Technical Memorandum ERL ARL-145

METEOROLOGICAL SUMMARY OF WATOX 1985 RESEARCH INTENSIVE, FEBRUARY-APRIL

Richard S. Artz
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Silver Spring, Maryland
May 1986

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Richard S. Artz, Uri Dayan*,
and Susan G. Sheridan

Abstract. Flow along the mid-Atlantic Coast and over Bermuda was studied using the NOAA King Air Aircraft and two ground sampling stations. The period studied was mid-February through mid-April 1985. This report presents the surface synoptic charts and the air parcel forecast trajectories associated with these events along with a climatology indicating what types of events were sought and how many could be expected between February and April of a typical year. Finally, the meteorological tools available for each forecast are discussed and examples are given.

1. INTRODUCTION

During 1985, as part of the Western Atlantic Ocean Experiment (WATOX), special intensive field studies were conducted. The geographical regions studied included the coastal areas of the mid-Atlantic states as well as the area surrounding Bermuda. It is the goal of this technical memorandum to show the synoptic situations and forecast trajectories for the events studied, to show what types of events were sought, and to discuss the meteorological tools available to predict these events.

2. FORECAST TRAJECTORIES AND SURFACE SYNOPTIC CONDITIONS FOR WATOX 1985 EVENTS

This section presents graphic depictions of the surface synoptic situations and the relevant forecast trajectories for each of the six WATOX 1985 events along the mid-Atlantic coast, as well as for the first 12 days of April in Bermuda during 1985. The East Coast WATOX maps (Figs. 1-6) are grouped by event; Bermuda maps (Figs. 8-11) are presented chronologically in 12-hour increments for all periods available during April. The time periods of forecast validity are given in the legend for each map in Figs. 1-11.

Interpretation of the forecast trajectories is straightforward. For each map, three forward isobaric trajectories are shown, denoted by L, M, and H. For all cases, L denotes 1000 mb trajectories, M denotes 850 mb trajectories, and H denotes 700 mb trajectories. Along each trajectory are integers starting at 1 (indicating the position after 6 hours) and running consecutively at 6-hour increments either until the trajectory leaves the page or until trajectory computation ceases because of lack of input data. Latitude and longitude are shown along map boundaries. Trajectories are calculated using the winds computed by the NOAA National Weather Service Limited-area Fine Mesh (LFM) forecast model. Trajectories originating in Ohio are indicated in the figure legend; all other trajectories originate in Newport News.

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3. CLIMATOLOGY OF WATOX EVENTS (1951-1983)

WATOX is designed to measure the transport of sulfur, nitrogen, metals, and organics offshore eastward from North America to Bermuda. The general synoptic situation leading to such an eastward transport to the ocean prevails during the winter season, when the Bermuda/Azores High migrates southward and weakens. Cold fronts crossing the western part of the Atlantic Ocean and approaching Bermuda seldom penetrate as far as Bermuda.

3.1 Typical Synoptic Condition for a Long and Short WATOX Event

3.1.1 Cold fronts dissipating before Bermuda--Short WATOX event

Cold fronts leaving the East Coast of the United States generally become weaker as they approach Bermuda. The length of the event depends primarily upon the sharpness of the frontal trough. The approach of a sharp V-shaped trough associated with a cold cyclone located south of the 40°N latitude line in the United States is usually conducive to a short event, defined as an eastward flow that does not last more than 24 hours. Persistence of this situation will depend upon the speed of the cold front associated with this flow. Travel time for passage of such a cold front from the U.S. East Coast to Bermuda is typically 18-24 hours at an average speed of approximately 40 kt in the layer through the first 3000 ft above sea level (Figs. 12a-d).

3.1.2 Cold fronts that pass Bermuda--Long WATOX event

The best situation for an event leading to persistent westerly flow over eastern United States and the whole western Atlantic Ocean occurs when the cold depression at 500 mb is located in northeastern Canada and has a very flat trough to the south. Ideally, the low at the surface would be located east of longitude 80°W and north of latitude 45°N under these conditions. Figures 13a-d show a 2-day event; Figs. 14a-f, a 3-day event. As seen in Table 1, highest frequencies for a long WATOX event occur during February and March.

3.2 Typical Synoptic Situation for Poor Sampling Conditions

By the end of March, the Bermuda High begins to build and migrate northward. There is an increasing tendency for the 500 mb trough to influence the west and central part of the United States with anticyclonic flow in the eastern part of the continent. Under this situation, weak lows may form at the surface along the East Coast of the United States and move at speeds in excess of 40 kt. These small systems have a low degree of perseverance and therefore are difficult to predict in advance (Figs. 15a-d).

4. METEOROLOGICAL PREDICTION OF WATOX EVENTS

Because of the availability of National Weather Service (NWS) and Air Resources Laboratory (ARL) automated meteorological products, the method of forecasting WATOX 1985 events is rather straightforward. The discussion in this section covers the major steps used to forecast the third WATOX event. These steps are typical of the methods used to forecast all WATOX events.

Table 1. Occurrence of short (1 day) and long (2 or 3 days) WATOX events (1951-1983)

Month	Mid-January				February				March				April			
	Short*	Long**		Tot.	Short	Long		Tot.	Short	Long		Tot.	Short	Long		Tot.
Duration (# of days)	1	2	3		1	2	3		1	2	3		1	2	3	
No. of cases per month	1.3	0.7	0.3	2.3	1.7	1.2	0.5	3.4	1.5	1.0	0.8	3.3	1.3	0.7	0.2	2.2
Percent frequency of total # of cases per month	57	30	13	100	50	35	15	100	46	30	24	100	59	32	9	100

* Short event defined as an event having good synoptic conditions for East Coast sampling.
**Long events, lasting over 24 hours, are defined as good synoptic conditions for East Coast and Bermuda sampling.

4.1 3-5 Day Forecast Charts

A panel of the 3-5 day forecast chart (Fig. 16) for March 1, 1985, gave the first indication of the favorable sampling situation that resulted in the third WATOX 1985 event. Northwesterly winds were predicted behind the cold front trailing from a low that was forecast to lie over Michigan on Tuesday, March 5. Typically, such a late winter front would be off the coast in about 24 hours; this information resulted in the early warning that Event 3 would probably occur on Wednesday, March 6.

4.2 LFM Forecast Products

Another very important group of products are the LFM prognostic charts. At 00Z and 12Z daily, an analysis map and four prognostic maps, valid from 12 to 48 hours after the analysis, are generated. These charts give a variety of information including expected areas of precipitation, relative humidity, heights, vorticity, and thickness at one or several levels over North America. Except for the analysis, which is a two-panel chart, the LFM maps are all four-panel charts. The analysis map shown as Fig. 17 indicates a cold core low centered over eastern Colorado and a large area of decreasing thicknesses over the southwest. This served as an early warning that a vigorous cold front would form just east of the Rocky Mountains.

4.3 Satellite Pictures

Beginning 48 hours prior to the event, several products are available either to pinpoint the optional sampling period or to indicate that the entire event should be abandoned. Figures 18 and 19 are examples of visible and infrared satellite pictures that clearly indicate the trailing edge of the frontal system through the mid-Atlantic states. Note that the atmosphere during this event is clear over the ocean just east of the Virginia shore (Fig. 18). A thick bed of clouds in the sampling area impedes or precludes sampling, a condition commonly observed when cold northwesterly winds cross the warm Atlantic.

4.4 850 mb LFM

Another forecast product available at 12 hour increments out to 48 hours is the 850 mb LFM. This particular chart is extremely important to WATOX because the 850 mb level lies nearly at the center of the region of sampling and is a far more useful guide for forecasting winds than are surface charts, which are affected by surface topography, or 500 and 700 mb charts, which are generally above the level of sampling. An example shown as Fig. 20 was valid for 12Z Tuesday, March 5. This chart indicates strong westerly and northwesterly flow southwest of a low centered over Southern Ontario. Areas where temperatures (dashed lines) are normal to heights (solid lines) indicate the general areas of surface fronts.

4.5 Analysis Charts

Closer to the actual sampling period, analysis charts become important. Figures 21 and 22 show analysis charts at the 500 mb and 850 mb levels. These charts are important because they give an accurate description of wind speed and direction as well as an indication of the location of surface fronts and small areas of cyclogenesis that may not have been forecast by the LFMs.

4.6 LFM Forecast Trajectories

Perhaps the most important forecast tool is the ARL forecast trajectory model based upon the LFM forecasts. A best-case WATOX 1985 situation is shown in Fig. 23. The trajectory forecast is valid for 12Z March 13, 24 hours after the intialization period. Note that the low pressure system is quite vigorous and that the best sampling period occurs well behind the front. The L, M, and H designations refer to constant-level trajectories at 1000, 850, and 700 mb respectively.

Trajectories are forecast for 0 to 36 hours after the initialization period at 6 hour intervals using LFM data. A complete set of trajectories may be produced as frequently as every 12 hours. Figures 24a-d show the forecast trajectories for the third WATOX event beginning 12Z March 5. The positions of the surface fronts and isobars have been superimposed. It is readily apparent that the best sampling window should fall shortly after 00Z March 6. As the high pressure system moves eastward, the ideal synoptic sampling period begins to deteriorate.

The forecast trajectory has at least one other purpose; source areas can also be estimated as in Fig. 25. Note that during the event window the source area for Newport News lies principally in Ohio and West Virginia. Forecast trajectories can be used to tailor sampling events to coincide with preferred source regions.

4.7 MOS Forecasts

A final forecast tool useful for predicting WATOX events is the Model Output Statistics (MOS) forecast available at 00Z and 12Z daily from the NOAA Techniques Development Laboratory (TDL). Figure 26 shows an example of a MOS forecast. Note that the optional sampling period using this tool should fall under the heading "06Z Tomorrow Night" when winds are out of the northwest at 7 mi/h. Although the code is not included here, the clouds category indicates clearing to coincide with the best sampling period.

5. ACKNOWLEDGMENTS

This work was funded by the National Acid Precipitation Assessment Program. The WATOX project is coordinated through the University of Virginia.

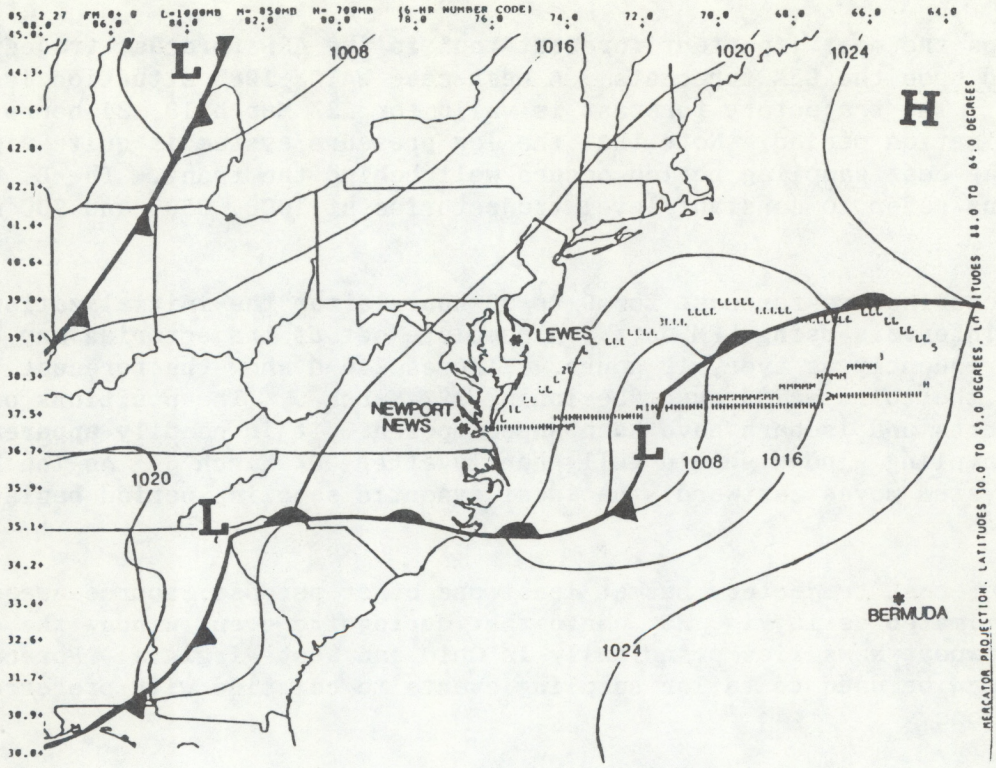


Figure 1a.--Event 1: Valid 00Z February 27, 1985.

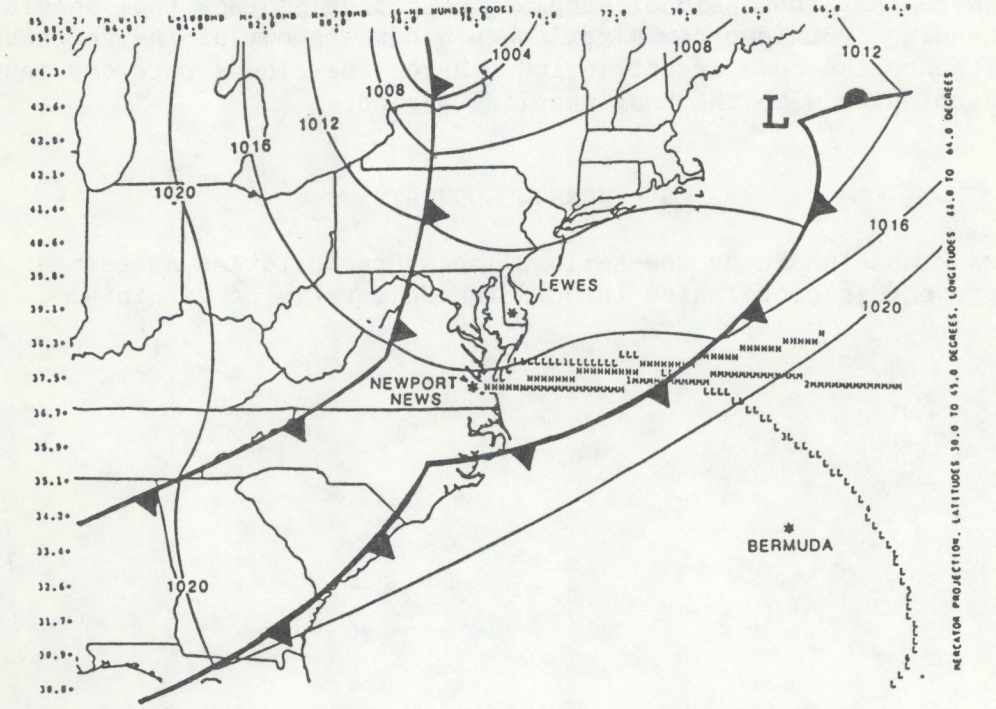


Figure 1b.--Event 1: Valid 12Z February 27, 1985.

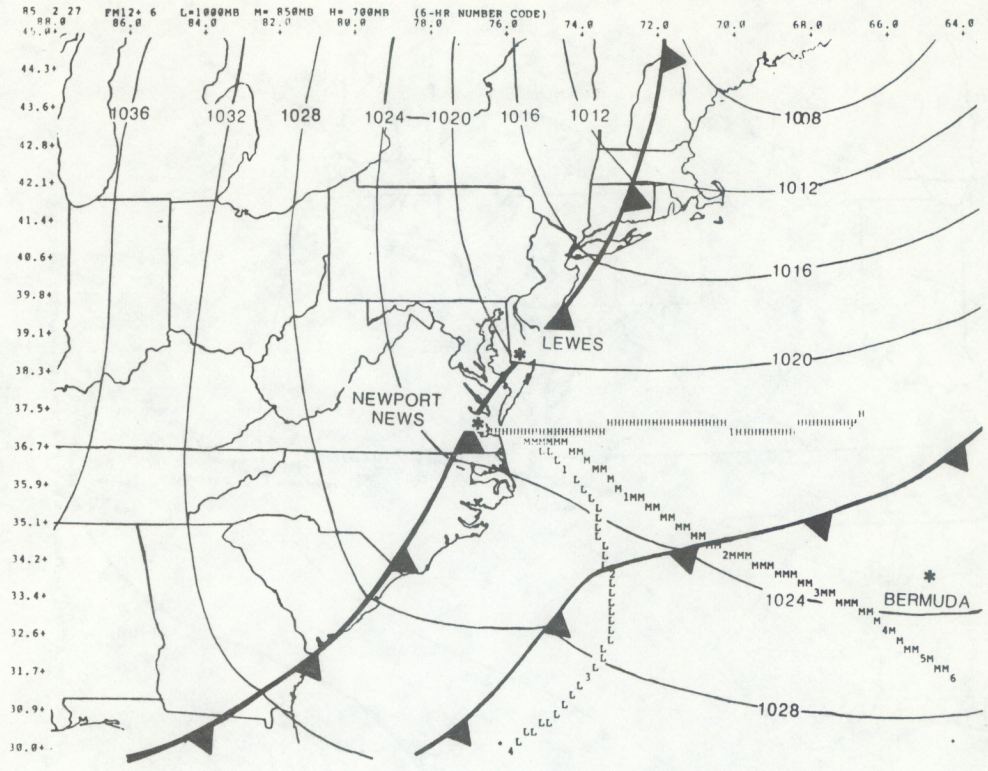


Figure 1c.--Event 1: Valid 18Z February 27, 1985.

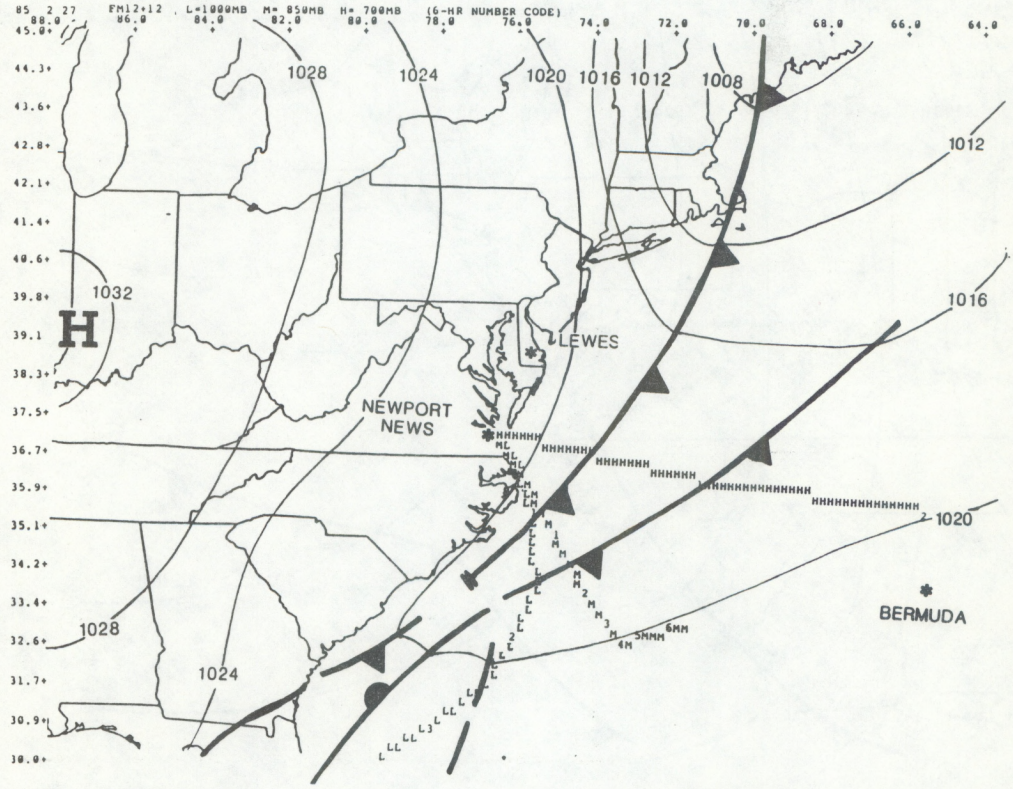


Figure 1d.--Event 1: Valid 00Z February 28, 1985.

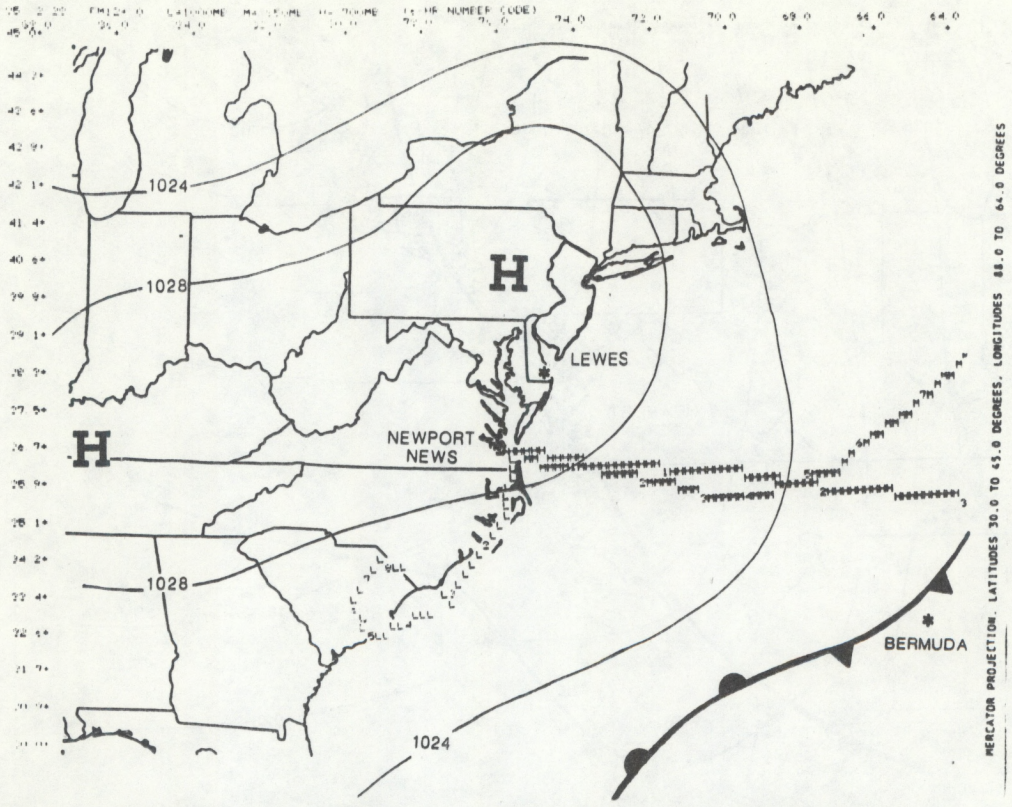


Figure 1e.--Event 1: Valid 12Z February 28, 1985.

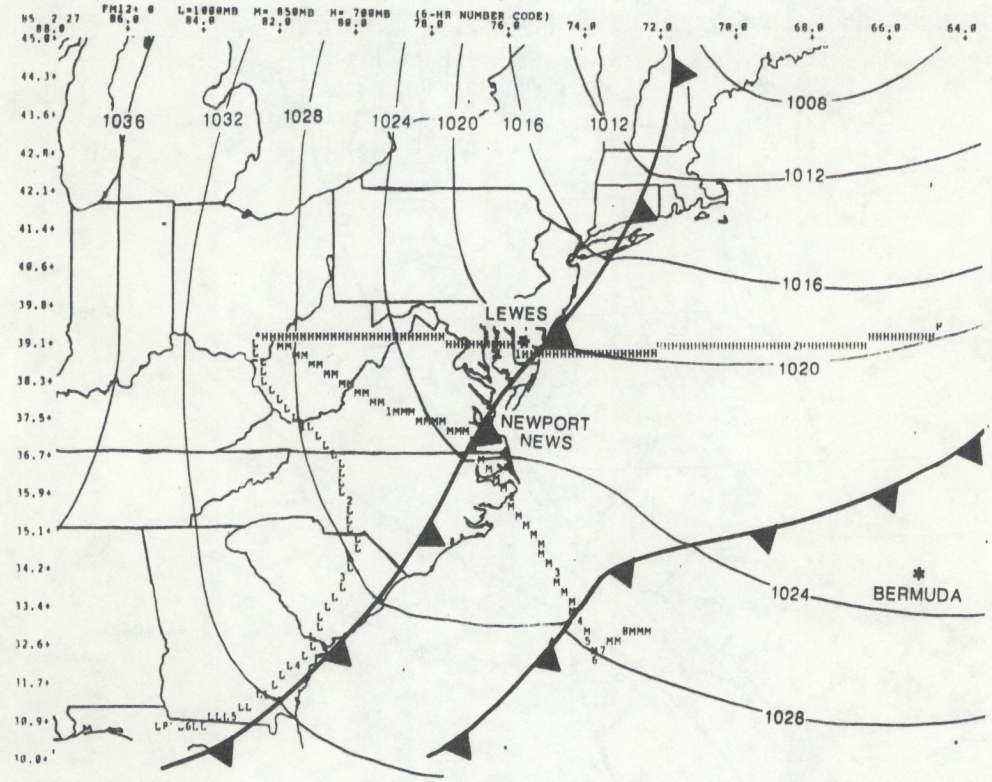


Figure 1f.--Event 1: Valid 12Z February 27, 1985 (from Ohio).

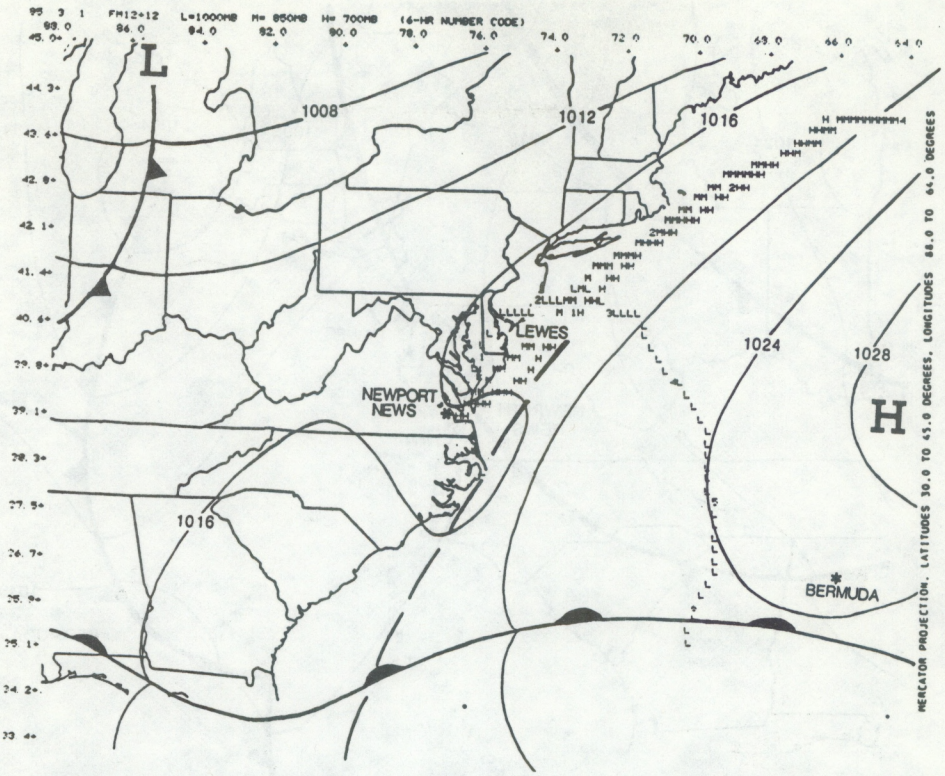
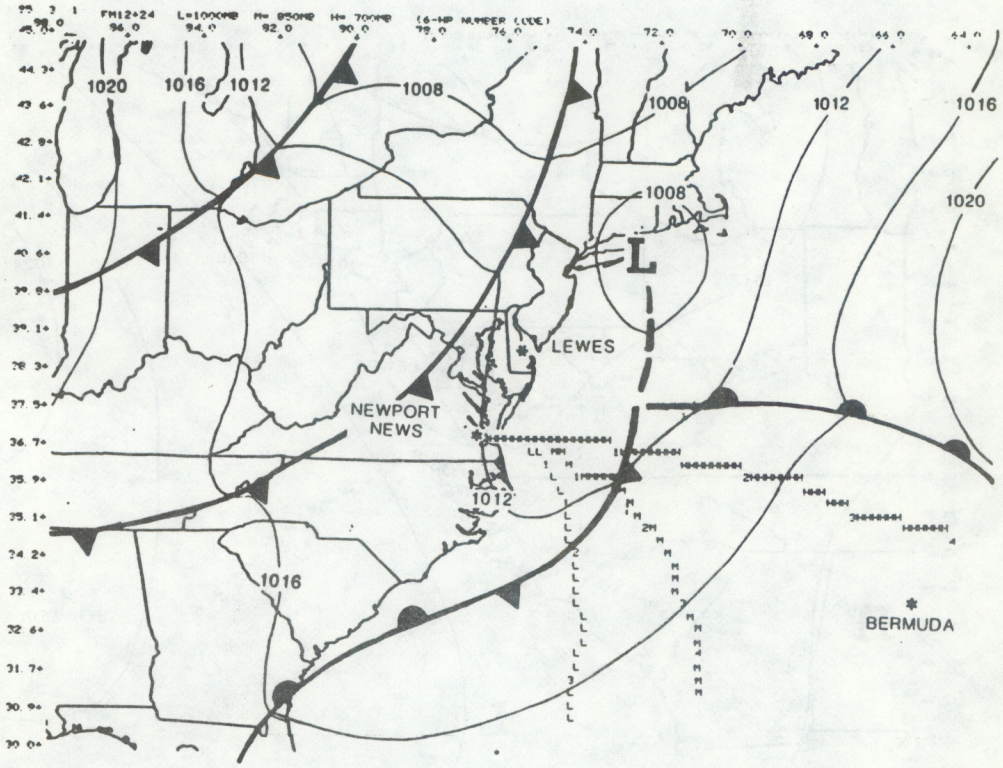


Figure 2a.--Event 2: Valid 00Z March 2, 1985.



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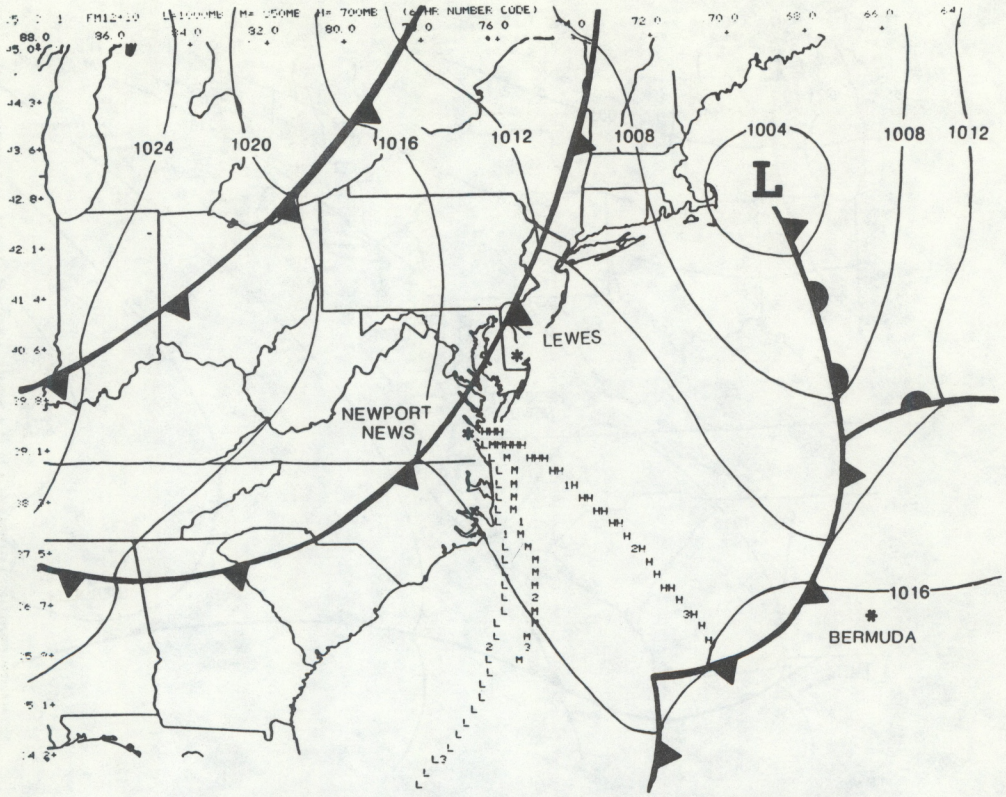

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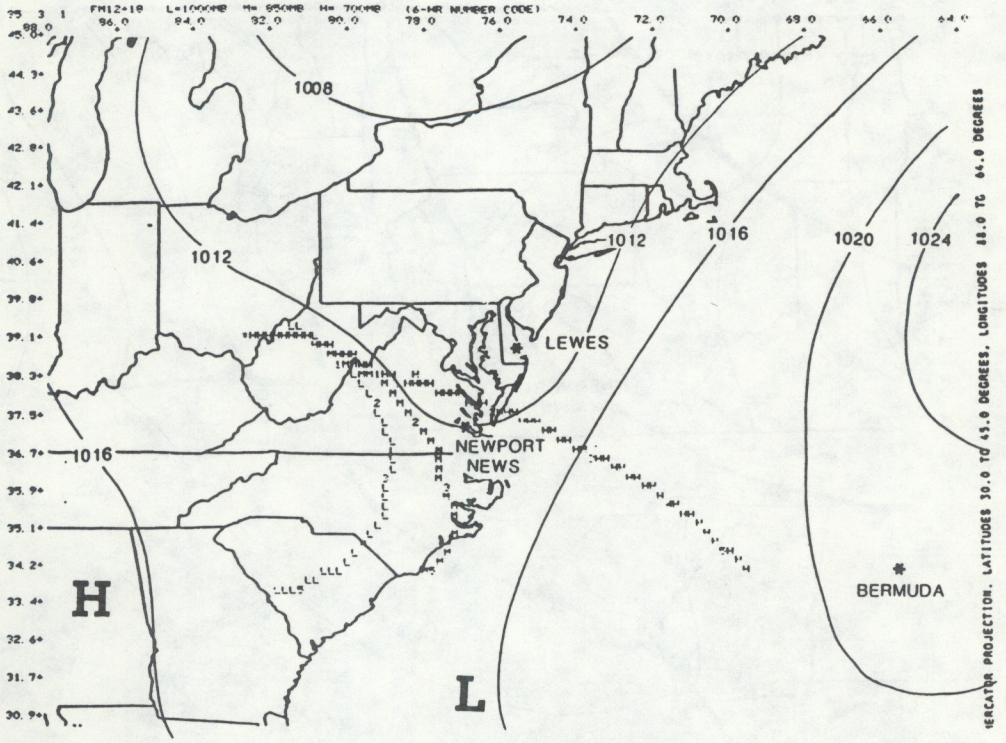
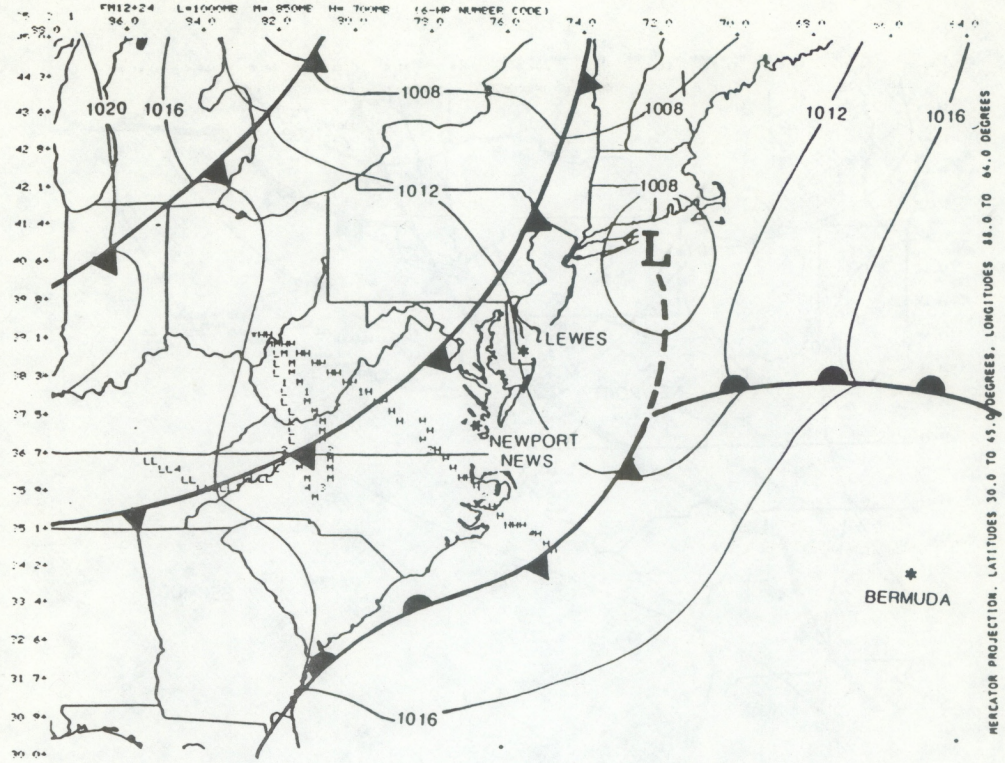


Figure 2d.--Event 2: Valid 06Z March 2, 1985 (from Ohio).



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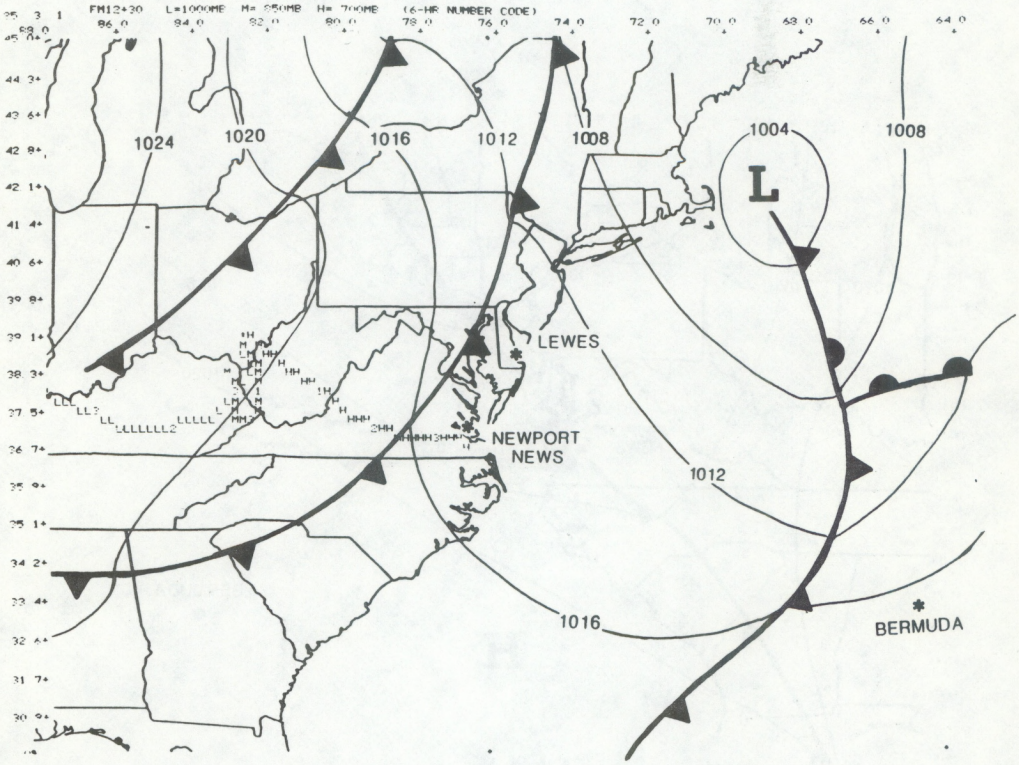

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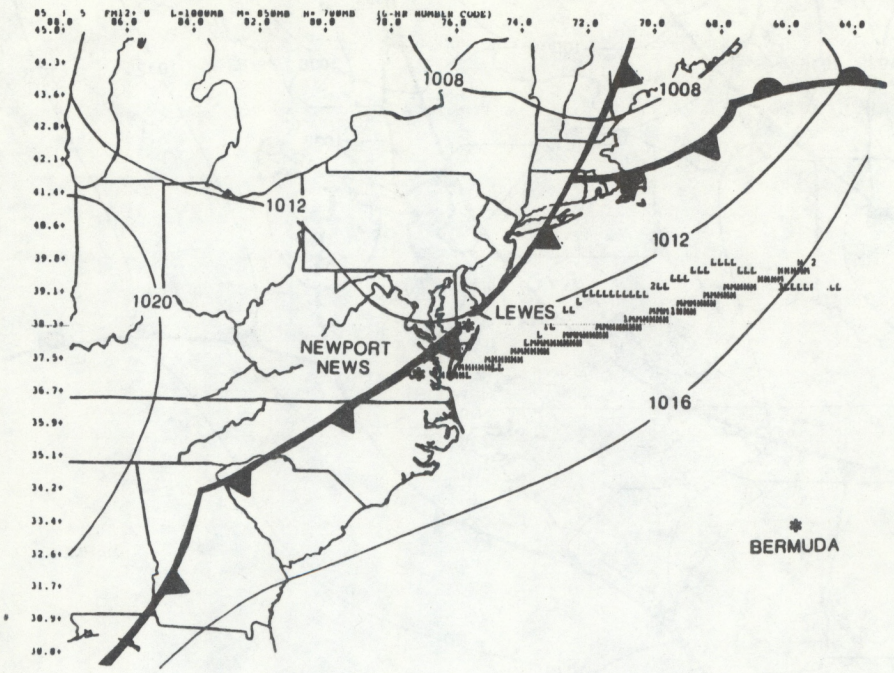


Figure 3a.--Event 3: Valid 12Z March 5, 1985.

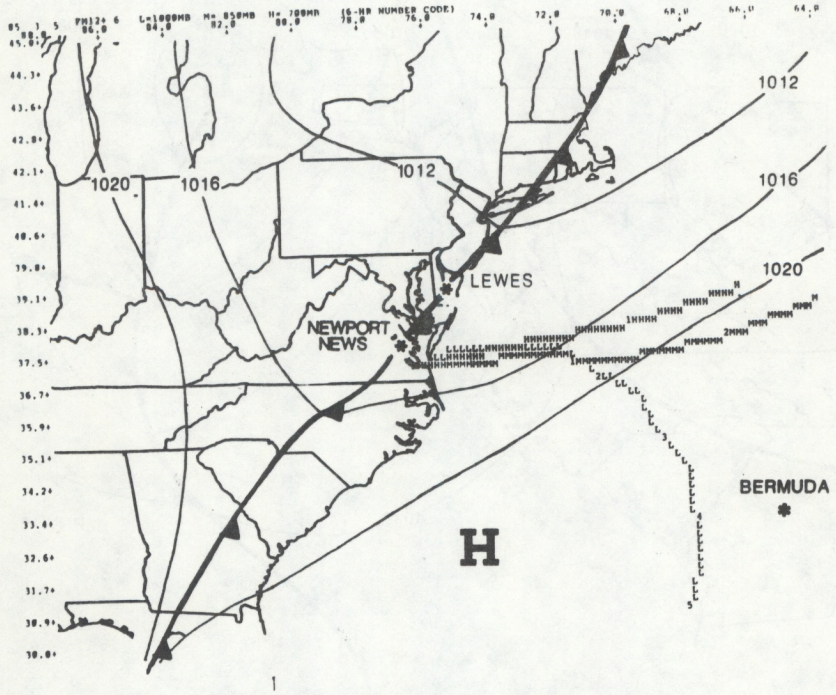


Figure 3b.--Event 3: Valid 18Z March 5, 1985.

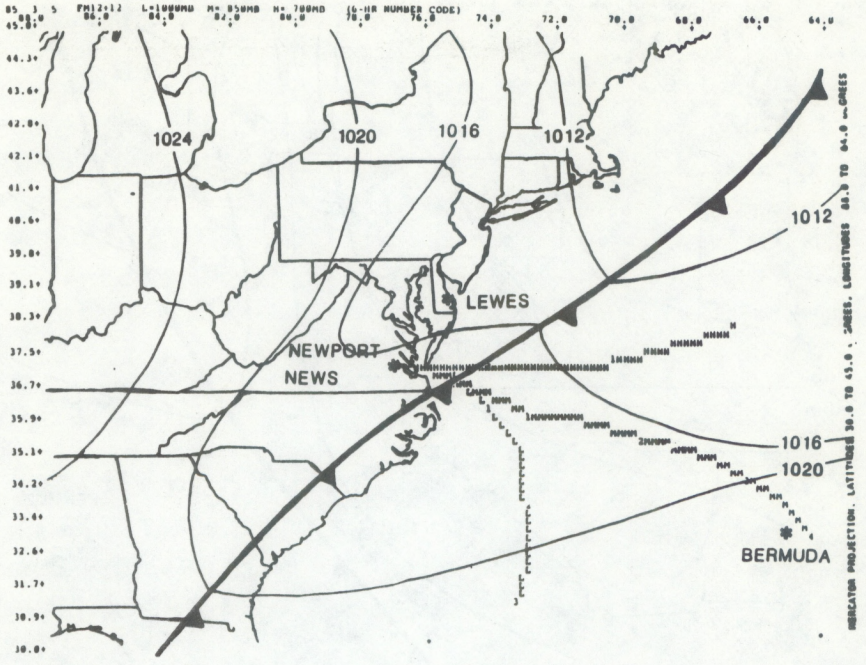


Figure 3c.--Event 3: Valid 00Z March 6, 1985.

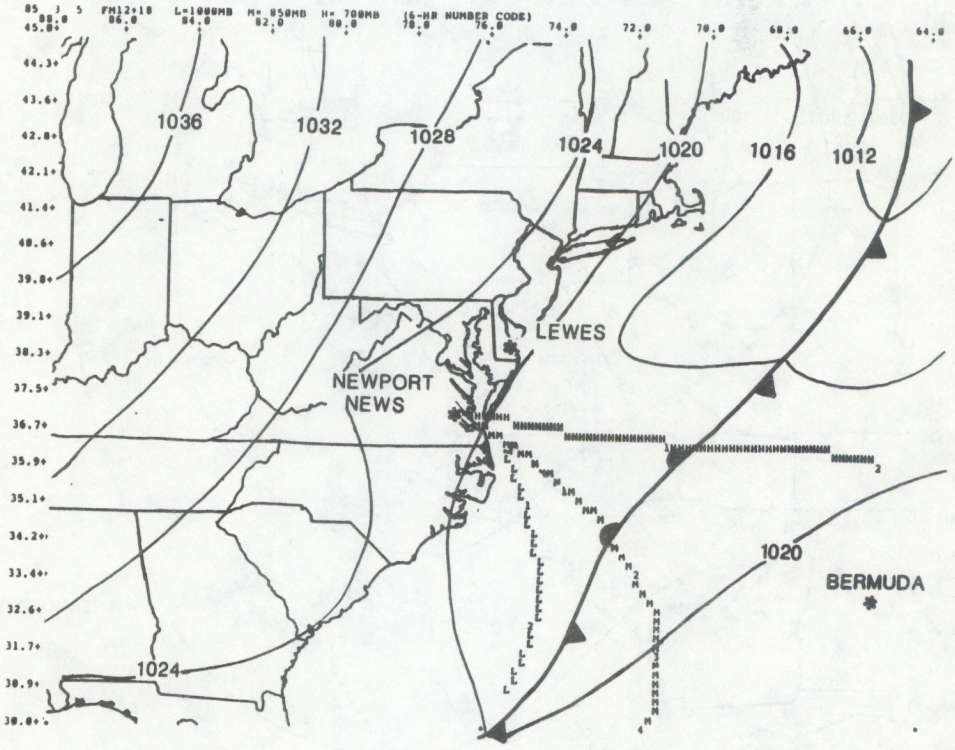
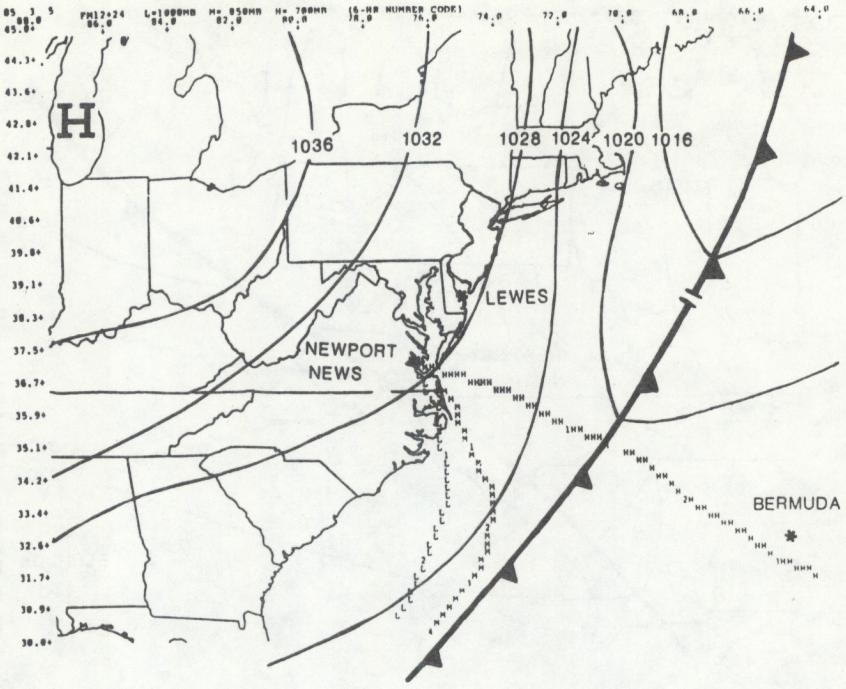


Figure 3d.--Event 3: Valid 06Z March 6, 1985.



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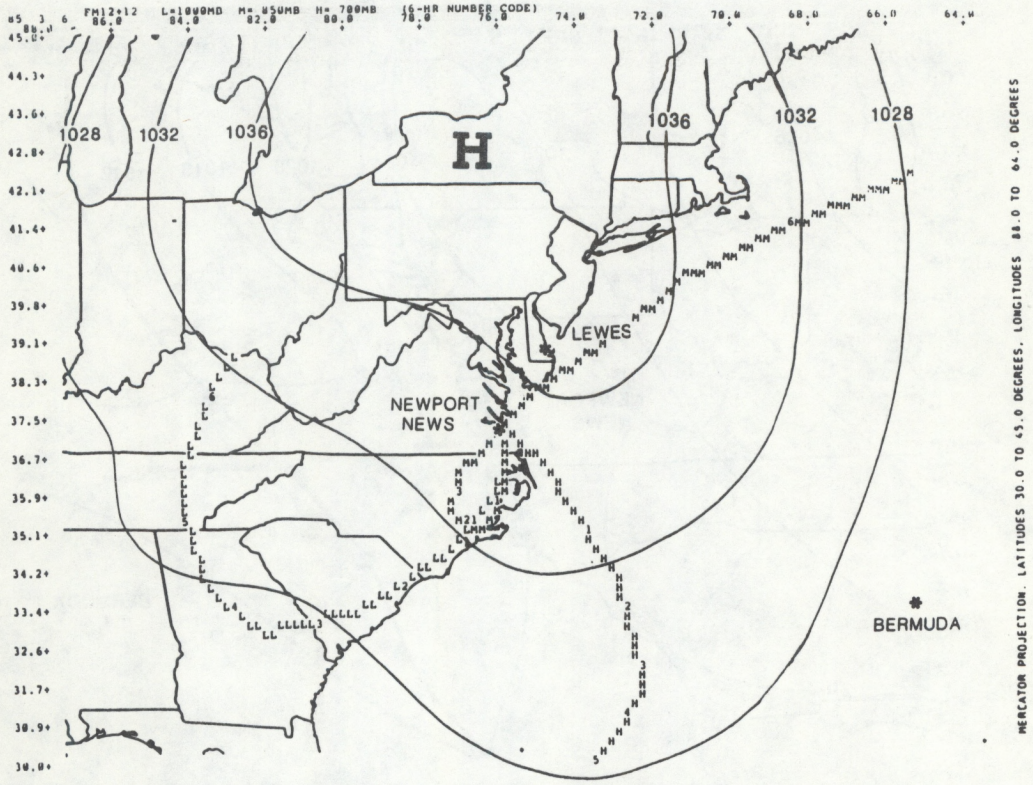

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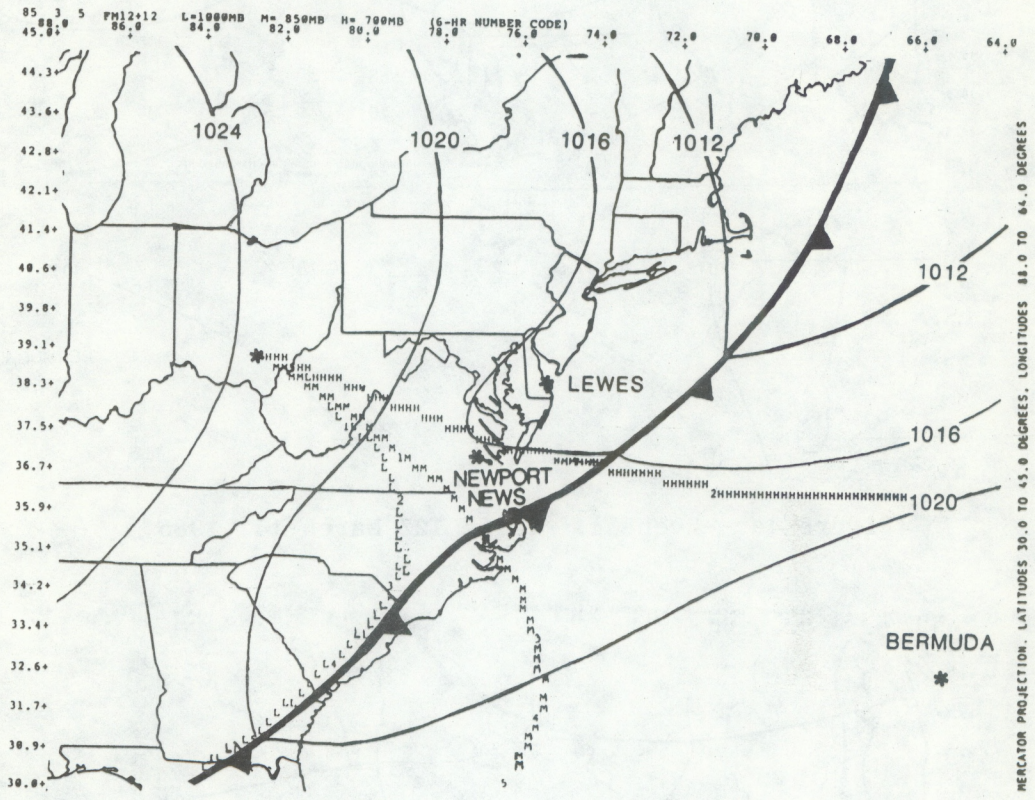


Figure 3g.--Event 3: Valid 00Z March 6, 1985 (from Ohio).

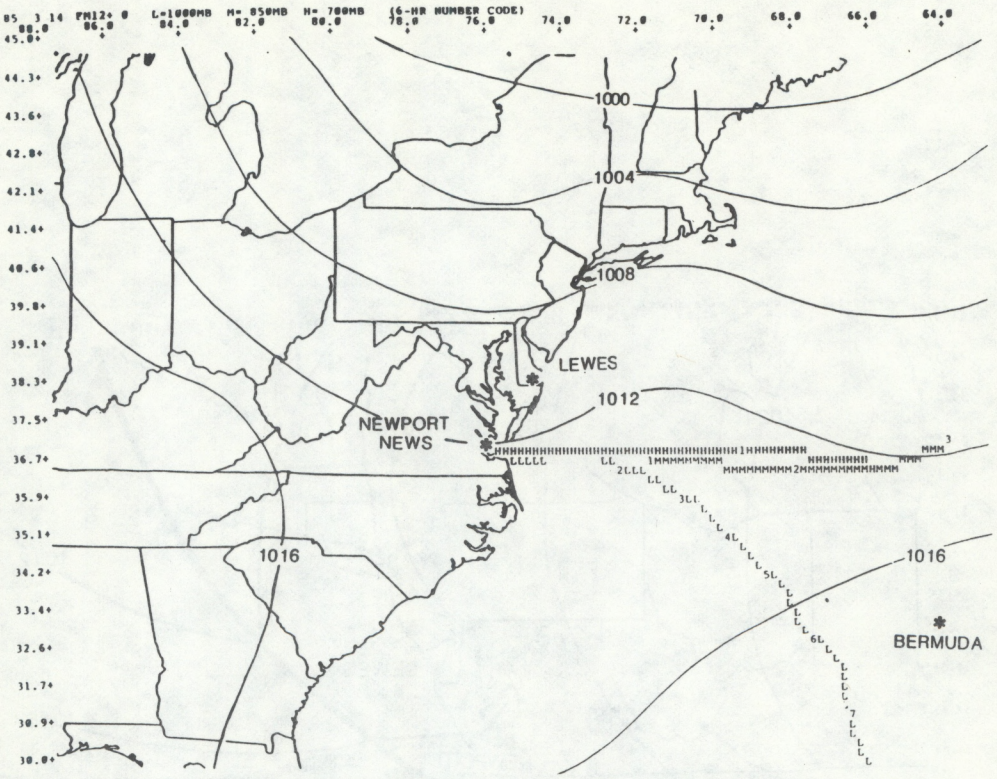
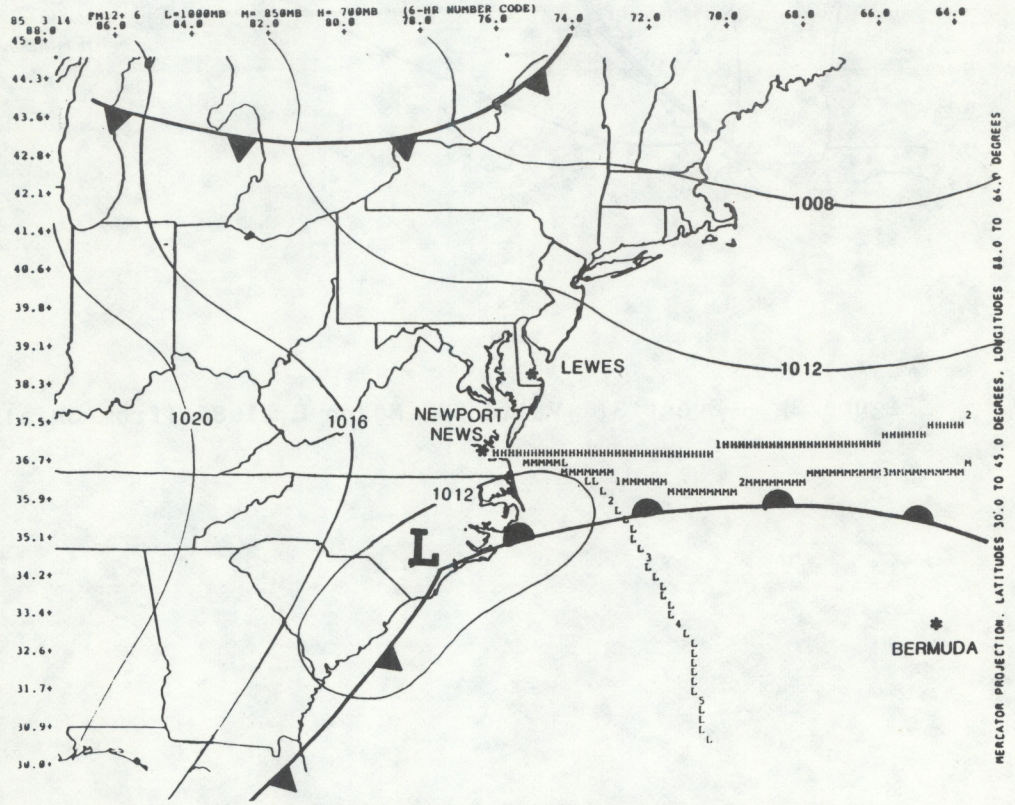


Figure 4a.--Event 4: Valid 12Z March 14, 1985.



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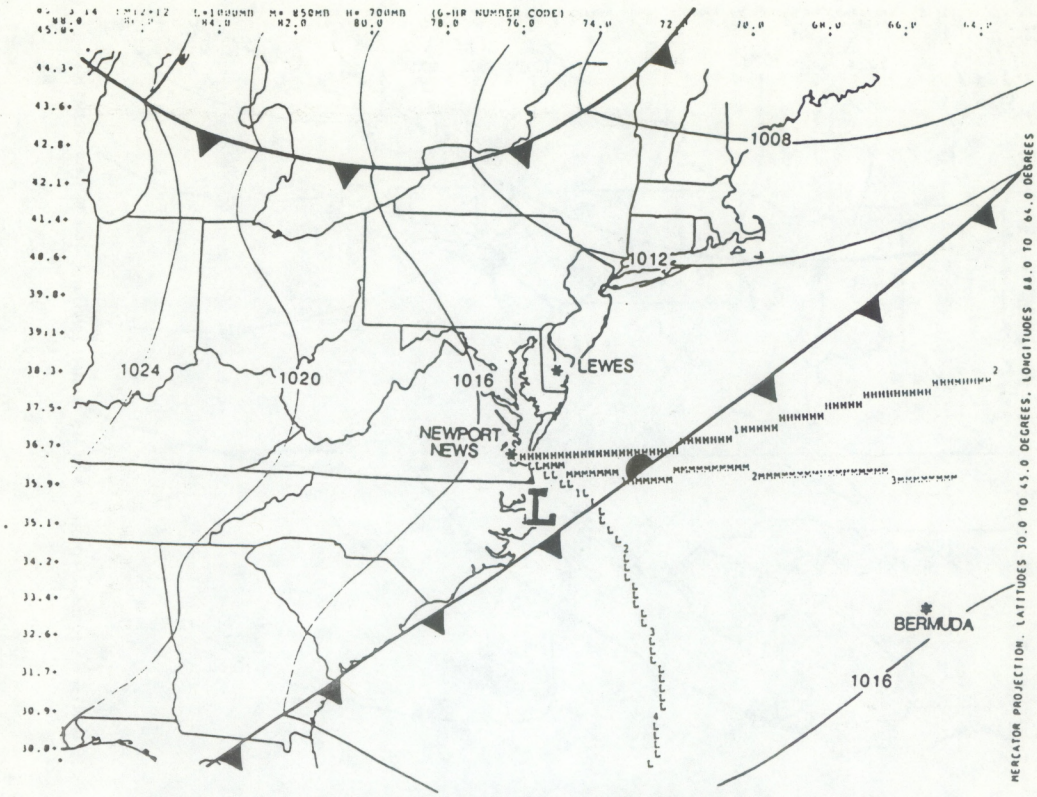

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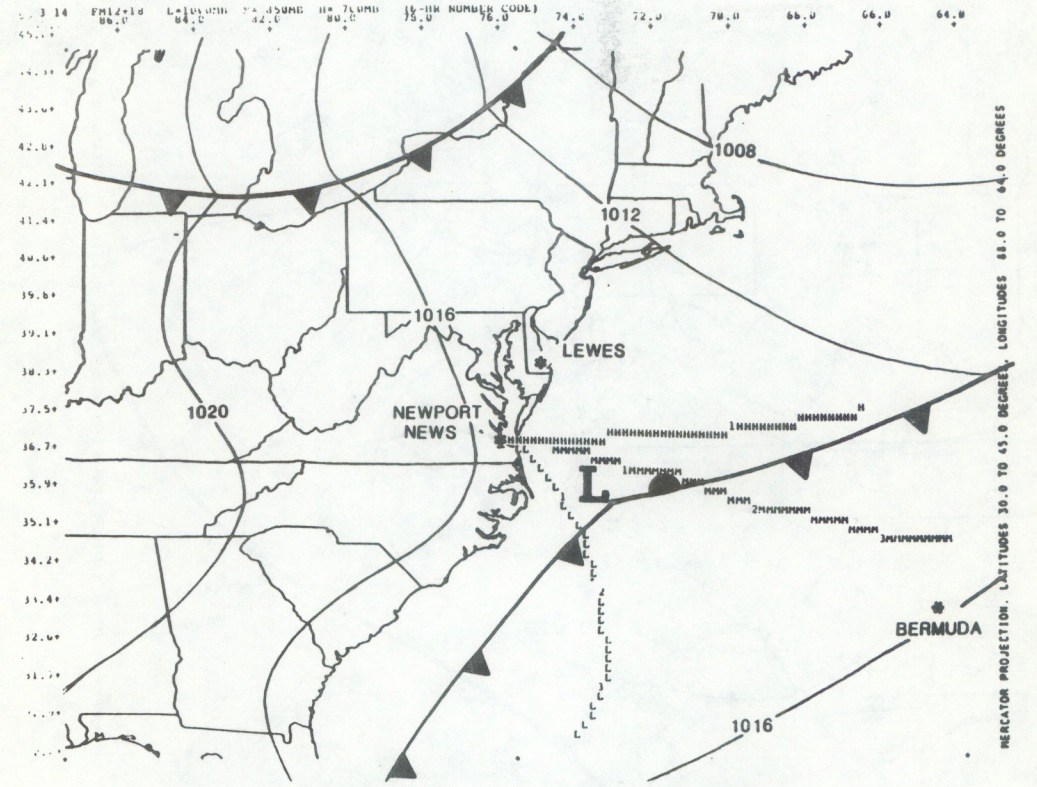

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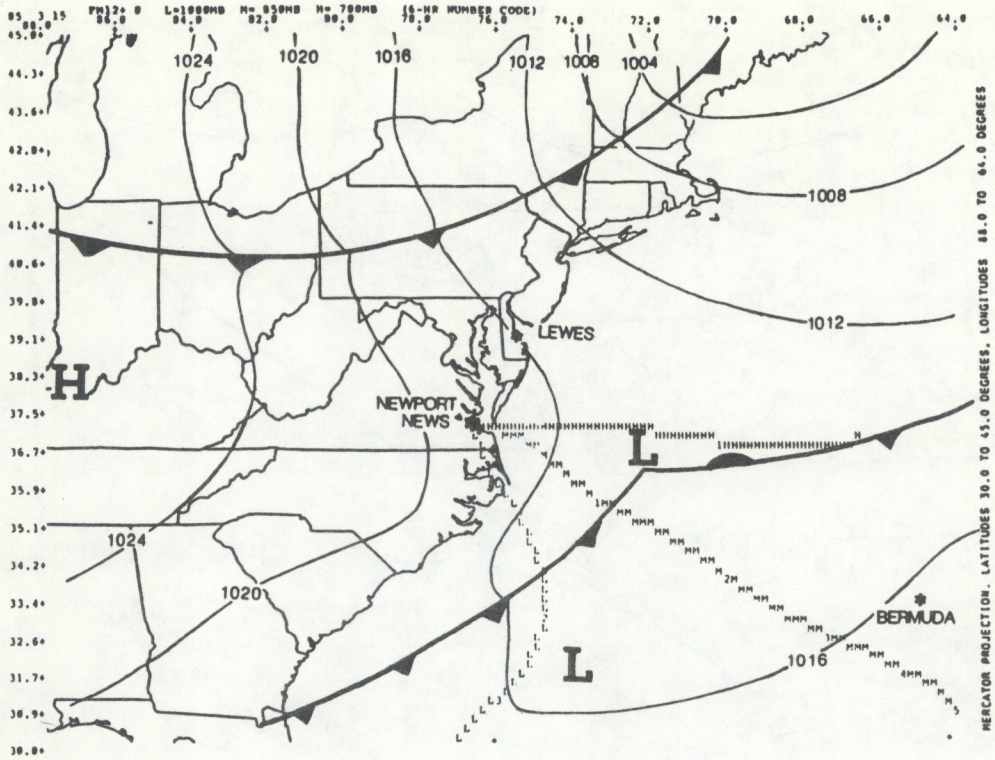

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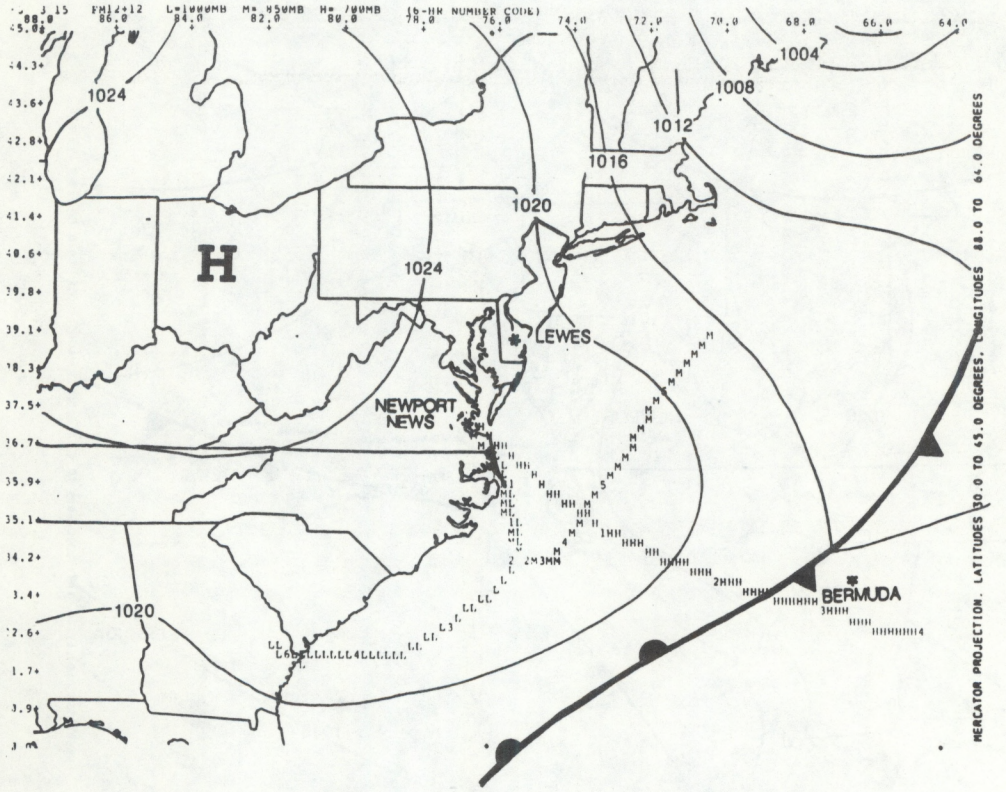

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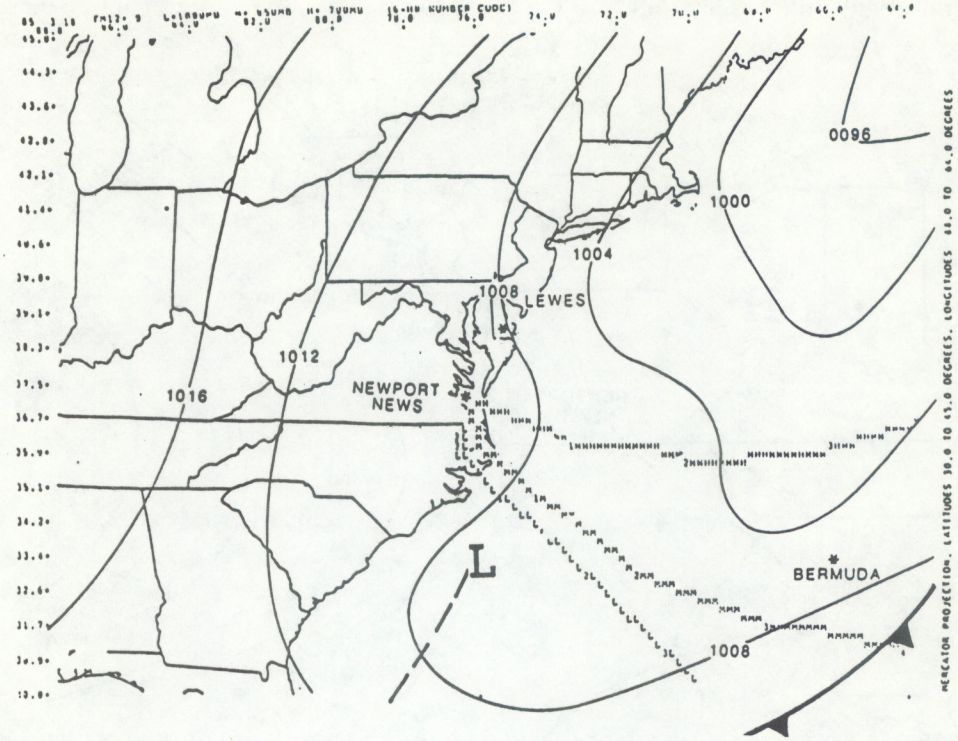
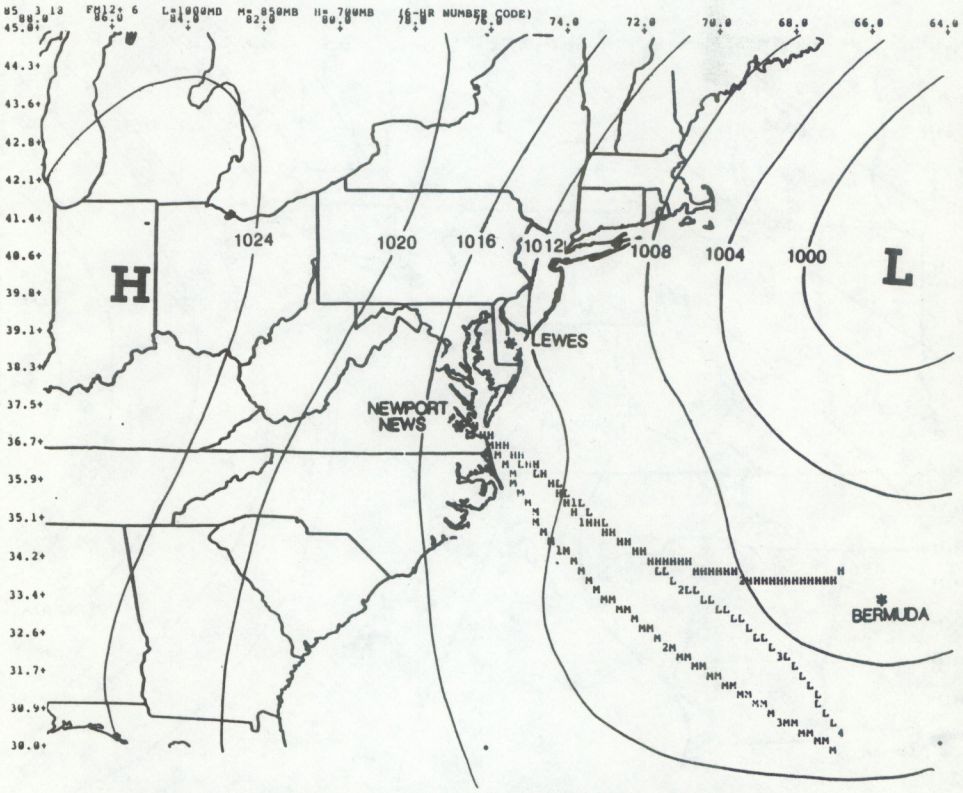


Figure 5a.--Event 5: Valid 12Z March 18, 1985.



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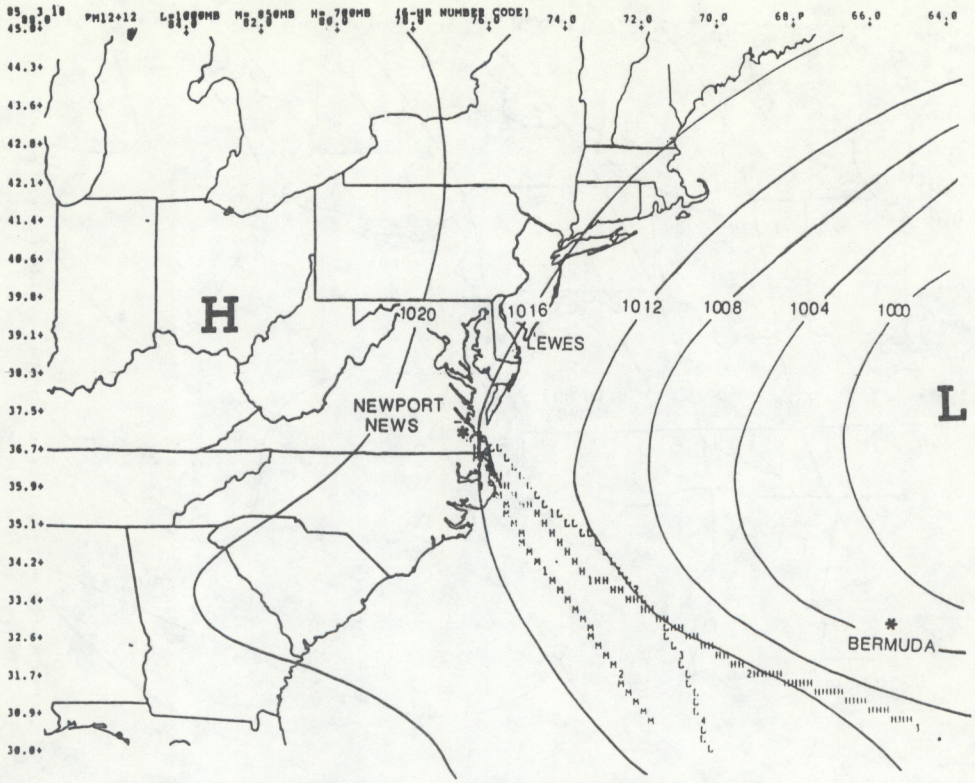

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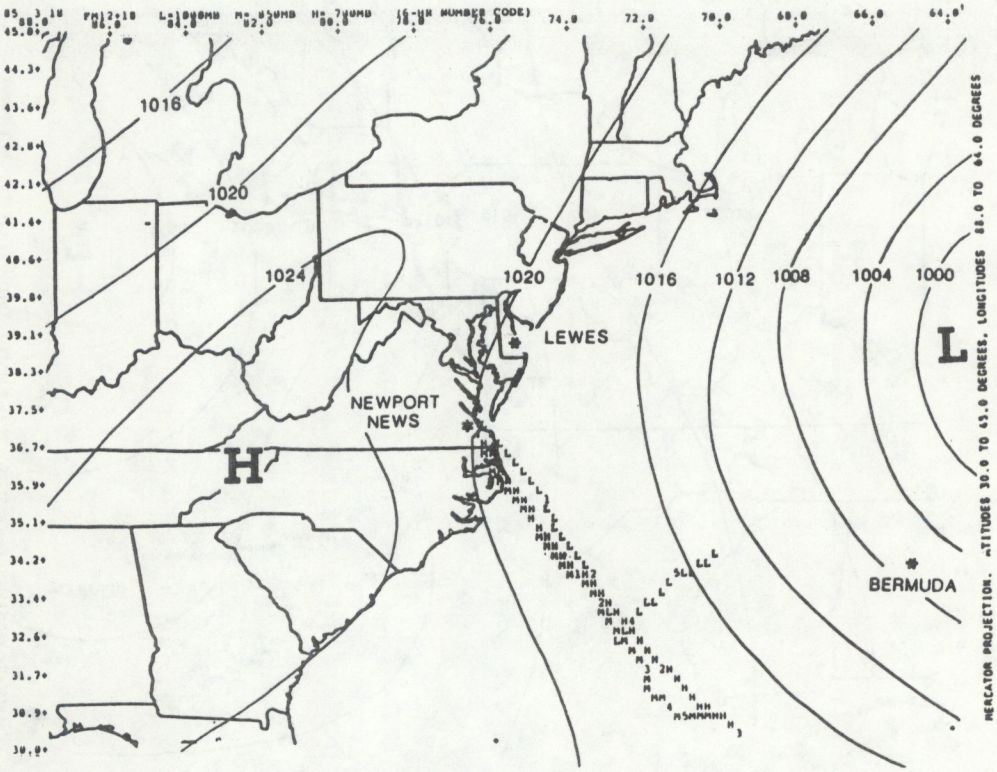

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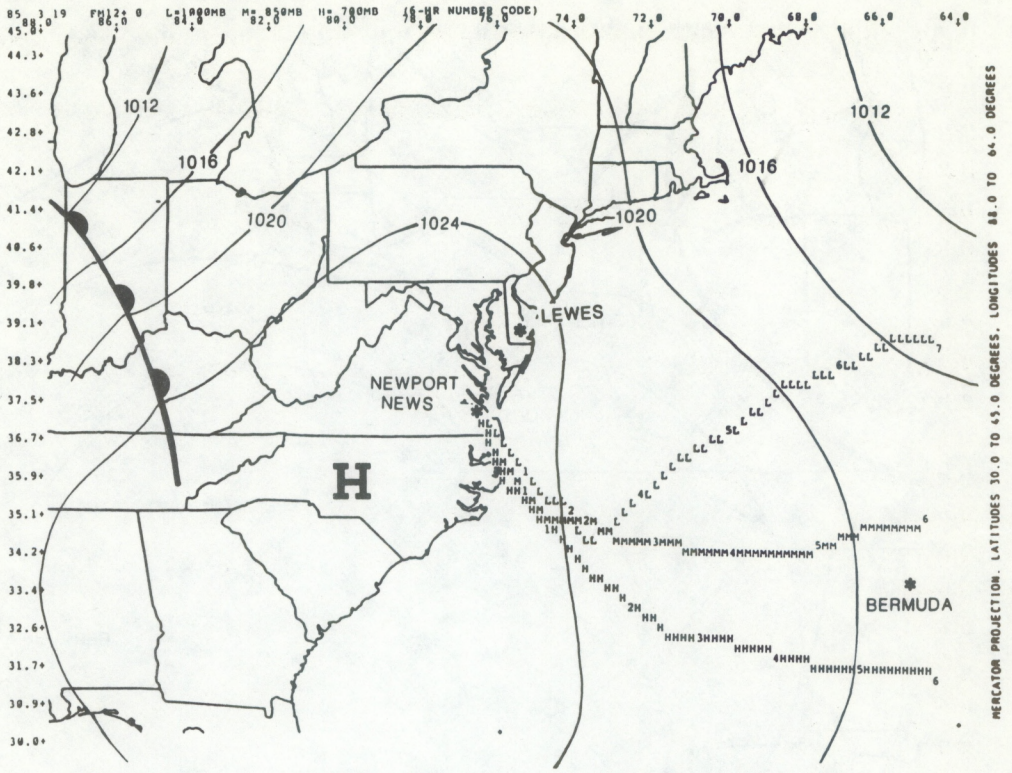

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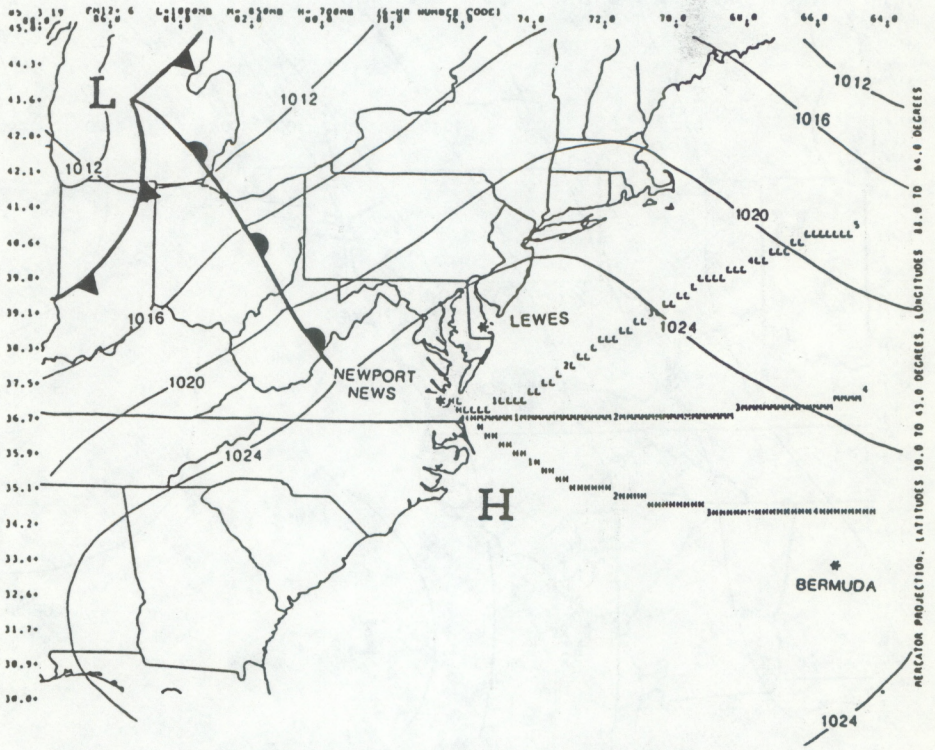

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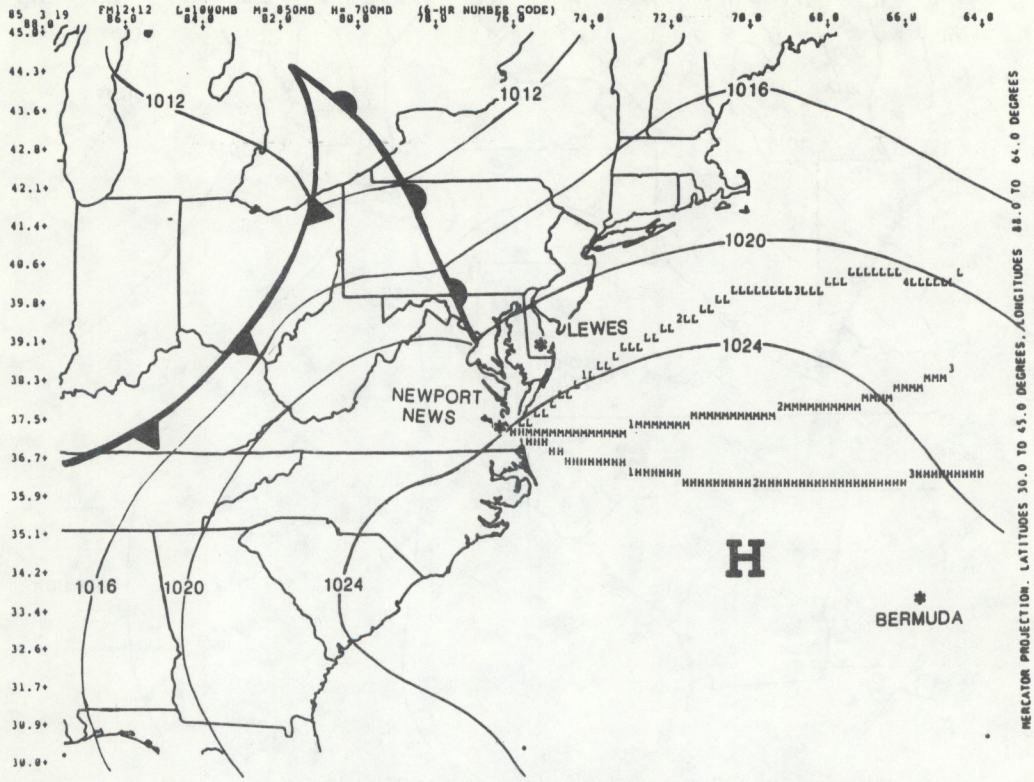

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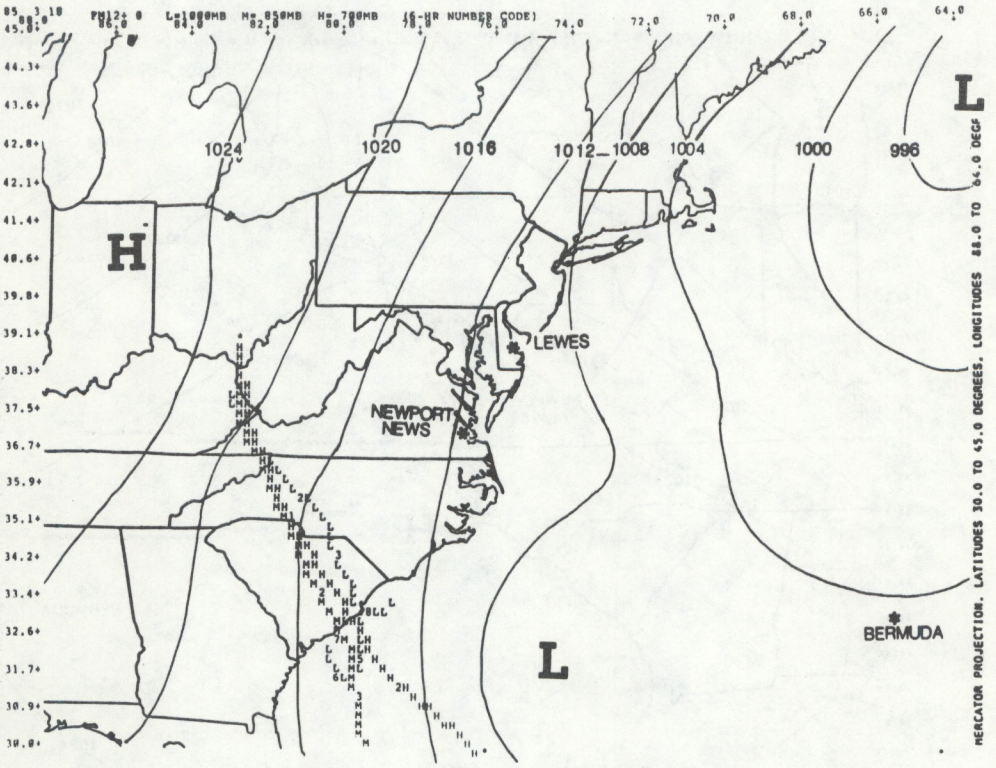

Figure 5h.--Event 5: Valid 12Z March 18, 1985 (from Ohio).

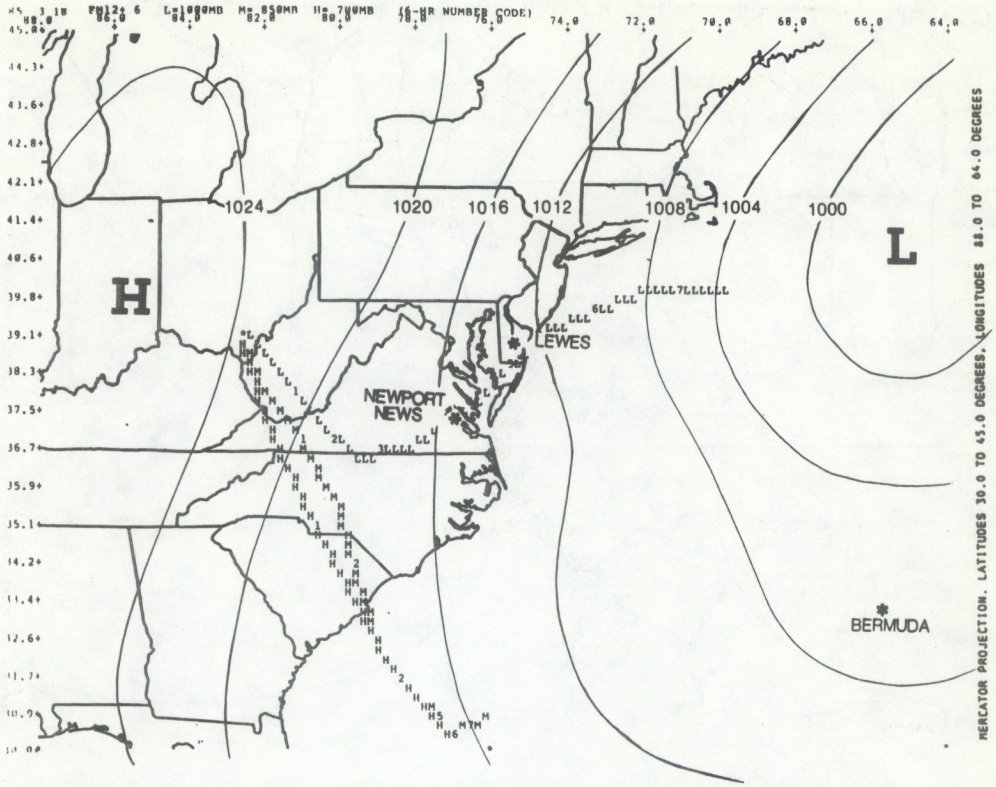

Figure 5i.--Event 5: Valid 18Z March 18, 1985 (from Ohio).

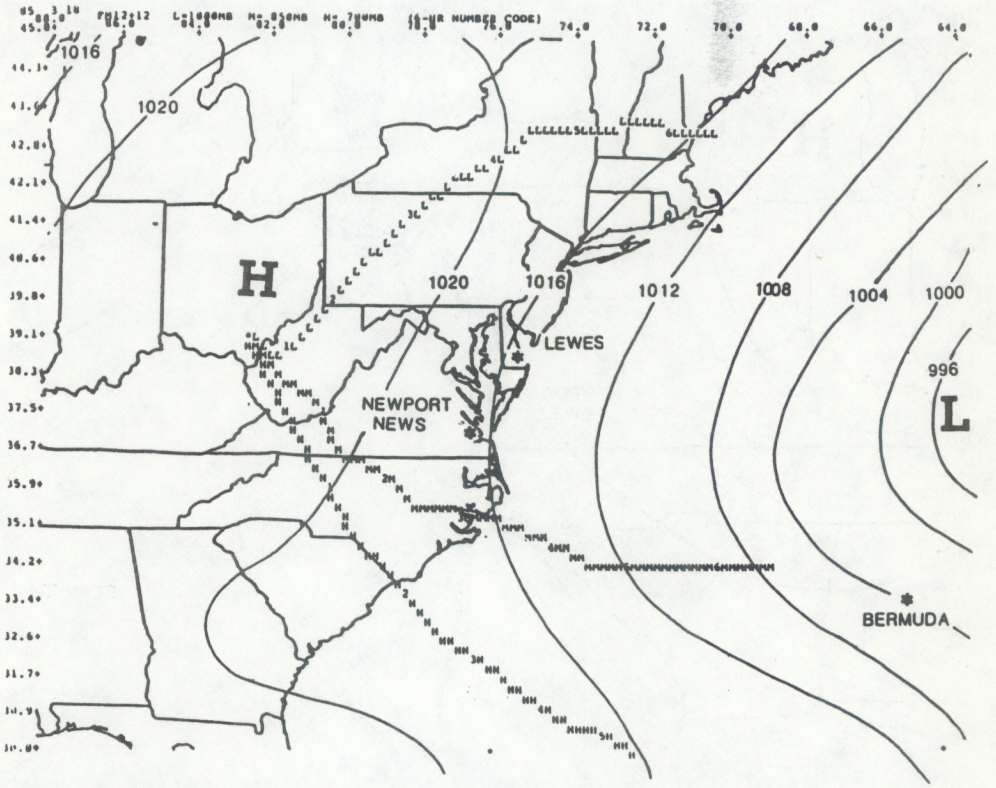

Figure 5j.--Event 5: Valid 00Z March 19, 1985 (from Ohio).

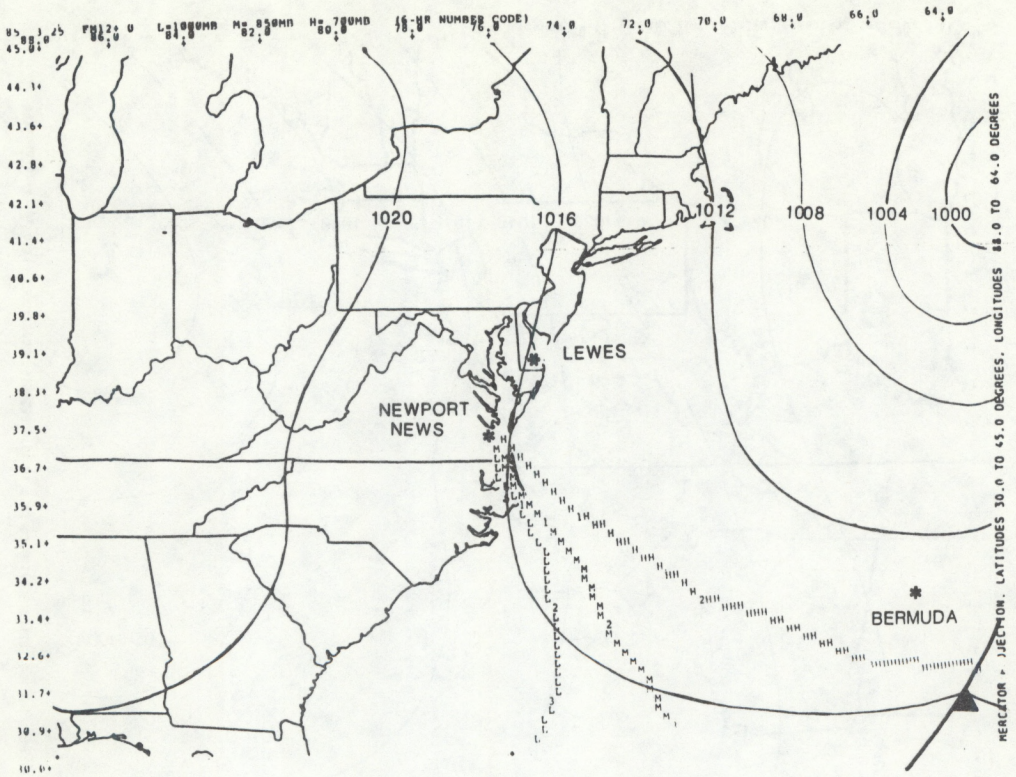

Figure 6a.--Event 6: Valid 12Z March 25, 1985.

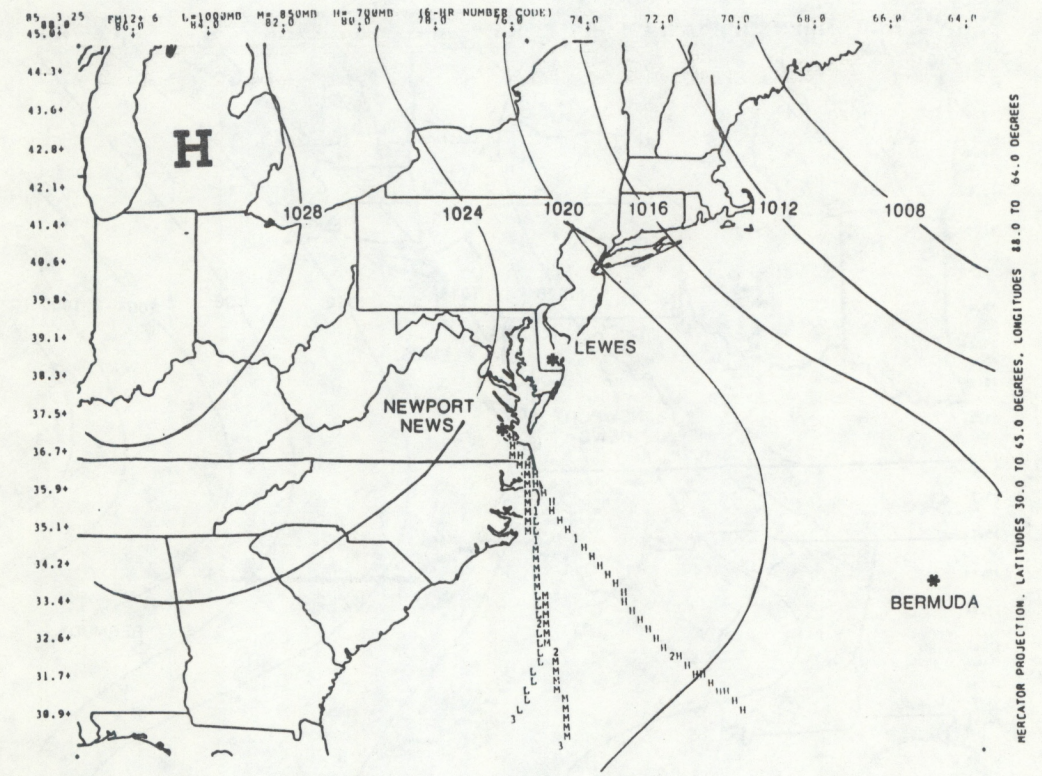

Figure 6b.--Event 6: Valid 18Z March 25, 1985.

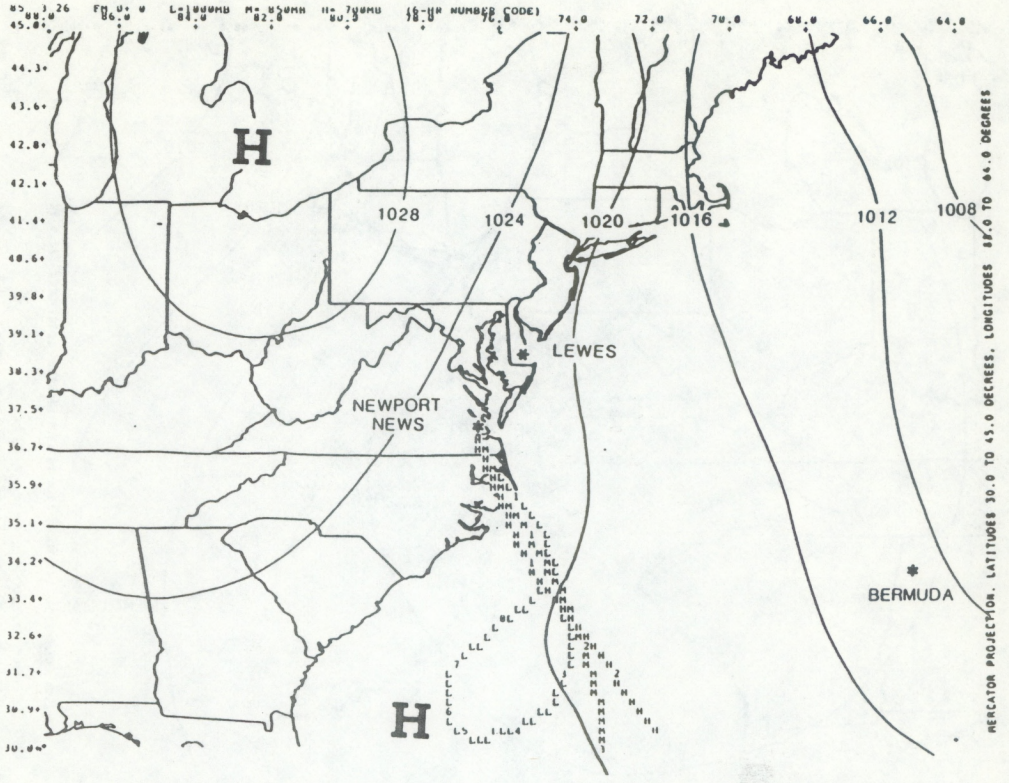

Figure 6c.--Event 6: Valid 00Z March 26, 1985.

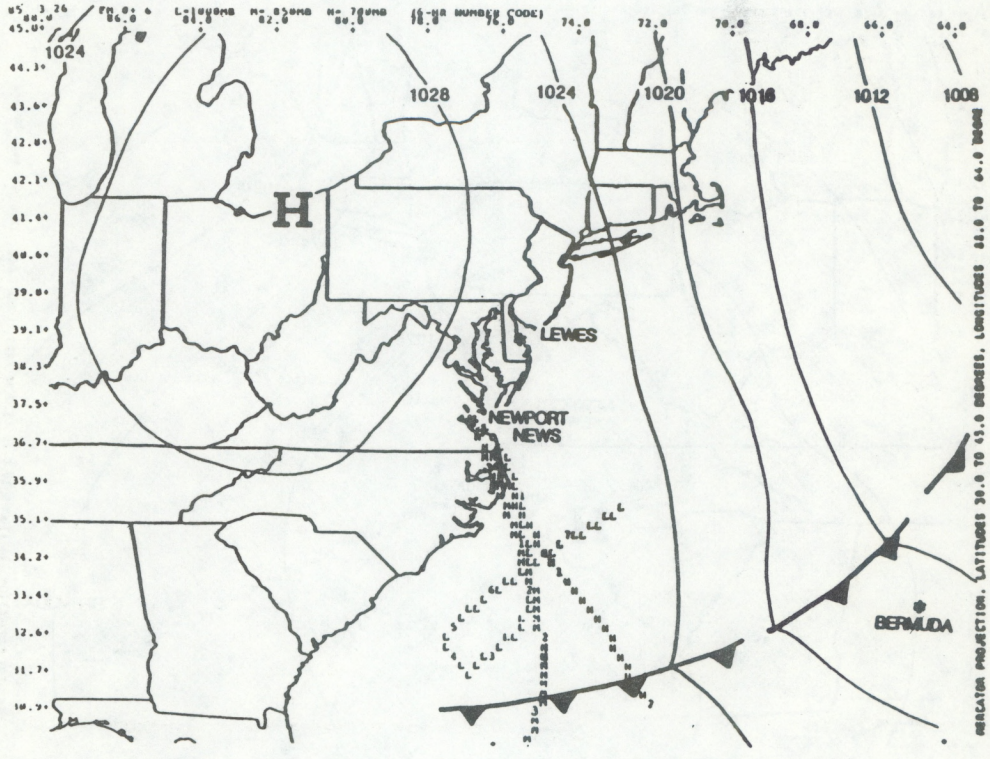

Figure 6d.--Event 6: Valid 06Z March 26, 1985.

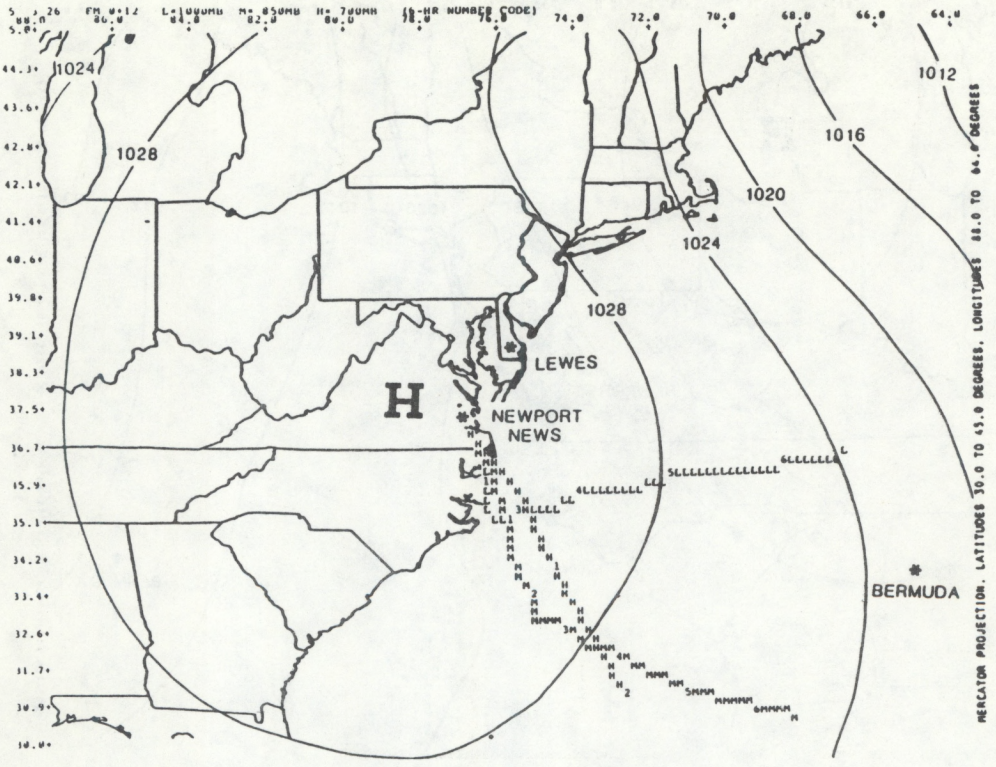

Figure 6e.--Event 6: Valid 12Z March 26, 1985.

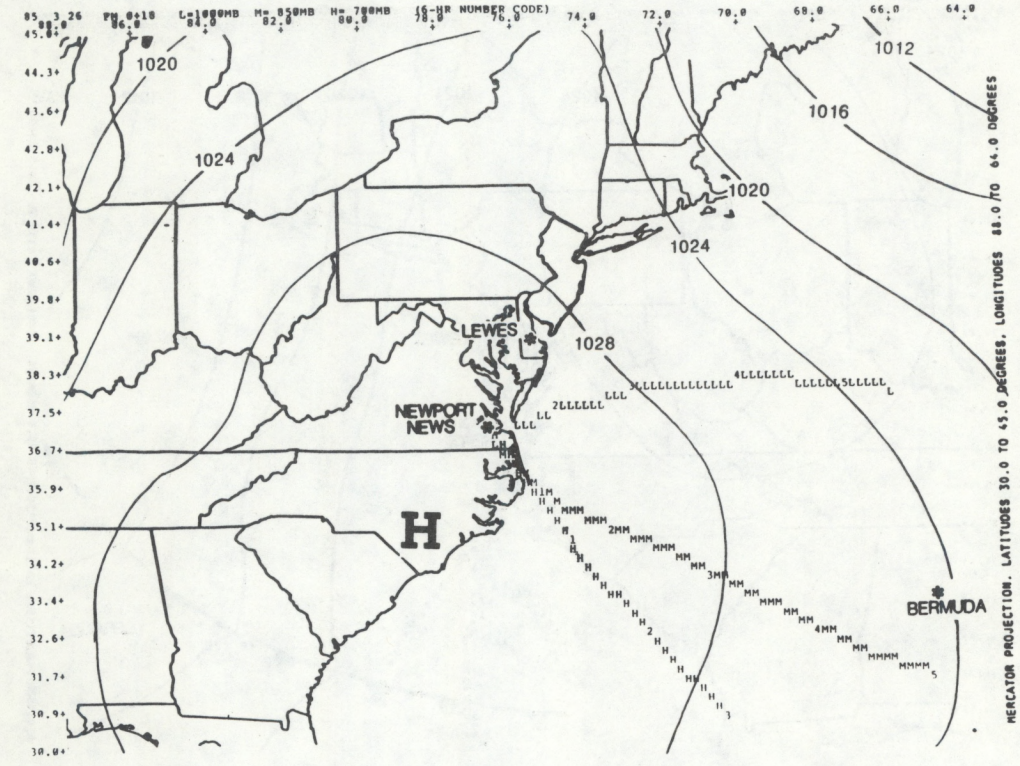

Figure 6f.--Event 6: Valid 18Z March 26, 1985.

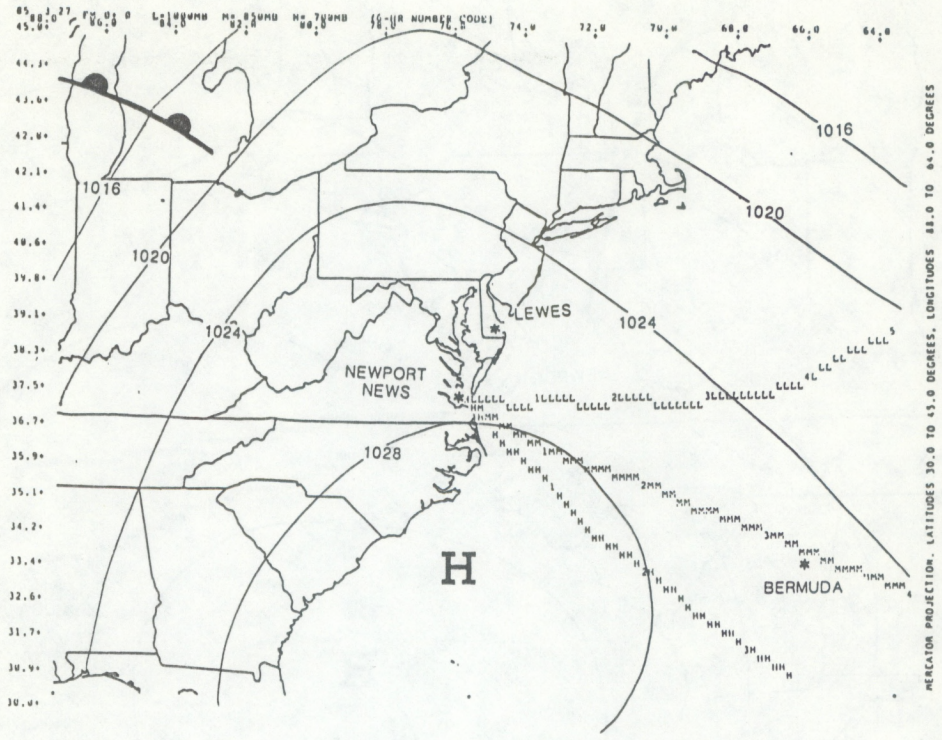

Figure 6g.--Event 6: Valid 00Z March 27, 1985.

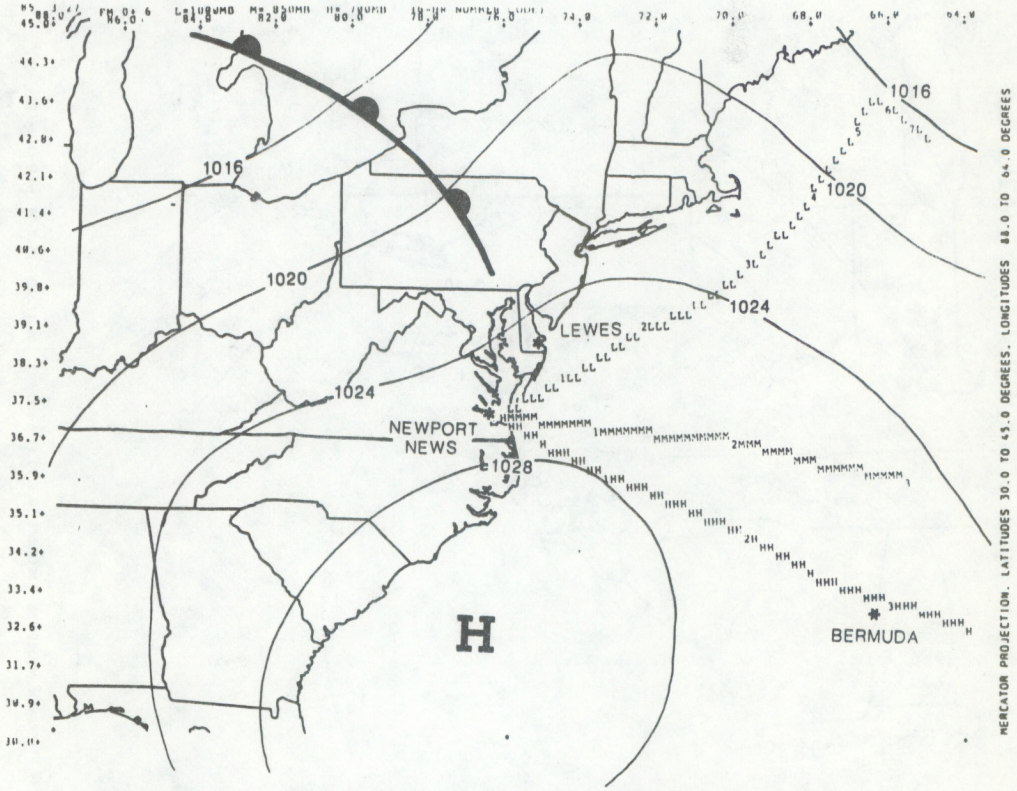

Figure 6h.--Event 6: Valid 06Z March 27, 1985.

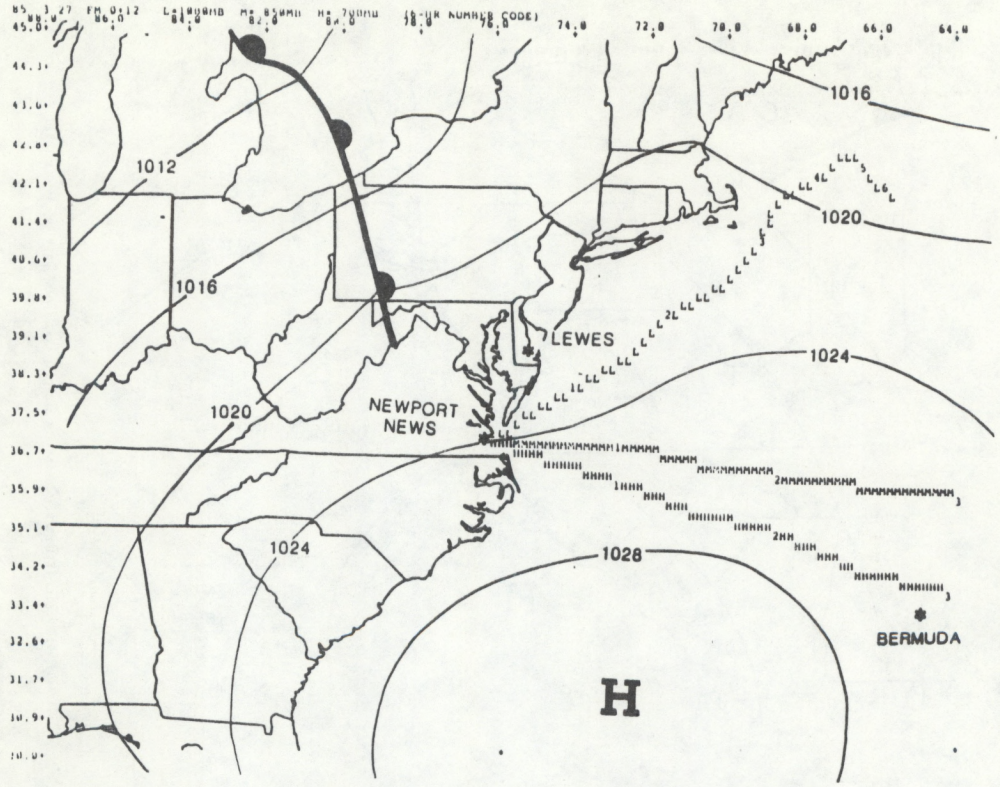

Figure 6i.--Event 6: Valid 12Z March 27, 1985.

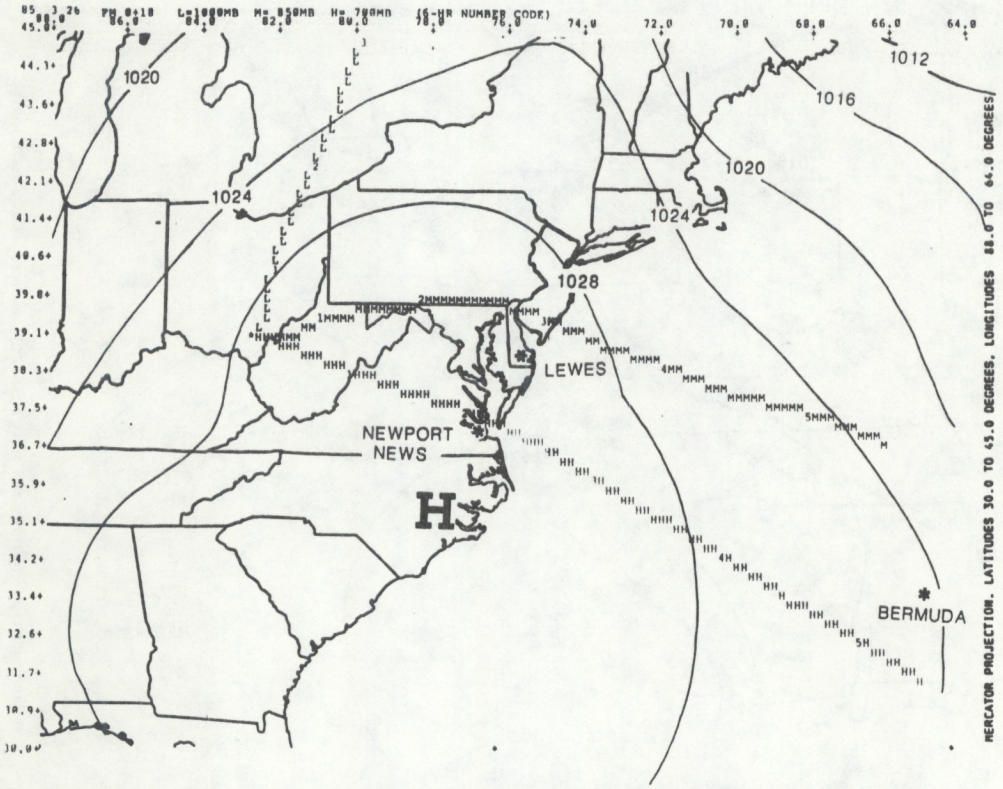

Figure 6j.--Event 6: Valid 18Z March 26, 1985 (from Ohio).

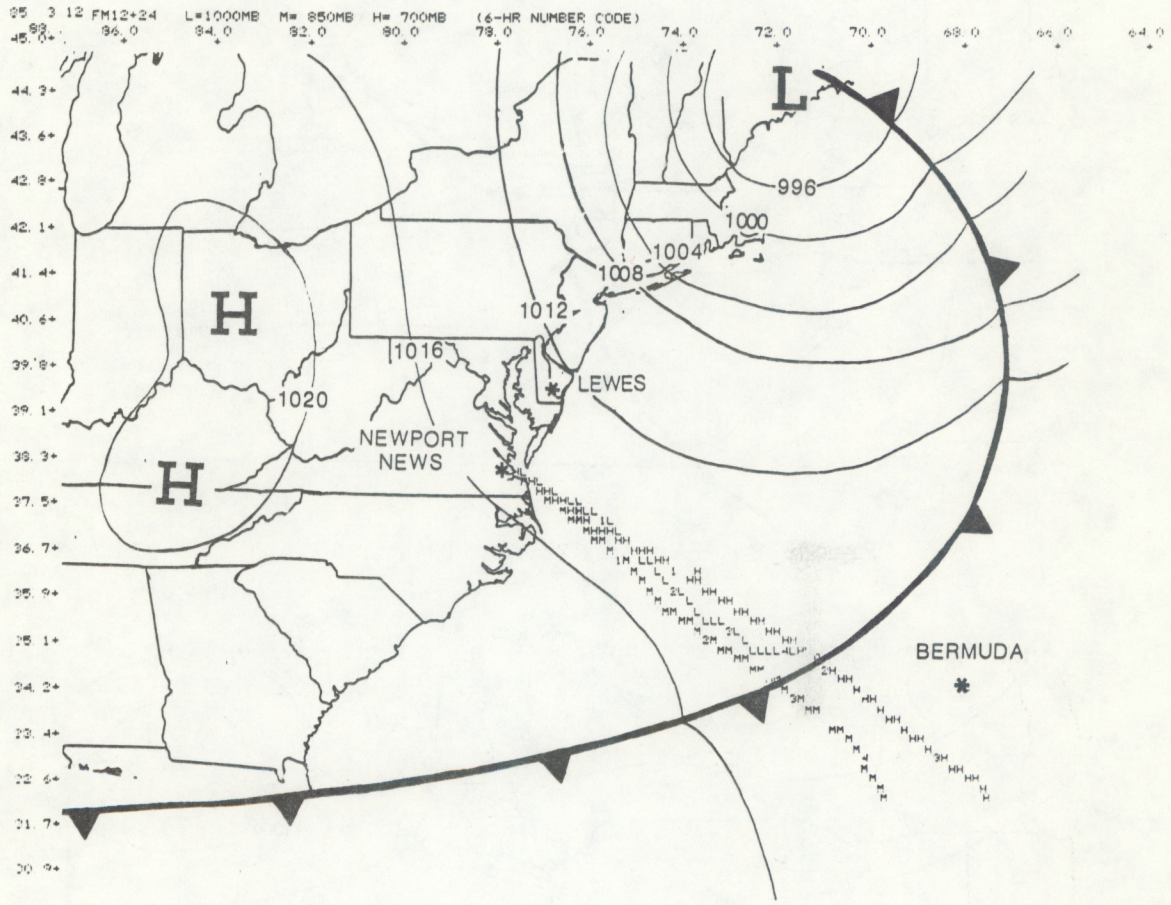

Figure 7.--Valid 12Z March 13, 1985 (optimal sampling conditions; not sampled).

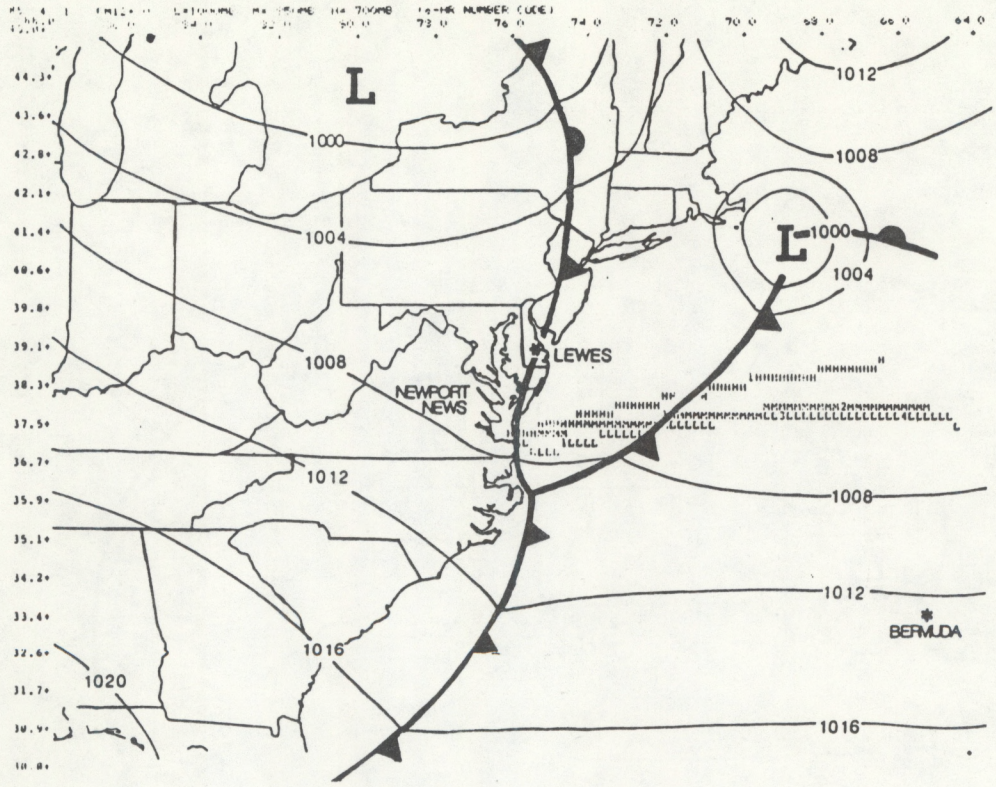

Figure 8a.--Valid 12Z April 1, 1985.

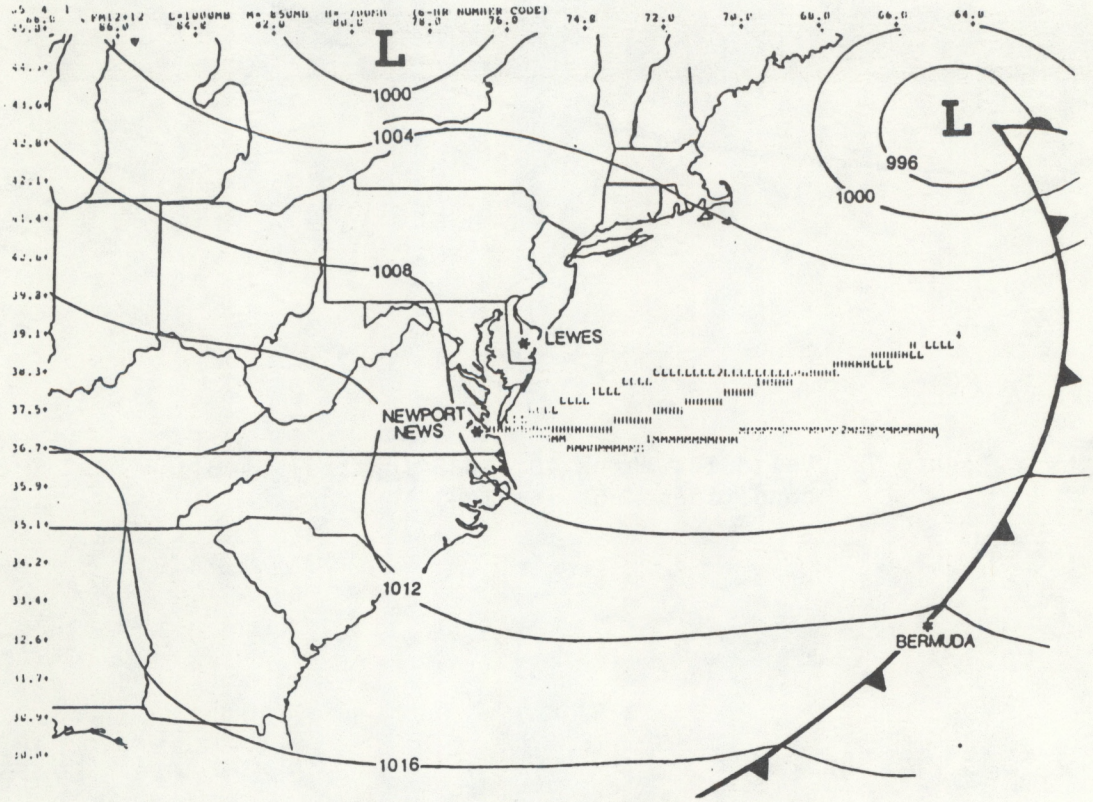

Figure 8b.--Valid 00Z April 2, 1985.

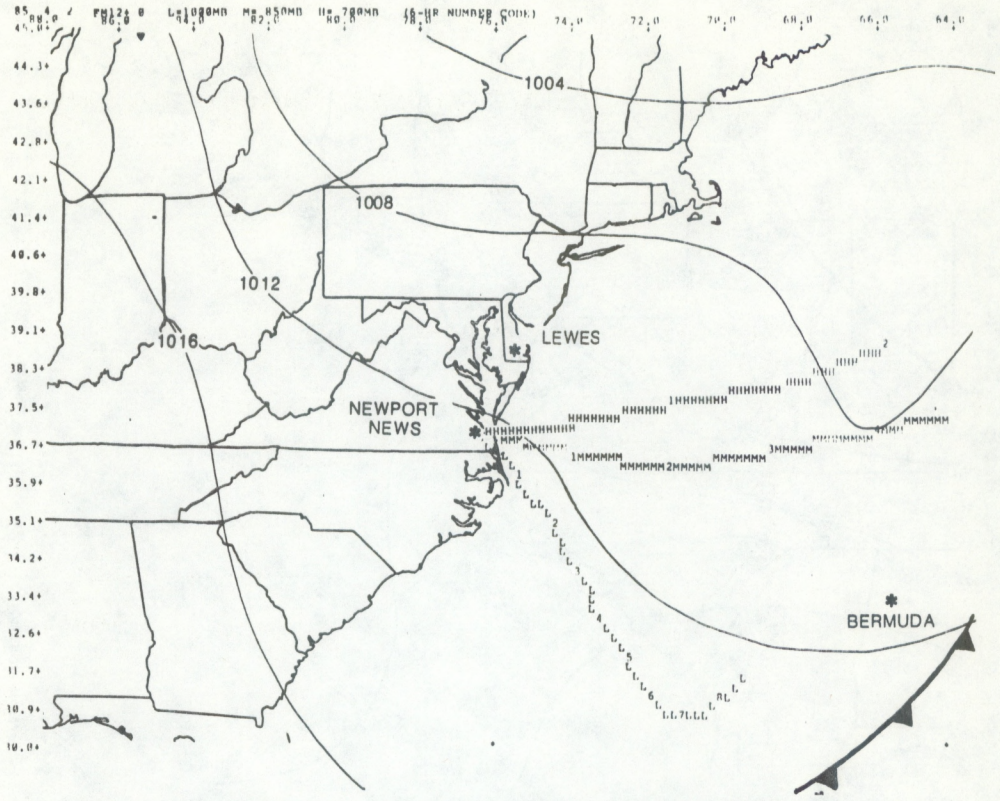

Figure 8c.--Valid 12Z April 2, 1985.

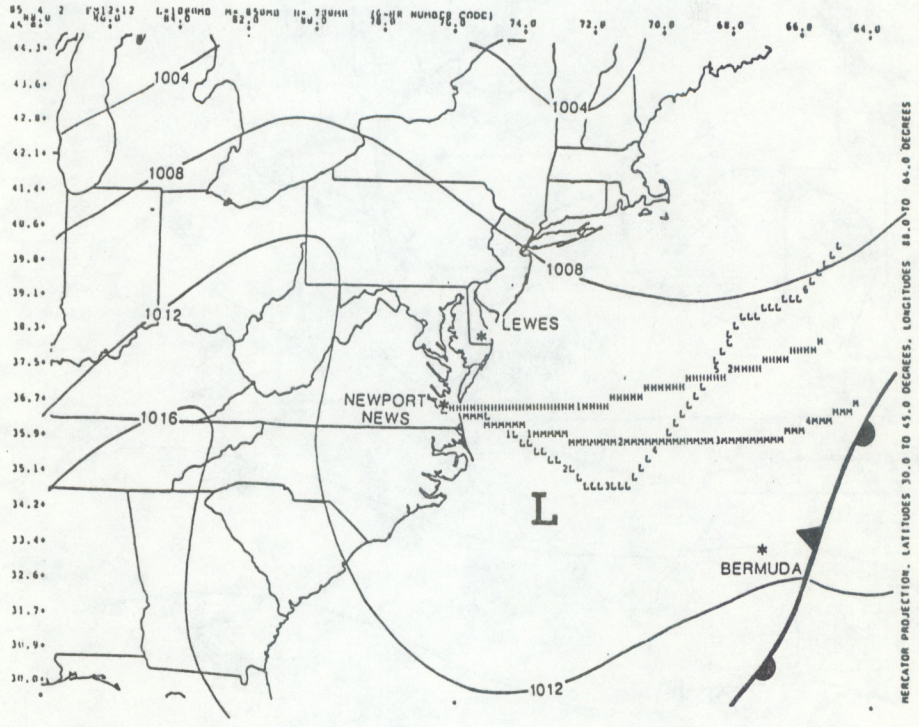

Figure 8d.--Valid 00Z April 3, 1985.

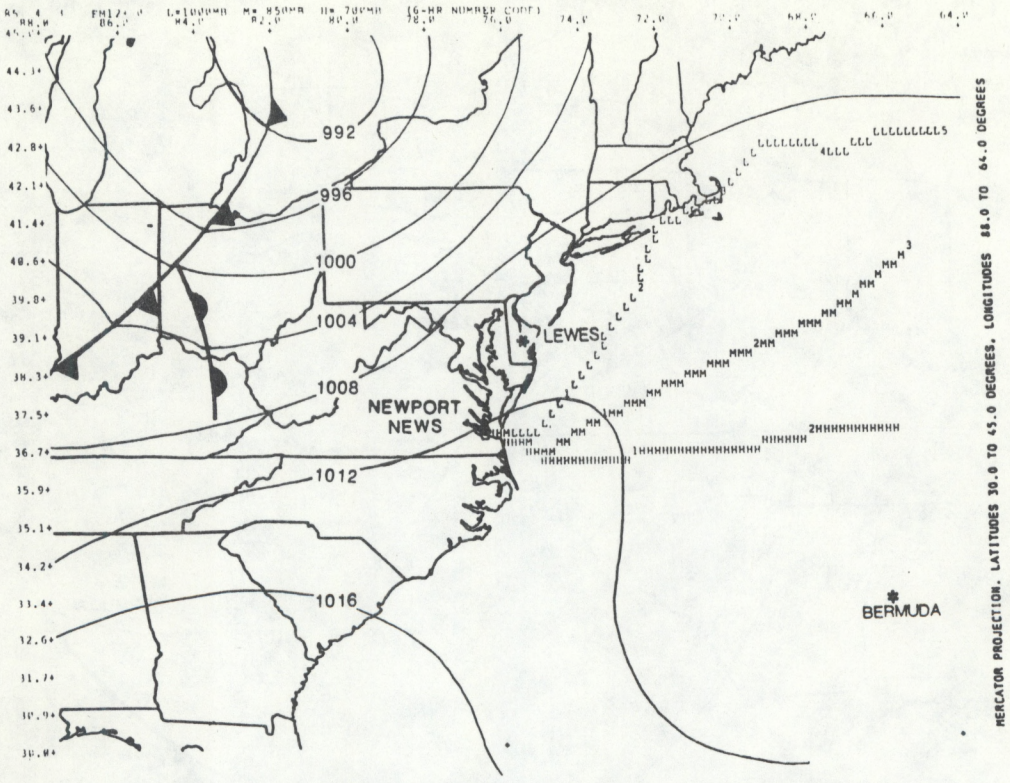

Figure 8e.--Valid 12Z April 3, 1985.

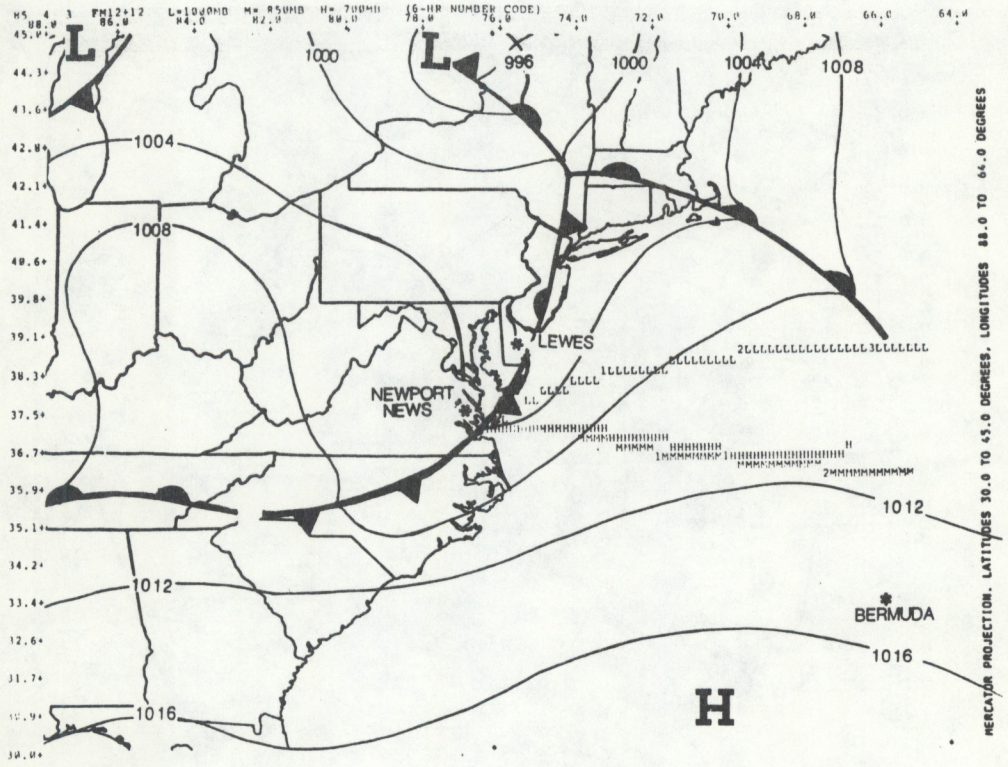

Figure 8f.--Valid 00Z April 4, 1985.

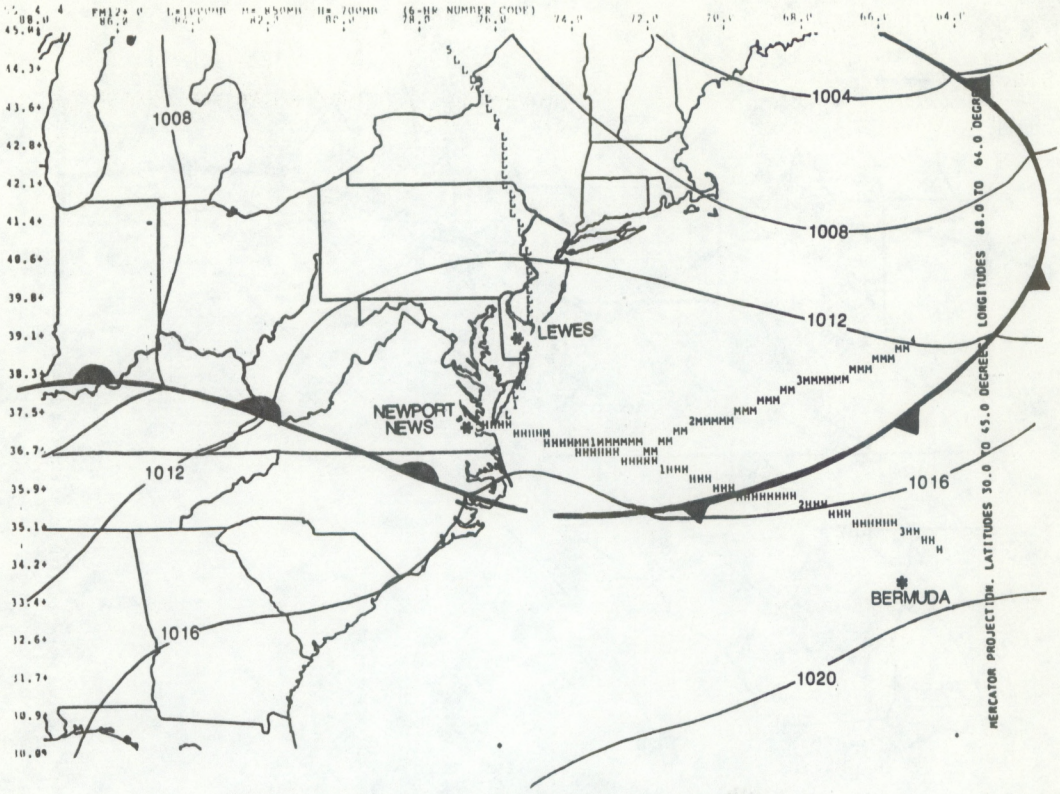

Figure 8g.--Valid 12Z April 4, 1985.

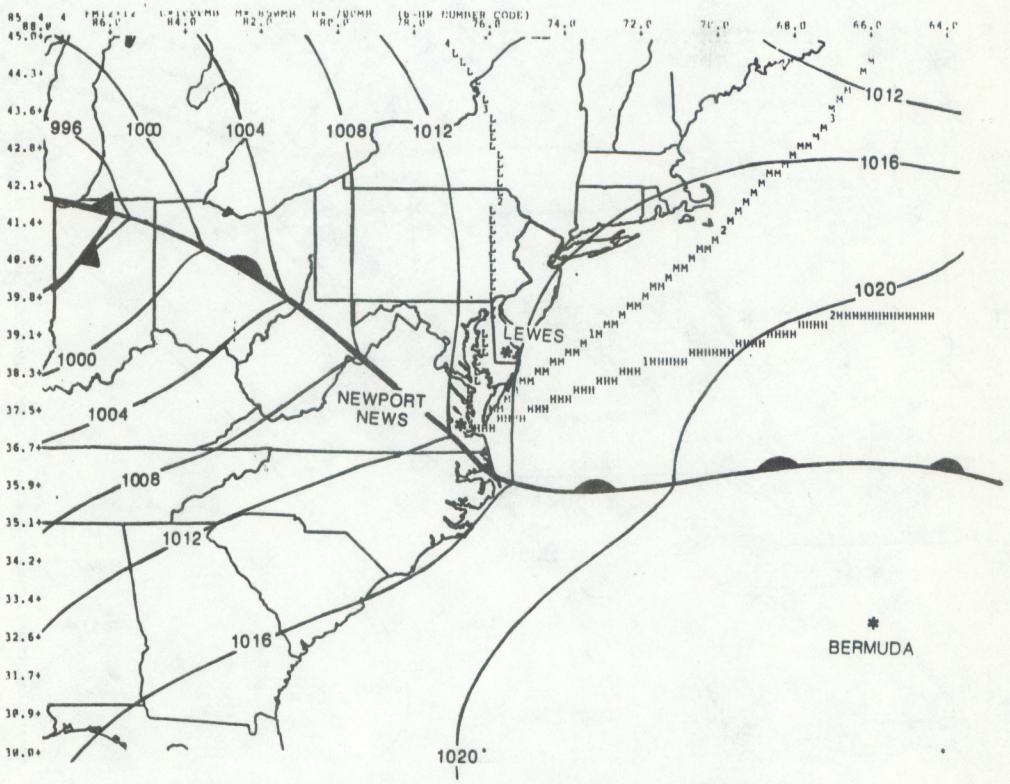

Figure 8h.--Valid 00Z April 5, 1985.

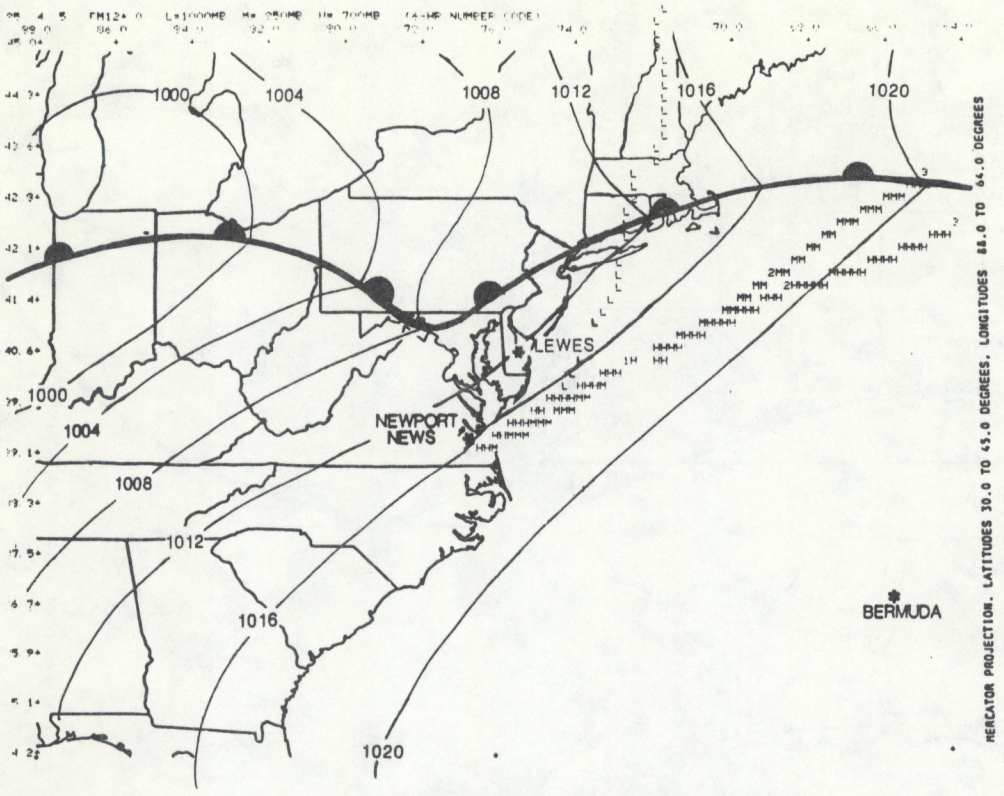

Figure 8i.--Valid 12Z April 5, 1985.

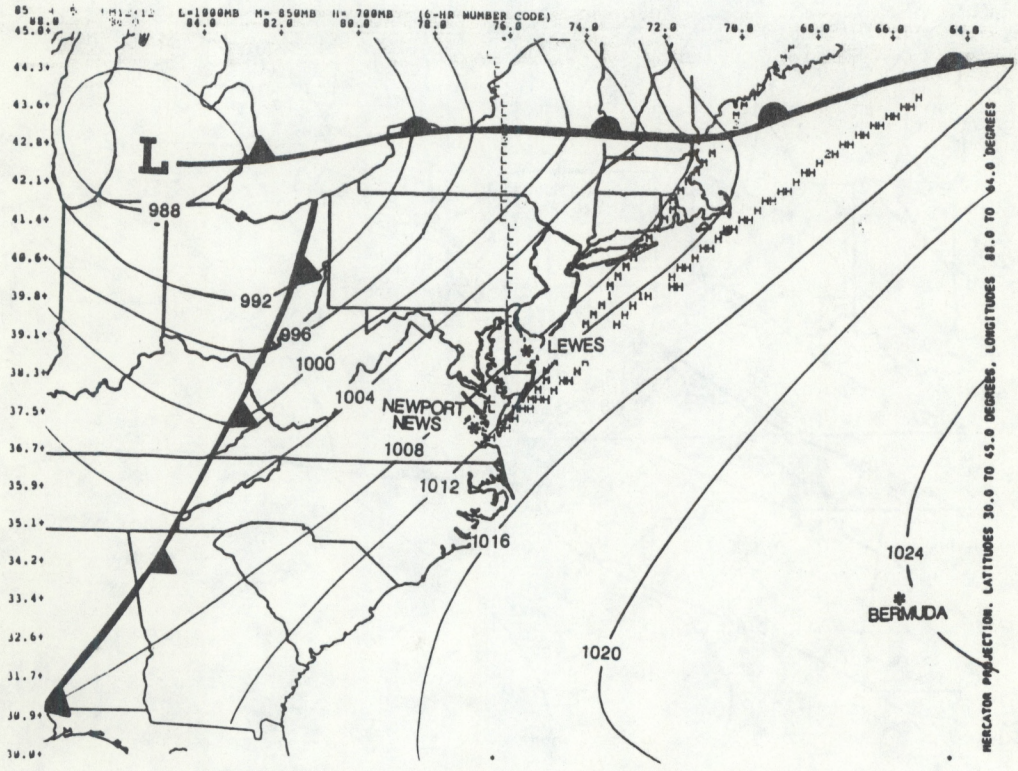

Figure 8j.--Valid 00Z April 6, 1985.

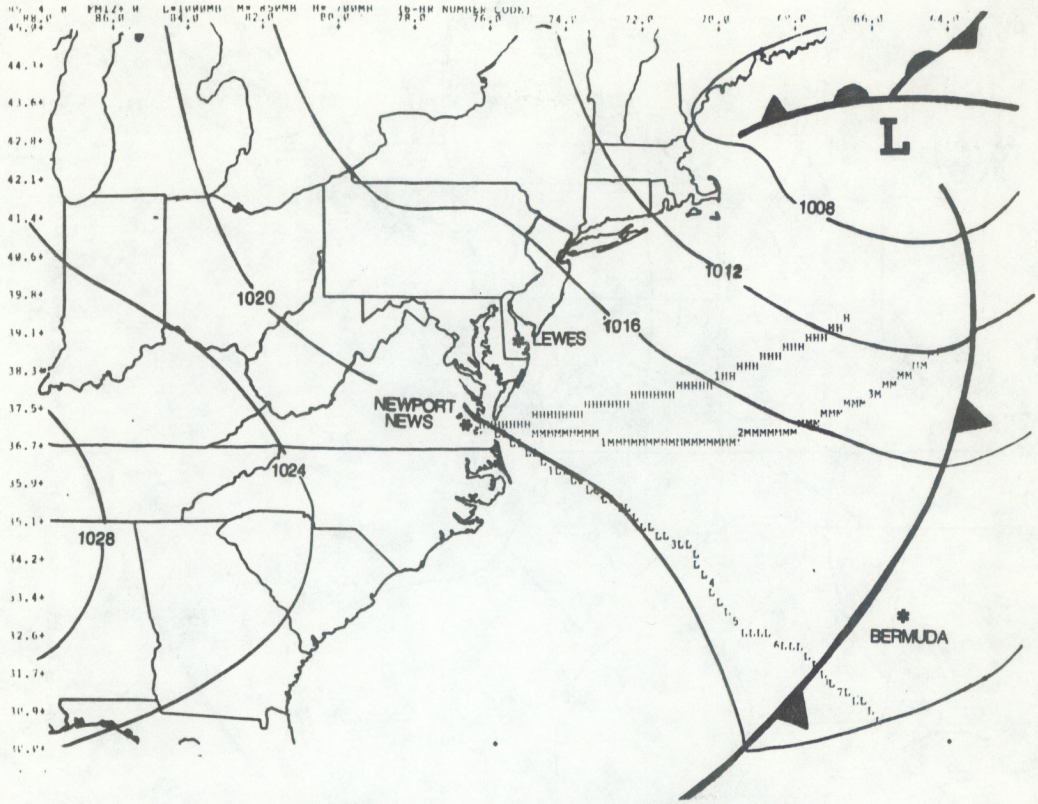

Figure 9a.--Valid 12Z April 8, 1985.

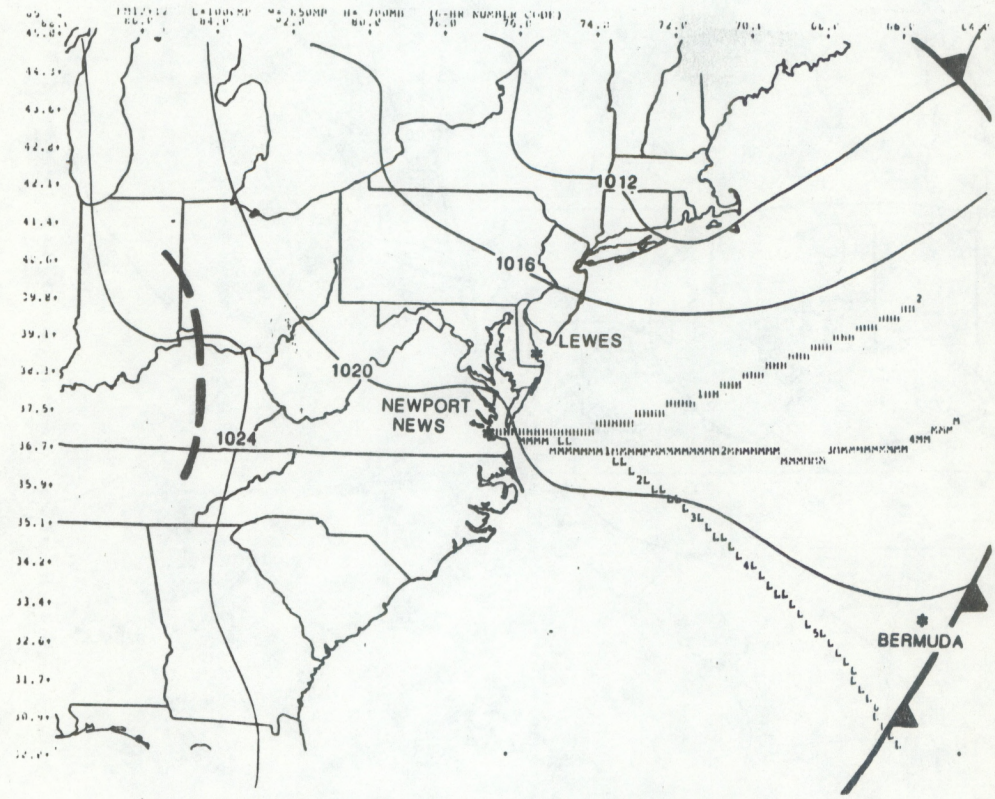

Figure 9b.--Valid 00Z April 9, 1985.

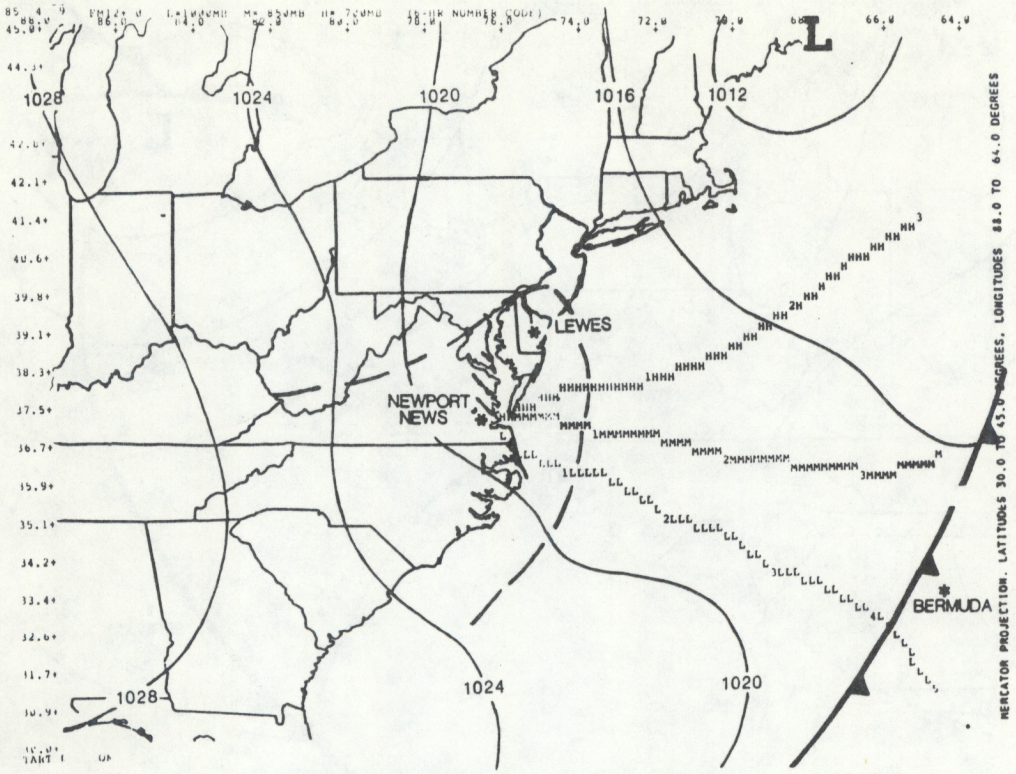

Figure 9c.--Valid 12Z April 9, 1985.

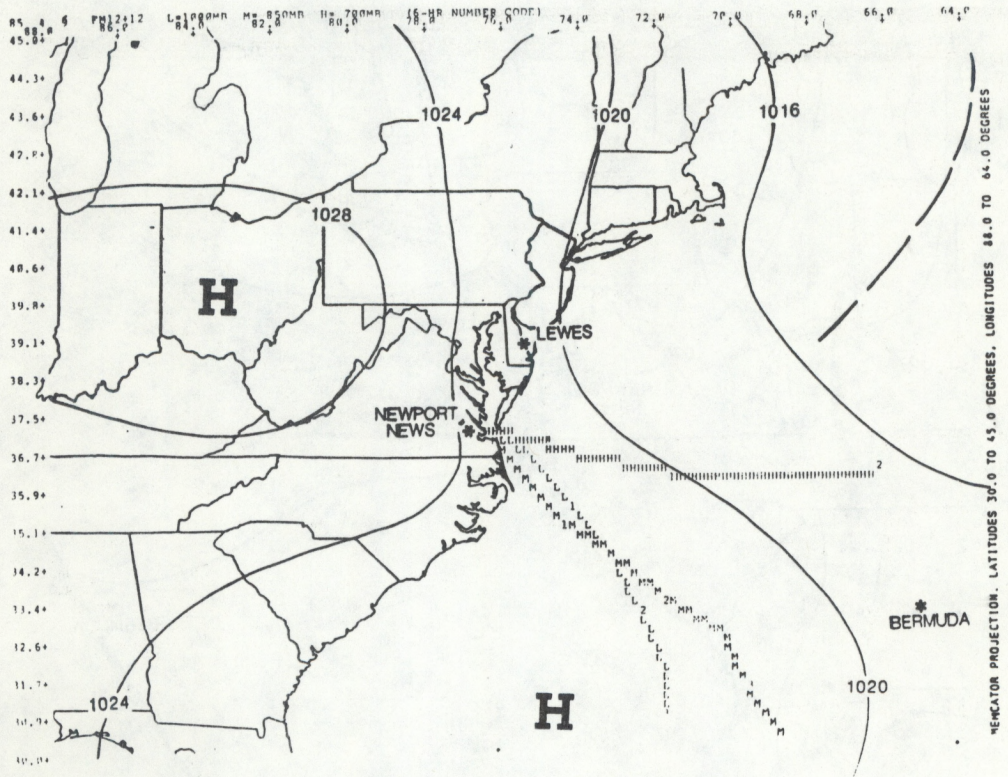

Figure 9d.--Valid 00Z April 10, 1985.

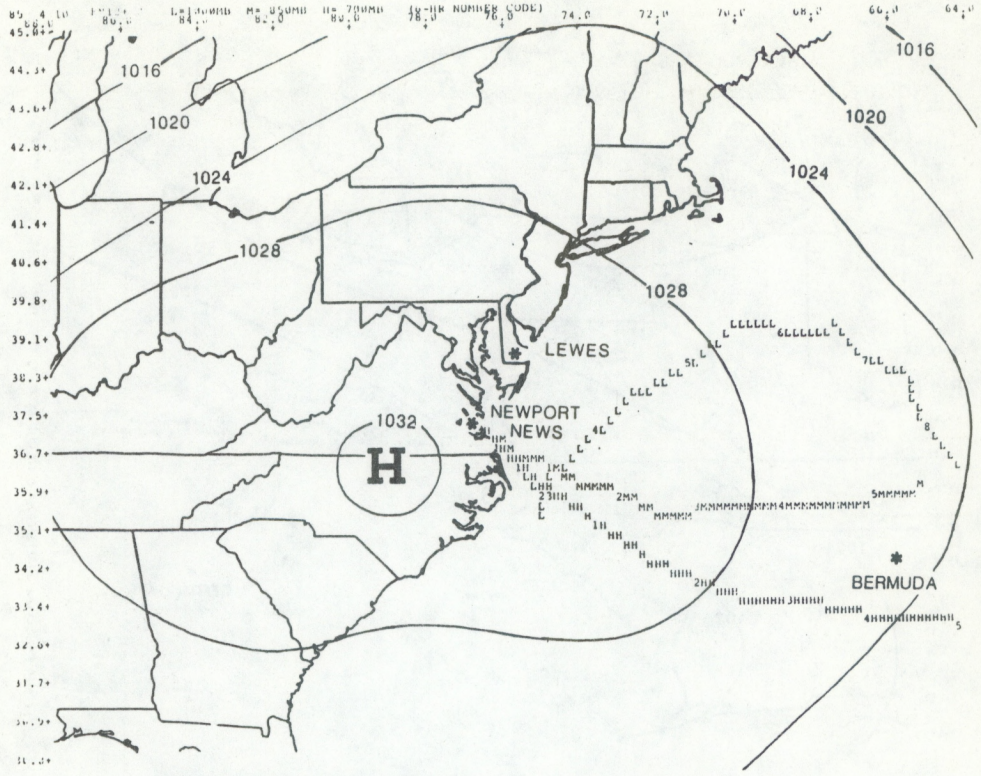

Figure 9e.--Valid 12Z April 10, 1985.

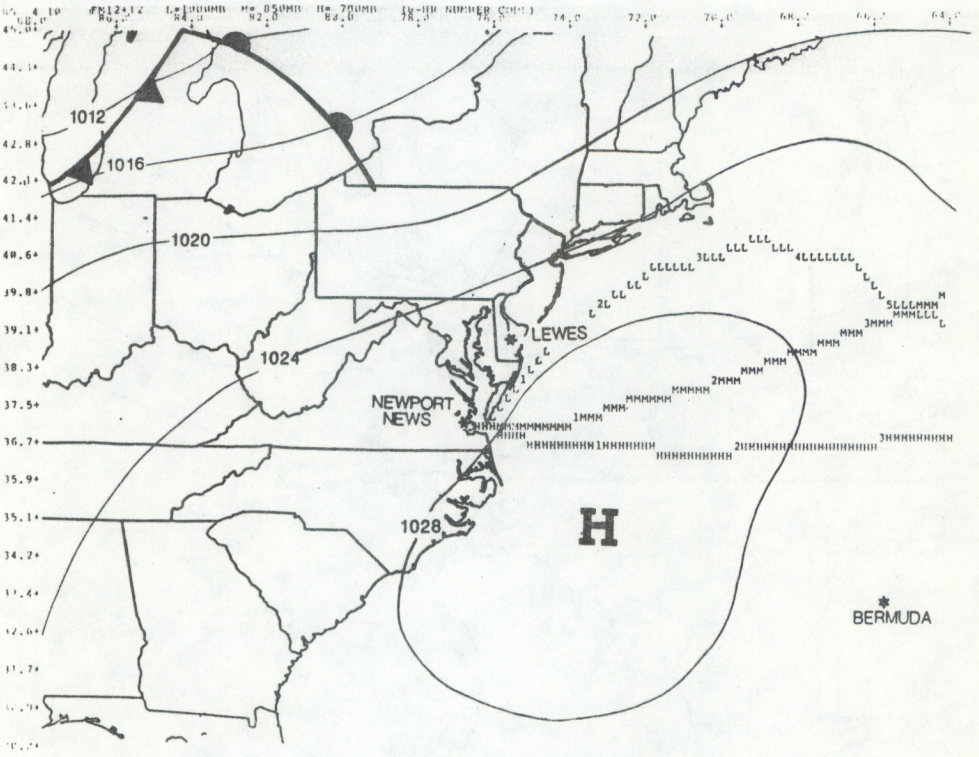

Figure 9f.--Valid 00Z April 11, 1985.

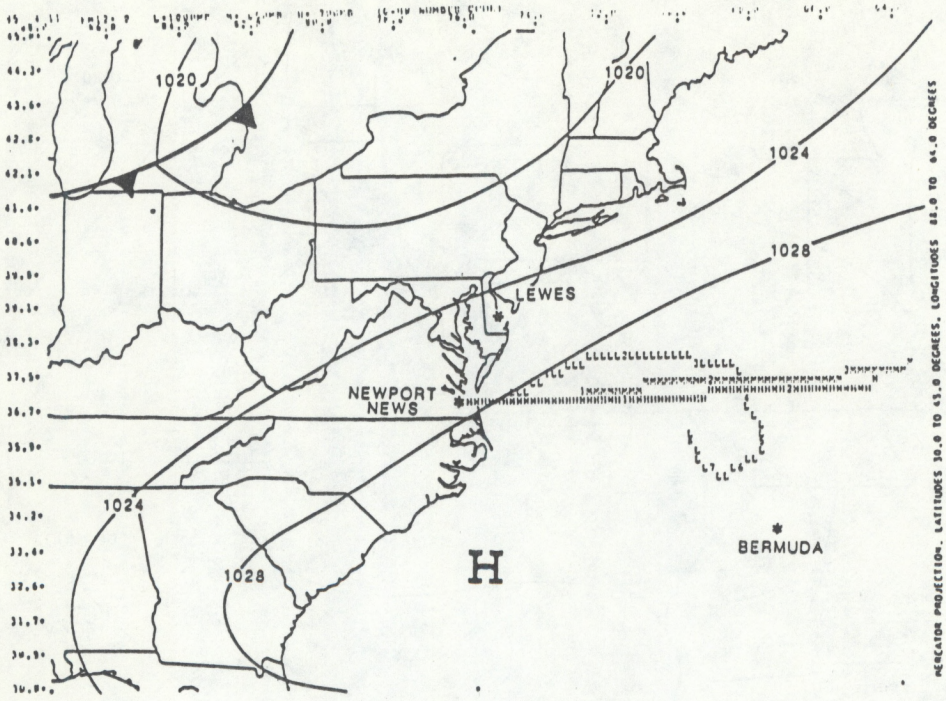

Figure 9g.--Valid 12Z April 11, 1985.

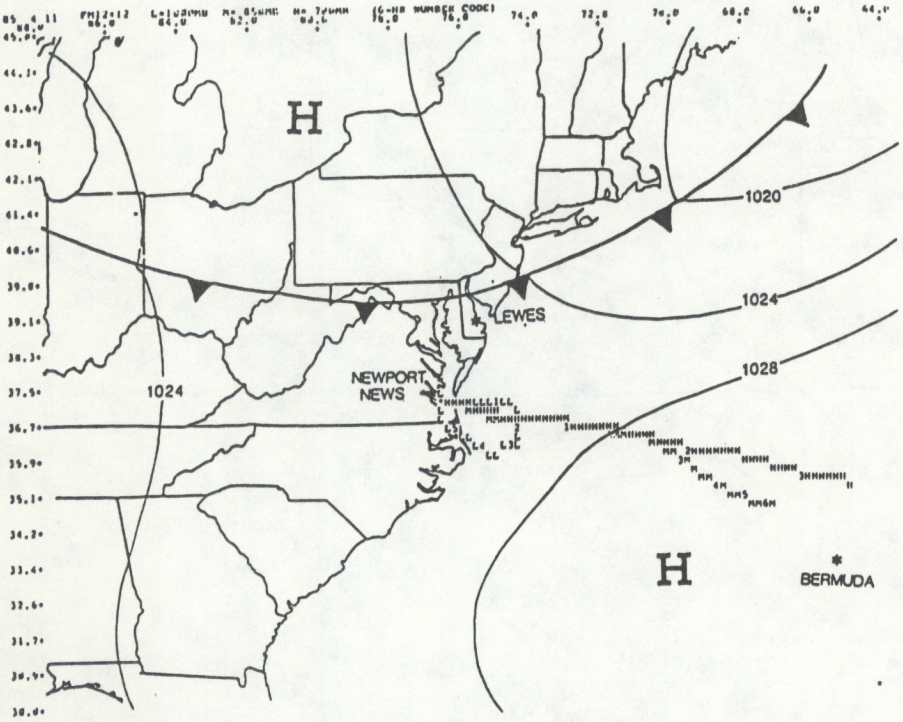

Figure 9h.--Valid 00Z April 12, 1985.

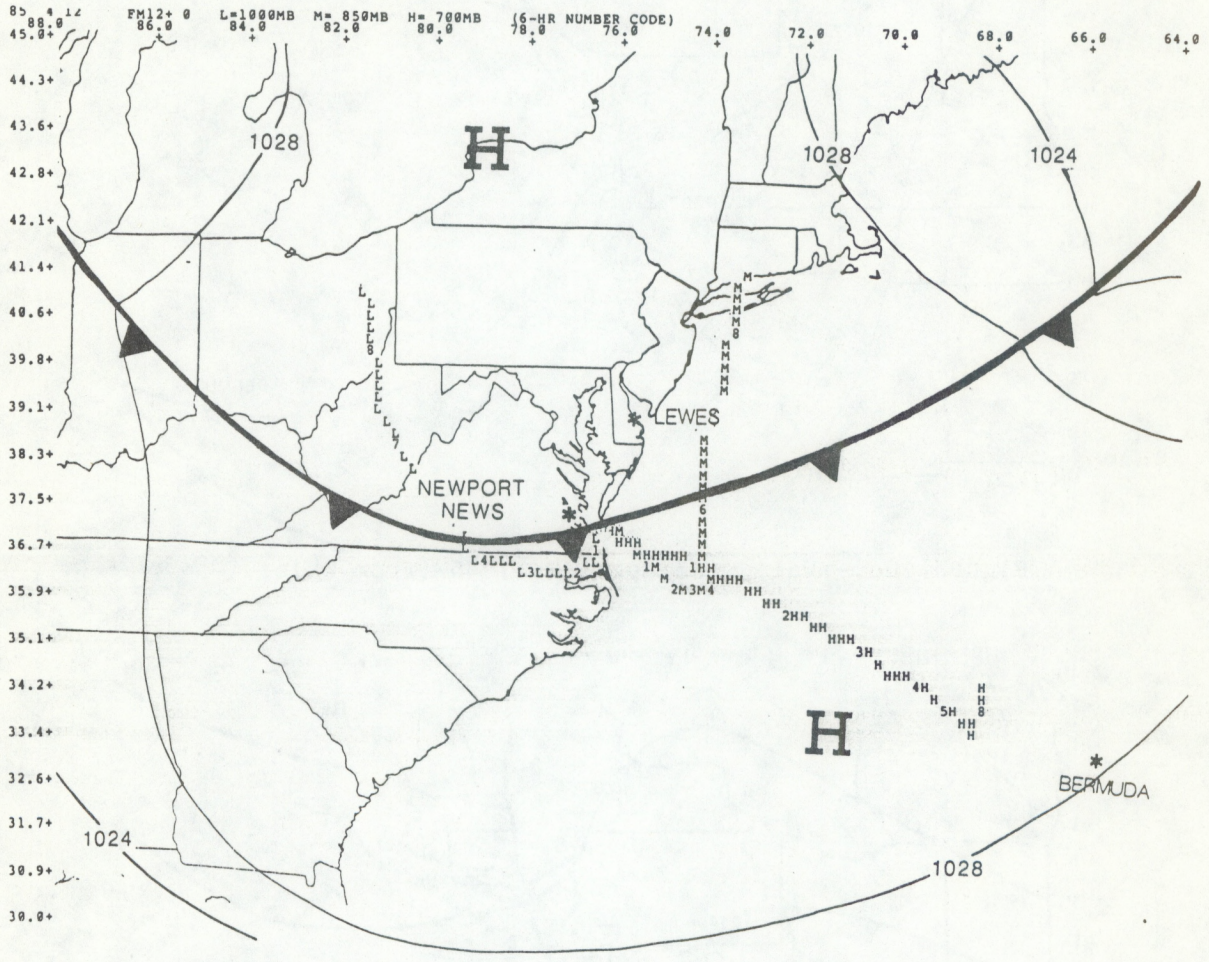

Figure 9i.--Valid 12Z April 12, 1985.

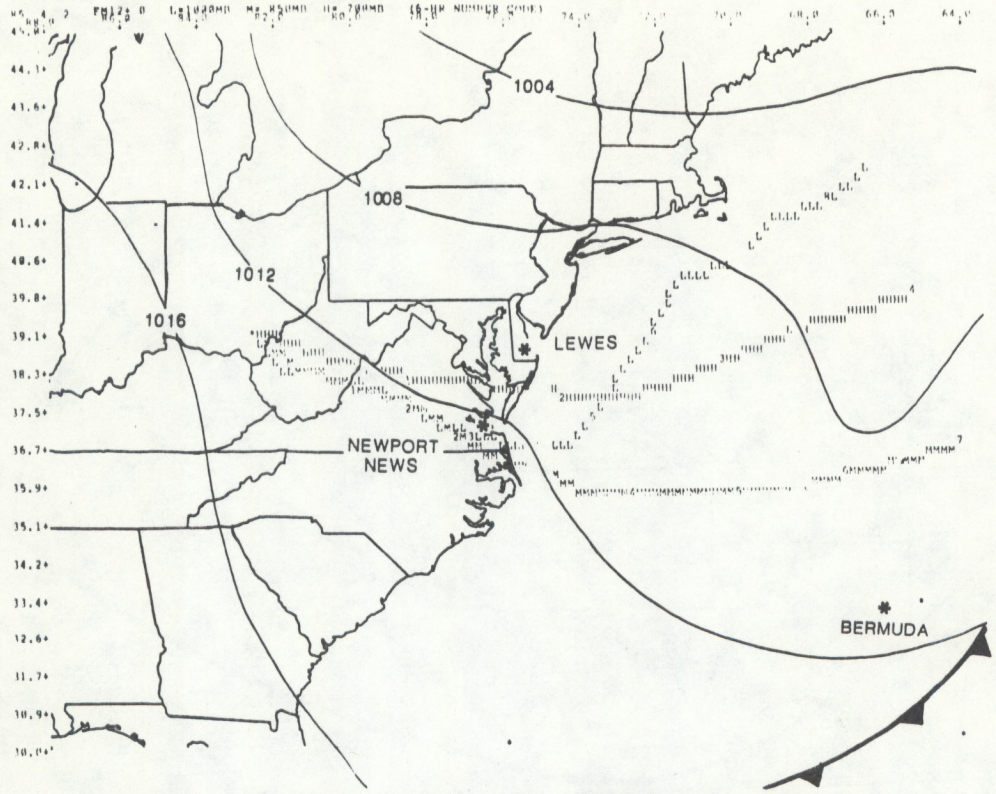

Figure 10a.--Valid 12Z April 2, 1985 (from Ohio).

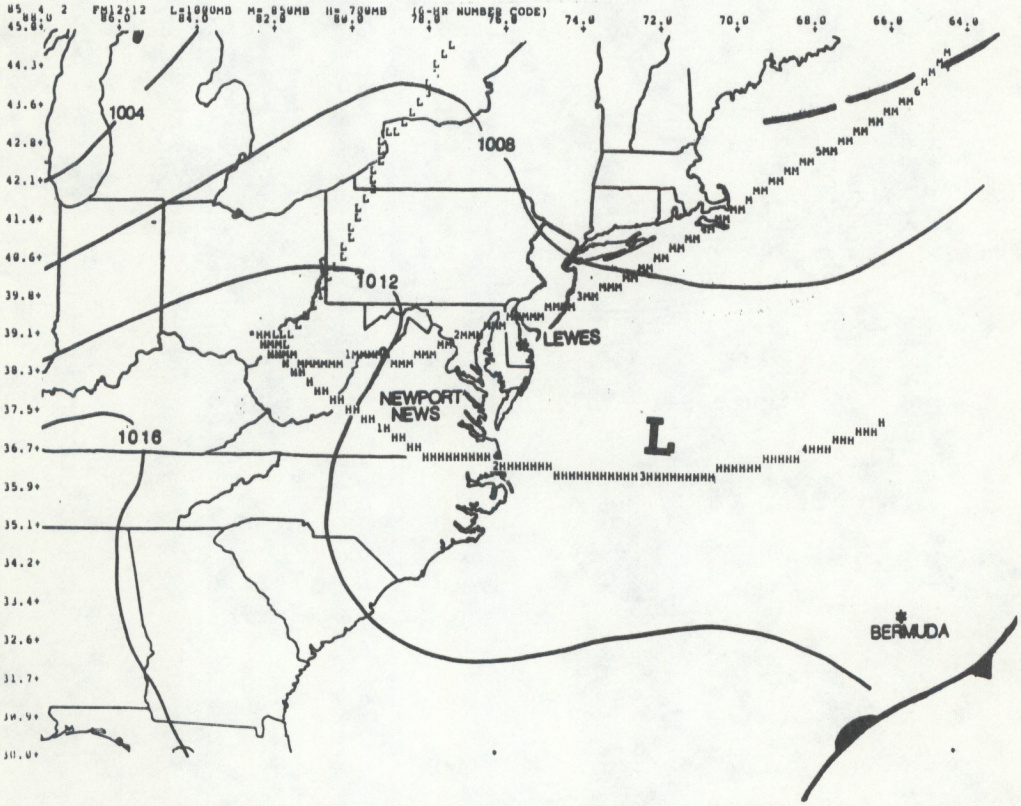

Figure 10b.--Valid 00Z April 3, 1985 (from Ohio).

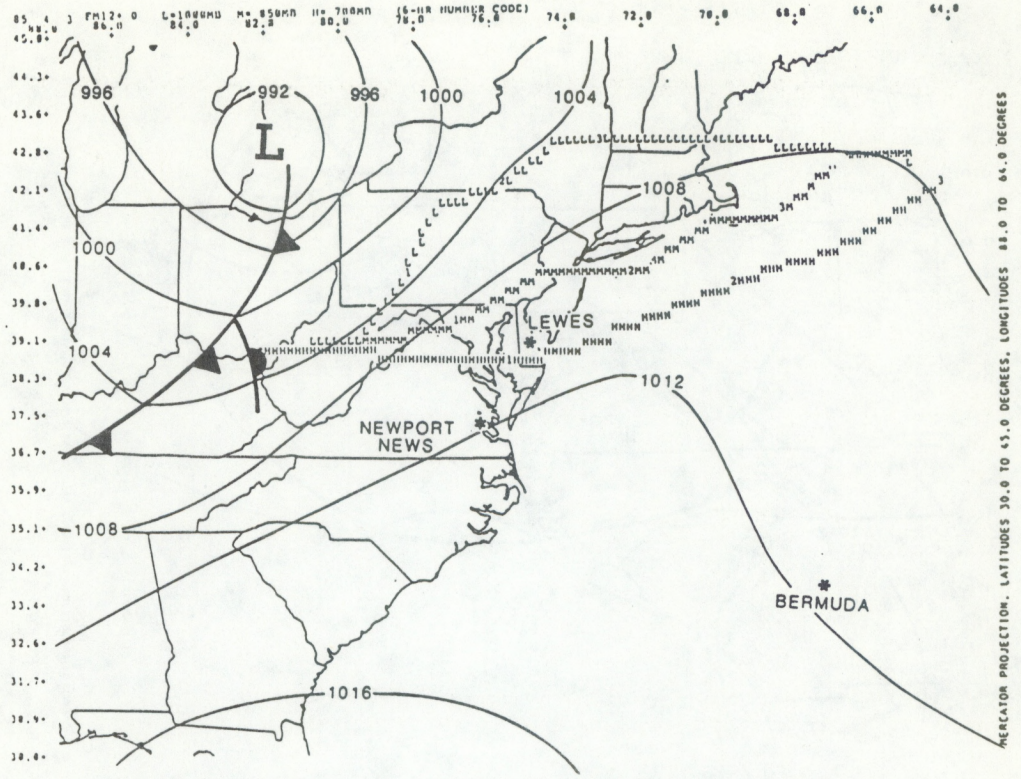

Figure 10c.--Valid 12Z April 3, 1985 (from Ohio).

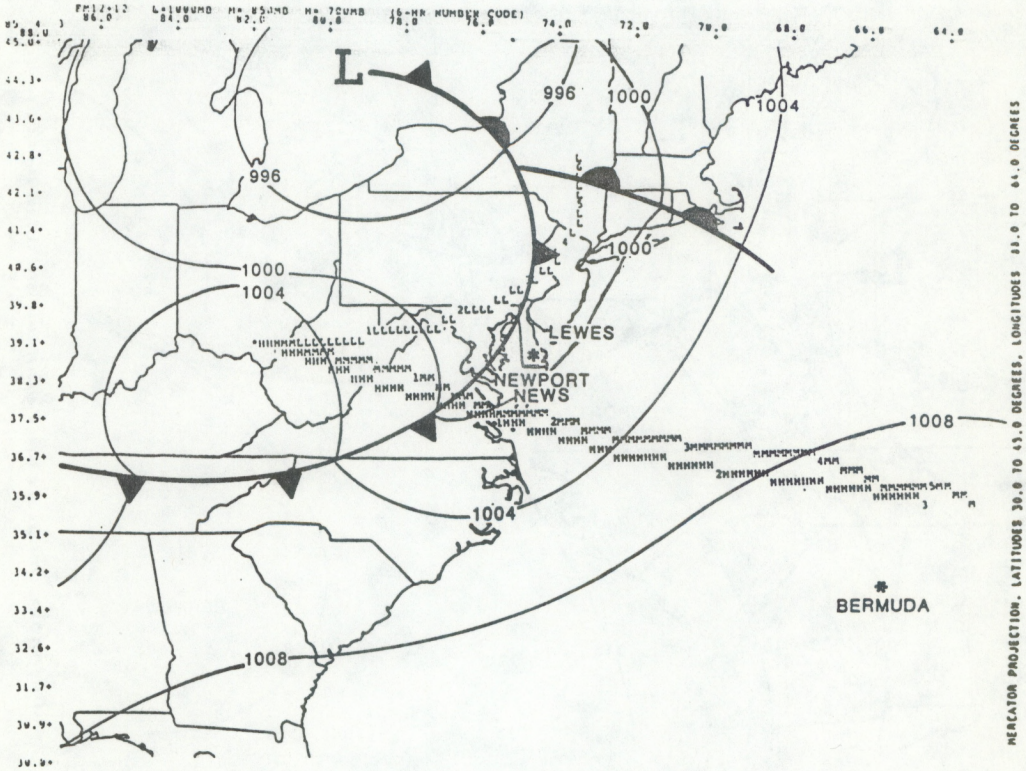

Figure 10d.--Valid 00Z April 4, 1985 (from Ohio).

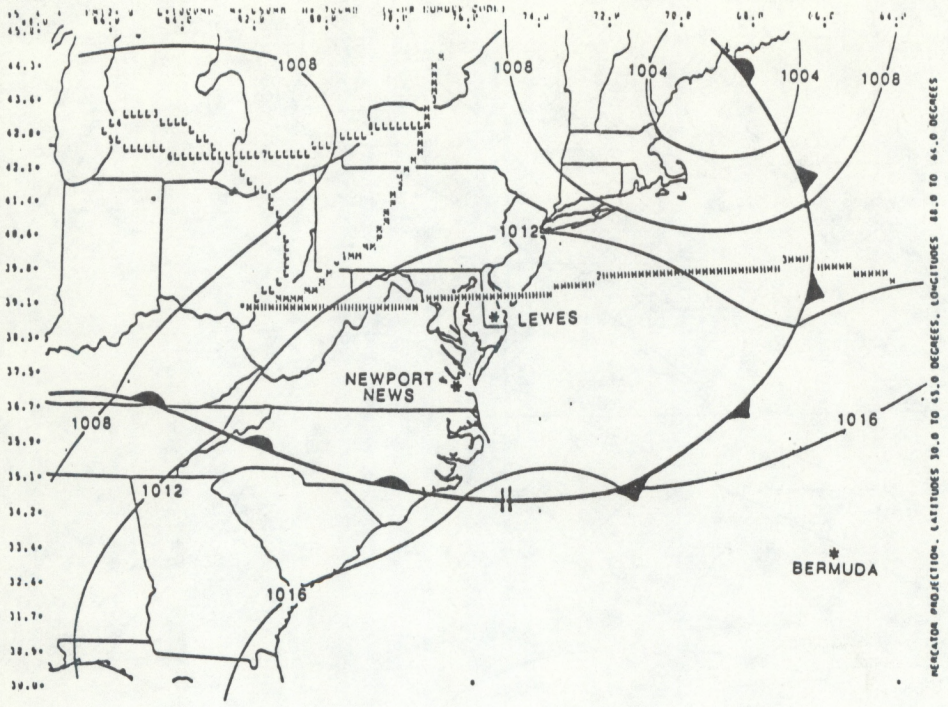

Figure 10e.--Valid 12Z April 4, 1985 (from Ohio).

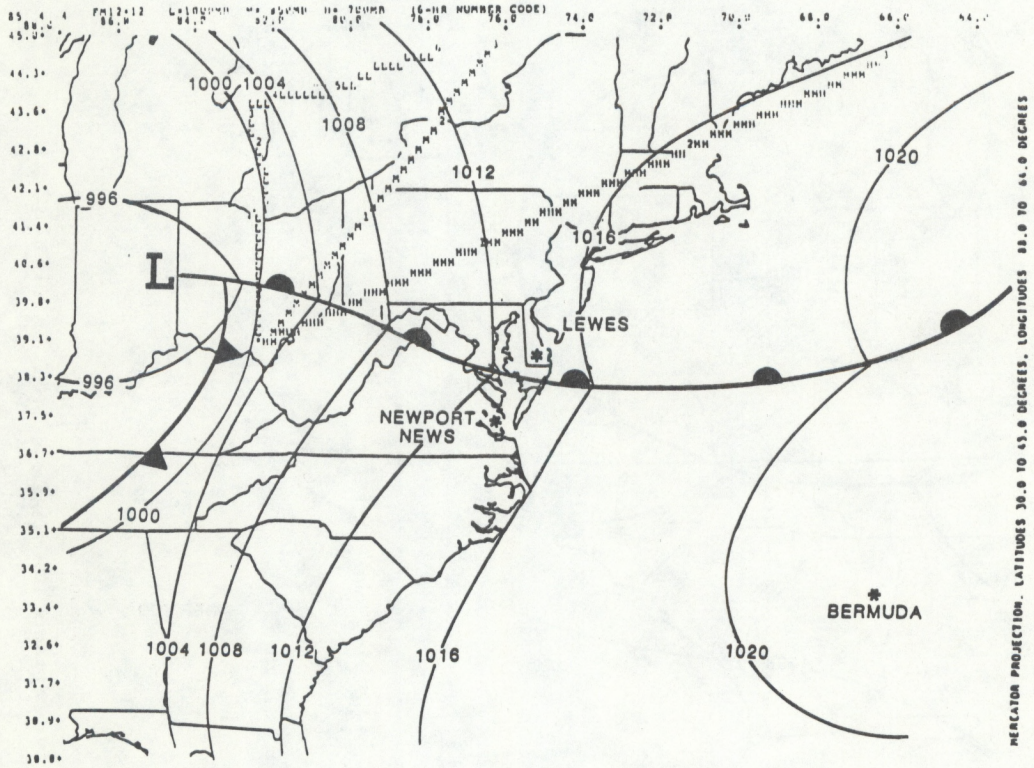

Figure 10f.--Valid 00Z April 5, 1985 (from Ohio).

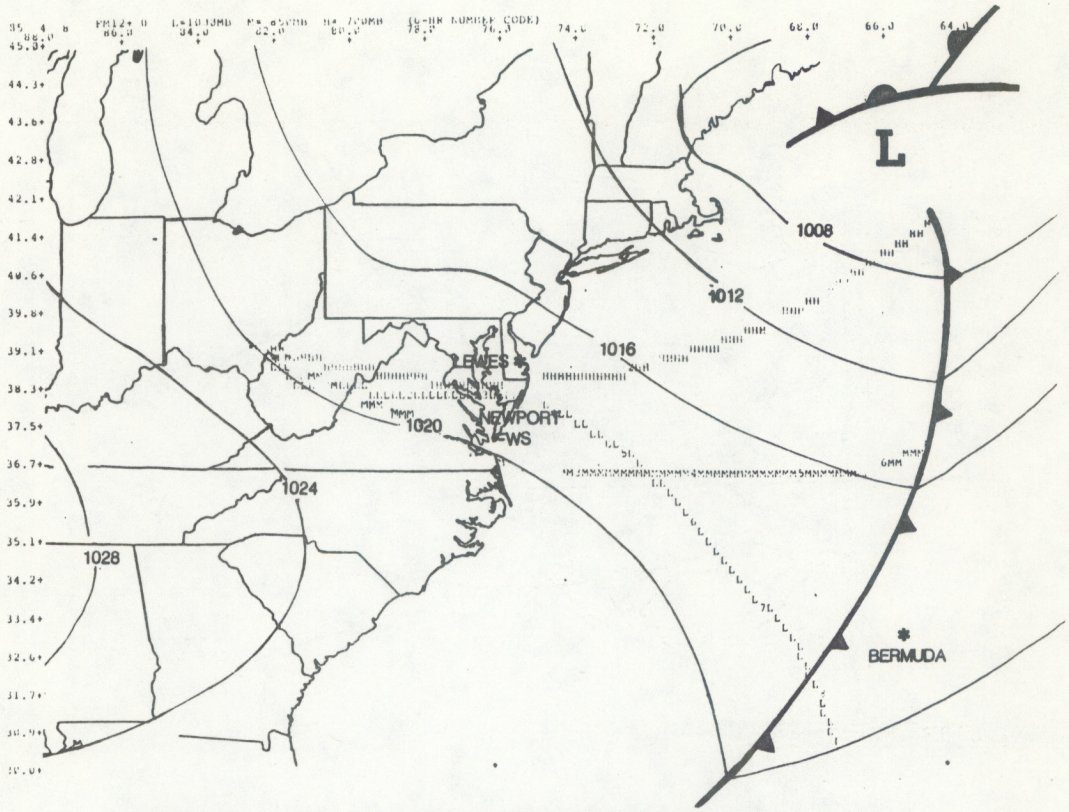

Figure 11a.--Valid 12Z April 8, 1985 (from Ohio).

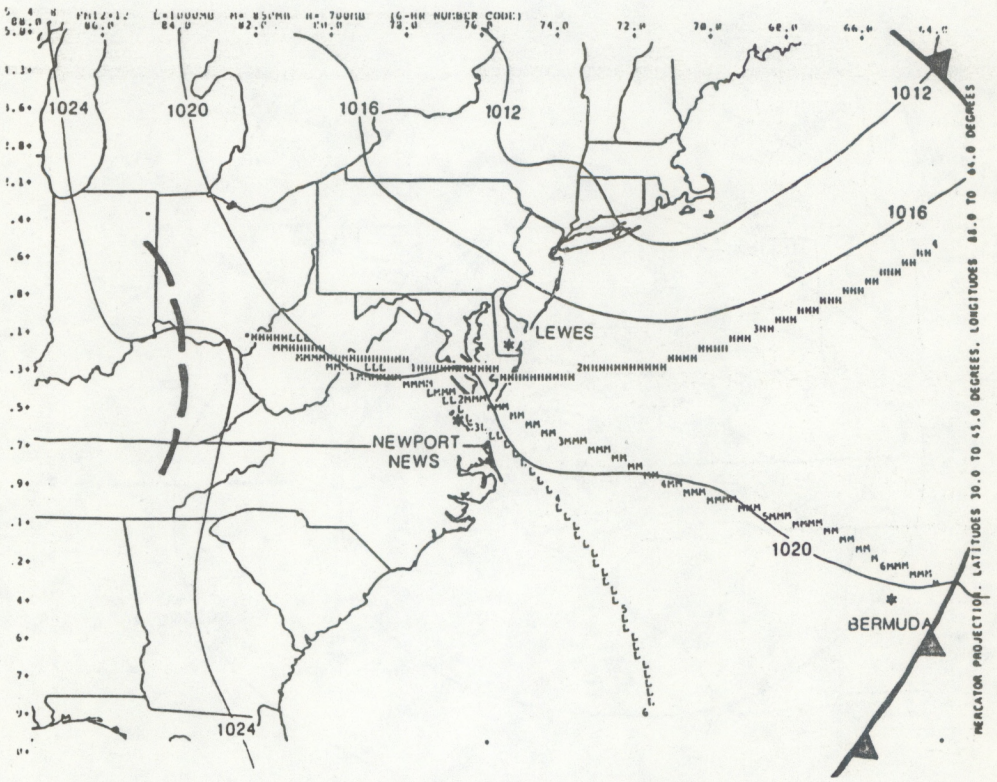

Figure 11b.--Valid 00Z April 9, 1985 (from Ohio).

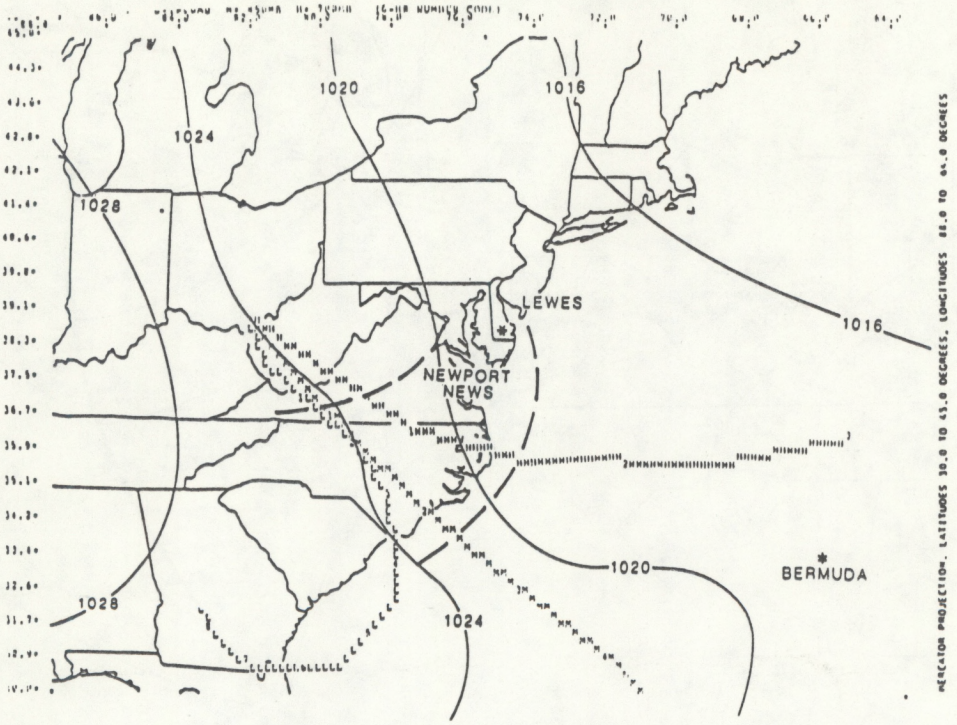

Figure 11c.--Valid 12Z April 9, 1985 (from Ohio).

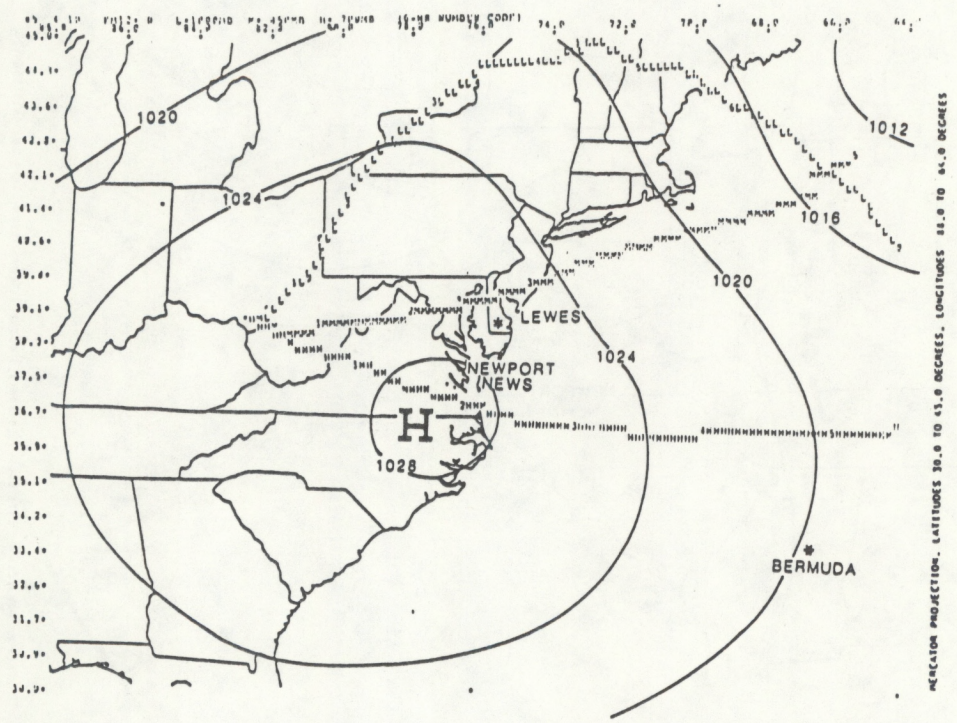

Figure 11d.--Valid 12Z April 10, 1985 (from Ohio).

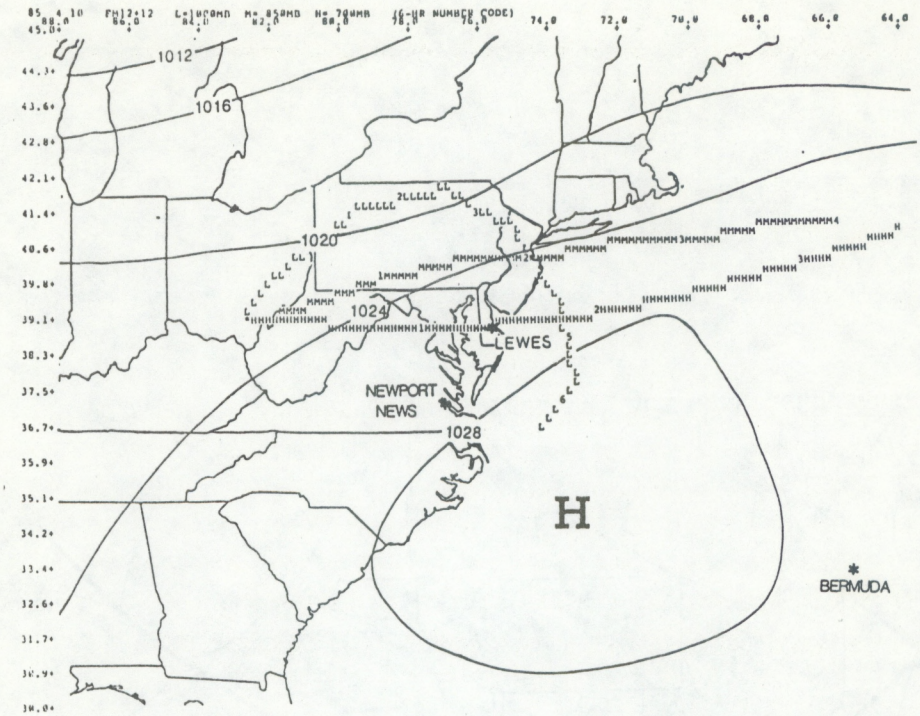

Figure 11e.--Valid 00Z April 11, 1985 (from Ohio).

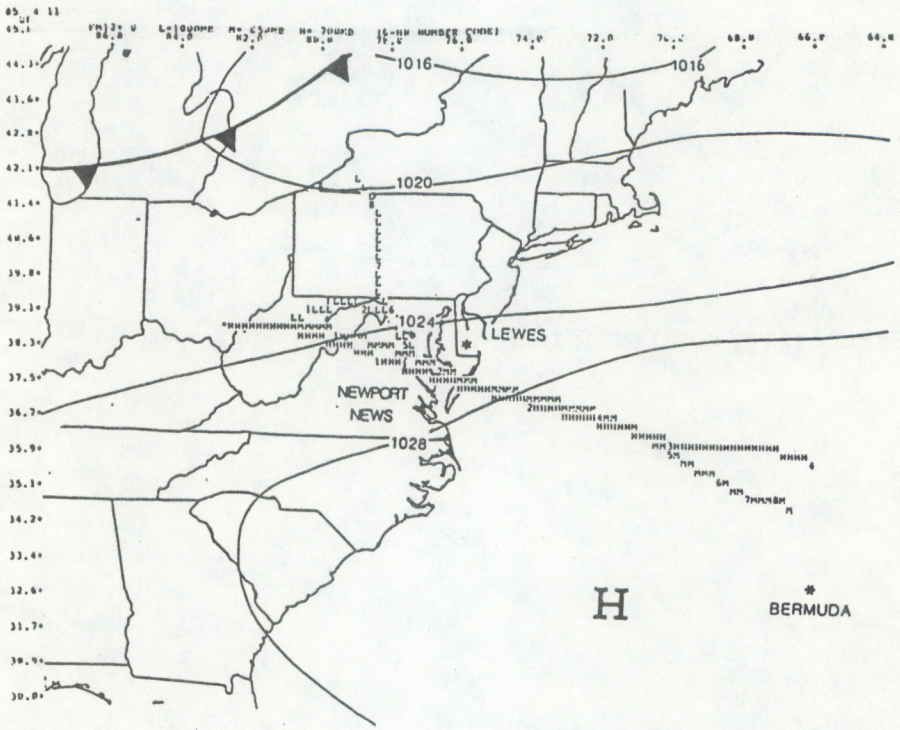

Figure 11f.--Valid 12Z April 11, 1985 (from Ohio).

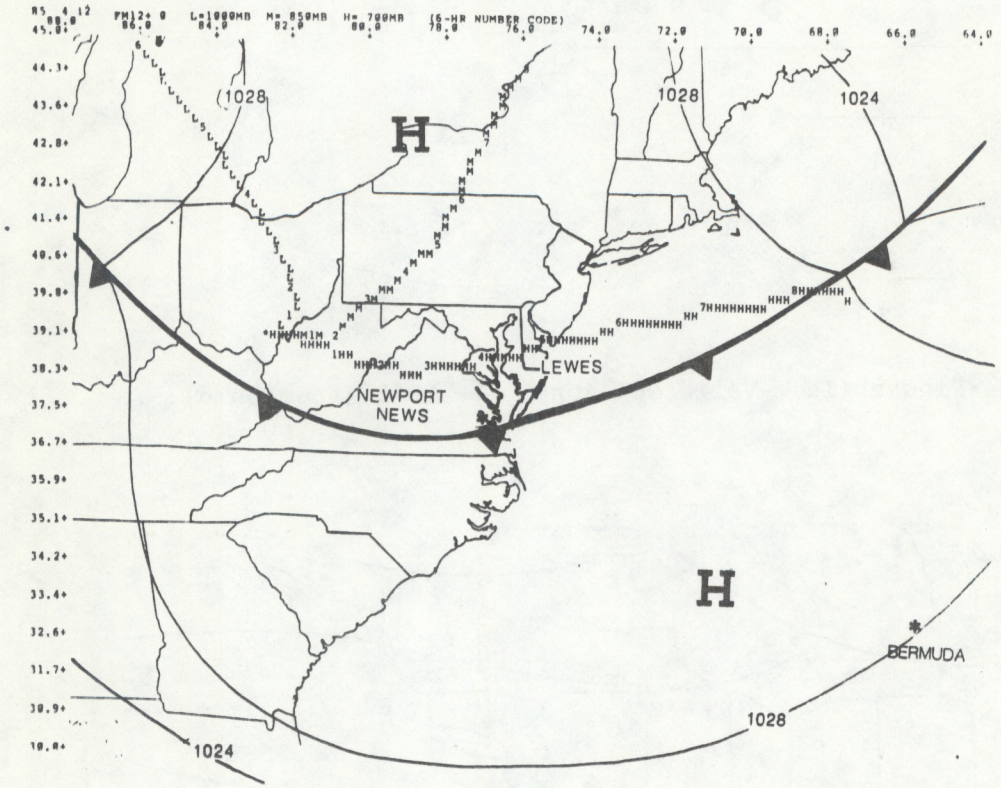

Figure 11g.--Valid 12Z April 12, 1985 (from Ohio).

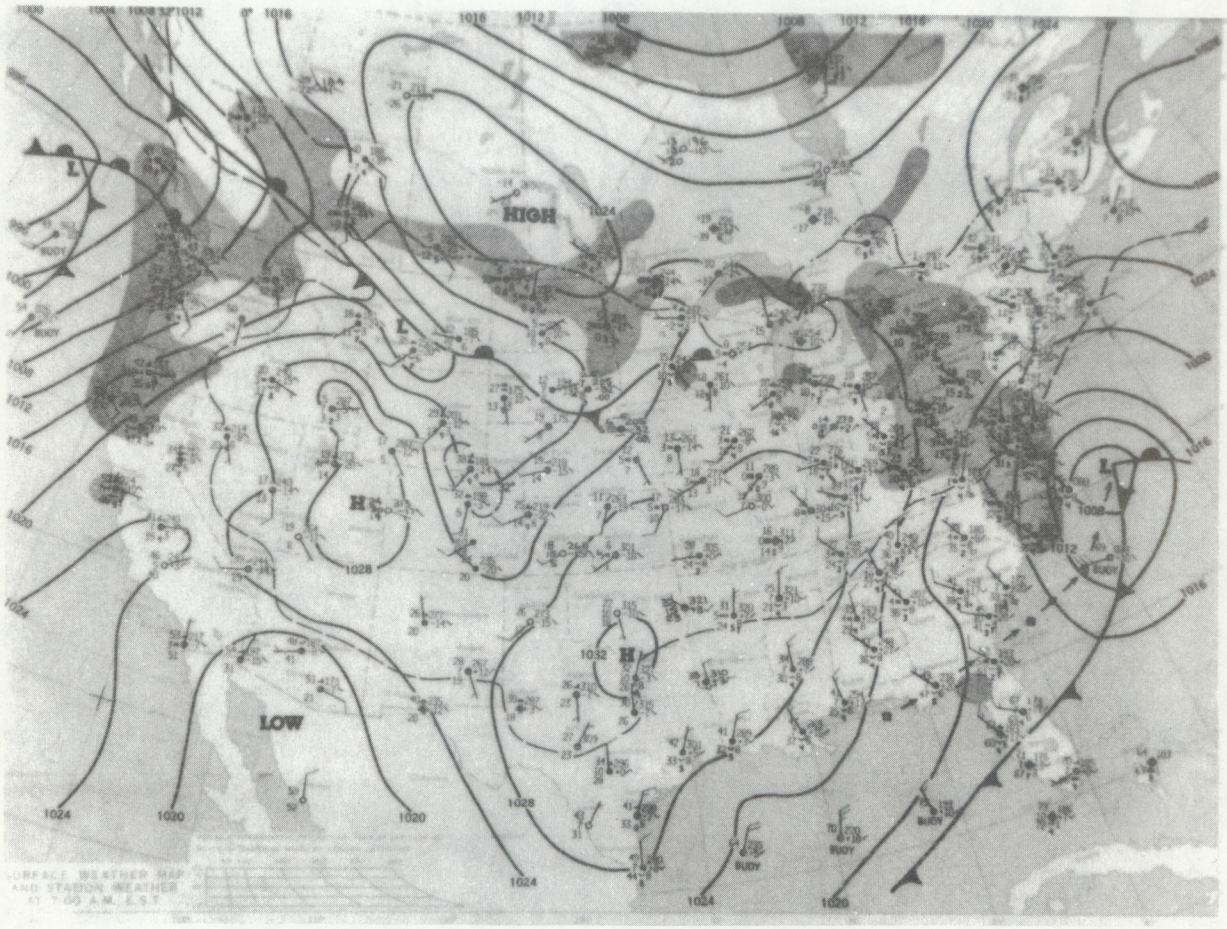

Figure 12a.--Typical surface synoptic conditions for a short WATOX event. Example shown is for 12Z February 13, 1982.

Figure 12b.--12Z February 14, 1982, surface map. See Fig. 12a for details.

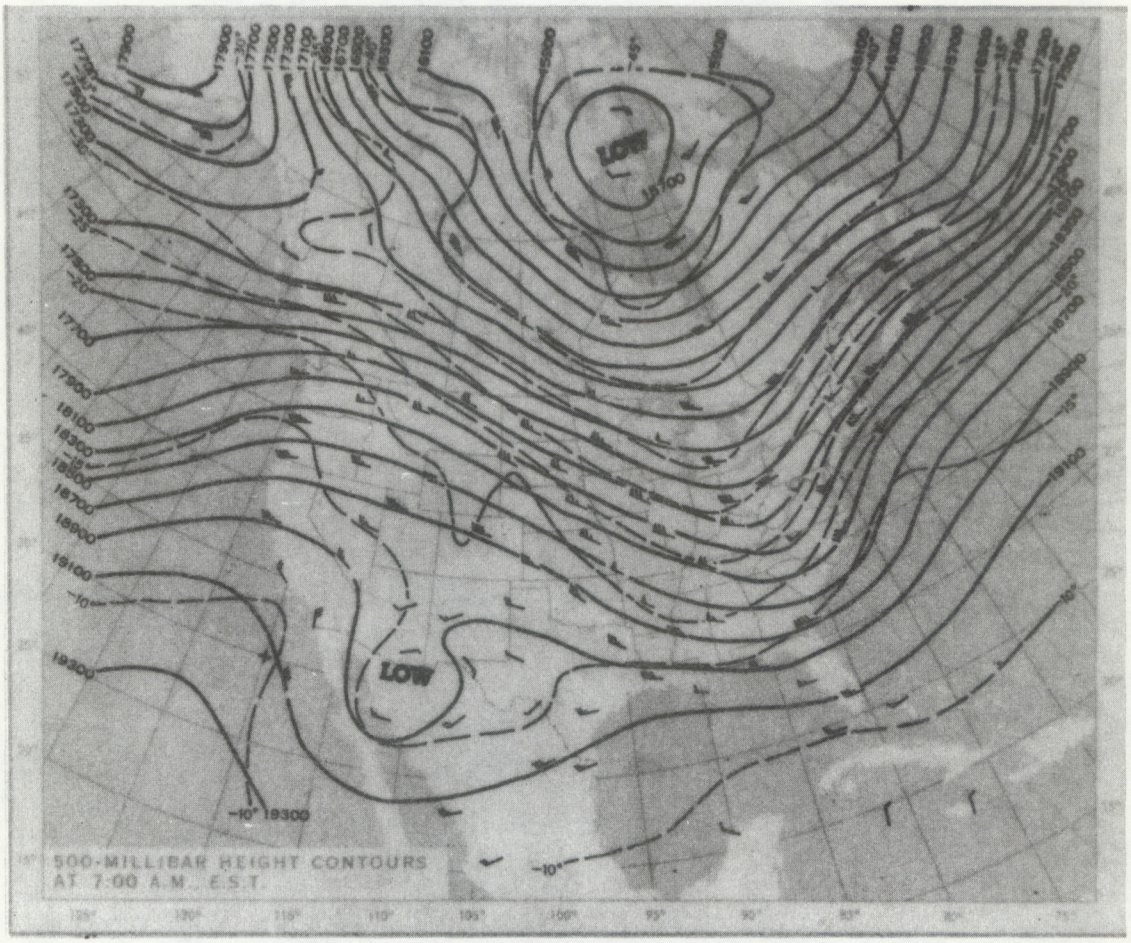

Figure 12c.--Typical 500 mb synoptic conditions for a short WATOX event. Example shown is for 12Z February 13, 1982.

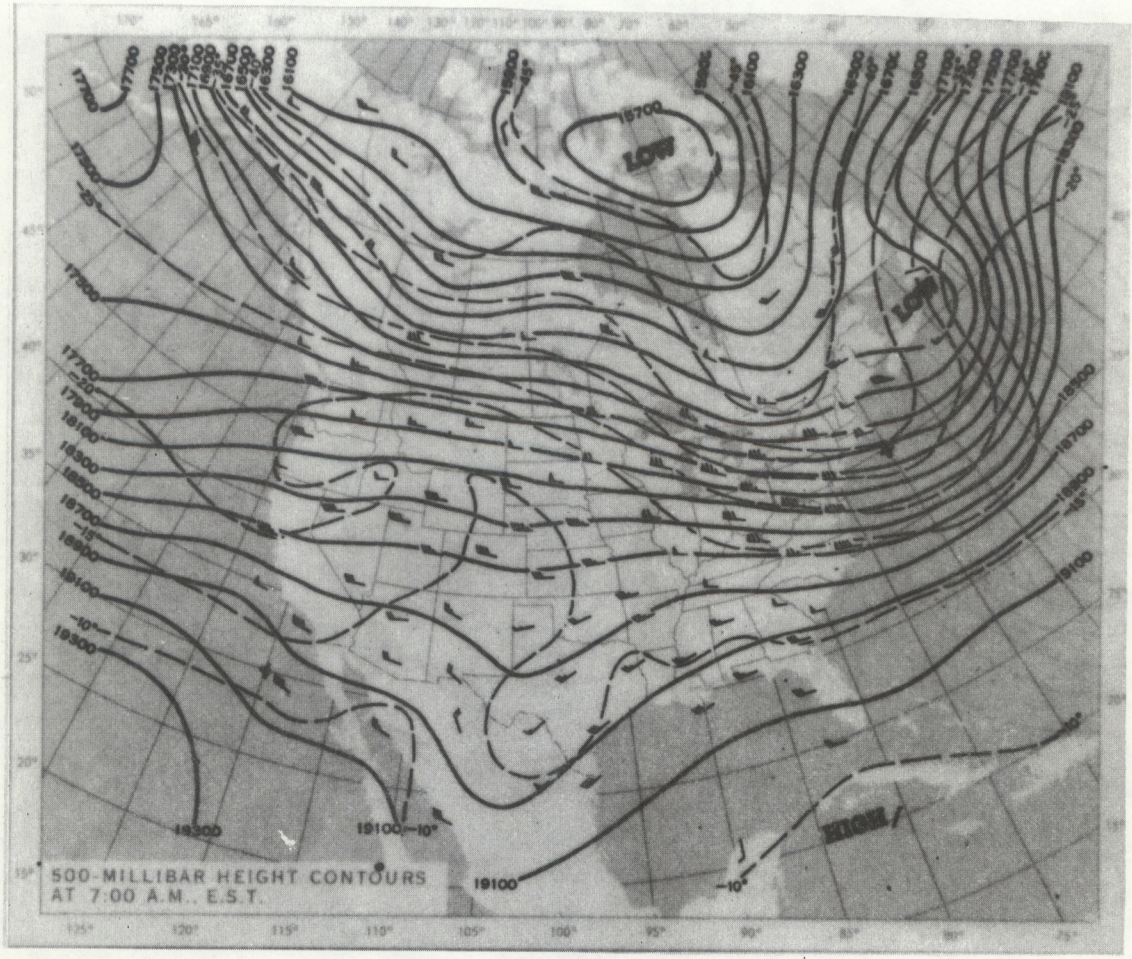

Figure 12d.--12Z February 14, 1982, 500 mb map. See Fig. 12c for details.

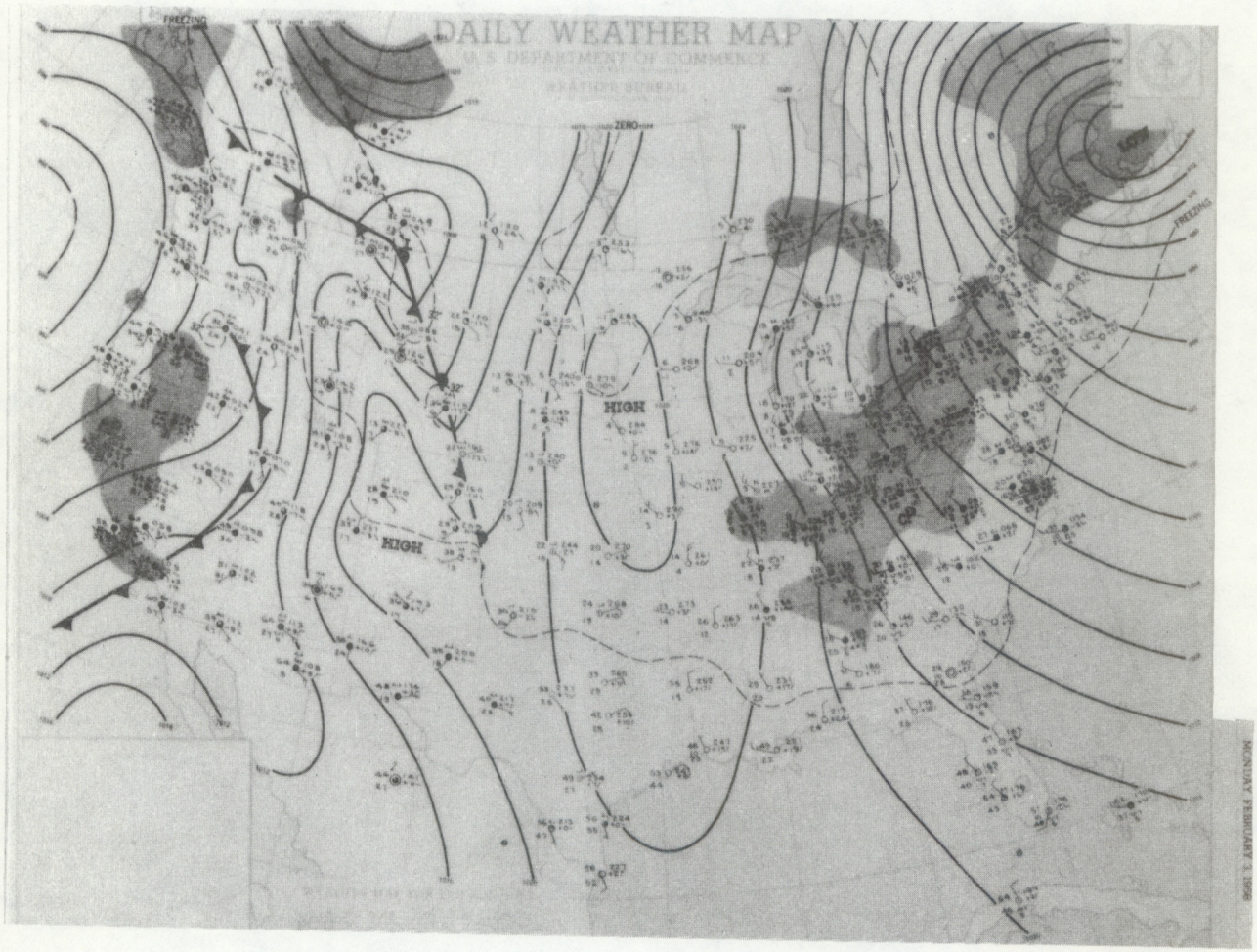

Figure 13a.--Typical surface synoptic conditions for a long WATOX event. Example shown is for 06Z February 3, 1958.

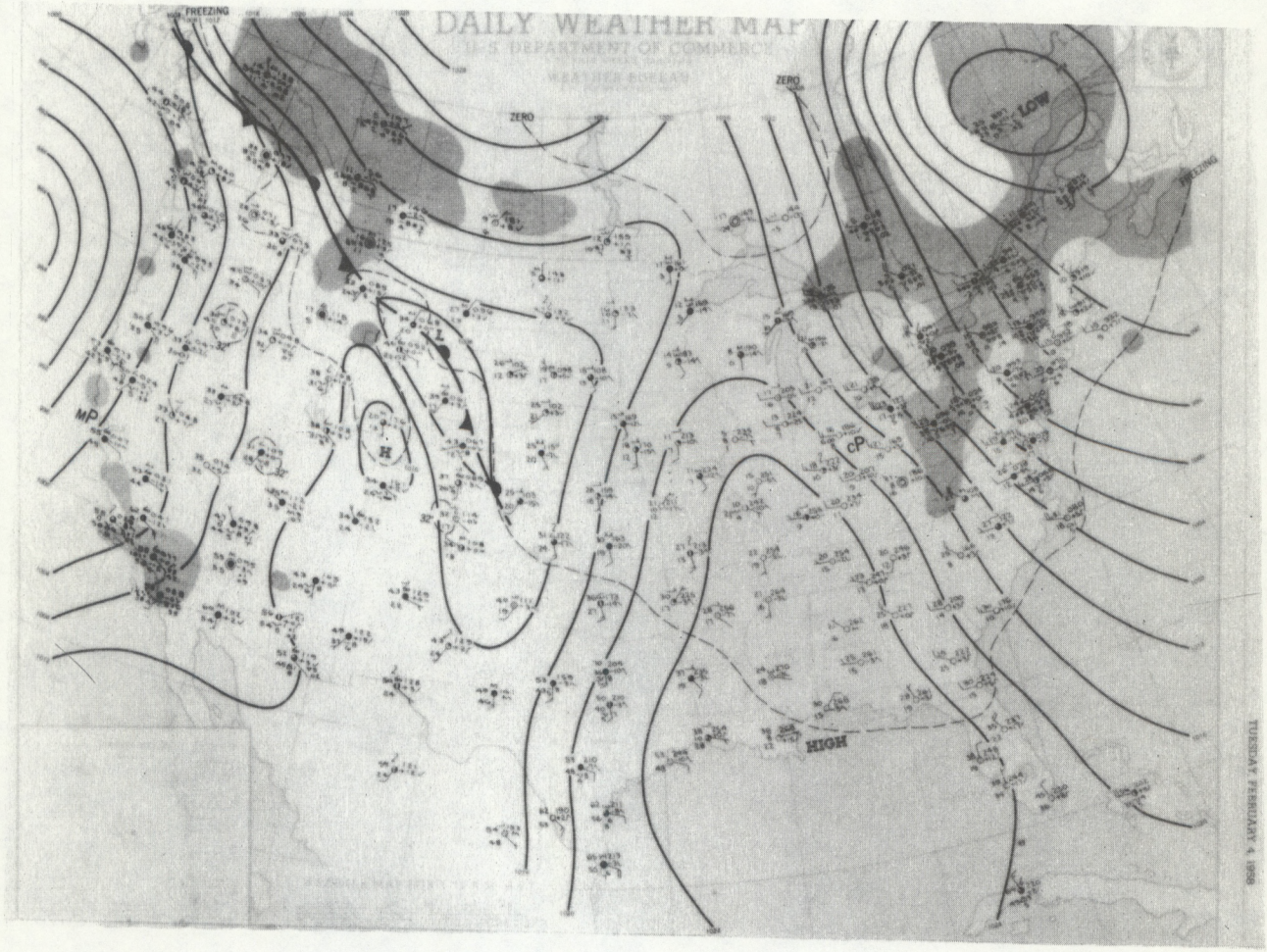

Figure 13b.--06Z February 4, 1958, surface map. See Fig. 13a for details.

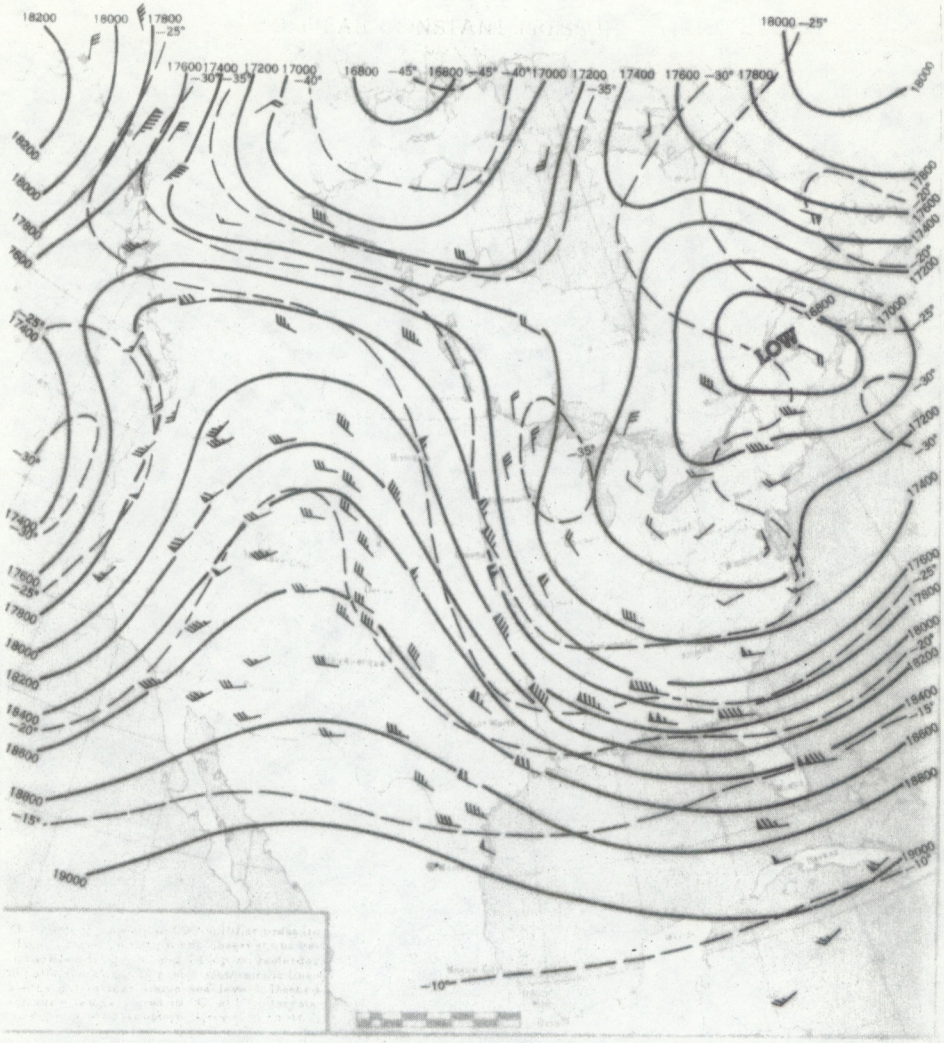

Figure 13c.--Typical 500 mb synoptic conditions for a long WATOX event. Example shown is for 12Z February 3, 1958.

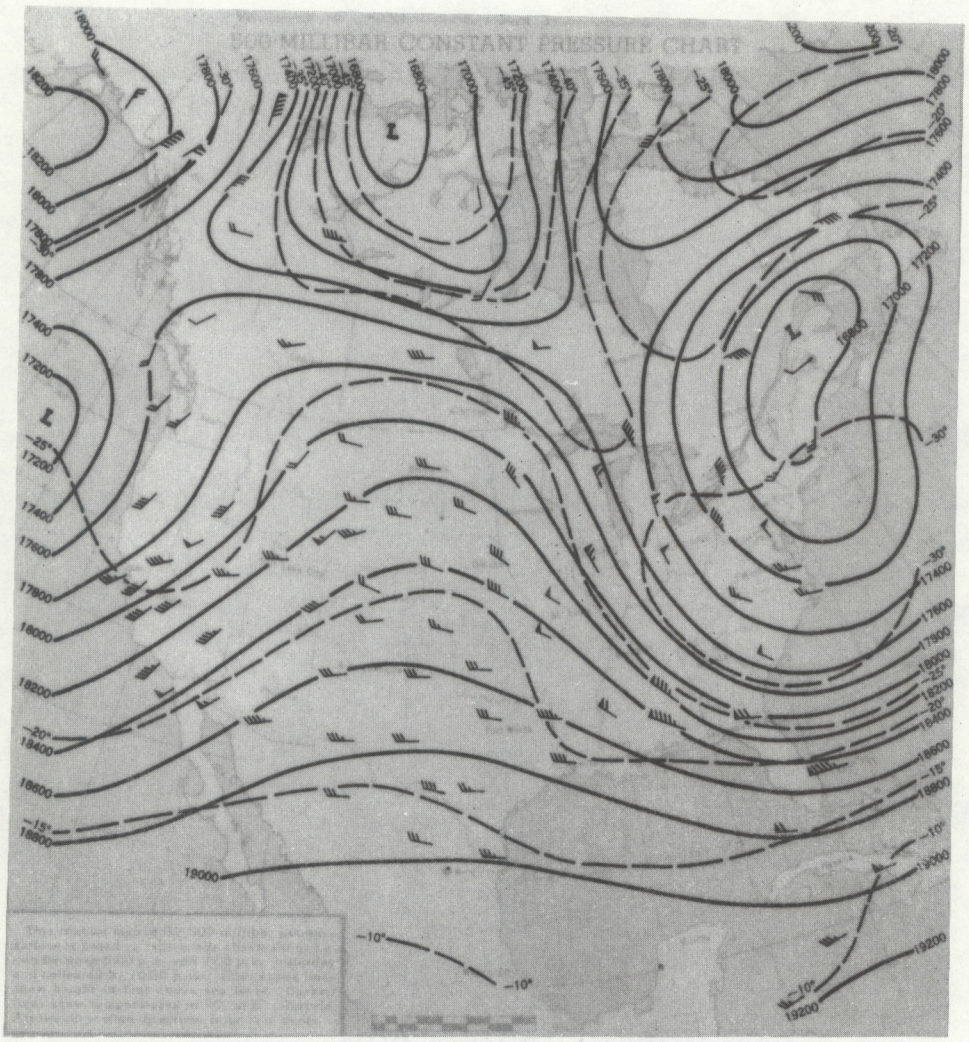

Figure 13d.--12Z February 4, 1958, 500 mb map. See Fig. 13c for details.

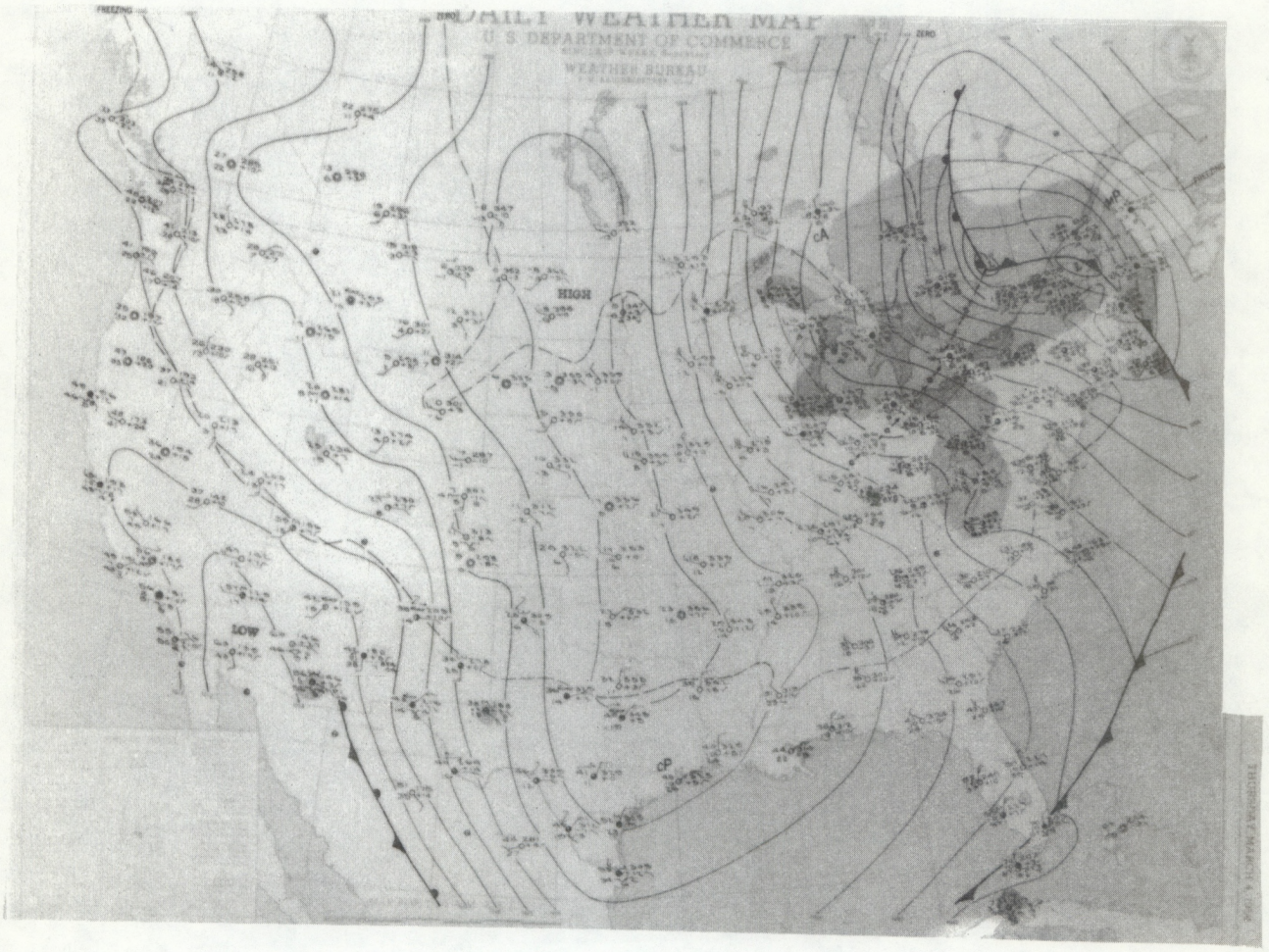

Figure 14a.--Typical surface synoptic conditions for a long WATOX event. Example shown is for 06Z March 4, 1954.

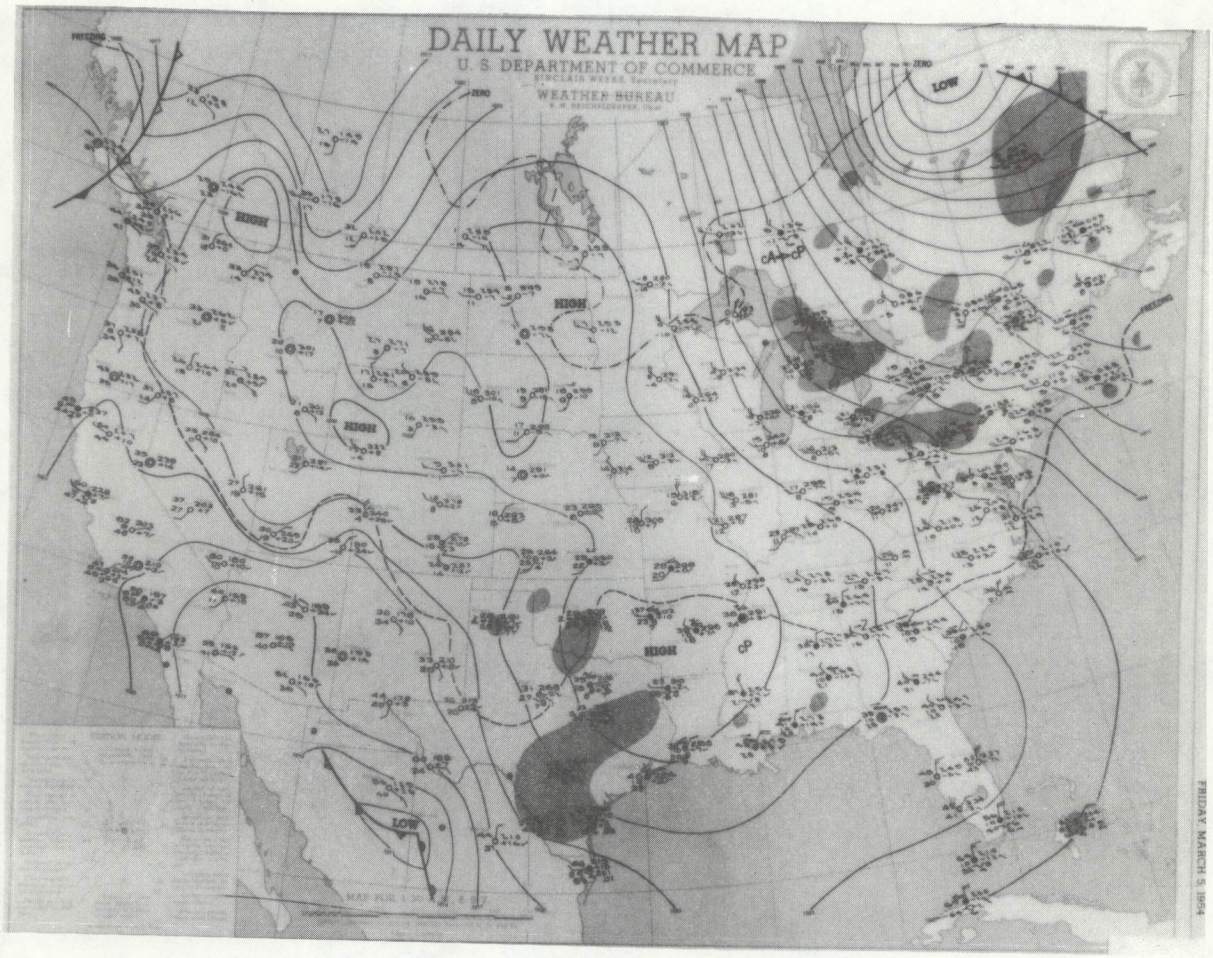

Figure 14b.--06Z March 5, 1954, surface map. See Fig. 14a for details.

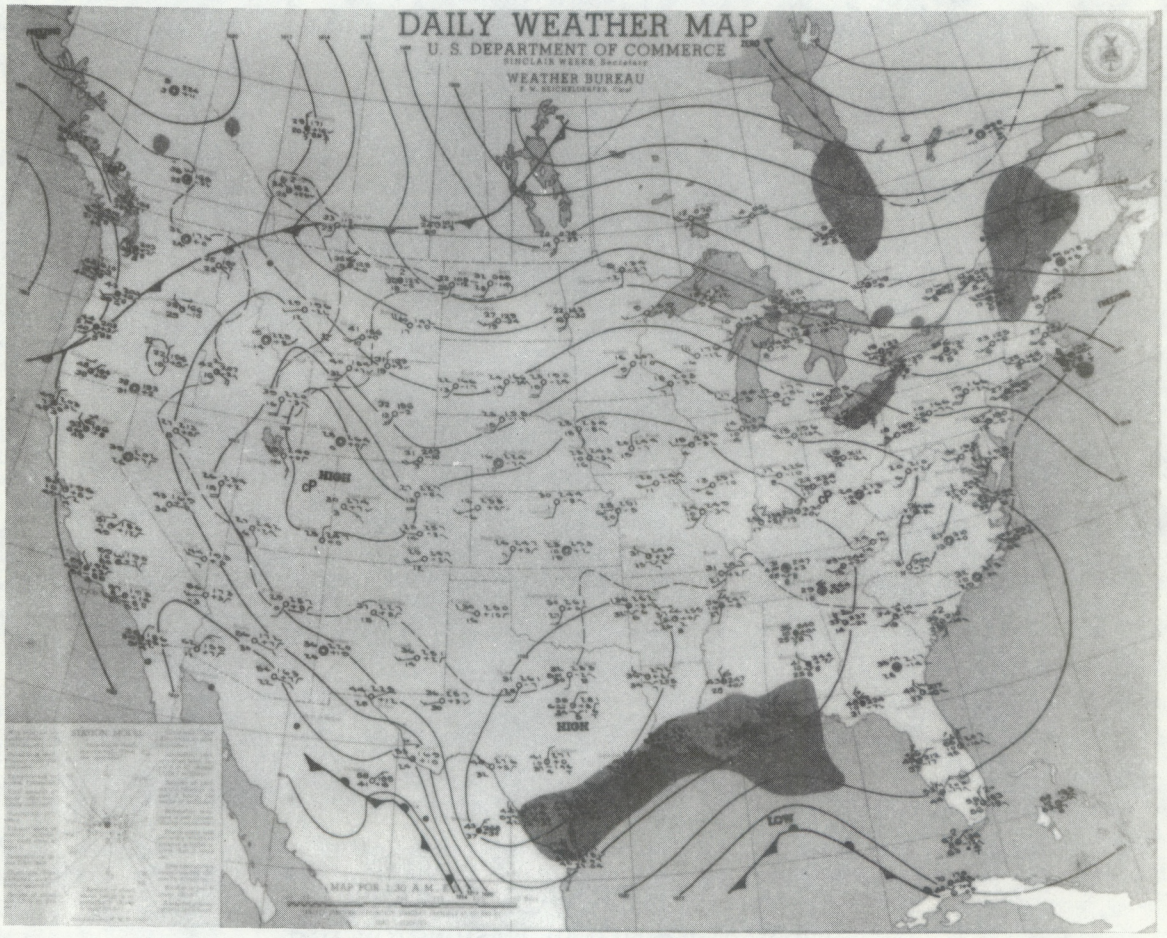

Figure 14c.--06Z March 6, 1954, surface map. See Fig. 14a for details.

WEATHER FORECASTS

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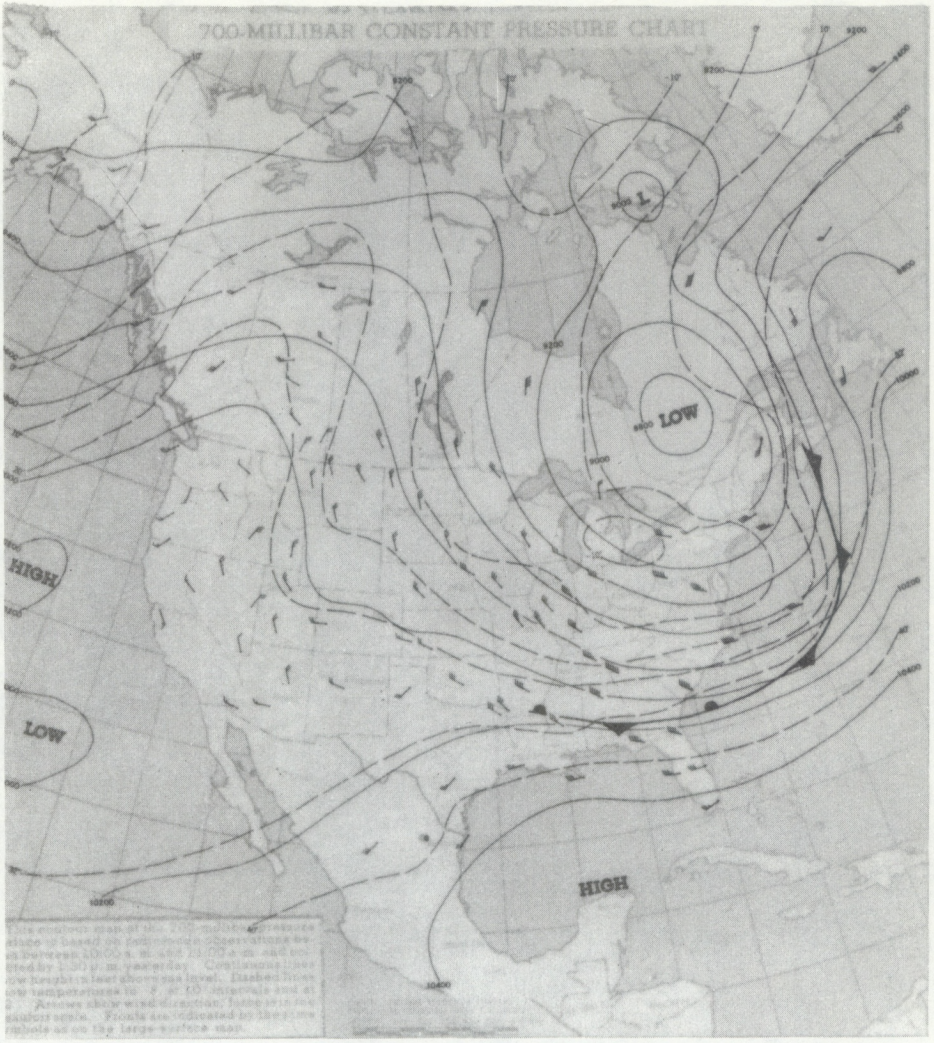
Figure 14d.--Typical 700 mb synoptic conditions for a long WATOX event. Example shown is for 12Z March 4, 1954.



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FRIDAY MARCH 5 1954

Figure 14e.--12Z March 5, 1954 700 mb map. See Fig. 14d for details.

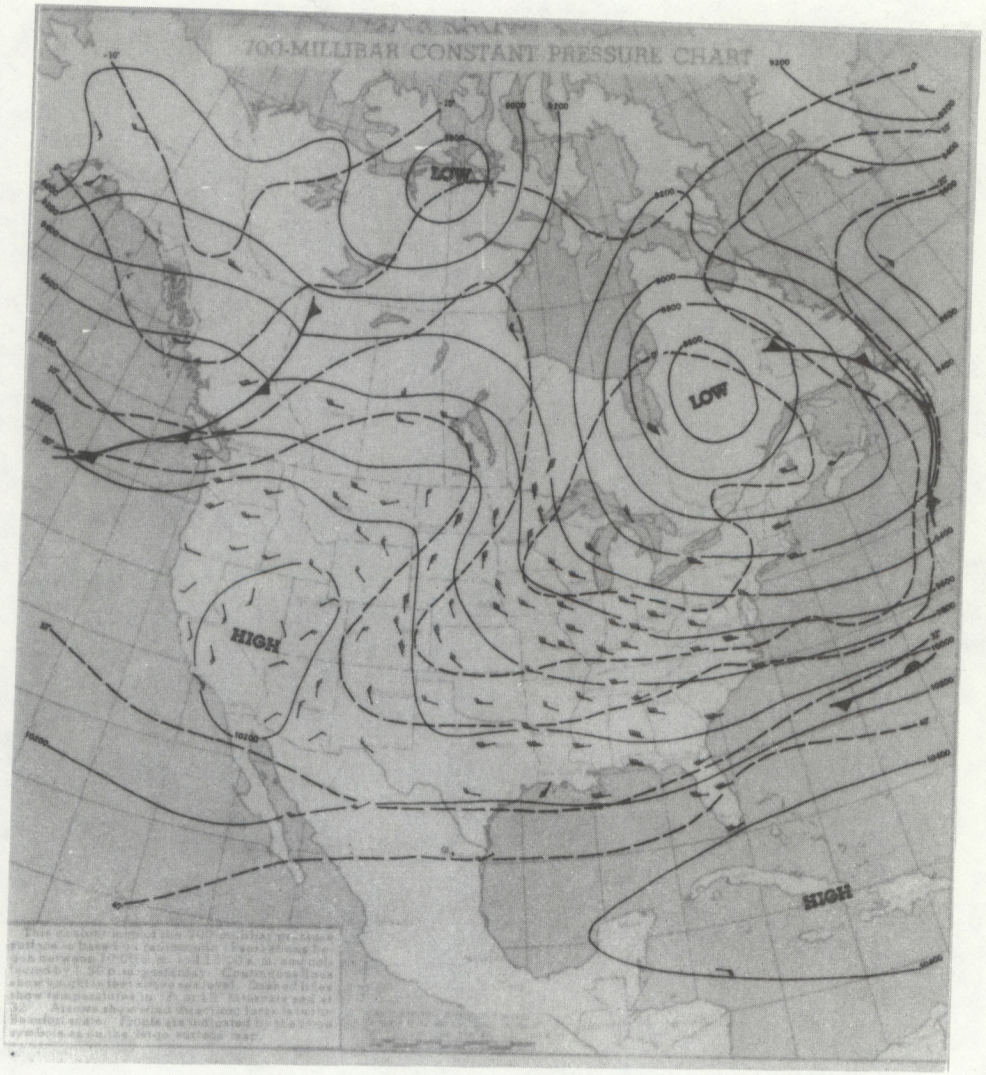

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Figure 14f.--12Z March 6, 1954 700 mb map. See Fig. 14d for details.

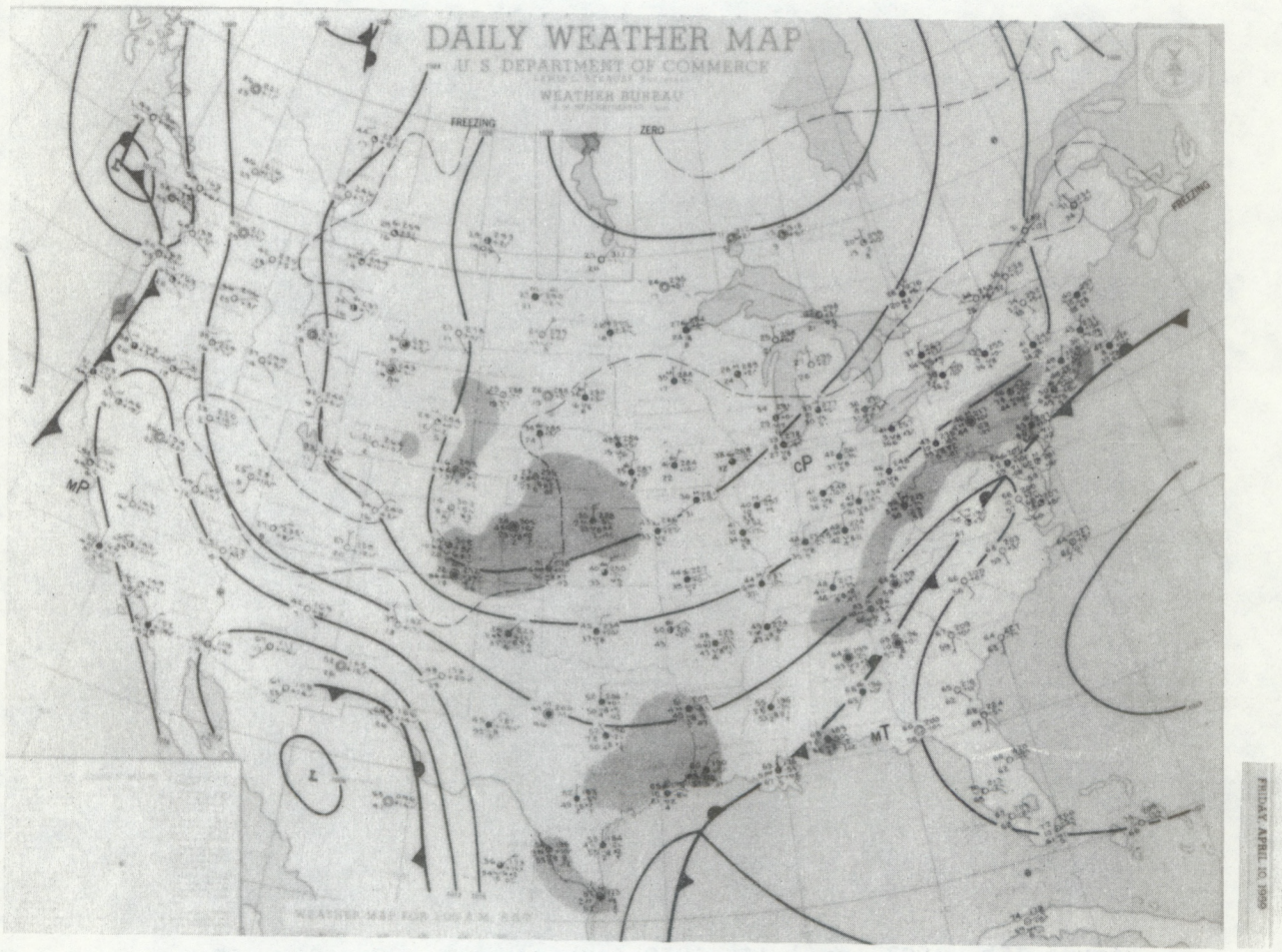

Figure 15a.--Typical surface synoptic conditions resulting in poor WATOX sampling conditions. Example shown is for 06Z April 10, 1959.

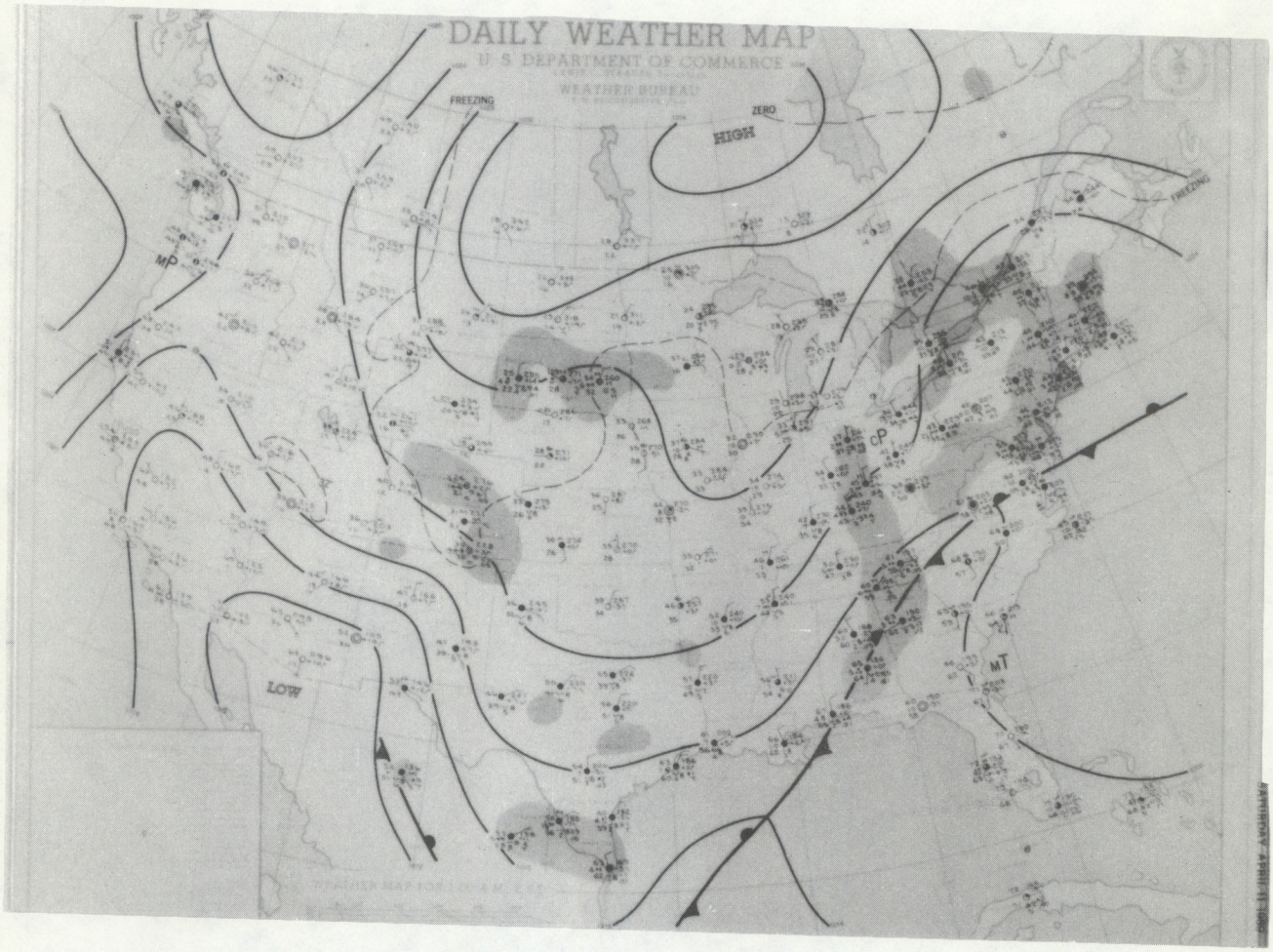

Figure 15b.--06Z April 11, 1959, surface map. See Fig. 15a for details.

Figure 15c.--Typical 500 mb synoptic conditions resulting in poor WATOX sampling conditions. Example shown is for 12Z April 10, 1959.

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Figure 15d.--12Z April 11, 1959, 500 mb map. See Fig. 15c for details.

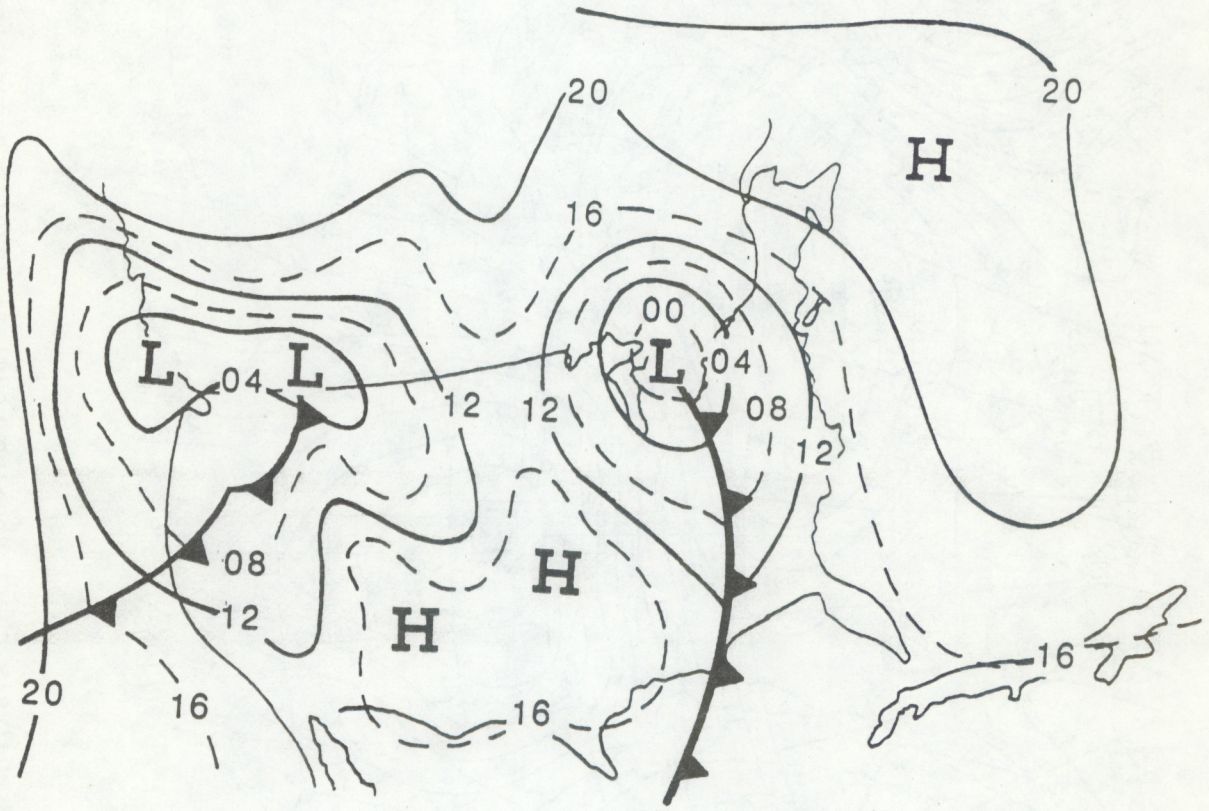

Figure 16.--Five-day forecast chart prepared Friday, March 1, 1985, and valid Tuesday, March 5, 1985. Note the low pressure system centered over Michigan and the trailing cold front extending south to the Gulf of Mexico.

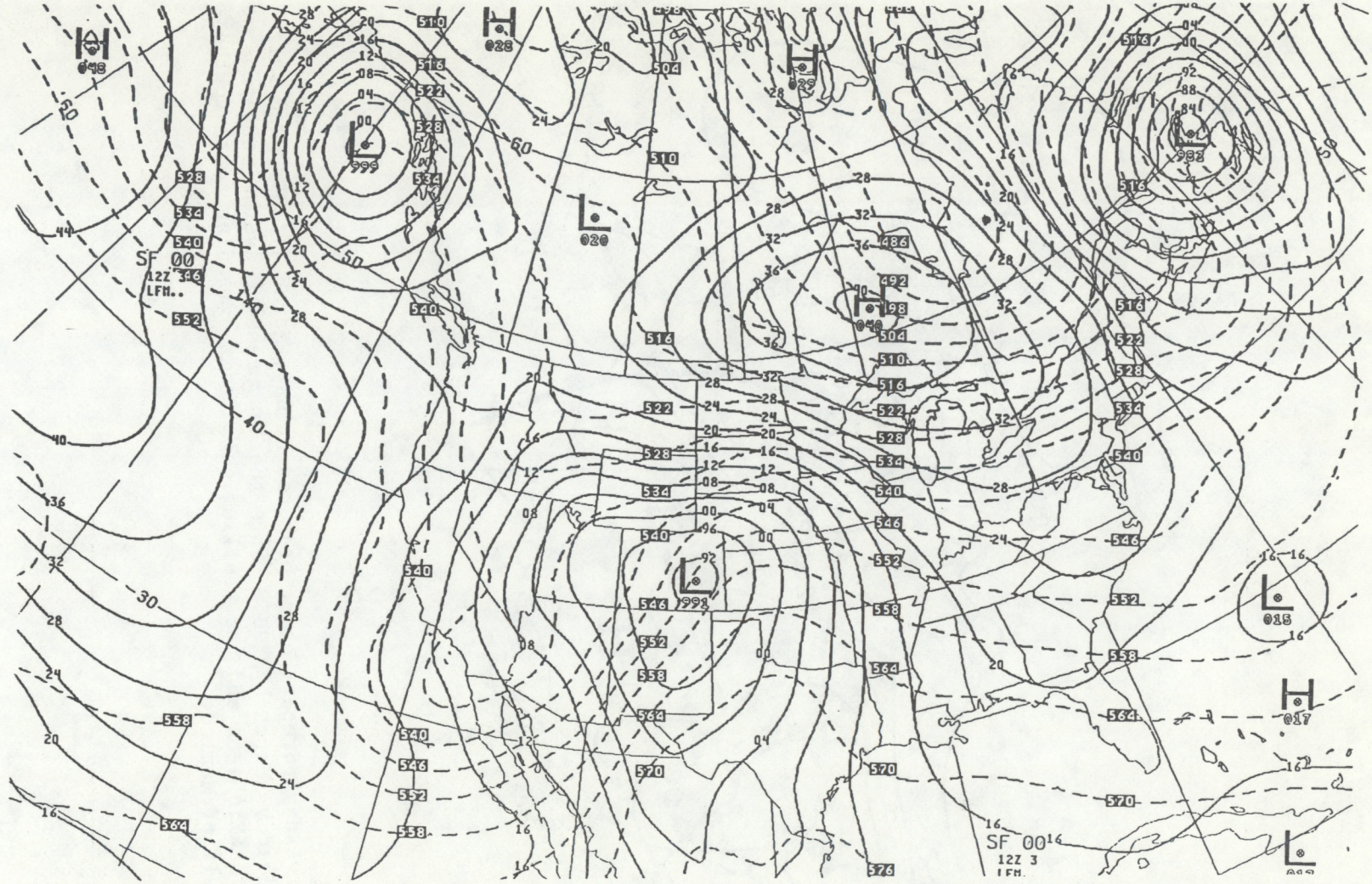

Figure 17.--One panel of an LFM analysis chart showing mean sea level pressure and 1000-500 mb thickness. Valid 12Z Sunday, March 3, 1985.

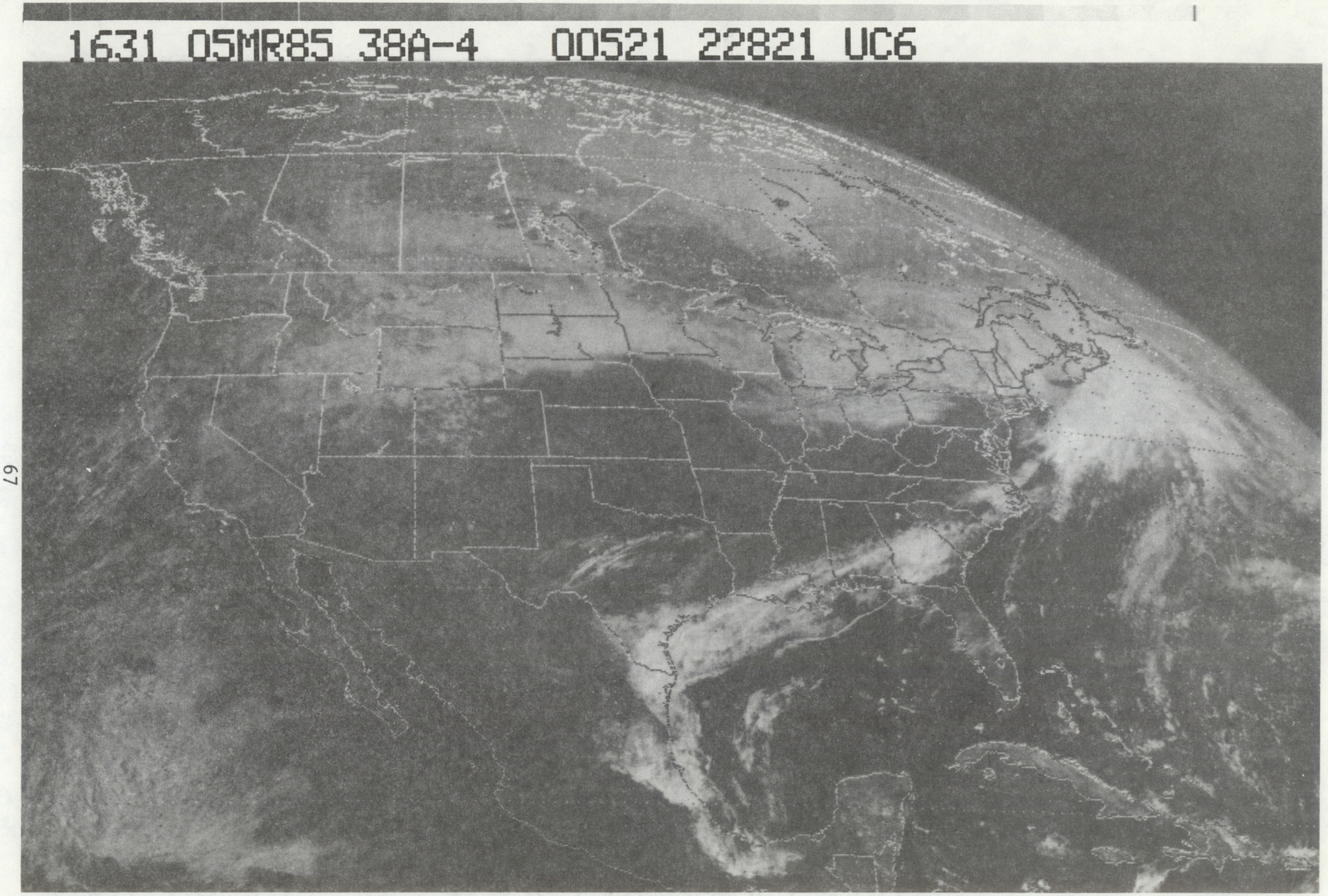

Figure 18.--Visible satellite photo valid 1631Z March 5, 1985.

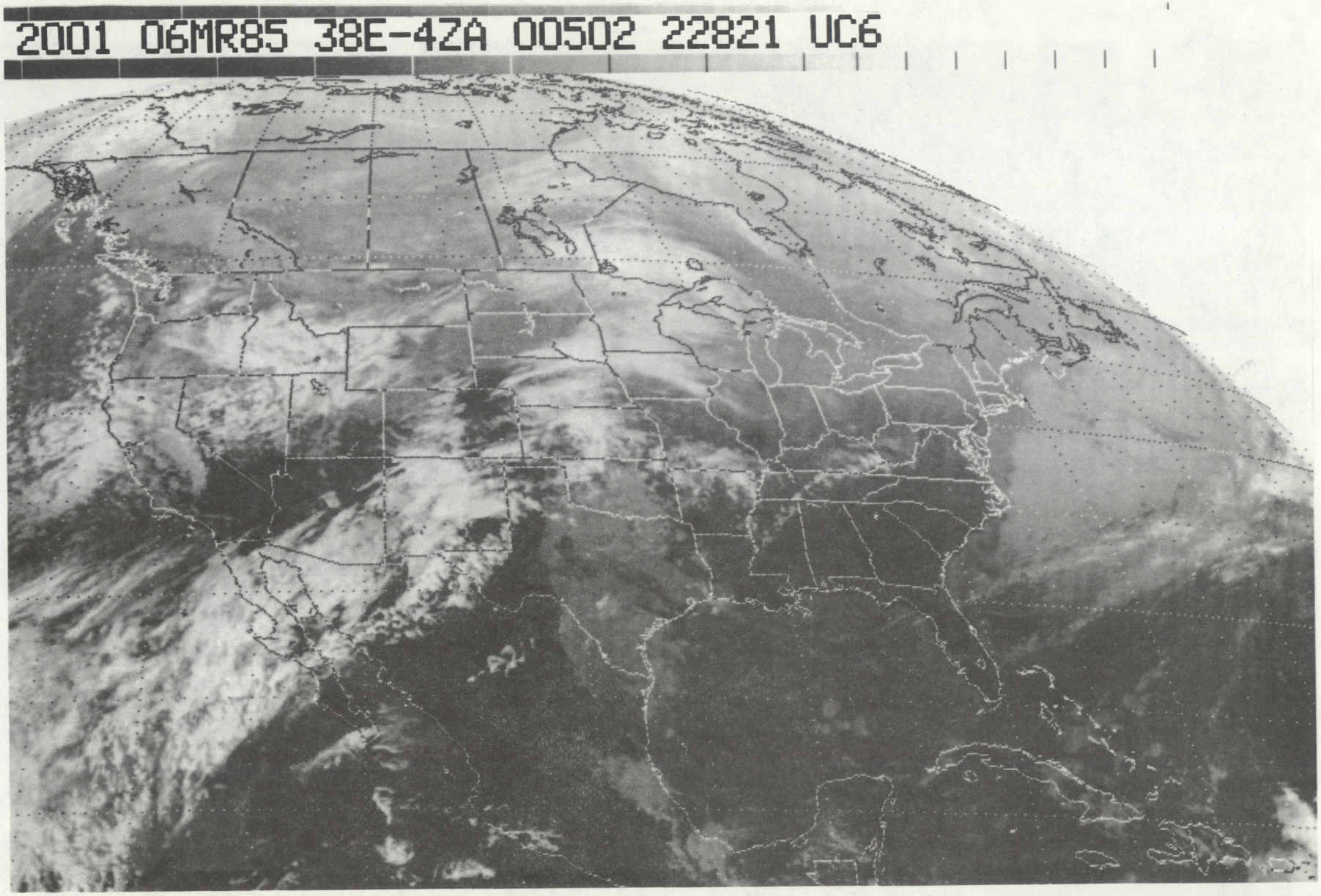

Figure 19.--Infrared satellite photo valid 2001Z March 6, 1985.

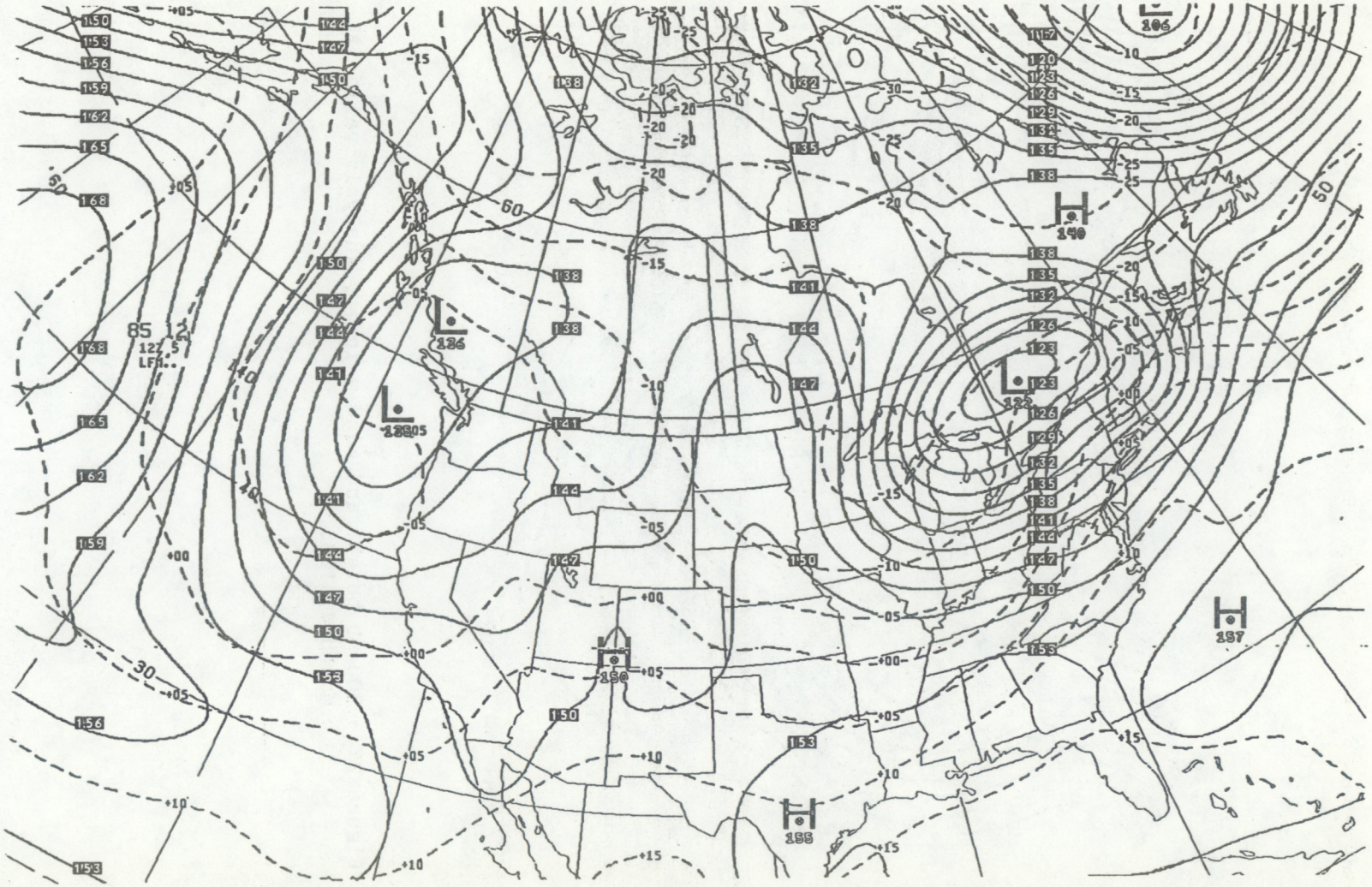

Figure 20.--850 mb LFM heights and temperatures valid 12Z March 5, 1985.

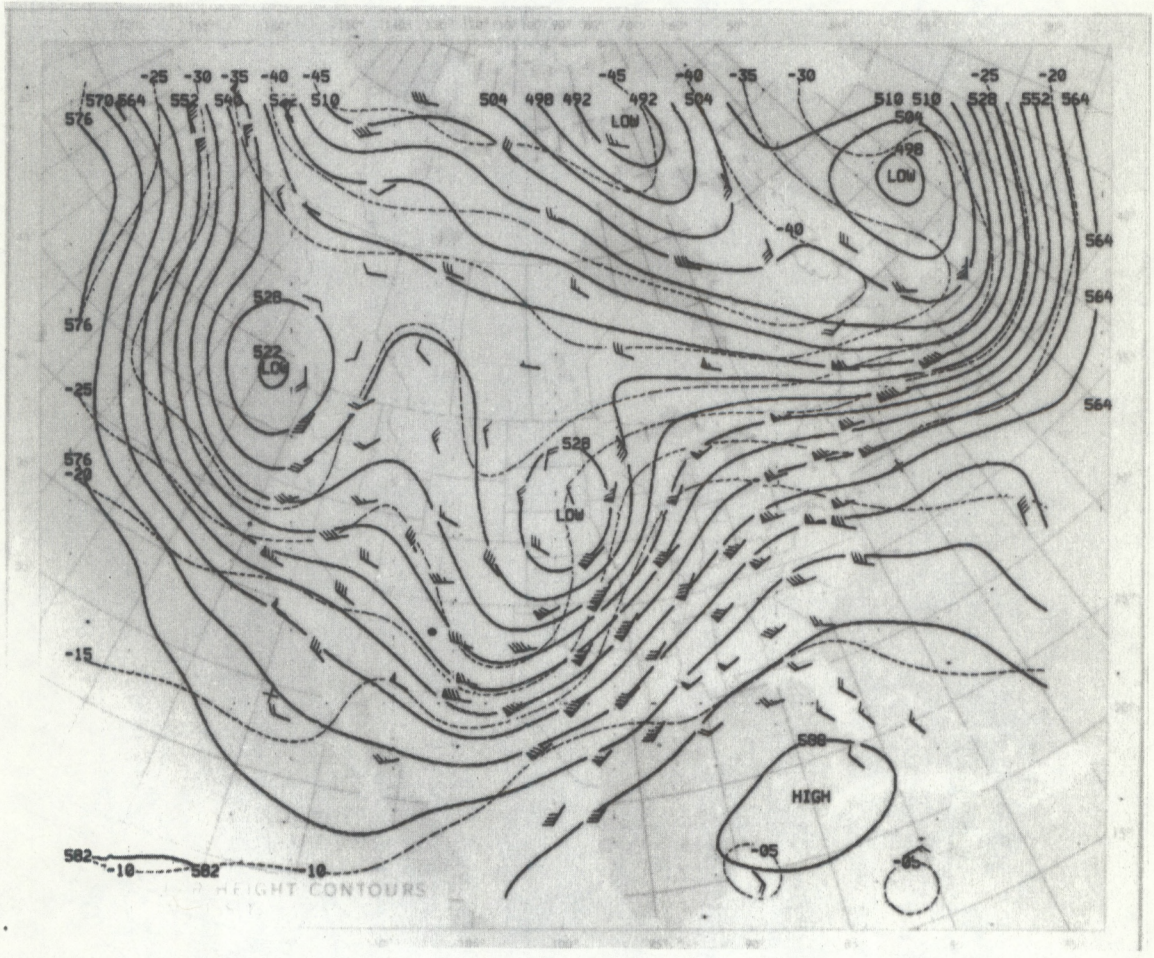

Figure 21.--500 mb height and wind velocity analysis valid 12Z March 4, 1985.

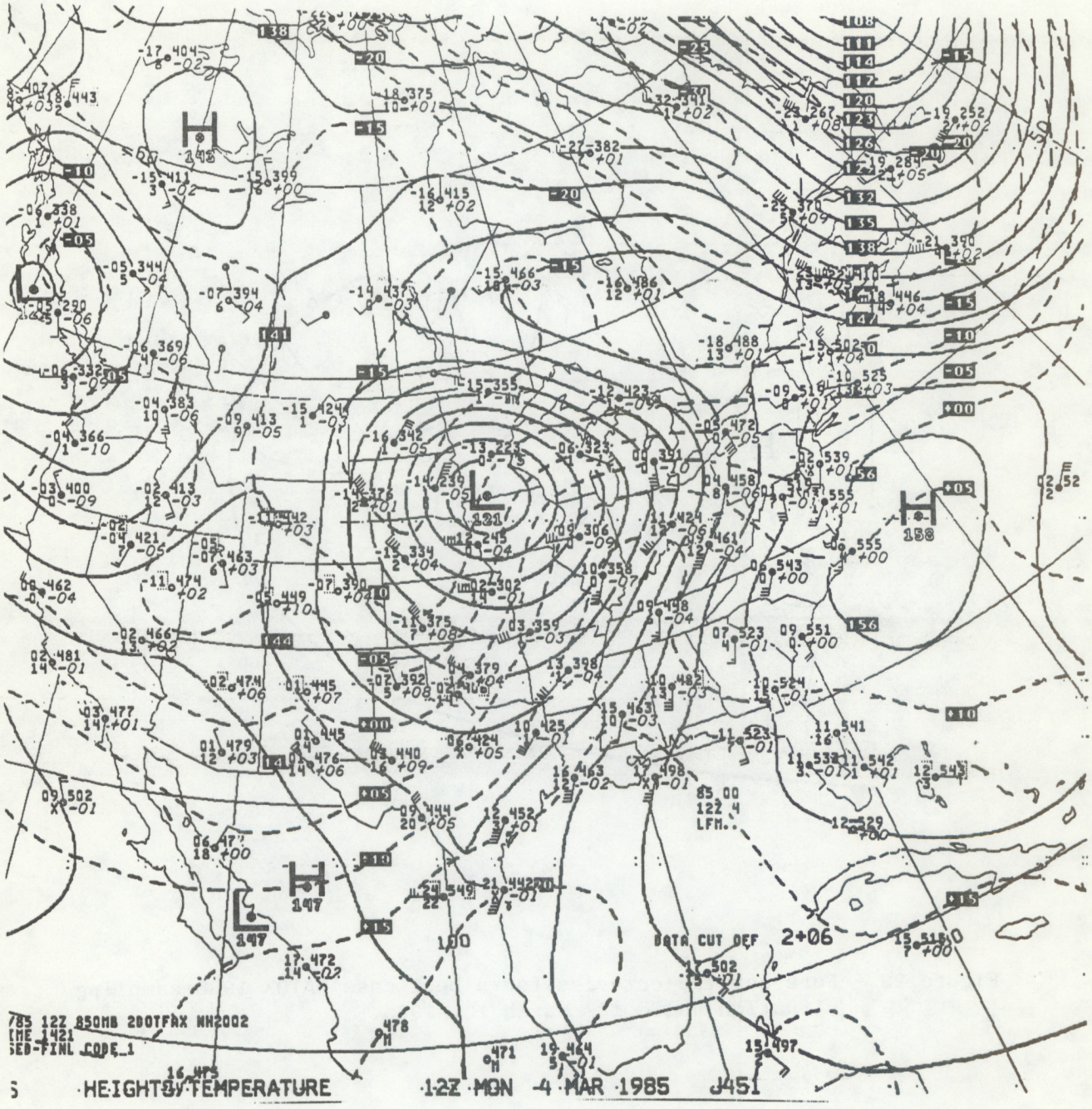

Figure 22.--850 mb height and temperature analysis valid 12Z March 4, 1985.

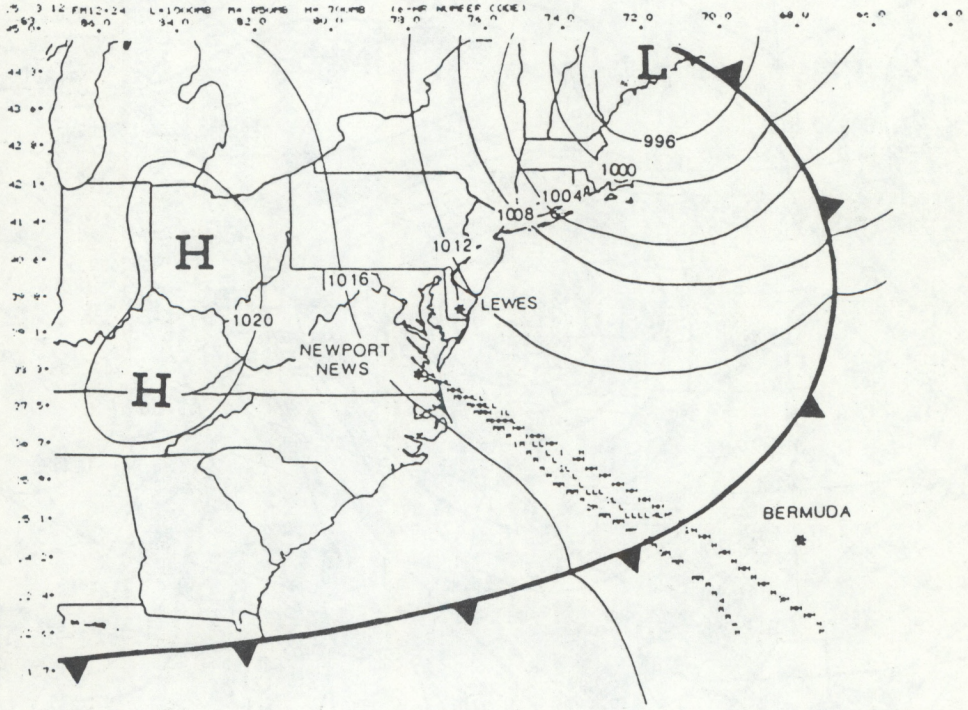

Figure 23.--Forecast trajectories for a best case WATOX 1985 sampling situation valid 12Z March 13, 1985.

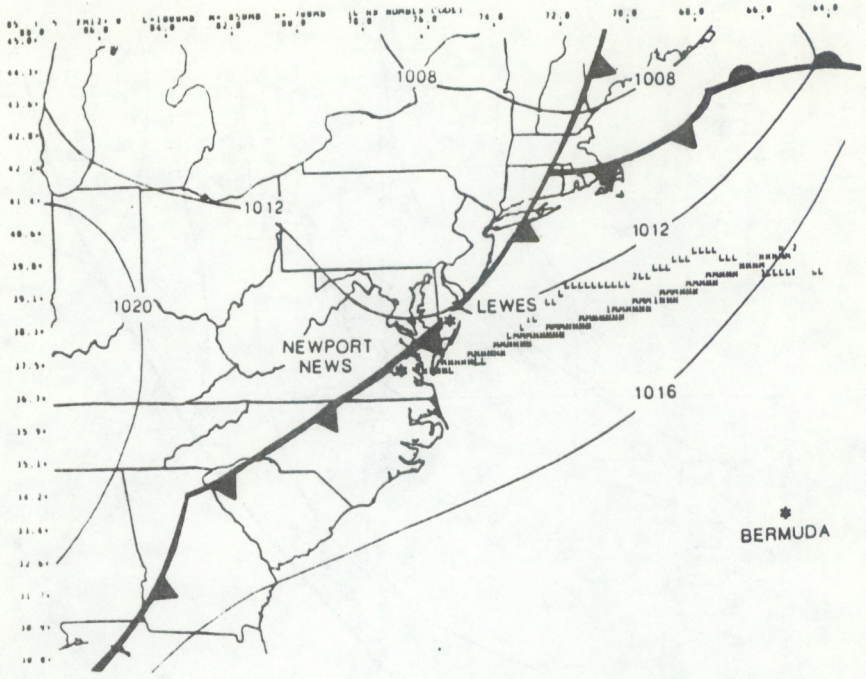

Figure 24a.--WATOX Event 3 forecast trajectories valid 12Z March 5, 1985.

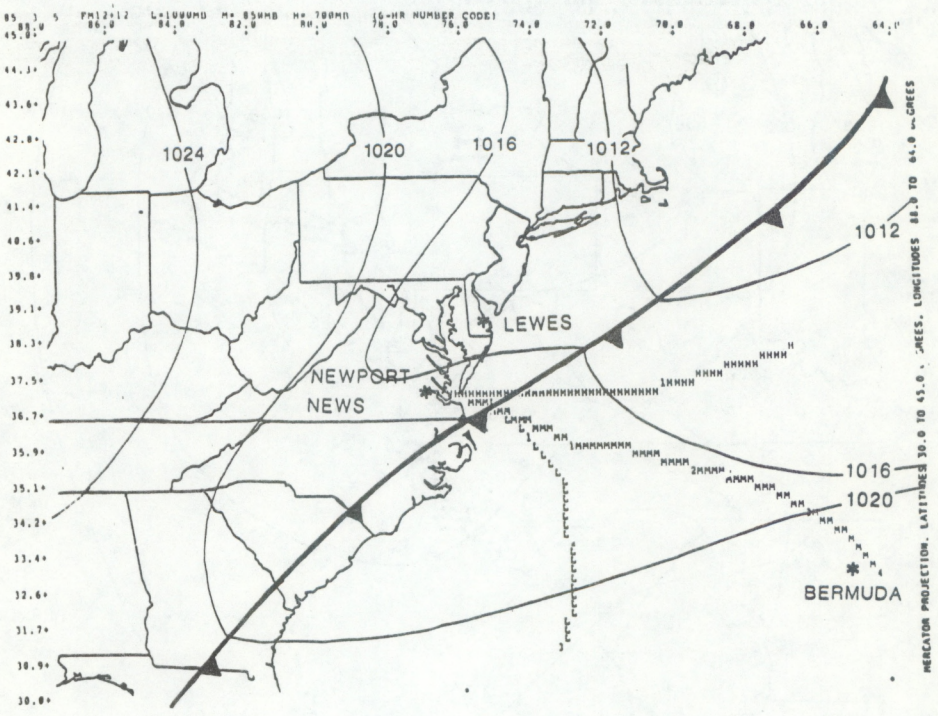

Figure 24b.--WATOX Event 3 forecast trajectories valid 00Z March 6, 1985.

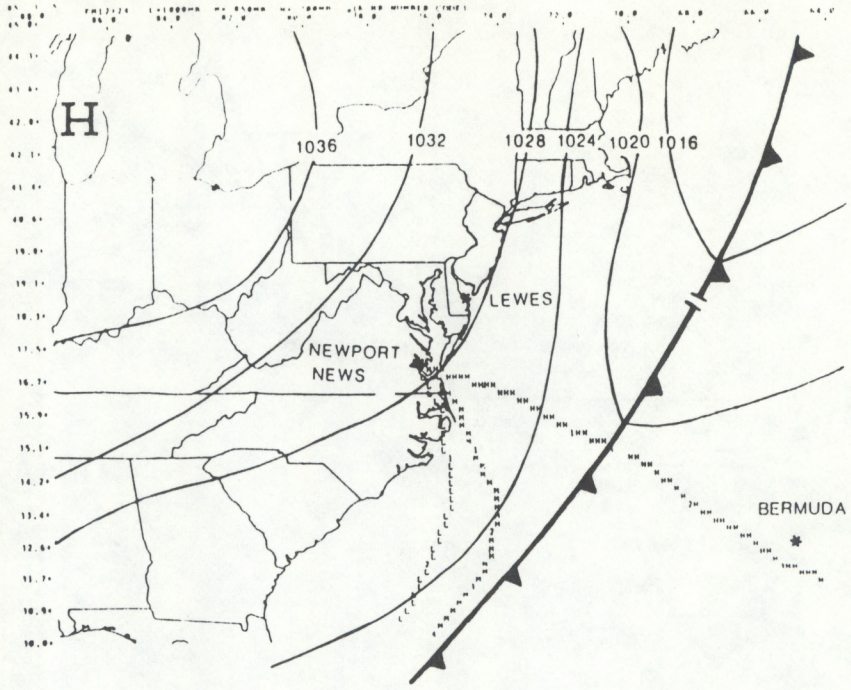

Figure 24c.--WATOX Event 3 forecast trajectories valid 12Z March 6, 1985.

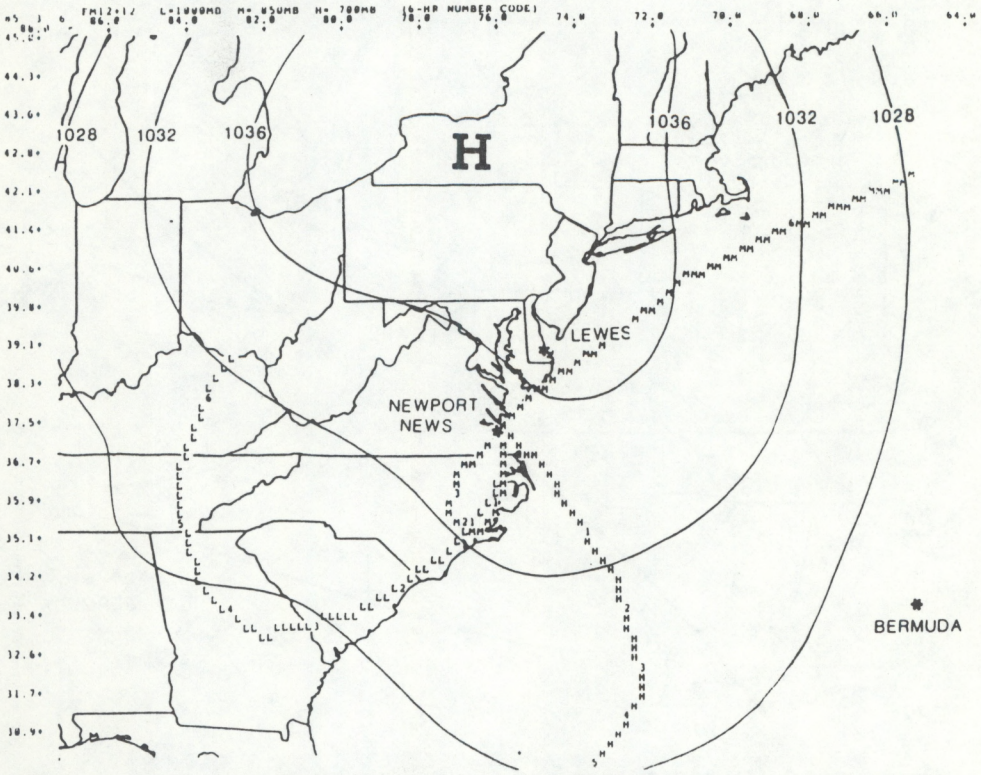

Figure 24d.--WATOX Event 3 forecast trajectories valid 00Z March 7, 1985.

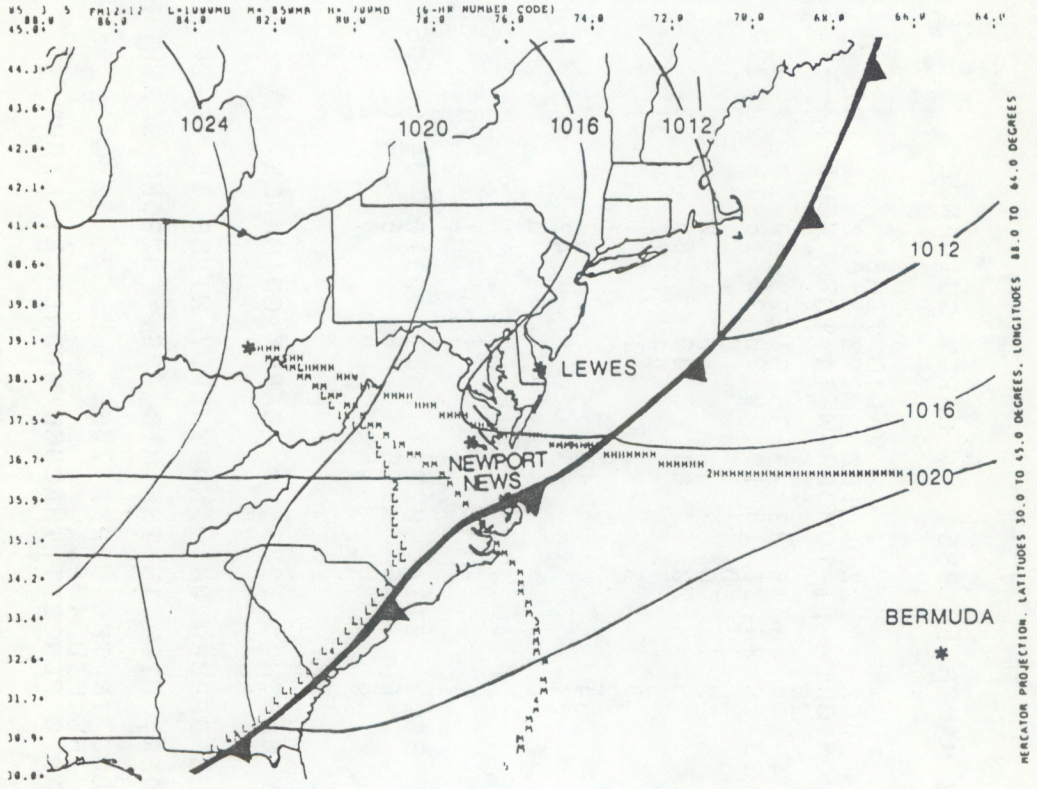

Figure 25.--WATOX Event 3 forecast trajectories originating from southeastern Ohio valid 00Z March 6, 1985. Note that flow from the midlevel (850 mb) and upper level (700 mb) crosses the WATOX 1985 sampling region along the Atlantic coast.

DATE OF FORECAST IS TUESDAY MARCH 5 1985 EARLY GUIDANCE

NORFOLK, VA

ELEMENT	UNITS	VALID TIME 00Z	06Z	12Z	18Z	00Z	06Z	12Z	18Z	00Z
		(--TONIGHT--)		(-TOMORROW-)		(-TMRW NGHT-)		(--NEXT DAY--)		
TEMP M/M	DEG F		29		44		29		46	
TEMP	DEG F	64 57 49	44 40	36 33	33 35	31 29	30 30	32 41		
DEW PT	DEG F	45 38 33	28 24	21 18	19 20	20 20	18 19	20 22		
POP(12)	PERCENT			0		0		0		13
POP(6)	PERCENT		0	0	0	0	0	0	0	7
POF(P)	PERCENT	0	5	20	80	39	65	52	36	16
POZR(P)	PERCENT	0	3	7	3	44	22	31	34	23
PREC TYP	CATEGORY	3	3	3	2	1	1	1	1	3
R SHR(L)	PERCENT		22		4		1		1	
DRZL(L)	PERCENT		54		41		57		12	
RAIN(L)	PERCENT		24		55		42		87	
TSTM	PERCENT		0		0		0		0	
SVR T(T)	PERCENT									
QPF	CATEGORY			1		1		1		
CLOUDS	CATEGORY	1	1	1	1	1	1	1	1	2
OB VIS	CATEGORY	1	1	1	1	1	1	1		
WIND D/S	DEG MPH	3009	3617	0114	0220	0411	0310	0410	0513	0709
CIG	CATEGORY	6	6	6	6	6	6	6		
VIS	CATEGORY	6	6	6	6	6	6	6		
SNOW AMT	CATEGORY			0						

DATE OF FORECAST IS TUESDAY MARCH 5 1985 EARLY GUIDANCE

NORFOLK, VA
.TONIGHT...CLEAR, LOW IN THE UPPER 20S. NORTHERLY WINDS 15 TO 20 MPH AFTER MIDNIGHT.
.WEDNESDAY...CLEAR AND COLDER, HIGH IN THE MID 40S. STRONG NORTHERLY WINDS 20 TO 30 MPH BY MIDDAY.
.WEDNESDAY NIGHT...CLEAR, LOW IN THE UPPER 20S.
.THURSDAY...SUNNY, HIGH IN THE MID 40S.
CHANCE OF PRECIPITATION NEAR 0 PERCENT THROUGH WEDNESDAY NIGHT.

Figure 26.--Example of Model Ouput Statistics (MOS). Forecast was made for March 5, 1985, for Norfolk, Virginia.