An Analysis of the "Blizzard of '88"

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Abstract

A collection of detailed surface weather observations is used to construct an analysis of the legendary "Blizzard of '88," an intense cyclone that was accompanied by unusually heavy snowfall, high winds and cold temperatures across the northeastern United States from 11 to 14 March 1888. The analysis follows the cyclone from genesis along a slow-moving frontal system, through rapid development and occlusion along the Middle Atlantic and southern New England coasts. Unusual aspects of the cyclone are highlighted. These include the limited areal extent of heavy snow accumulations, the establishment of very cold air across western New England and the Middle Atlantic states, a persistent stationary frontal zone across central New England that separated frigid continental air from maritime air, and the slow movement and rapid warming associated with the decay of the storm.

1. Introduction

Between 11 March and 14 March 1888, an intense cyclone battered the northeastern United States with an unprecedented combination of heavy snows, high winds, and bitterly cold temperatures. Twenty to 50 in (51 to 102 cm) snowfalls were common across sections of Pennsylvania, New Jersey, New York and New England and accompanied by winds as high as 80 mph (36 m s^{-1}) and temperatures close to 0°F (−18° C). Several photographs taken during the storm period are presented in Fig. 1. More than 400 individuals perished at land and at sea as the storm raged along the coastline for three days. All transportation came to a halt and thousands of telegraph lines were downed, severing communications between the nation's largest cities and the rest of the world for several days. (See Hughes (1976) for a detailed discussion of the effects of the storm.) Despite having occurred nearly a century ago, the "Blizzard of '88" is still used as a gauge to compare similar storms.

The storm has been the subject of numerous books and articles (e.g. Bahr, 1979; Brandt, 1977; Hughes, 1981, 1976; Ludlum, 1983, 1976; Strong, 1938; and Werstein, 1960), but no detailed meteorological analysis has appeared in recent literature. As such, the intent here is to present a series of surface weather maps that documents the evolution of the cyclone.[1] The analyses are intended to provide a chronicle of one of the most famous meteorological events on record and to shed some light on the processes that may have contributed to its formation and unusual intensity. The study is constrained by the limited spatial and temporal resolution of the data at hand. Sixty years would pass before upper air observations became routinely available. However, organized surface weather reports were taken three times daily in 1888 at a considerable number of observing stations, making relatively detailed surface analyses possible.

Over the years, embellishment and exaggeration of snow depth, temperature, and winds have added to the notoriety of the storm. This article will attempt to clarify these points using actual measurements made by qualified observers at that time. However, erroneous observations, instrument inaccuracies, conditions unfit for proper measurement, and even exaggeration by the observers, may have contaminated some of the records. In spite of these possible shortcomings, a coherent and consistent set of analyses emerges.

This article is subdivided as follows: 1) a brief historical overview of the storm and its impact are discussed in Section 2; snowfall measurements are summarized in Section 3; sources of data used to generate the series of weather maps are discussed in Section 4; weather maps and a comprehensive discussion are included in Section 5; and a summary of findings is presented in Section 6.

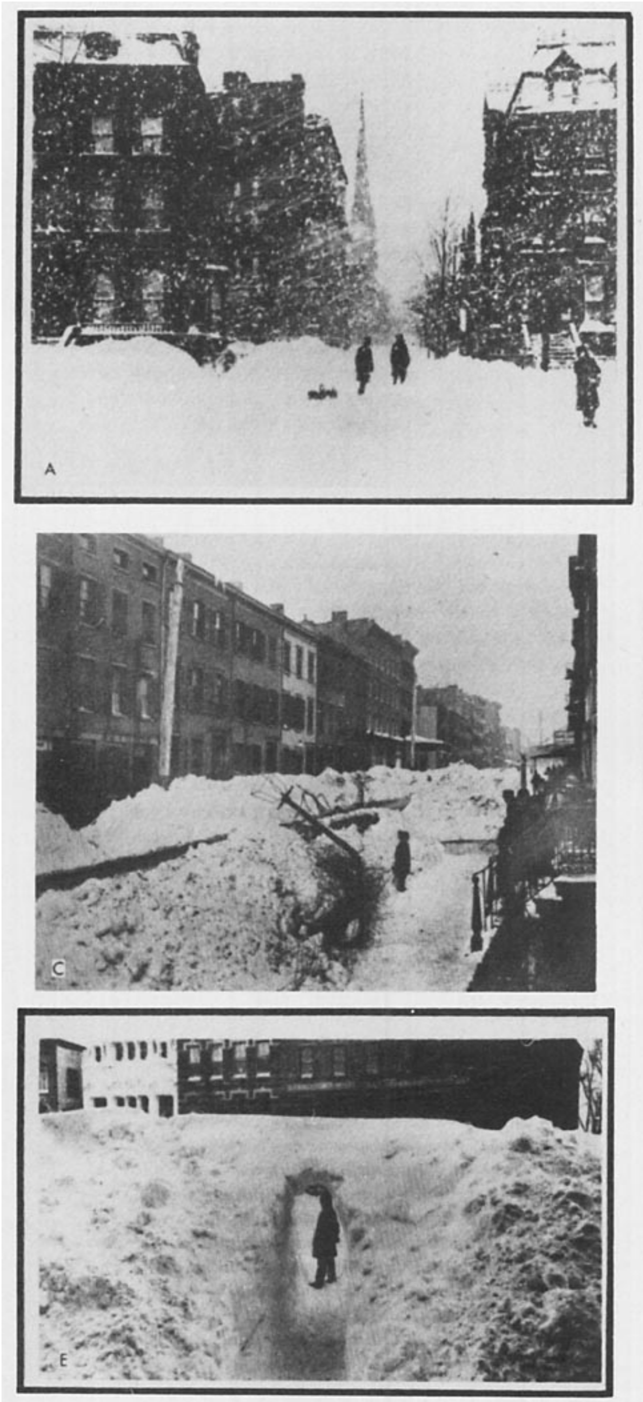
2. Historical overview

On Sunday, 11 March 1888, the weather forecasts or "indications" from the Washington, D.C. office of the United States Signal Service (USSS), a branch of the Department of War and the predecessor of today's National Weather Service, noted weather conditions over the eastern half of the United States that presented little threat for the next two days.[2] A trough of "low barometer" extended from southern Canada to the eastern Gulf of Mexico with two weak surface low pressure centers, one just east of Lake Huron and the other over Georgia. "Fresh to brisk easterly winds, with rain, will prevail tonight followed on Monday by colder, brisk westerly winds and fair weather throughout the Atlantic States," read the forecast issued for Sunday night and Monday 12 March. This particular Sunday, weather observers or "prophets", as the local newspapers called them, studied their surface weather charts (Fig. 2) and saw a retreating mass of seasonable cool air over New England, a low pressure trough moving in from the west and rain that had fallen the day before as far north as Michigan and southern Canada. How could it snow?

On Saturday morning, 10 March the pilot boat, *Charles H. Marshall,* set sail from Staten Island, New York on a routine journey (see Hayden, 1888, pp. 42–43). By late Sunday afternoon, with rain falling as the ship passed about twenty miles

[1] All values and units used in the figures and referred in the text were chosen to be consistent with their original presentation and to conform to the station model used in "Daily Weather Maps, Weekly Series", published by the Government Printing Office.

[2] Tri-Daily Weather Charts of the Signal Service for the month of March, 1888, United States Weather Bureau.



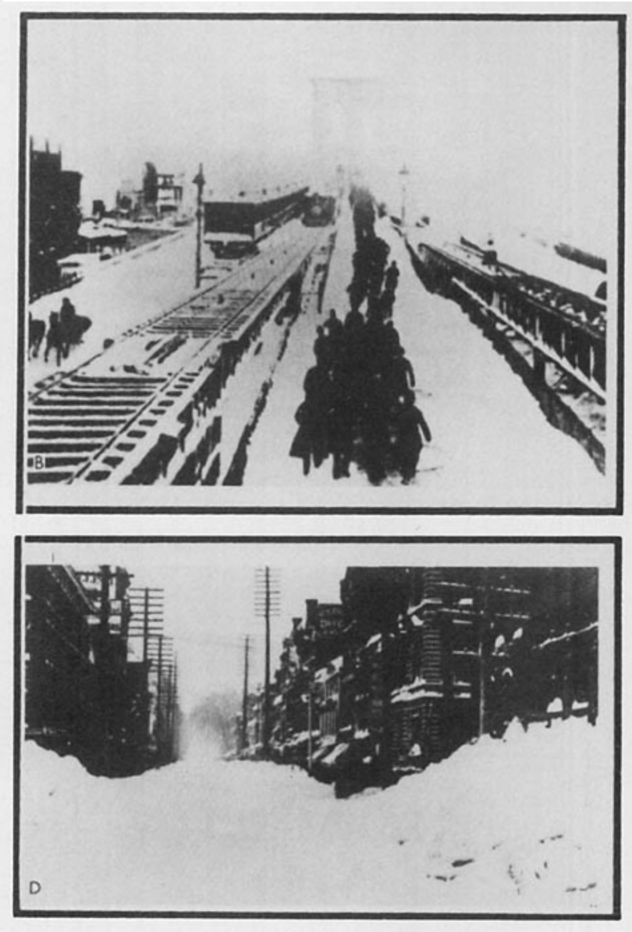


FIG. 1. (a) Joralemon Street, Brooklyn, New York City, at the height of the storm (New York Historical Society). (b) Workers crossing the Brooklyn Bridge in New York City before bridge was closed due to fear of its collapse on 12 March 1888. After bridge was closed, there were no means to either enter or leave Manhattan Island (New York Historical Society). (c) Debris and snow piles on West 13th Street, New York City, in the aftermath of the storm (Brown Bros.). (d) Chapel Street, New Haven, Conn. after 45 in (114 cm) snowfall (New York Historical Society). (e) Northampton, Mass. (New York Historical Society).

off the southern New Jersey shore, winds began to increase from the southeast. Weather conditions soon deteriorated rapidly and the vessel headed to shore to seek a safe harbor. Before reaching its destination, the ship was forced to wait out the approaching storm as dense fog formed. By 3 a.m. Monday, the wind began to moderate somewhat but the sky appeared "threatening" to the northwest and further precautions were made for impending heavy weather. At 3:30 a.m., the winds virtually ceased but the ship was engulfed by towering waves. In less than a half hour, the wind veered sharply to the northwest and increased to a "hurricane". The ship tipped over and nearly submerged as it would several more times in the next 24 hours, but managed to right itself. In two hours, the ship resembled a bobbing iceberg as waves crashed over the deck in blinding snow and falling temperatures. During the next two days, the *Charles H. Marshall* was blown 170 km off course as its crew struggled to keep the vessel afloat. Despite these hardships, the ship and its crew were fortunate since more than two hundred other vessels off the Atlantic coast either vanished or were damaged severely. Portions of detailed storm reports from the *Charles H. Marshall* and another ship, the *Annie M. Smull*, are included in the appendix to provide an account of weather conditions at sea during the height of the storm.

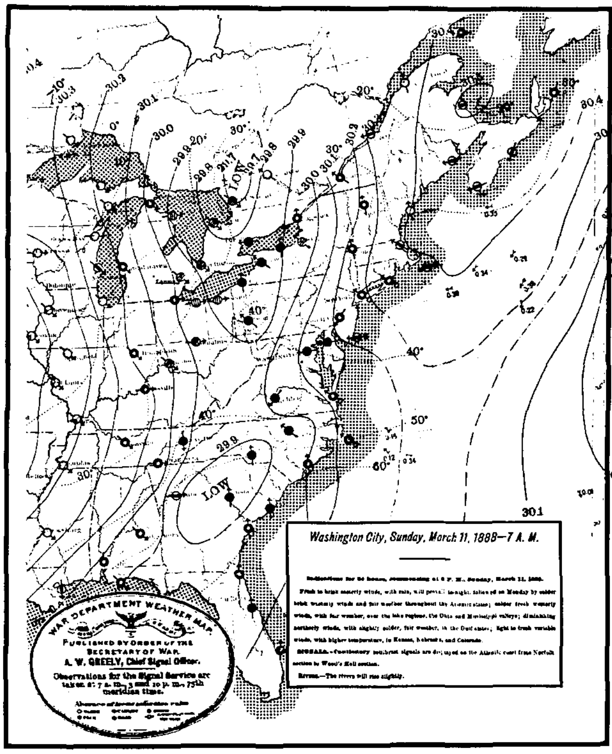


FIG. 2. Portion of 7 a.m. (75th Meridian Time—1200 GMT) Signal Service weather chart for 11 March 1888, including a weather forecast for much of the United States for the 24-hour period ending at 3 p.m. (75th Meridian Time—2000 GMT) 12 March 1888. Figure includes isobars (solid and dashed) and isotherms (dotted).

As the *Charles H. Marshall* was reeling under the onslaught of wave, wind and snow, most of New York City's residents had already gone to sleep during a chilly, rainy and windy Sunday evening. When they awoke the following morning, they were greeted by a blinding snowstorm, 10 in (25 cm) of snow on the ground with temperatures falling through the low twenties (−5°C). Many left home for work but were unable to reach their destinations since most forms of transportation were disabled. Some tried to venture out on foot and a few became disoriented, fatigued and collapsed into the drifts. By days end, fallen telegraph, telephone and electrical lines, shattered windows and other debris littered many streets as blowing snow, howling winds and temperatures falling through the teens into the single digits (−8° to −13°C) left Manhattan streets deserted. When skies finally cleared on Wednesday, the storm had claimed an estimated 200 lives in New York City alone (Hughes, 1976).

The official meteorological record for Central Park Observatory, New York City for 10–15 March 1888 is shown in Fig. 3 and provides a complete summary of weather conditions for the city during the entire storm period. Twenty-one inches (53 cm) of snow were recorded officially through 5:30 p.m., 12 March, although no further snow measurements were mentioned until 11 a.m., 14 March. Many other records (discussed later in the text) and newspaper accounts indicated that snow continued to fall during the night of 12 March and throughout a good part of 13 March. The wind movement, in miles, shows that wind speeds averaged 33.1 mph (15 m s^{-1}) over the 14-hour period ending at 9 p.m. on 12 March, while the hourly temperature record shows mild conditions on 10–11 March, followed by the rapid descent of temperatures on 12 March from 33°F (1°C) at midnight to 8°F (−13°C) by 10 p.m. The combination of these elements produced blizzard conditions in New York City from 12 March through 13 March. Weather observations for New York City in subsequent figures were taken at another site, as described by Mcguire (1961).

By the time the snow ended on 14 March 1888, the storm had left its mark as one of the most devastating in American history. It has achieved more notoriety than all the other great winter storms that have affected the Northeast United States for the following reasons: 1) near-record late winter cold temperatures and high winds combined with very heavy snow to create prolonged blizzard conditions over the most populated section of the country; 2) for many areas of the Northeast, this was (and still is) the heaviest snowstorm on record (see Ludlum, 1976, p. 139); 3) the number of deaths that resulted was more typical of a major hurricane or tornado outbreak than a winter storm; 4) there was little forewarning of a major cyclone as the weather across the eastern United States was fair and mild prior to the storm with temperatures generally above freezing. The weather system that spawned the intense cyclone caused little concern as it drifted innocuously across the country spreading light rain and snow; and 5) the storm caused severe damage to transportation, shipping and communications. The political outcry following the communications blackout between the industrial cities of the Northeast and the rest of the world led to a revamping of the nation's telegraph system (Hughes, 1976, p. 75).

NEW YORK METEOROLOGICAL OBSERVATORY

CENTRAL PARK — MARCH, 1888 — NEW YORK CITY

DAY	HYGROMETER: RELATIVE HUMIDITY 7 AM	2 PM	9 PM	CLOUDS: CLEAR = 0 OVERCAST = 10 7 AM	2 PM	9 PM	RAIN AND SNOW: DEPTH IN INCHES BEGINNING	ENDING	DURATION	WATER	SNOW	REMARKS 7 AM	2 PM
10	75	90	88	0	SE 4 CU	7 CU						MILD, PLEASANT	MILD, PLEASANT
11	91	90	93	10	10	10	2:30 PM	12:00 PM	9:30	.65		RAW, OVERCAST	COOL, OVERCAST
12	100	100	100	10	10	10	0:00 AM	5:30 PM	17:30	1.45	21"	COLD, WINDY, SNOWING	COLD, WINDY SNOWING; SEVERE STORM
13	100	100	100	10	10	10						COLD, WINDY	COLD, WINDY
14	89	89	93	3 CIR	10	8 CU	11:00 AM	2:00 PM	3:00	.02	SLIGHT	CLEAR, COLD	COLD, SLIGHT SNOW
15	70	89	86	0	0	6 CU						MILD, PLEASANT	MILD, PLEASANT

BAROMETER — WIND

DAY	BAROMETER (REDUCED TO FREEZING) 7 AM	2 PM	9 PM	MAXIMUM	TIME	MINIMUM	TIME	WIND DIRECTION 7 AM	2 PM	9 PM	MOVEMENT IN MILES 9 PM TO 7 AM	7 AM TO 2 PM	2 PM TO 9 PM	TOTAL	FORCE IN POUNDS PER SQUARE FOOT 7 AM	2 PM	9 PM	MAXIMUM	TIME
10	30.388	30.342	30.300	30.390	10 AM	30.294	12 PM	N	SE	ESE	38	46	62	146	0	¼	0	1¼	8:00 AM
11	30.182	39.988	29.814	30.294	0 AM	29.732	12 PM	ENE	ESE	ENE	51	82	88	221	0	2¼	1¼	4¼	12:00 PM
12	29.616	29.488	29.500	29.732	0 AM	29.400	12 PM	NNW	NW	NW	172	225	239	636	14¼	31	18	36¼	2:15 PM
13	29.276	29.268	29.400	29.422	12 PM	29.240	10 AM	WNW	NW	NW	278	163	149	590	6	10	4½	15¼	1:00 PM
14	29.598	29.720	29.900	29.910	12 PM	29.422	0 AM	NNW	NNW	NW	138	70	76	284	¼	1½	3½	4	0:50 AM
15	29.986	29.986	29.968	29.998	11 AM	29.910	0 AM	W	NW	WNW	123	87	83	293	0	2¼	¼	3½	0:30 PM

HOURLY READINGS FROM THE DRAPER SELF-RECORDING THERMOMETER IN THE SHADE

FAHRENHEIT DEGREES

DAY / TIME	AM 1	AM 2	AM 3	AM 4	AM 5	AM 6	AM 7	AM 8	AM 9	AM 10	AM 11	NOON	PM 1	PM 2	PM 3	PM 4	PM 5	PM 6	PM 7	PM 8	PM 9	PM 10	PM 11	MIDNIGHT	MEAN
10	29	29	29	28	27	27	27	30	34	35	39	42	44	42	43	45	43	40	38	37	37	36	37	36	35.6
11	36	36	35	34	35	36	36	37	38	40	42	42	41	40	39	38	38	38	38	36	35	34	34	33	37.1
12	32	31	29	26	24	24	22	20	18	17	15	14	16	16	15	14	14	12	11	10	10	8	8	8	17.2
13	8	6	6	6	6	6	6	6	6	7	8	9	10	11	11	10	10	10	10	10	10	11	12	12	8.5
14	13	14	17	17	18	19	20	22	25	28	29	29	31	33	34	35	37	36	36	36	32	31	31	31	27.2
15	31	30	30	30	30	29	28	29	32	34	36	36	35	36	37	37	38	34	33	31	32	32	33	33	32.7

FIG. 3. Records of the meteorological observatory at Central Park, New York City for 10–15 March 1888.

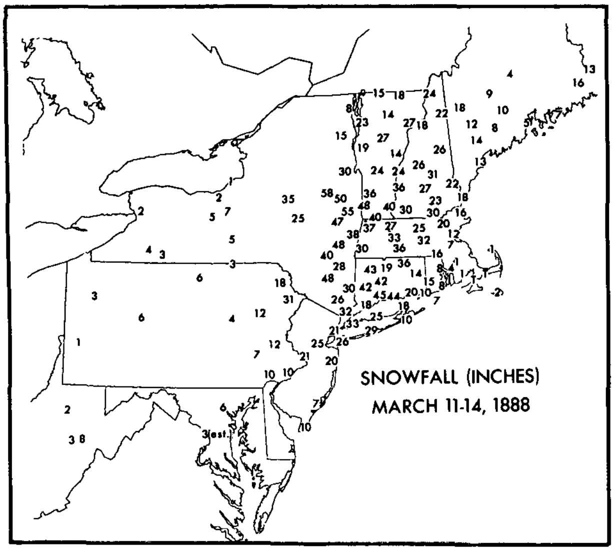


FIG. 4. Total storm snowfall in inches. "T" represents trace amounts.

3. Snowfall measurements

Snowfall measurements were taken from Upton (1888), Ludlum (1983) and the records of the USSS, on microfilm at the National Archives in Washington, D.C. In spite of the difficulty of accurately measuring snow amounts because of the high winds, many observations were taken. A representative sample is presented in Fig. 4.

The Washington, D.C., area was paralyzed by wind-blown snow and ice that amounted to several inches late on 11 March. Snow accumulations extended as far south as northern Virginia and the eastern shores of Maryland, Delaware and Virginia. Philadelphia, Pa., received over 10 in (27 cm) of snow early on 12 March, while Atlantic City, N.J. accumulated 7 in (18 cm) before skies cleared by afternoon. However, snow totals and duration increased dramatically further north as northeastern Pennsylvania, northern New Jersey, eastern New York, Long Island, Vermont, western and central Massachusetts, most of Connecticut and New Hampshire, and parts of Rhode Island and Maine received anywhere from 1½ to nearly 5 ft (38 to 150 cm) of snow. In many of these areas, snow fell for two to three days before ending on 14 March. New York City officially recorded 21 in (53 cm) while Brooklyn received 26 in (65 cm). Communities across Long Island measured anywhere from 18 to 36 in (45 to 90 cm), while eastern Long Island received only about 10 in (25 cm), since rain was slow to change over to snow. Snow amounts increased north of New York City where 30 to 50 in (75 to 127 cm) were common throughout New York's Hudson Valley. Albany, N.Y. came in with 46.7 in (119 cm) and Troy, N.Y. measured 55 in (138 cm). The area around Saratoga Springs, N.Y. recorded the greatest amounts, with reports of 50 to 58 in (127 to 145 cm). While eastern New York was inundated with snow, a rather sharp dividing line between very heavy snow amounts and relatively little snow can be seen across central New York and Pennsylvania. Over New England, snow totals were equally impressive with 20 to 40 in (51 to 102 cm) accumulations widespread, including 44.7 in (114 cm) in New Haven, Conn., 32 in (80 cm) at Worcester, Mass. and 27 in (68 cm) at Concord, N.H. Much of the snowfall in western New England and in New York State was accompanied by temperatures dropping to near 0°F (−18°C) and high winds, producing blizzard to severe blizzard conditions. Southeastern New England received most of their precipitation in the form of rain. Whereas Boston, Mass., alternated between rain and snow, receiving seven to 12 in (18 to 30 cm) of very wet snow, many locations in southeastern Massachusetts received 2 in (5 cm) or less, including Woods Hole, Mass., where only a trace was recorded. Temperatures across eastern New England generally ranged from the low 20s to the low to mid 30s (−5°C to 2°C) during the storm period, with readings as high as the low 40s (5°C) in southeastern New England.

4. Data sources

Meteorological observations were obtained from a variety of sources.[3] The main reporting, or "regular" stations of the USSS provided the most complete and reliable set of readings, which were made three times daily at 7 a.m., 3 p.m. and 10 p.m. (75th meridian time—equivalent to 1200, 2000 and 0300 Greenwich Mean Time). In the late 1880s there were 170 regular stations of the USSS, whose reports were sent via telegraph to Washington, D.C., where they were compiled to generate synoptic maps. The observations included uncorrected readings of pressure (inches of mercury), dry and wet bulb temperature (°F), dew point temperature (°F), relative humidity, wind velocity (miles per hour), cloudiness (amount, kind and estimated velocity), precipitation (time, form, duration and quantity), current weather, and totals and averages for various meteorological quantities. In addition to the reports of the regular stations, reports from voluntary observers of the Smithsonian Institution and the Surgeon General's office numbered nearly 2000 in all and included a slightly less complete summary of weather conditions than the regular stations. These observations were also taken three times daily, but at 7 a.m., 2 p.m., and 9 p.m. (1200, 1900, and 0200 GMT). Weather logs kept aboard ships provided offshore data during cyclogenesis, but unfortunately, many of these reports are suspect since conditions at sea were so poor. An example of the large amount of information when the USSS "regular" reports are combined with reports from voluntary observers, the Surgeon General's office and ship weather logs, is presented in Fig. 5. This analysis depicts surface weather conditions at 7 a.m. (75th meridian time) 12 March 1888, and will be discussed in the following section.

Original records of the USSS, the Smithsonian Institution and the Surgeon General's Office, were examined on microfilm at the National Archives in Washington, D.C. Original ship weather reports can also be found at the National Archives. Several publications that were written in the late 19th century also contributed to the analysis. These include the

[3] Stations recording weather observations in 1888 are summarized in the "List of Climatological Records in the National Archives", The National Archives, Washington, D.C., March, 1942 (revised in 1981).

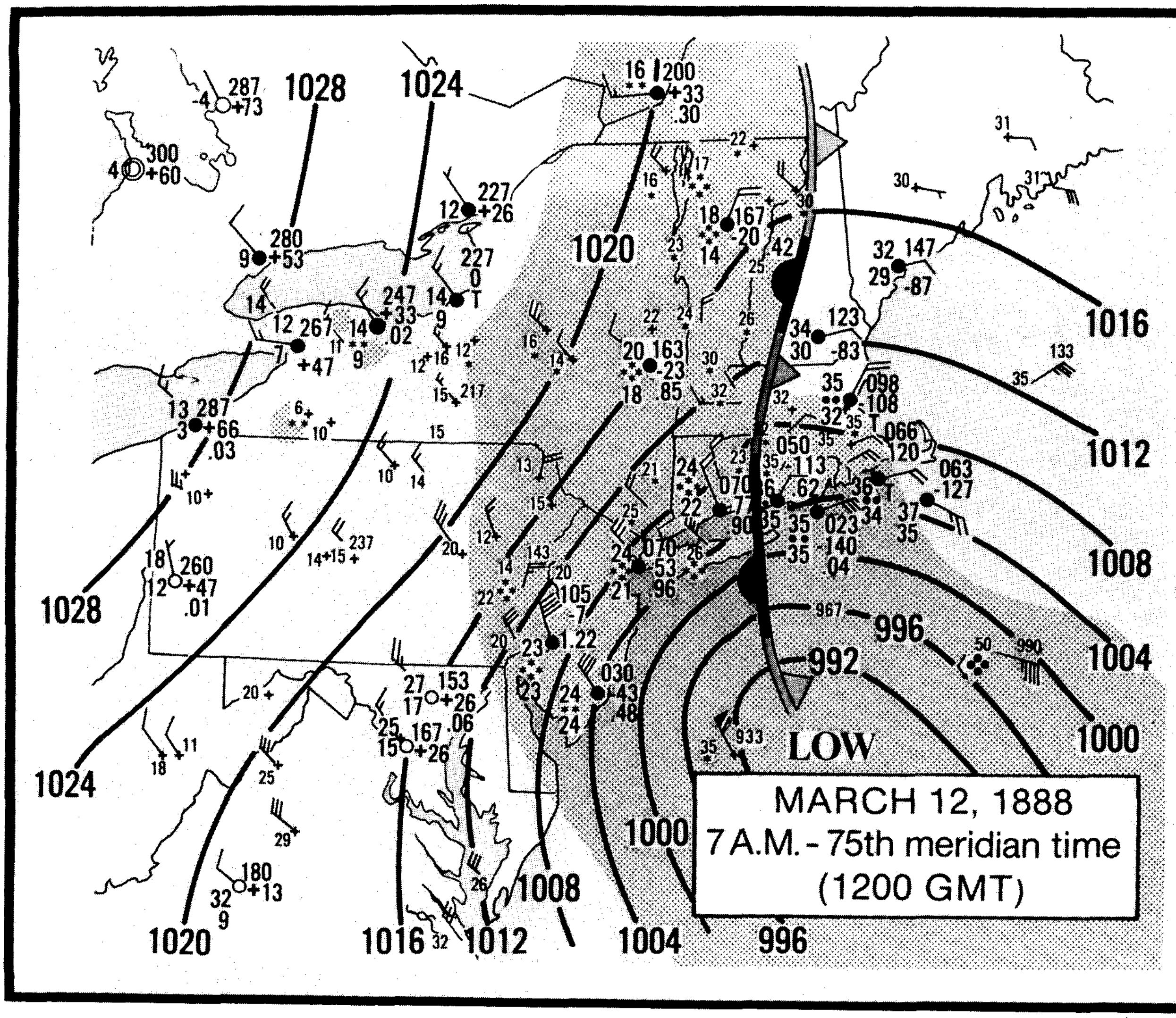


FIG. 5. Surface weather map at 7 a.m. 75th meridian time (1200 GMT) 12 March 1888. Analysis (which includes sea-level isobars (solid, mb) and position of stationary front) incorporates data from Signal Service regular reports, voluntary and Surgeon General reports and ship weather logs. The regular station reports are printed boldly and include (reading clockwise from upper right) corrected sea-level pressure (mb, 070 = 1007.0 mb), pressure change in nine hours preceding observation (−28 = −2.8 mb), precipitation in past nine hours (inches), dew point temperature (°F), current precipitation type and intensity, and air temperature (°F). Wind velocity (feathers and half feathers representing 10 and 5 knots, respectively)[4] and cloud cover are also included. Other reports shown include wind velocity, precipitation type (and intensity, where applicable) and temperature (°F).

"Tri-Daily Weather Maps" for March, 1888 printed by the USSS and original analyses of the storm by Cleveland Abbe, the first editor of the *Monthly Weather Review*, which are maintained at the Cartographic section of the National Archives in Alexandria, Va. Additional information was contained in the first edition of National Geographic Magazine (October, 1888, Vol. 1) and in a Navy monograph entitled "The Great Storm Off the Atlantic Coast of the United States, March 11–14, 1888", both written by Everett Hayden, head of the U.S. Navy Division of Marine Meteorology. Articles in the May 1888 issue of the American Meteorological Journal and the March 1888 Monthly Weather Review, both written by Winslow Upton, professor and secretary of the New England Meteorological Society, also provided comprehensive accounts of the storm. Finally, newspaper accounts of the storm were also valuable sources of information.

The surface analyses that follow are presented over a six day period encompassing the lifetime of the storm from its inception along a propagating frontal trough to cyclogenesis, occlusion and decay. These maps cover a larger region and present a less detailed collection of reports than those presented in Fig. 5 in order to provide a general overview of the cyclone's development. Weather maps are presented at 7 a.m., 3 p.m. and 10 p.m. (75th meridian time) and include many of the reports of the USSS although several are omitted to avoid clutter. The 7 a.m. analyses were generated from more reports than the other times since the USSS, Smithsonian Institution, Surgeon General's office, and several ships made simultaneous measurements. At 3 p.m. and 10 p.m., less data were available for the analyses since the Smithsonian and Surgeon General's reports were made an hour earlier.

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[4] See explanatory sheet for the Daily Weather Maps, Weekly Series, published through the Government Printing Office.

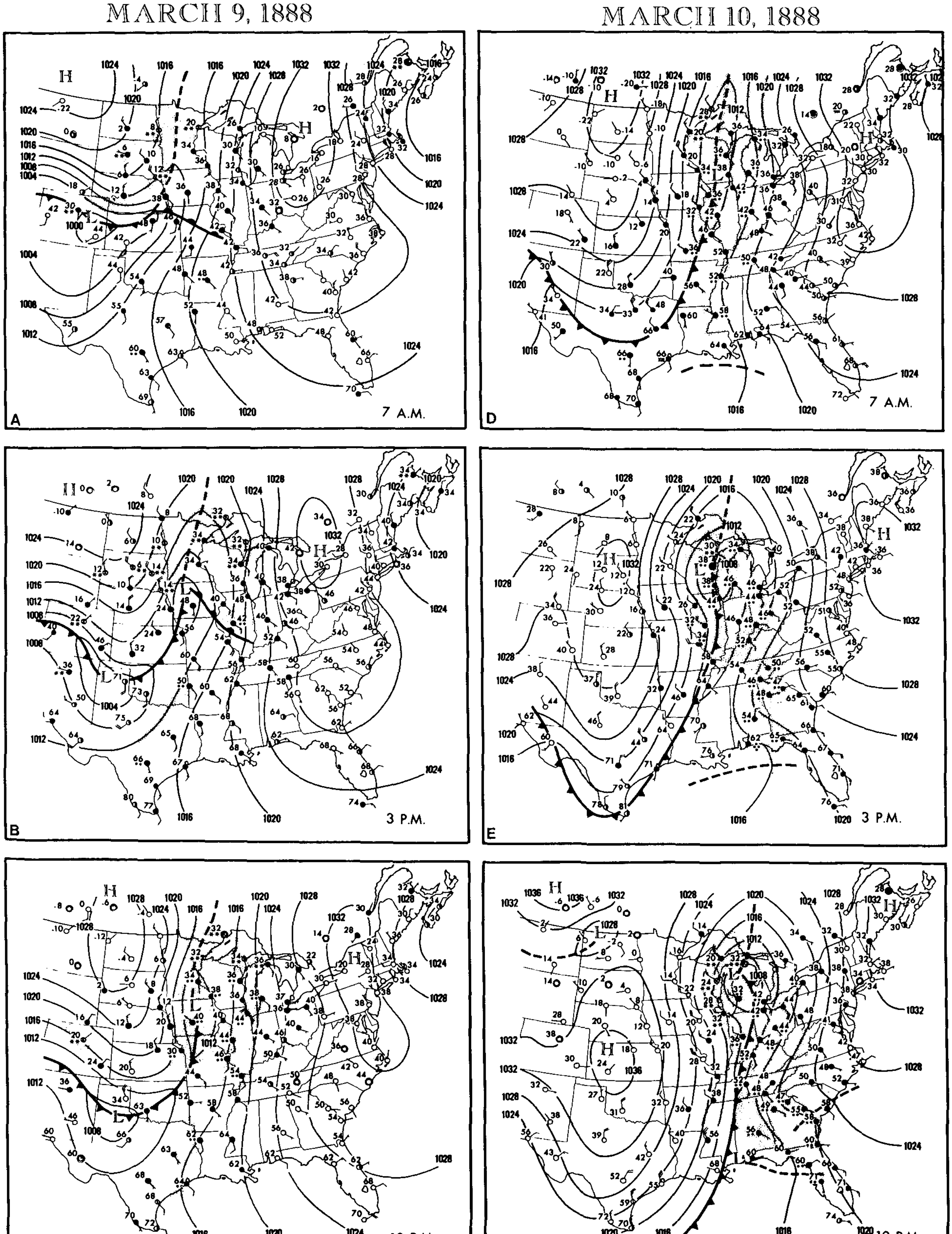

FIG. 6. Sea-level pressure (mb) and surface frontal analyses for 9 March 1888 at (a) 7 a.m. 75th meridian time (1200 GMT), (b) 3 p.m. 75th meridian time (2000 GMT), (c) 10 p.m. 75th meridian time (0300 GMT), and for 10 March 1888 at the same times; (d), (e), and (f). Observations include cloud cover, temperature (°F), precipitation type and intensity (if unknown, light intensity is plotted), and wind velocity. Shading denotes patterns of precipitation.

However, these other reports were very useful in defining frontal and cyclone locations in areas where regular station coverage was poor or where weather conditions changed rapidly over small distances.

Pressure analyses over the ocean are included to provide a consistent picture of the cyclogenetic process. There is generally enough coverage (see Hayden, 1888, pp. 10–63) to generate a plausible synoptic analysis at 7 a.m. each day, and intermediate reports are used to approximate frontal and cyclone positions at 3 p.m. and 10 p.m. However, oceanic weather analyses at these intermediate times are derived from fewer reports and are primarily based on extrapolations and times of frontal passage inferred from ship weather logs.

The surface maps include isobars at 4 mb intervals (corrected sea-level pressures were supplied from Cleveland Abbe's hand-drawn maps and the Tri-Daily Weather Charts published by the USSS), frontal positions, high and low pressure centers, temperature (°F), current weather (rain or snow and intensities), shading for precipitation, cloud coverage, and wind velocity. While the original values of wind speed are used for this study, the anemometers used at the time were later found to overestimate the wind speed (Ferguson and Covert, 1924). If precipitation intensity is not known, it is plotted as light precipitation. These analyses conform basically to the conventions employed in the "Daily Weather Maps, Weekly Series".

5. 9–14 March 1988 surface analyses

a. 9–10 March 1888

The surface weather maps for Friday, 9 March 1888 (Figs. 6a, b, c) show that skies were mainly clear across the northeastern United States with afternoon temperatures (°F) in the 30s (−1°C to 5°C) and 40s (5°C to 10°C), fairly typical of late winter. A slowly moving cold frontal system across the center of the nation separated mild, moist air circulating around a ridge of high pressure over the Eastern United States from bitterly cold Canadian air poised over the Plains and Rocky Mountain states. The temperature difference across the front was considerable with 70°F (21°C) readings over northern Texas and Oklahoma, and temperatures in the teens (−12°C to −7°C) in Nebraska (Fig. 6b).

Two low pressure centers are analyzed along the frontal zone with one developing in Iowa and the other propagating from Colorado to the Texas panhandle. Light rain and snow are associated with the Iowa low while little precipitation is observed with the Colorado-Texas low. The cyclone center moving into northern Texas can be traced back to the California coast on 6–7 March and was associated with heavy snow at Salt Lake City, Utah the following day. This cyclone center may be a reflection of the upper-level system associated with the intense cyclone along the Atlantic seaboard a few days later. To the east of this low, drizzle, light rain, and a thunderstorm were reported over eastern Texas, where moist air was moving northward from the Gulf of Mexico. This humid airflow streamed ahead of the slowly advancing cold front and produced light to moderate rainfall throughout the Midwest, and light snow across the upper Great Lakes states.

During the night and the early morning of 10 March (Figs. 6c, d), the frontal system continued to move slowly toward the east, accompanied by rain from Louisiana and Mississippi to as far north as Michigan. Heaviest rainfall in the nine-hour period ending at 7 a.m. occurred over Louisiana and Arkansas, where Shreveport measured 1.42 inches (3.6 cm) and Little Rock reported .84 inches (2.1 cm). By 7 a.m. 10 March (Fig. 6d), the low pressure center over Texas had filled as the cold front plunged southward across Oklahoma and northern Texas, a "Texas Norther" accompanied by overnight falls of 50°F (28°C). Further north, bitterly cold air sent temperatures to as low as −20°F (−29°C) in North Dakota and Montana.

By Saturday afternoon, 10 March (Fig. 6e), high pressure drifted off the New England coast allowing frosty early morning temperatures to climb to 50°F (10°C) or higher as far north as Pennsylvania and New York. Clouds began to increase from west to east across the Atlantic States as the north-south aligned frontal system advanced to a line from Michigan to Mississippi by 10 p.m. (Fig. 6f). The low pressure center over Iowa on Friday had advanced to Michigan and deepened to 1006 mb, accompanied by widespread light precipitation, with rainy skies common across the Midwest. High pressure behind the front (1036 mb) plunged southward to Kansas as cold air poured toward the western Gulf of Mexico. Along the Gulf Coast, an expanding area of rain and the first evidence of a developing cyclonic circulation appeared in the isobars across Alabama, Georgia and northern Florida. Heavy rainfall of 1–2 in (2.5 to 5.1 cm) was common throughout this region and Pensacola, Fla. recorded over 4 in (10.2 cm), mostly in seven hours. By 10 p.m., rainfall was widespread across the Southeast with a weak low pressure center located near Mobile, Ala.

b. 11 March 1888

On Sunday, 11 March 1888 (Figs. 7a, b, c), the gentle rain-producing system that had slowly crossed the nation was transformed into a dangerous storm with high winds and heavy precipitation. At 7 a.m. (Fig. 7a), the frontal trough had progressed to a line extending from a 1004 mb low just northeast of Lake Huron to a second low (1010 mb) over Georgia, into the Gulf of Mexico. A warm front extending eastward from the Georgia low moved northward overnight through the Carolinas with early morning temperatures approaching 60°F (15°C) in southeastern North Carolina. Rain was now widespread along the Eastern U.S. coast, falling at Buffalo, N.Y., Pittsburgh, Pa., Washington, D.C., and Roanoke, Va. (heavy rain). As rain spread eastward across Pennsylvania and New York (wet snow at higher elevations), clouds spread into New England as high pressure moved eastward off the coast with temperatures ranging from the high 20s (−4°C) to the mid-30s (2°C). Much of the central United States was dominated by high pressure as cold air (though greatly modified) and strong winds extended across the Midwest and Gulf states. A weak frontal trough is analyzed across the Midwestern states throughout the day separating the high pressure system that had plunged southward across the Plains States the day before from another, colder air mass north of the Canadian border. During the day, the trough can be tracked southeastward and was followed by colder air across the upper Midwest with temperatures in the single digits and teens (−15° to −10°C).

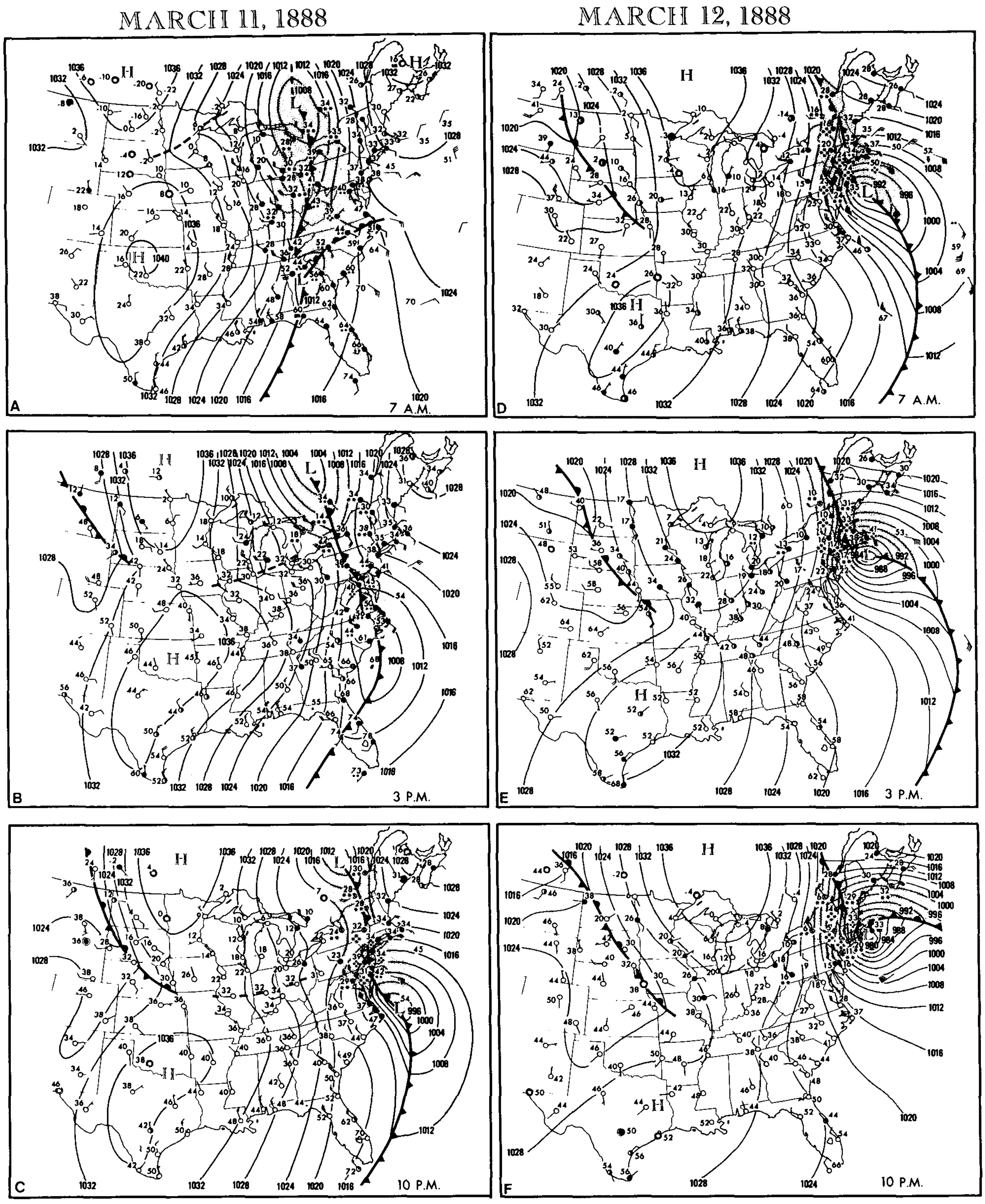

FIG. 7. As in Fig. 6 except for 11–12 March 1888.

By afternoon (Fig. 7b), the eastern frontal system and its two associated low pressure centers continued to move eastward. The northern low moved northeastward into Canada but the southern system progressed to a point just east of Wilmington, N.C. and had deepened 6 mb in eight hours to 1004 mb. A narrow but intense band of rain accompanied the low and frontal passage over the Carolinas with 1–2 in (2.5 to 5.1 cm) rainfalls occurring within a couple of hours, followed by a wind shift to the northwest and falling temperatures. To the north of the low, precipitation was becoming moderate to heavy from Virginia to Pennsylvania with heavy rain reported at Washington, D.C. Most of the precipitation was falling as rain along and to the east of the cold front between the two low pressure systems. To the west of the front, colder air from the Midwest caused the temperature to drop along the Appalachians, but only by 10° to 15°F (5° to 8°C) as the air mass had been greatly modified. Only further north, in New York and Michigan for example, did temperatures drop significantly as very cold air was drawn in behind the storm center northeast of Lake Huron.

Following 3 p.m., the developing cyclone moved east of the North Carolina coast and out into the open Atlantic. Weather conditions deteriorated rapidly along much of the Middle Atlantic coast as the storm continued to intensify. Ships east of the Carolina coast reported rapidly falling pressures with the "Andes" recording 994 mb about 75 mi (125 km) northeast of Cape Hatteras at 10 p.m. (Fig. 7c) (Hayden, 1888, pp. 19, 40). If this reading is accurate (another ship nearby recorded 999 mb (Hayden, 1888, p. 15)) a substantial pressure gradient must have developed immediately to the west of the surface low. This increasing pressure gradient may have been responsible, in part, for the violent increase of wind speeds Sunday evening along the southeastern Virginia, Maryland, and North Carolina coastlines after winds shifted to the northwest. While rain had ended across this region, several Signal Service and other observers reported extensive structural damage (roofs of houses blown off, trees uprooted, etc.) while many ships in supposedly protected areas suffered significant damage. In fact, nearly 100 sea-going vessels were sunk, wrecked or badly damaged along the Maryland-Virginia coast at this time (Hayden, 1888, pp. 38–39). Both Norfolk, Va. and Cape Hatteras, N.C. recorded average wind speeds of 48 mph (21 m s^{-1}) at 10 p.m.

Precipitation ended across the Southeastern states and from southern and western Virginia into western Pennsylvania and New York (where a remarkably clear and calm evening prevailed). The cold front north of the coastal storm continued to propagate toward the Middle Atlantic coast and New England while pressures rose from the northern Midwest to the western Appalachians. Subsequently, temperatures began to fall behind the front as winds shifted to the northwest and rain changed to snow from west to east across northern Virginia into Maryland, Pennsylvania, and New York. Rain changed to snow at 5 p.m. at Washington, D.C. and by 7 p.m. at Baltimore, Md. By 10 p.m., the nation's capital lay under an estimated 3 in (8 cm) mantle of snow with northwest winds exceeding 25 mph (11 m s^{-1}) as Baltimore was reporting heavy snow, receiving 6 in (15 cm) in a very short period of time. At this time, snow was increasing in intensity over eastern Pennsylvania and eastern New York following frontal passage. In extreme eastern Pennsylvania, New Jersey, and southeastern New York, rain continued to fall at 10 p.m. The front had just passed Philadelphia and would not reach New York City for another couple of hours. Philadelphia reported heavy rain with 1.18 inches (3.0 cm) during the past seven hours. In New York City, some streets and exposed objects were becoming icy as wind-blown rain fell with temperatures hovering just above freezing. In New England, skies were now completely overcast and some rain had spread into southwestern New England as winds increased out of the east.

c. 12 March 1888

Monday, 12 March (Figs. 7d, e, f) became "blizzard Monday" as heavy snow, high winds and colder temperatures paralyzed much of the Northeast United States. Overnight, the Atlantic cyclone continued to intensify. Several ships off the Middle Atlantic and southern New England coasts noted rapid pressure falls, a windshift to the northwest accompanied by a tremendous increase of wind speed, rapidly dropping temperatures, and the development of heavy snow (see Appendix). Rain gradually spread across southern and southeastern New England. However, as the cyclone intensified and moved toward the southern New England coast, colder air behind the front northwest of the low center continued to move eastward across Long Island, western Connecticut, Massachusetts, and Vermont. While rain spread across southern and southeastern New England, winds turned to the northwest behind the front and rain quickly changed to snow. Philadelphia changed over at 11:15 p.m.; New York City, around midnight; and New Haven, Conn. recorded its changeover at 2:30 a.m. Northwest winds increased to a gale and snowfall intensified toward daybreak.

As the storm deepened south of Long Island, pressures rose across western New York as a 1040 mb high pressure center north of the Great Lakes expanded slowly eastward. The combination of the developing low and slowly moving high pressure system (see pressure tendencies in Fig. 5) produced an increasing pressure gradient to the north and west of the cyclone that induced colder air to funnel southward from eastern Canada into New York, western New England and the Middle Atlantic states. The north-south oriented front to the north of the cyclone center became stationary across central New England during the day. It became a prominent feature on the surface maps throughout the next 48 hours as it separated cool, maritime air in eastern New England from increasingly colder air to the west. This crucial feature may have been responsible for the generation of the heavy snowfall as a mechanism through which low-level convergence and large-scale ascent was maintained for a considerable period of time.

By morning (Figs. 5 and 7d), snow had ended across northern Virginia and Maryland leaving behind bright blue skies, cold temperatures and very gusty winds. Near-blizzard conditions were spreading across eastern Pennsylvania, New Jersey, New York City, eastern New York, and western New England. New York City and Philadelphia both recorded heavy snow at 7 a.m., each with 10 in (25 cm) on the ground, winds averaging 30 to 50 mph (13 to 22 m s^{-1}), and temperatures in the low 20s (−5°C) and falling rapidly. Winds were gusting to 70 mph (31 m s^{-1}) at Block Island, R.I. and 80 mph

(36 m s^{-1}) at Atlantic City, N.J. The cyclone was located south of Long Island with a central pressure estimated at approximately 988 mb (the lowest pressure recorded at 7 a.m. was 993 mb aboard the *Kensett* off the New Jersey coast (Hayden, 1888, pp. 17, 59)). Pressures were falling less rapidly over western New England than to the east of the front positioned over central New England, reflecting the effect of colder temperatures on the surface pressure field. This differential pressure tendency produced an asymmetry in the surface pressure pattern as low pressure "bulged" toward eastern New England and became more pronounced as the day wore on.

By 3 p.m. (Fig. 7e), the cyclone moved to a position just south of Rhode Island. A ship east of Long Island reported a pressure of 984 mb and Block Island recorded 987 mb, a drop of 17 mb in the past eight hours. Snow ended by mid-morning across Philadelphia and southern New Jersey, and skies cleared by afternoon. New York City now had 16 in (40 cm) of snow on the ground with 2 ft (60 cm) common in outlying areas. Winds were averaging 35–50 mph (16–22 m s^{-1}) and temperatures had dropped into the teens (−7°C–−12°C) throughout much of New York State, creating true blizzard conditions. Blizzard conditions also existed throughout much of Vermont, western Massachusetts, and Connecticut. The front that had stalled over central New England was very pronounced with 10°–20°F (5°–10°C) differences common across the boundary. Colder air was now beginning to filter slowly eastward into eastern Connecticut where rain was changing to sleet and snow. Inland sections of Massachusetts, Rhode Island and New Hampshire were also receiving heavy snow amounts although they were within the oceanic air mass to the east of the stationary front. Southeastern coastal New England, however, remained under the influence of maritime air with temperatures rising slowly toward 40°F (4°C) with strong easterly winds and occasional heavy rain.

By 10 p.m. (Fig. 7f), the storm center moved to a point between Block Island, R.I., and Nantucket, Mass. The central pressure had now fallen to approximately 978 mb. The frontal zone to the north of the low remained virtually stationary and the temperature contrast across the front was spectacular. As an example, Northfield, Vt. recorded 4°F (−15°C) at the same time that Nashua, N.H. was registering 34°F (1°C) to the east of the front. Heavy snow and blizzard conditions were the rule over much of the Northeast at this time. Temperatures had fallen through the single digits (−12°C to −17°C) across western New England and New York and by midnight, New York City dropped to 8°F (−13°C) with snow still falling. 31 in (78 cm) of snow had accumulated at Albany, N.Y. and 28 in (70 cm) at New Haven, Conn., 24 hour records that still stand today. Clouds and scattered snow were beginning to work their way westward and southward across interior New York and Pennsylvania as moisture "wrapped around" the occluding cyclone.

As the storm center approached the southeastern Massachusetts coast, temperatures began to fall rapidly across eastern Connecticut and Rhode Island as winds shifted from the east to the north and rain changed to snow. At Block Island, the temperature fell 18°F (10°C) in the seven hours ending at 10 p.m., with winds of 42 mph (19 m s^{-1}) and 7 in (18 cm) of new snow. At Nantucket, rains ended and winds shifted to the southeast and diminished as temperatures began to fall quite rapidly. Foggy skies developed after an afternoon of rain, winds gusting to 55 mph (25 m s^{-1}) and temperatures in the low 40s (5°–6°C). Cold air was spilling around the occluded cyclone center and beginning to pour into southeastern New England on *southerly* winds. This air would be modified by its short trajectory over the ocean but would produce a significant drop of temperature that changed rain to snow throughout the night across eastern New England.

d. 13–14 March 1888

During the nine hours between 10 p.m. Monday, 12 March and 7 a.m. Tuesday 13 March, both the position and the central pressure (978 mb) of the cyclone changed little. Snow was still falling over much of New England and New York and temperatures continued to drop. Blizzard conditions persisted through much of the night from New Jersey northward. Paterson, N.J. recorded −4°F (−20°C) and temperatures in New York City dropped to 5°F (−15°C) which established a record for late-season cold and began a day that remains tied as that city's coldest March day in 112 years of record-keeping. Temperatures plunged to near 0°F (−18°C) across much of New York and Pennsylvania.

Although the central pressure of the storm had not risen by 7 a.m. (Fig. 8a), there were signs that the cyclone was weakening. The sea-level pressure gradients surrounding the surface low were diminishing and the region of snowfall had become less organized. Some stations received heavy amounts while others nearby measured little accumulation. The surface low center was now "cold-core" with cold air enveloping the entire low-level cyclonic circulation. At Nantucket, winds remained out of the south as temperatures fell overnight, reaching 21°F (−7°C) by morning with occasional snow. Boston also felt the influence of colder continental air sweeping in around the cyclone center as temperatures fell overnight despite easterly flow off the ocean. In Maine, temperatures remained in the low 30s (0°C) as colder air remained further south.

During the day, the cyclone drifted slowly westward across Block Island (note the change in wind direction in Figs. 8a, 8b) and weakened almost as rapidly as it had intensified the previous two days. By 10 p.m., its central pressure rose 17 mb to 995 mb (Fig. 8c). Surface pressure gradients remained strong west of the low center with 42 mph (19 m s^{-1}) average wind speeds at New York City at 3 p.m. and 36 mph (16 m s^{-1}) winds at Philadelphia at 10 p.m. Snow diminished during the day across New England although isolated pockets of heavy snow remained with new accumulations of 10 or more inches (>25 cm) across parts of New York and western New England. Snow showers were widespread but scattered across the Middle Atlantic states and the eastern Ohio Valley although the sun's appearance across parts of New England was further evidence of the cyclone's decay.

The distinct thermal boundary that had evidently played an important role in the generation and maintenance of heavy precipitation remained pronounced throughout 13 March, but began to erode under the persistent, relatively mild easterly flow to the northeast of the storm center. By 10 p.m., Montreal's temperature rose to 30°F (−1°C), an increase of nearly 20°F (11°C) since morning, and was considerably higher than cities located to the south where readings were mainly in the teens (−12° to −7°C). Since the rising temperatures occurred where no obvious wind shift or propagating pressure trough was observed, it is difficult to analyze a warm front moving cyclonically around the northwest quadrant of the storm circulation. Rather, the mixing of warmer air aloft with shallow, cold surface air, similar to that described by Spar (1956) for a region ahead of a warm front, appears to be responsible for raising temperatures across northern and central New England late on 13 March.

Warming progressed southward into southern New England and the Middle Atlantic States on Wednesday 14 March (Figs. 8d, e, f) as the stationary front across central New England lost its frontal characteristics and disappeared by 7 a.m. (Fig. 8d). Snow finally ended Wednesday morning after an additional inch or two (2.5–5 cm) accumulated across southern New England and southeastern New York. Temperatures recovered to near 40°F (4°C) from Philadelphia to Boston, while an area around east-central New York and southern Vermont soared into the middle and upper 40s (7°–9°C), in spite of a fairly uniform 4 ft (120 cm) snow cover. Colder temperatures persisted further west and south, as Washington, D.C. reported 34°F (1°C) with sunny skies at 3 p.m., (Fig. 8e) while Albany, N.Y. concurrrently registered similar clear sky conditions, but a temperature of 42°F (5°C) with much more snow on the ground.

At 7 a.m., the poorly defined region of low pressure had drifted south of Long Island. The central pressure of the dying storm rose to 1002 mb, based on ship reports. By Wednesday afternoon and evening (Figs. 8e, f), the low pressure area drifted out to sea, skies slowly cleared across the northeastern United States, and the storm was history.

6. Summary and concluding remarks

Weather observations from several sources were combined to generate analyses of the March, 1888 "Blizzard of '88". Some general findings from the study are briefly summarized in this section.

The cyclone developed along a progressive north-south aligned frontal trough. One low pressure center along the northern extension of the front moved northeastward into Canada and was followed by a surge of cold air that spread across New York and Pennsylvania into western New England. A second low center developed over the southeastern United States, moved offshore near Cape Hatteras, N.C. and intensified as it propagated toward the southern New England shore. This low center became the primary storm system and remained near the Massachusetts-Rhode Island coastline for two days.

The cyclone produced severe winter weather conditions only in the Middle Atlantic states and New England. Heaviest snow fell across northeastern Pennsylvania, northern New Jersey, eastern New York and western New England where 20 to as much as 50 in (51 to 127 cm) fell over a three-day period. Precipitation fell mainly as rain across extreme eastern Connecticut, central and southern Rhode Island, and southeastern Massachusetts. Rain changed to snow as cold air enveloped the surface cyclone and temperatures fell dramatically on east to southeasterly winds across eastern New England.

The combination of rapid pressure falls near the coast and rising pressure across western New York produced an intensifying pressure gradient to the west and northwest of the cyclone center on 12 March. This pressure gradient was associated with high winds and rapidly falling temperatures. To the north of the cyclone, a nearly stationary front separated very cold air to the west of the front from warmer maritime air across eastern New England and may have enhanced low-level convergence. The cold air and increasing pressure gradient to the west of the front provided an overrunning surface for heavy precipitation and severe blizzard conditions resulted. The cyclone remained stationary off the southern New England coast for a 48-hour period, prolonging the precipitation. The decay of the storm was characterized by a general breakup of the precipitation area and the establishment of warmer temperatures across the Northeast states, as maritime air to the north of the dying cyclone worked its way west and then south.

The surface observations provide several clues that help identify processes that may have influenced the development of the storm. Of course, such simple speculations cannot be verified since the data base is so incomplete. To assess whether the cyclone developed in a manner similar to other intense East Coast snowstorms, approximately thirty such cases during the past quarter century were briefly examined. A climatological study of these cyclones will be presented in a future paper.

A comparison of these storms shows that the development of this cyclone differed in several respects from other East Coast winter storms. Many other cases of winter cyclogenesis were preceded by an outbreak of very cold air across the Eastern states, usually in association with an intense cell of high pressure over New England. However, no such air mass was entrenched over the Middle Atlantic states or New England prior to the "Blizzard of '88". Rather, colder air moved into both regions as the cyclone was intensifying off the southern New England coast. As a consequence, precipitation started as rain and later changed to snow over a large section of the Northeast. The stationary front and large temperature contrast to the north of the cyclone was also a unique feature rarely exhibited in the other cases. Coastal frontogenesis (Bosart *et al.*, 1972) and cold air "damming" along the eastern slopes of the Appalachians (Richwein, 1980), two features observed frequently in the early stages of wintertime East Coast cyclogenesis, were weak or absent during the development of this storm. Despite these unusual aspects, the cyclone exhibits several characteristics of the "Type B" cyclone described by Miller (1946), with a secondary low pressure center developing south or southeast of an initial storm center over the Great Lakes. Other surface weather features can be used to identify processes linked to cyclogenesis. These include the following:

1) An east-west oriented frontal system over Kansas early on 9 March plunged southward into the Gulf of Mexico by the evening of 10 March and became aligned from north to south. The change in orientation of the surface front, its rapid movement to the south, and the redevelopment of a surface low pressure center from Colorado to near Mobile, Ala., suggest the amplification of an upper-level trough propagating from the Rocky Mountain states to the central United States.

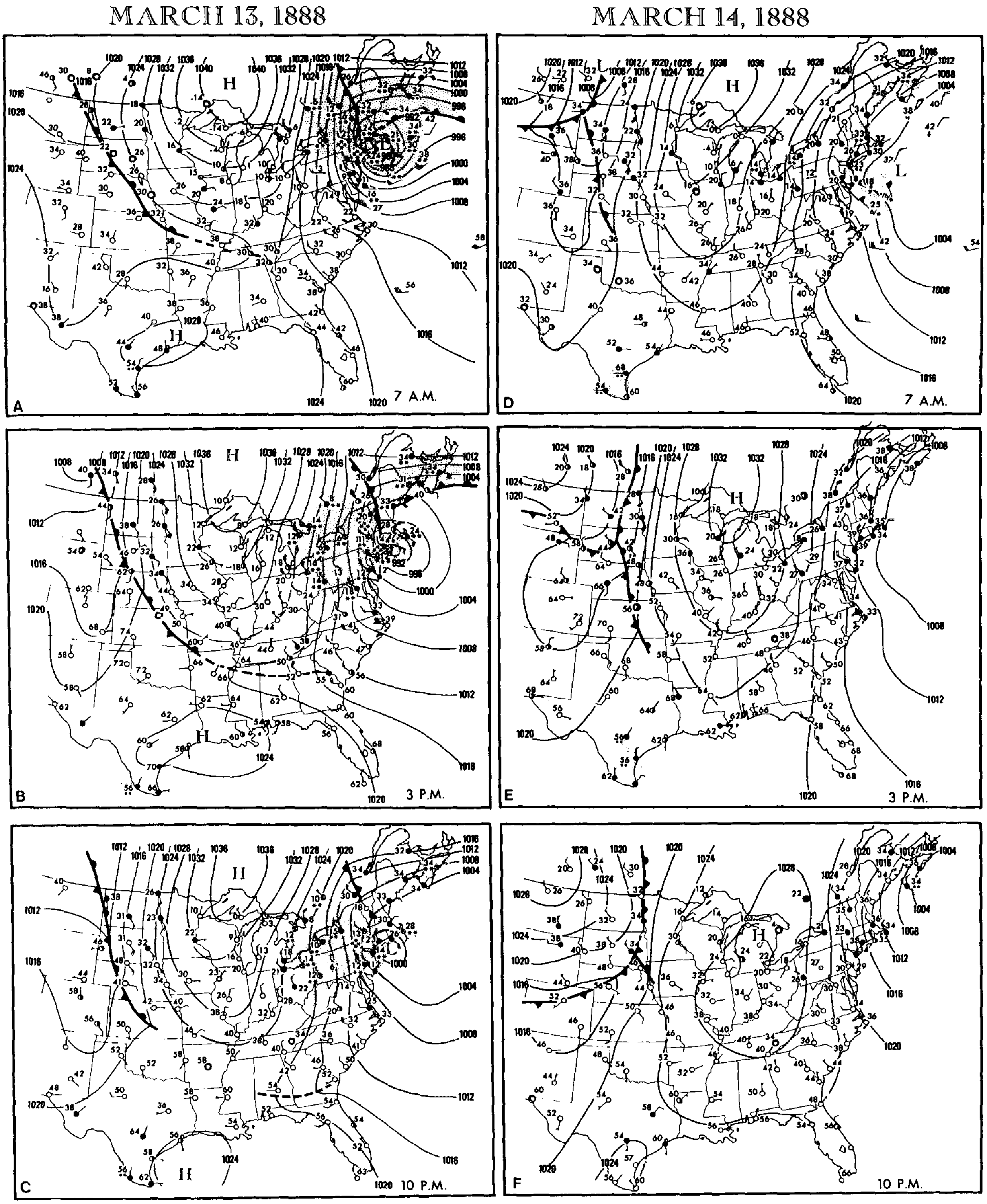

FIG. 8. As in Fig. 6 except for 13–14 March 1888.

2) Two distinct and separate low pressure systems along the front are evidence of two short waves imbedded within the trough system just mentioned: a) The short wave associated with the low pressure center propagating from Michigan to Canada during 10–11 March may have played a role in driving the cold air across the Northeast United States on 11–12 March. b) The short wave associated with the low pressure center that ultimately became the intense cyclone, probably amplified and formed a major vortex near New England late on 12 March.
3) Once the cyclone passed east of North Carolina, it began to move on a more northerly track toward eastern New England. The associated frontal system, which had been oriented on a north-south line, began to take on a northwest-southeast tilt as the cold front south of the cyclone moved rapidly eastward. The movement of the cyclone and the changing axis of the surface front suggest that the upper-level trough along the East Coast assumed a negative tilt, a configuration typical of rapidly intensifying cyclones.
4) The rapid deepening of the cyclone as it moved over the Atlantic Ocean indicates that moisture and heat fluxes from the ocean, low-level baroclinicity and frictional effects may have aided the cyclone's intensification. "Electric phenomena", or convection, was reported at sea during the storm's development and waterspouts were observed during the storm's decay (Hayden, 1888, pp. 34–35). (See Anthes and Keyser (1979), Bosart (1981), Sanders and Gyakum (1980), Tracton (1973) and Uccellini *et al.* (1983) for recent studies of processes that influence East Coast cyclones.)
5) In a recent study by Colucci *et al.* (1981), blocking is described as an obstruction of the eastward progression of synoptic-scale weather systems by persistent meridional flow. While meridional flow is difficult to determine, the presence of a stationary cyclone off New England and anticyclone north of the Great Lakes on 13–14 March indicates that blocking may have become a predominant mode of circulation over the eastern half of North America at the time.

Despite the speculation, the mechanisms that transformed a benign weather system into one of the most violent storms to ever affect the Northeast United States can never really be known.

Appendix

Excerpts from the logs of the *Charles H. Marshall* (see Hayden, 1888, pp. 42–43) and the *Annie M. Smull* (Hayden, 1888, p. 41) provide graphic descriptions of weather and ocean conditions off the New Jersey coast during the storm's development.

New York pilot-boat Charles H. Marshall (No. 3)

". . . March 11. At 10 a.m. the pilots, who are good judges of the weather, thought by the threatening weather that there was going to be a storm, but not so bad a one as it proved to be. Put two more reefs in the sails and steered to the northward, intending to go in for harbor if possible. At 4 p.m. it was blowing a moderate gale from SE., increasing at 5 p.m. to a strong gale, when put three reefs in the mainsail and furled the jib; were then about 18 miles SE from the lightship; but it shut down a dense fog, so would not run in, but concluded to stop out and take it as it came, which it did. Hove to on the starboard tack, heading to the eastward, remaining that way until 2 a.m., March 12.

March 12. At 2 a.m. wore around, the wind hauling to the east. At 3 a.m. the wind moderated, but the weather looked so threatening in the NW that the fourth reef was taken in the mainsail and treble reefed the foresail. At 3:30 a.m. the wind died out completely, and the boat lay broadside on to the heavy SE sea, which was threatening every minute to engulf the little craft; but she did not have to wait long for wind, for at 3:55 a.m., at which time were about 12 miles ESE from Sandy Hook Light-ship, it came out from the NW with such force that the boat went over on her beam ends, but righted again immediately. In two hours the boat was so much iced up by the snow and water that struck her that she resembled a small iceberg. At 8 a.m. the wind increased to a hurricane. Had to lower the foresail, but before the sail could be hauled down had to get iron bars and sledge-hammers to beat the ice off the ropes and mast, and even then only got it down about half-way, so had to lash it up with ropes the best way possible, to save it from blowing away. Then hauled down the forestay-sail and did the same thing with it, much at the risk of the lives of the crew, for the seas by this time were running in every direction, owing to the NW sea coming down in contact with the one from SE. The little vessel was in danger of being swamped, for no one but those who were out in that blizzard and saw those large breaking seas coming down on top of her know what danger she was in. At 10 a.m. the snow and rain came with such force that it was impossible to look to windward, and the boat was lying broadside on to the sea, heading about SW. . . . While lying there fighting for life against the gale the oil-bags were filled every half hour with fresh oil, and it was expected every moment that some passing vessel would run the boat down, for one could not see from one end of her to the other; but trusting in Providence to pull her safely through, not one man on board showed the least sign of fear, the feelings of each one known only to himself. When it got dark on the evening of the 12th the boat looked like a wreck, being encased in ice; it was not expected that she would live until daylight, but continued replenishing the oil-bags every half hour during the night, the members of the crew taking turn and turn about to go on deck to haul them in, taking care, however, that each man had a rope around him as a precaution against being washed overboard, for it was necessary to crawl on hands and knees along the deck to reach the bags. No one on board slept that night. At 11:45 p.m. a heavy sea struck the boat and sent her over on her side, shifting everything that was movable down below, sending all flying to leeward; the water rushed down the forward hatch, and it was thought all were lost, when all of a sudden the little boat righted again; but had another sea struck her at that time she would have been done for.

March 13. Blowing the same, with squalls that came down shrieking as though they would lift the boat out of water. Going forward at 5 a.m. to inspect the oil-bags, discovered that both the hawsers were gone at the hawse-holes, but did not make this known to the crew at once for fear of making them uneasy. At noon, however, it brightened up to the westward, and at 4 p.m. it moderated; but the foresail could not be set, it was frozen so hard, but the storm try-sail was bent and set instead, and the boat came up more head to the sea. At 5 p.m. drifted on top of a pilot-boat's broken mast (No. 6), and this was a very discouraging sight; but it was shoved clear with a boat hook. At 6 p.m. wore around to the northward, but not before considering the risk that would be run of the boat foundering on account of the great weight of ice; but she got around, her deck being swept, however, upon broaching to, and one man was nearly washed overboard, but escaped with a bruised arm. At 7 p.m. commenced to start to clear the ice off the fore stay-sail. After three and a half hours' hard work the sail was set and the boat rendered safer.

March 14. Clear and moderate weather. After five hours' work the sails and spars were cleared of ice, and with all sail set and a moderate breeze stood to the westward. Steered NNW for 96 miles, and made Jersey Beach 20 miles to the southward of the Highlands, after drifting over 100 miles in forty-eight hours. . . ."

American ship Annie M. Smull

(voyage from Colombo, Ceylon to New York)

". . . March 12. 2 a.m.: Wind shifted to NNW., force 11 to 12; barometer 29.61, but at 4 a.m. fell to 29.36, then steadily rising until noon, when, in latitude 39° N., longitude 73° 40′ W., it reached 29.51; barometer record ended here. At 2 a.m., when wind shifted to NNW., braced around, clewed down upper main-topsail and hauled up foresail and mizzen-topsail and sent men to furl them, but gale increased to a hurricane and blew them to pieces, also blowing lower foretop-sail away, and main-topsail yard broke short off in the slings. We also lost both topsails. Terrific gale and blinding snow, ship lying on beam-ends with yard-arms in water and making water fast. Ship covered with snow, and ice making fast. At 10 a.m. shipped a sea which took two boats, one man, and everything about decks; saved the man; five men with hands and feet frost-bitten and three injured by washing about; all hands lashed to pumps and working them continually. All rooms and galley washed out; ship lying with hatch-coamings under water. Cargo shifted at 8 p.m.; wheel-shaft broke, and steering-gear completely smashed; secured rudder with tackle as well as possible. Foreyard sprung, main-yard gone at sheave-hole, and the remainder of sails cut from the yards to keep ship to wind. . . . Midnight: Gale still raging and frightful sea; oil-bags over, which work well for the NW sea, but have no effect on the NE and SE sea. Pumps still going, but don't gain any; 4 feet of water in the ship; snowing hard all the time. This is the worst gale I ever experienced; ship making bad work of it and straining badly. Eight men unfit for duty; bad outlook; covered with snow and ice. Hard Luck!

March 13. Midnight to 8 a.m.: No change, still snowing, and gale as bad as ever; ship straining badly, and can't gain any on the pumps, working them continually as well as we can with a disabled crew; sea very bad, making a clean breach over the ship; at daylight a little less wind, and sea more regular; still snowing. Noon: Moderating. At 3 p.m.: Set upper foretop-sail and jib; managed to get before the wind; lost the jib. I intend to run for warm water and thaw out; steering with tackles on tiller; pumps going constantly, no suck; ship has about 4 feet list to starboard and steers badly. Bent spare lower foretop-sail and set it. More moderate at midnight. . . . Heavy snow squalls. Large sea from N. My hands are swelled so I can hardly hold a pen. . . ."

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announcements[1]

NRC senior and postdoctoral research associateships

The National Research Council (NRC) announces the 1984 Postdoctoral, Resident, and Cooperative Research Associateship Programs for science and enigineering research to be conducted in 19 federal agencies or research institutions at laboratories throughout the United States. The programs provide Ph.D. scientists and engineers of unusual promise and ability with opportunities to perform research on problems largely of their own choosing, yet compatible with the research interests of the support laboratory. Initiated in 1954, the Associateship Programs have contributed to the career development of over 3800 scientists, ranging from recent Ph.D. recipients to distinguished senior scientists.

Approximately 250 new full-time associateships will be awarded on a competitive basis in 1984 for research in chemistry, engineering, and mathematics, and in the earth, environmental, physical, space, and life sciences. Most of the programs are open to both U.S. and non-U.S. nationals, and to both recent Ph.D. degree holders and senior investigators.

Awards are made for one or two years; senior applicants who have held doctorates at least five years may request shorter tenures. Stipends for the 1984 program year will range from $24 500 per year for recent Ph.D.s up to approximately $50 000 per year for senior associates. A stipend supplement up to $5000 may be available to regular (not senior) awardees holding recognized doctoral degrees in those disciplines where the number of degrees conferred by U.S. graduate schools is significantly below the current demand. In the 1983 program year, engineering, computer science, space-related biomedical science, and petroleum-related earth sciences were the areas covered by the supplementary stipend.

Allowances are made for relocation costs and for limited professional travel during tenure. The host laboratory provides the associate with programmatic assistance including facilities, support services, necessary equipment, and travel.

Applications to the NRC must be postmarked no later than 15 January 1984. Initial awards will be announced in March and April.

Information on specific research opportunities and federal laboratories, as well as application materials, may be obtained from Associateship Programs, Office of Scientific and Engineering Personnel, JH 608–D3, National Research Council, 2101 Constitution Avenue, NW, Washington, D.C. 20418 (tel.: 202–334–2760).

NSF announces awards for visiting professorships for women

The National Science Foundation (NSF) has announced 32 Visiting Professorships for Women, which will enable experienced women scientists and engineers to participate in the research and teaching programs of a host institution. The awards will be made to scientists in industry and government, as well as in the academic world. Eligible candidates must have the Ph.D. in an NSF-supported research field; independent research experience in the academic, industrial, or public sectors; be currently affiliated with a U.S. institution; and not have a salaried position with the host institution. The professorships will last from one semester to two years, with the average stay lasting one year. Applications must be received by 15 January 1984, and award winners will be announced in June 1984. For more information, contact Margrete S. Klein, Program Director, Visiting Professorships for Women, NSF, 1800 G St. NW, Washington, D.C. 20550 (tel.: 202–357–7734).

Air pollution modeling system available from EPA and NTIS

The Environmental Protection Agency (EPA) and the National Technical Information Service (NTIS) have announced the availability of a computer tape for air pollution modeling. A

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[1]Notice of registration deadlines for meetings, workshops, and seminars, deadlines for submittal of abstracts or papers to be presented at meetings, and deadlines for grants, proposals, awards, nominations, and fellowships must be received at least three months before deadline dates.—*News Ed.*