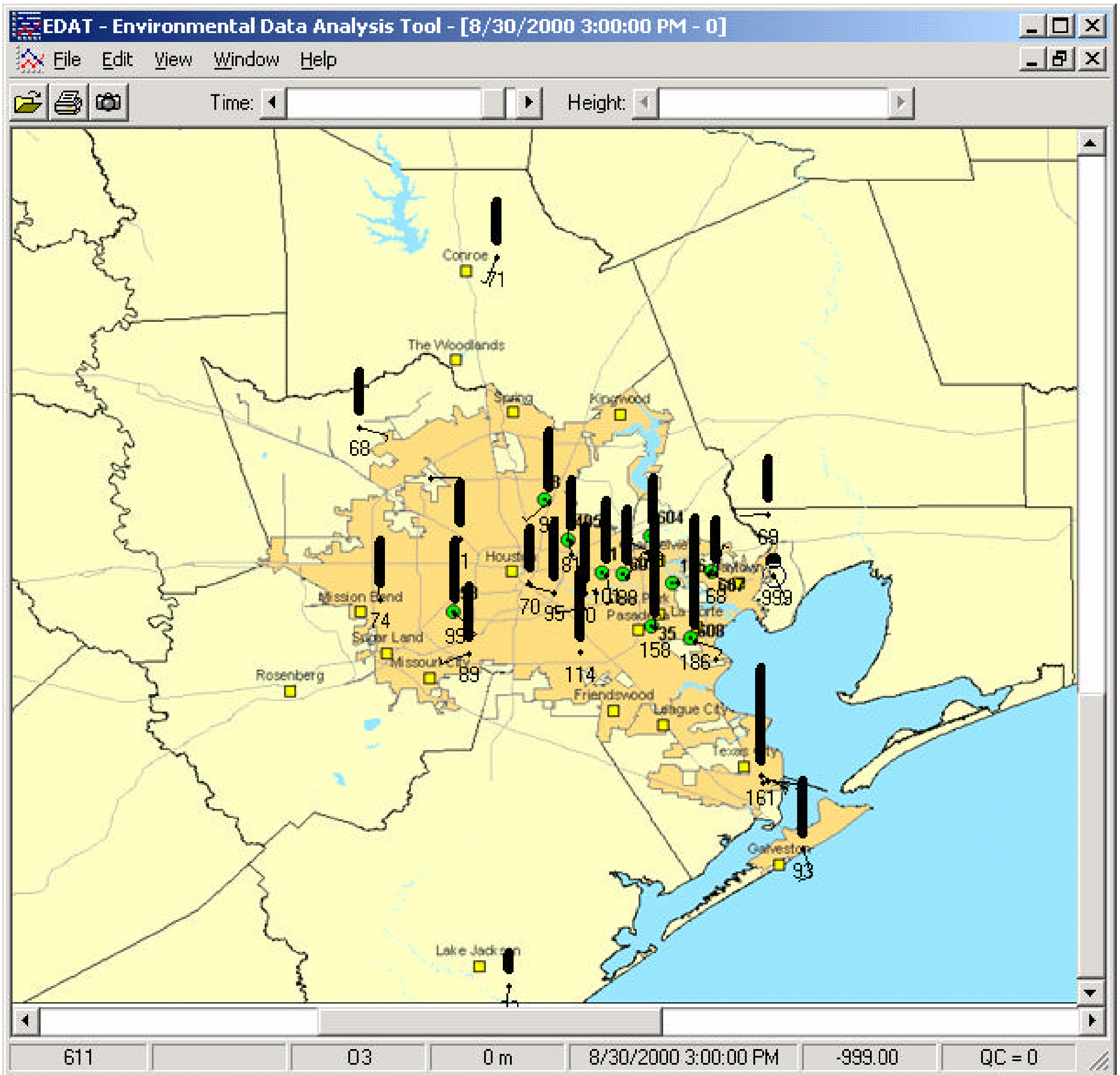


Figure 4-60. Spatial plot of hourly surface winds and ozone concentrations at CAMS sites on August 30, 2000, at 1500 CST. For winds, one-half of a flag = 2.5 m/sec and one flag = 5 m/sec. The wind blows from the end of the flagstaff, toward the monitoring site. For ozone, the plain text below each site shows the concentration in parts per billion, and the bar above each site shows the concentration by bar size. Note that missing data are reported as -999. The CAMS numbers of selected sites are also shown.

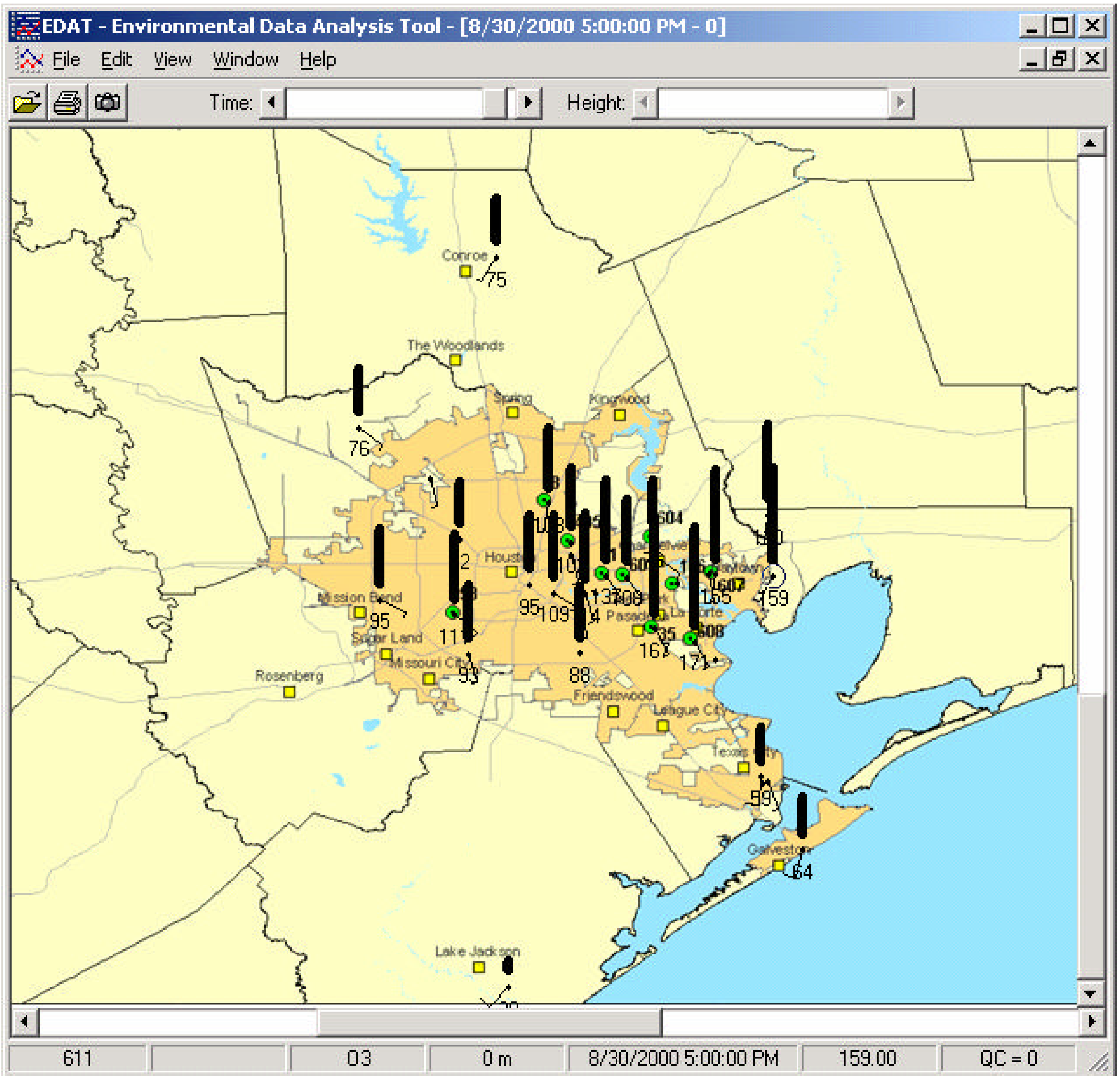


Figure 4-61. Spatial plot of hourly surface winds and ozone concentrations at CAMS sites on August 30, 2000, at 1700 CST. For winds, one-half of a flag = 2.5 m/sec and one flag = 5 m/sec. The wind blows from the end of the flagstaff, toward the monitoring site. For ozone, the plain text below each site shows the concentration in parts per billion, and the bar above each site shows the concentration by bar size. The CAMS numbers of selected sites are also shown.

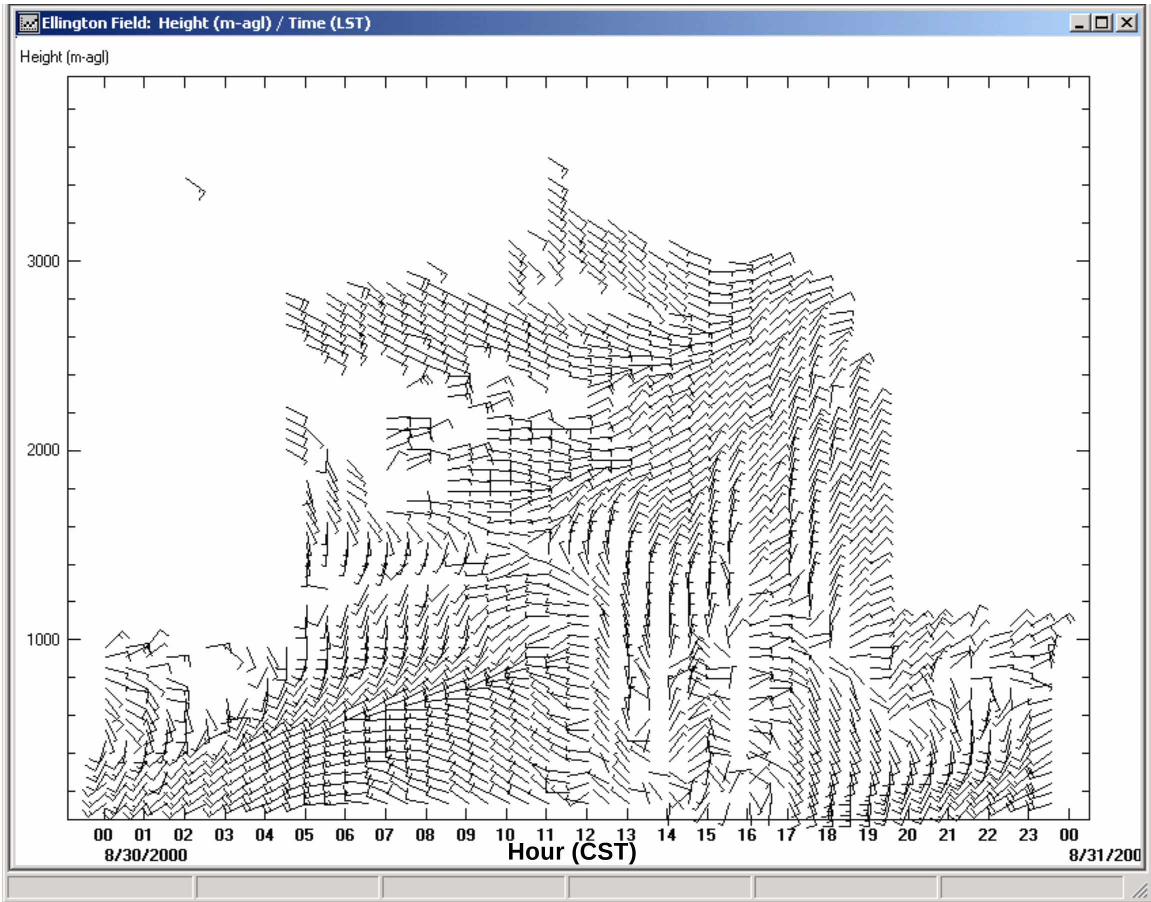


Figure 4-62. Time-height cross-section of radar profiler winds collected at Ellington Field on August 30, 2000.

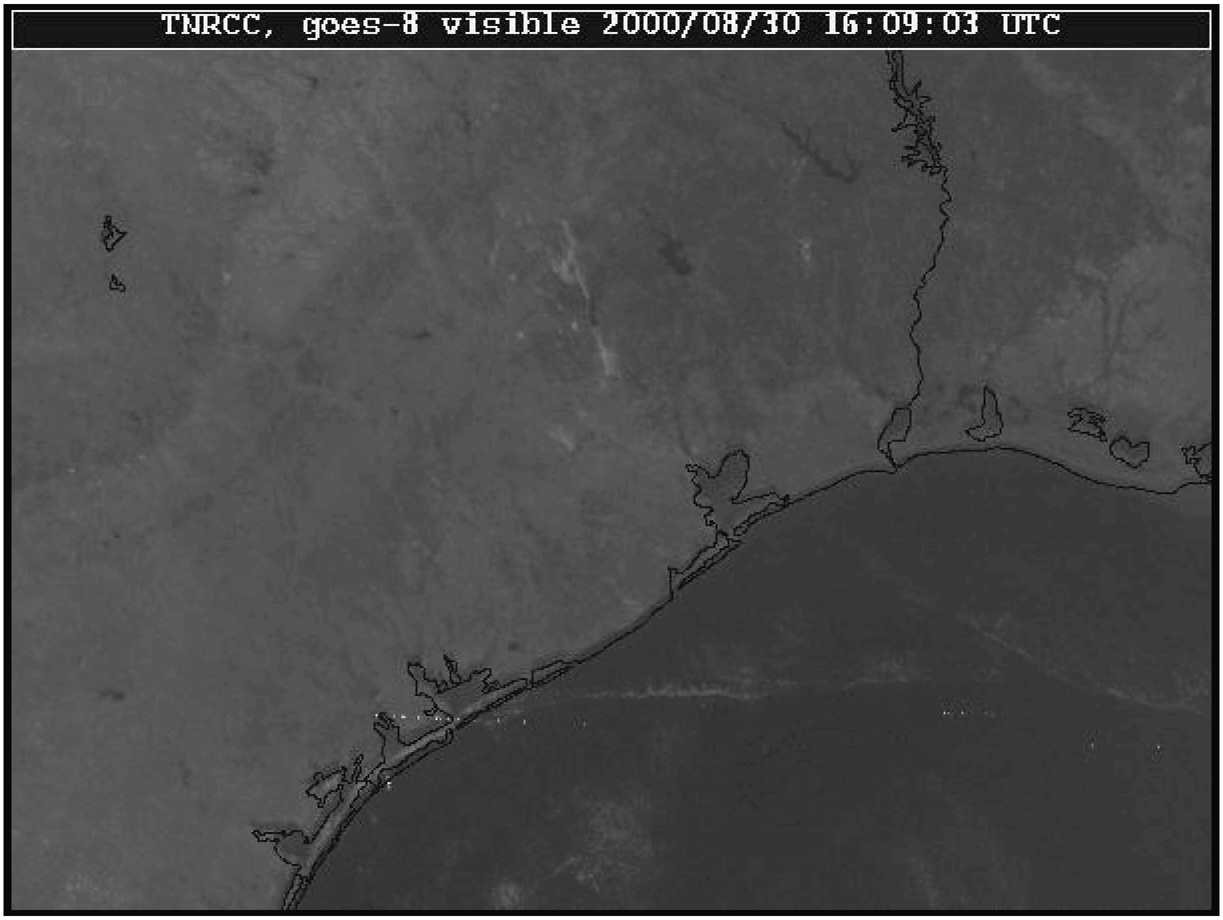


Figure 4-63. Visible satellite image for August 30, 2000, at 1009 CST (1609 UTC).

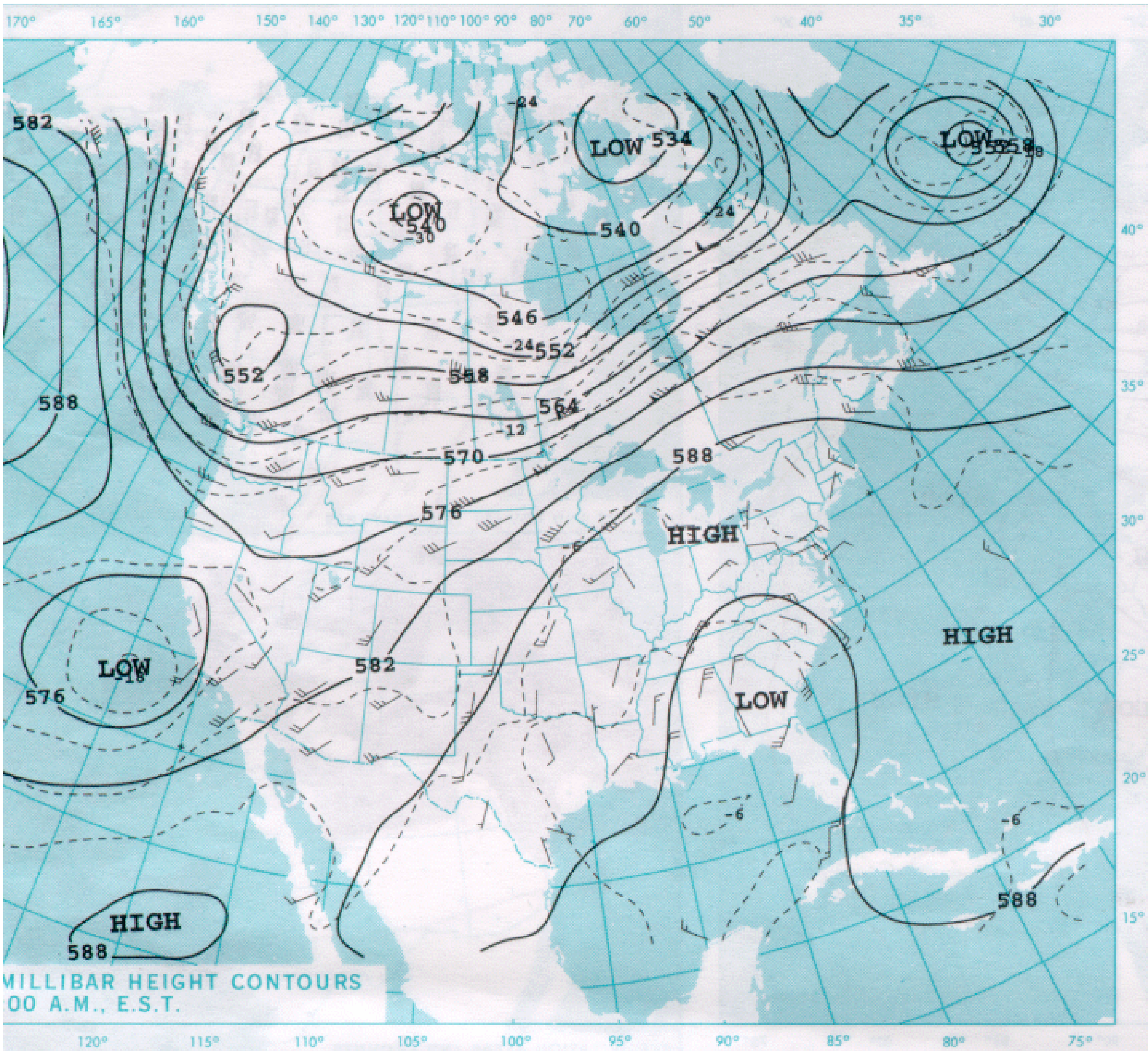


Figure 4-64. Contours of the height of the 500-mb surface pressure for August 31, 2000, at 0600 CST.

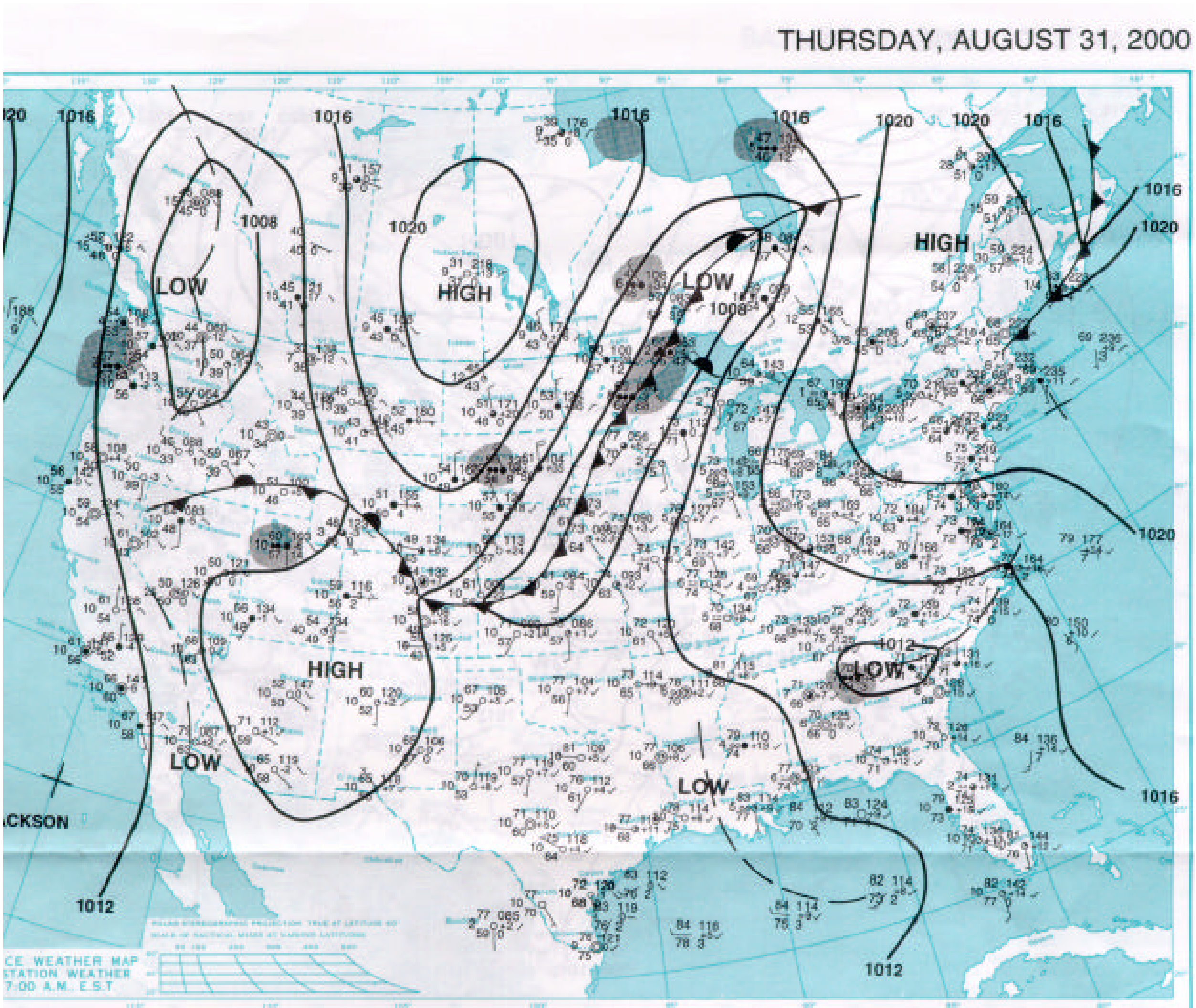


Figure 4-65. Surface analysis chart showing the winds, contours of surface pressure, and other weather conditions on August 31, 2000, at 0600 CST.

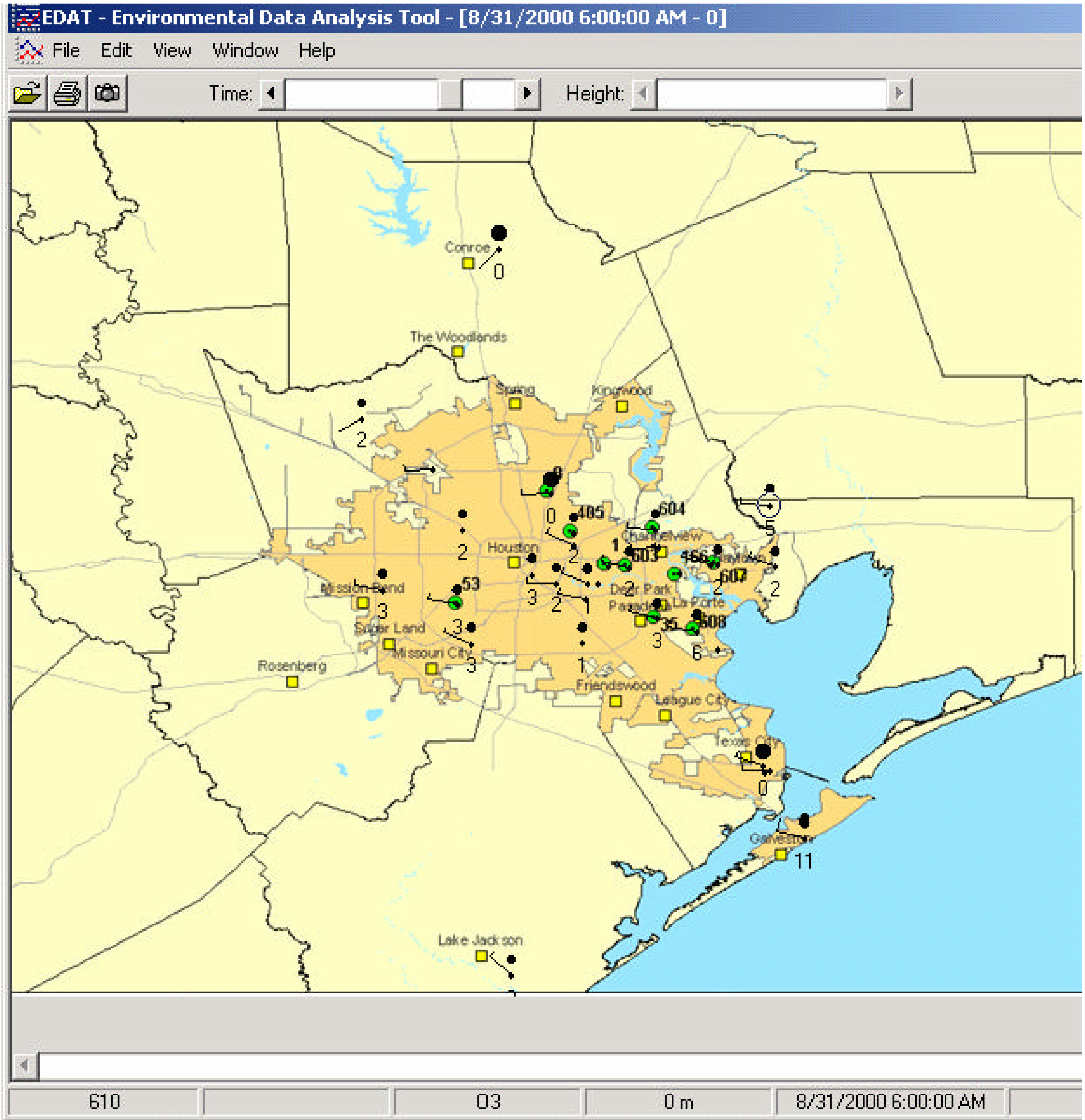


Figure 4-66. Spatial plot of hourly surface winds and ozone concentrations at CAMS sites on August 31, 2000, at 0600 CST. For winds, one-half of a flag = 2.5 m/sec and one flag = 5 m/sec. The wind blows from the end of the flag staff, toward the monitoring site. For ozone, the plain text below each site shows the concentration in parts per billion, and the bar above each site shows the concentration by bar size. The CAMS numbers of selected sites are also shown.

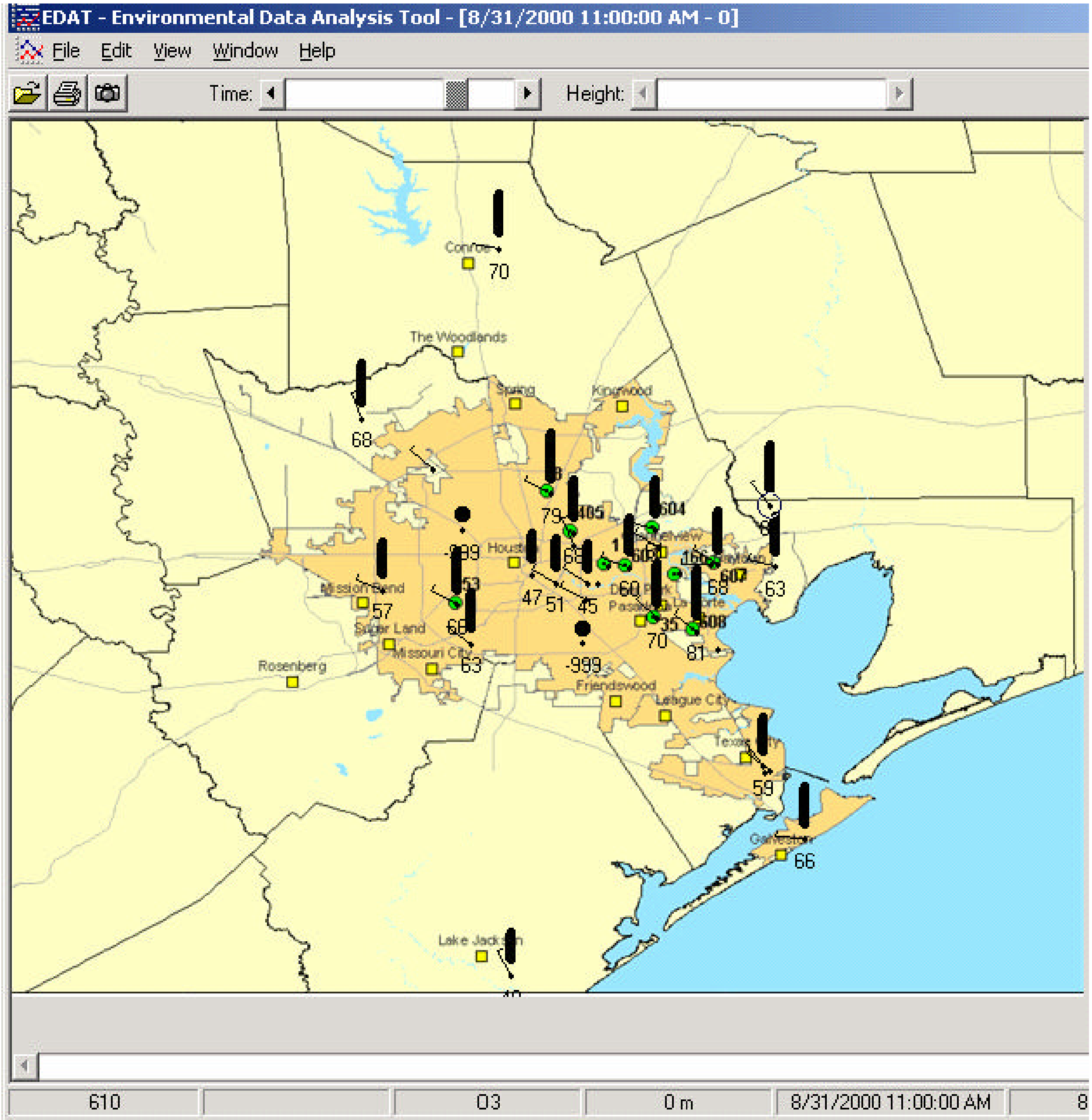


Figure 4-67. Spatial plot of hourly surface winds and ozone concentrations at CAMS sites on August 31, 2000, at 1100 CST. For winds, one-half of a flag = 2.5 m/sec and one flag = 5 m/sec. The wind blows from the end of the flag staff, toward the monitoring site. For ozone, the plain text below each site shows the concentration in parts per billion, and the bar above each site shows the concentration by bar size. Note that missing data are reported as -999. The CAMS numbers of selected sites are also shown.

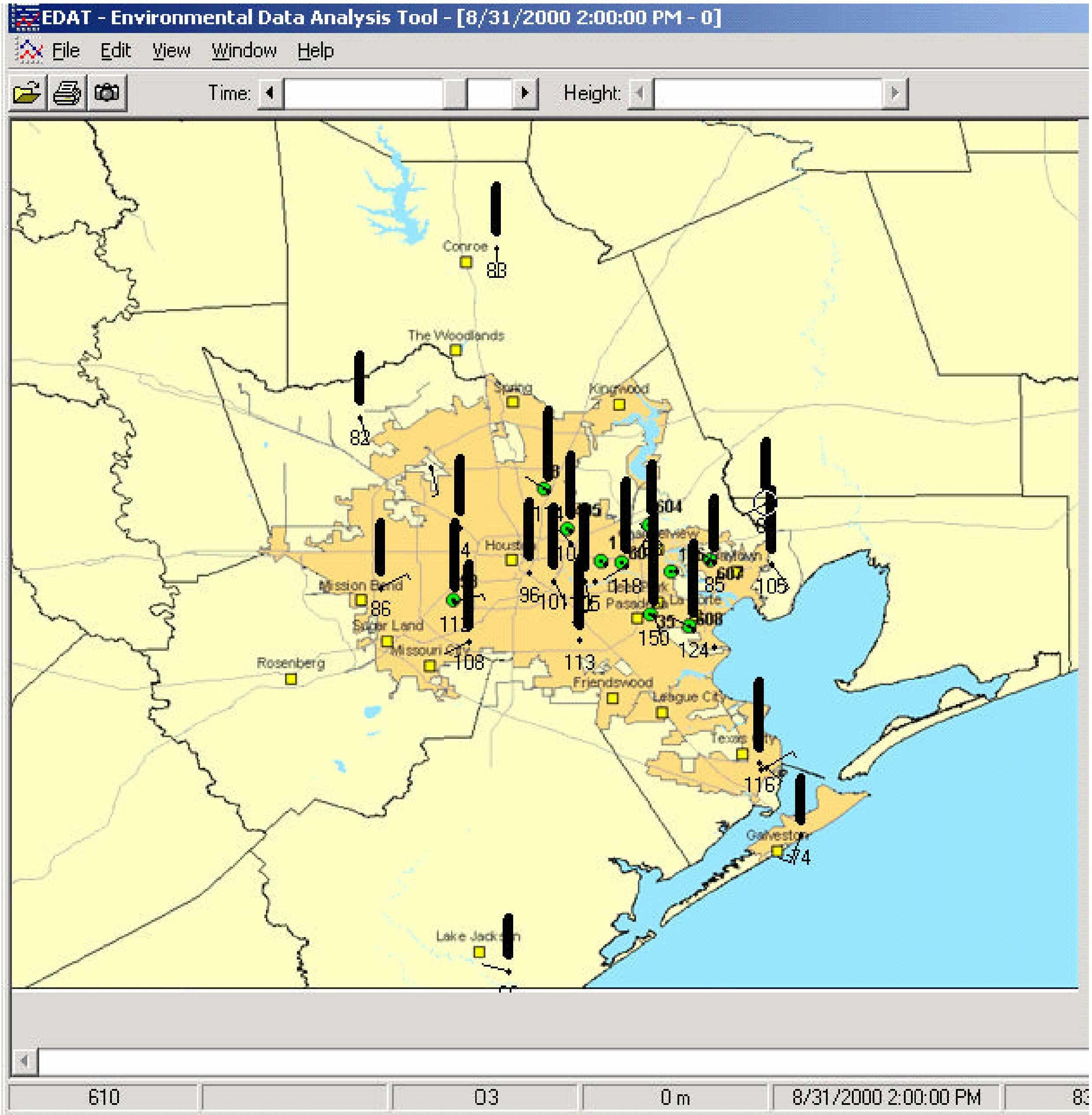


Figure 4-68. Spatial plot of hourly surface winds and ozone concentrations at CAMS sites on August 31, 2000, at 1400 CST. For winds, one-half of a flag = 2.5 m/sec and one flag = 5 m/sec. The wind blows from the end of the flag staff, toward the monitoring site. For ozone, the plain text below each site shows the concentration in parts per billion, and the bar above each site shows the concentration by bar size. The CAMS numbers of selected sites are also shown.

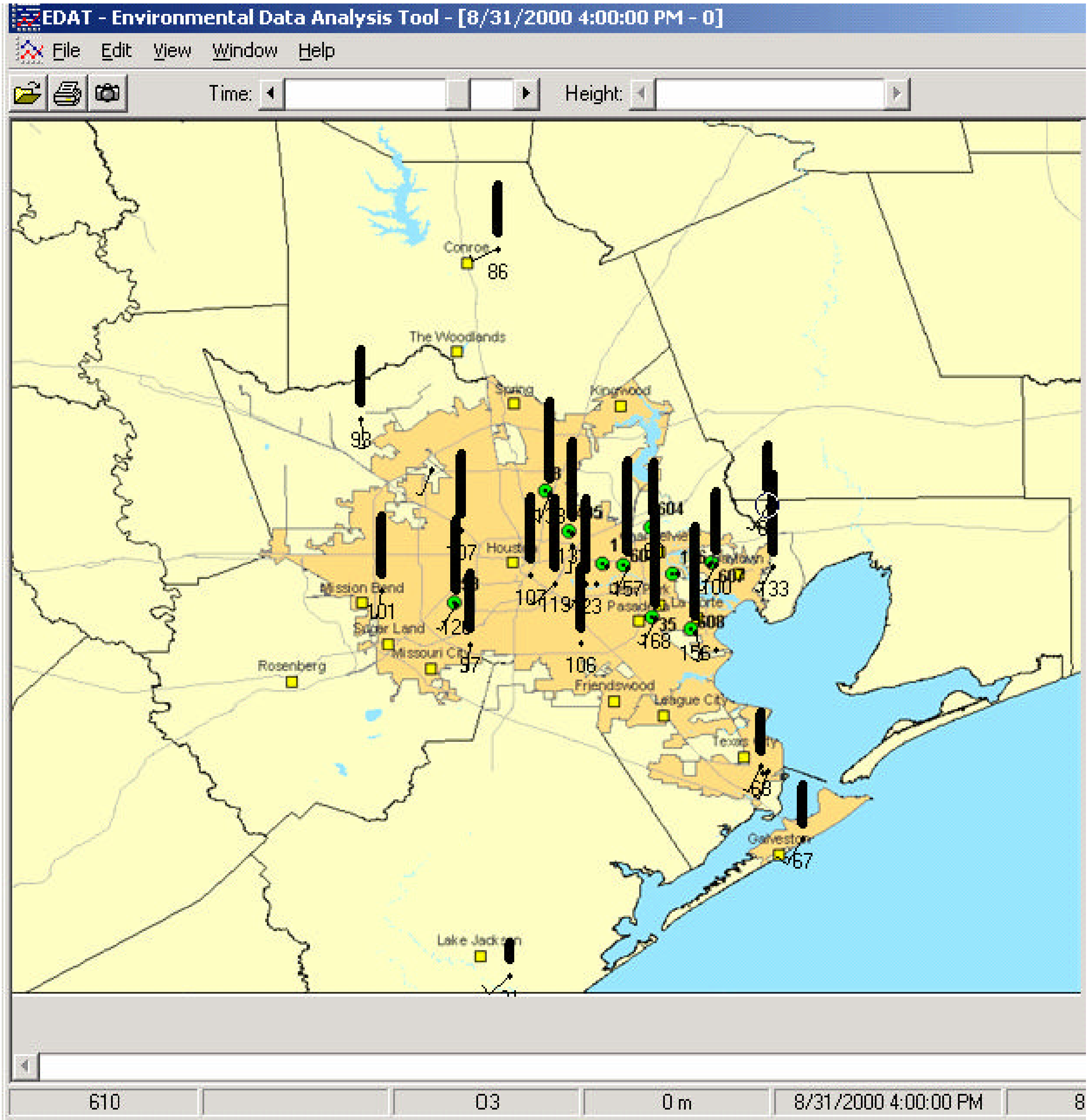


Figure 4-69. Spatial plot of hourly surface winds and ozone concentrations at CAMS sites on August 31, 2000, at 1600 CST. For winds, one-half of a flag = 2.5 m/sec and one flag = 5 m/sec. The wind blows from the end of the flag staff, toward the monitoring site. For ozone, the plain text below each site shows the concentration in parts per billion, and the bar above each site shows the concentration by bar size. The CAMS numbers of selected sites are also shown.

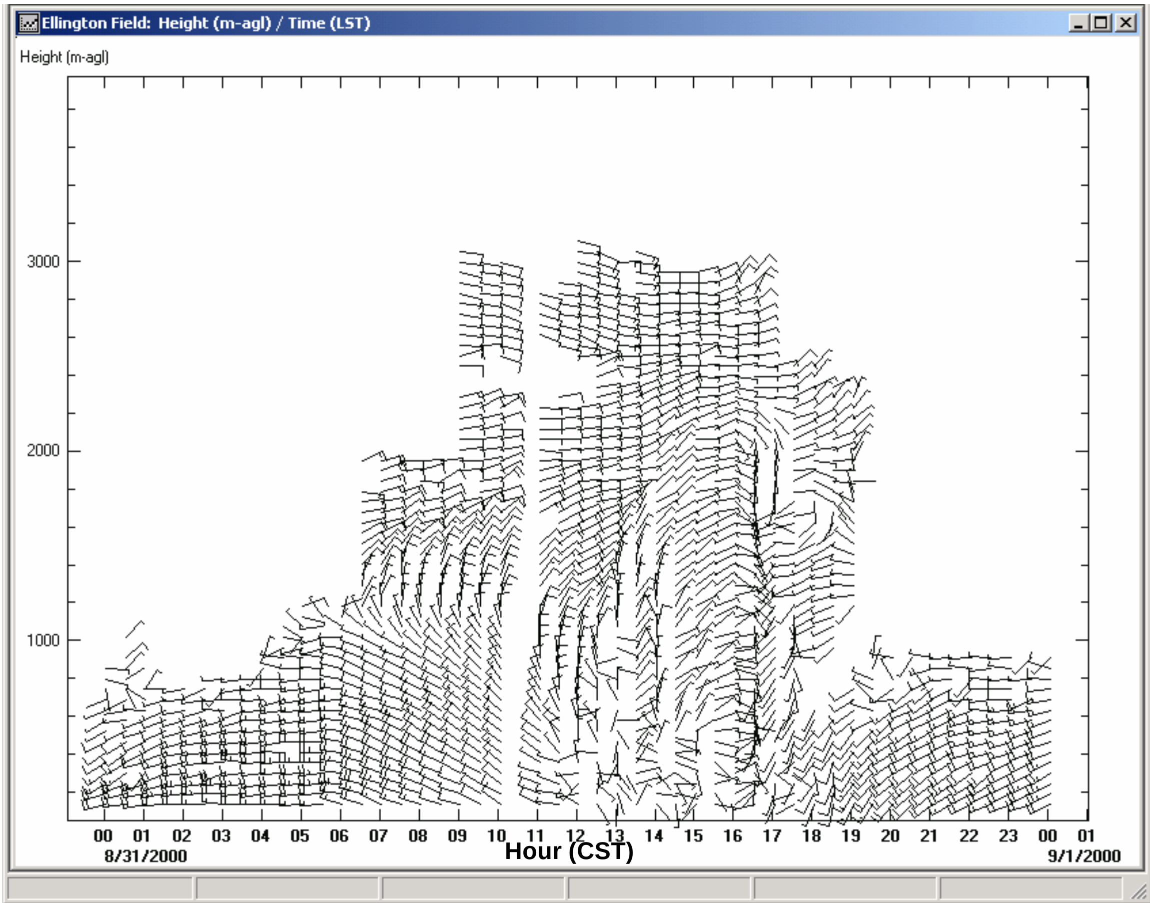


Figure 4-70. Time-height cross-section of radar profiler winds collected at Ellington Field on August 31, 2000.

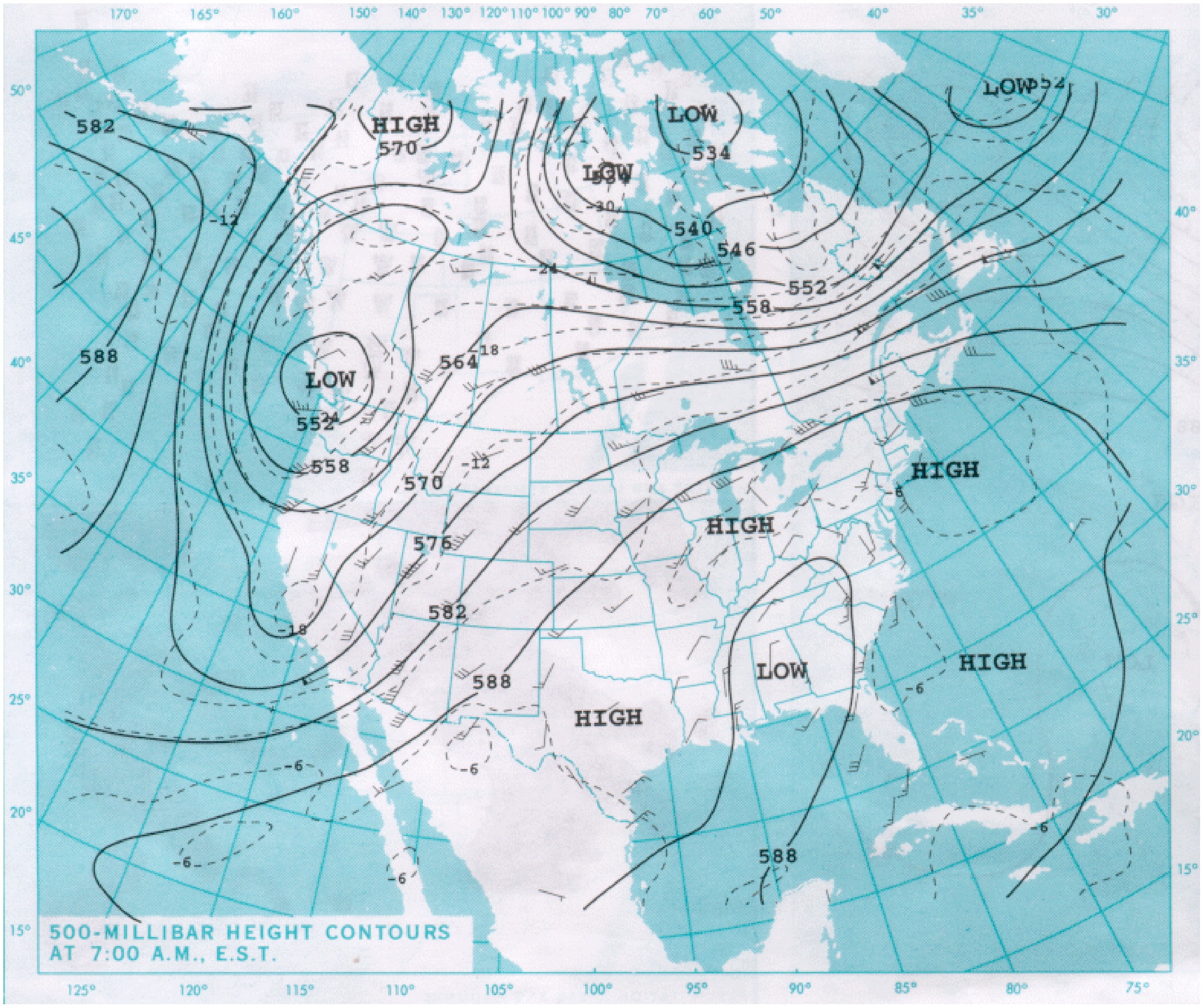


Figure 4-71. Contours of the height of the 500-mb surface pressure for September 1, 2000, at 0600 CST.

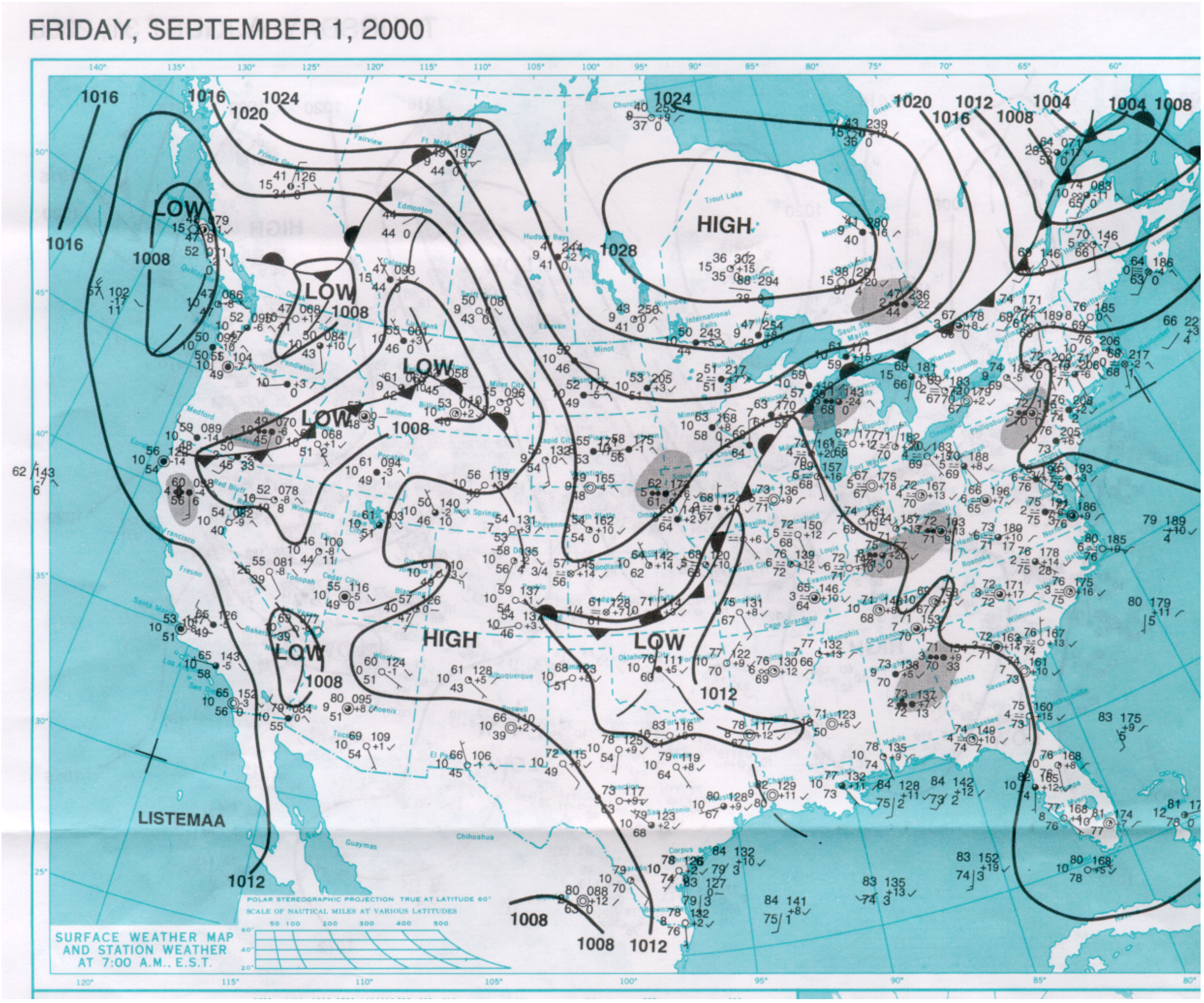


Figure 4-72. Surface analysis chart showing the winds, contours of surface pressure, and other weather conditions on September 1, 2000, at 0600 CST.

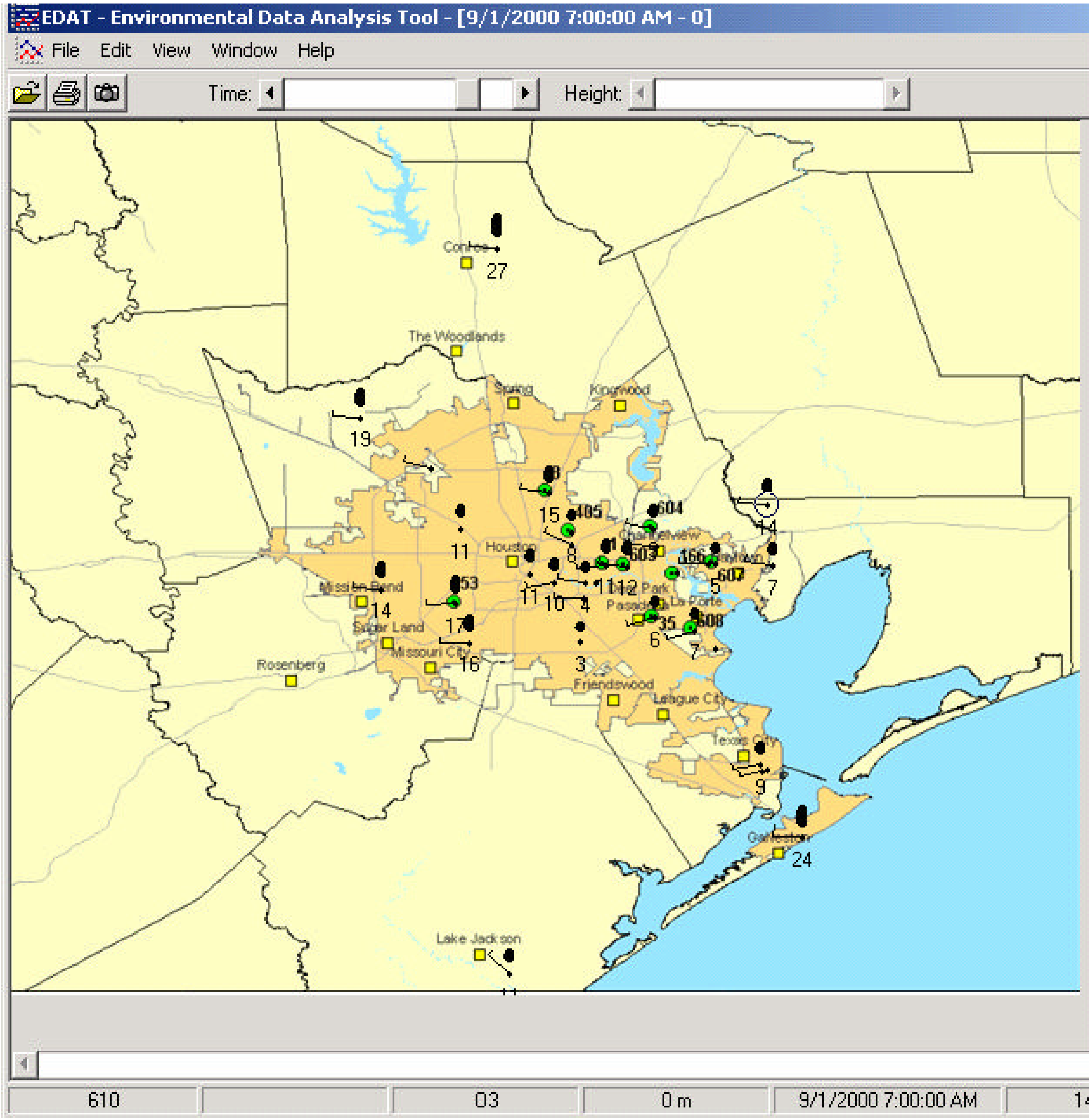


Figure 4-73. Spatial plot of hourly surface winds and ozone concentrations at CAMS sites on September 1, 2000, at 0700 CST. For winds, one-half of a flag = 2.5 m/sec and one flag = 5 m/sec. The wind blows from the end of the flag staff, toward the monitoring site. For ozone, the plain text below each site shows the concentration in parts per billion, and the bar above each site shows the concentration by bar size. The CAMS numbers of selected sites are also shown.

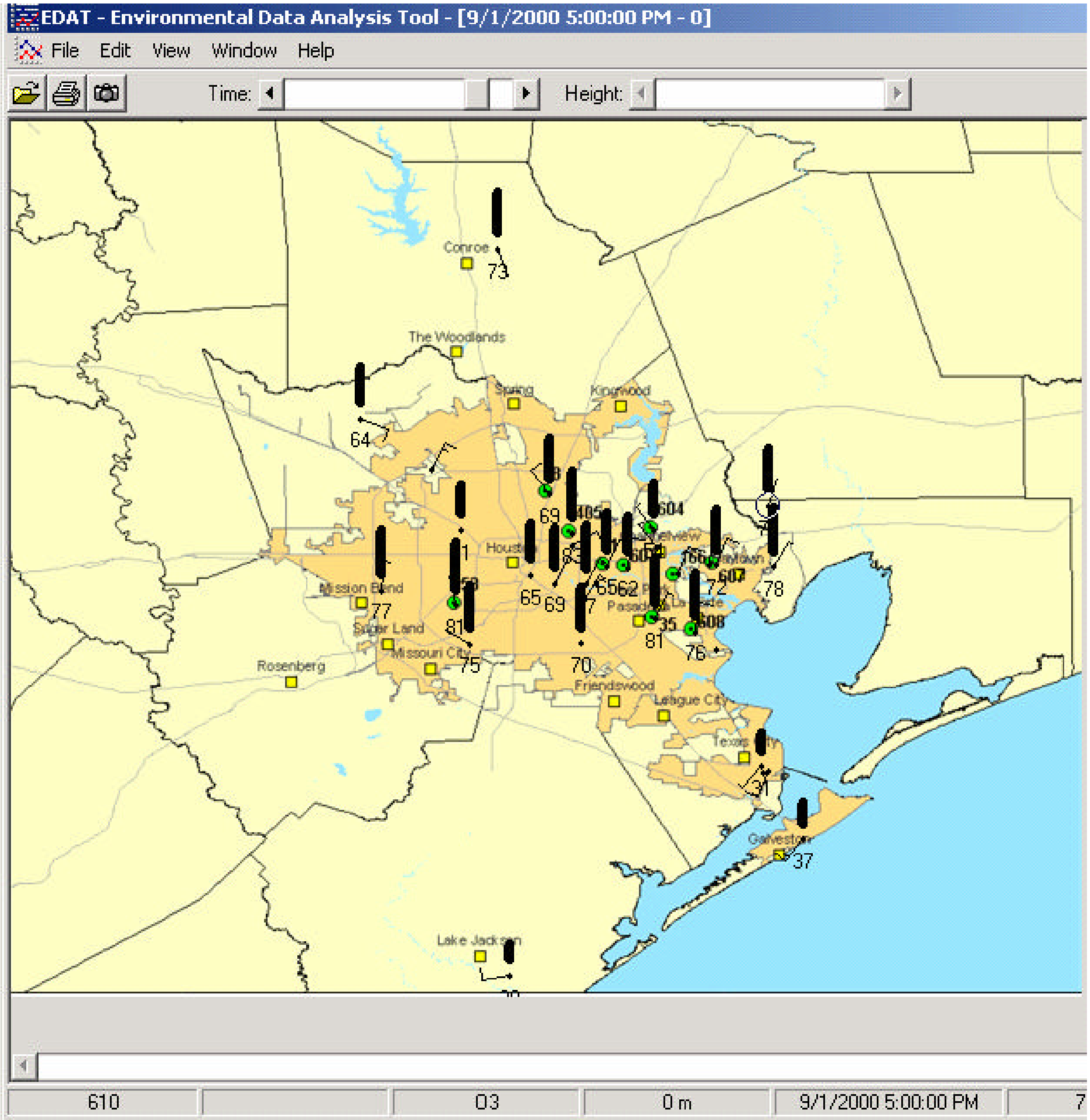


Figure 4-74. Spatial plot of hourly surface winds and ozone concentrations at CAMS sites on September 1, 2000, at 1700 CST. For winds, one-half of a flag = 2.5 m/sec and one flag = 5 m/sec. The wind blows from the end of the flag staff, toward the monitoring site. For ozone, the plain text below each site shows the concentration in parts per billion, and the bar above each site shows the concentration by bar size. The CAMS numbers of selected sites are also shown.

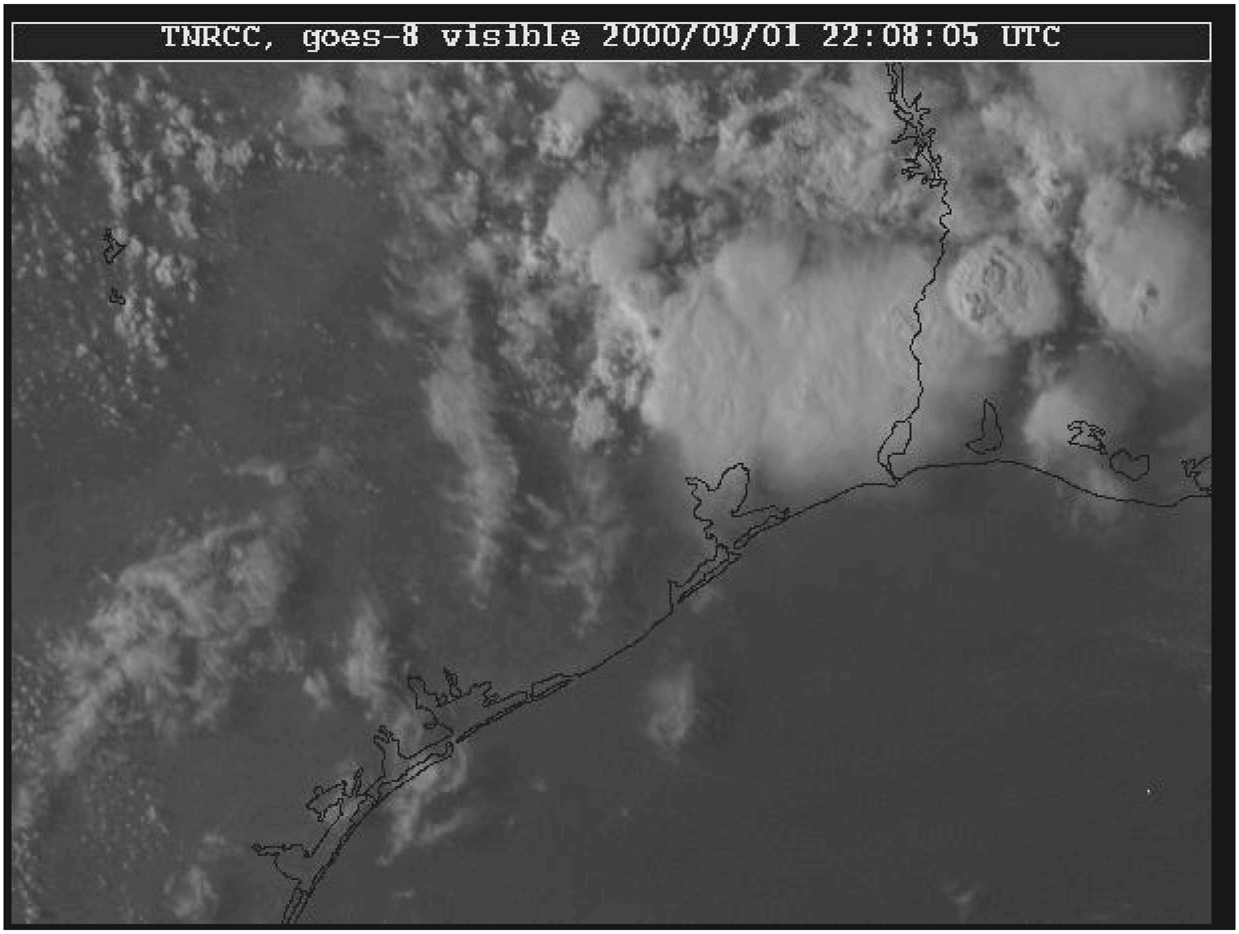


Figure 4-75. Visible satellite image for September 1, 2000, at 1609 CST (2208 UTC).

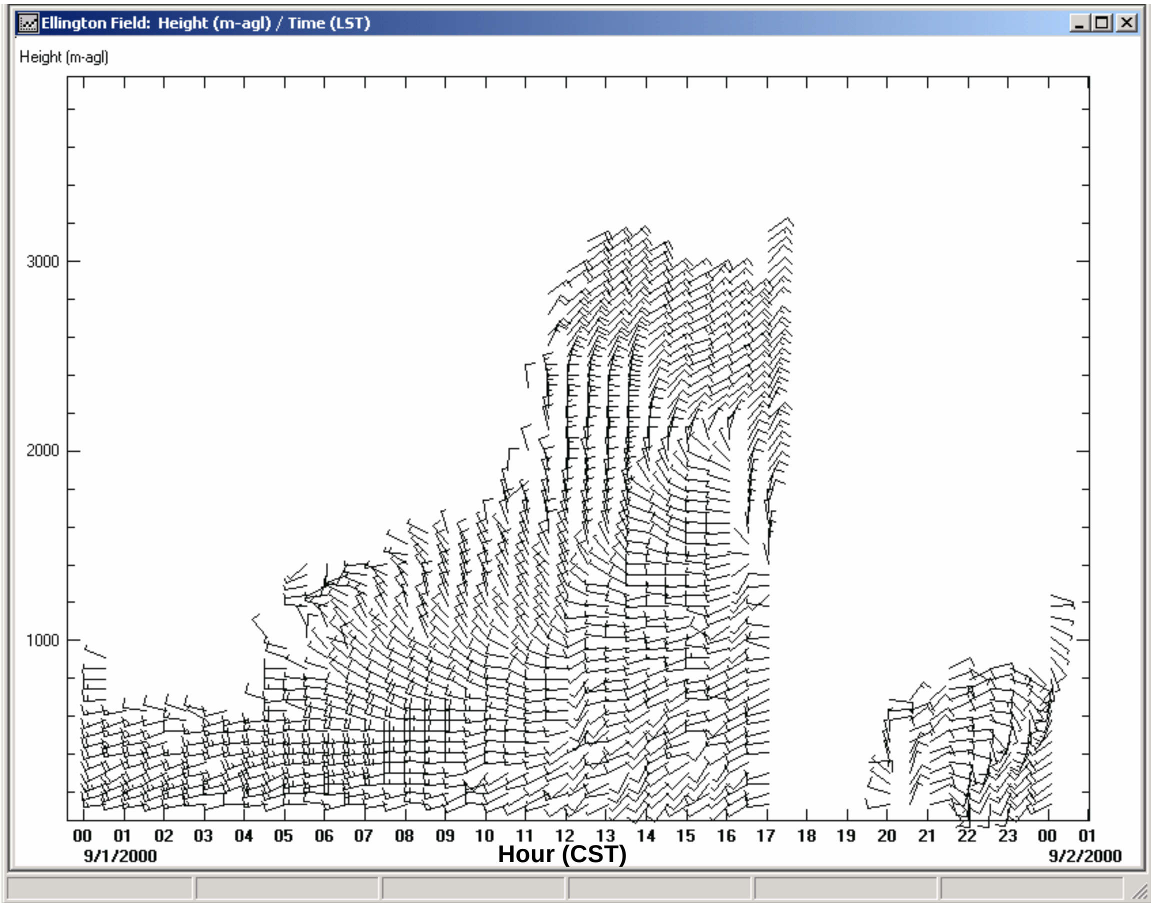


Figure 4-76. Time-height cross-section of radar profiler winds collected at Ellington Field on September 1, 2000.

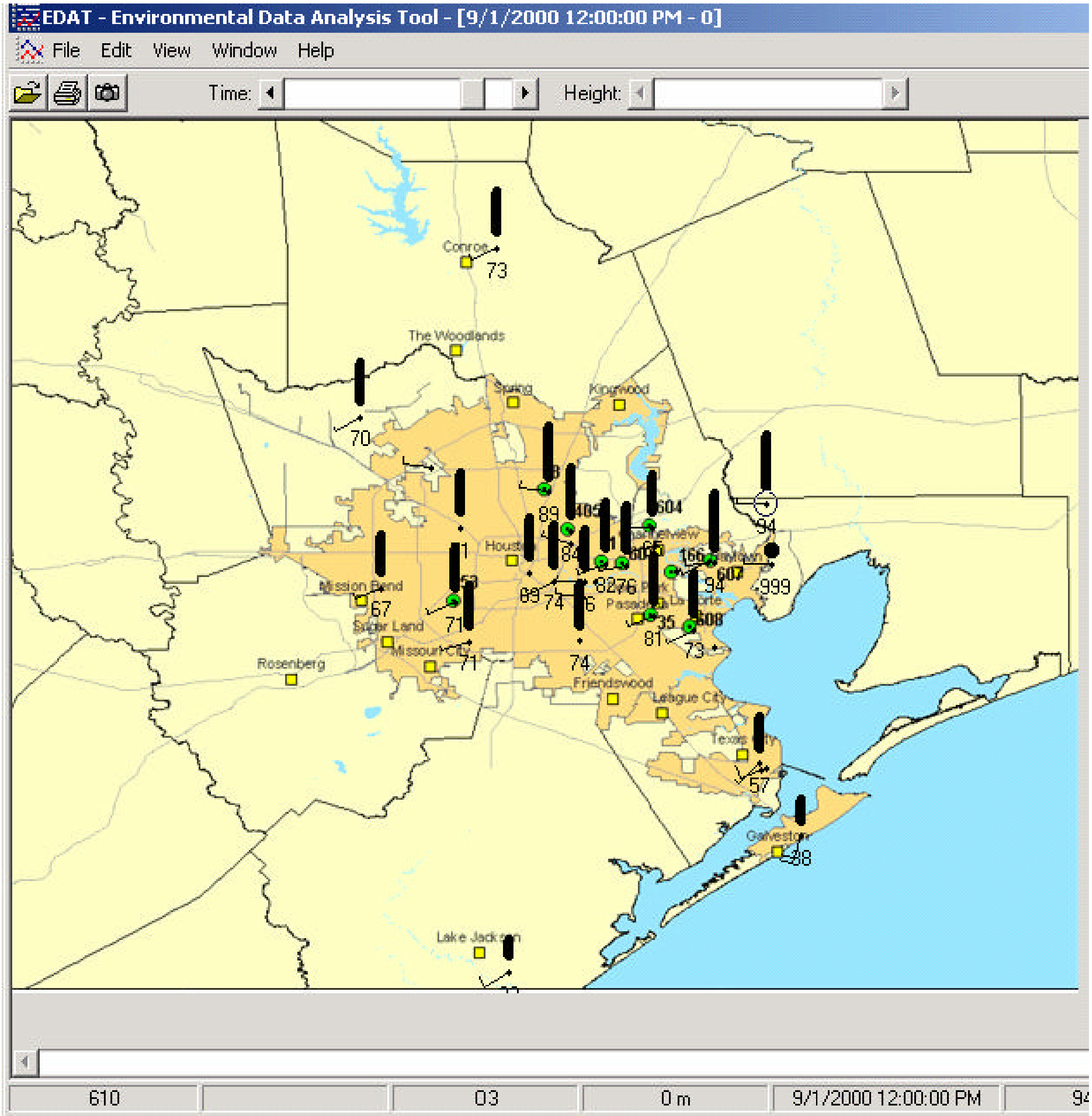


Figure 4-77. Spatial plot of hourly surface winds and ozone concentrations at CAMS sites on September 1, 2000, at 1200 CST. For winds, one-half of a flag = 2.5 m/sec and one flag = 5 m/sec. The wind blows from the end of the flag staff, toward the monitoring site. For ozone, the plain text below each site shows the concentration in parts per billion, and the bar above each site shows the concentration by bar size. Note that missing data are reported as -999. The CAMS numbers of selected sites are also shown.

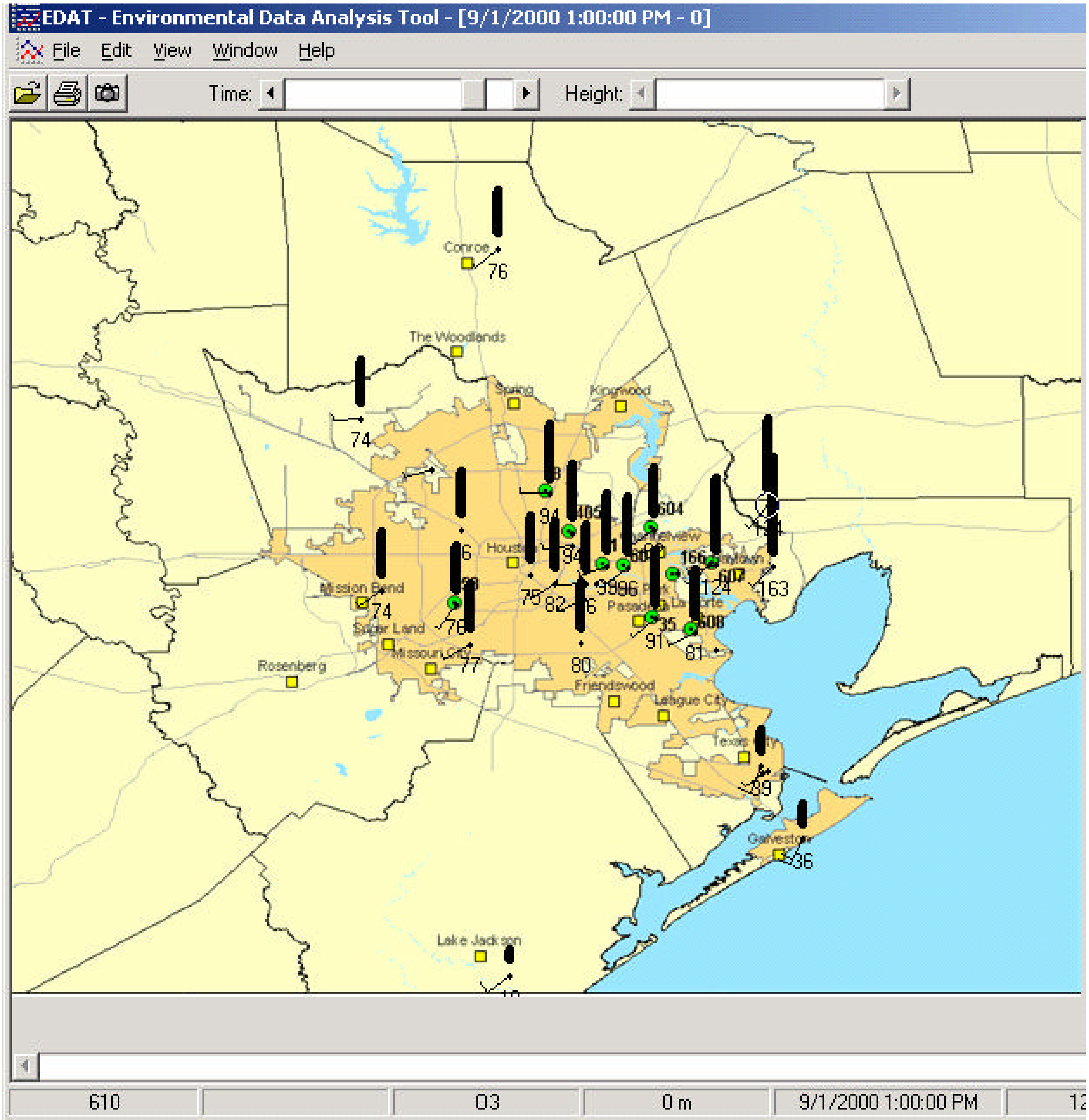


Figure 4-78. Spatial plot of hourly surface winds and ozone concentrations at CAMS sites on September 1, 2000, at 1300 CST. For winds, one-half of a flag = 2.5 m/sec and one flag = 5 m/sec. The wind blows from the end of the flag staff, toward the monitoring site. For ozone, the plain text below each site shows the concentration in parts per billion, and the bar above each site shows the concentration by bar size. The CAMS numbers of selected sites are also shown.

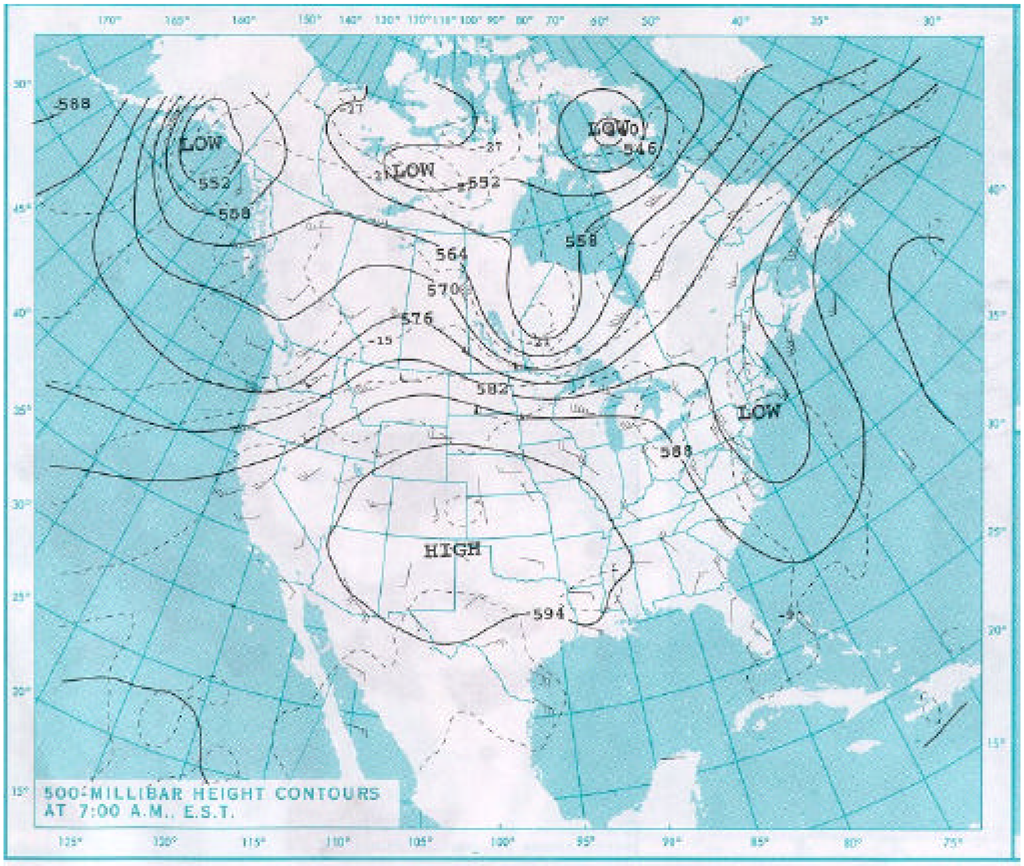


Figure 4-79. Contours of the height of the 500-mb surface pressure for August 15, 2000, at 0600 CST.

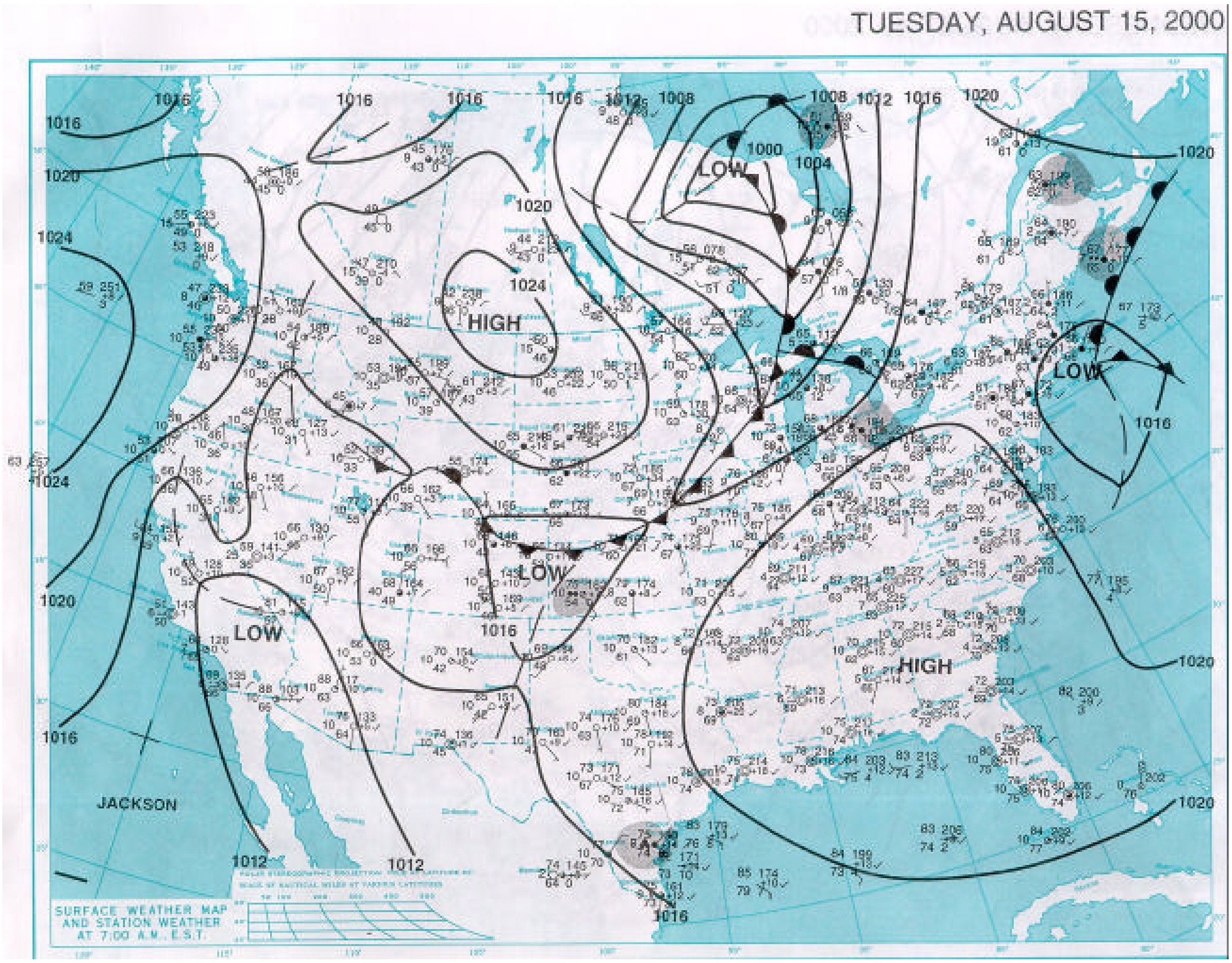


Figure 4-80. Surface analysis chart showing the winds, contours of surface pressure, and other weather conditions on August 15, 2000, at 0600 CST.

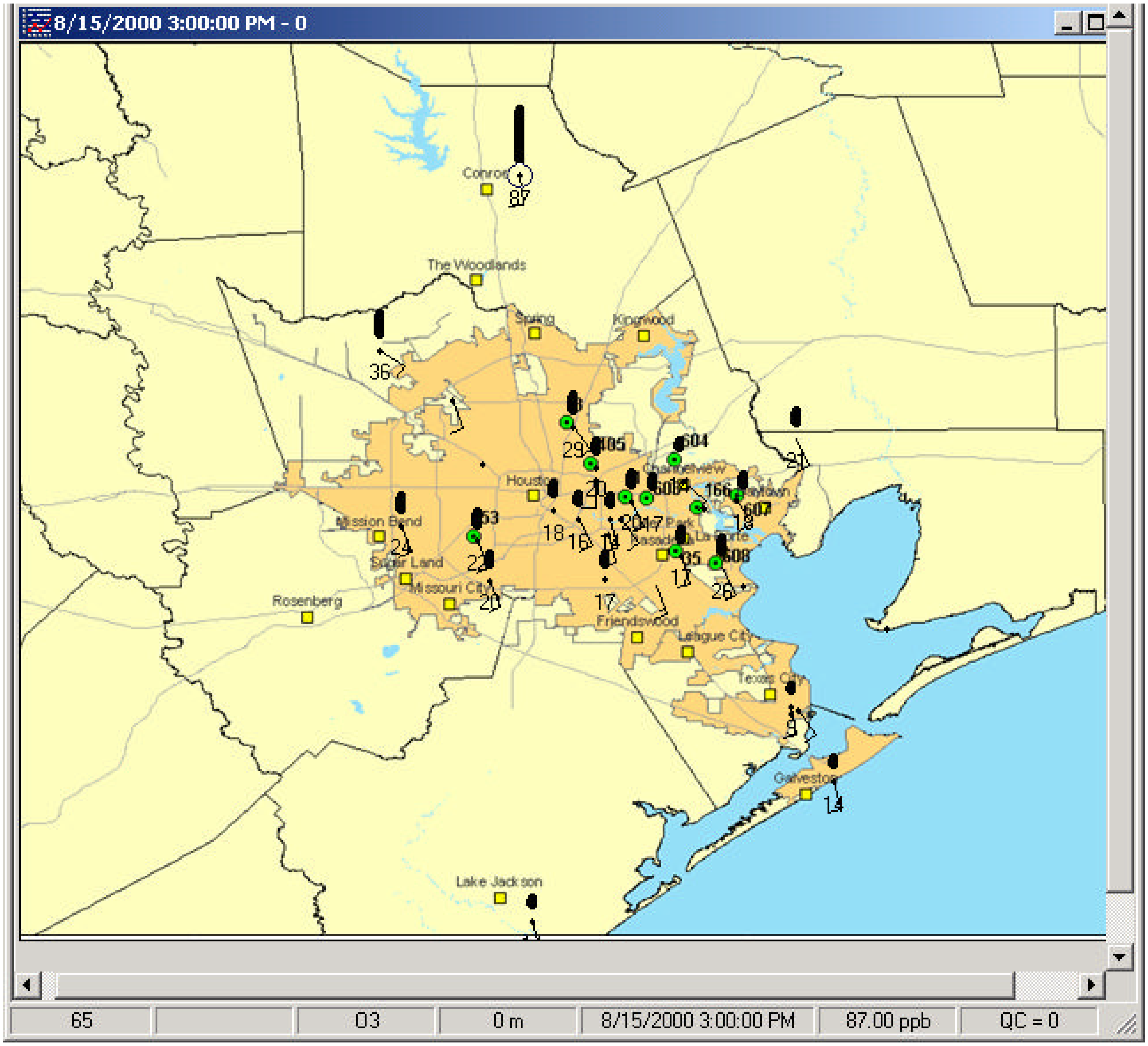


Figure 4-81. Spatial plot of hourly surface winds and ozone concentrations at CAMS sites on August 15, 2000, at 1500 CST.

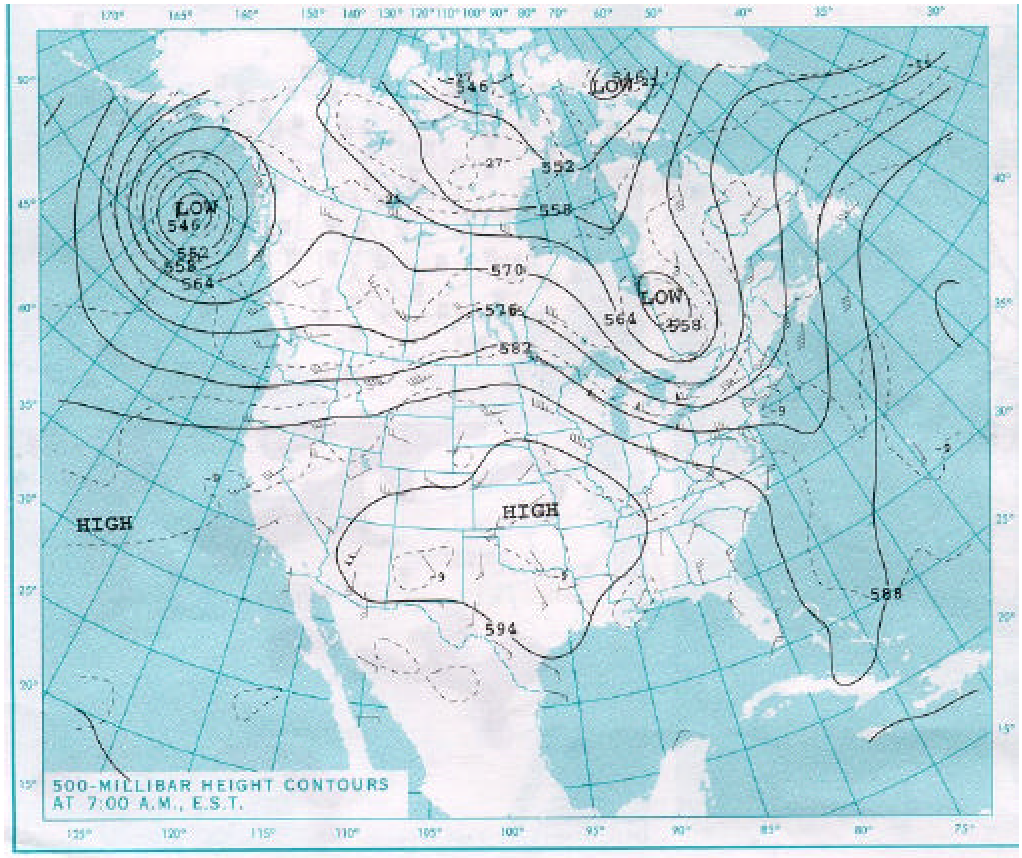


Figure 4-82. Contours of the height of the 500-mb surface pressure for August 16, 2000, at 0600 CST.

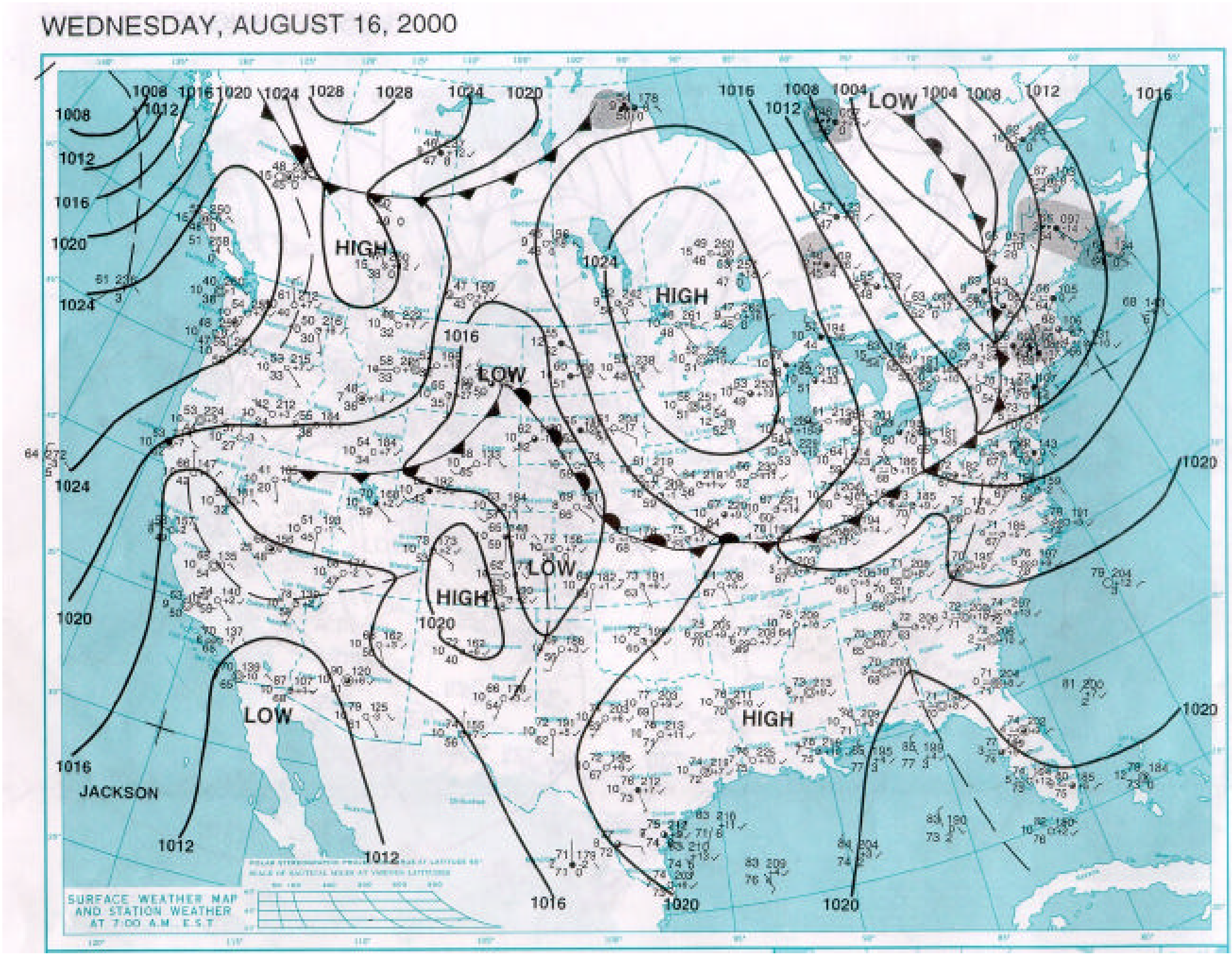


Figure 4-83. Surface analysis chart showing the winds, contours of surface pressure, and other weather conditions on August 16, 2000, at 0600 CST.

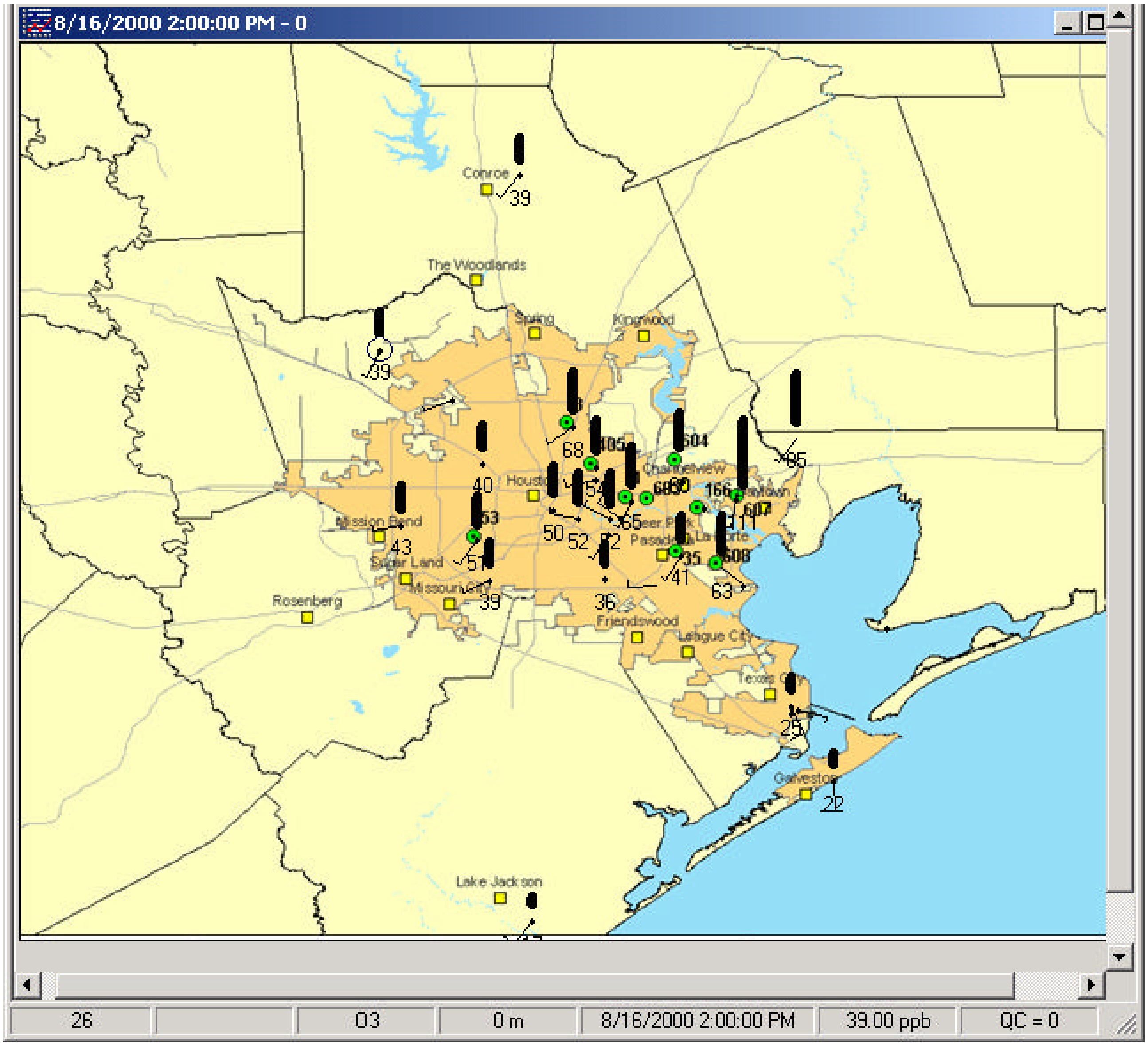


Figure 4-84. Spatial plot of hourly surface winds and ozone concentrations at CAMS sites on August 16, 2000, at 1400 CST.

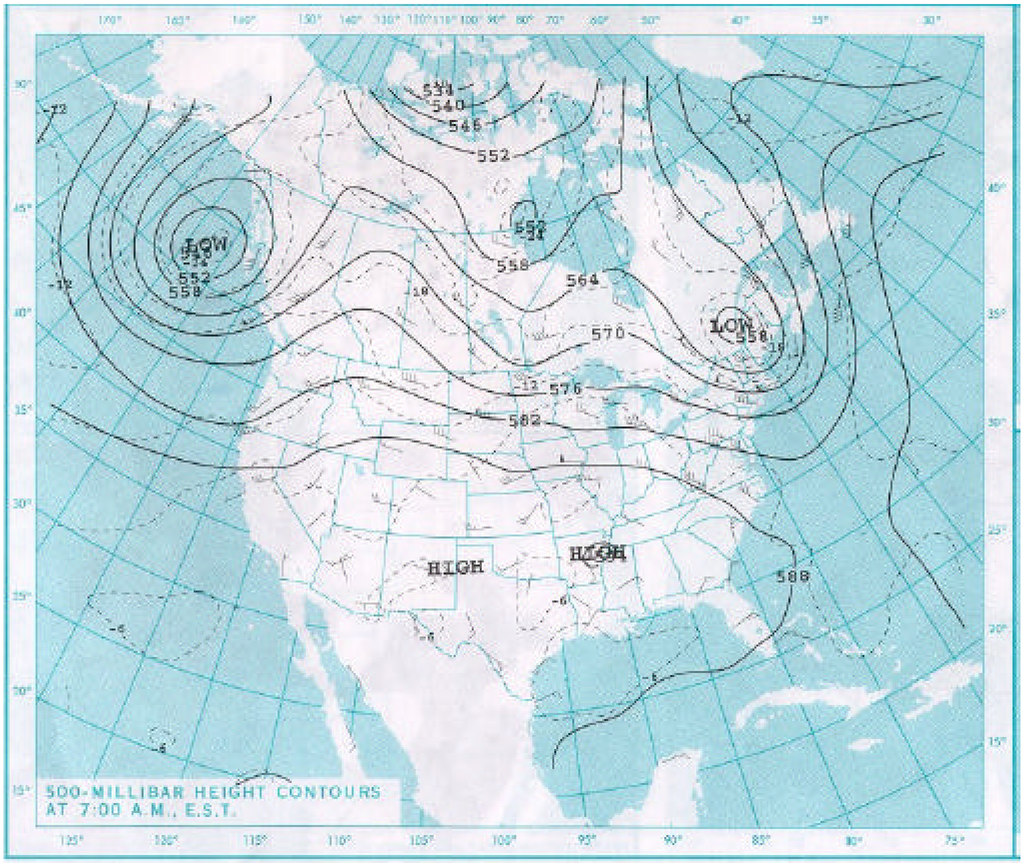


Figure 4-85. Contours of the height of the 500-mb surface pressure for August 17, 2000, at 0600 CST.

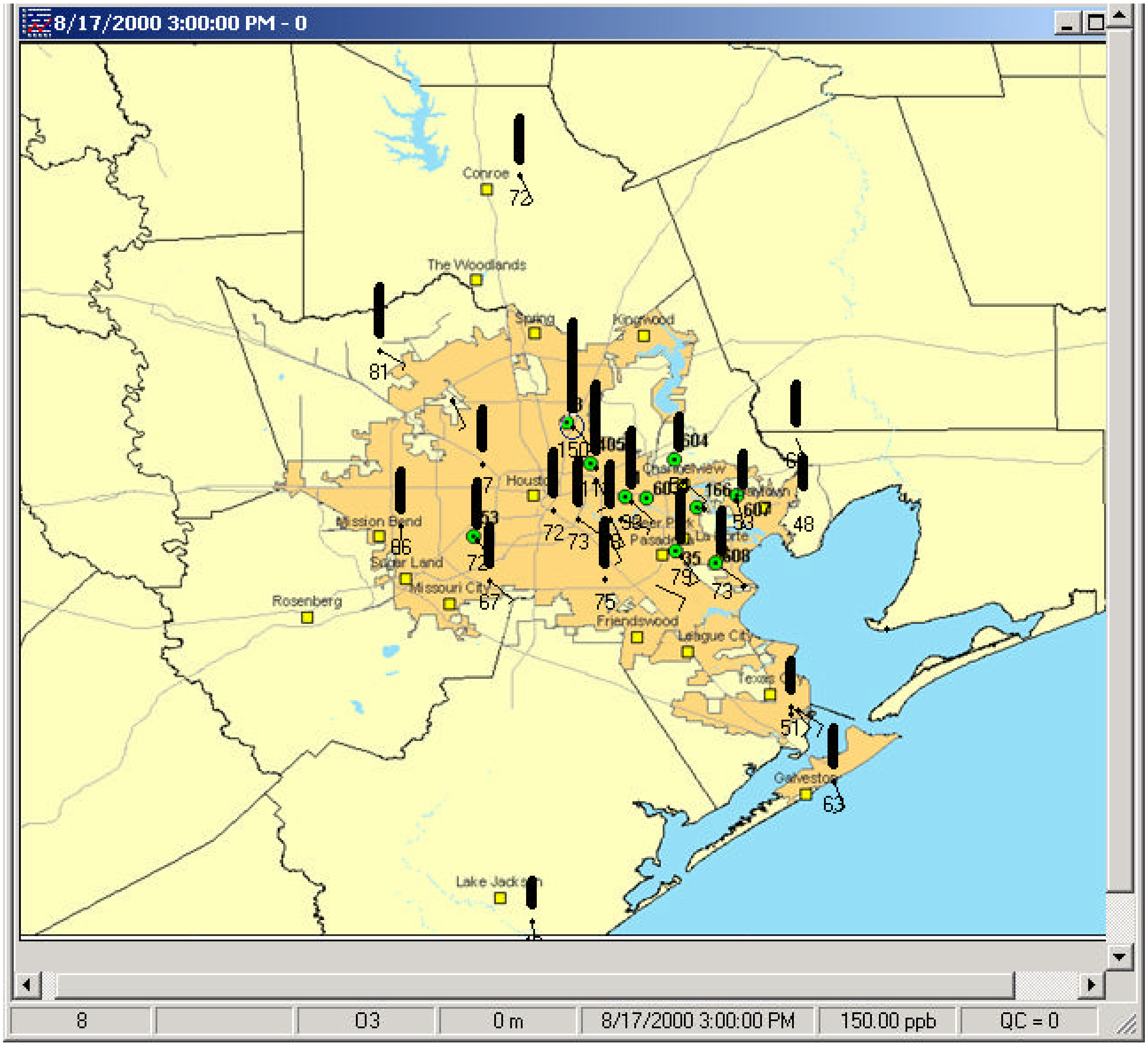


Figure 4-86. Spatial plot of hourly surface winds and ozone concentrations at CAMS sites on August 17, 2000, at 1500 CST.

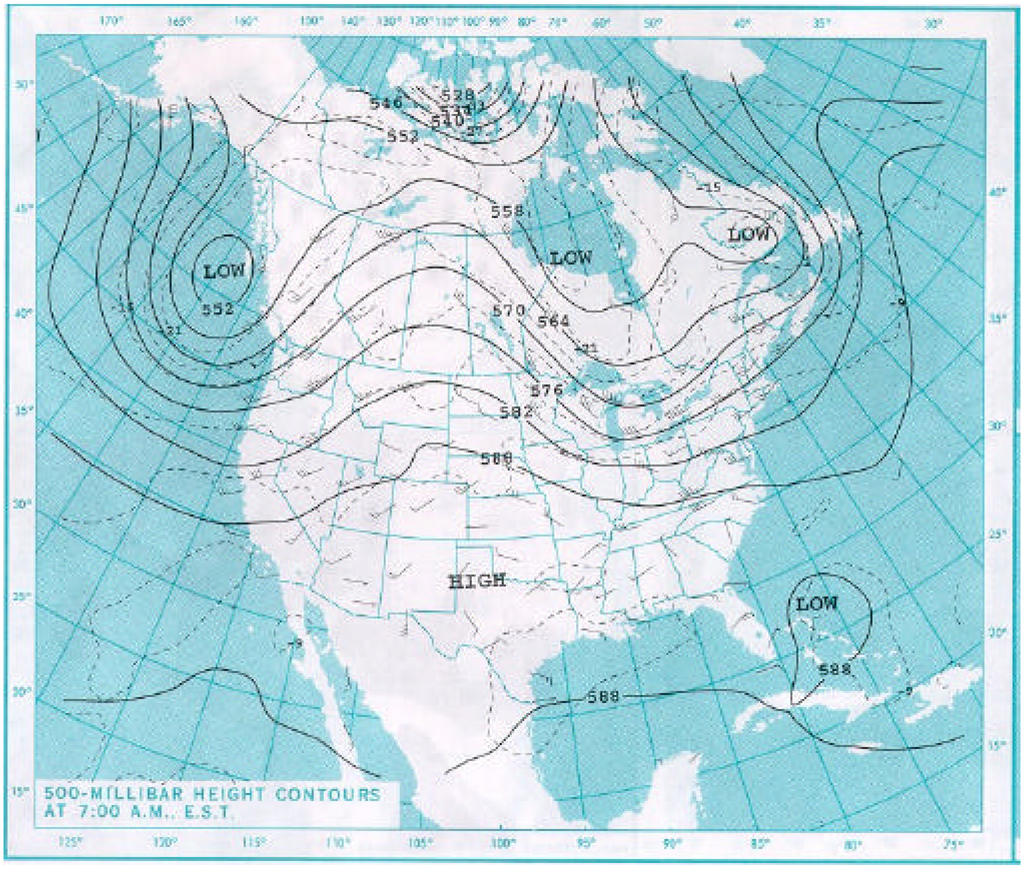


Figure 4-87. Contours of the height of the 500-mb surface pressure for August 18, 2000, at 0600 CST.

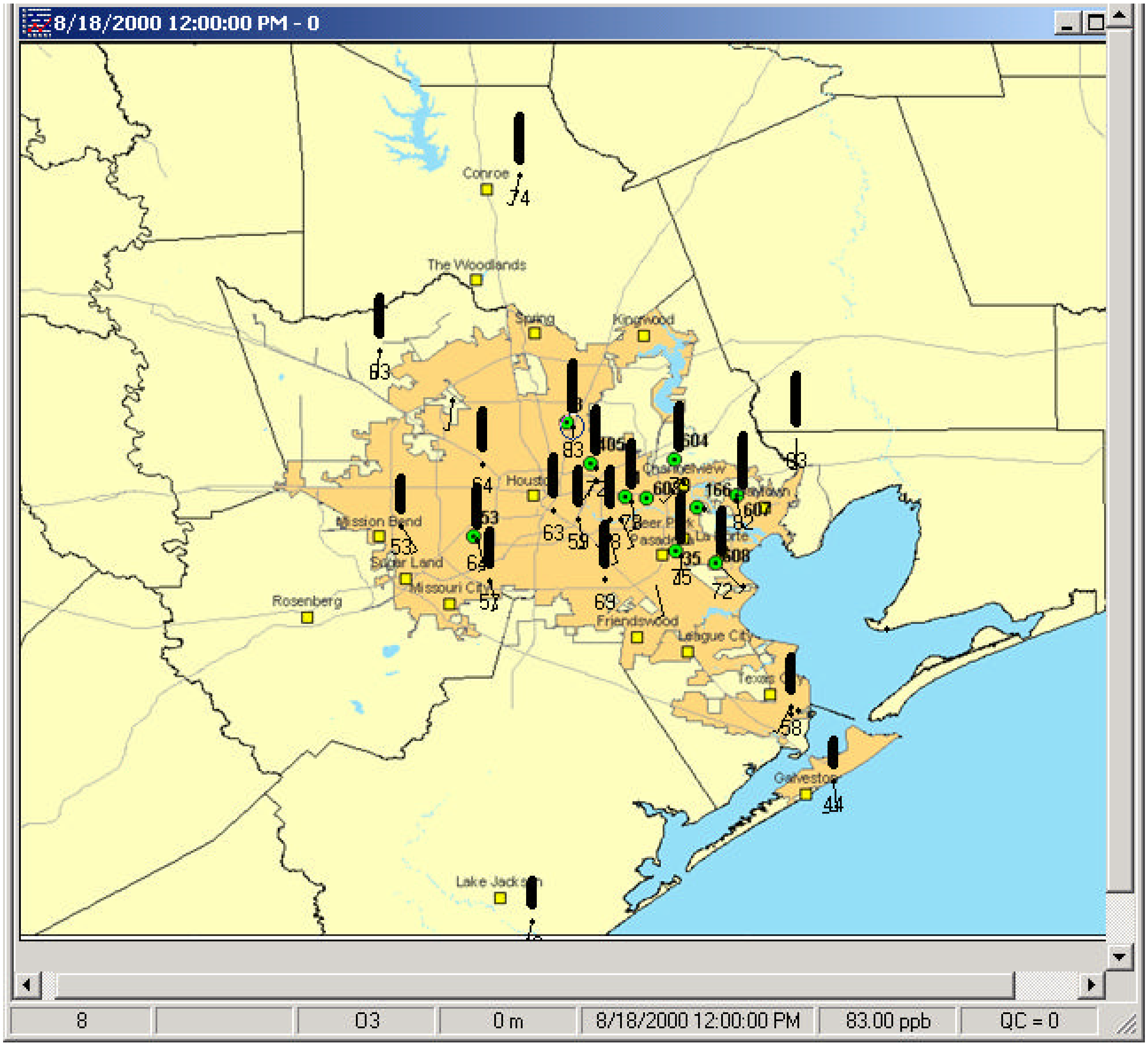


Figure 4-88. Spatial plot of hourly surface winds and ozone concentrations at CAMS sites on August 18, 2000, at 1200 CST.

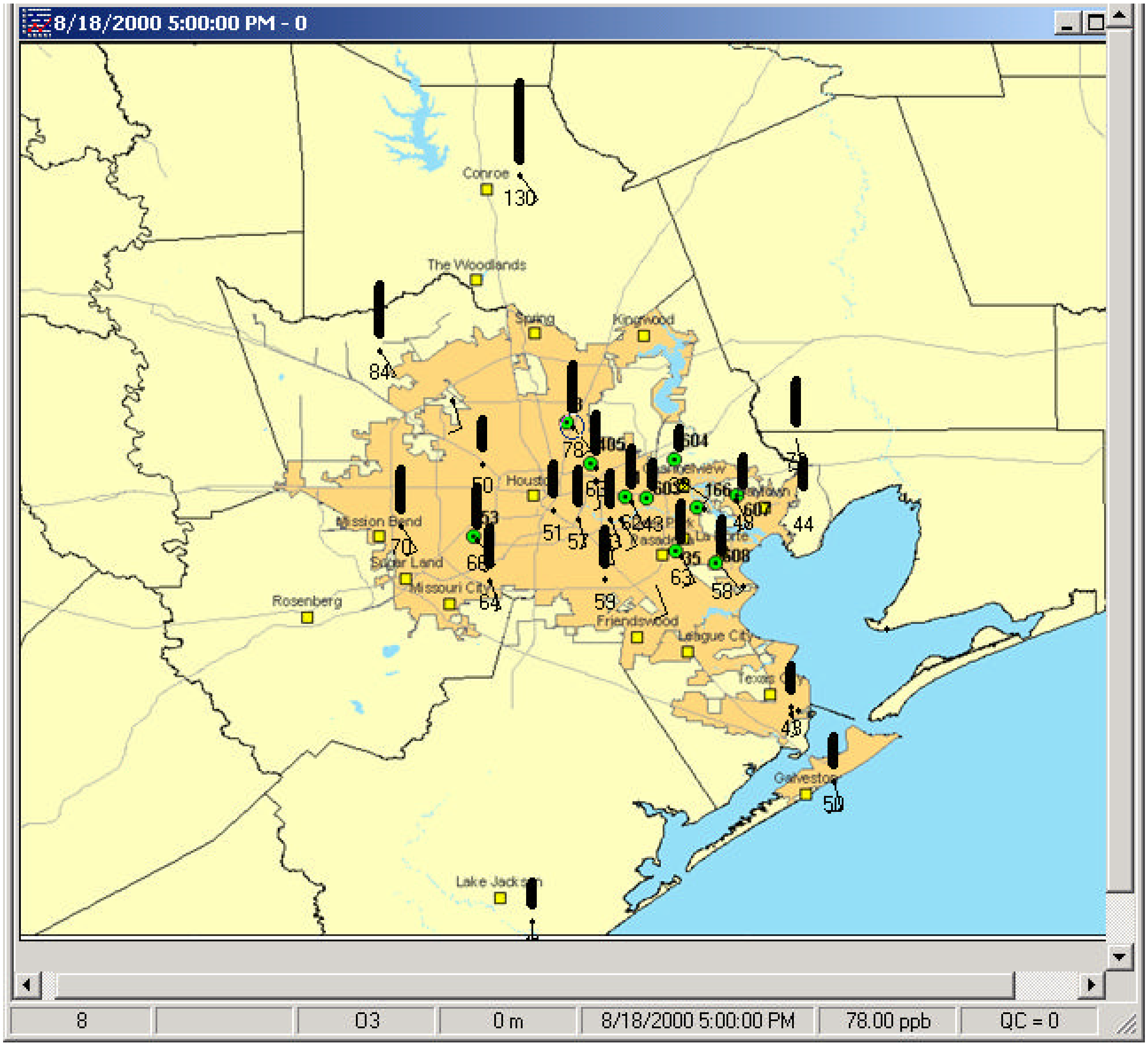


Figure 4-89. Spatial plot of hourly surface winds and ozone concentrations at CAMS sites on August 18, 2000, at 1700 CST.

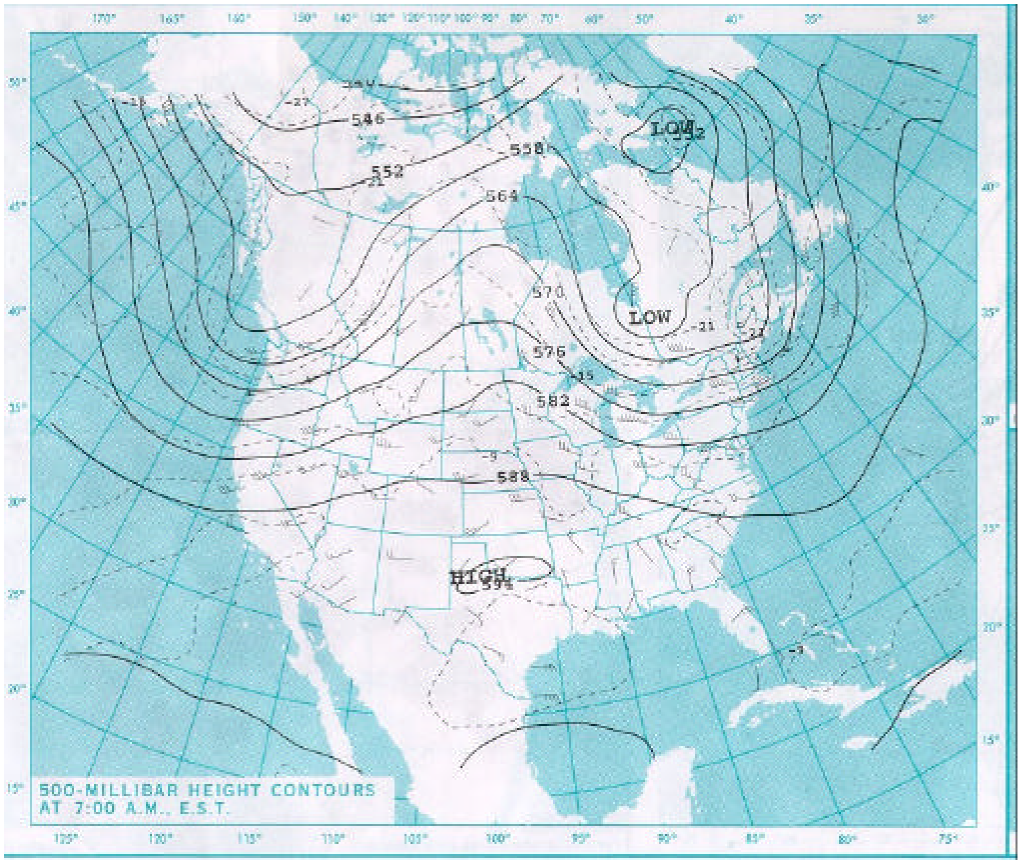


Figure 4-90. Contours of the height of the 500-mb surface pressure for August 19, 2000, at 0600 CST.

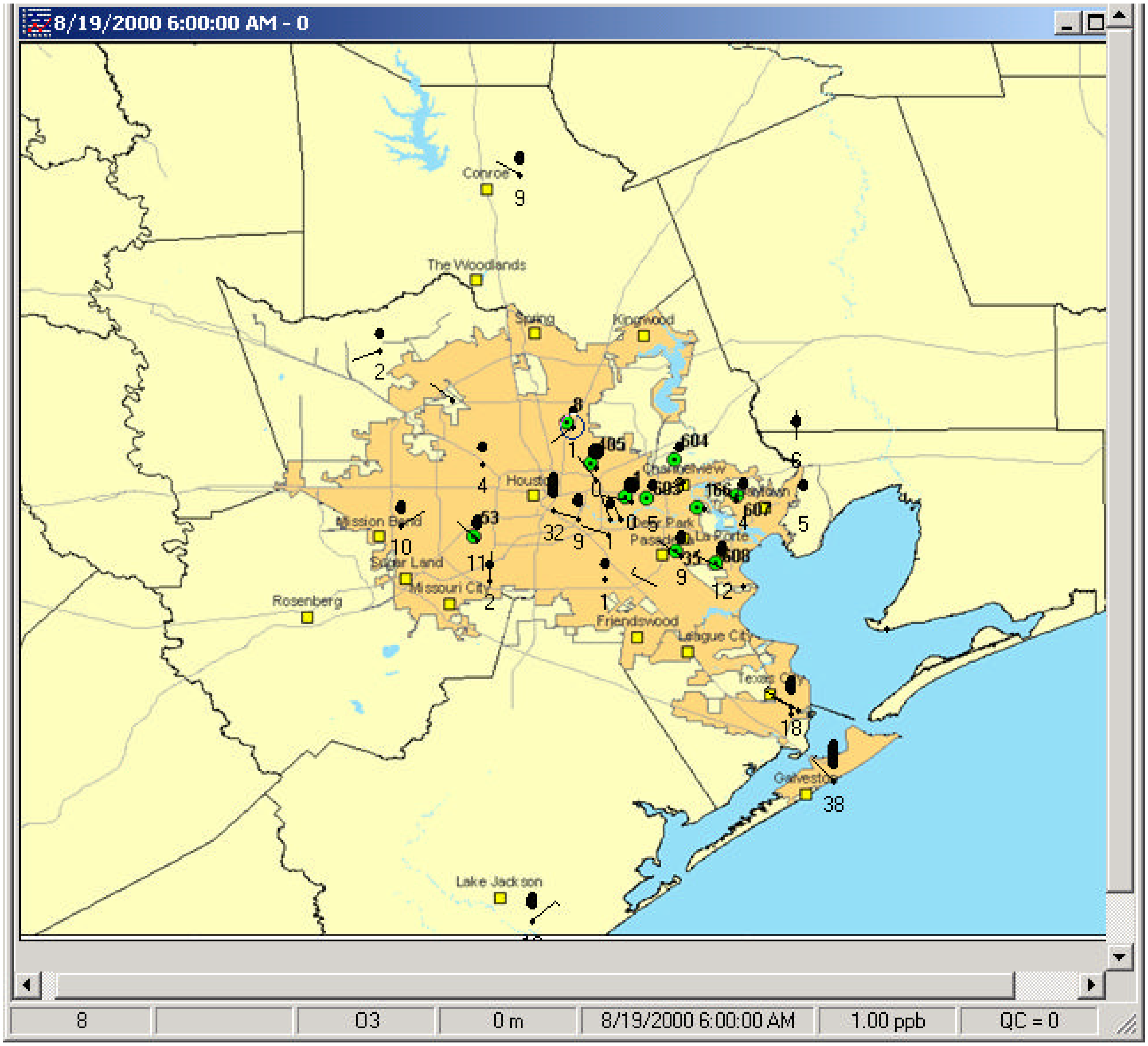


Figure 4-91. Spatial plot of hourly surface winds and ozone concentrations at CAMS sites on August 19, 2000, at 0600 CST.

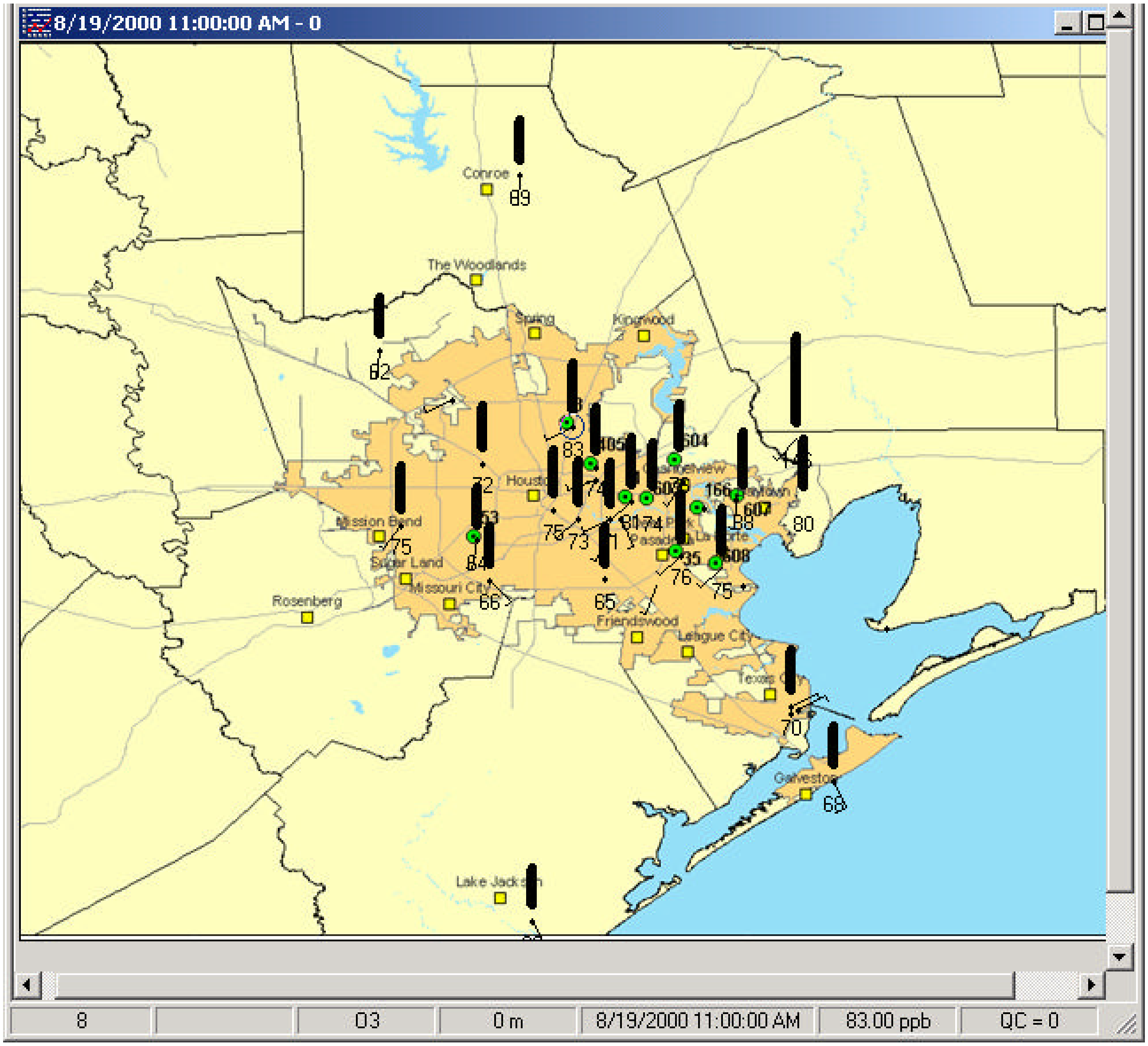


Figure 4-92. Spatial plot of hourly surface winds and ozone concentrations at CAMS sites on August 19, 2000, at 1100 CST.

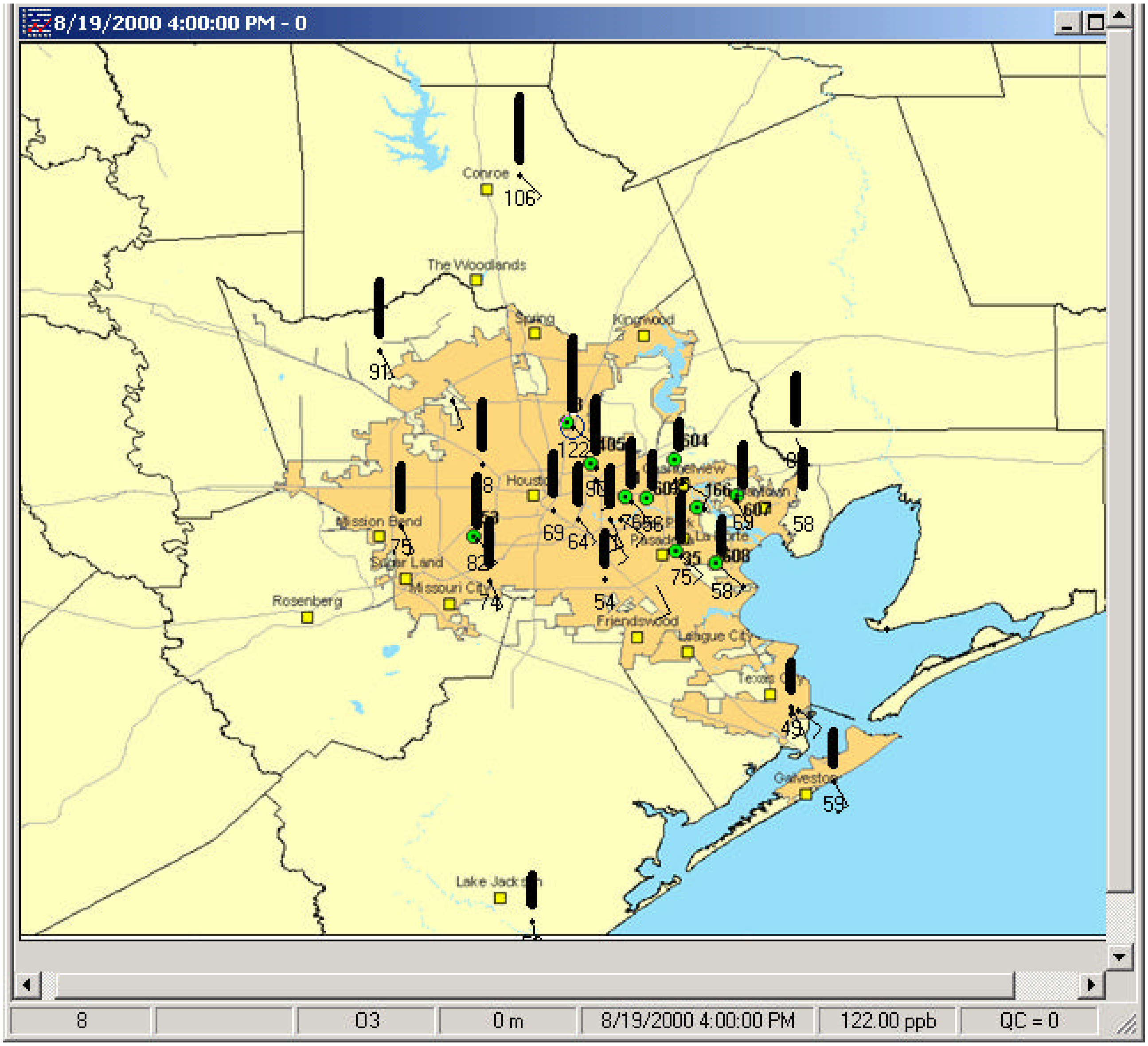


Figure 4-93. Spatial plot of hourly surface winds and ozone concentrations at CAMS sites on August 19, 2000, at 1600 CST.

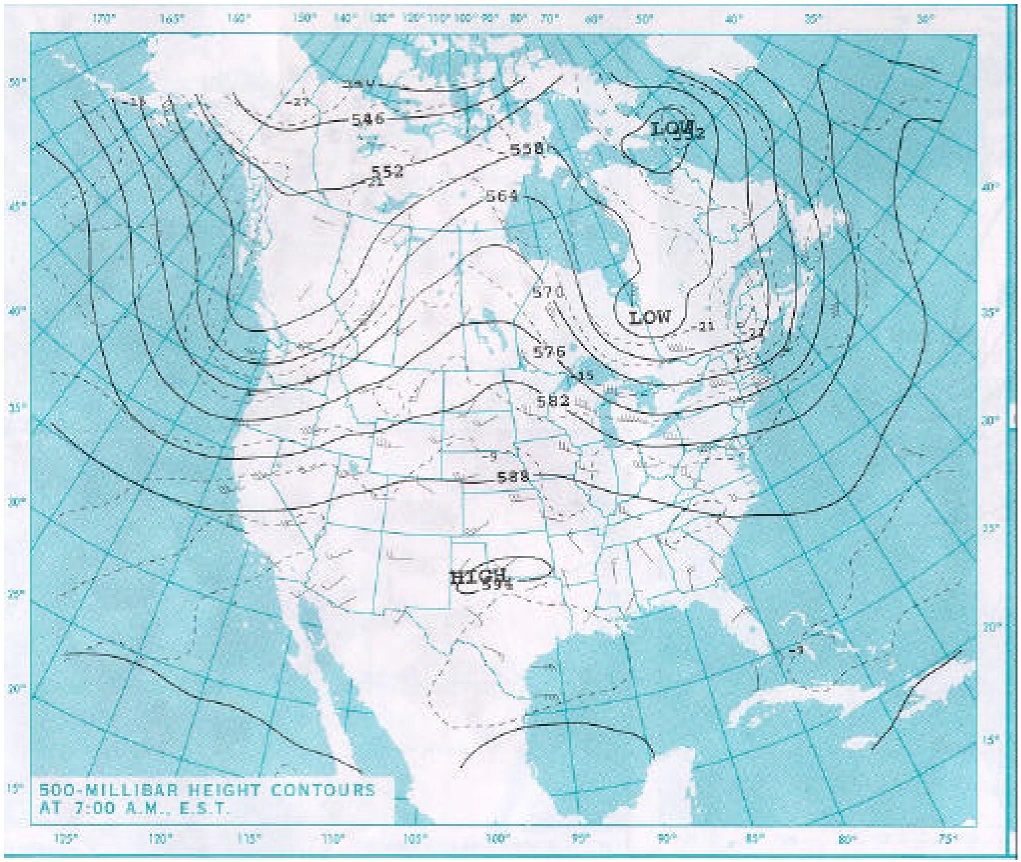


Figure 4-94. Contours of the height of the 500-mb surface pressure for August 20, 2000, at 0600 CST.

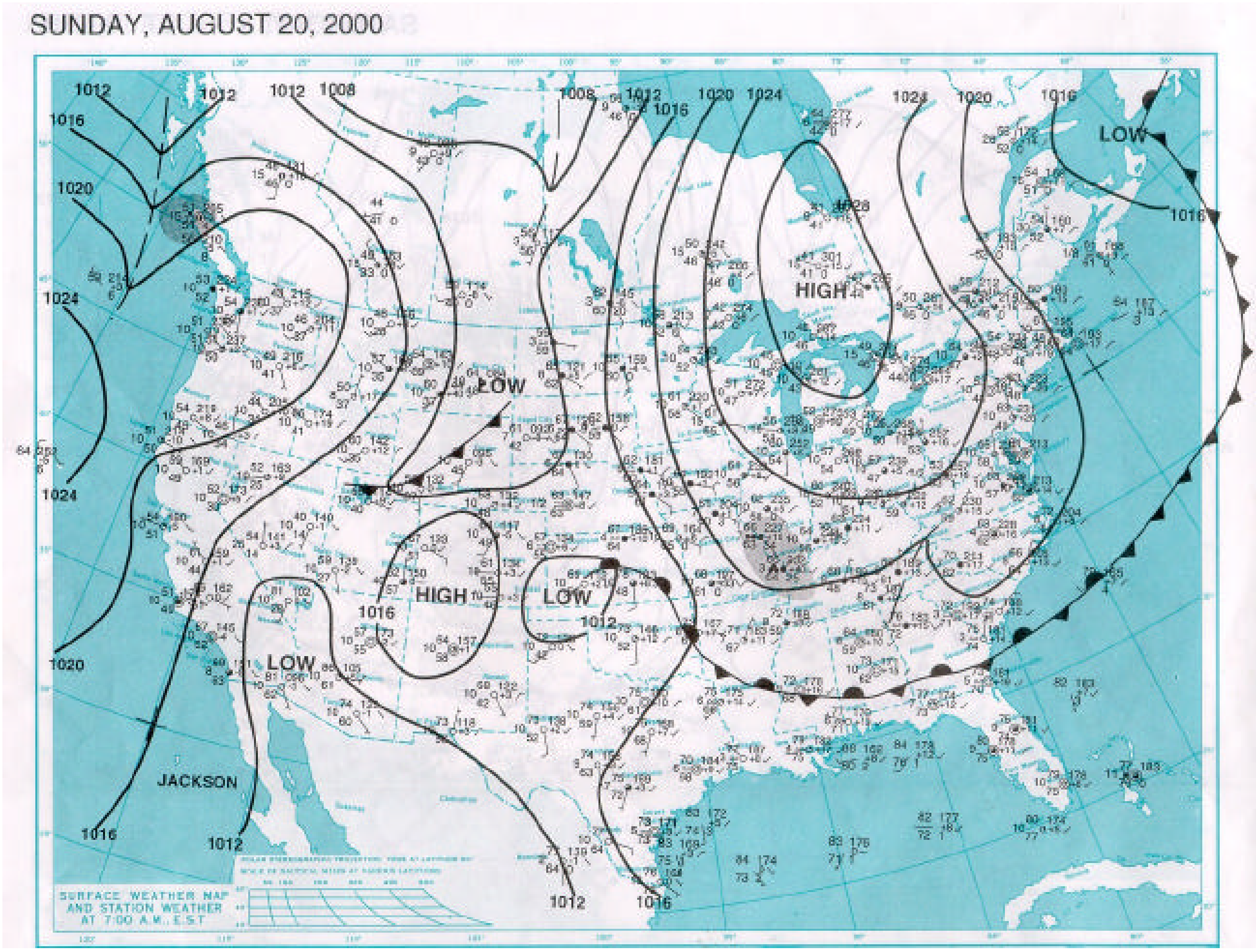


Figure 4-95. Surface analysis chart showing the winds, contours of surface pressure, and other weather conditions on August 20, 2000, at 0600 CST.

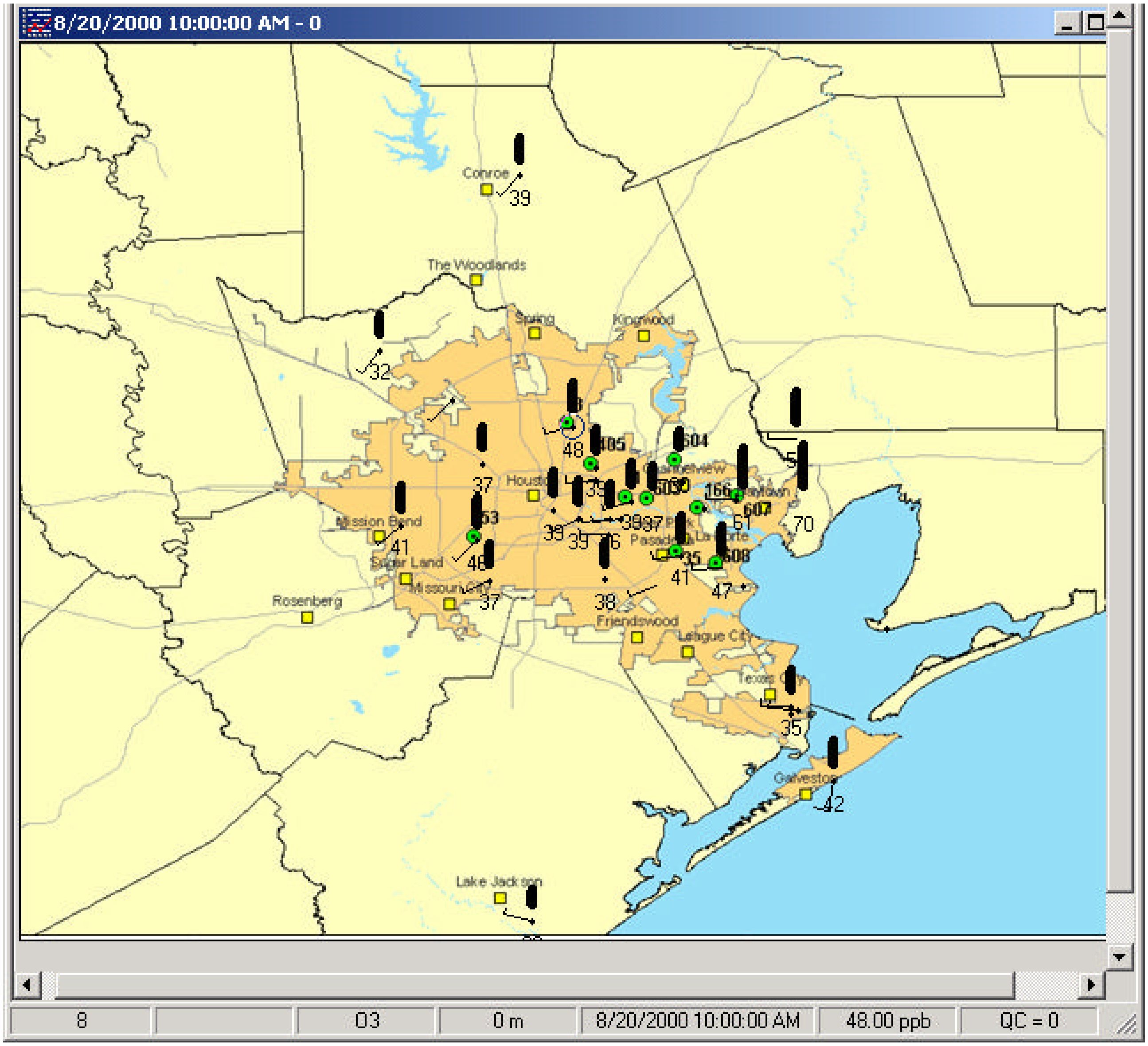


Figure 4-96. Spatial plot of hourly surface winds and ozone concentrations at CAMS sites on August 20, 2000, at 1000 CST.

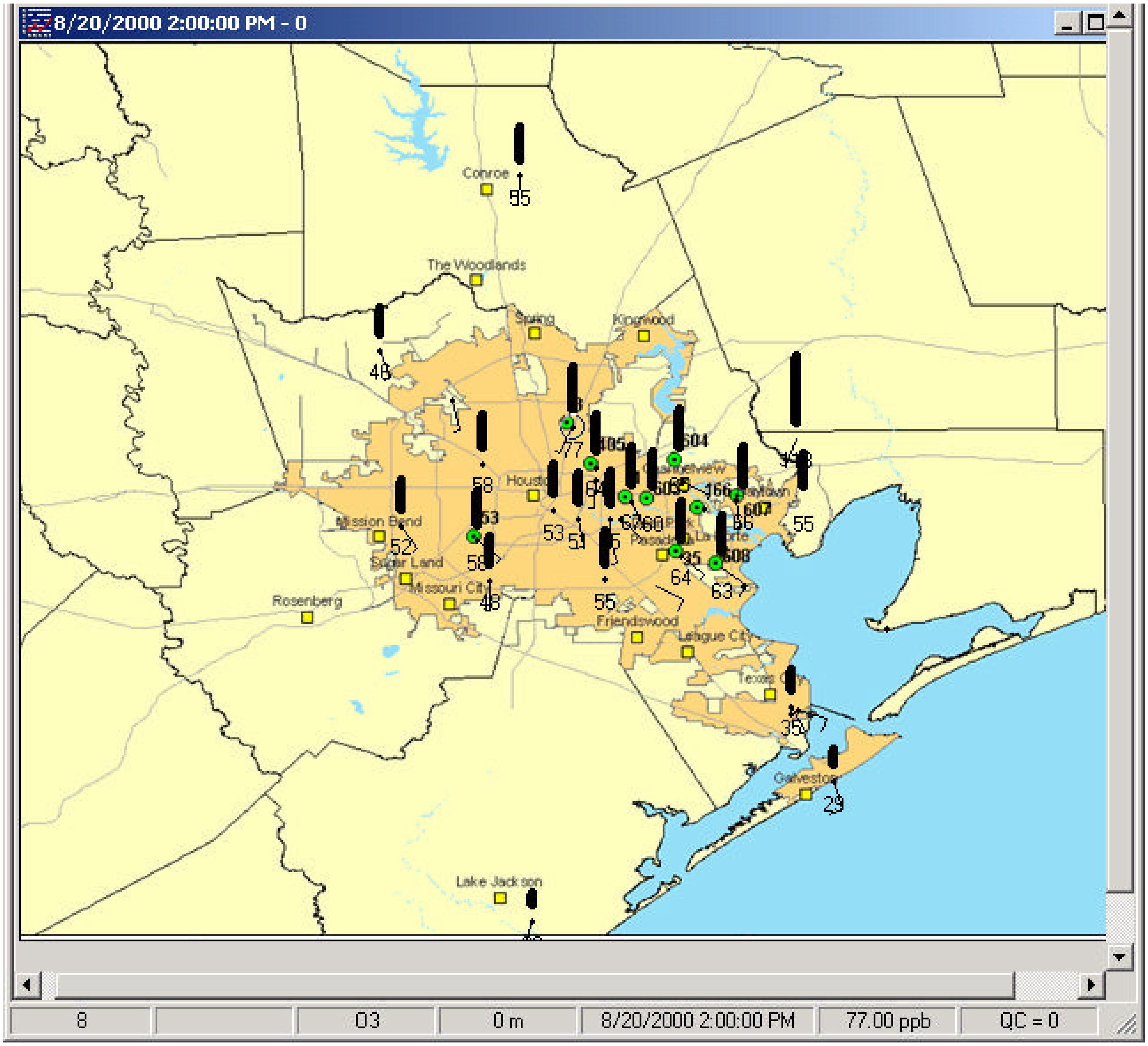


Figure 4-97. Spatial plot of hourly surface winds and ozone concentrations at CAMS sites on August 20, 2000, at 1400 CST.

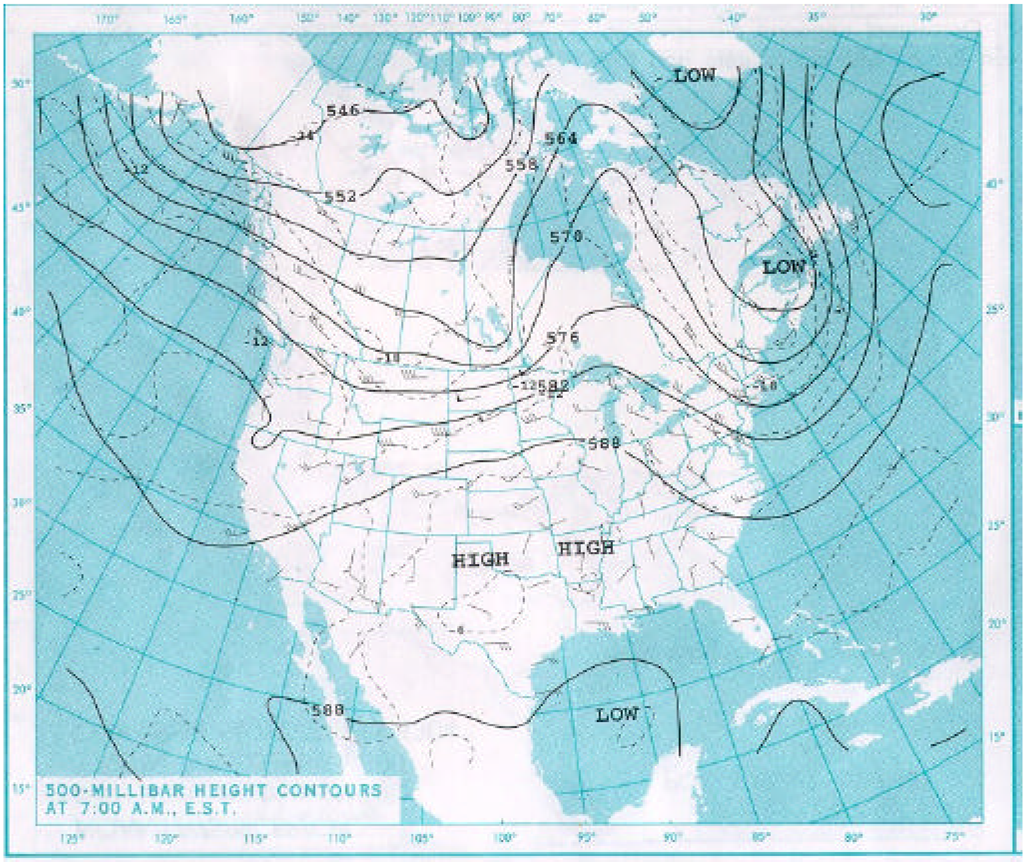


Figure 4-98. Contours of the height of the 500-mb surface pressure for August 21, 2000, at 0600 CST.

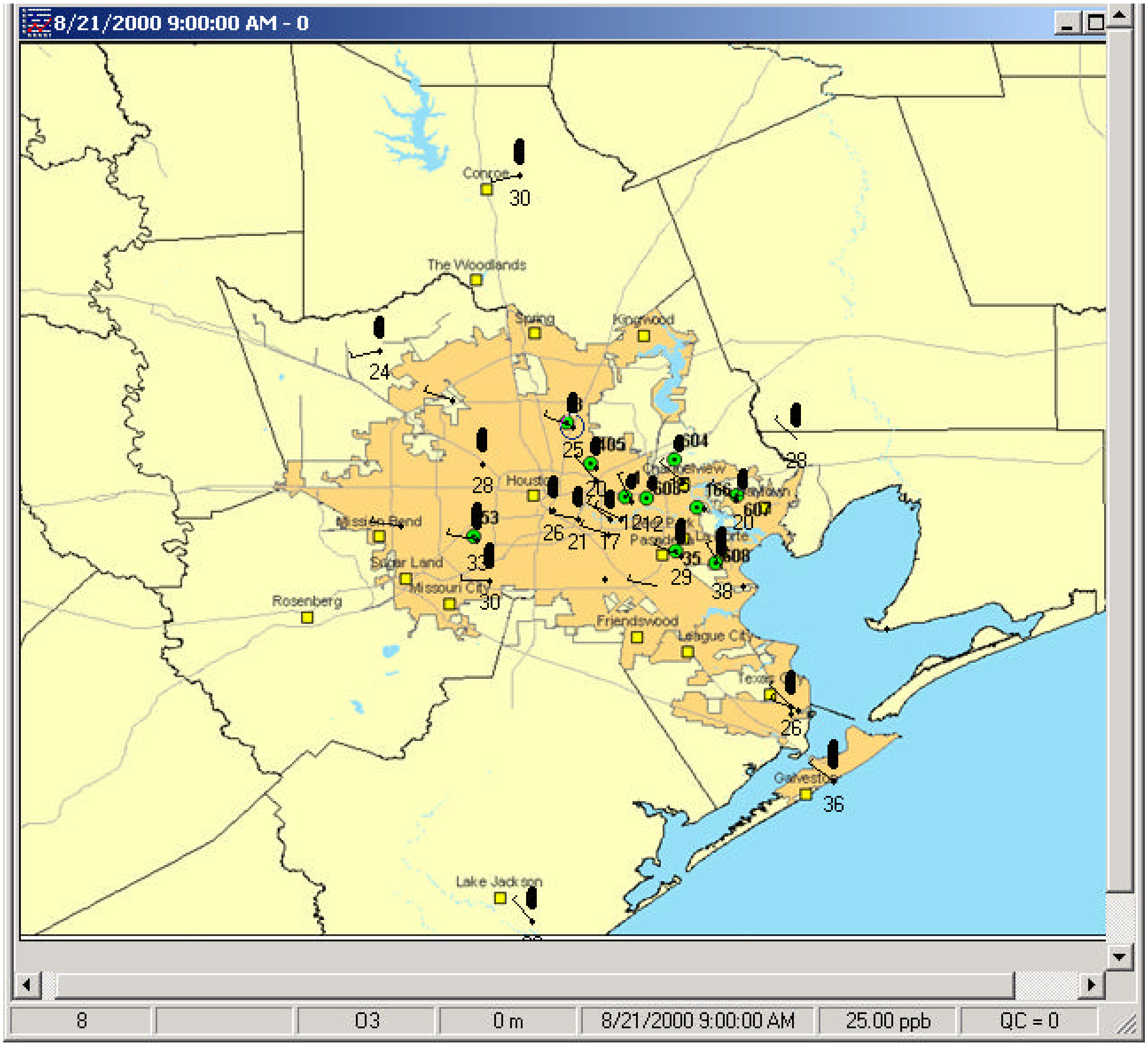


Figure 4-99. Spatial plot of hourly surface winds and ozone concentrations at CAMS sites on August 21, 2000, at 0900 CST.

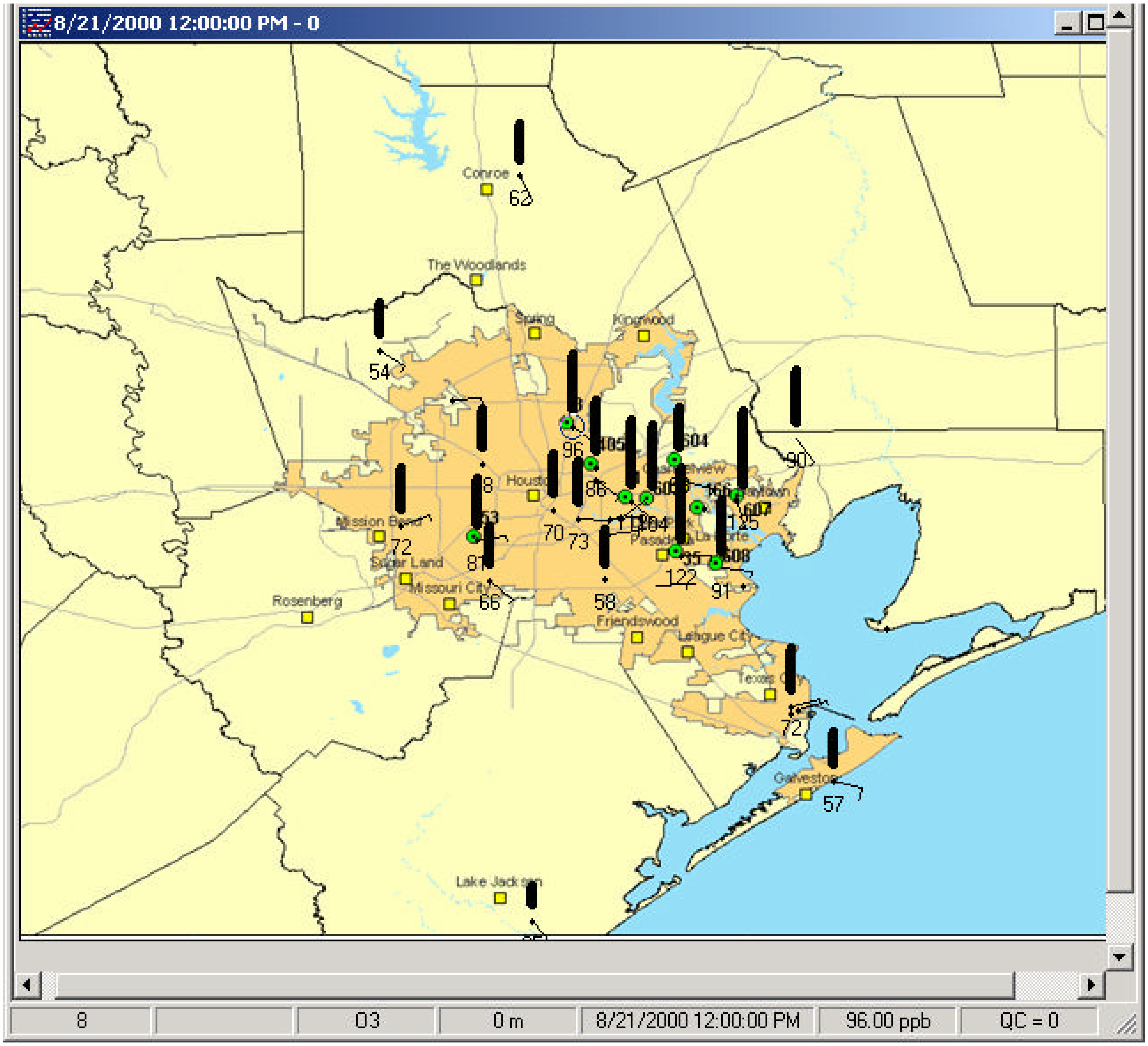


Figure 4-100. Spatial plot of hourly surface winds and ozone concentrations at CAMS sites on August 21, 2000, at 1200 CST.

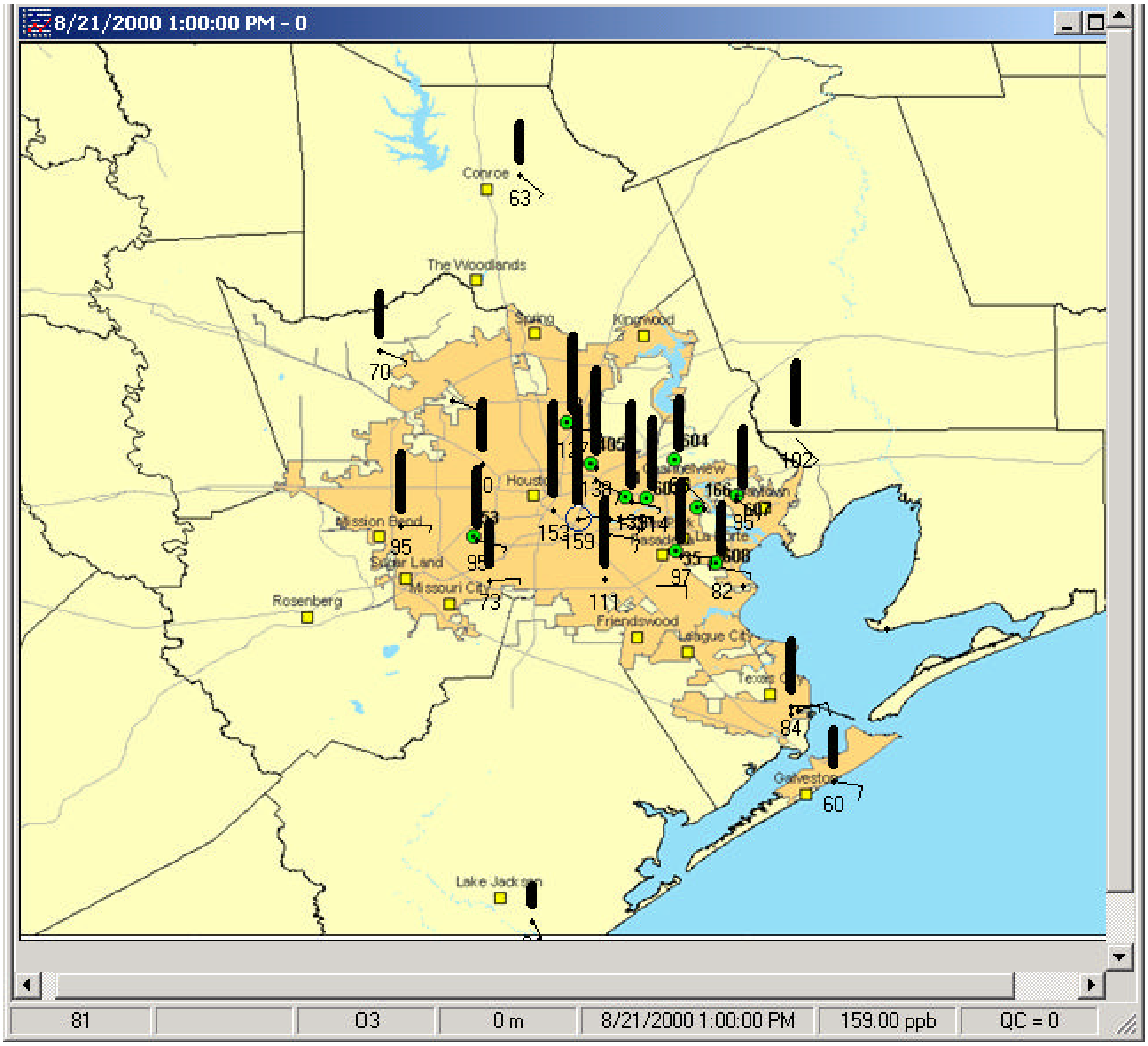


Figure 4-101. Spatial plot of hourly surface winds and ozone concentrations at CAMS sites on August 21, 2000, at 1300 CST.

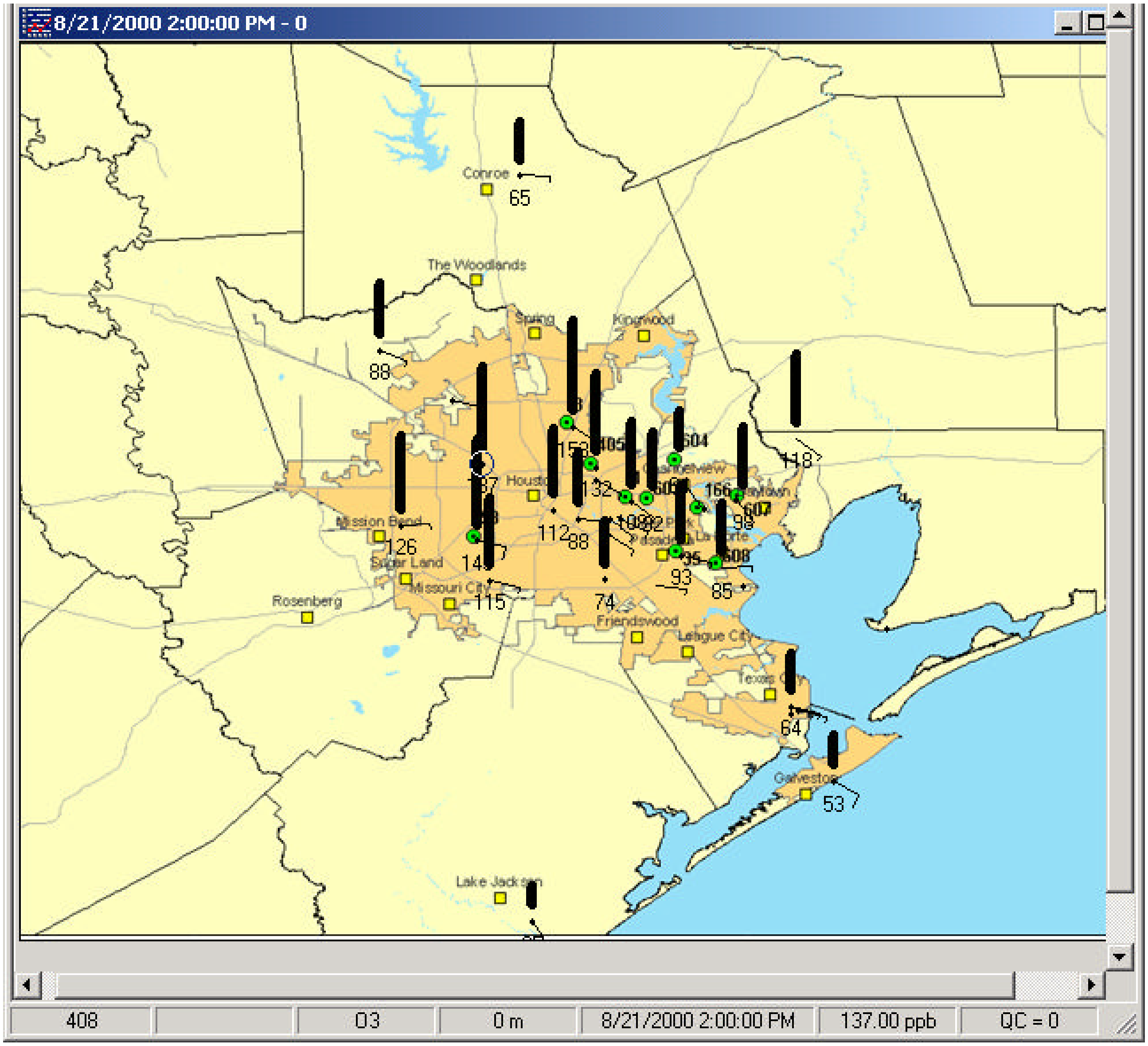


Figure 4-102. Spatial plot of hourly surface winds and ozone concentrations at CAMS sites on August 21, 2000, at 1400 CST.

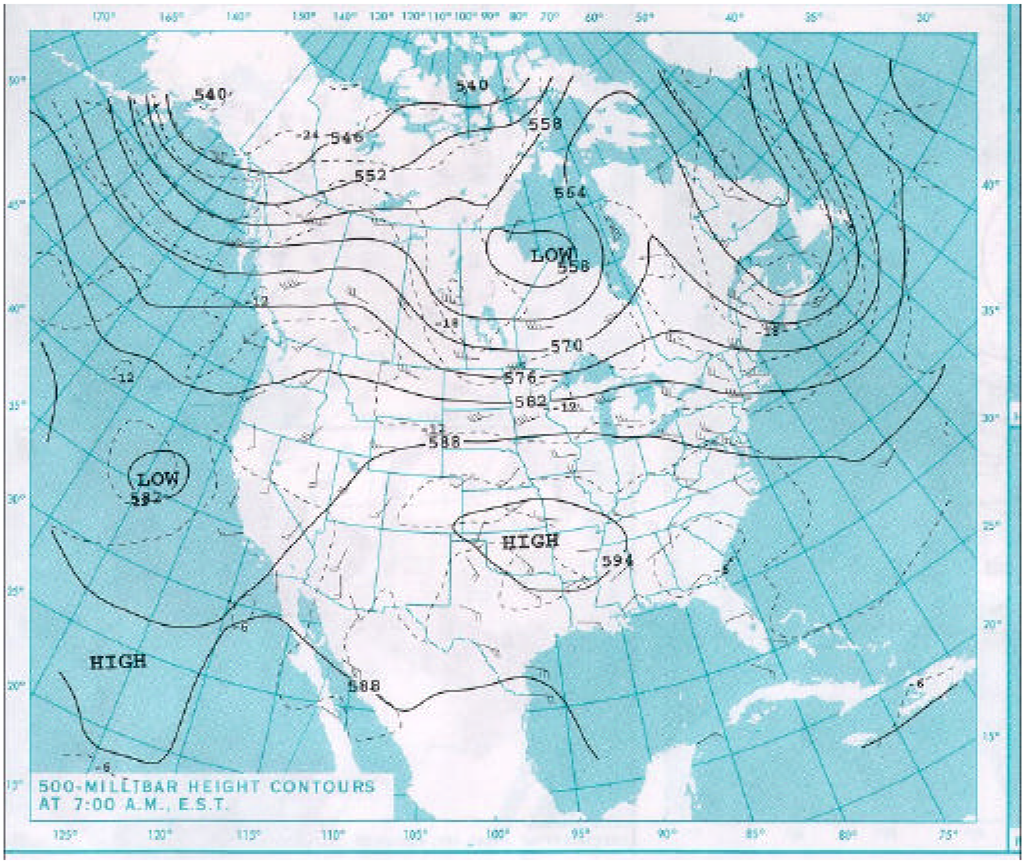


Figure 4-103. Contours of the height of the 500-mb surface pressure for August 22, 2000, at 0600 CST.

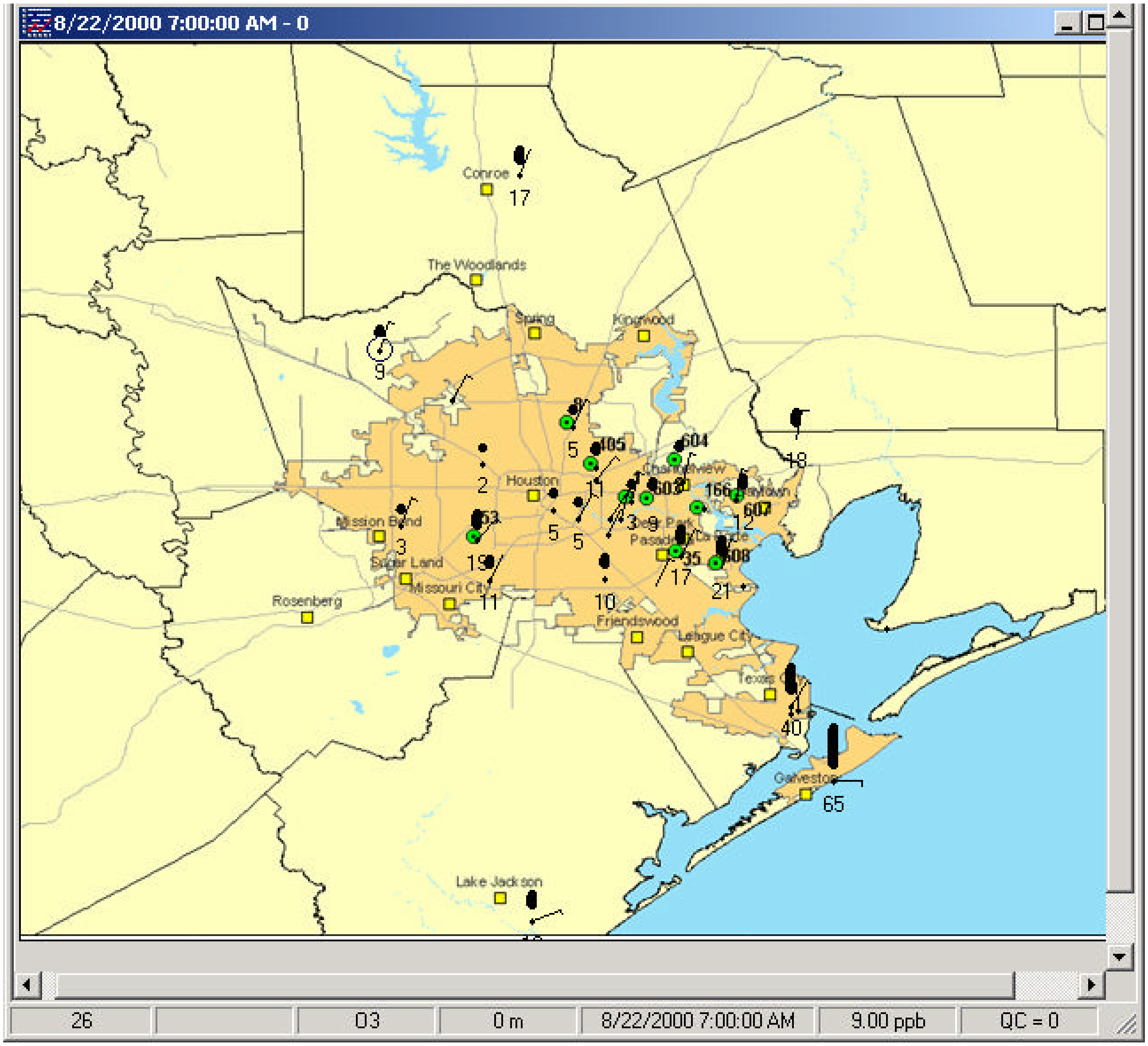


Figure 4-104. Spatial plot of hourly surface winds and ozone concentrations at CAMS sites on August 22, 2000, at 0700 CST.

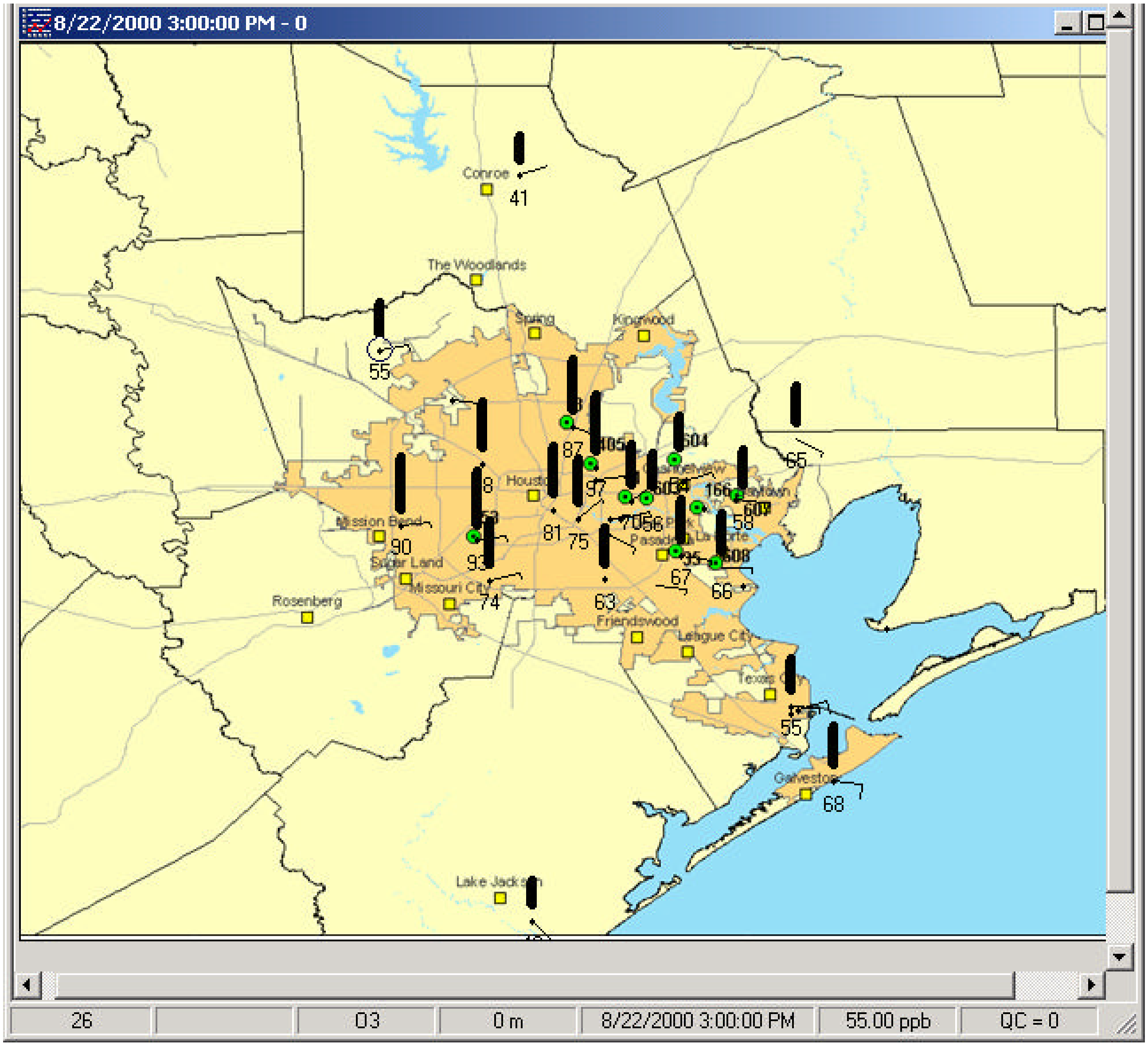


Figure 4-105. Spatial plot of hourly surface winds and ozone concentrations at CAMS sites on August 22, 2000, at 1500 CST.

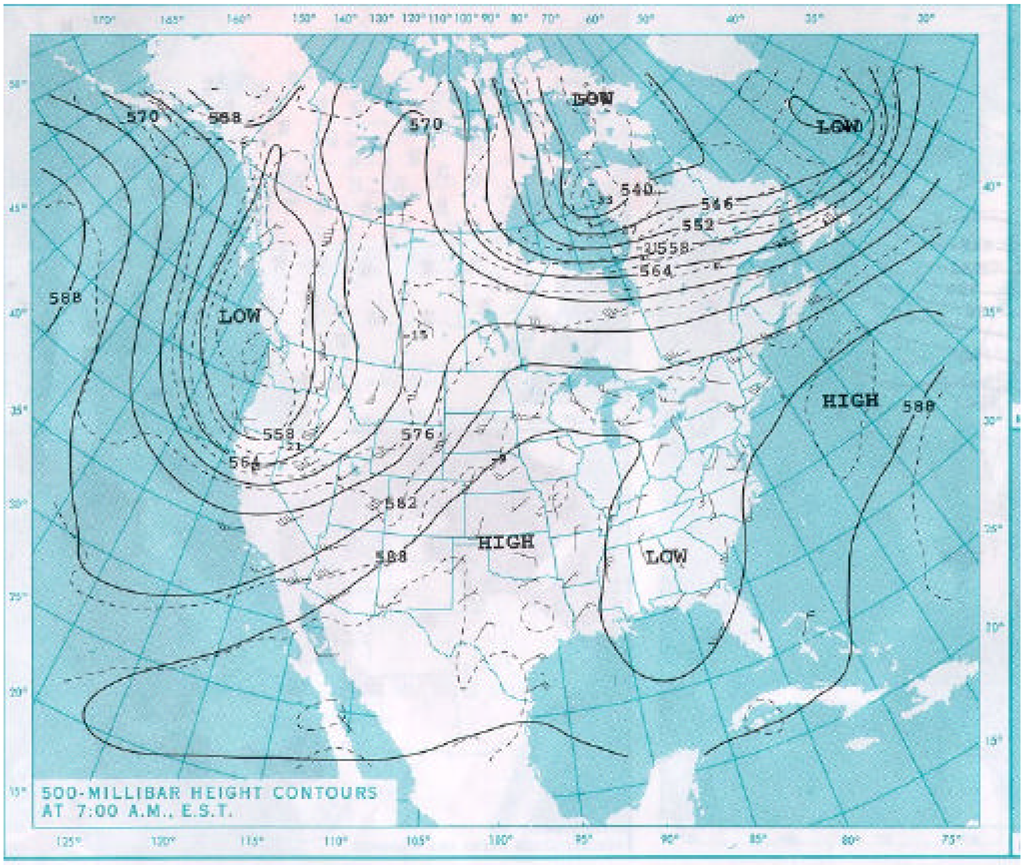


Figure 4-106. Contours of the height of the 500-mb surface pressure for September 2, 2000, at 0600 CST.

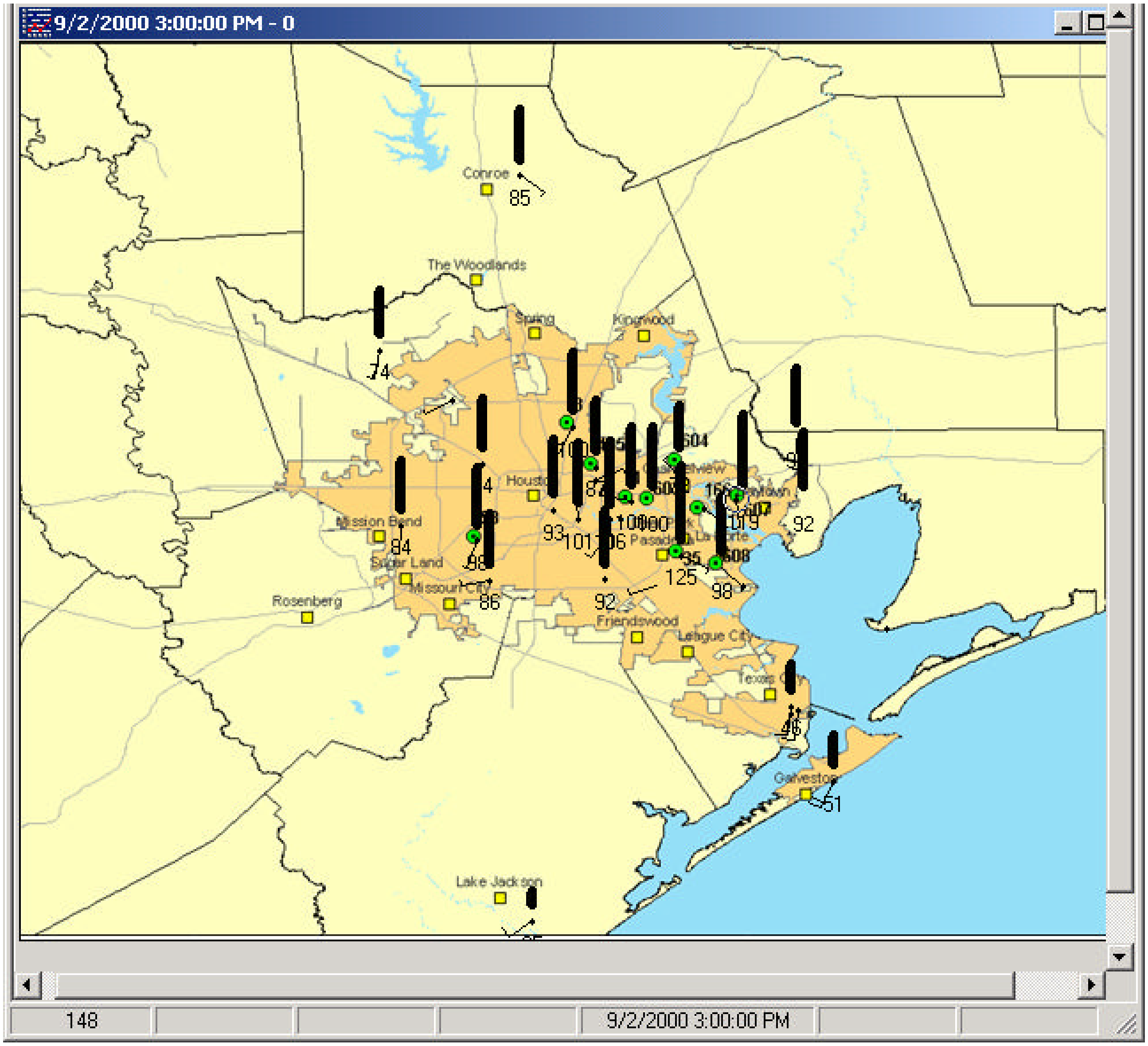


Figure 4-107. Spatial plot of hourly surface winds and ozone concentrations at CAMS sites on September 2, 2000, at 1500 CST.

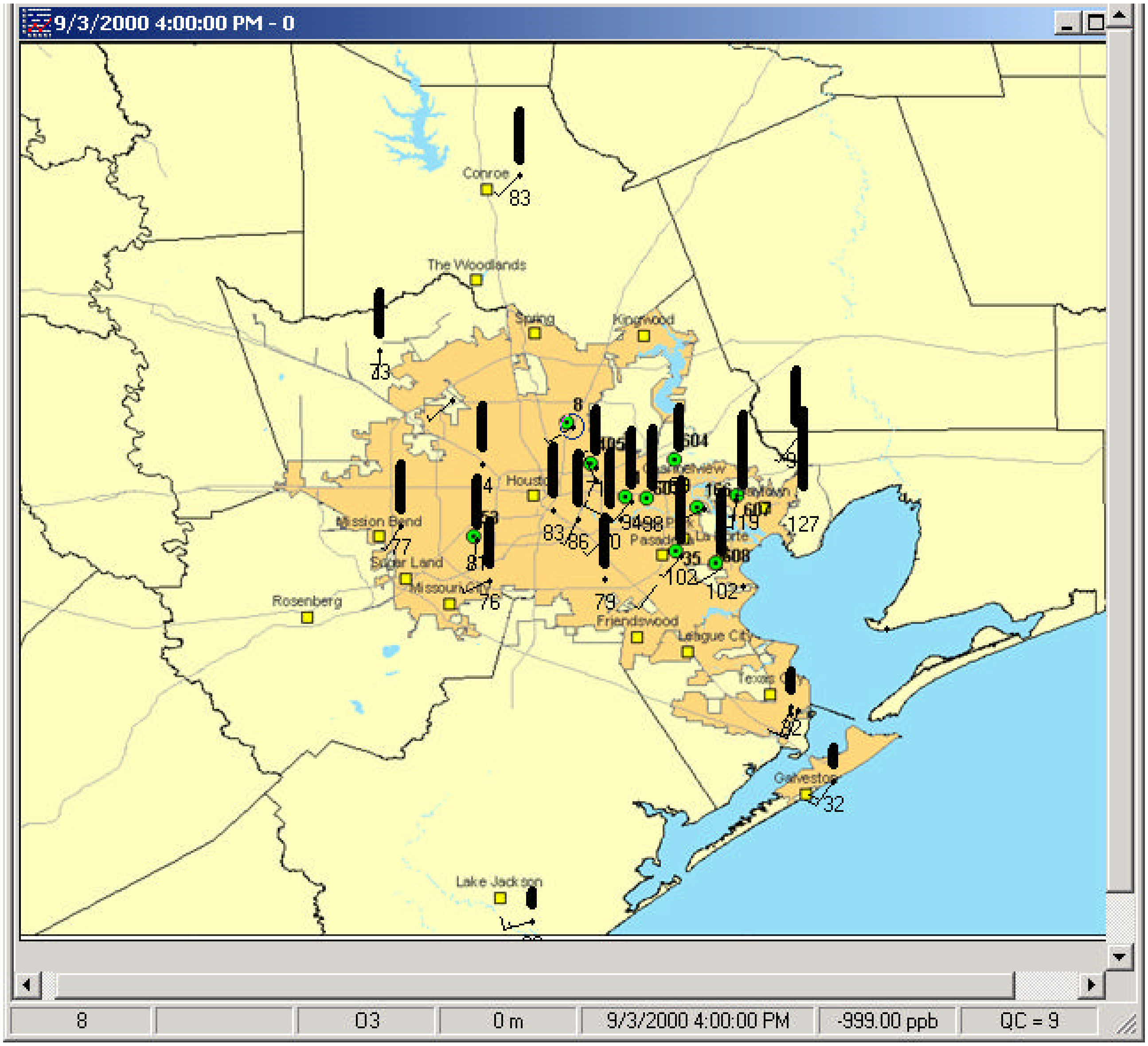


Figure 4-108. Spatial plot of hourly surface winds and ozone concentrations at CAMS sites on September 3, 2000, at 1600 CST.

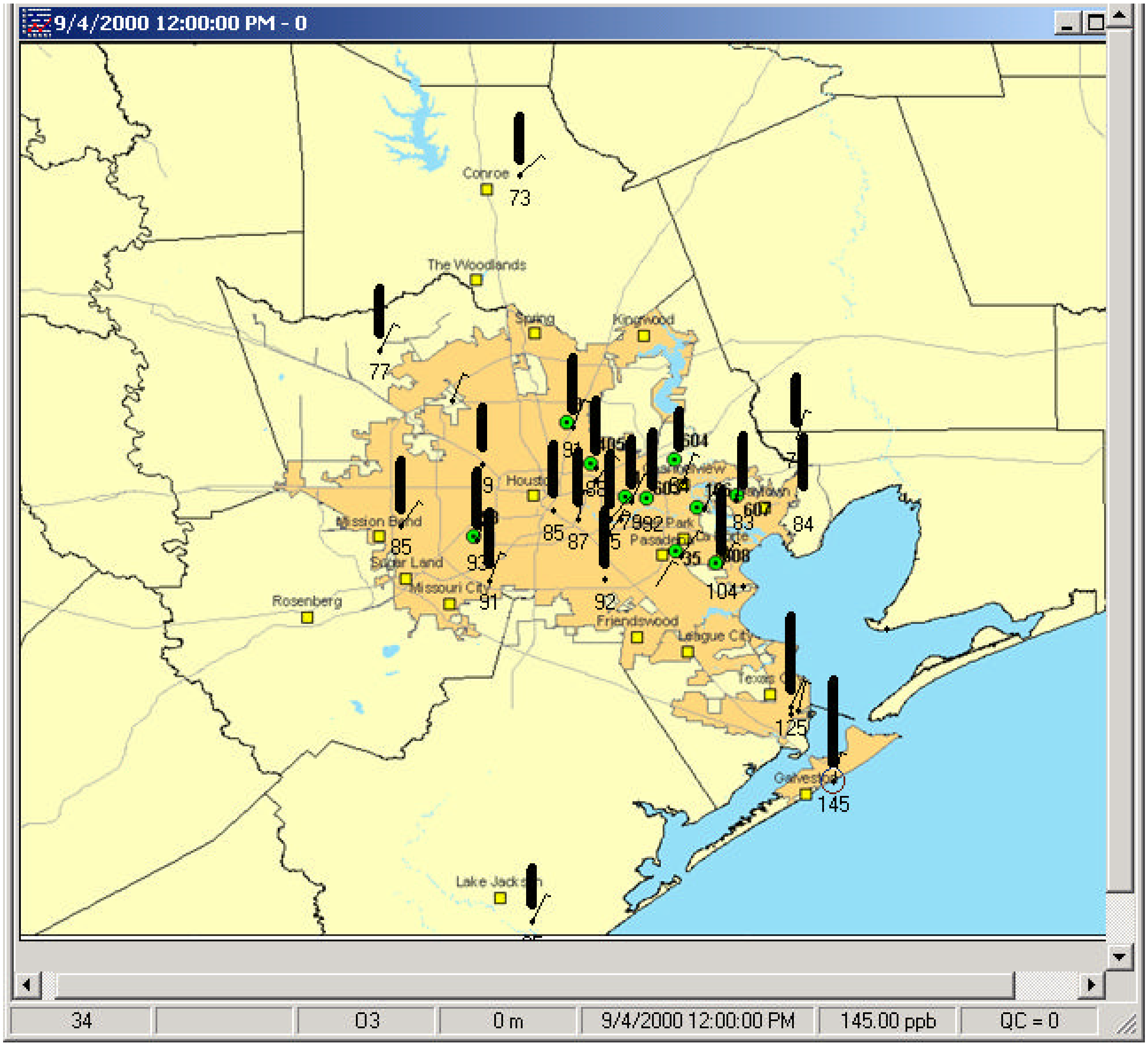


Figure 4-109. Spatial plot of hourly surface winds and ozone concentrations at CAMS sites on September 4, 2000, at 1200 CST.

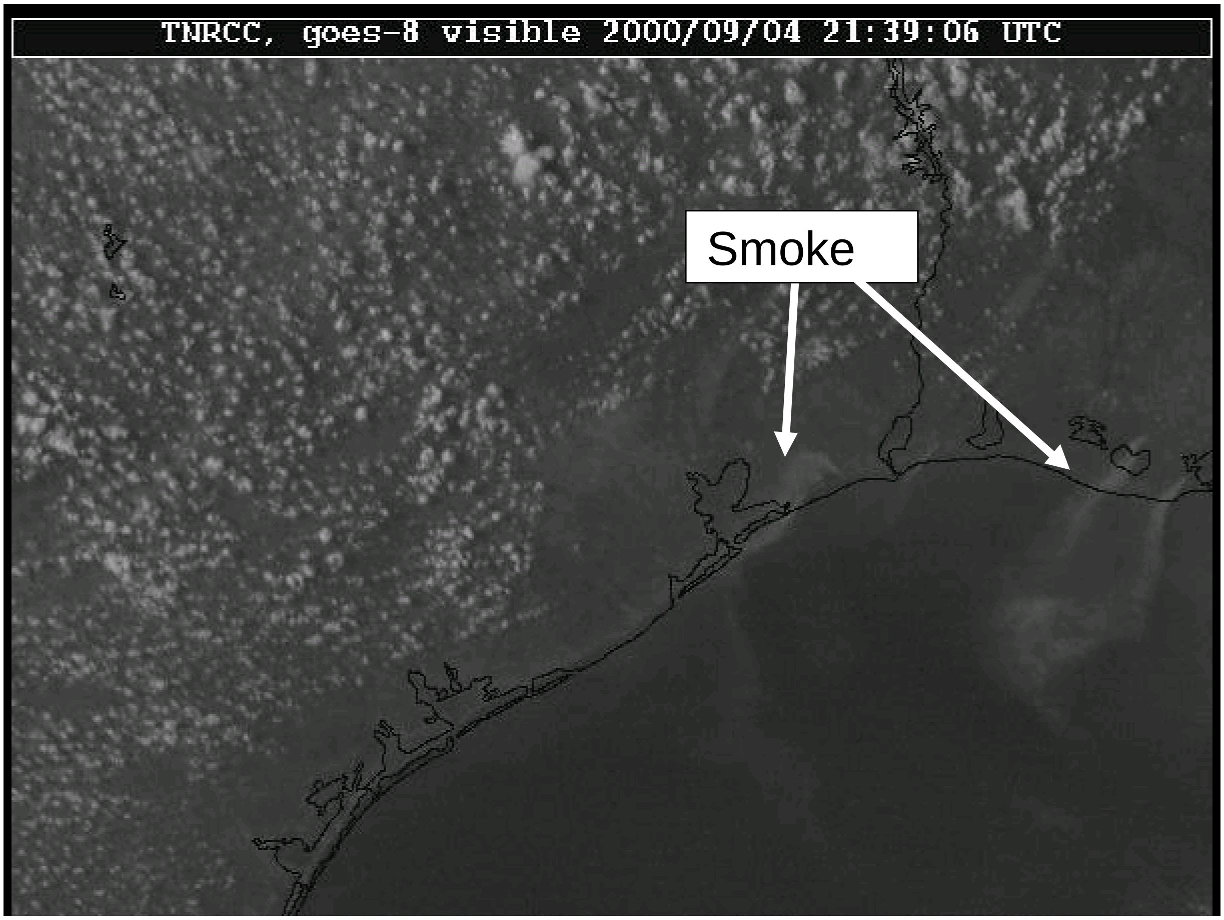


Figure 4-110. Visible satellite image for September 4, 2000, at 1539 CST (2139 UTC).

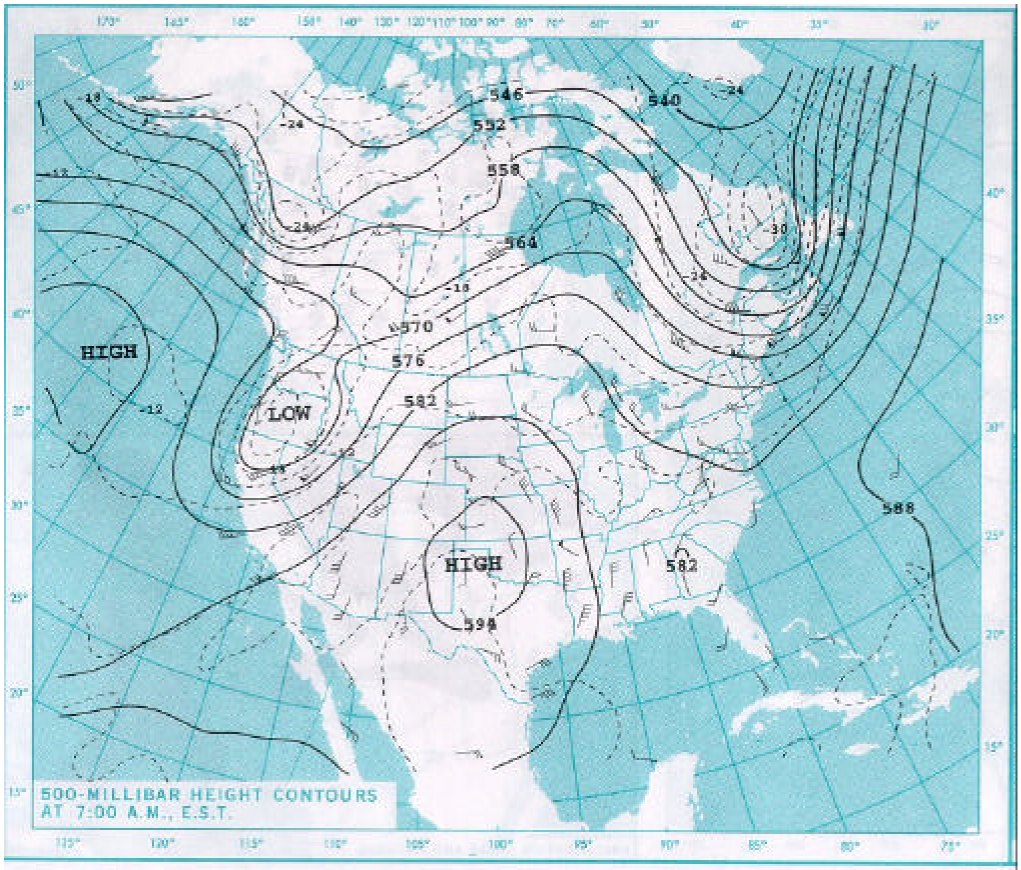


Figure 4-111. Contours of the height of the 500-mb surface pressure for September 5, 2000, at 0600 CST.

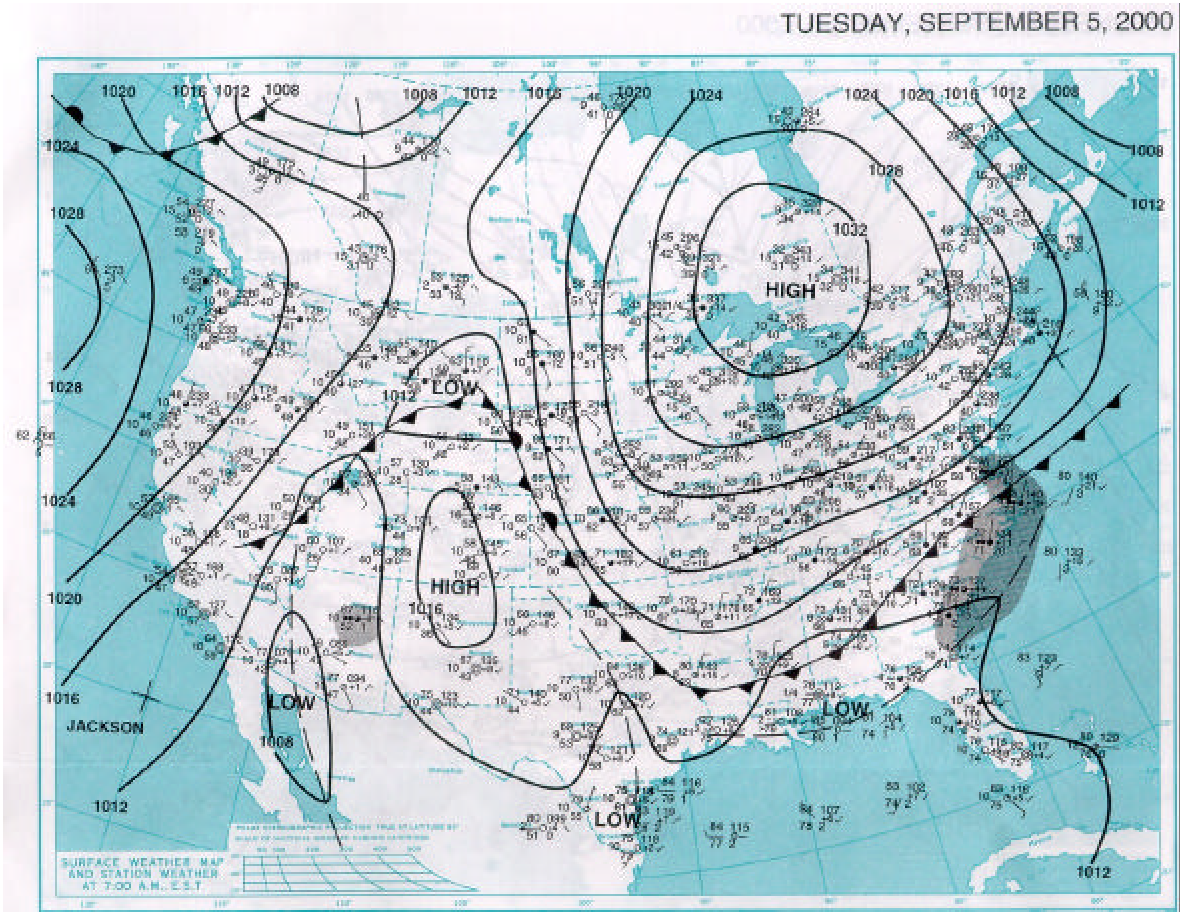


Figure 4-112. Surface analysis chart showing the winds, contours of surface pressure, and other weather conditions on September 5, 2000, at 0600 CST.

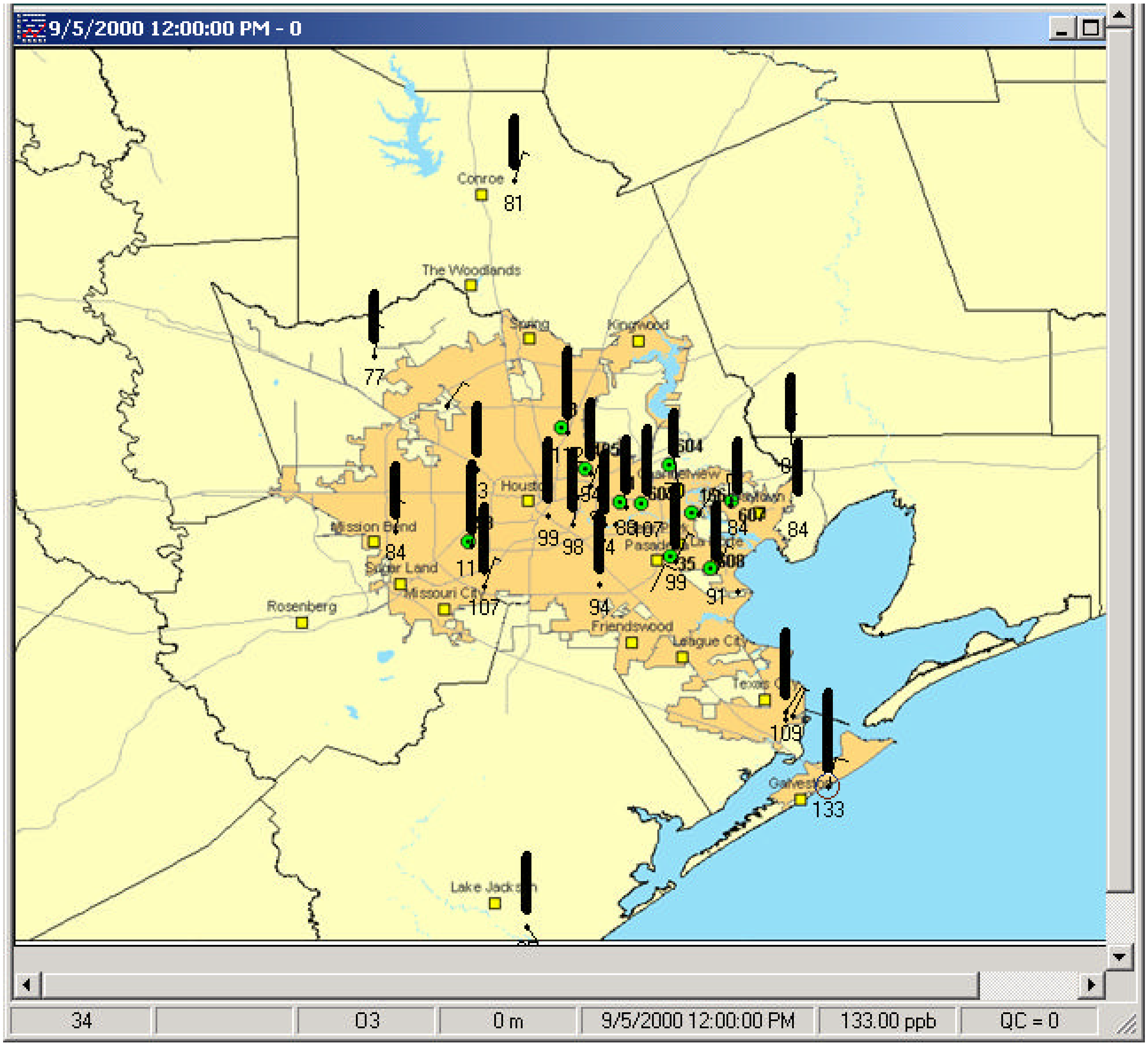


Figure 4-113. Spatial plot of hourly surface winds and ozone concentrations at CAMS sites on September 5, 2000, at 1200 CST.

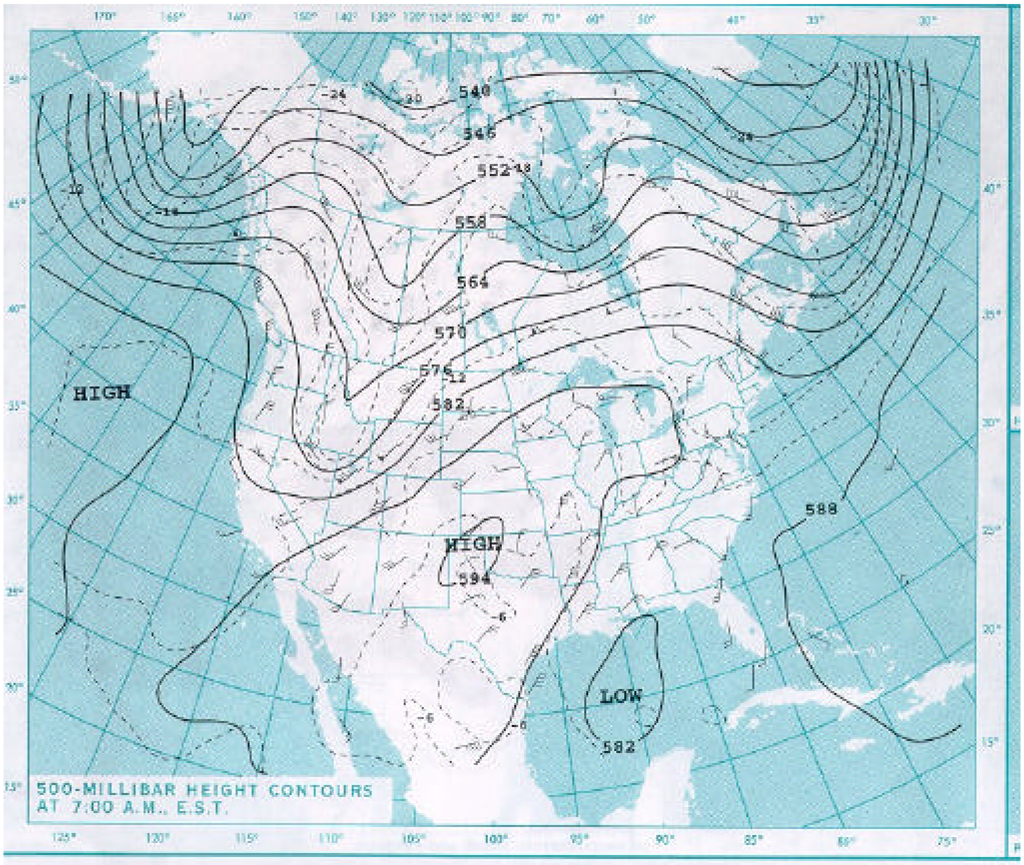


Figure 4-114. Contours of the height of the 500-mb surface pressure for September 6, 2000, at 0600 CST.

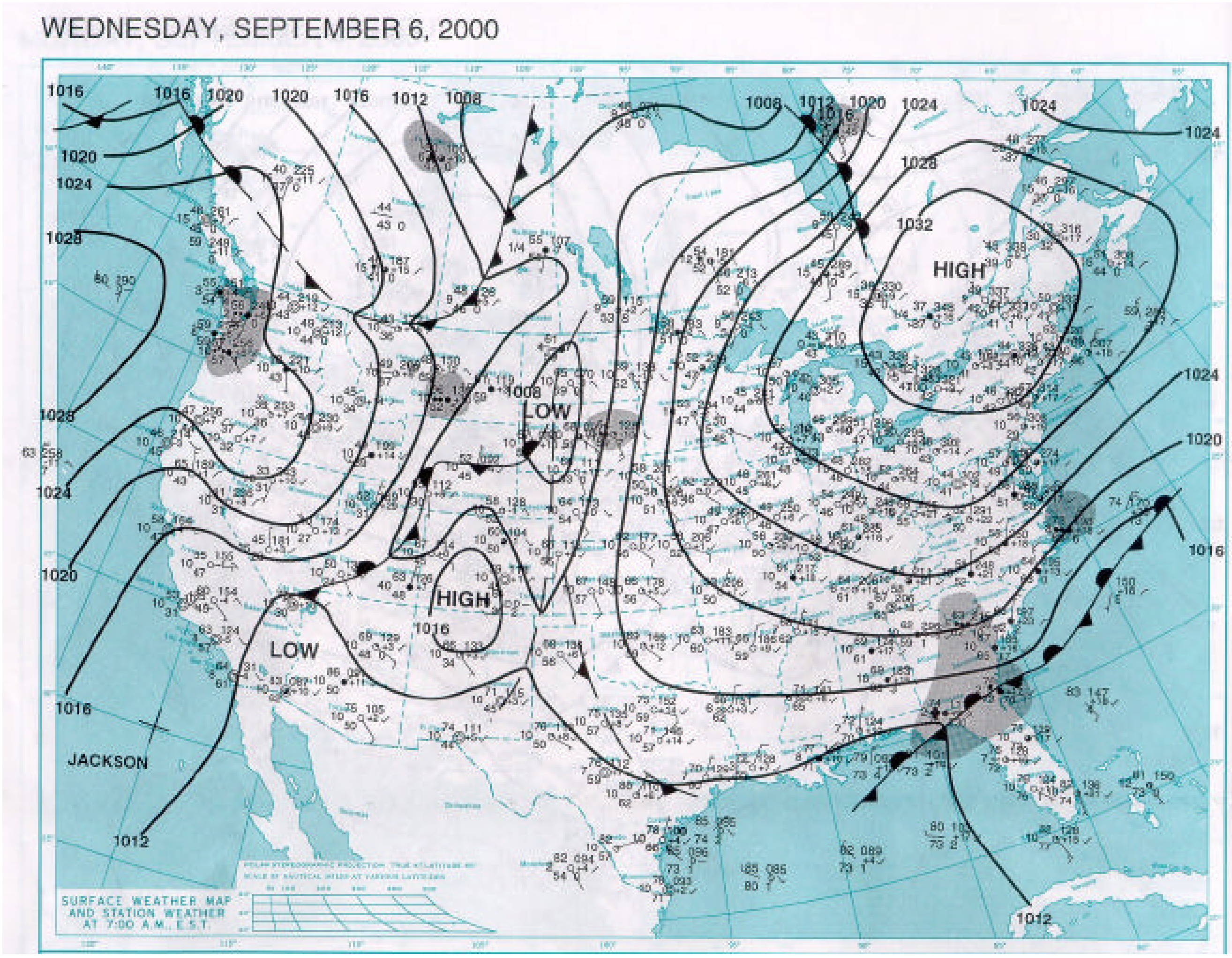


Figure 4-115. Surface analysis chart showing the winds, contours of surface pressure, and other weather conditions on September 6, 2000, at 0600 CST.

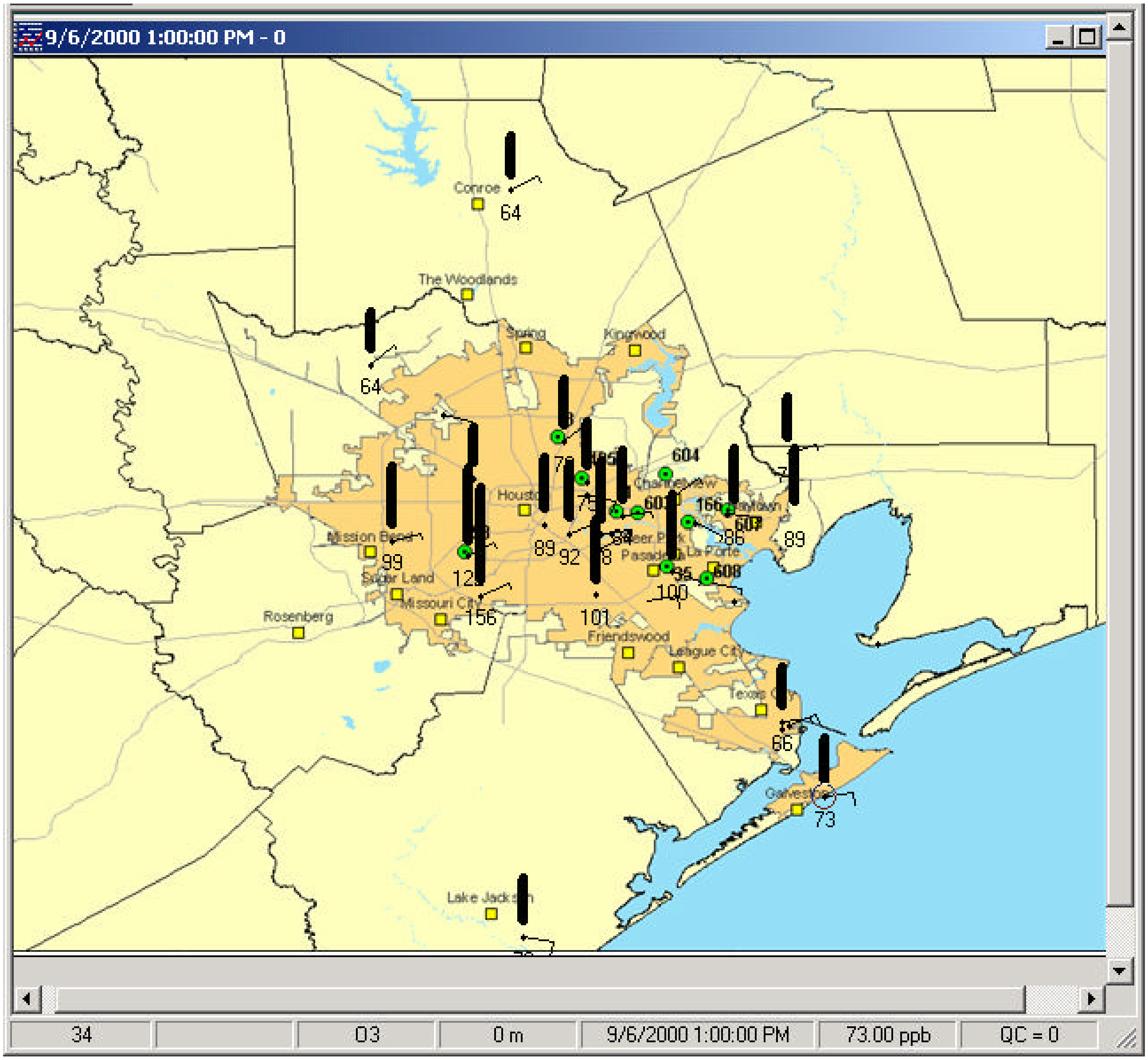


Figure 4-116. Spatial plot of hourly surface winds and ozone concentrations at CAMS sites on September 6, 2000, at 1300 CST.

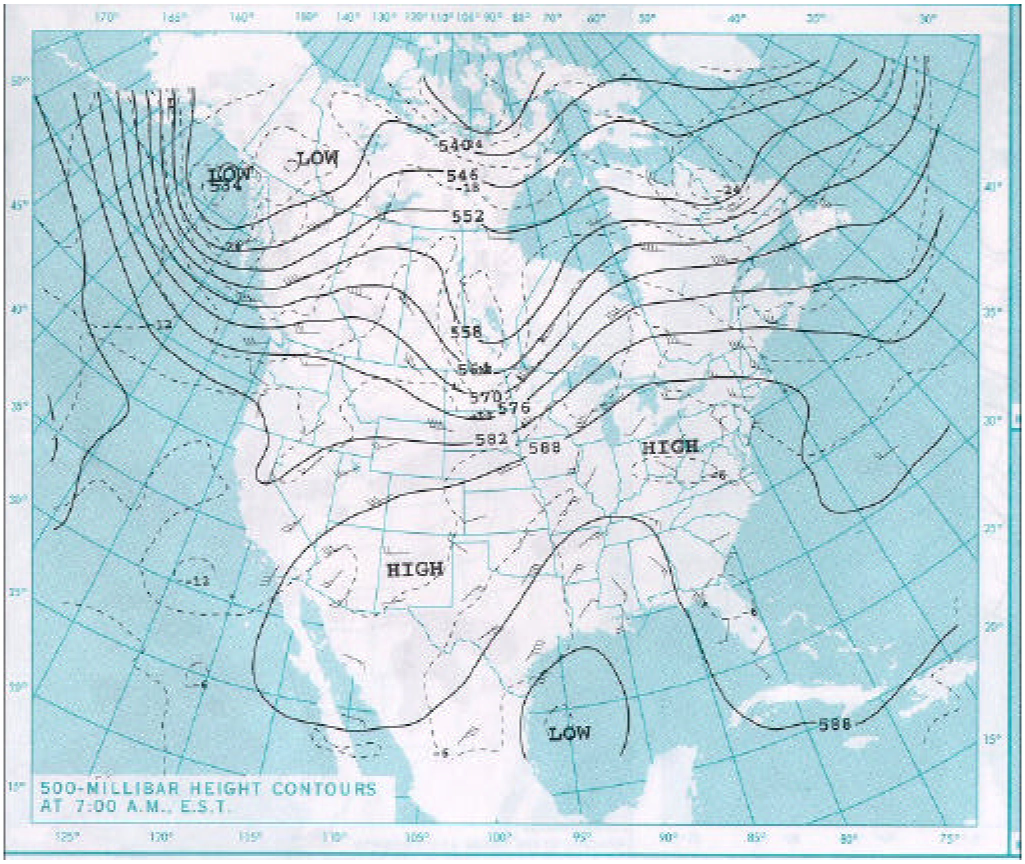


Figure 4-117. Contours of the height of the 500-mb surface pressure for September 7, 2000, at 0600 CST.

APPENDIX A

BAR PLOTS OF AIR QUALITY AND METEOROLOGICAL METRICS

This appendix contains daily bar plots of parameters that represent the important meteorological and chemical phenomena that influence the magnitude, duration, and distribution of high ozone concentrations from August 15 through September 15, 2000. Thus, these plots provide a "fingerprint" of the meteorological and chemical conditions on each day. The fingerprint plots were used to assist in the analysis of the daily meteorological and ozone characteristics that is presented in Section 3 and are included in this appendix to provide additional information. The fingerprint plots provide a quick visual way to compare the daily variation of parameters and the resulting influence on ozone. In these plots larger meteorological and precursor metrics are theoretically more conducive to high ozone concentrations.

METRICS

Meteorological metrics depicted on the fingerprint plots include

Maximum Temperature Metric – Daytime maximum temperature (degrees F) at Houston International Airport (IAH) divided by 100.

Inversion Strength Metric – Maximum temperature minus the minimum temperature (degrees F) at IAH divided by 10.

Solar Radiation Metric – Average 0900 to 1500 CST (15 to 21 Z) solar radiation (w/m^2) at IAH divided 1000.

Morning Mixing Metric – Mixing height (m) at 1000 CST at Ellington Field as estimated from the radar profiler reflectivity data (Cn^2) divided by 1000.

Daytime Vertical Mixing Metric – Maximum mixing height (m) at or before 1400 CST at Ellington Field as estimated from the radar profiler reflectivity data (Cn^2) divided by 1000.

North/South Pressure Gradient Metric – Pressure (mb) difference between offshore buoy 42019 and Waco at 0700 CST times 200. Positive gradient indicates a southerly component to the wind.

East/West Pressure Gradient Metric – Pressure (mb) difference between Corpus Christi and Lake Charles times 200. Positive gradient indicates a westerly component to the wind.

Scalar Wind Metric – Scalar average 0900 to 1500 CST (15 to 21 Z) wind speed (knots) at IAH divided by -10.

Vector Wind Metric – Vector average 0900 to 1500 CST (15 to 21 Z) wind speed (knots) at IAH divided by -10.

Wind Direction Metric – Vector average 0900 to 1500 CST (15 to 21 Z) wind direction at IAH divided by 100.

Recirculation Metric – One minus the vector average wind speed (0900 to 1500 CST) divided by the scalar average wind speed (0900 to 1500 CST) at IAH. A recirculation metric near 1 indicates recirculation and a recirculation metric near zero indicates flowthrough. A small scalar wind speed (<1 m/sec) indicates stagnation and the recirculation metric should be ignored.

Upper-Level Synoptic Pattern Metric – Three categories were used to capture subtle differences in the 500-mb height pattern:

1. Broad high with no well-defined ridge over Houston (metric equals 1).
2. An aloft high pressure ridge in a position where the atmospheric dynamics associated with the ridge would cause local weather conditions favorable for ozone formation (metric equals 2).
3. Aloft anti-cyclonic flow over the Houston area (metric equals 3).

Precursor metrics depicted on the fingerprint plots include

- Median morning (0500 to 0900 CST) propylene concentration (ppbC) at Clinton divided by 10.
- Median morning (0500 to 0900 CST) total nonmethane organic carbon concentration (ppbC) at Clinton divided by 100.
- Median morning (0500 to 0900 CST) propylene (ppbC) divided by NO_x (ppb) concentration at Clinton times 10.

Ozone metrics depicted on the finger print plots include

- Maximum 1-hr ozone concentration (ppb) in the Houston-Galveston area divided by 100.
- Maximum 8-hr ozone concentration (ppb) in the Houston-Galveston area divided by 100.
- Number of sites with 1-hr ozone concentration greater than 125 ppb divided by 10.
- Number of sites with 1-hr ozone concentration greater than 150 ppb divided by 10.
- Number of sites with 1-hr ozone concentration greater than 175 ppb divided by 10.
- Number of site hours with 1-hr ozone concentration greater than 125 ppb divided by 10.
- Maximum ozone spikes (ozone concentration [ppb] increase per hour) divided by 100.

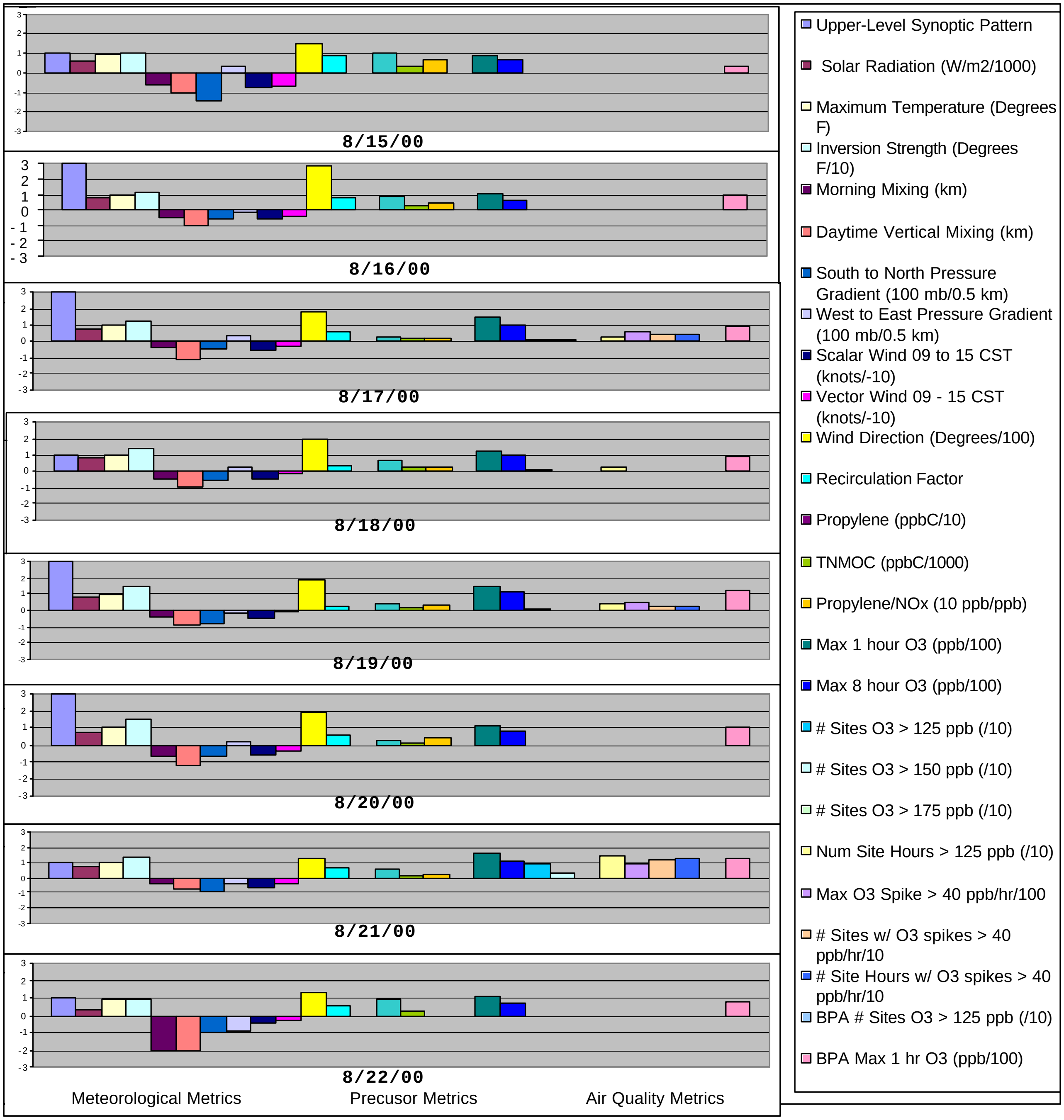
- Number of sites with hourly ozone concentration increase greater than 40 ppb divided by 10.
- Number of sites in the Beaumont/Port Arthur area with 1-hr ozone concentration greater than 125 ppb divided by 10.
- Maximum 1-hr ozone concentration in the Beaumont/Port Arthur area divided by 100.

OBSERVATIONS

The following observations were made after a review of the fingerprint plots:

- High ozone conditions, as indicated by a variety of metrics, occurred on August 21, 25, 29-31, and September 1, 5, and 9 in the Houston/Galveston area, and August 30-31 and September 1 in the Beaumont/Port Arthur area. The meteorological metrics show that these days have common meteorological characteristics including high solar radiation, high temperature, large maximum minus minimum temperature, limited afternoon mixing (morning mixing does not appear to be important factor), modest pressure gradients, and rotation/recirculation.
- On August 31, the upper air meteorological pattern was the most favorable for producing high ozone. Additionally, low mixing heights, abundant sunshine, light winds, a strong inversion, and hot surface temperatures combined to produce the second highest number of site hours experiencing ozone over 125 ppb.
- The largest ozone spike occurred on August 25 at 91 ppb in one hour. This day was characterized by the least favorable of upper air patterns; however, mixing heights remained low and winds light. Eleven sites recorded ozone spikes greater than 40 ppb/hr.
- On August 23, and September 11 and 13, the lack of solar radiation and strong mixing appear to kept ozone concentrations low whereas, on August 26 and 28, and September 3, 6-8, and 12, no rotation/recirculation appears to have kept ozone concentrations low.
- Nineteen of the 32 days had high values (greater than 4 ppbC) for propylene. Of these 19 days, 7 days had readings above 10 ppbC. These 7 days are August 15, 23-25, and September 5, 11, and 13. September 11 and 13 were the only 2 of these 7 days when ozone was not high.
- Total nonmethane organic carbon was high on 11 days during the period from August 15 to September 15.
- The highest propylene to NO_x ratios occurred during the last week of this period from September 7 through 14.
- Three days had ozone concentrations greater than 175 ppb with an ozone spike greater than 40 ppb: August 25 and 30 and September 5.
- Three days had ozone concentrations between 175 ppb and 150 ppb and an ozone spike greater than 40 ppb: August 17, 21, and 31.
- Four days had ozone concentrations between 150 ppb and 125 ppb and an ozone spike greater than 40 ppb: August 19, 26, 29, and September 4.

- Three days had ozone concentrations less than 125 ppb with an ozone spike greater than 40 ppb: August 23, 24, and September 9.
- Five days had peak 8-hr ozone concentrations greater than 85 ppb: August 18 and September 1-3, and 6.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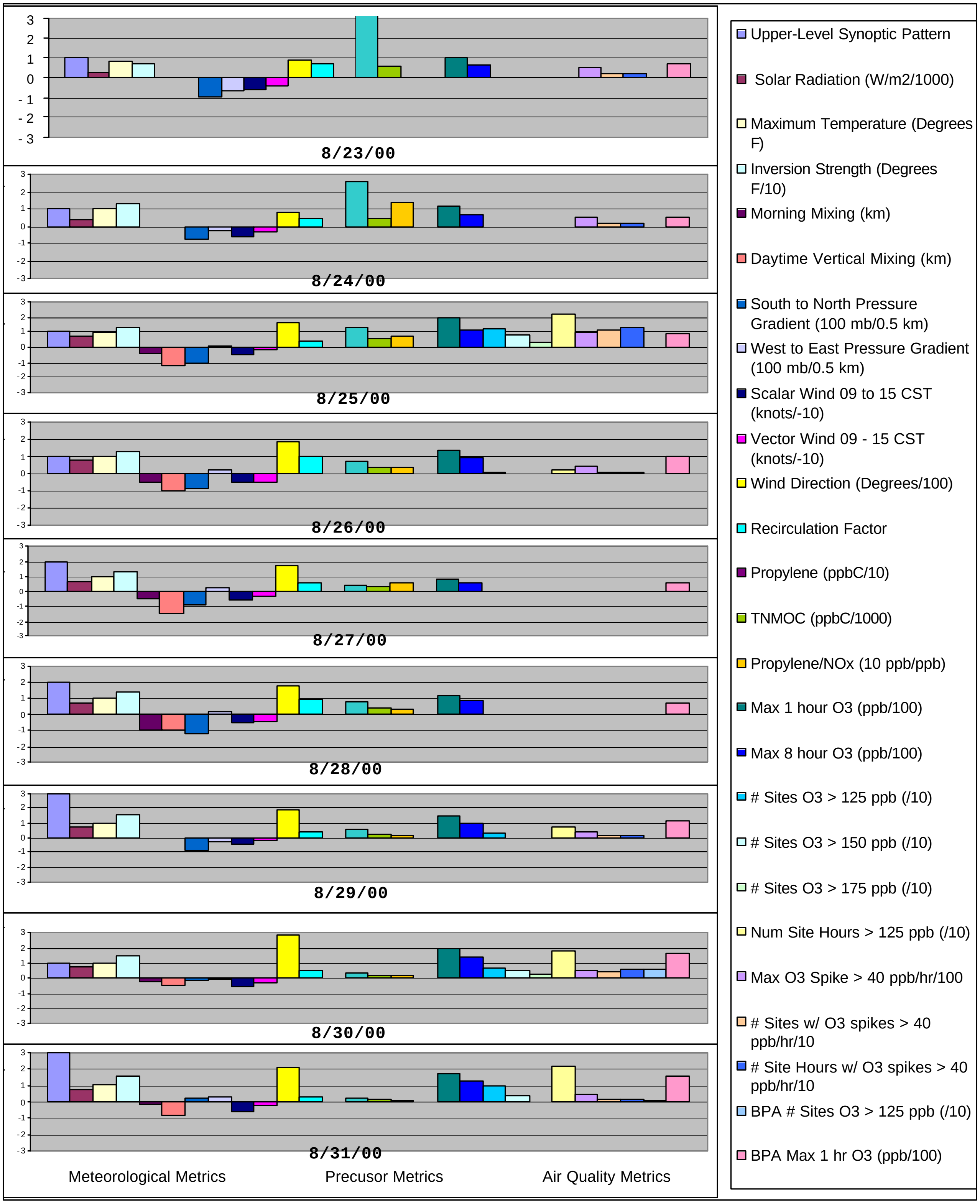
Meteorological Metrics
Precusor Metrics
Air Quality Metrics
Upper-Level Synoptic Pattern
Solar Radiation (W/m2/1000)
Maximum Temperature (Degrees F)
Inversion Strength (Degrees F/10)
Morning Mixing (km)
Daytime Vertical Mixing (km)
South to North Pressure Gradient (100 mb/0.5 km)
West to East Pressure Gradient (100 mb/0.5 km)
Scalar Wind 09 to 15 CST (knots/-10)
Vector Wind 09 - 15 CST (knots/-10)
Wind Direction (Degrees/100)
Recirculation Factor
Propylene (ppbC/10)
TNMOC (ppbC/1000)
Propylene/NOx (10 ppb/ppb)
Max 1 hour O3 (ppb/100)
Max 8 hour O3 (ppb/100)
Sites O3 > 125 ppb (/10)
Sites O3 > 150 ppb (/10)
Sites O3 > 175 ppb (/10)
Num Site Hours > 125 ppb (/10)
Max O3 Spike > 40 ppb/hr/100
Sites w/ O3 spikes > 40 ppb/hr/10
Site Hours w/ O3 spikes > 40 ppb/hr/10
BPA # Sites O3 > 125 ppb (/10)
BPA Max 1 hr O3 (ppb/100)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Meteorological Metrics
Precusor Metrics
Air Quality Metrics
Upper-Level Synoptic Pattern
Solar Radiation (W/m2/1000)
Maximum Temperature (Degrees F)
Inversion Strength (Degrees F/10)
Morning Mixing (km)
Daytime Vertical Mixing (km)
South to North Pressure Gradient (100 mb/0.5 km)
West to East Pressure Gradient (100 mb/0.5 km)
Scalar Wind 09 to 15 CST (knots/-10)
Vector Wind 09 - 15 CST (knots/-10)
Wind Direction (Degrees/100)
Recirculation Factor
Propylene (ppbC/10)
TNMOC (ppbC/1000)
Propylene/NOx (10 ppb/ppb)
Max 1 hour O3 (ppb/100)
Max 8 hour O3 (ppb/100)
Sites O3 > 125 ppb (/10)
Sites O3 > 150 ppb (/10)
Sites O3 > 175 ppb (/10)
Num Site Hours > 125 ppb (/10)
Max O3 Spike > 40 ppb/hr/100
Sites w/ O3 spikes > 40 ppb/hr/10
Site Hours w/ O3 spikes > 40 ppb/hr/10
BPA # Sites O3 > 125 ppb (/10)
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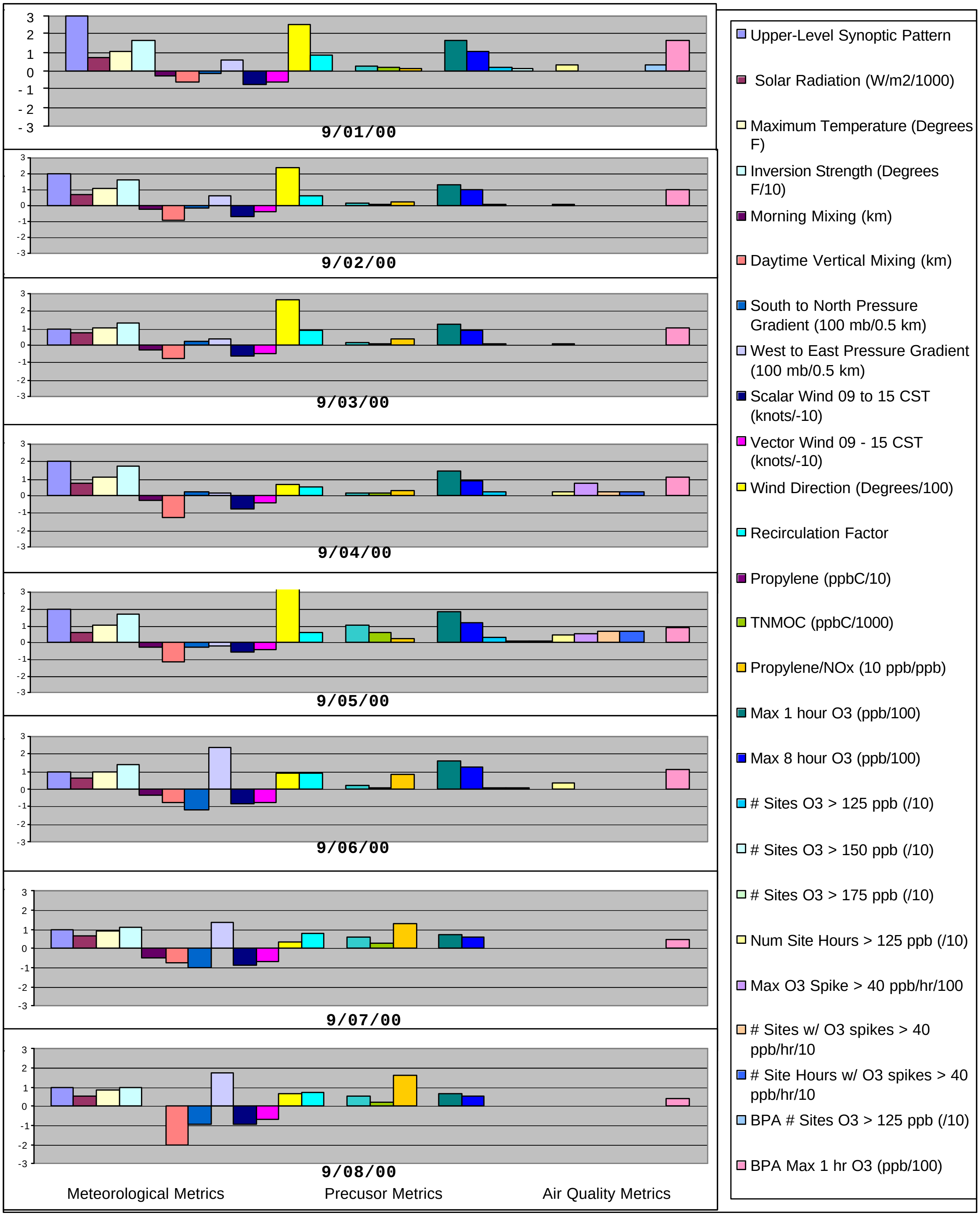

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Meteorological Metrics
Precusor Metrics
Air Quality Metrics
Upper-Level Synoptic Pattern
Solar Radiation (W/m2/1000)
Maximum Temperature (Degrees F)
Inversion Strength (Degrees F/10)
Morning Mixing (km)
Daytime Vertical Mixing (km)
South to North Pressure Gradient (100 mb/0.5 km)
West to East Pressure Gradient (100 mb/0.5 km)
Scalar Wind 09 to 15 CST (knots/-10)
Vector Wind 09 - 15 CST (knots/-10)
Wind Direction (Degrees/100)
Recirculation Factor
Propylene (ppbC/10)
TNMOC (ppbC/1000)
Propylene/NOx (10 ppb/ppb)
Max 1 hour O3 (ppb/100)
Max 8 hour O3 (ppb/100)
Sites O3 > 125 ppb (/10)
Sites O3 > 150 ppb (/10)
Sites O3 > 175 ppb (/10)
Num Site Hours > 125 ppb (/10)
Max O3 Spike > 40 ppb/hr/100
Sites w/ O3 spikes > 40 ppb/hr/10
Site Hours w/ O3 spikes > 40 ppb/hr/10
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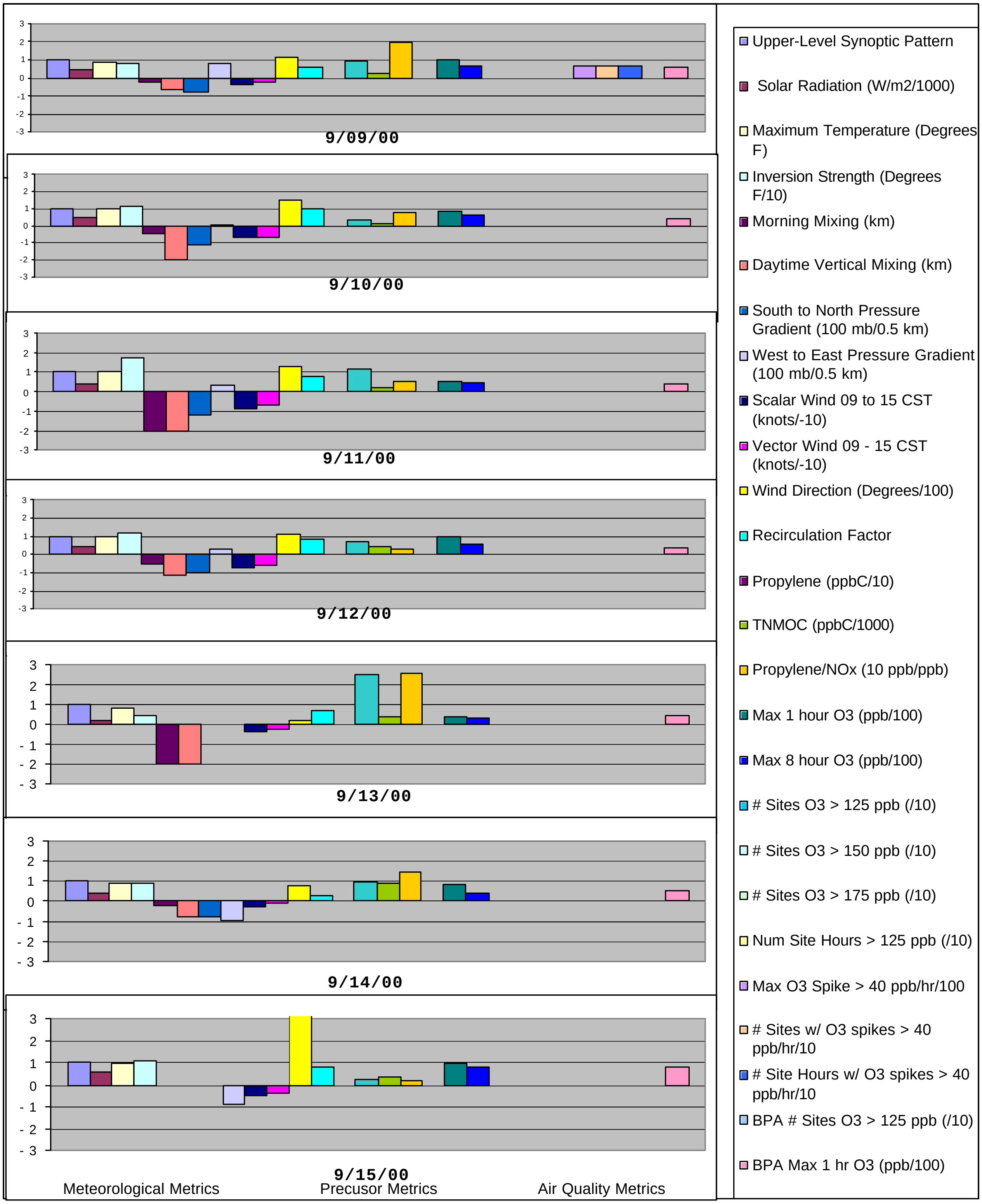
BPA Max 1 hr O3 (ppb/100)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Meteorological Metrics
Precusor Metrics
Air Quality Metrics
Upper-Level Synoptic Pattern
Solar Radiation (W/m2/1000)
Maximum Temperature (Degrees F)
Inversion Strength (Degrees F/10)
Morning Mixing (km)
Daytime Vertical Mixing (km)
South to North Pressure Gradient (100 mb/0.5 km)
West to East Pressure Gradient (100 mb/0.5 km)
Scalar Wind 09 to 15 CST (knots/-10)
Vector Wind 09 - 15 CST (knots/-10)
Wind Direction (Degrees/100)
Recirculation Factor
Propylene (ppbC/10)
TNMOC (ppbC/1000)
Propylene/NOx (10 ppb/ppb)
Max 1 hour O3 (ppb/100)
Max 8 hour O3 (ppb/100)
Sites O3 > 125 ppb (/10)
Sites O3 > 150 ppb (/10)
Sites O3 > 175 ppb (/10)
Num Site Hours > 125 ppb (/10)
Max O3 Spike > 40 ppb/hr/100
Sites w/ O3 spikes > 40 ppb/hr/10
Site Hours w/ O3 spikes > 40 ppb/hr/10
BPA # Sites O3 > 125 ppb (/10)
BPA Max 1 hr O3 (ppb/100)

APPENDIX B

NATIONAL WEATHER SERVICE
DAILY UPPER-AIR AND SURFACE WEATHER MAPS

This appendix contains the National Weather Service daily upper-air and surface weather maps for August 15 through September 15, 2000. The upper-air maps depict the height of the 500-mb constant-pressure level and winds at 500 mb. The surface maps depict the large-scale surface pressure pattern and regional winds.

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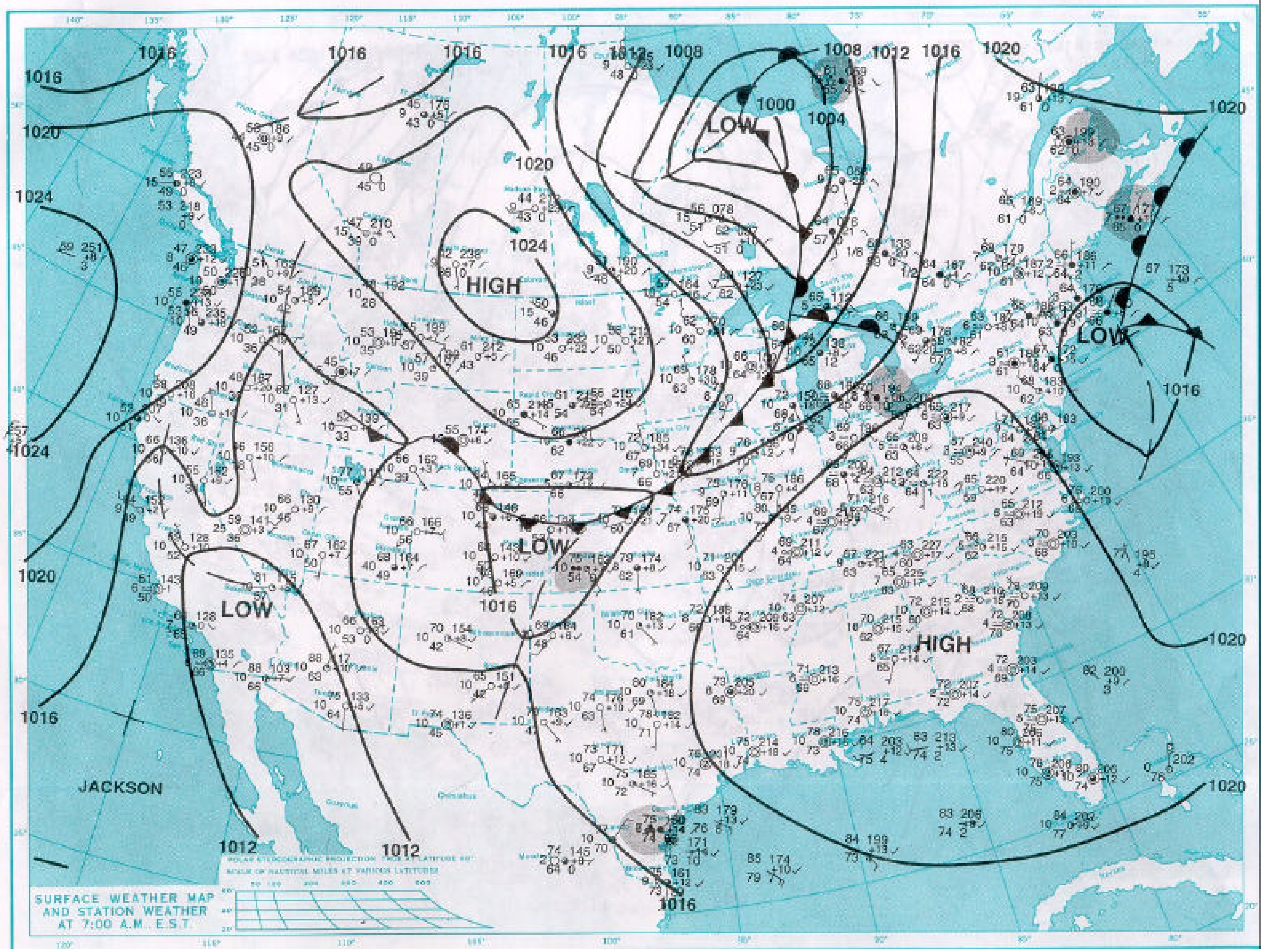
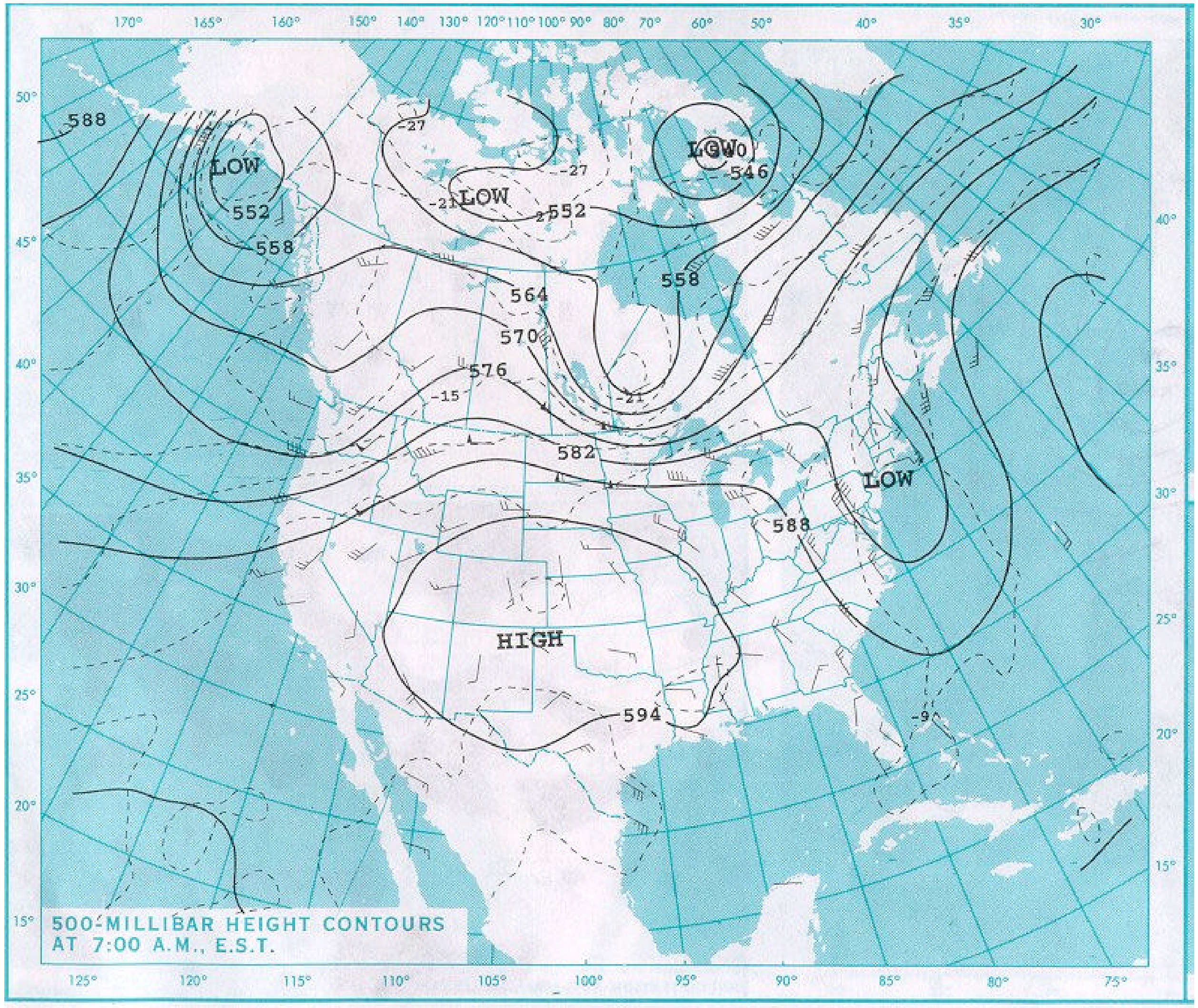
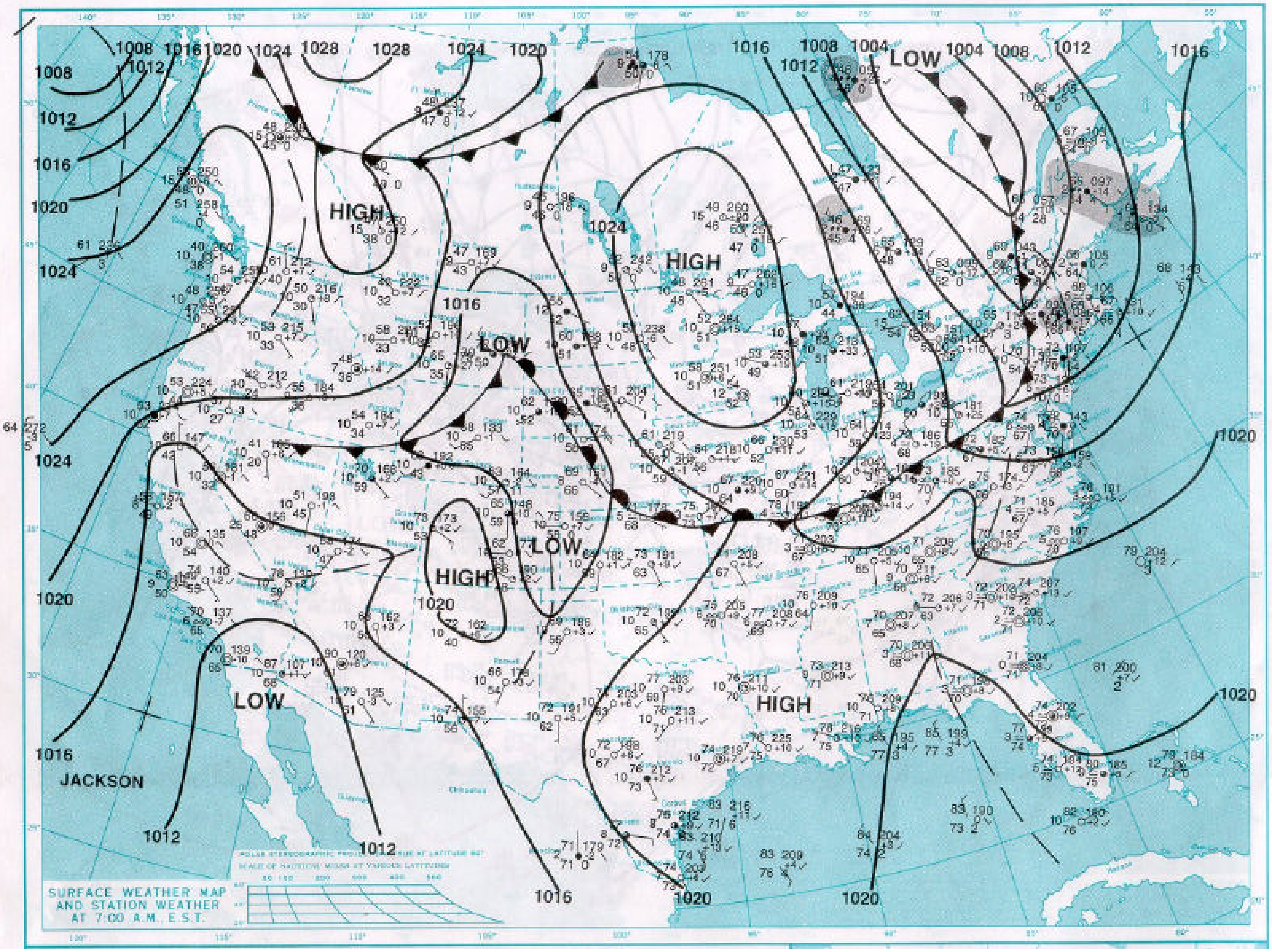
TUESDAY, AUGUST 15, 2000

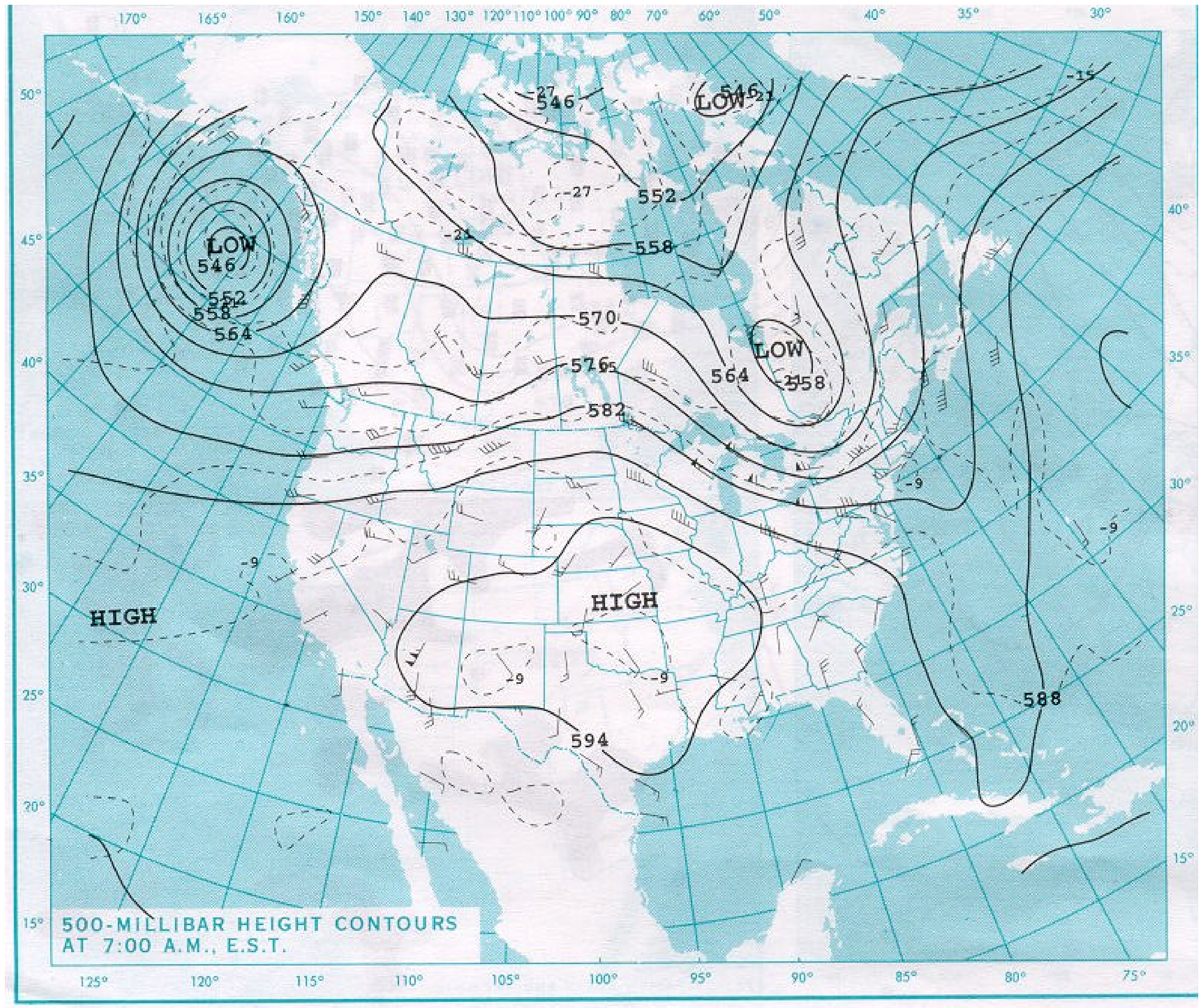




August 15, 2000

WEDNESDAY, AUGUST 16, 2000





August 16, 2000

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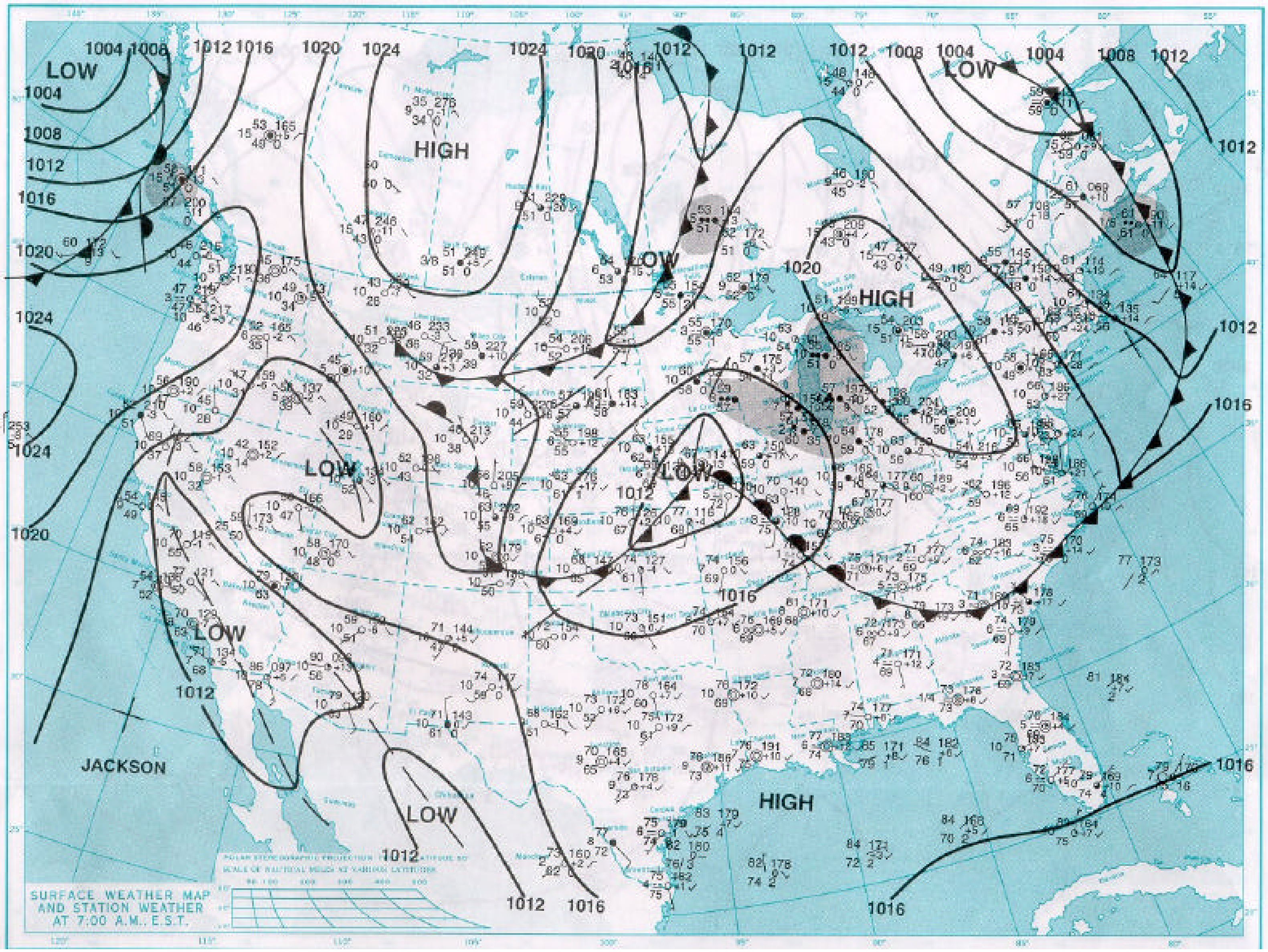

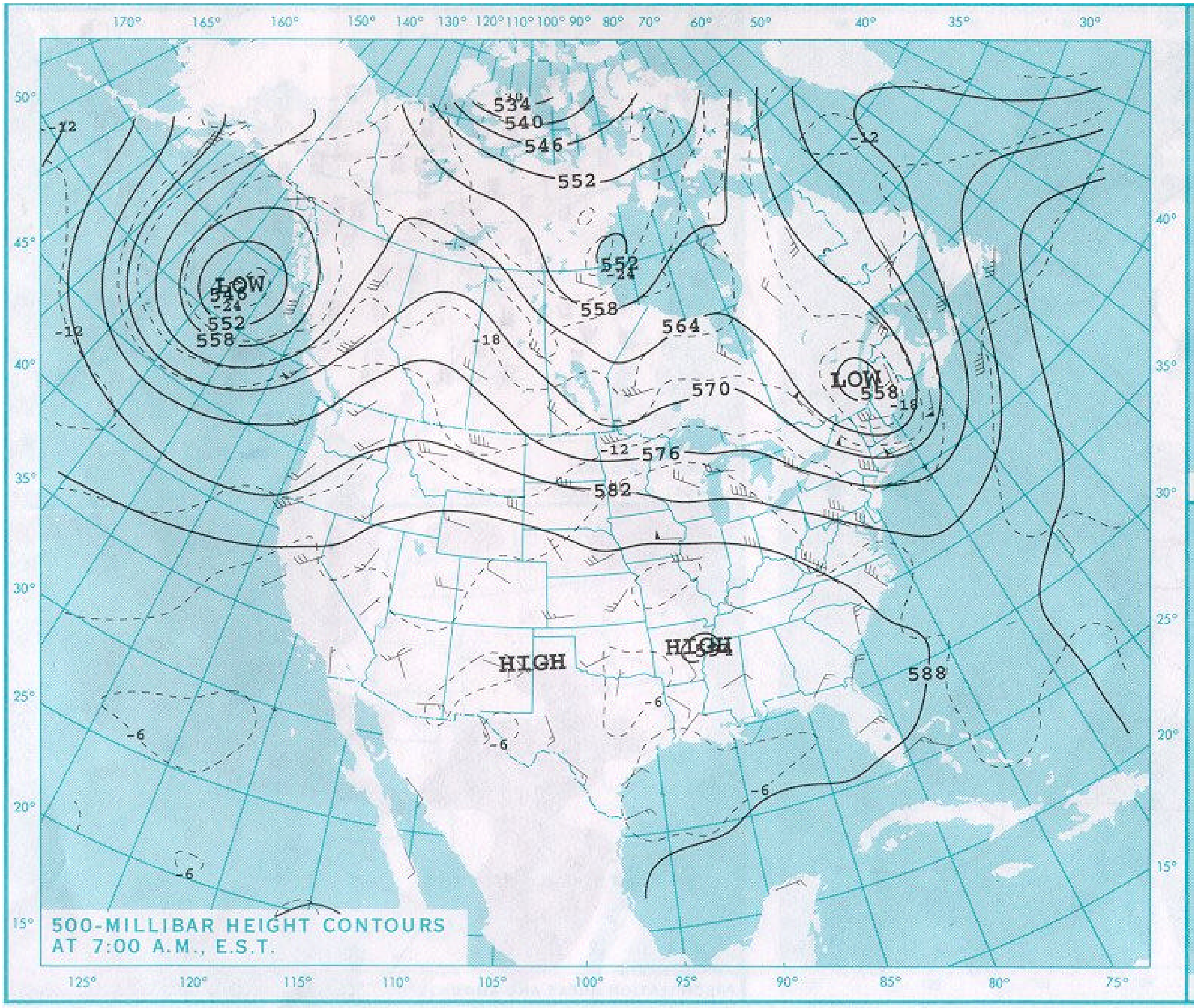

August 17, 2000

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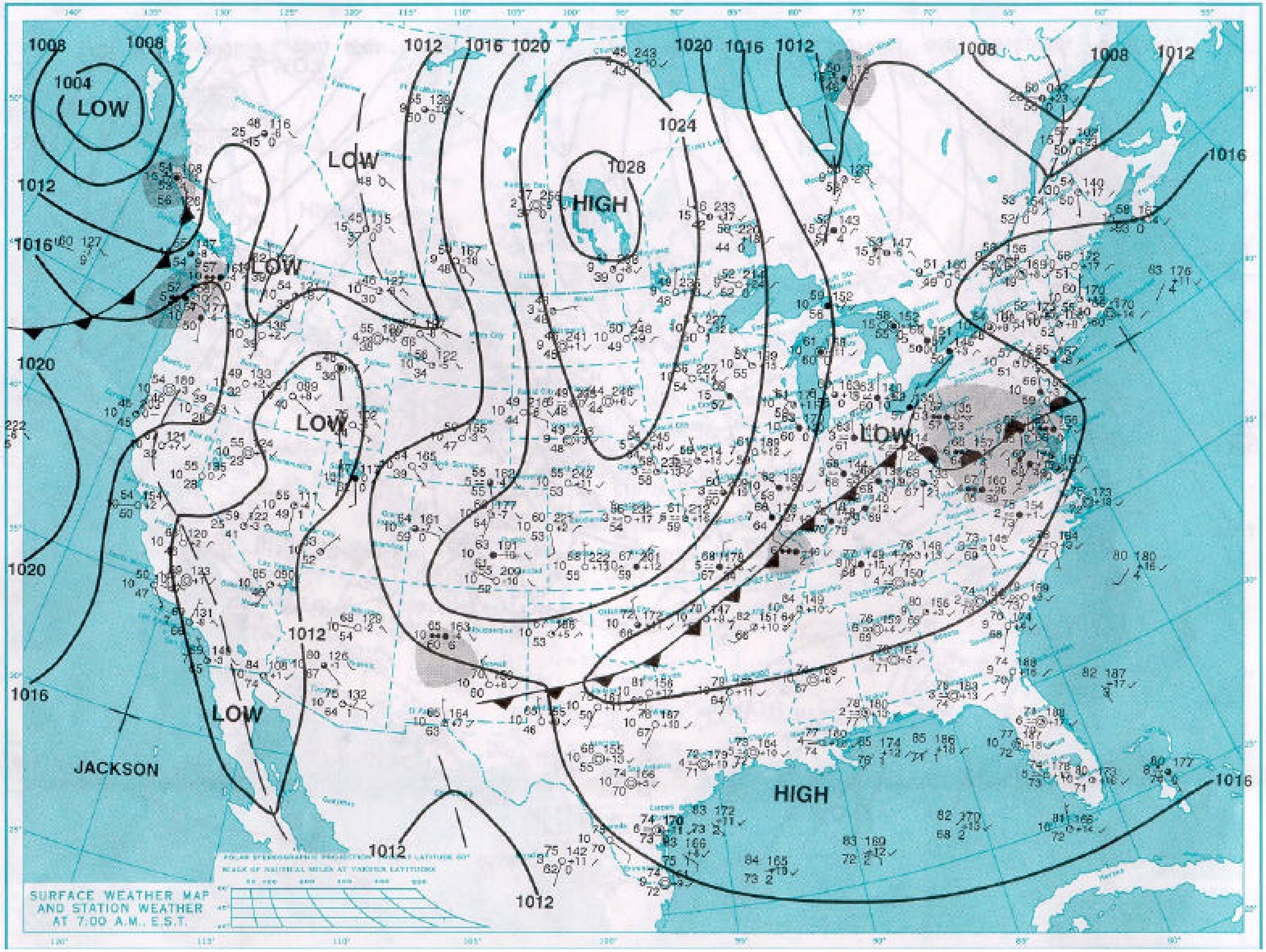
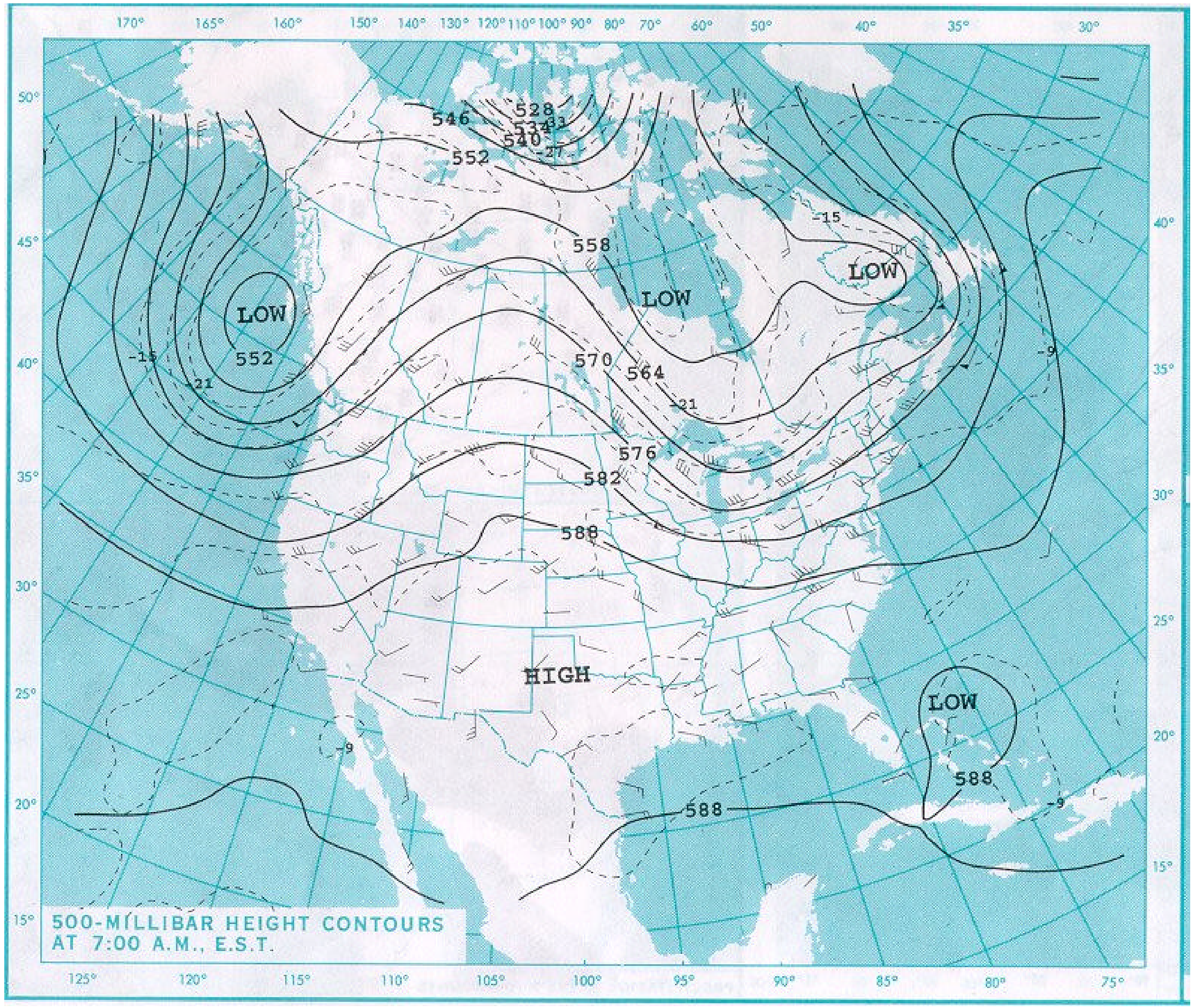
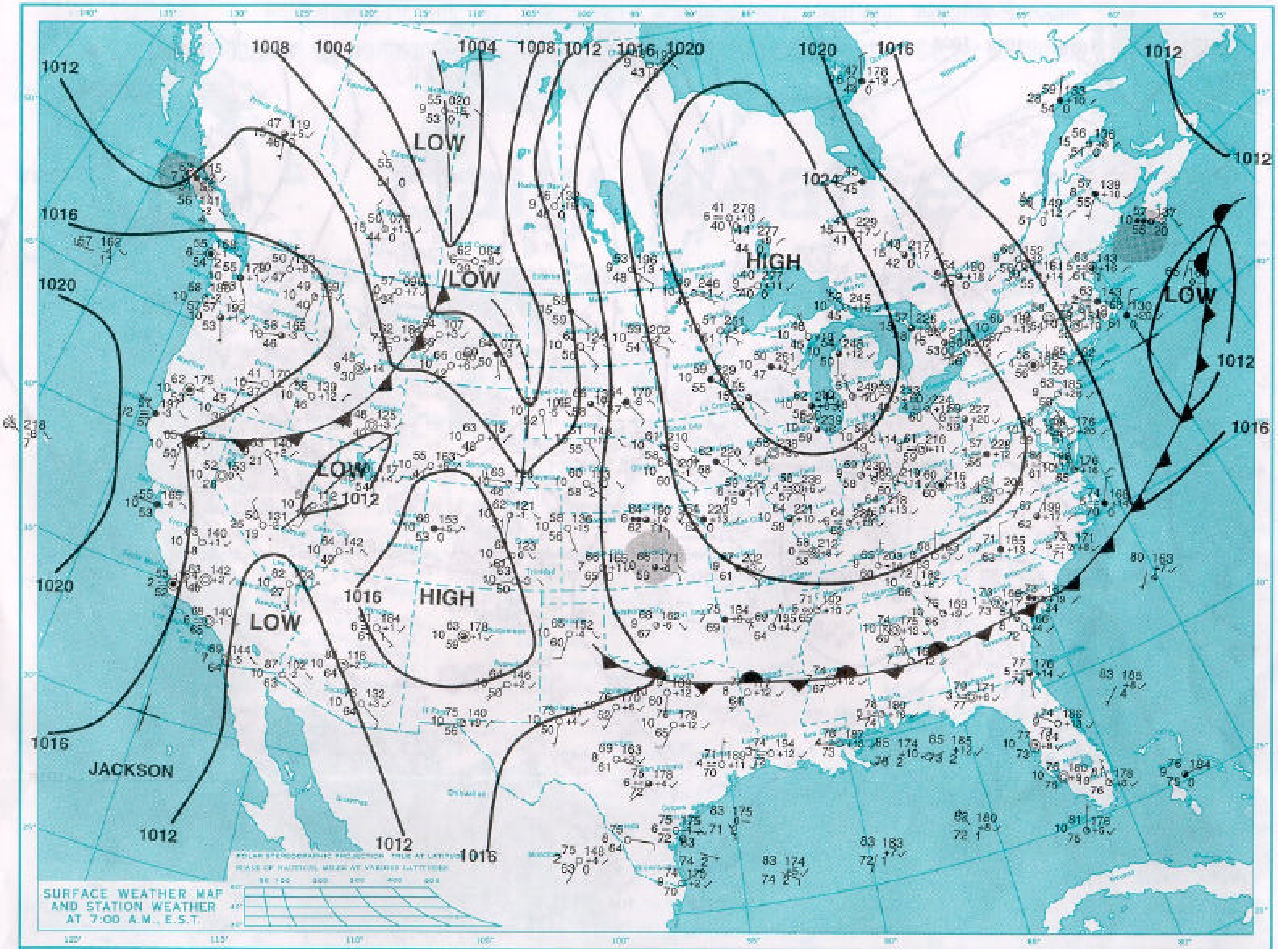
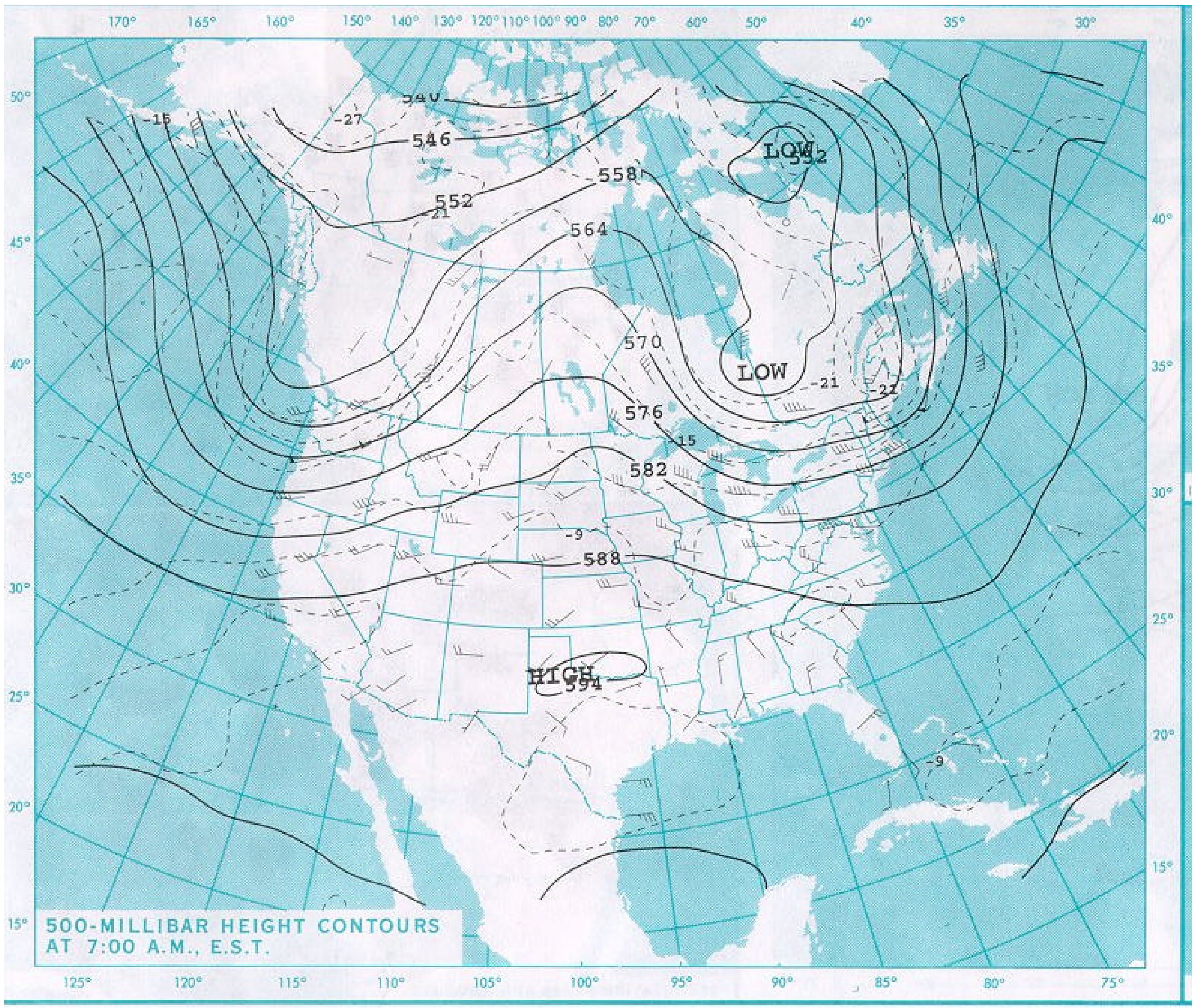




August 18, 2000

SATURDAY, AUGUST 19, 2000





August 19, 2000

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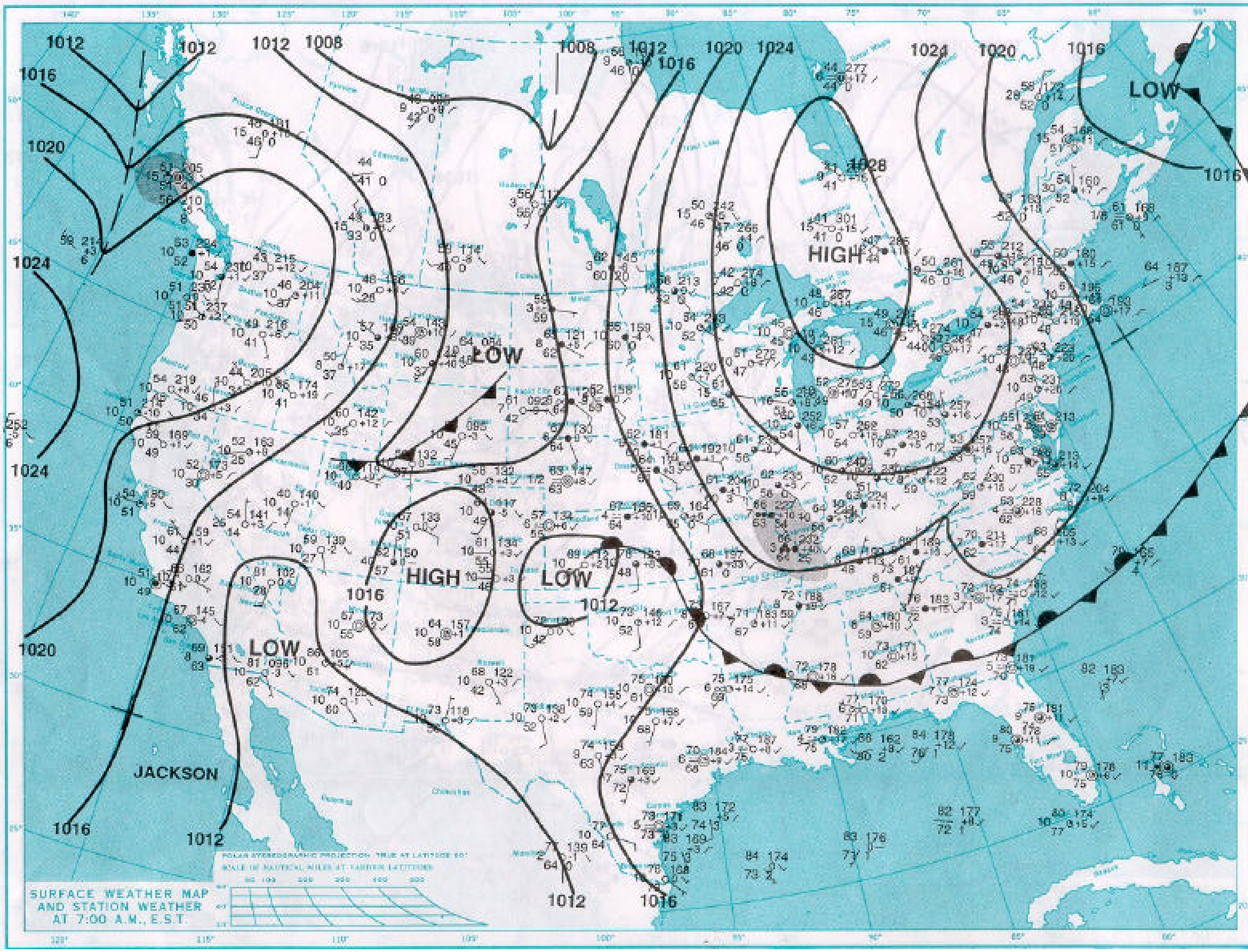

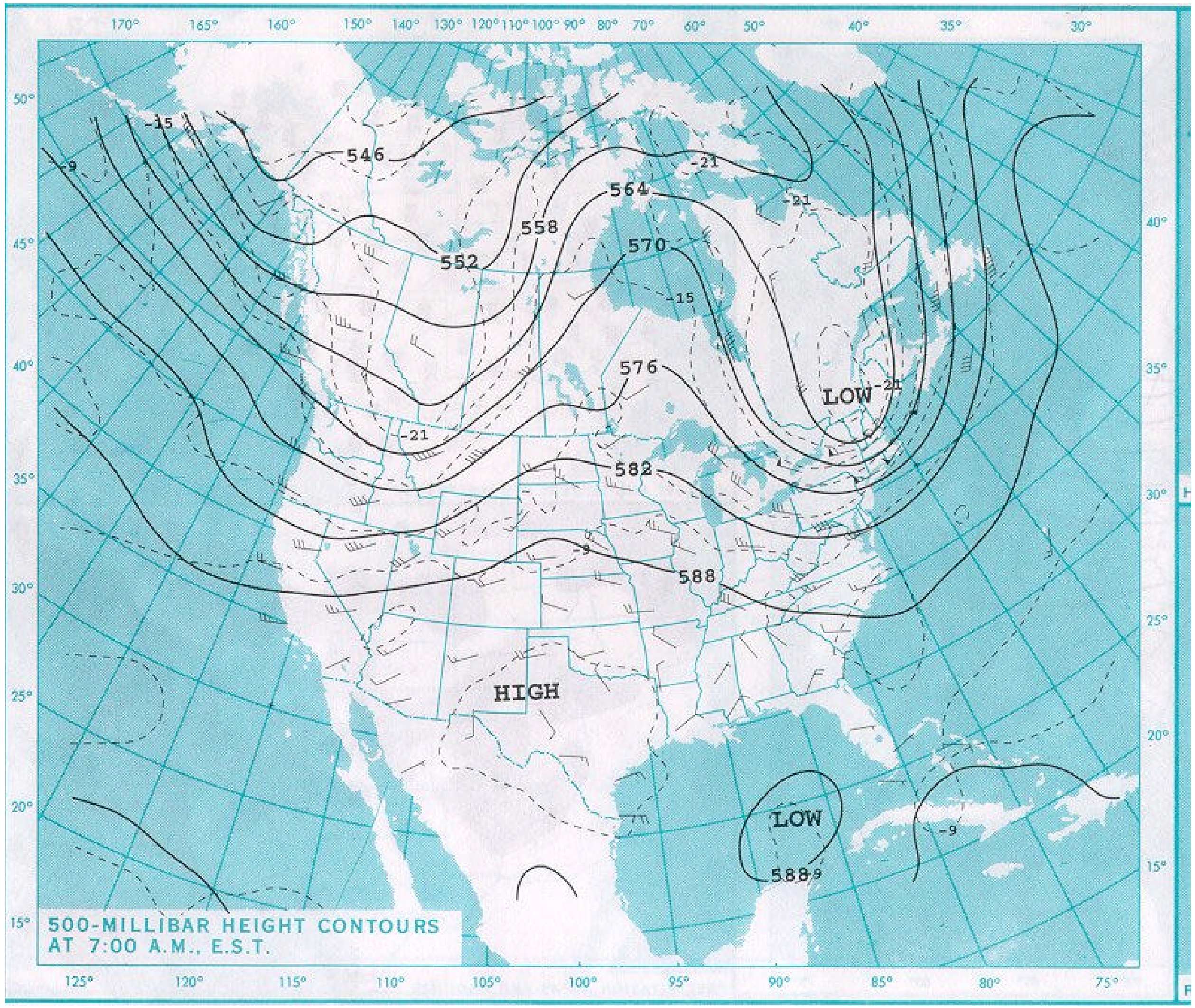

August 20, 2000

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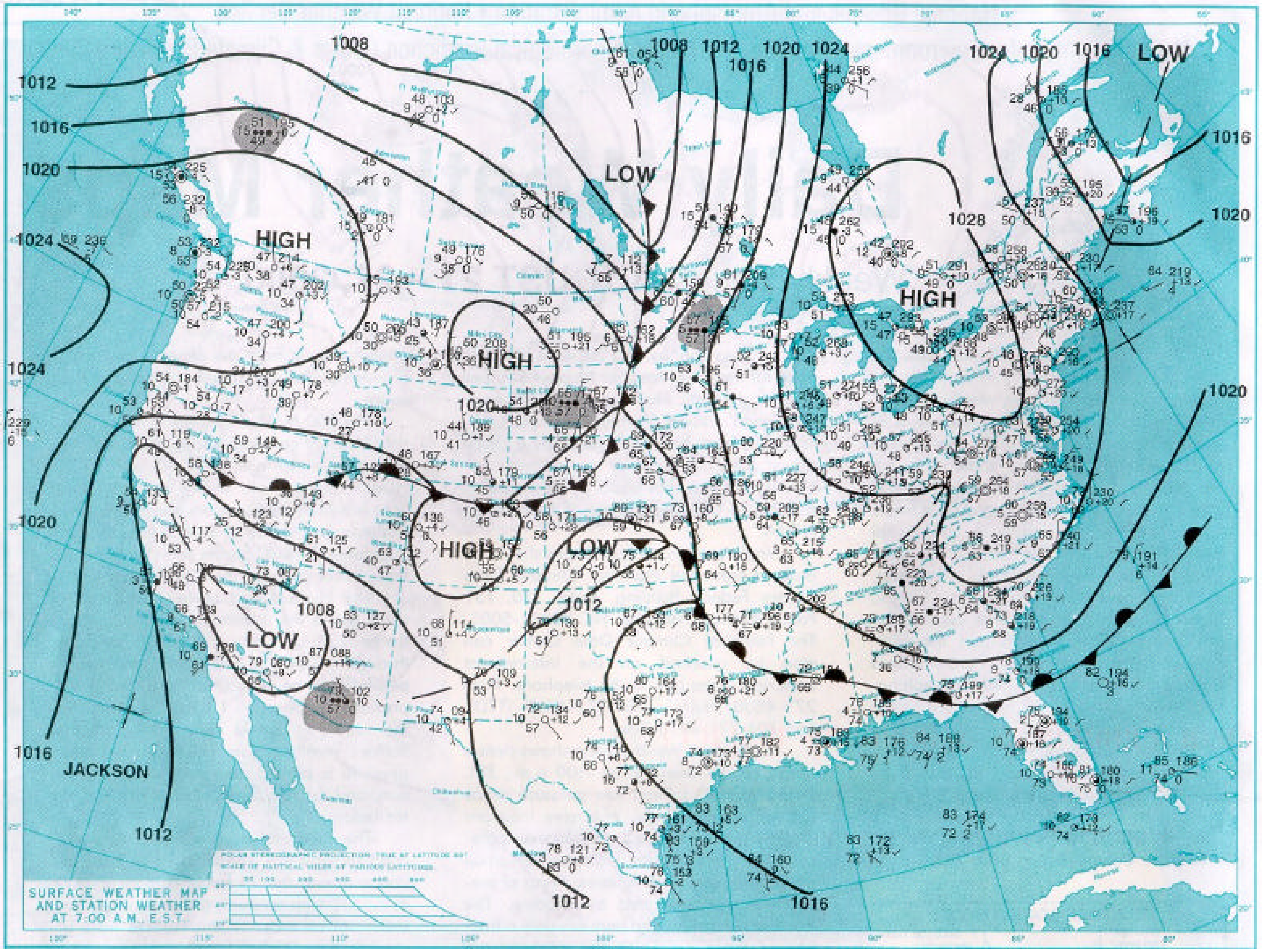
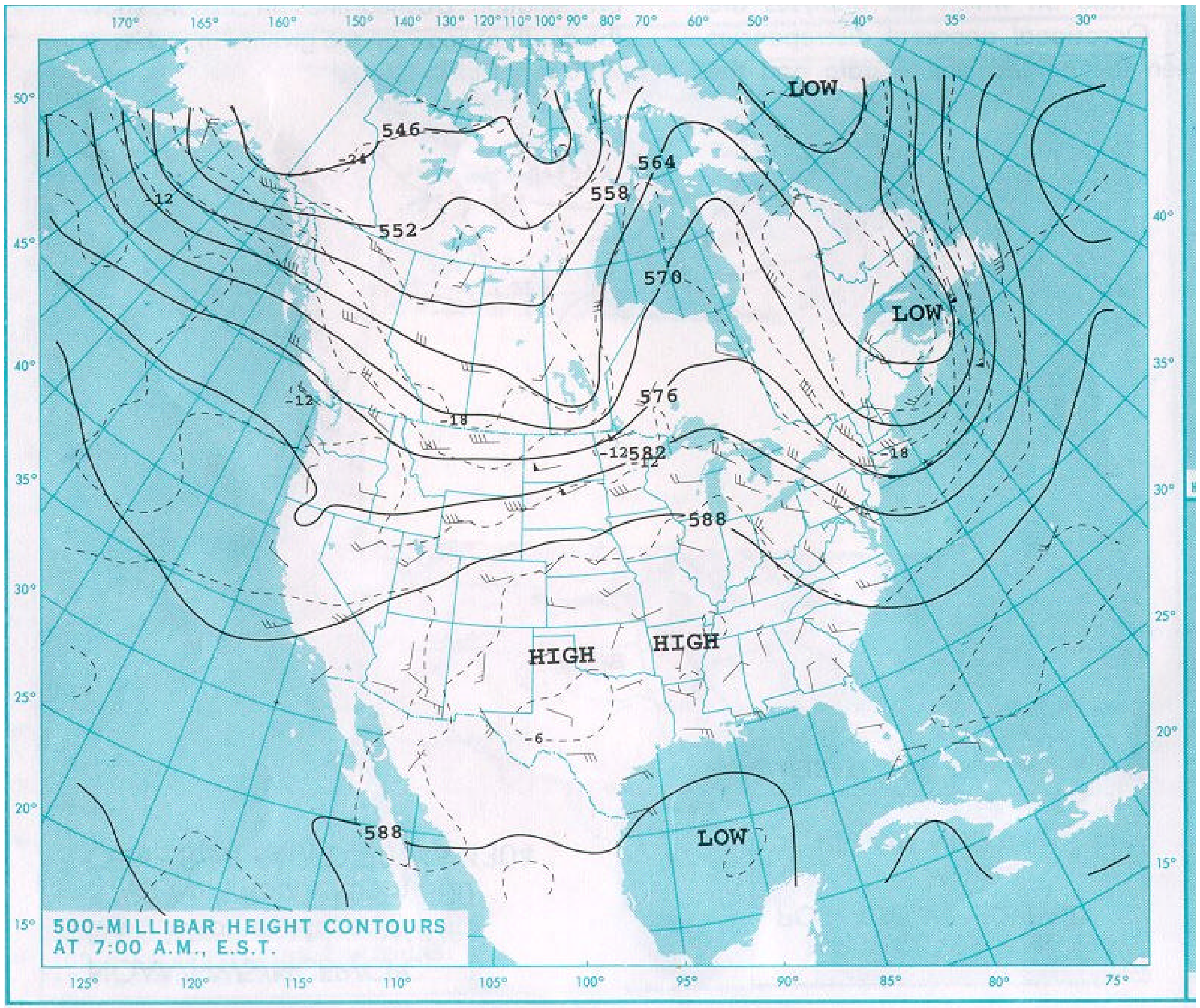
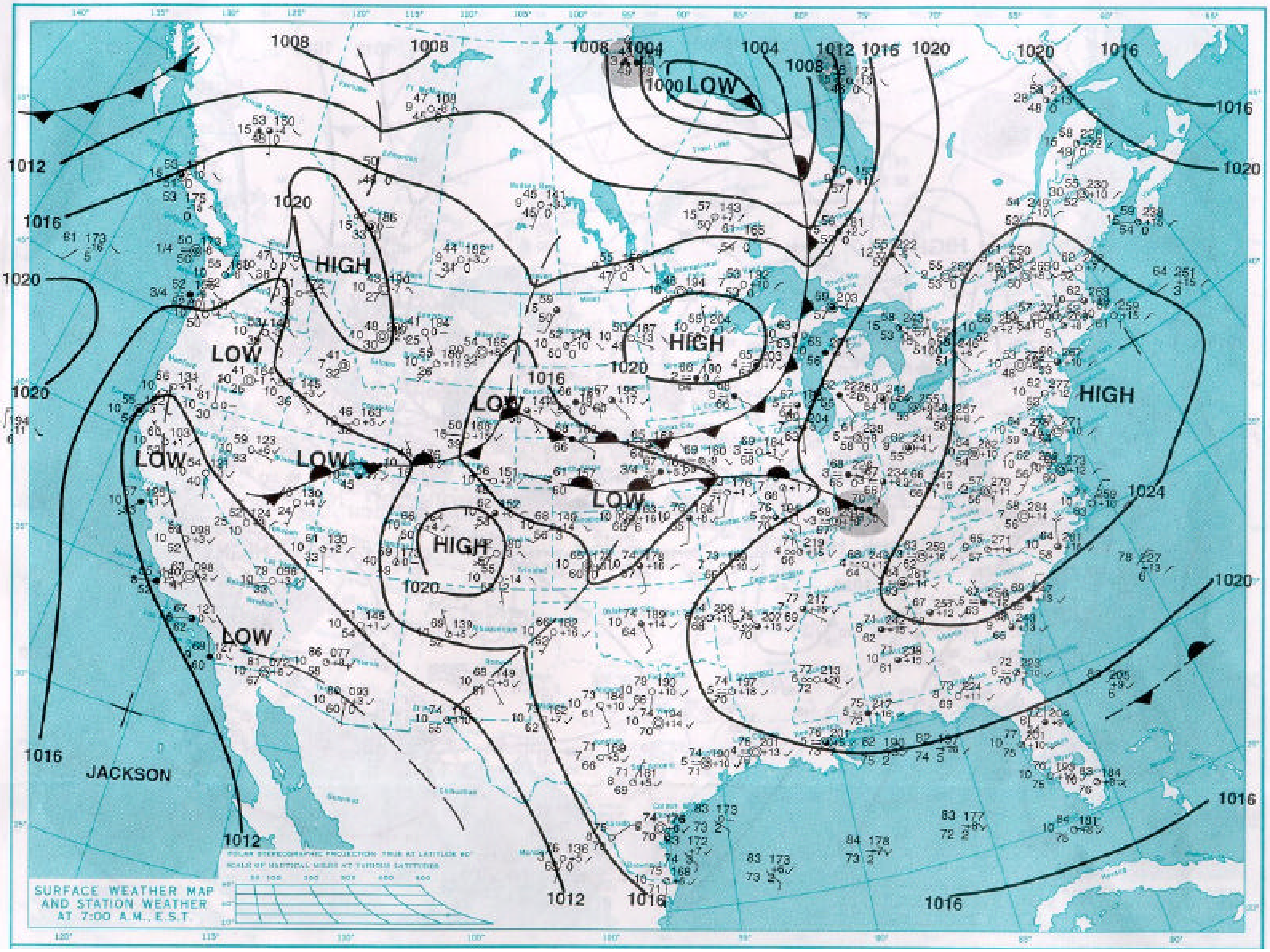
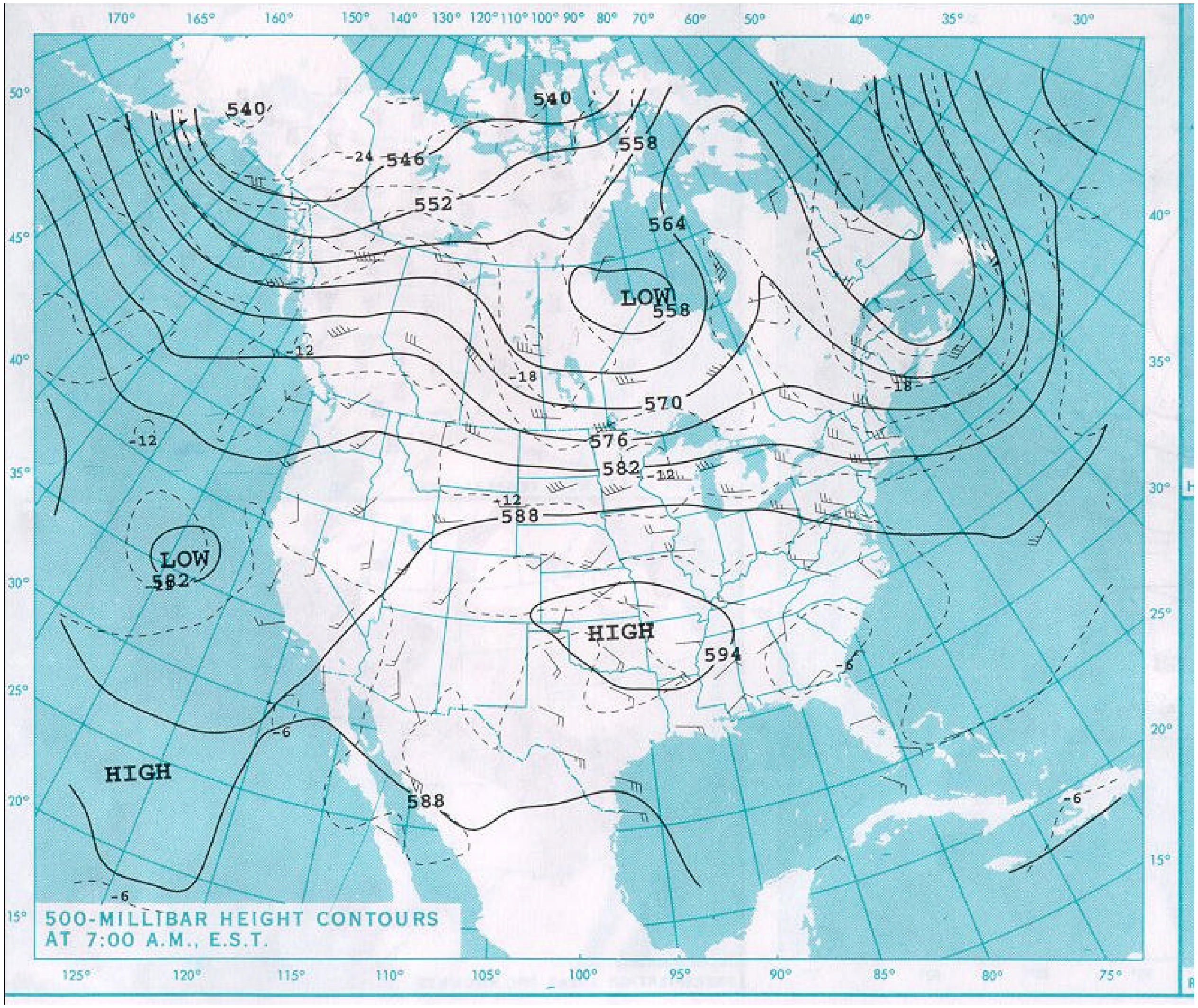




August 21, 2000

TUESDAY, AUGUST 22, 2000





August 22, 2000

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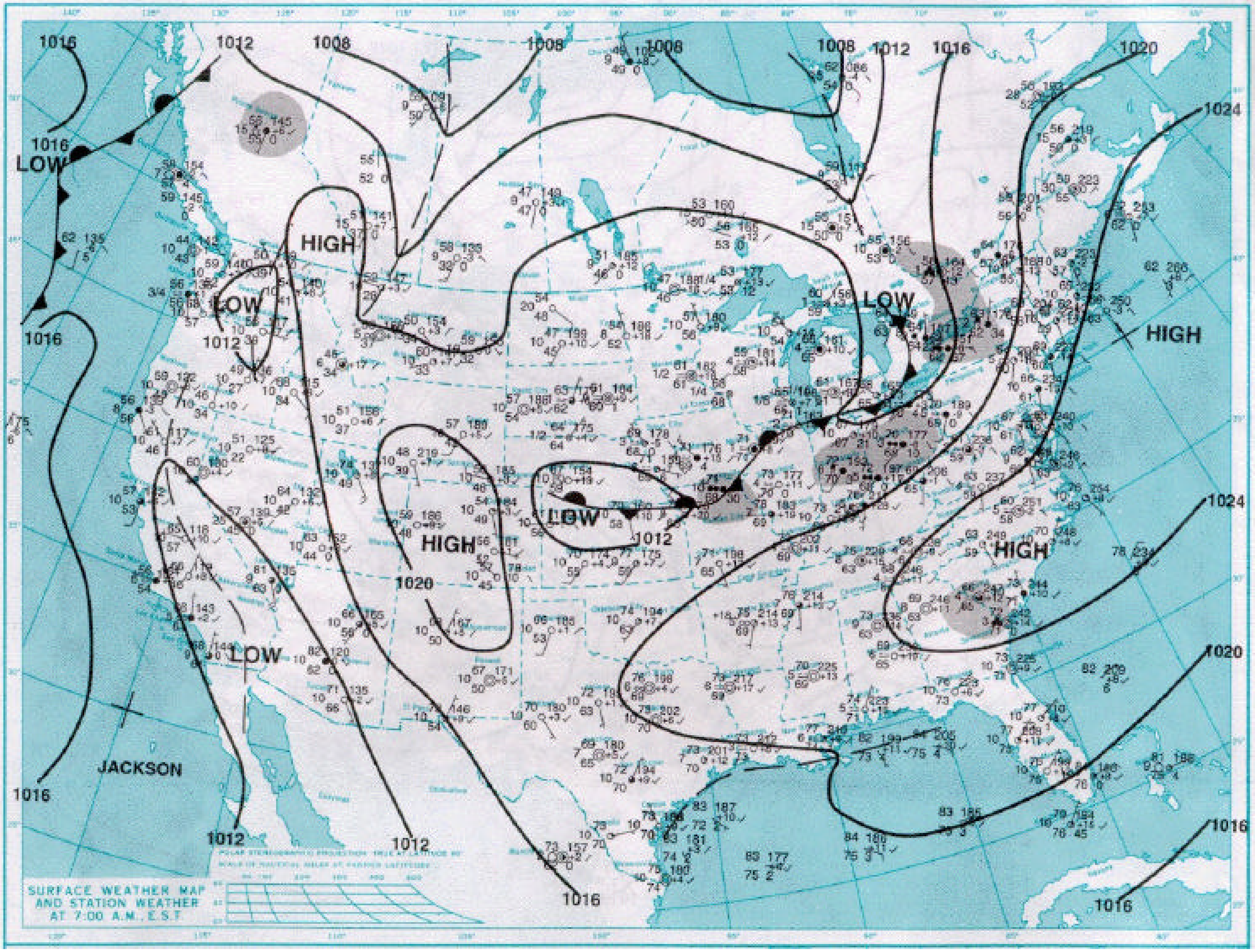
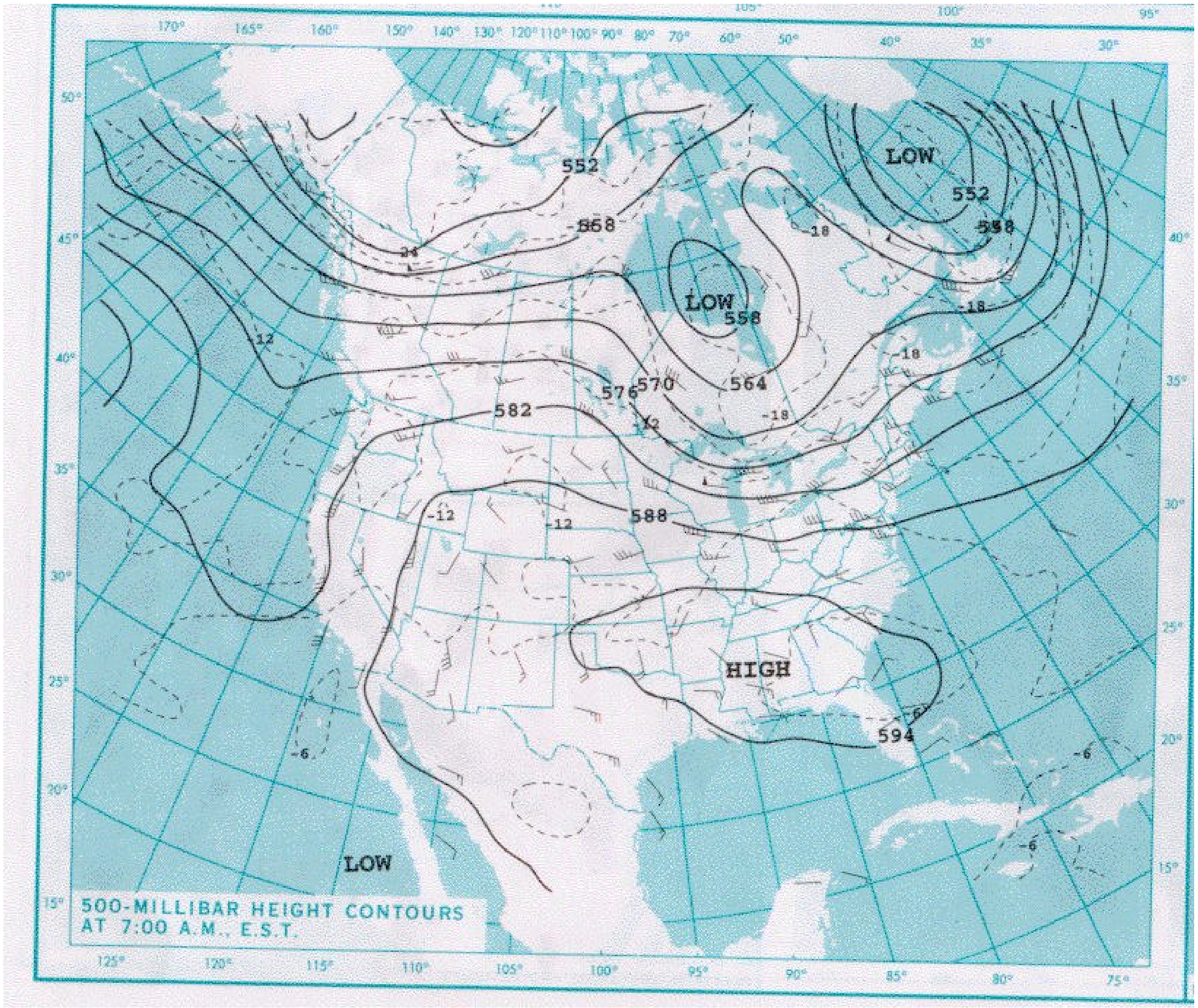
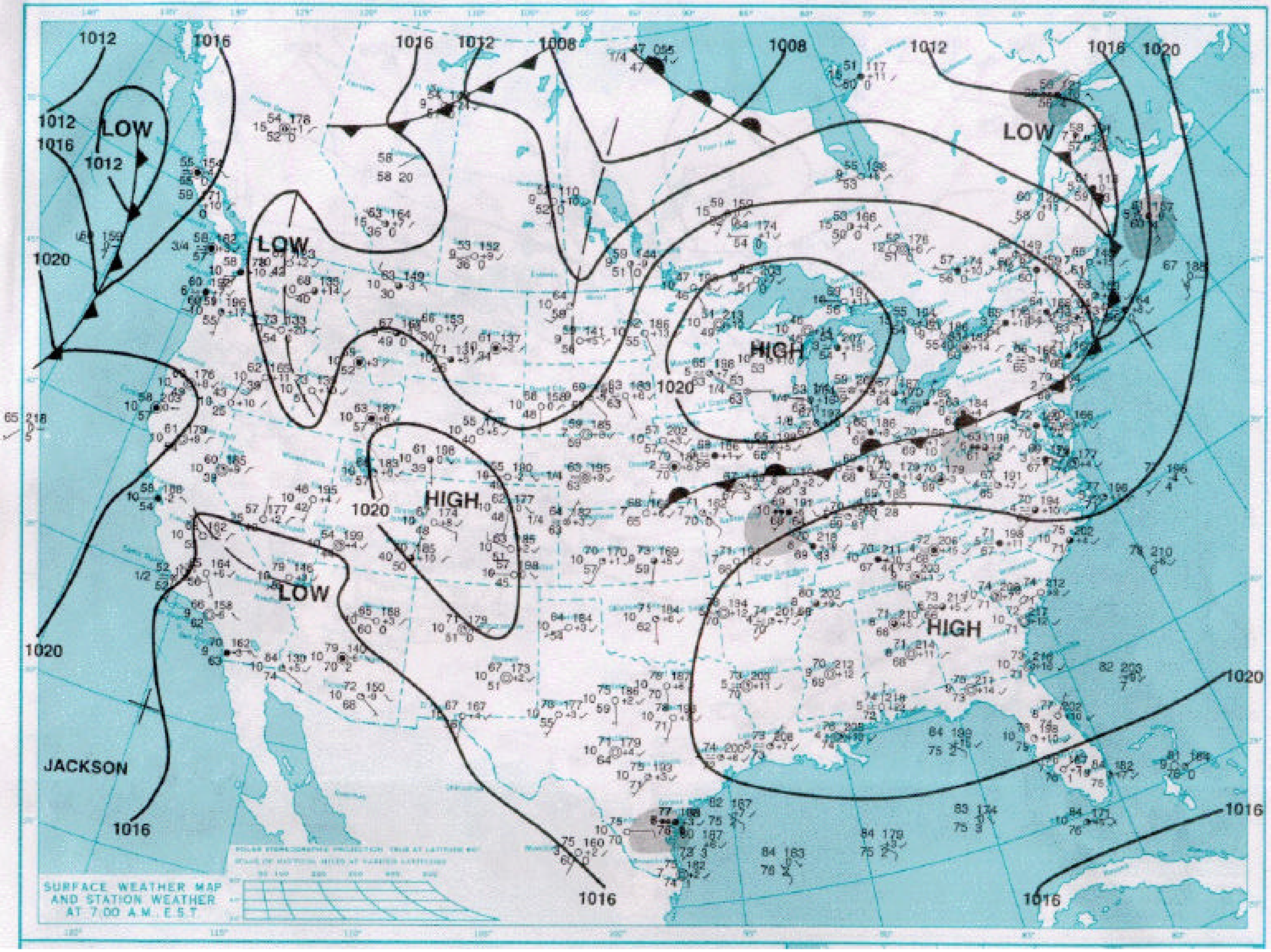
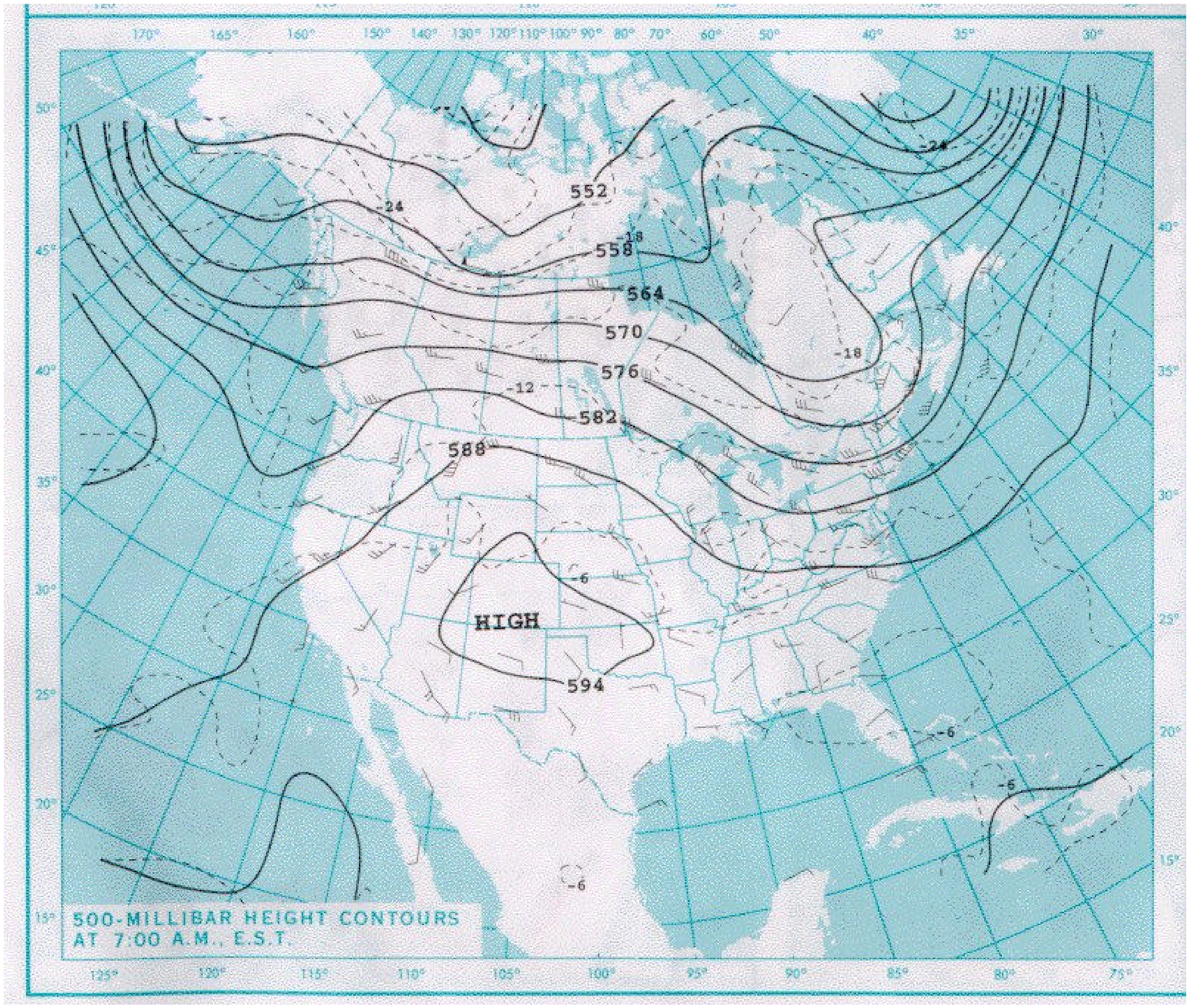




August 23, 2000

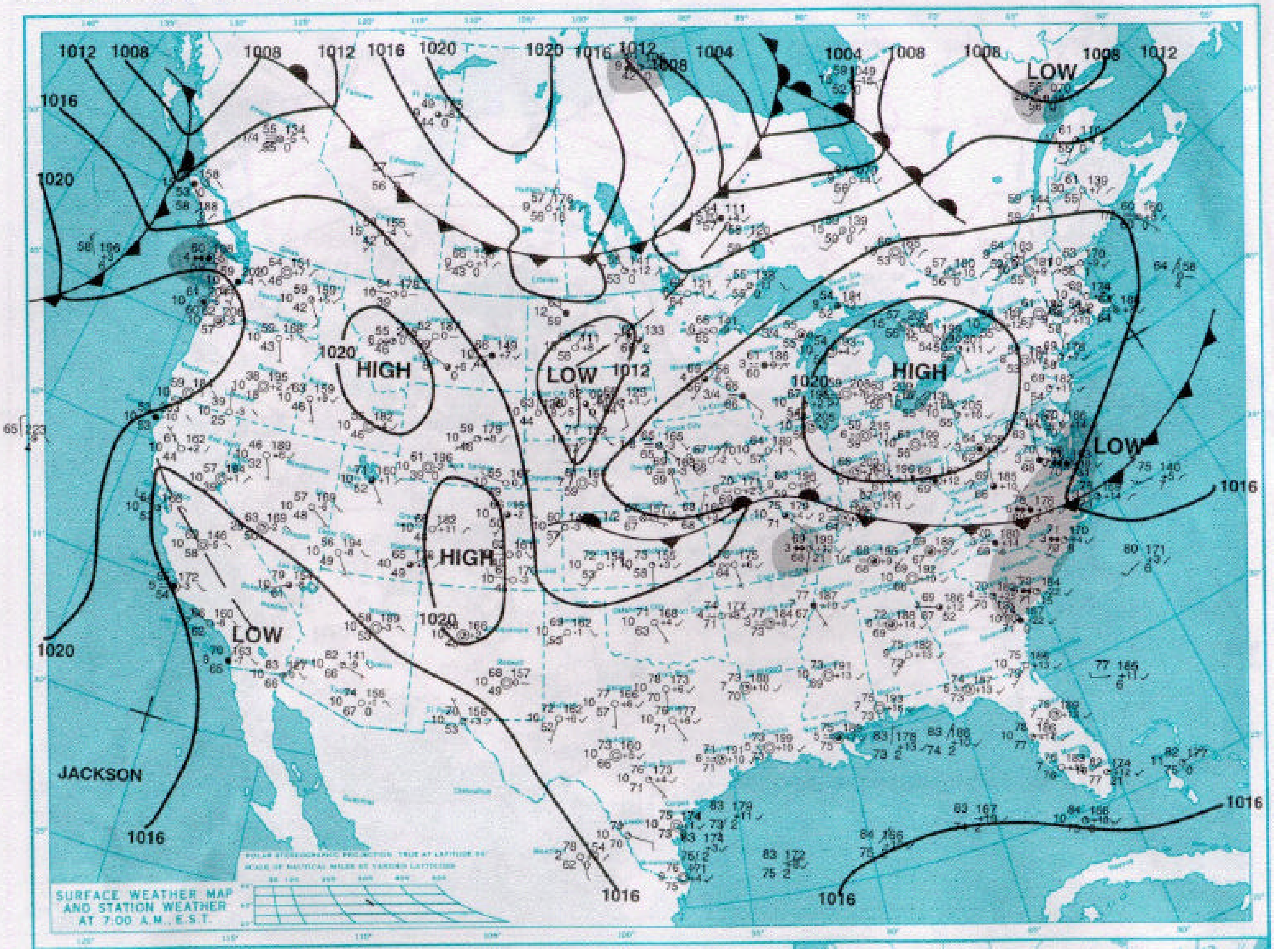
THURSDAY, AUGUST 24, 2000

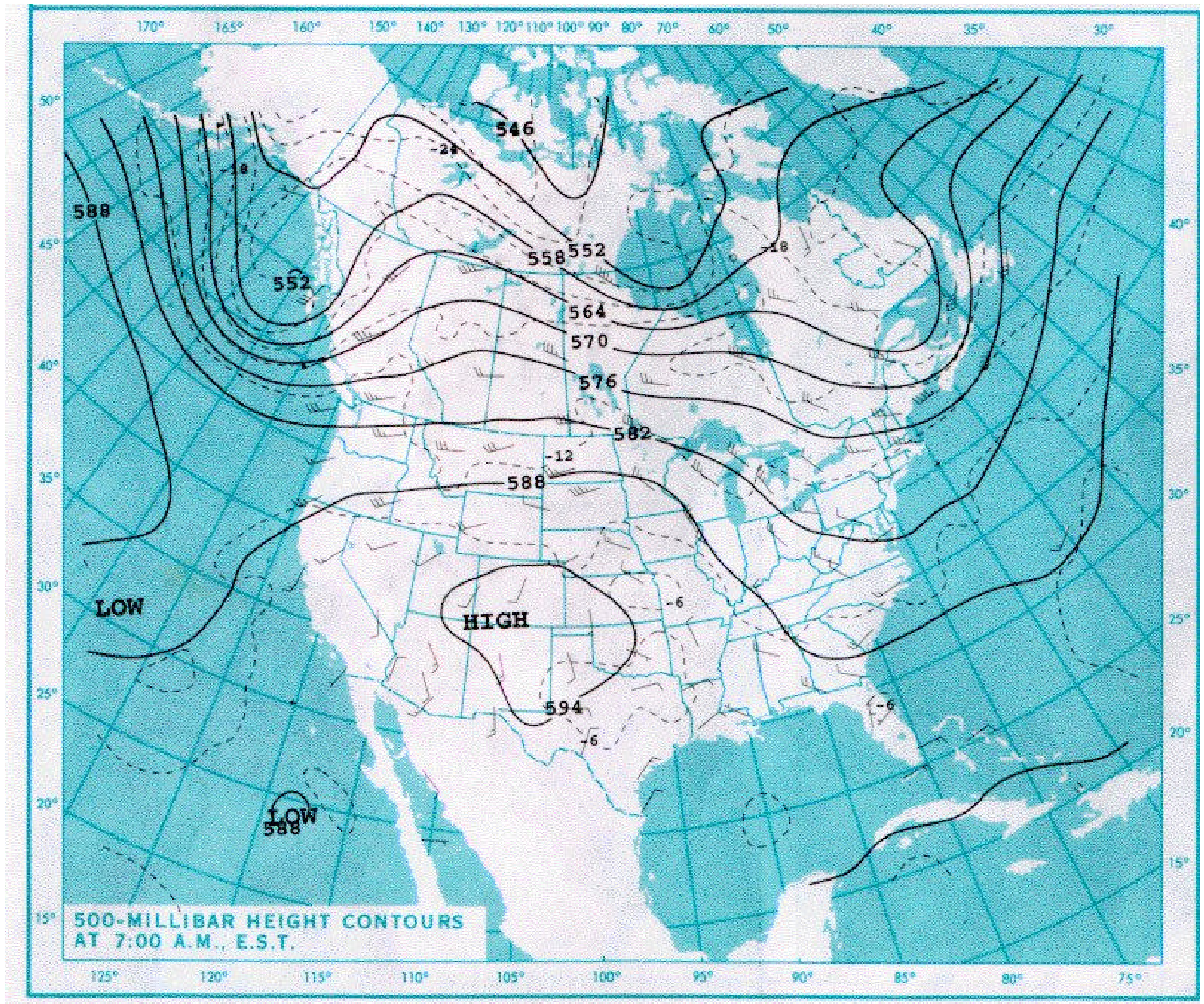




August 24, 2000

FRIDAY, AUGUST 25, 2000





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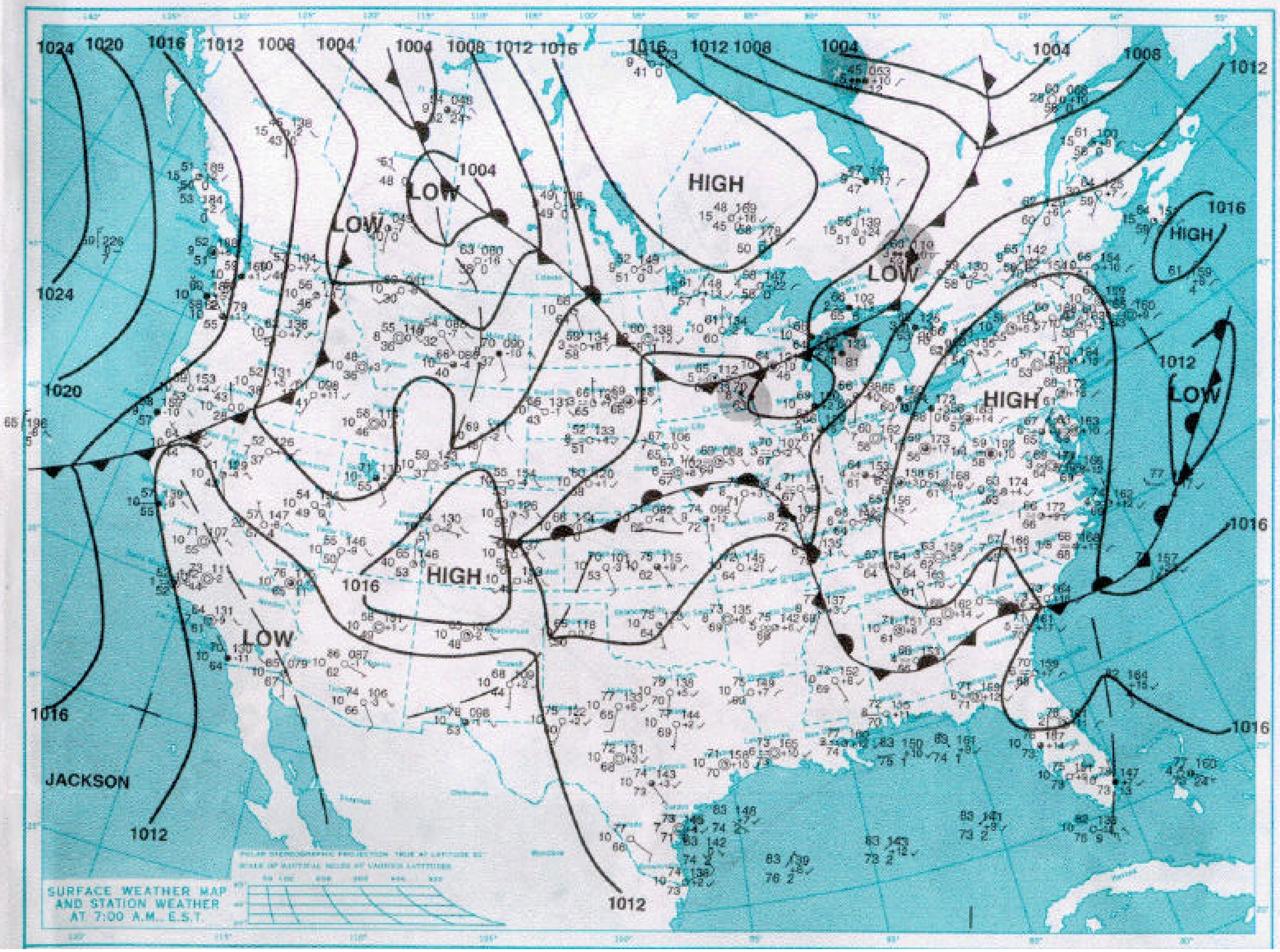
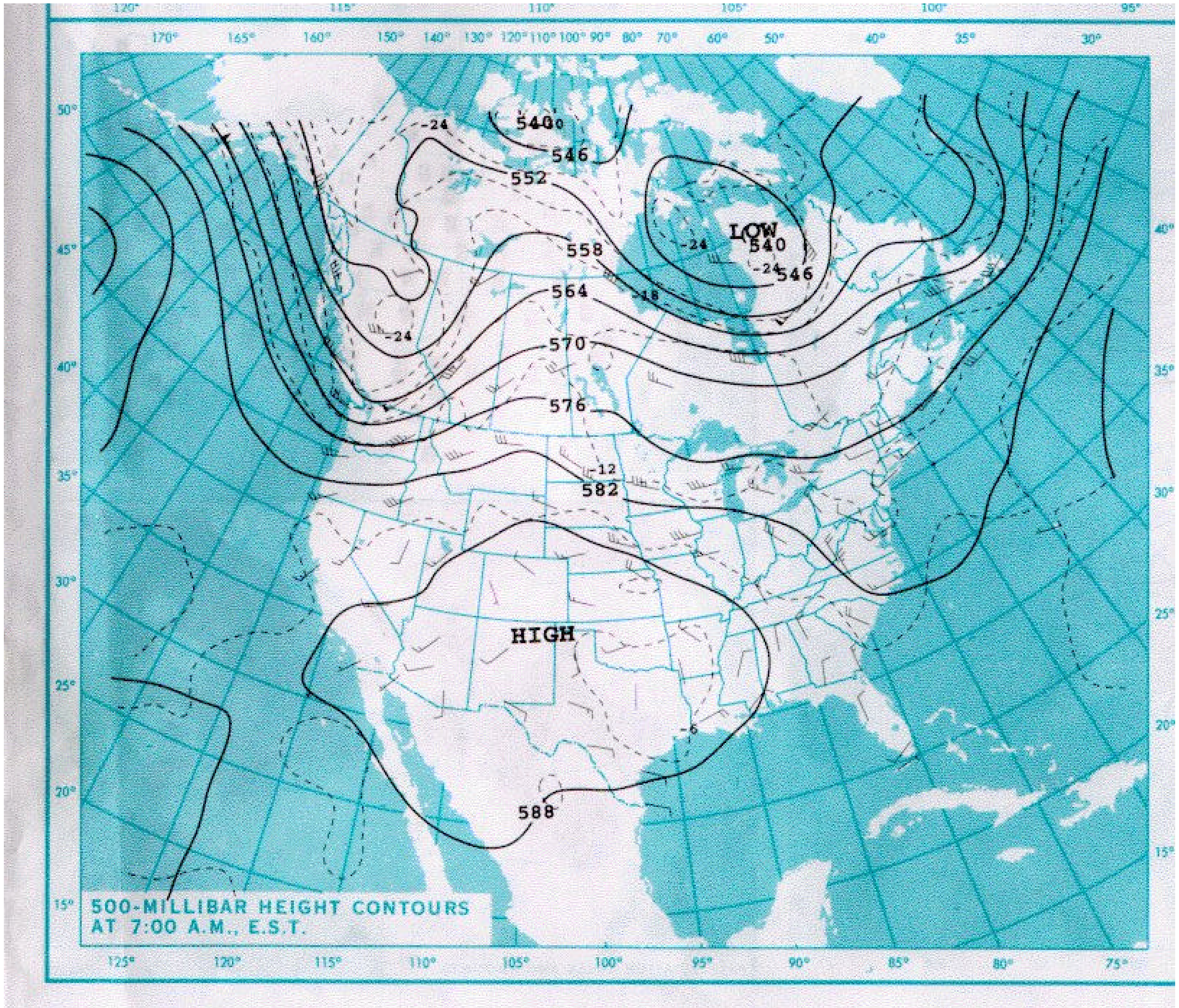
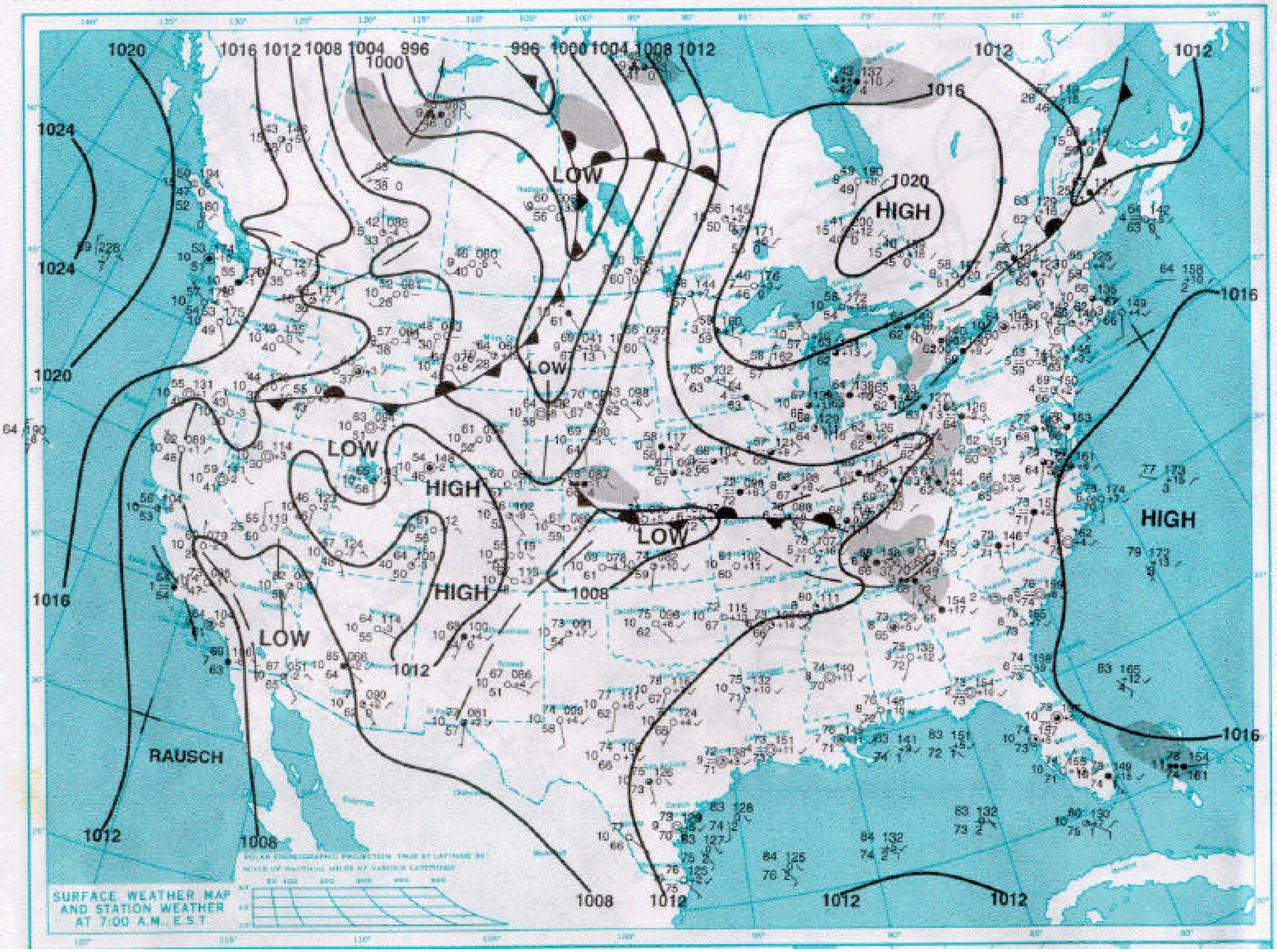
SATURDAY, AUGUST 26, 2000

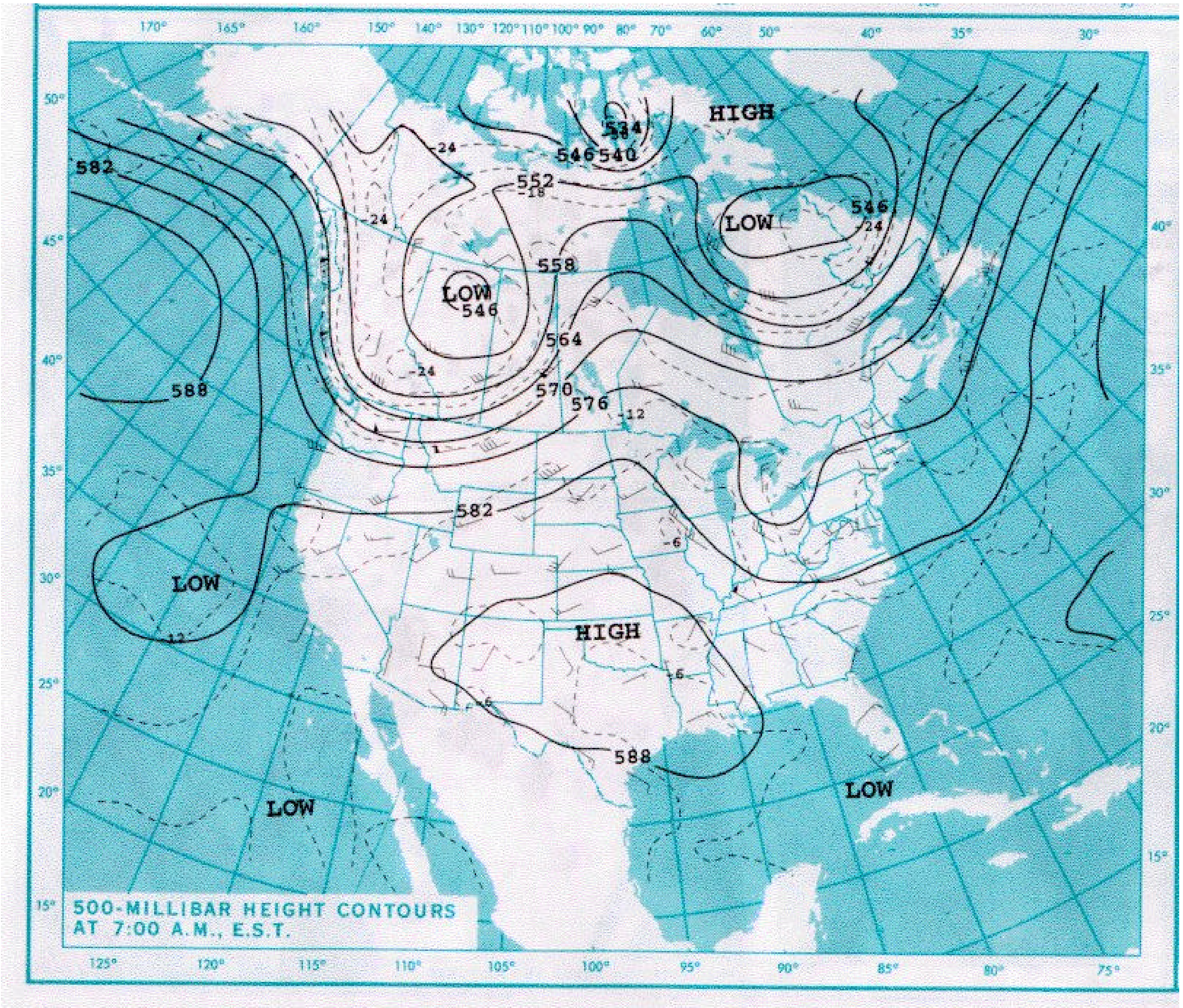




August 26, 2000.

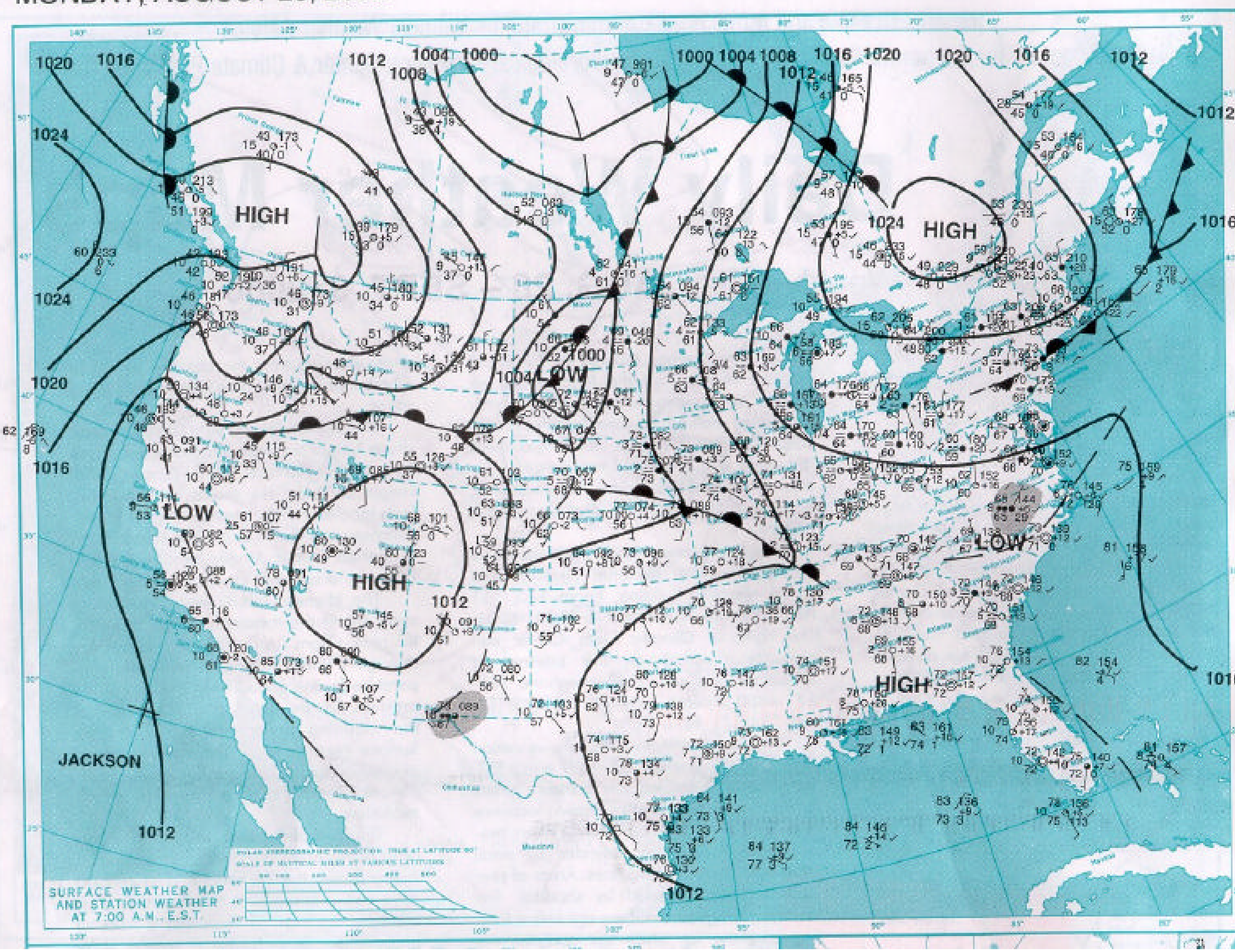
SUNDAY, AUGUST 27, 2000

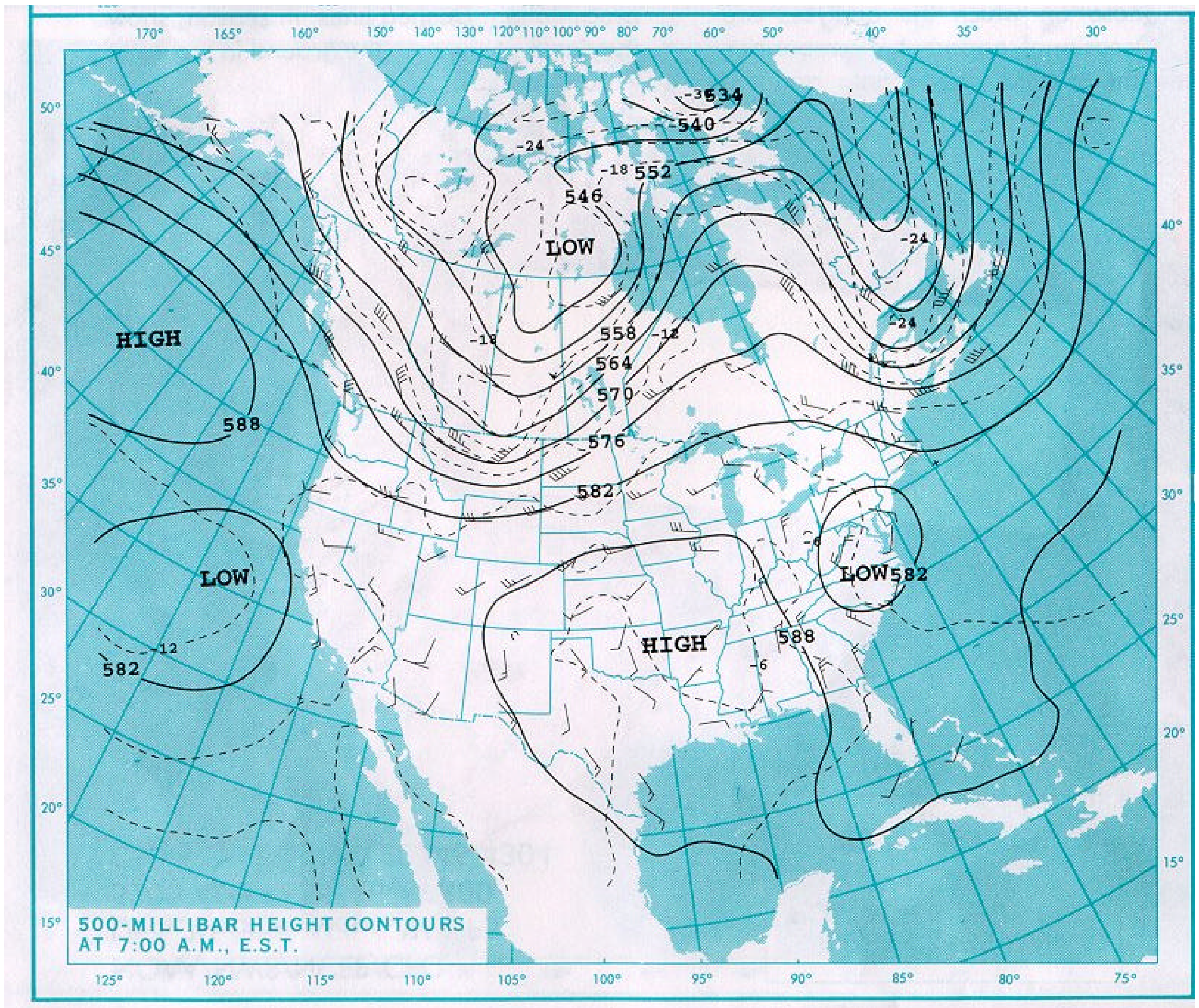




August 27, 2000

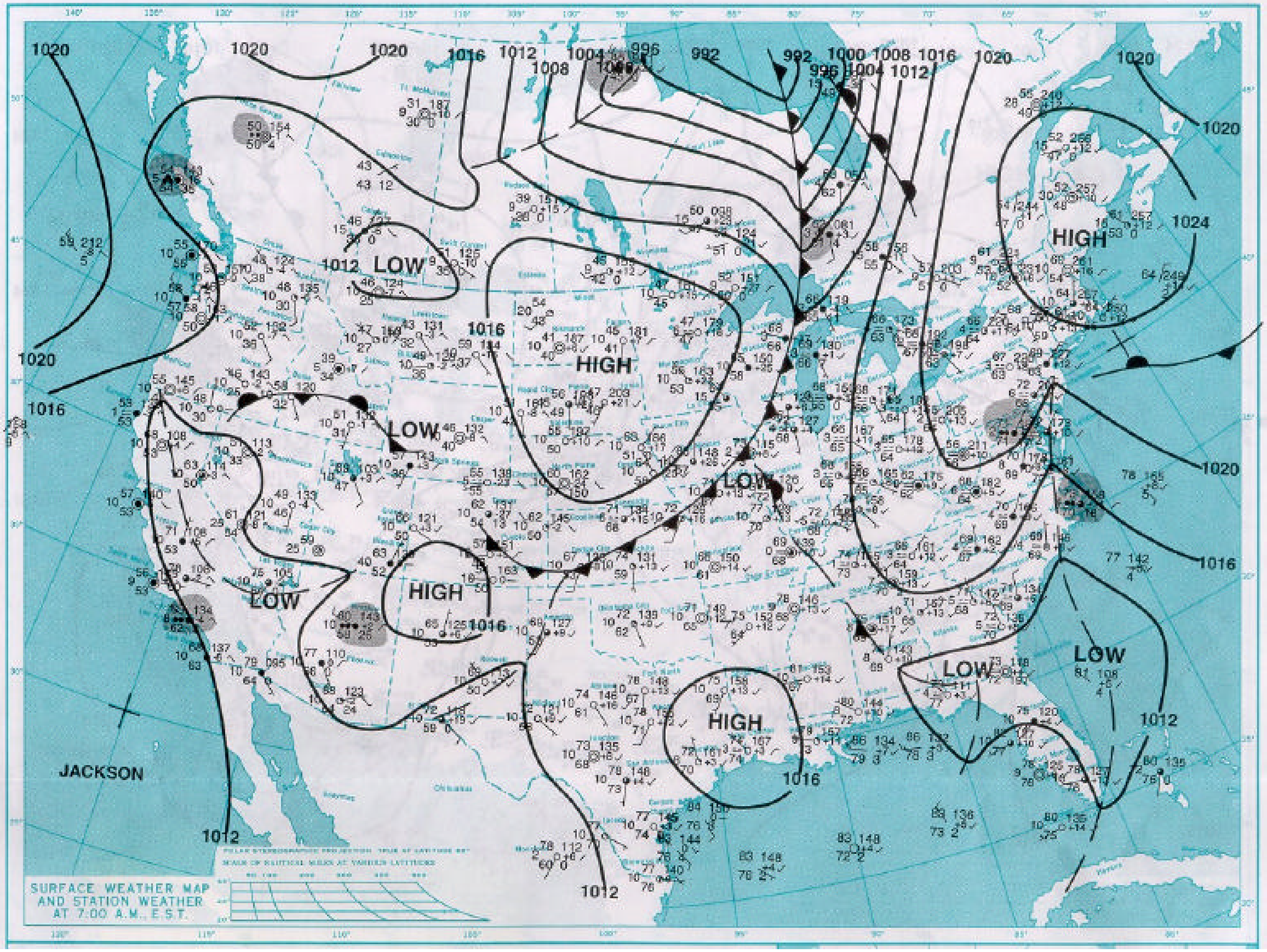
MONDAY, AUGUST 28, 2000

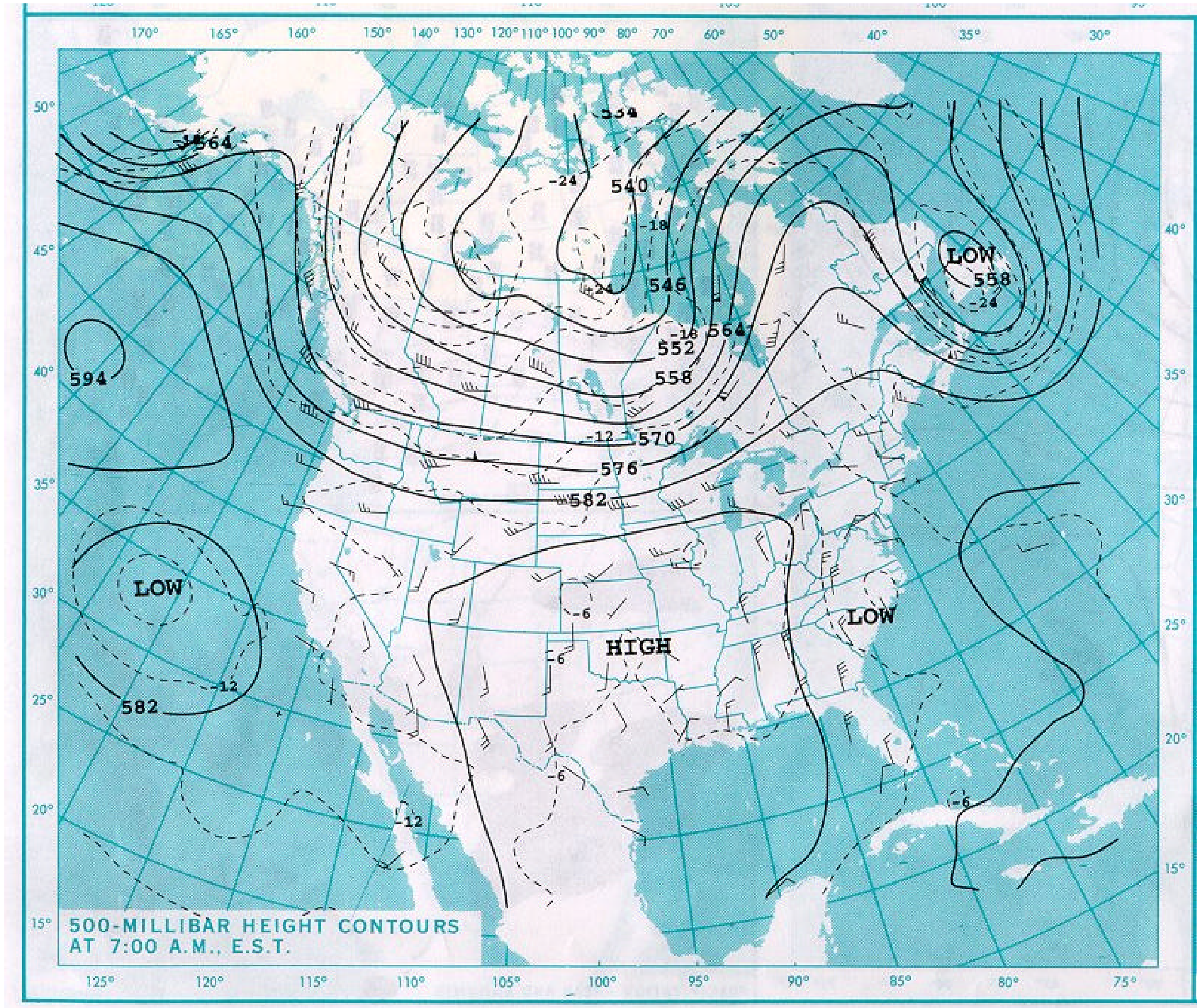




August 28, 2000

TUESDAY, AUGUST 29, 2000





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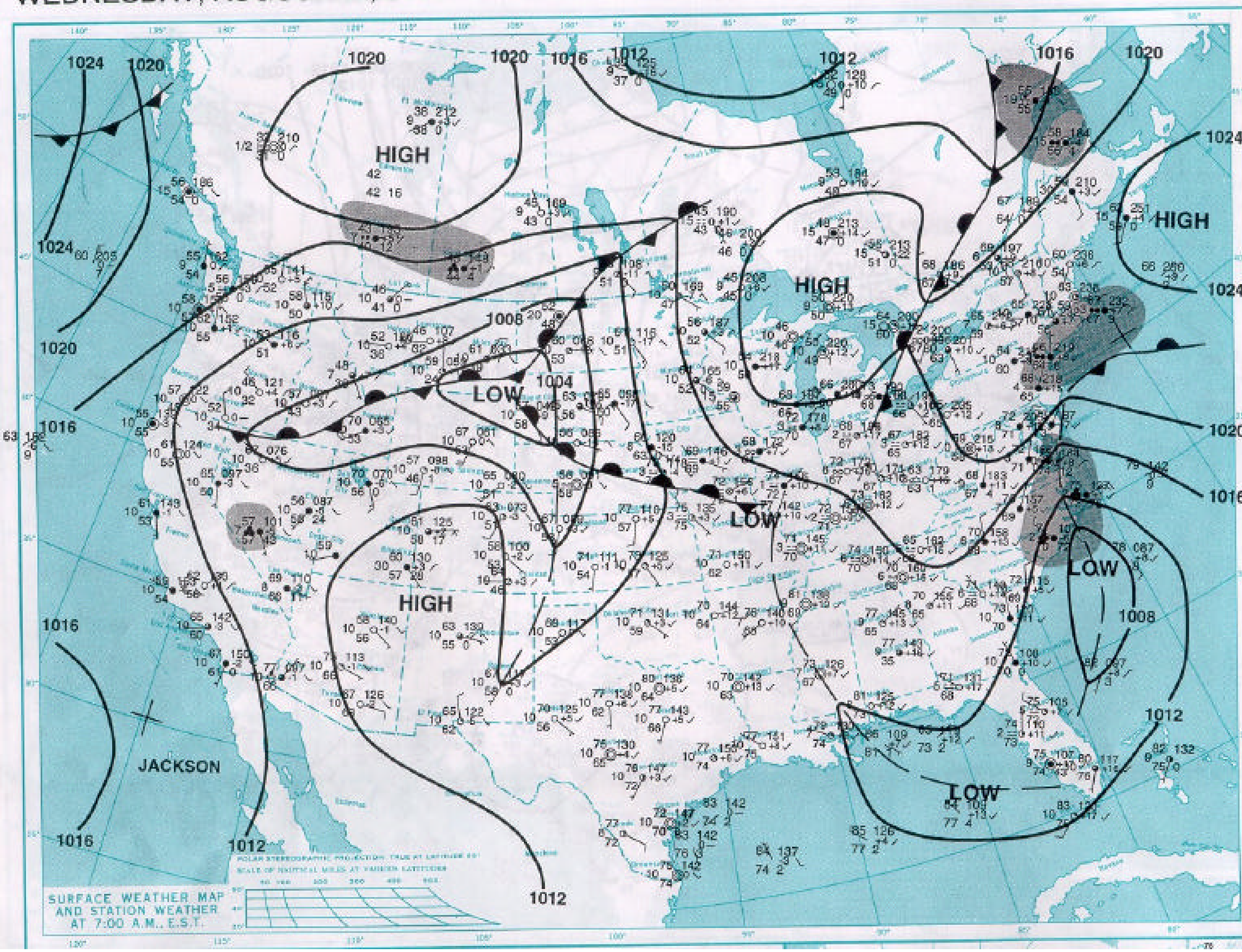

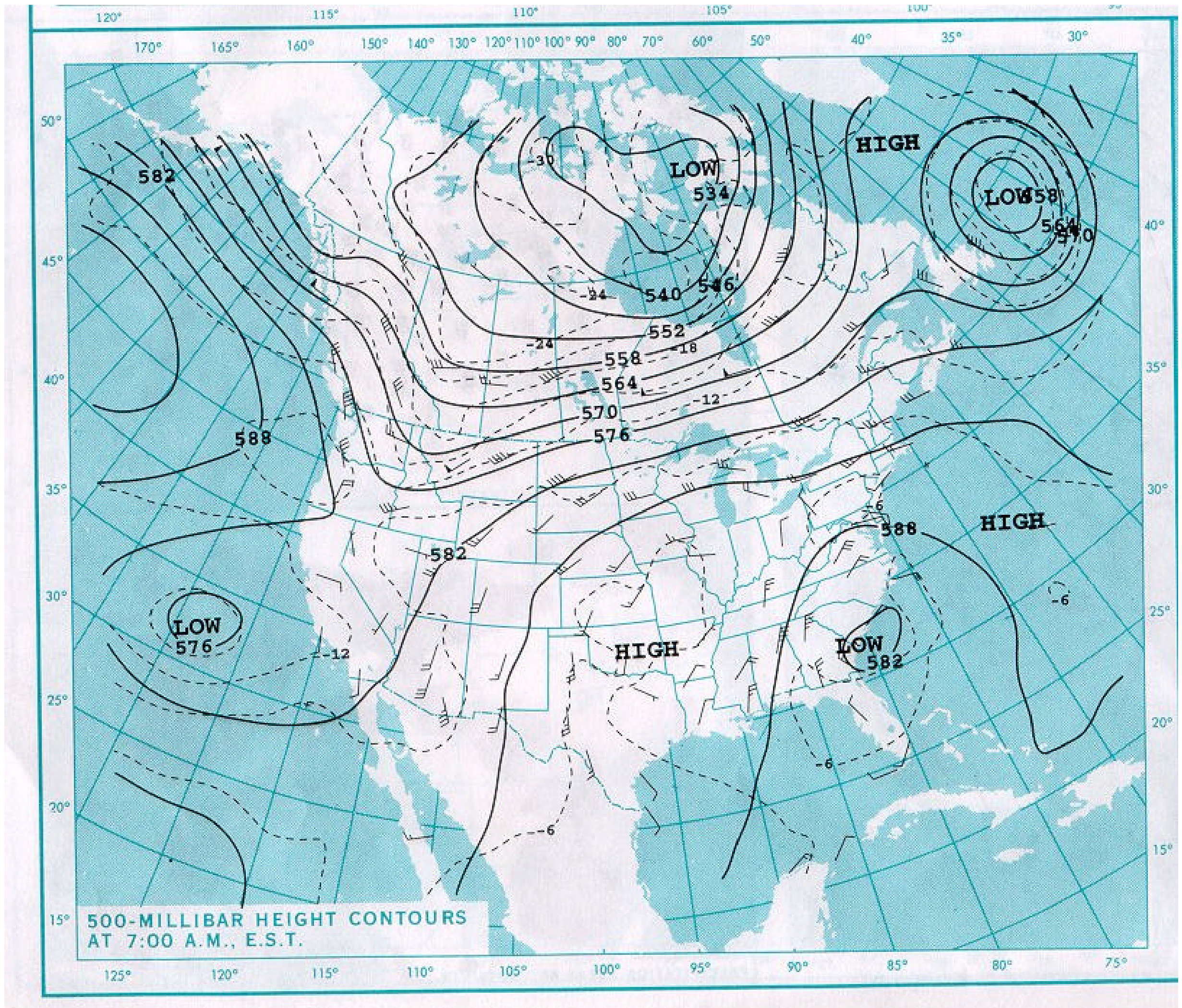

August 30, 2000

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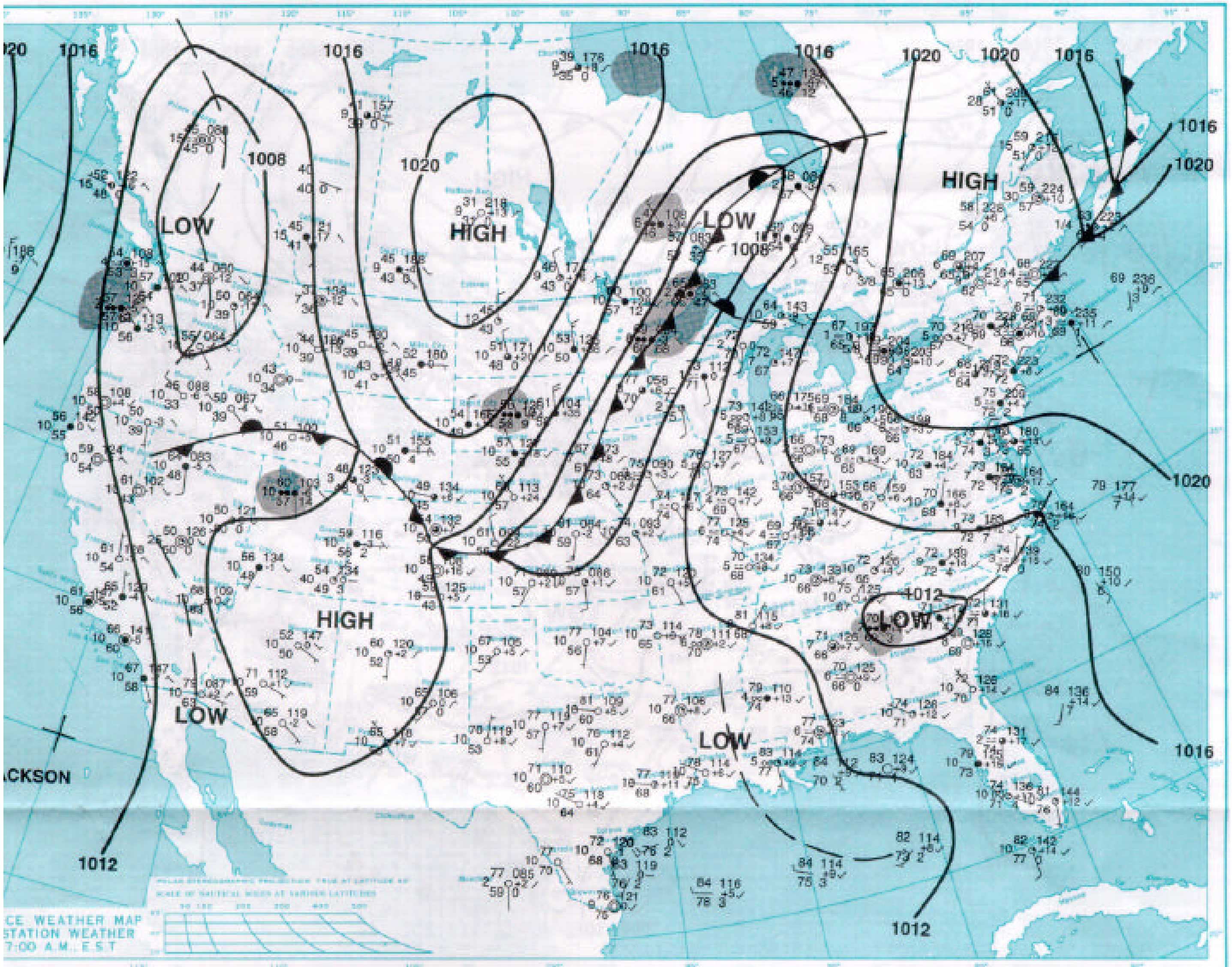

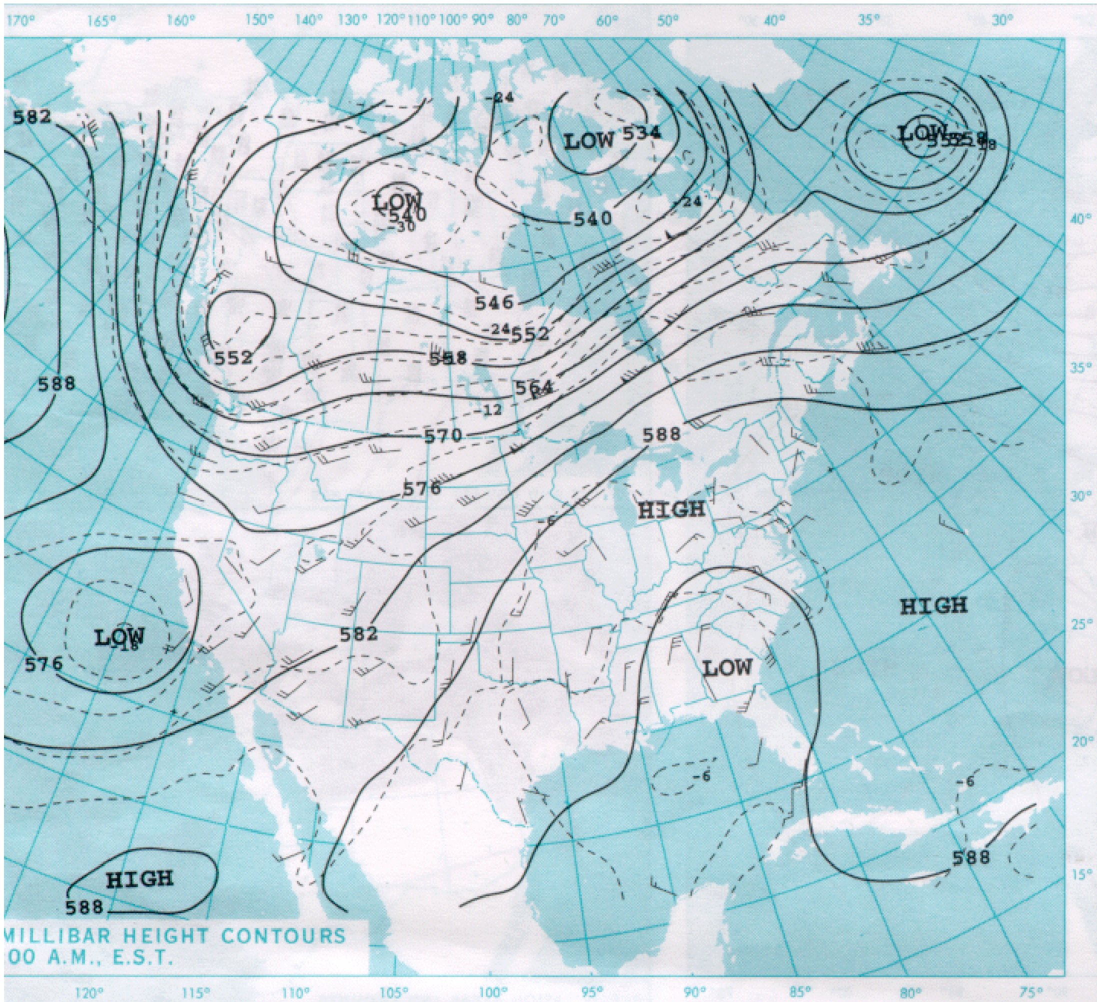

August 31, 2000

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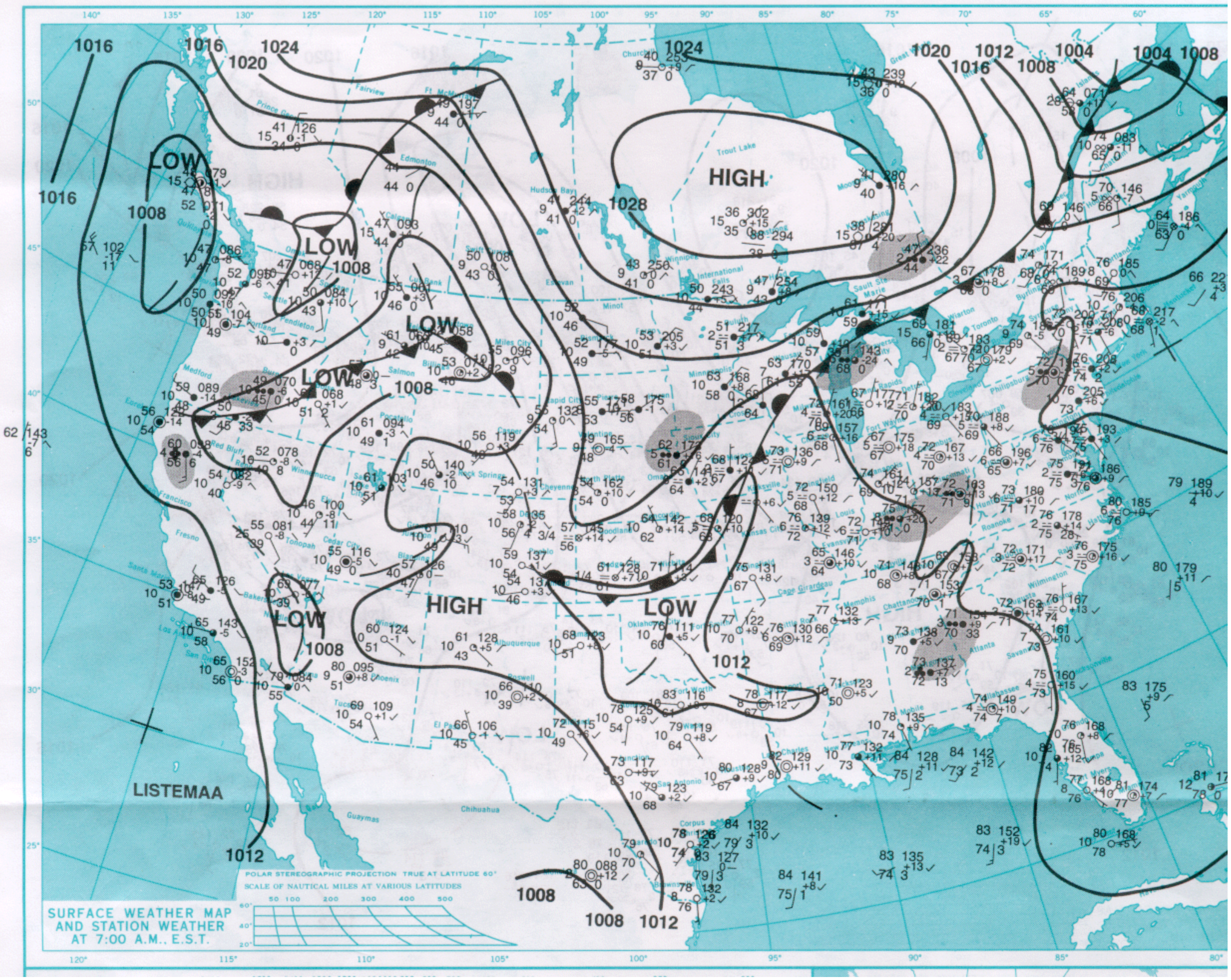

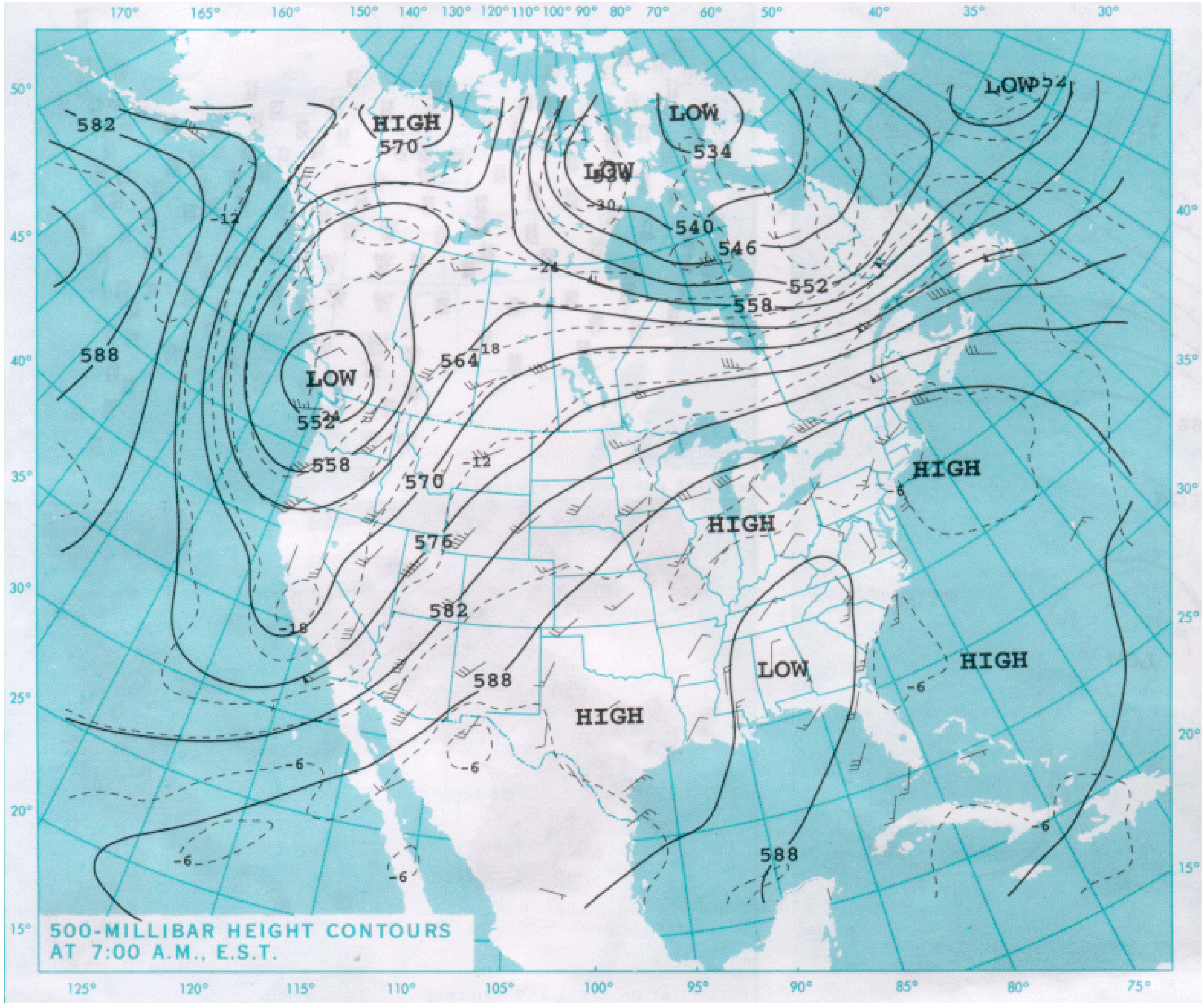

September 1, 2000

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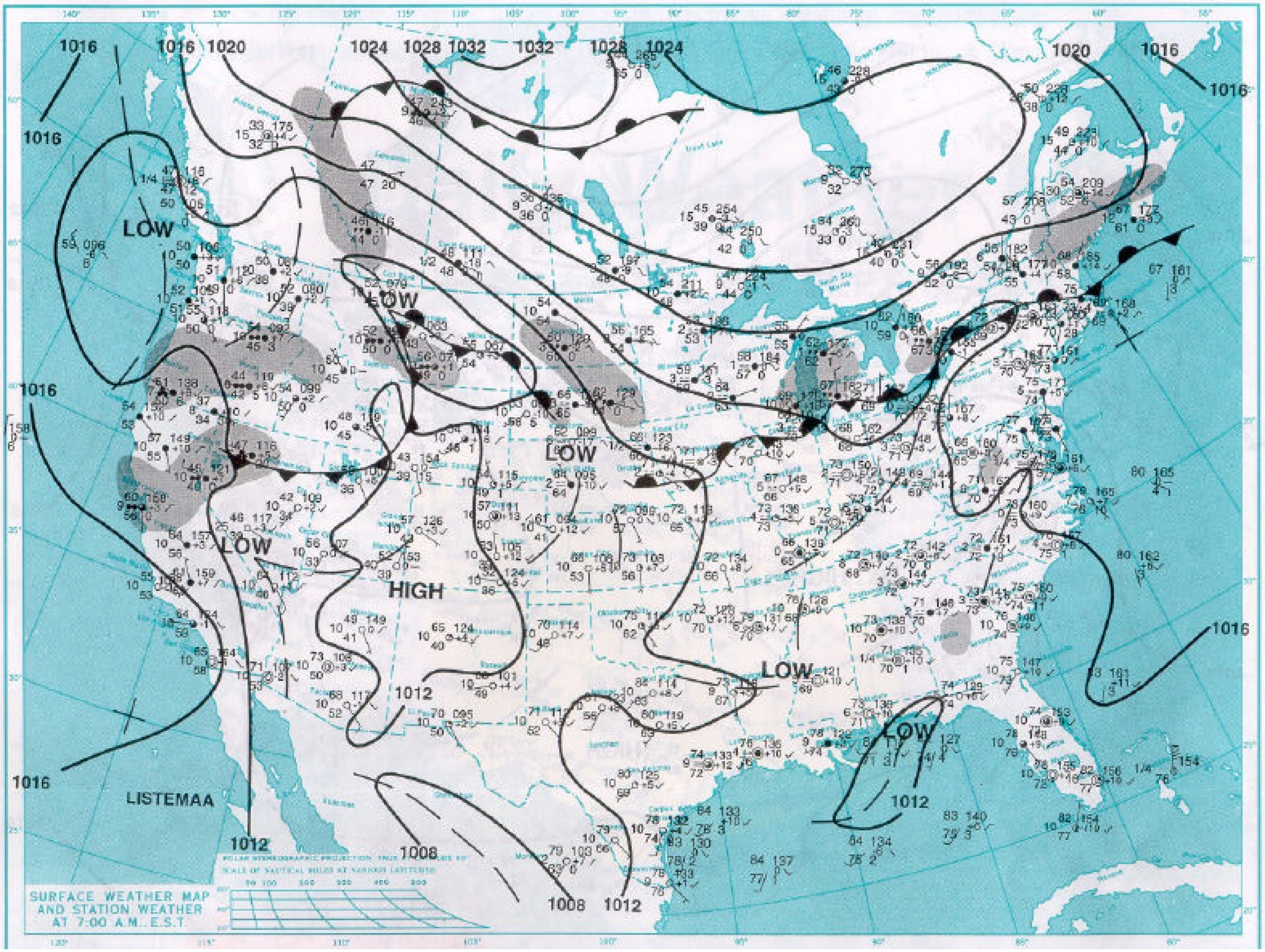

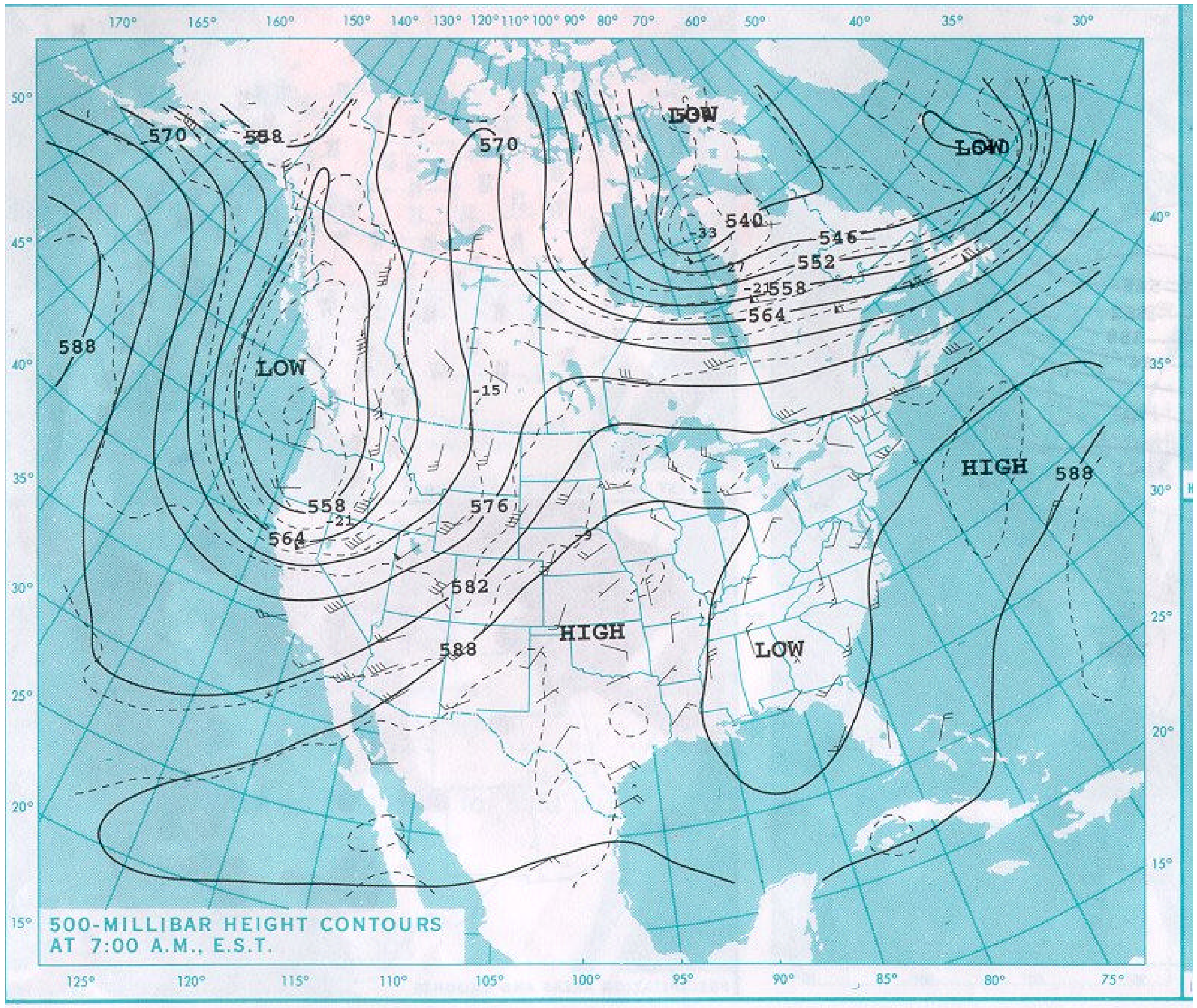

September 2, 2000

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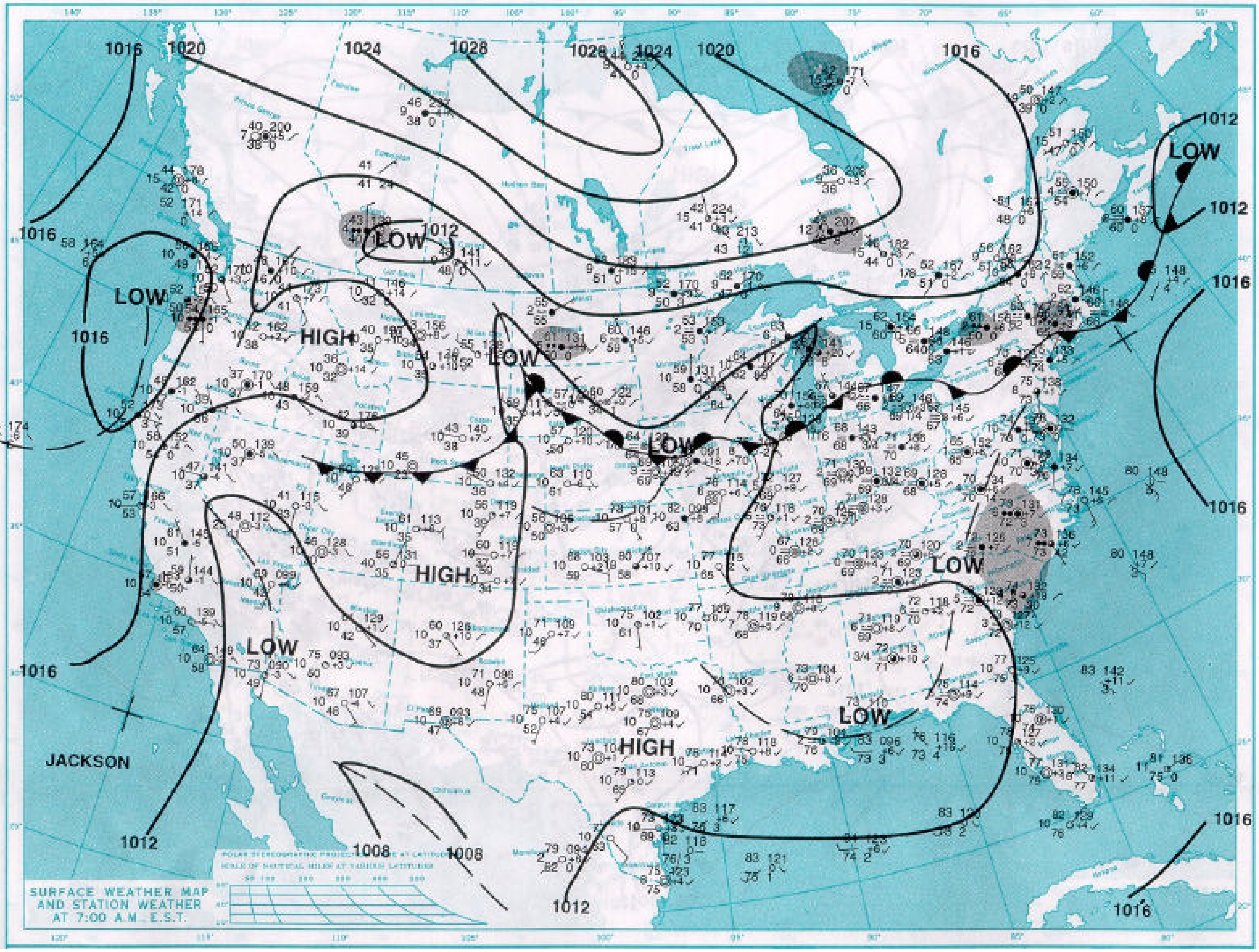

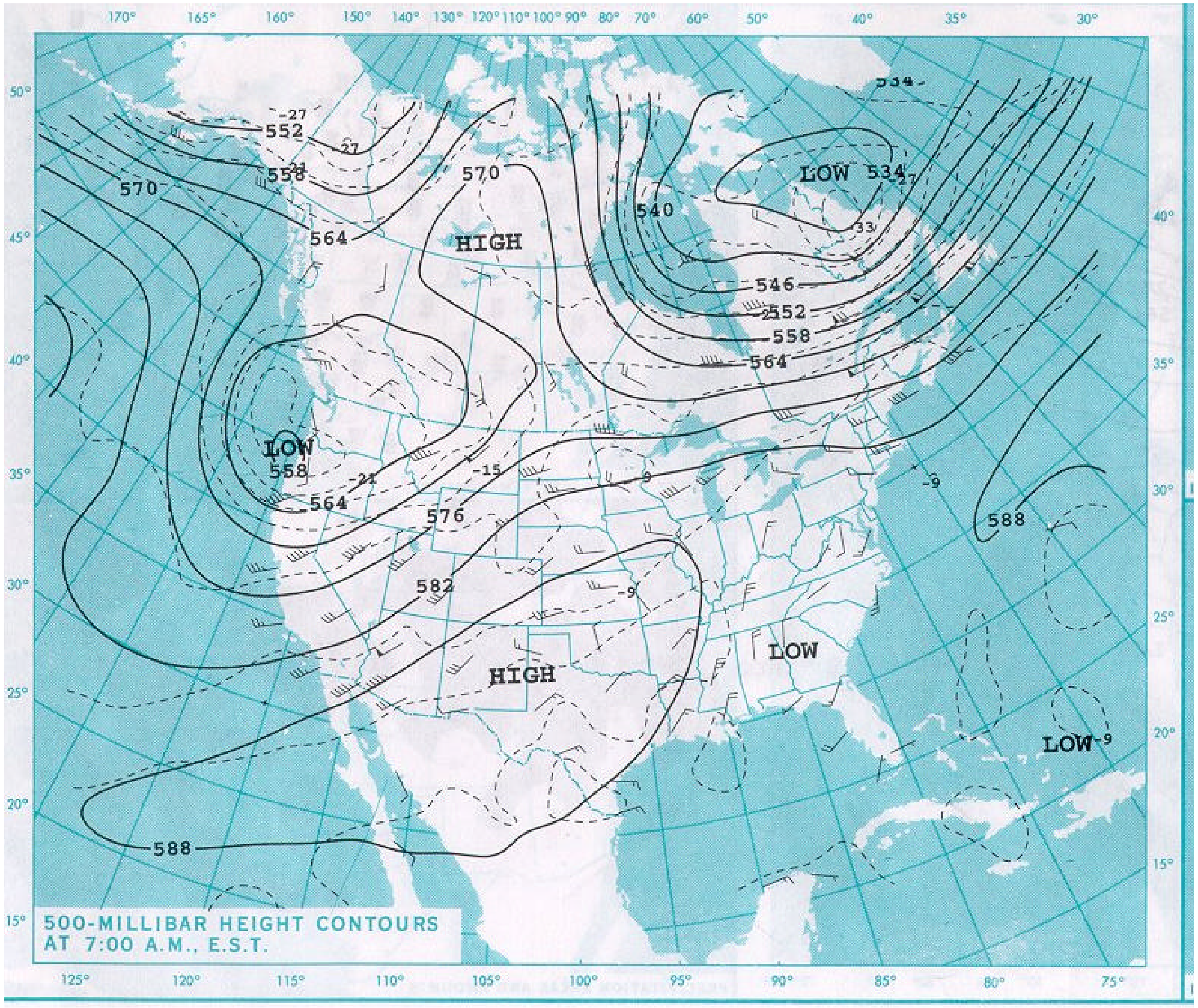

September 3, 2000

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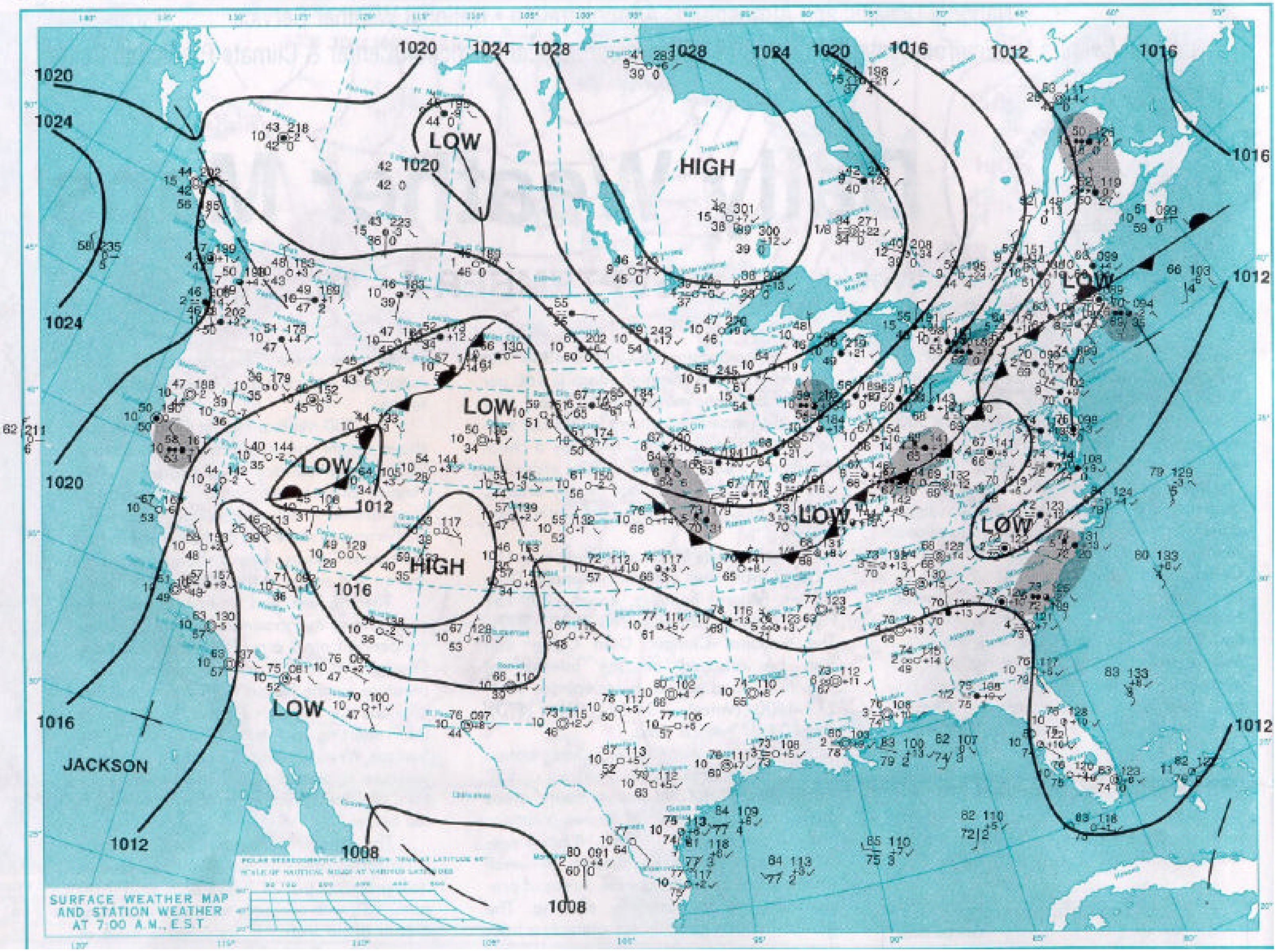

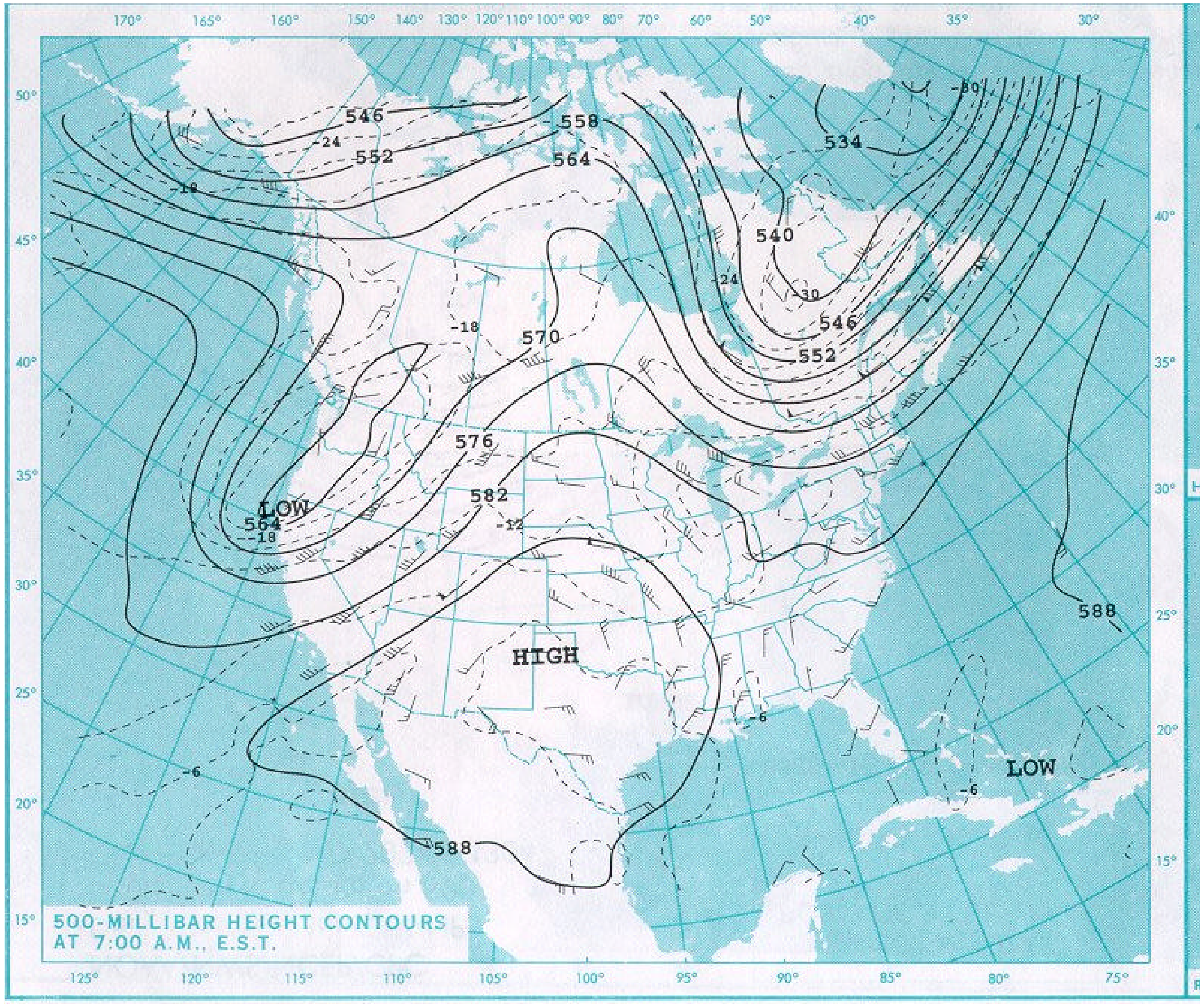

September 4, 2000

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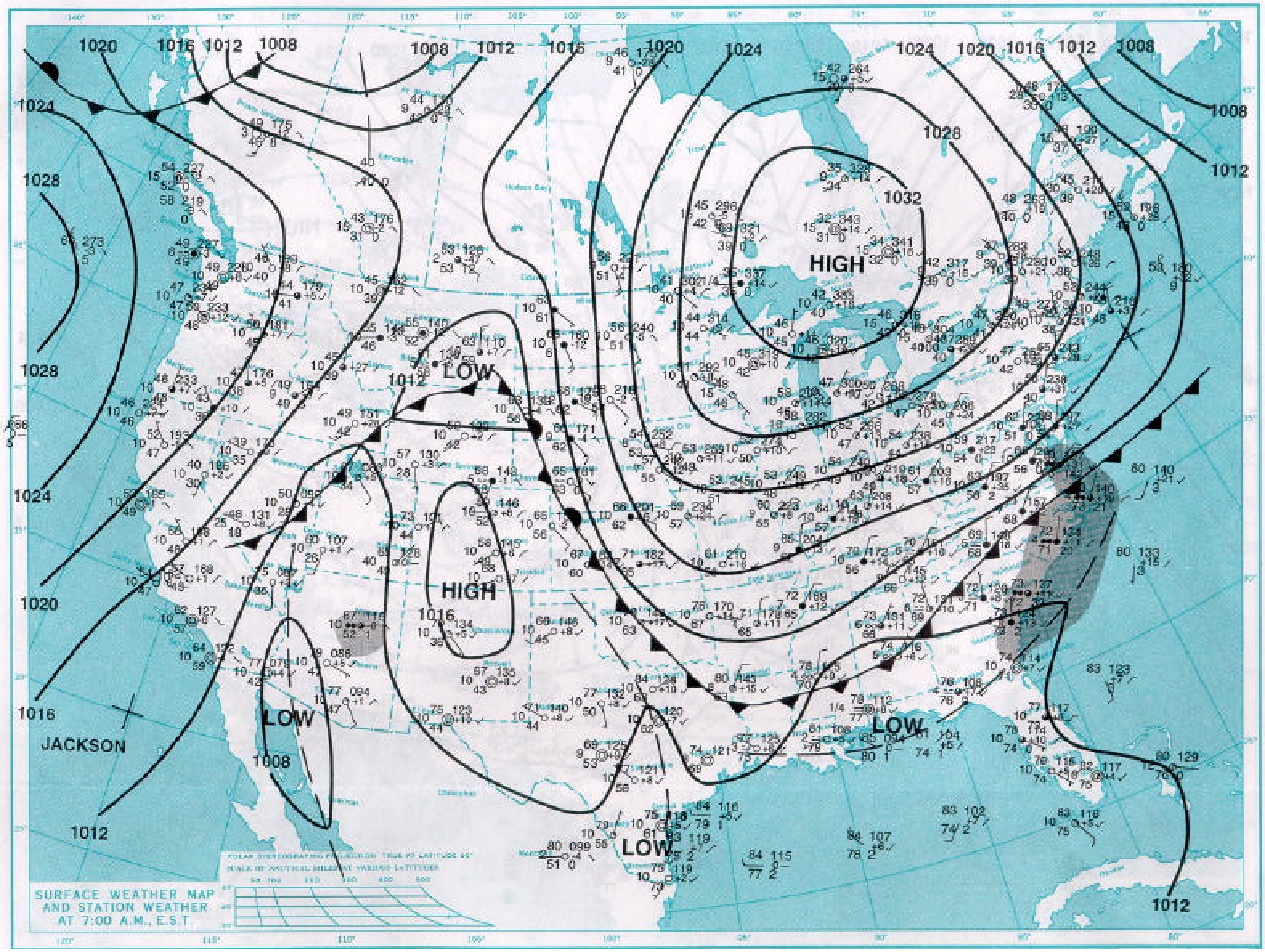

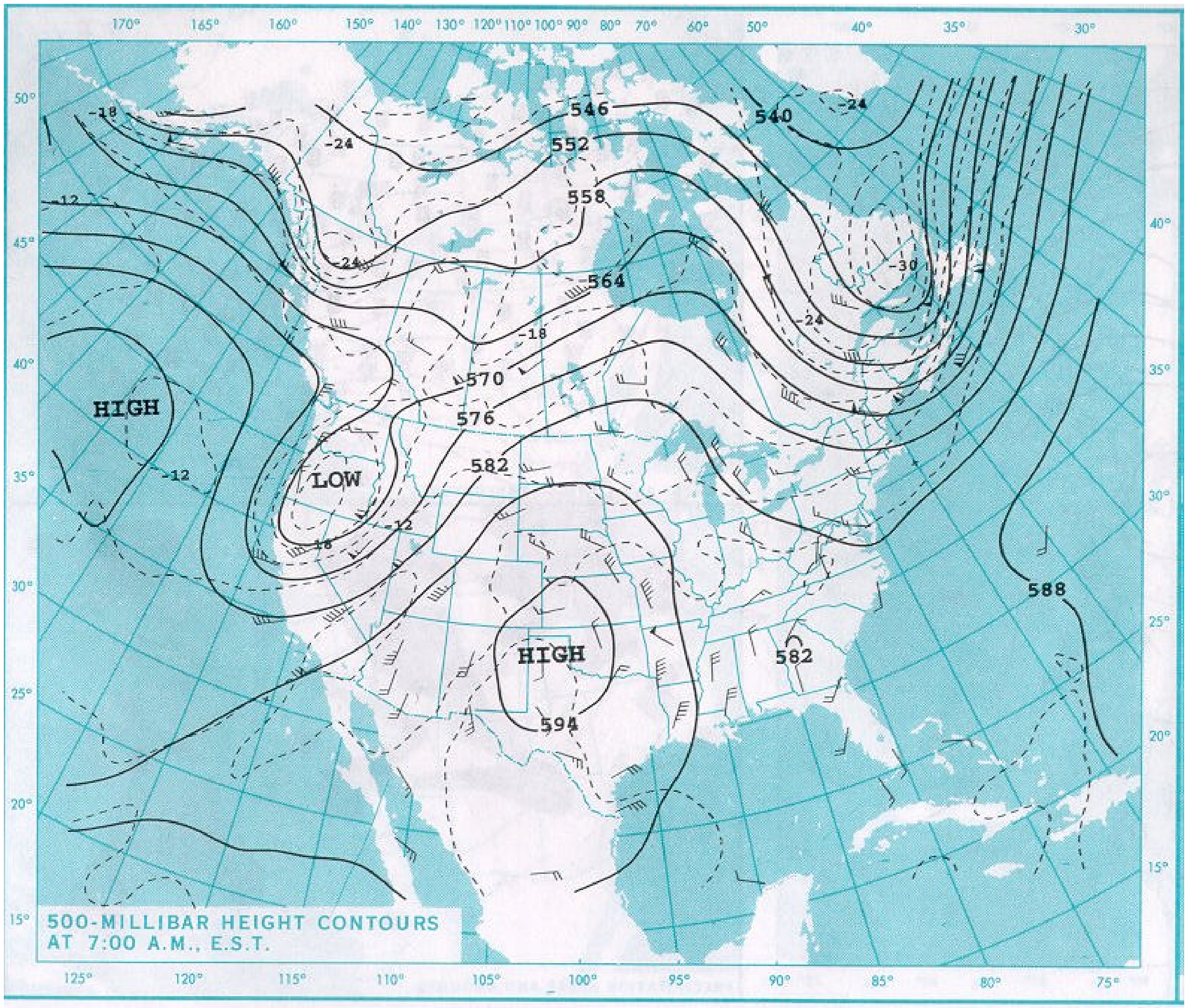

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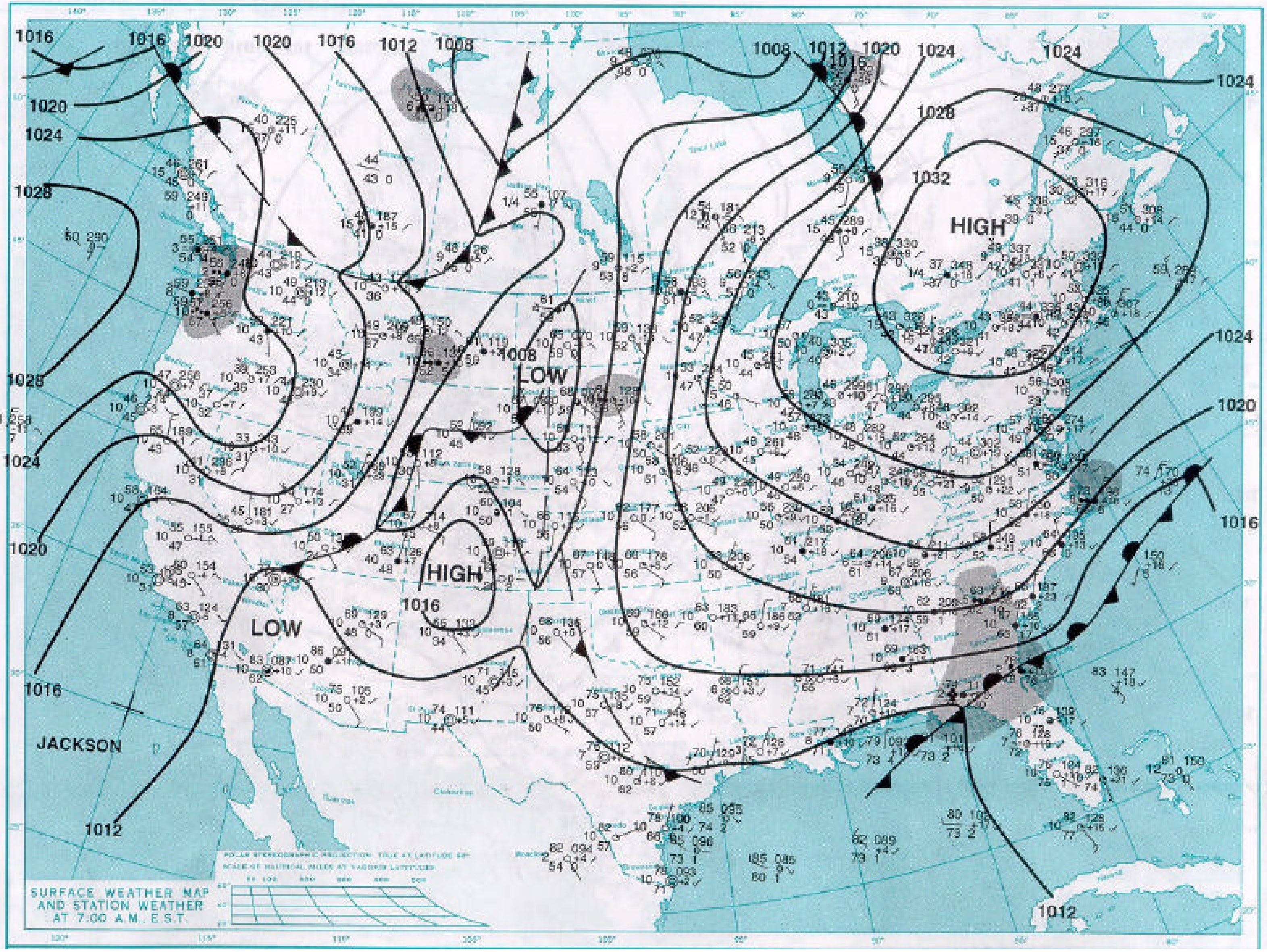

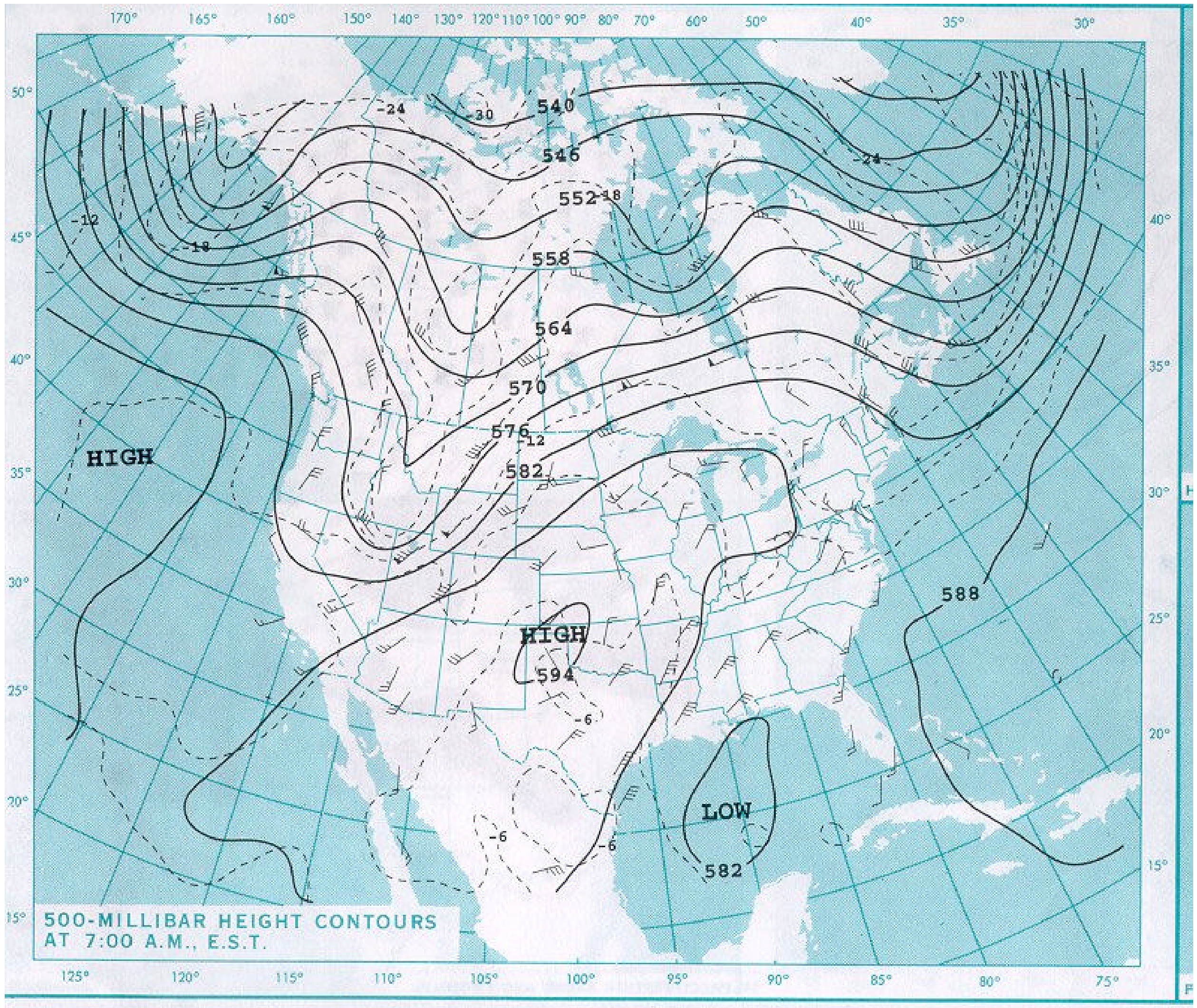

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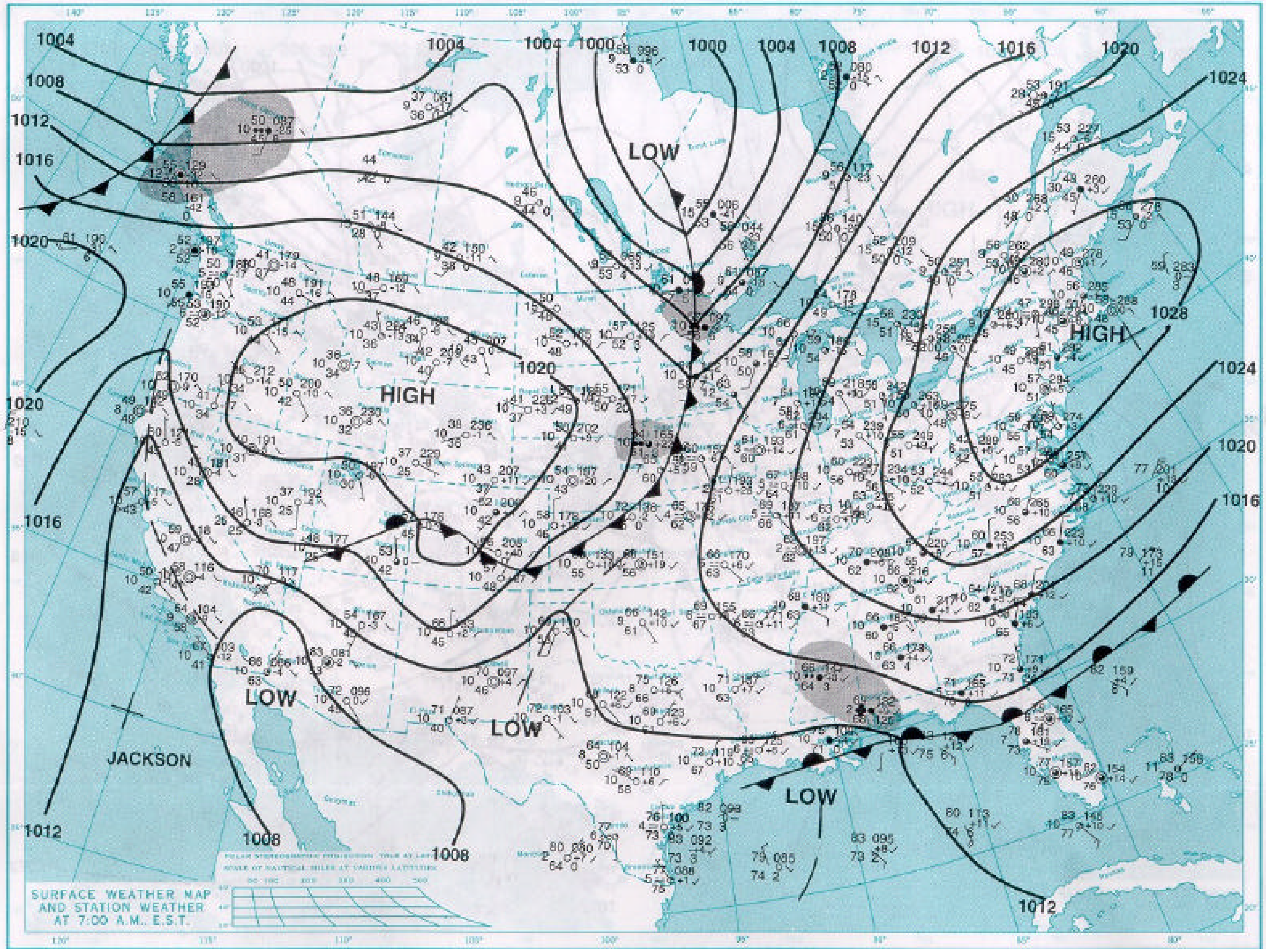

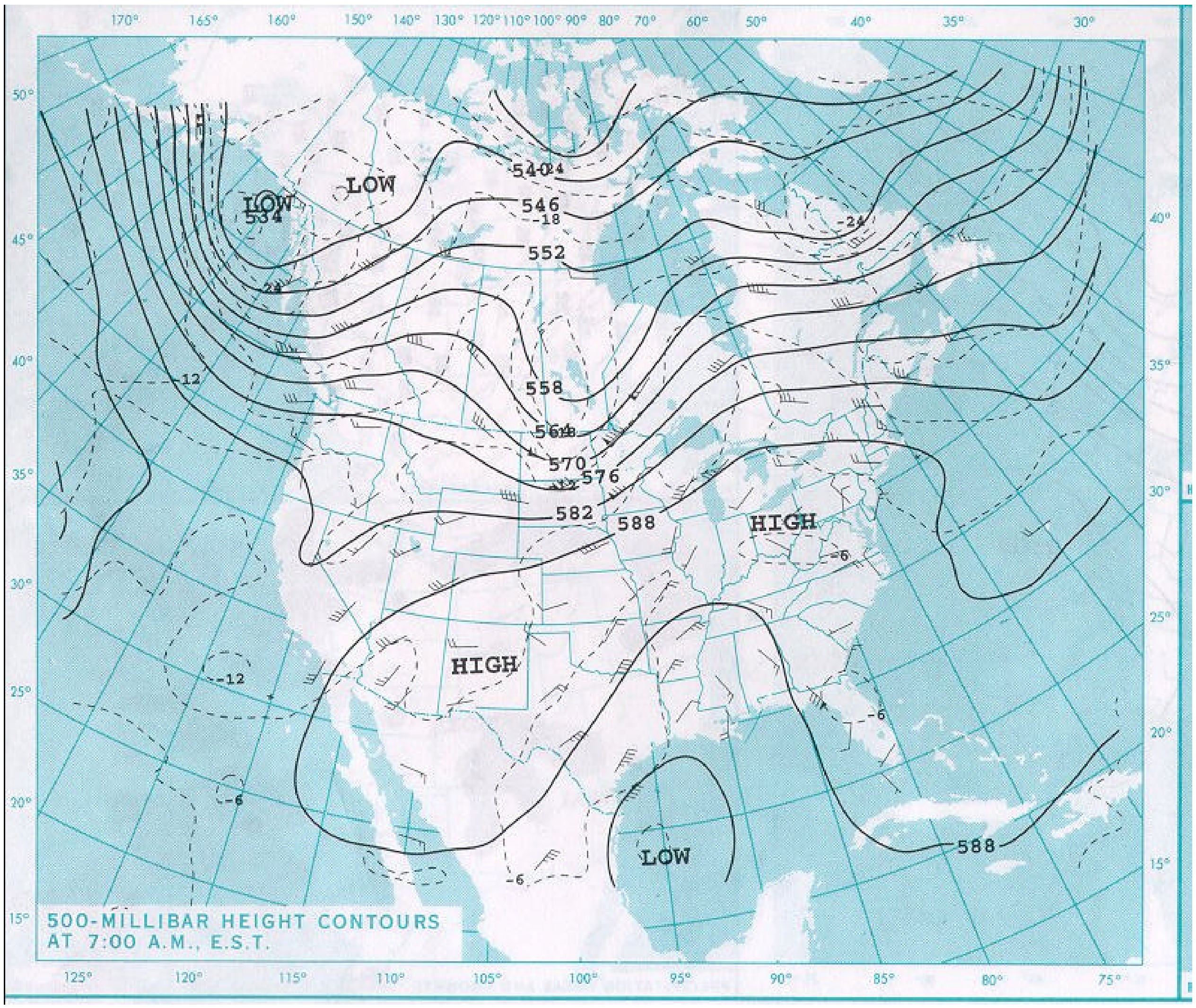

September 7, 2000

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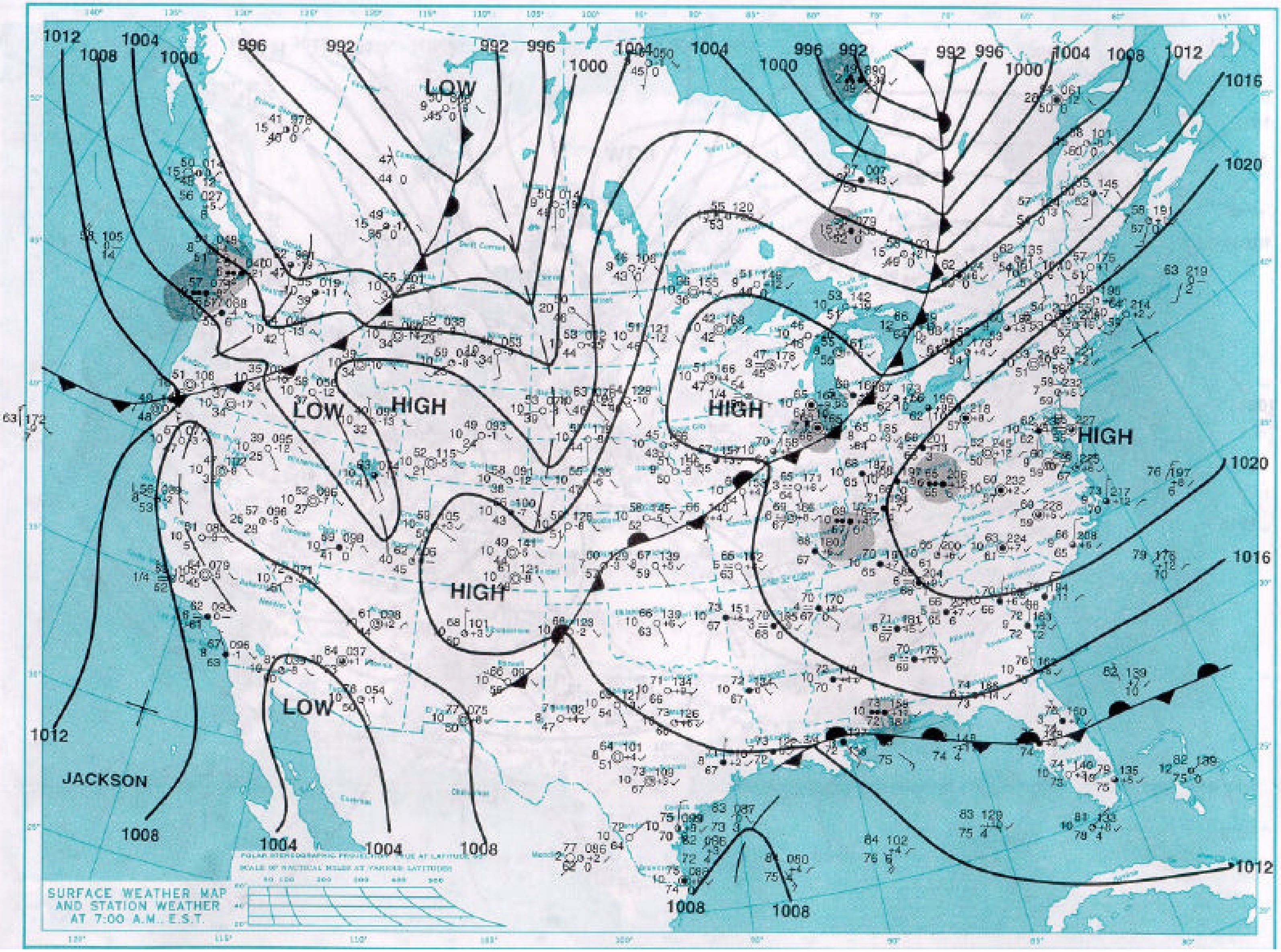

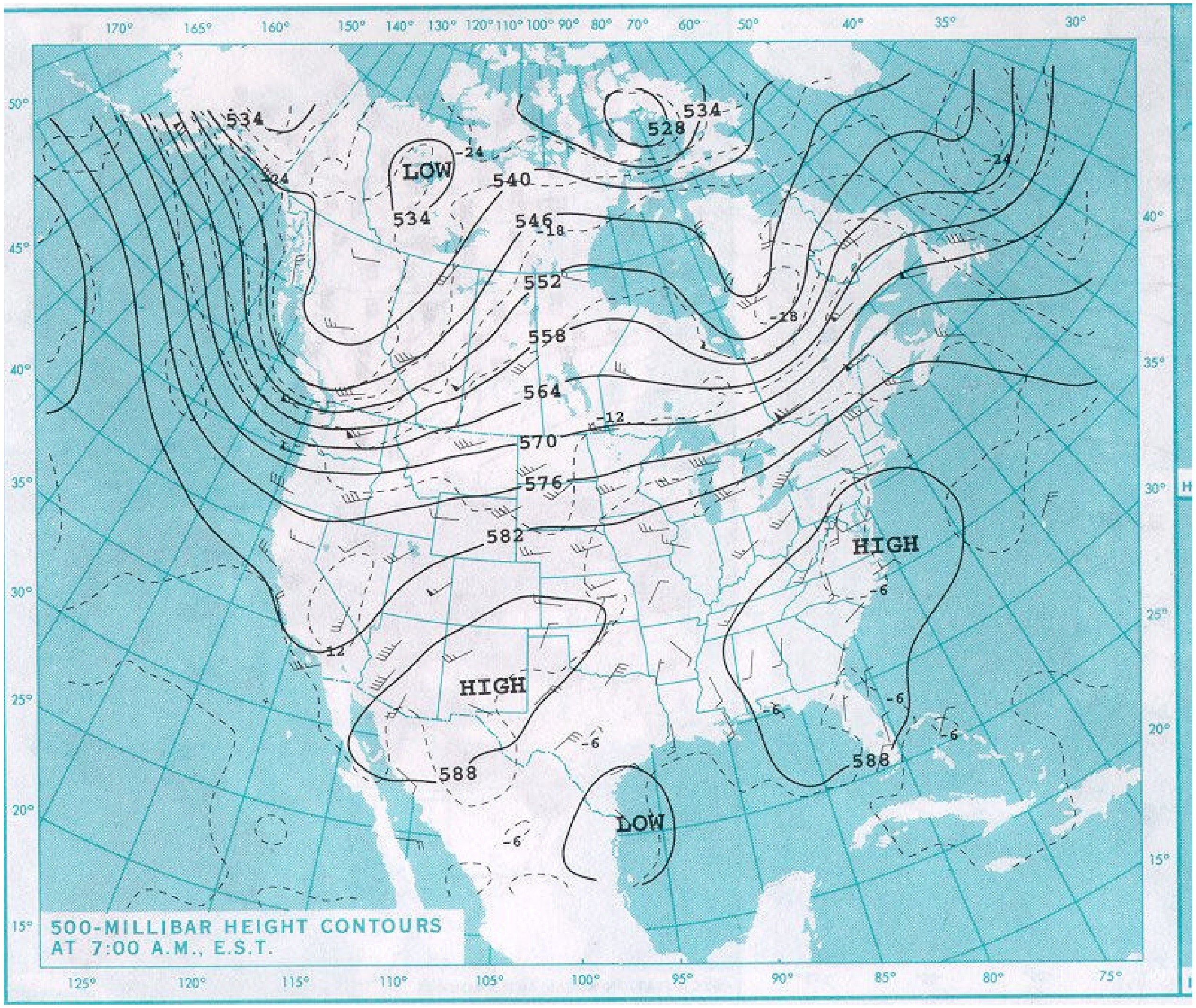

September 8, 2000

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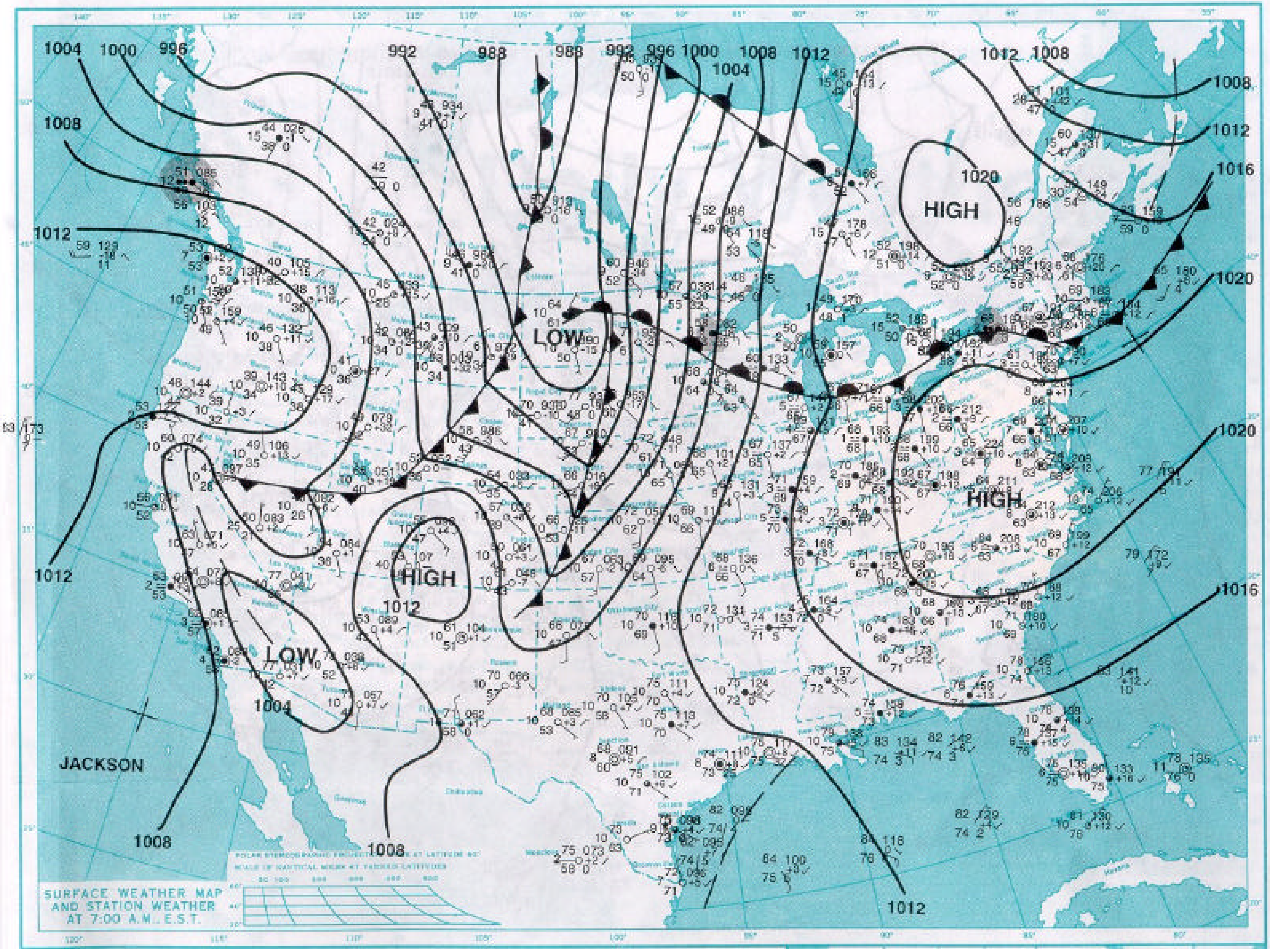

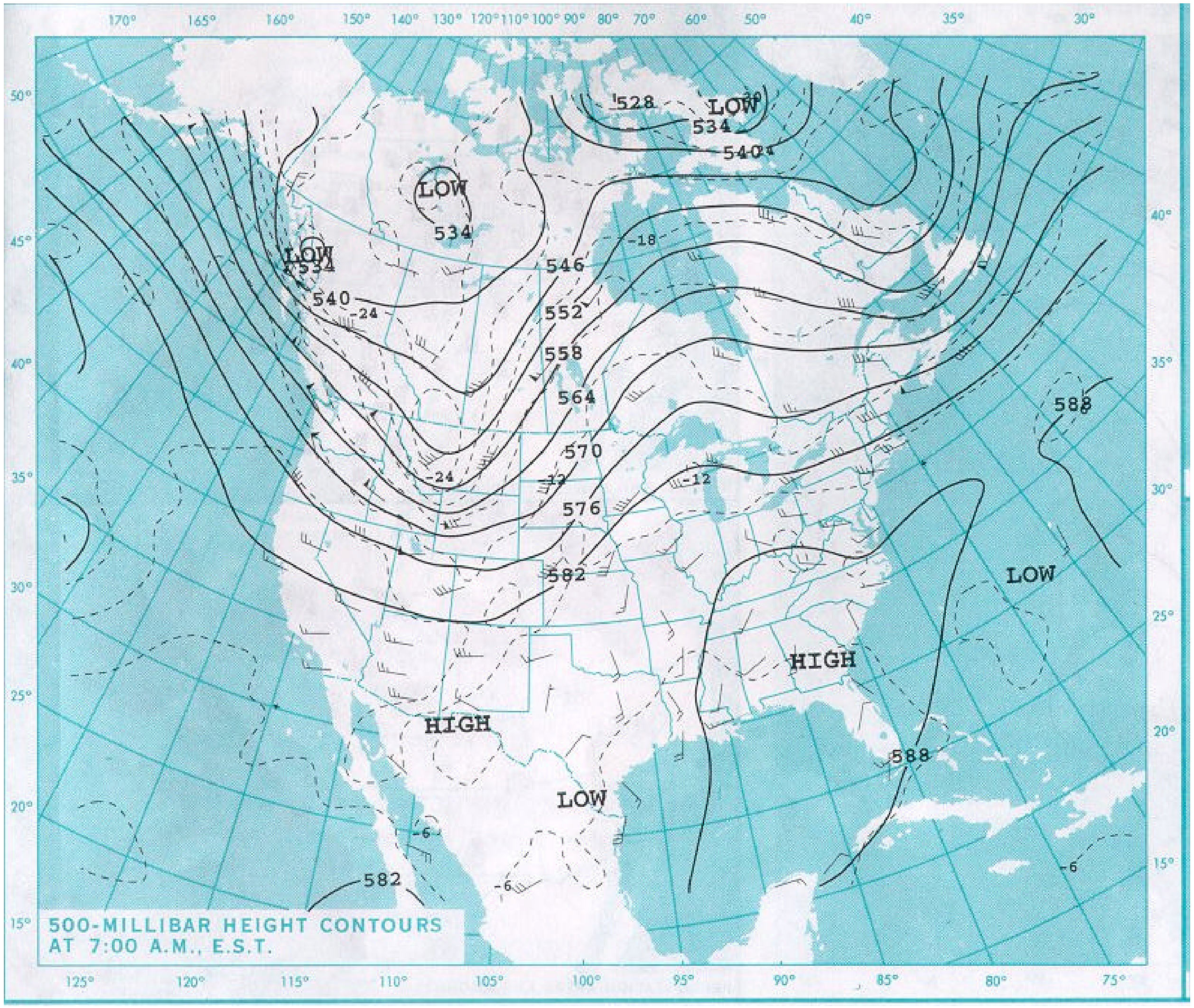

September 9, 2000

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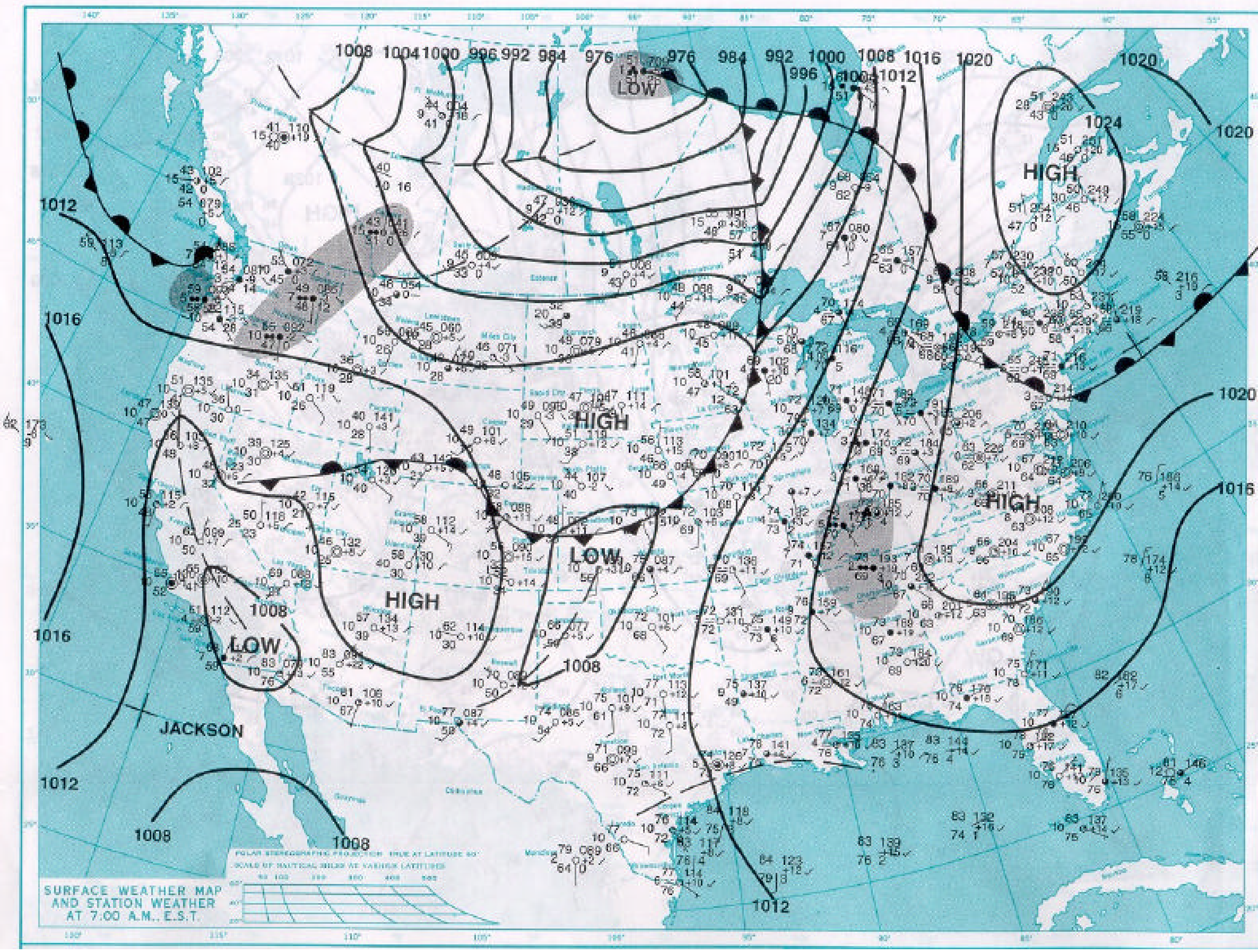

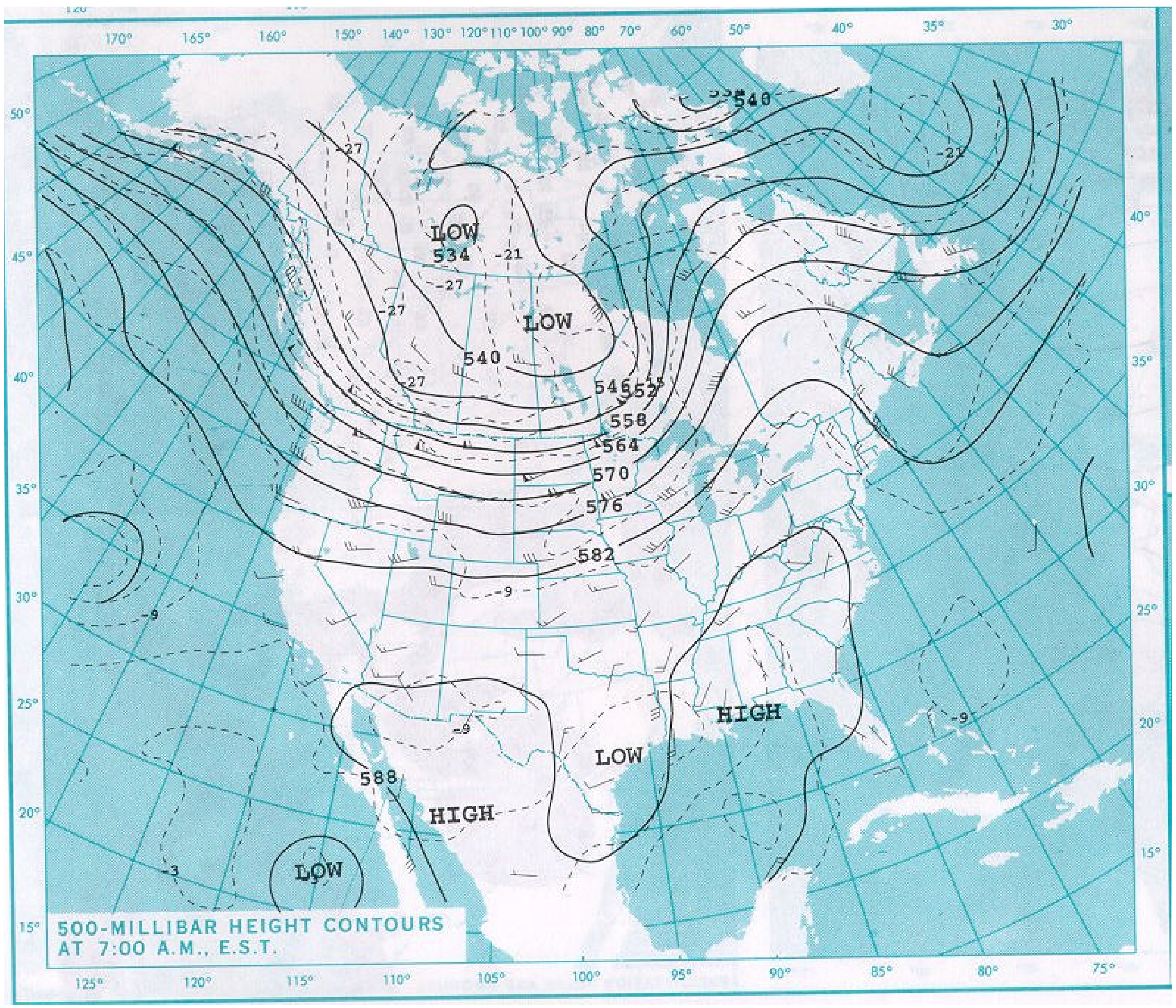

September 10, 2000

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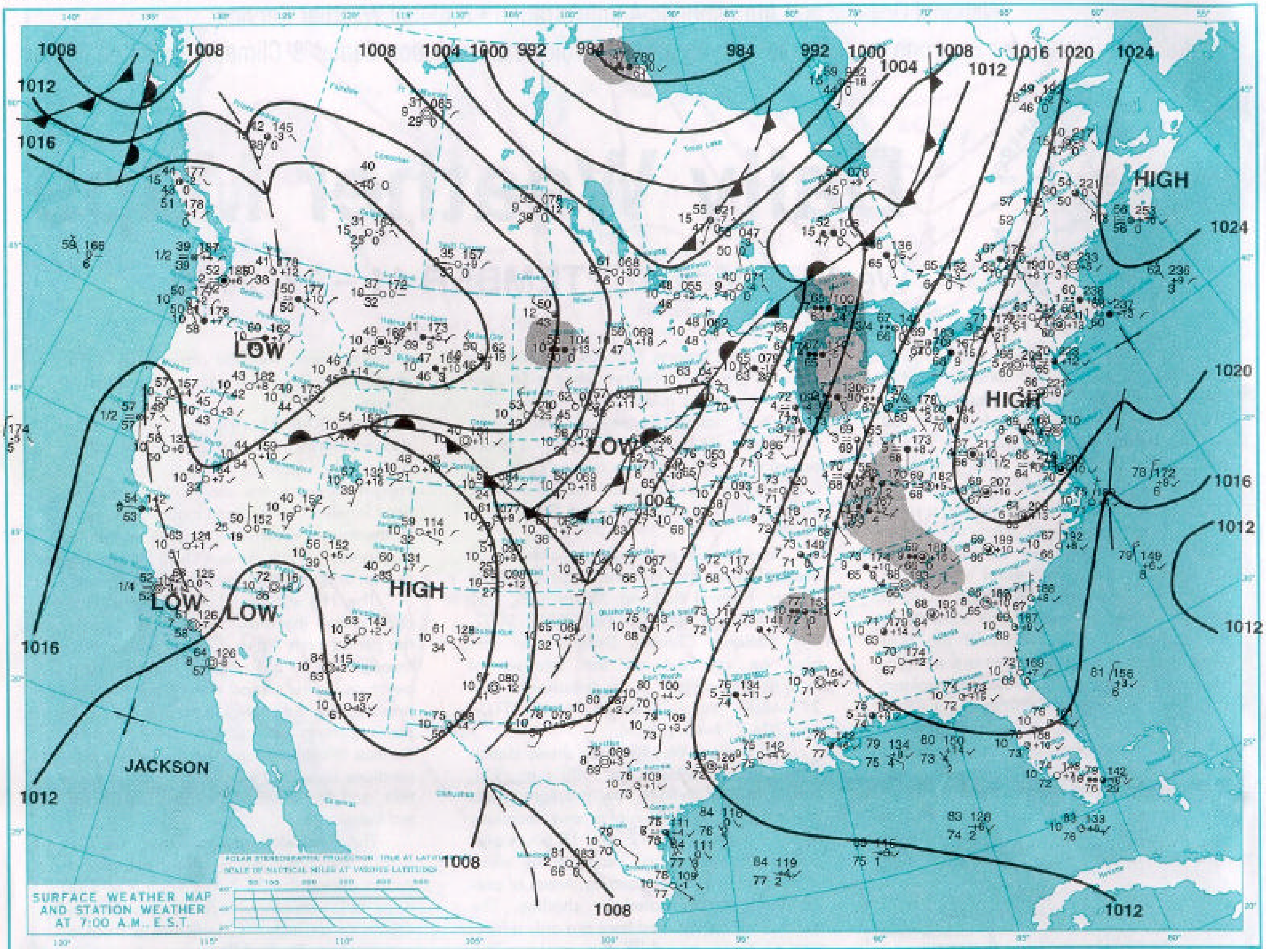

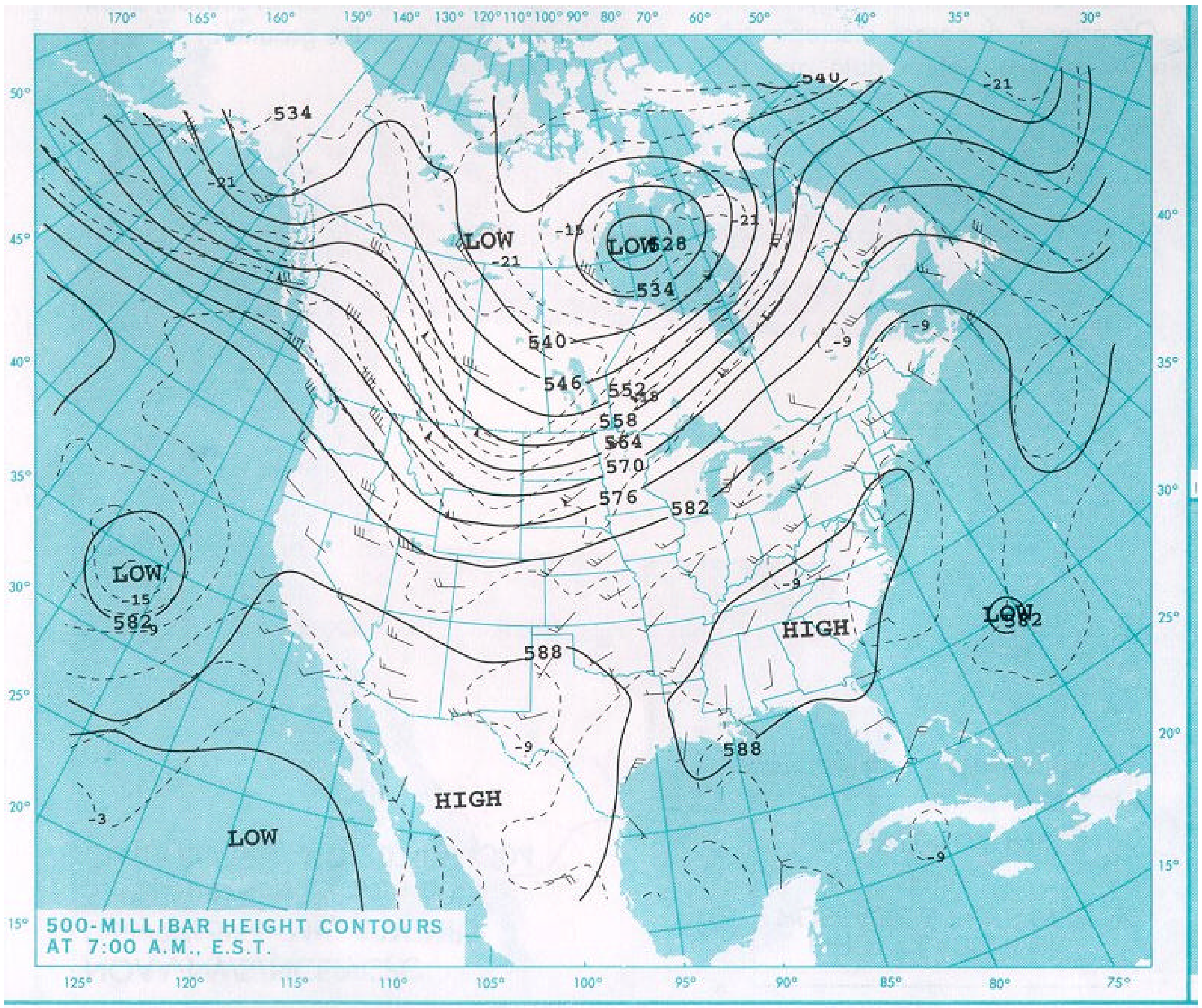

September 11, 2000

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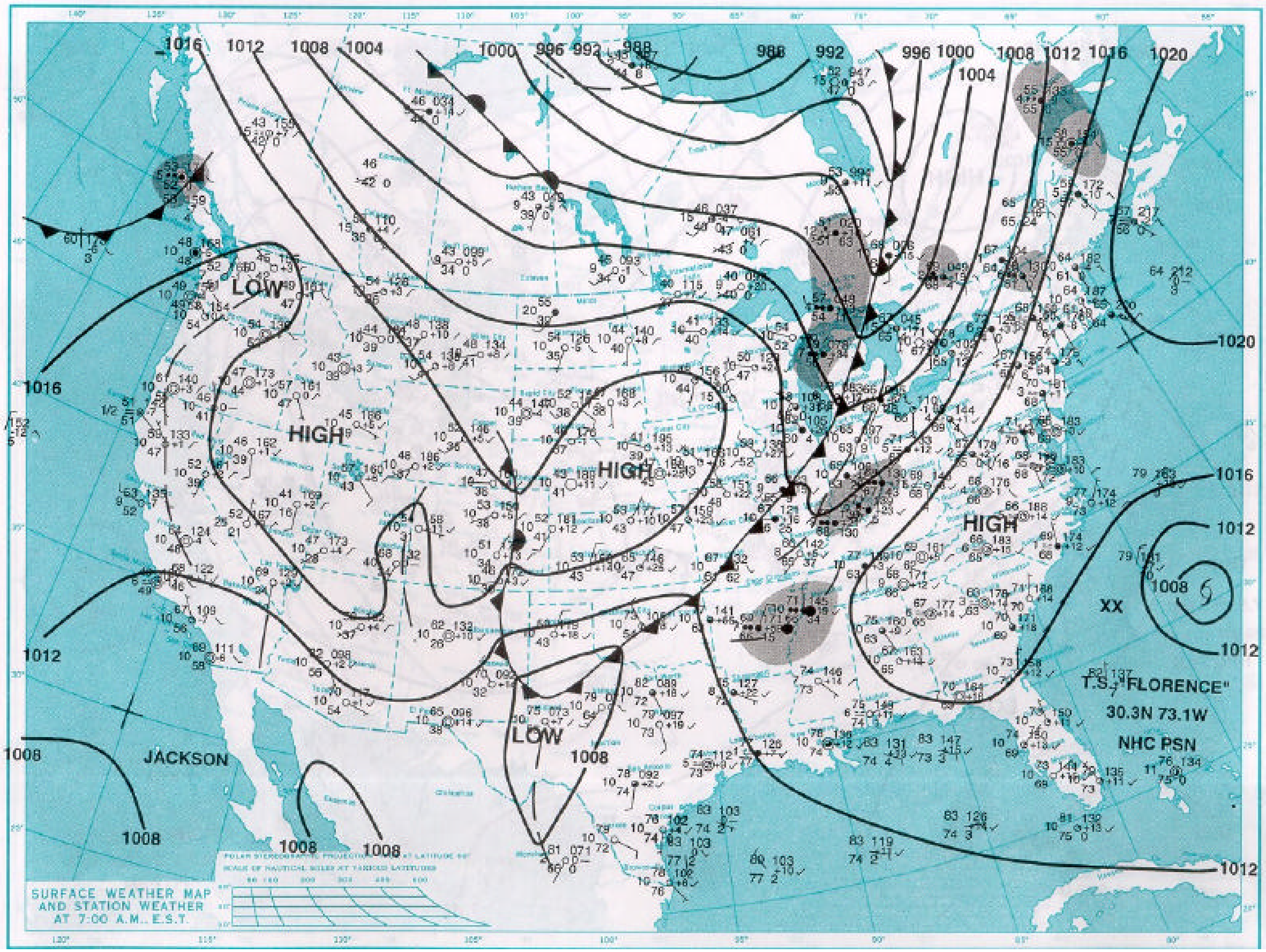

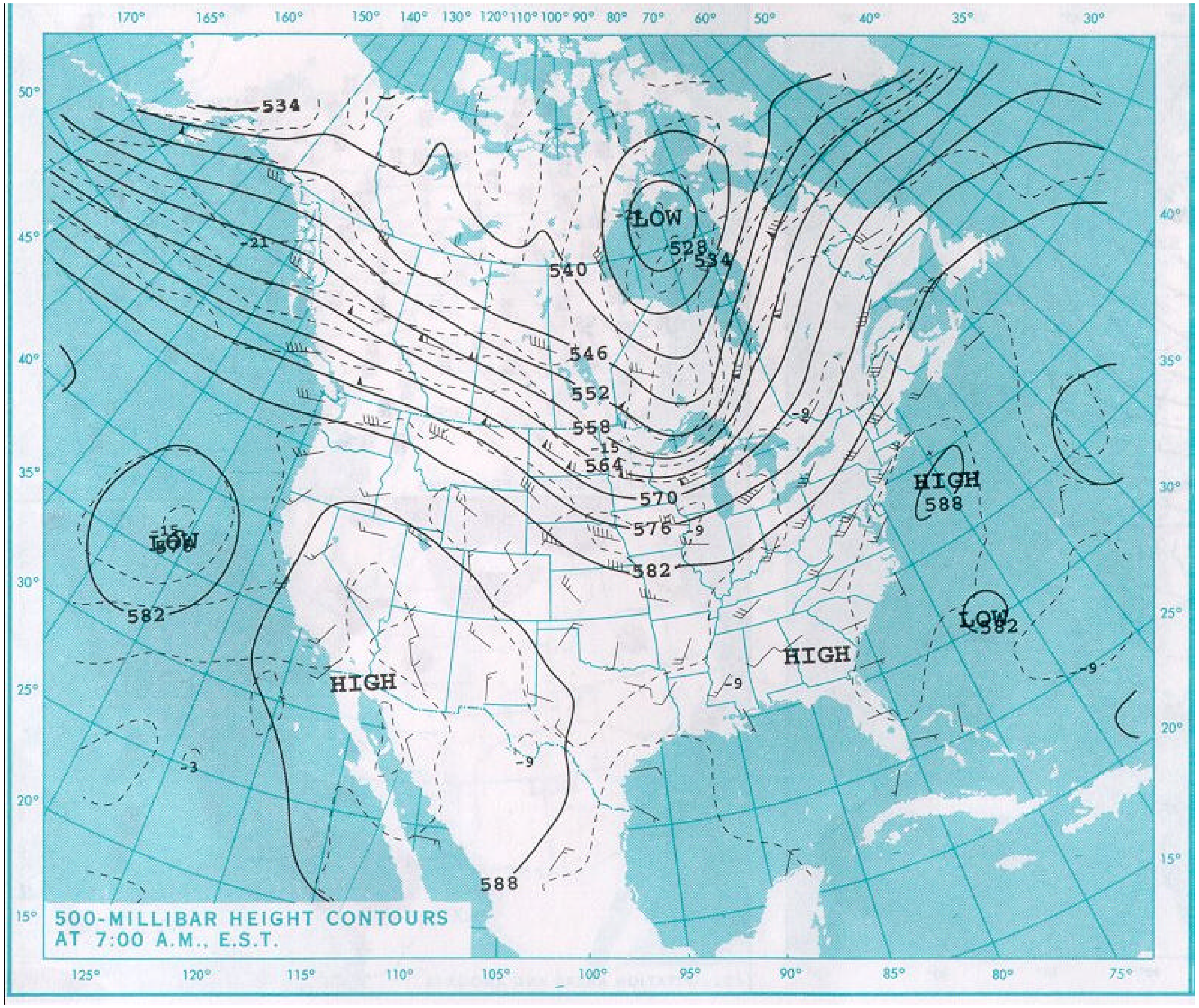

September 12, 2000

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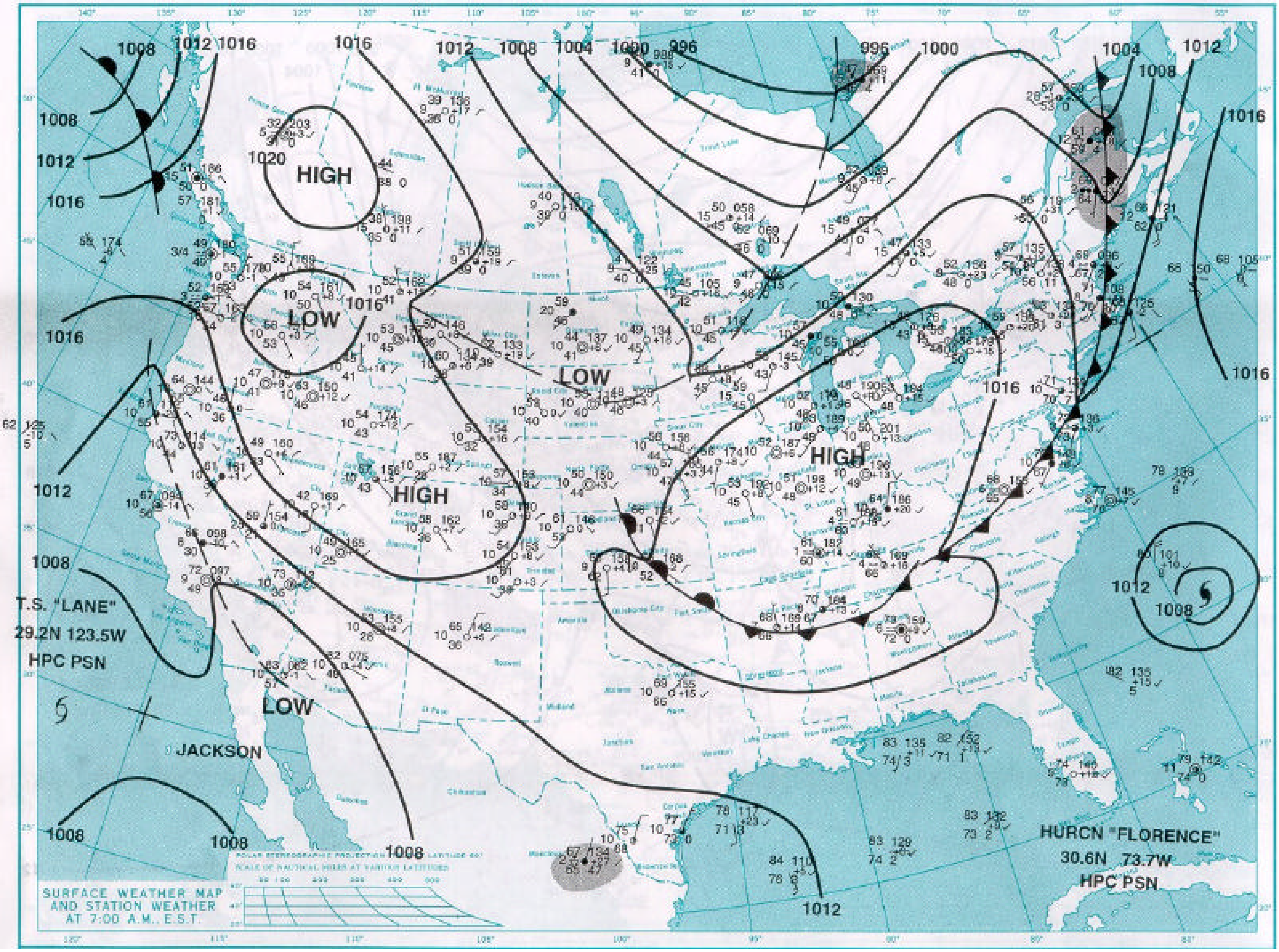

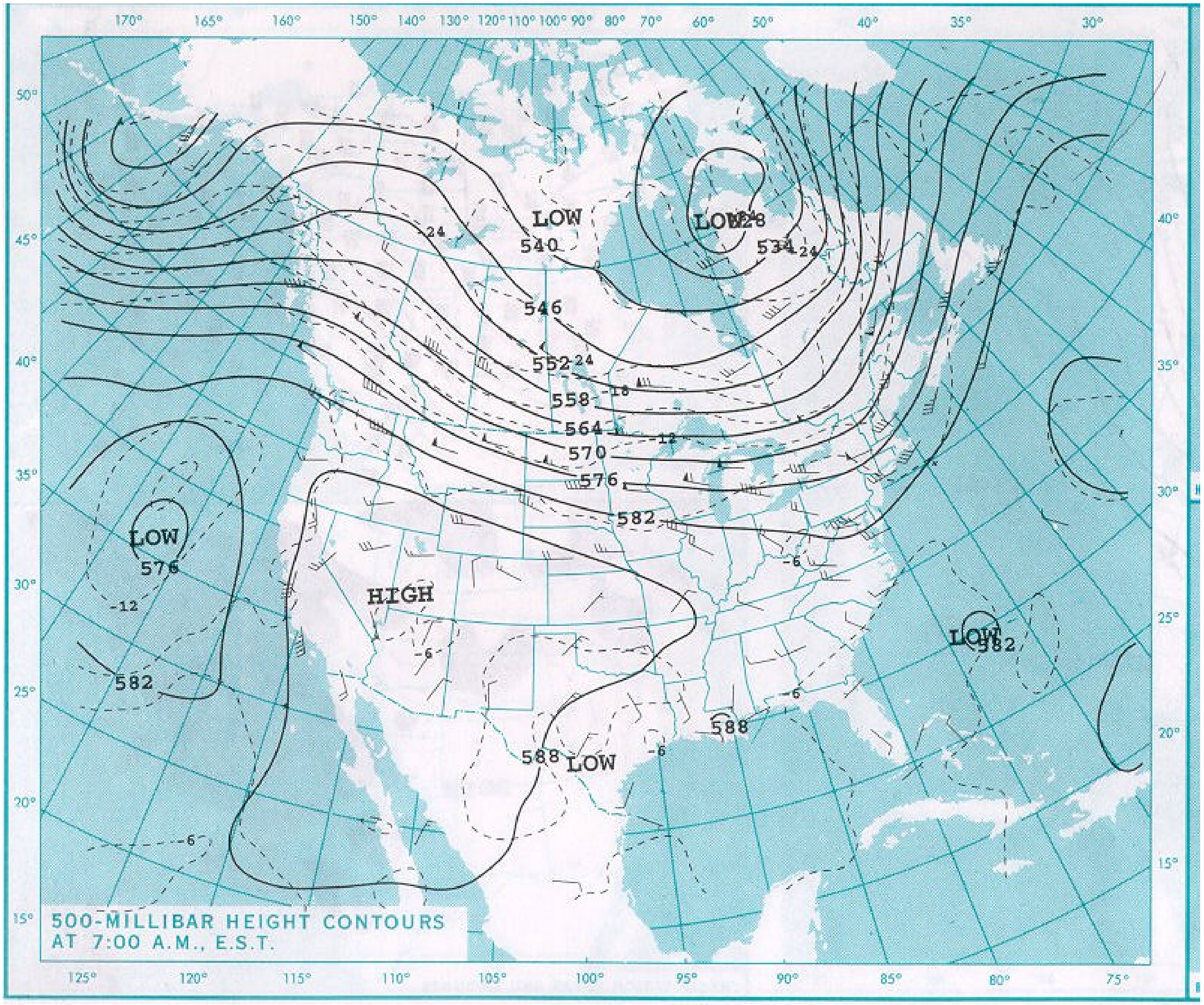

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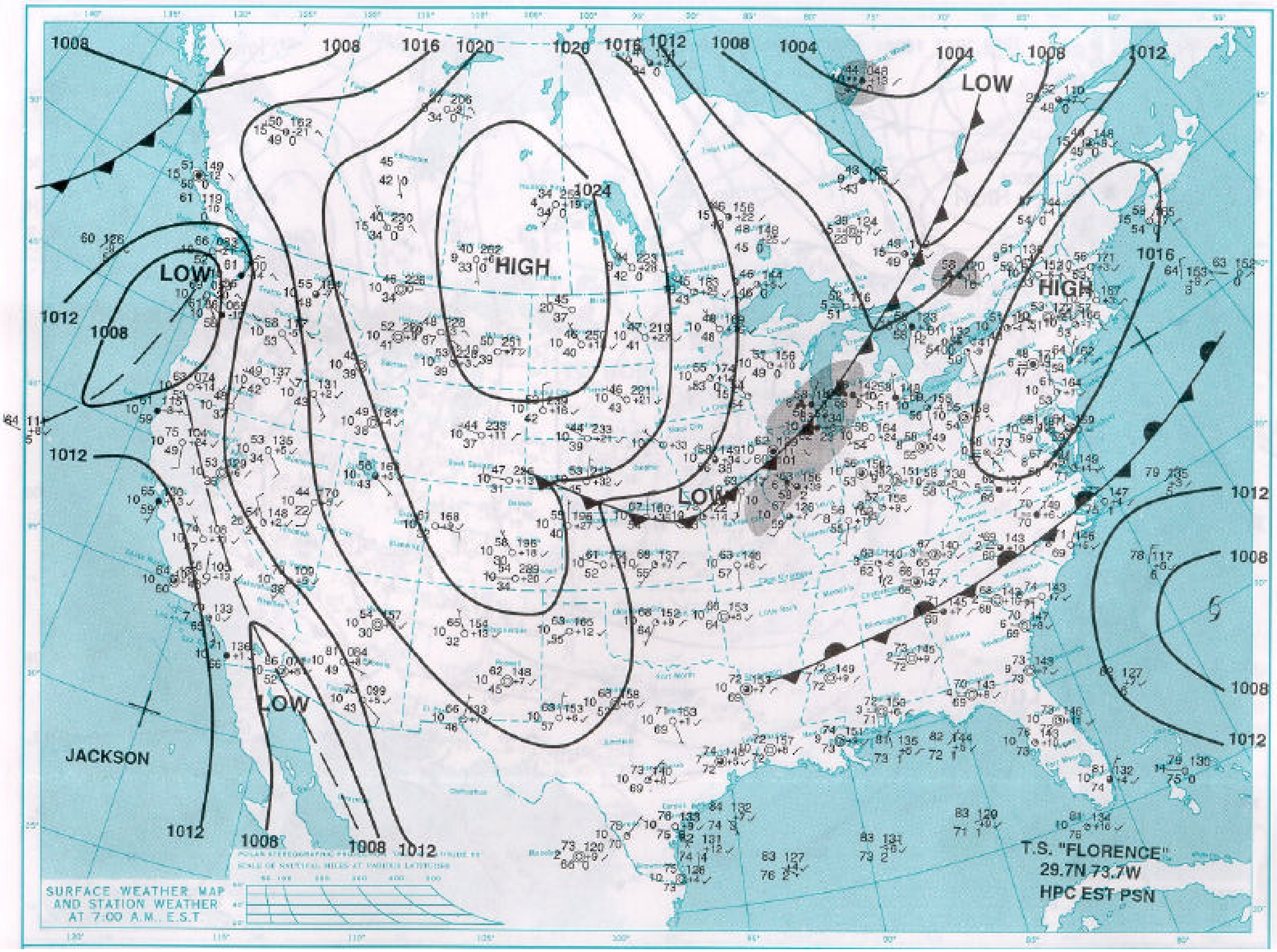
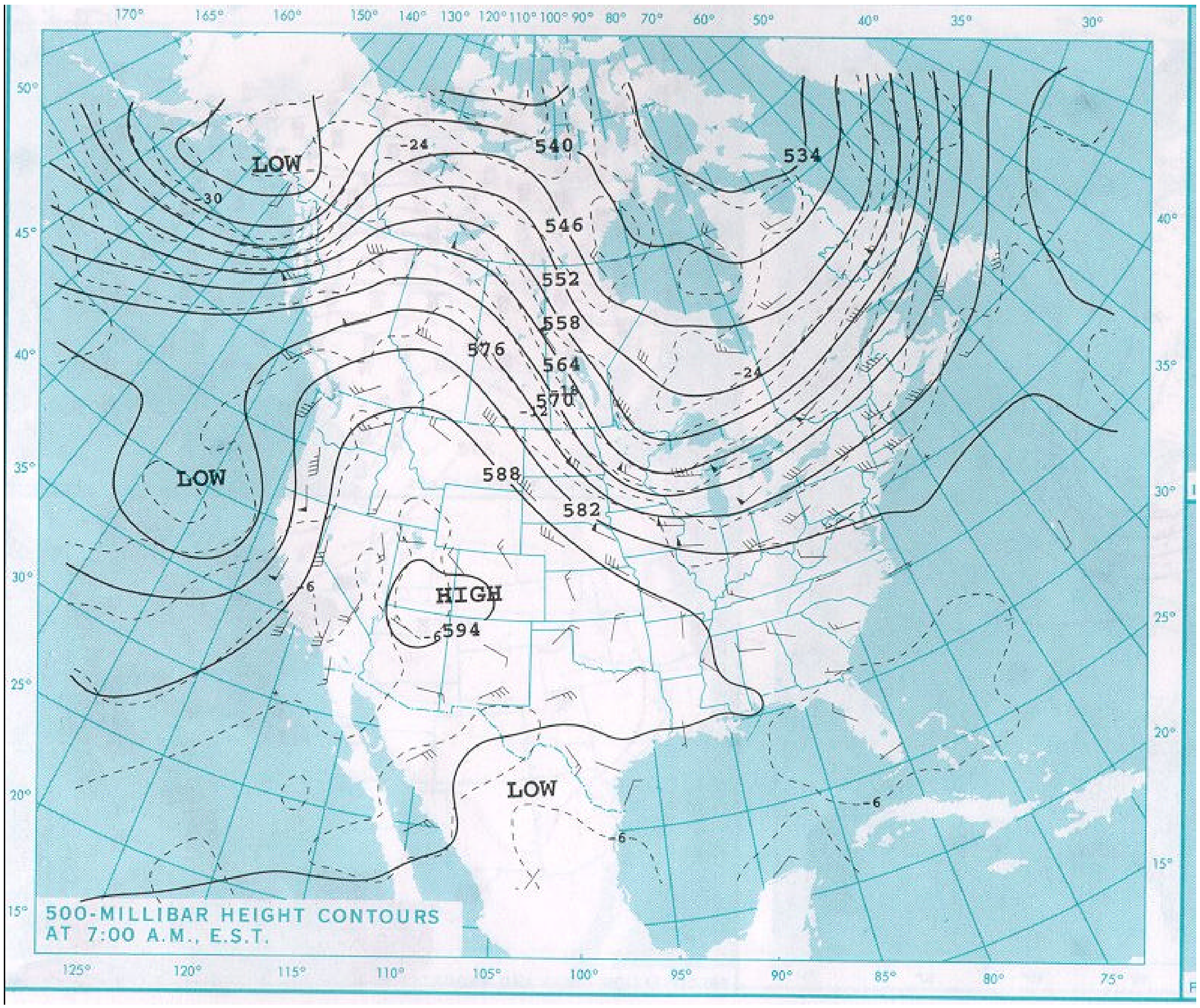
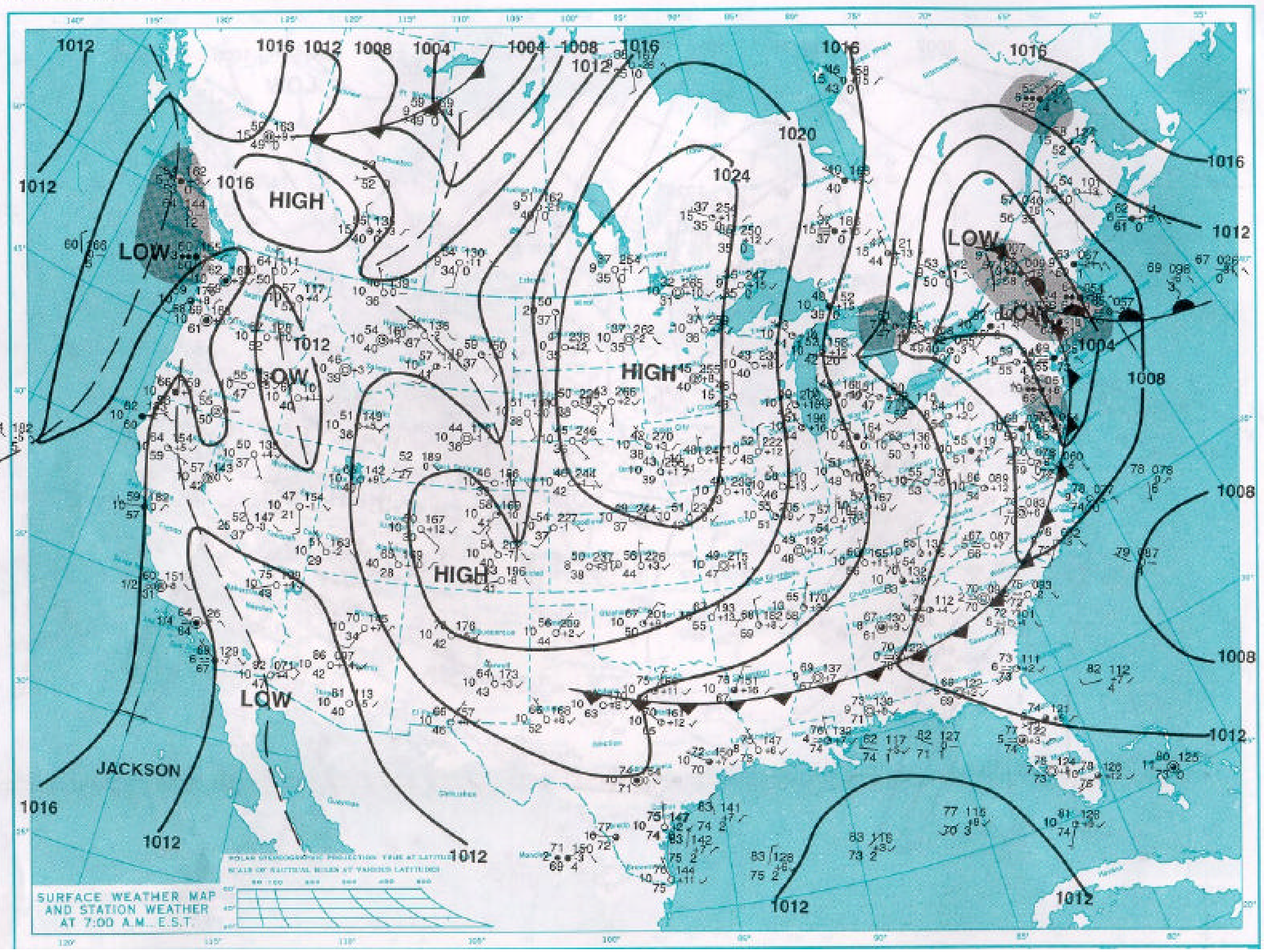
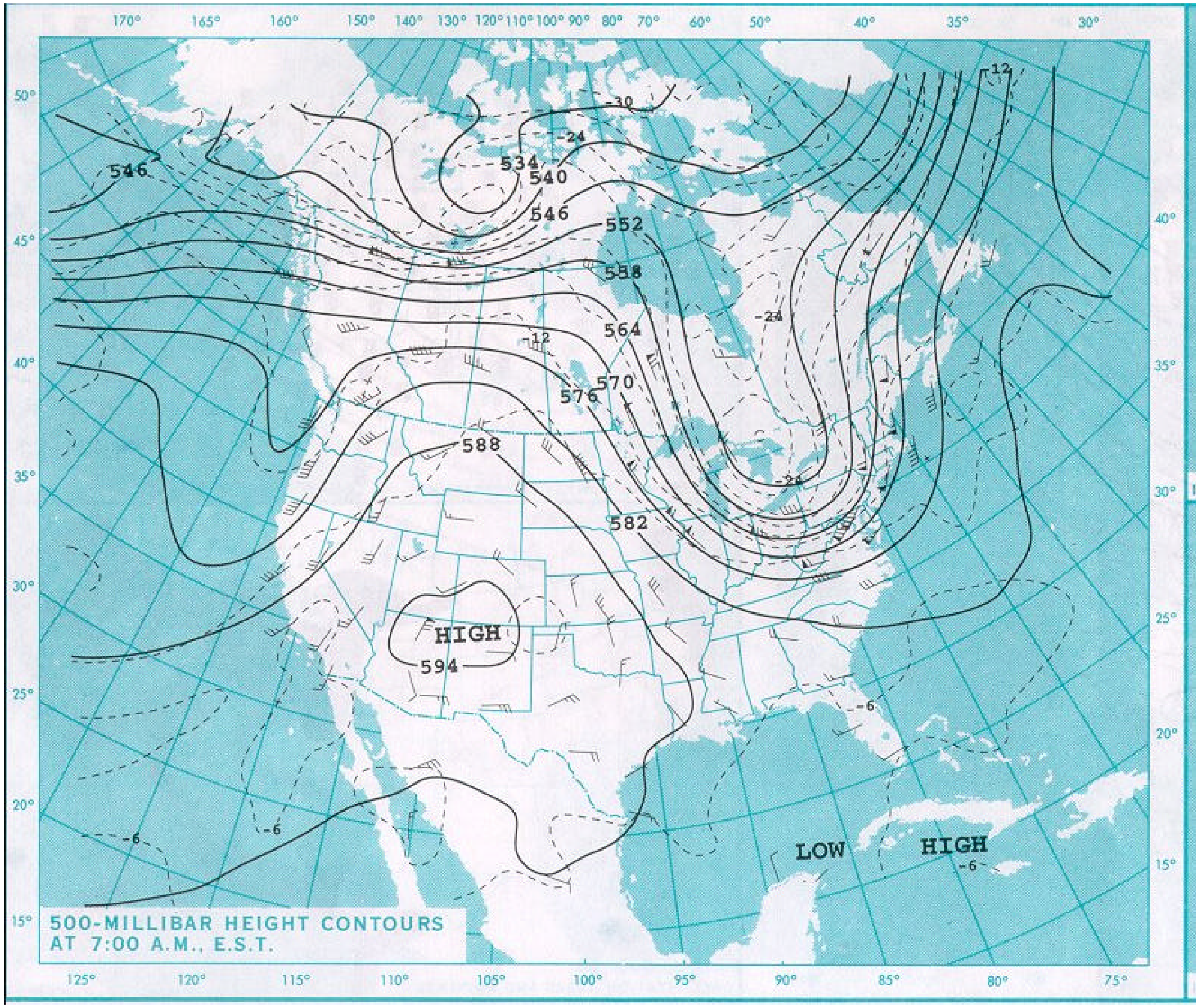




September 14, 2000

FRIDAY, SEPTEMBER 15, 2000





September 15, 2000