Unexpected Cyclogenesis in the Western North Atlantic Ocean, June 1981

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Abstract

An outbreak of unusually cold air into the western North Atlantic Ocean on 27 June 1981 led to surface cyclogenesis along its eastern edge, the development of a cut-off pool of cold air, westward retrogression of both the surface and thermal systems, and the development of an intense mesoscale vortex on the western flank of the cyclone, ultimately denoted Tropical Storm Bret. None of this was predicted adequately by operational numerical models. A study of the stituation indicates that the model physics are inadequate when dealing with this type of situation, and the sparsity of data makes the initial analysis unreliable as well. The experiences of two sailing yachts in passage from Bermuda to the United States during this period are recounted.

1. Introduction

The intense Atlantic storms of the cold season represent hazards for even the largest ships, as is documented monthly in the *Mariner's Weather Log*. A recent paper by Sanders and Gyakum (1980) presents a climatology of these storms and points to their low predictability by current operational numerical models. During the warm season, extratropical cyclogenesis, while sufficiently less severe that damage to large ships rarely occurs, can still produce discomfort or distress in small craft that often undertake offshore passages at this time. This paper is an account of one such cyclogenetic event, and was prompted by the author's presence as navigator aboard the 12 m cutter *Valiant Lady* during a passage departing from Bermuda on 27 June 1981, with intended landfall in New England. Actual arrival was in Norfolk, Va., on 2 July. Discomfort was experienced, but not distress. We will examine the evolution of the storm, as well as the limited fine mesh (LFM) predictions and forecast guidance for the period of passage.

2. 27 June

A compilation of winds taken from the ship observations received on Service C teletypewriter appears in Fig. 1a for the day of departure. A cold front lay just north of 35°N along the intended course, followed by northeasterly and then northwesterly winds of up to 29 kt. Cyclonic curvature of polar air flow near 38°N, 70°W is a regular winter feature of cold-air outbreaks over warm water, but is seen relatively rarely in summer. Its presence here attests to the unusual coldness of the air, as does the 552 dam thickness line along the New England coast. The thickness analysis is based on observed values and vertical wind shears at coastal stations and at Bermuda (33°N, 65°W) and Sable Island (43°N, 60°W). The weak frontal wave near 39°N, 63°W normally would be expected to propagate toward the northeast. The weak low near 39°N, 68°W showed little time continuity.

The satellite picture for 1230 GMT (Fig. 2) shows a typical northeast-southwest cloud band led by a frontal "rope" of bright, not particularly high, cloud from near 38°N, 63°W to about 32°N, 75°W. Towering cumulonimbi lay south of the cold front and east of 75°W, a longitude of cyclonic shear along the western edge of vigorous flow around an anticyclone in the central Atlantic.

The LFM initial analysis at this time (Fig. 1b) underestimated the depth of the frontal trough by as much as 4 mb. A similar error is seen in the 24 and 48 h forecasts for this same time (Fig. 1c and 1d). The central pressure was more accurately forecast than initialized, in fact, but the predictions underestimated the strength of the flanking ridges of high pressure so that the error in the predicted geostrophic circulation in the frontal trough was about the same.

The west-central North Atlantic forecast for 1539 GMT (1139 EDT), evidently relying on the LFM forecasts, as we shall see, asserted that the front "will move southeast and out of the area, [32 to 40°N, west of 65°W] tonight," while "high pressure will build eastward just north of the area tonight and Sunday [28 June]." Peak northwesterly to northeasterly winds of 15–20 kt (7.7–10.3 $m \cdot s^{-1}$) were predicted. Some

[1] Authors should submit manuscripts for this section directly to Dr. Robert W. Burpee, Editor, Focus on Forecasting, Hurricane Research Division, Atlantic Oceanographic and Meteorological Laboratory, NOAA, 4301 Rickenbacker Causeway, Miami, Fla. 33149. Four copies of each manuscript (text and illustrations) are required. Manuscripts should be prepared in accordance with "Information for Contributors" on the inside covers of a recent issue of an AMS research journal or with the *Authors' Guide to the Journals of the American Meteorological Society* (1983).

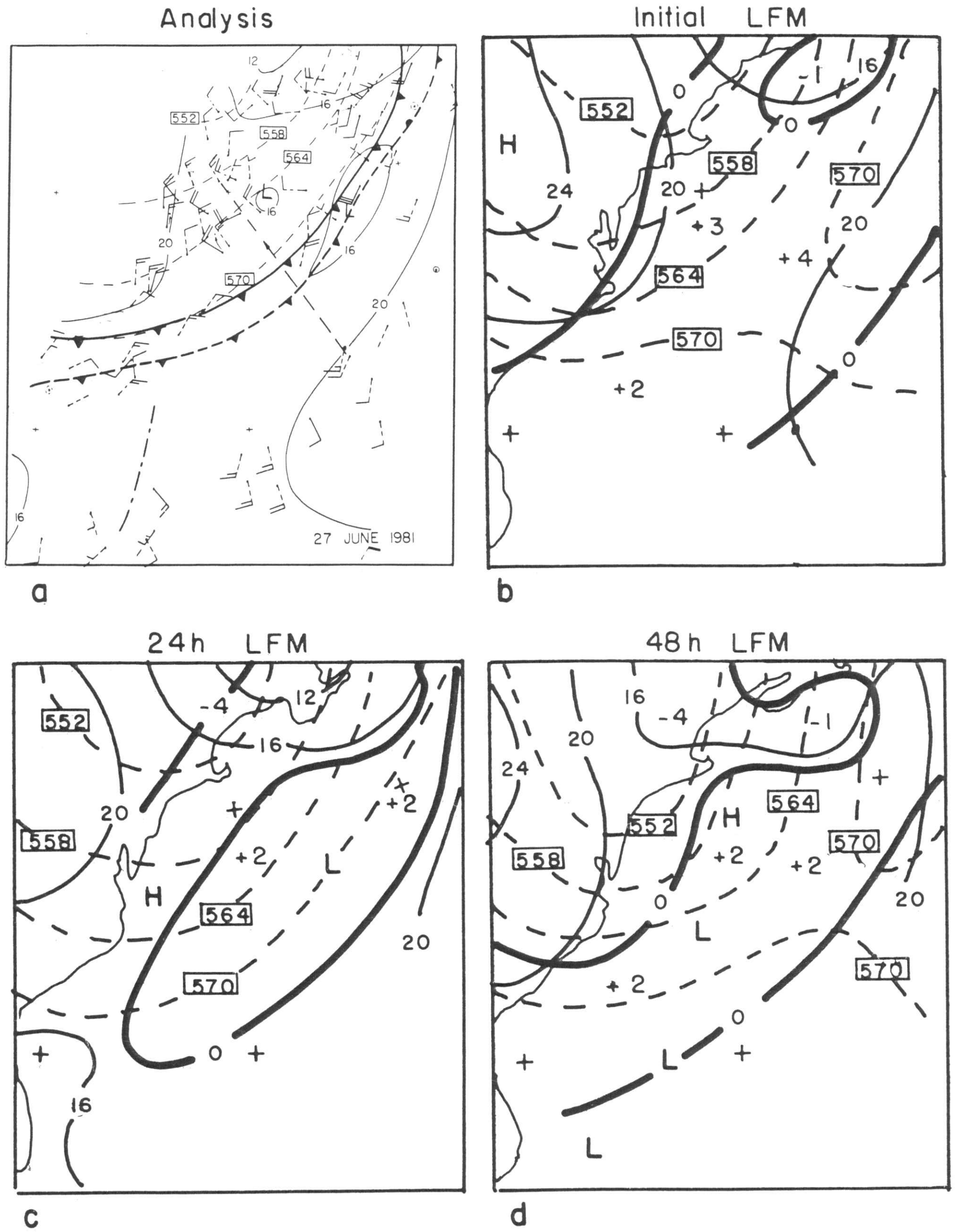

FIG. 1. Sea-level pressure maps for 1200 GMT 27 June 1981: a) manual analysis, b) LFM initial analysis, c) LFM 24 h forecast, and d) LFM 48 h forecast, all verifying at this time. Thin solid lines are sea-level isobars at intervals of 4 mb, labeled as excess over 1000 mb. Light dashed lines represent thickness of the layer from 1000 mb to 500 mb, labeled in dam. Ship wind data for the entire day are plotted in Fig. 1a in the conventional manner, solid shafts denoting observations at 0000 GMT and 0600 GMT, and dashed shafts denoting observations at 1200 GMT and 1800 GMT. The closely spaced series of observations (4 h intervals beginning at 0000 GMT) is for *Valiant Lady*. Heavy dashed line is the intended course. Heavy solid lines and numbers denote errors, in mb, of the LFM charts. Ten-degree latitude-longitude intersections are denoted by crosses.

trepidation evidently was responsible for mentioning 5 kt (2.6 m $\cdot$ s^{-1}) and 2 ft (0.6 m) increases in wind speed and wave height, respectively, over some portions of the postfrontal region.

3. 28 June

Valiant Lady encountered the front of 1000 GMT on the 28th, altering course to the westward in a northwesterly squall of 25 kt (12.9 m $\cdot$ s^{-1}) that soon eased and veered to the north-northeast. We anticipated only a brief deflection from our intended course. Had we seen the map for the next day (Fig. 3a) we would have reconsidered our intent to carry on, for a broad region of vigorous northerly flow lay between us and the mainland, as the front had advanced briskly southward west of 65°W. The wave had not propagated northeastward along the thickness lines, appearing rather to have intensified

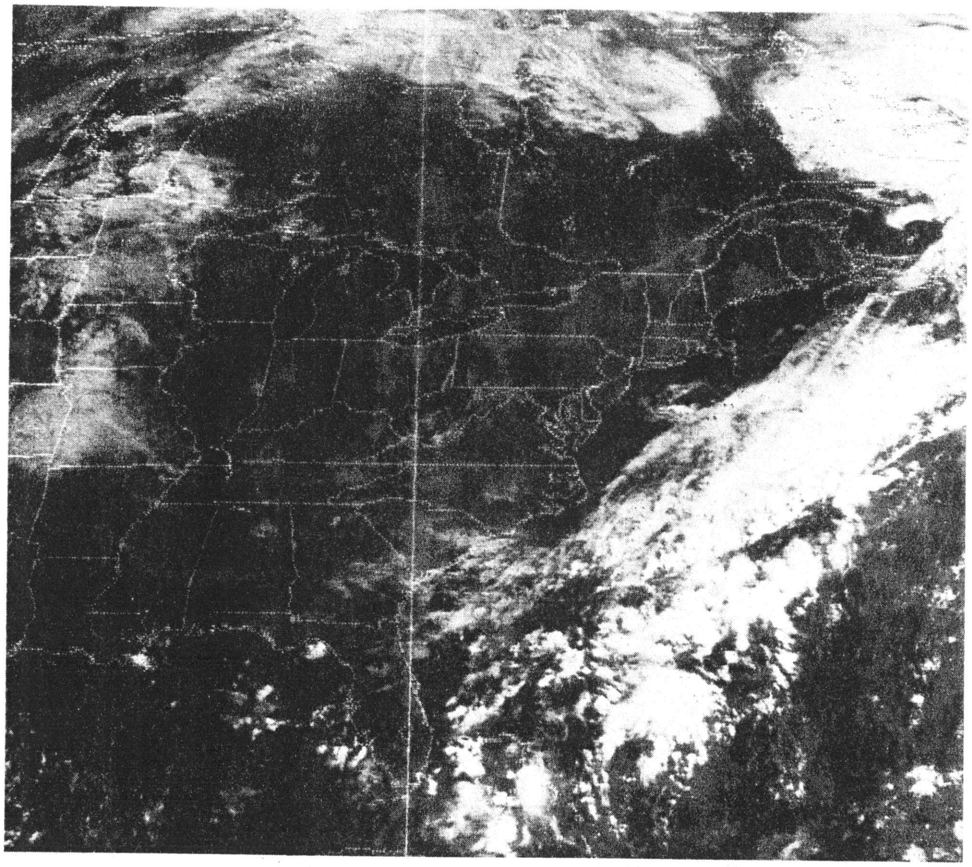

FIG. 2. GOES-E visible imagery for 1230 GMT 27 June.

greatly and moved southwestward very slightly. There was no indication that the initial wave had progressed northeastward and that the wave in Fig. 3a was a discrete new development. Continuous regeneration of new cyclonic circulation to the southwest, of course, would be indistinguishable from retrogression. Winds near gale force were observed northwest of the wave, while speeds between 20 and 30 kt (10.3 and 15.5 $m \cdot s^{-1}$) were observed north of the Bahamas and in the region of cyclonic circulation within the cold air, now near 35°N, 70°W. The satellite view in Fig. 4 shows an extensive deep layer of cloud over the wave, but weaker clouds over the western portion of the cold front and weakening convection to the south of the front. Low cloud lines were seen in the cold-air cyclonic circulation. As shown by the thickness pattern, a cold pool had formed off the mid-Atlantic states, due to cold advection to the south and subsidence warming to the north, over New England.

The forecasts for this time (Fig. 3b–d) simply missed the development of both the wave and the cold pool, although weak ascent and a little precipitation was predicted east of the cold trough. Qualitatively, the cyclonic thermal vorticity advection east of the cold trough is known to favor low-level cyclonic development, but the model response was minimal.

The west-central North Atlantic forecast at 2139 GMT (1739 EDT) still assured us that "high pressure in Pennsylvania . . . . will move slowly east and cover the area through Monday [29 June] night." The strong winds east of 70°W were forecast to diminish to 10–15 kt (5.2–7.7 $m \cdot s^{-1}$) after 24 h, while 10–20 kt (5.2–10.3 $m \cdot s^{-1}$) were forecast to continue to the west of this longitude.

4. 29 June

The situation on 29 June is depicted in Fig. 5a. The frontal wave had retrograded to the southwest and gained amplitude, the warm front advancing northwestward while the cold front moved eastward beyond Bermuda and southward through the Bahamas. Northerly to northeasterly winds of 25–30 kt (12.9–15.5 $m \cdot s^{-1}$) were common from just south of Nova Scotia through the Bahamas. The region of cyclonic circulation in the colder air had moved to near 31°N, 68°W, following the postfrontal region of cold advection. The cold pool, now quite pronounced, had moved slowly south-southeastward as thicknesses rose over a broad region to the north, owing to subsidence in the west and warm advection in the east.

The satellite view (Fig. 6) for 1230 GMT had changed substantially from that of the preceding day, as the frontal band was now broken. A mass of warm-front cloudiness had moved westward in the region of warm advection associated

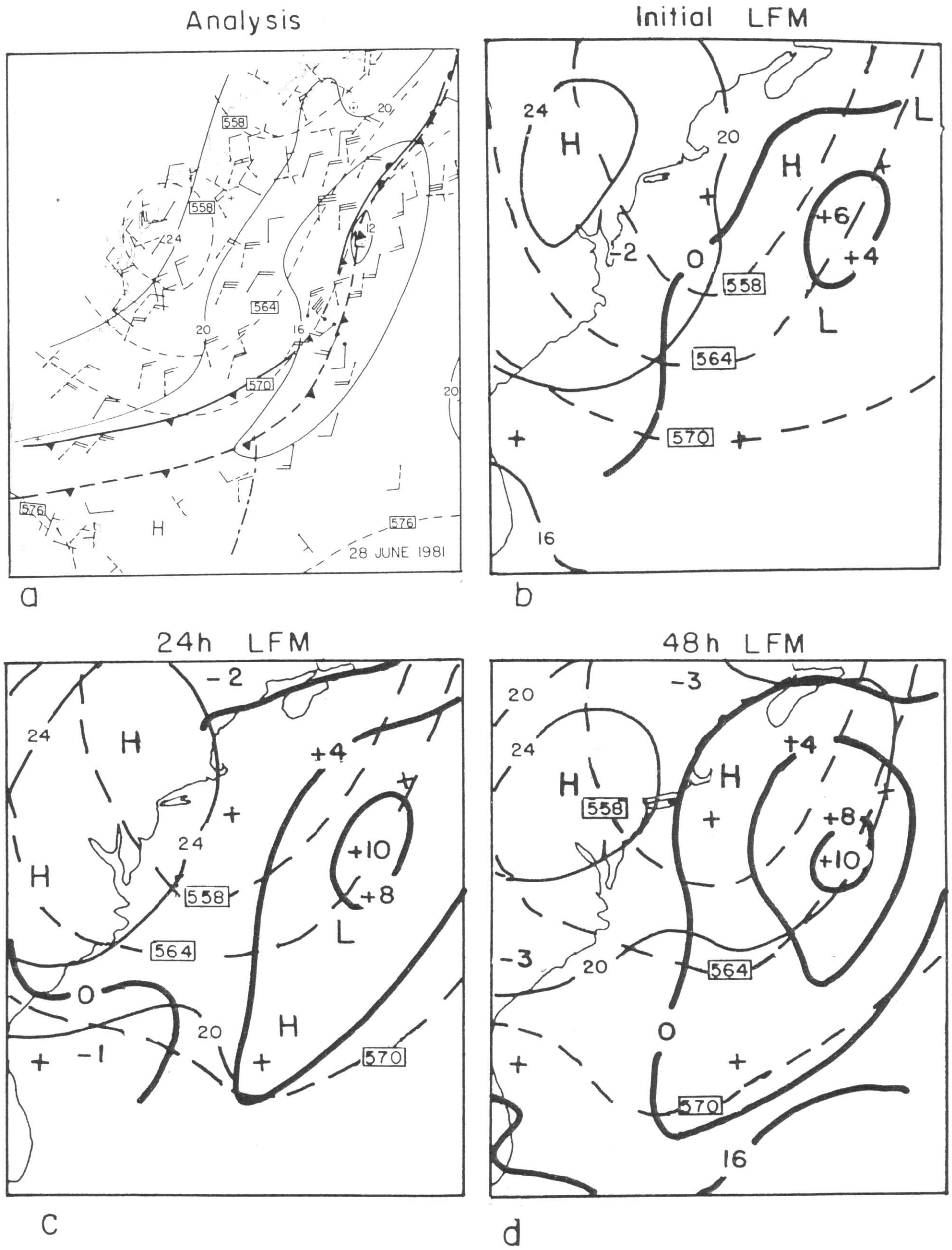

FIG. 3. Same as Fig. 1, except for 1200 GMT 28 June. Fig. 3b is a 12 h forecast generated from data at 0000 GMT, as the 1200 GMT initialization and forecast were not available.

with the retrograding pressure system. Deep convective cloudiness developed just northeast of the cold pool, later to merge with the approaching warm-front cloud mass. The cold-front cloud band remained strong in the south, but there was little cloud near the synoptic-scale pressure minimum. The vortex indicated by weak lines of low clouds near 37°N, 63°W could be seen in the imagery (mainly visible), moving northwestward at about 15 kt (7.7 $m \cdot s^{-1}$) between 1100 GMT and 1730 GMT. Southerly winds at this location and to the west in Fig. 5a show that this vortex was well removed from the synoptic-scale circulation center.

It was an uncomfortable day of westward progress for *Valiant Lady* as north-northeasterly winds gradually increased to over 25 kt (12.9 $m \cdot s^{-1}$). Substantial pounding of the hull occurred with any attempt to take up a more northward heading. A particularly intense squall occurred between 1730 GMT and 1900 GMT, the wind first strengthening and backing in heavy rain, then veering and weakening as we passed through one of the elements of the convective region, probably near the center of the cold pool. Undilute ascent of surface air with a temperature of 22°C and a dewpoint of 16°C, suggested by the nearest available ship observations, yields a

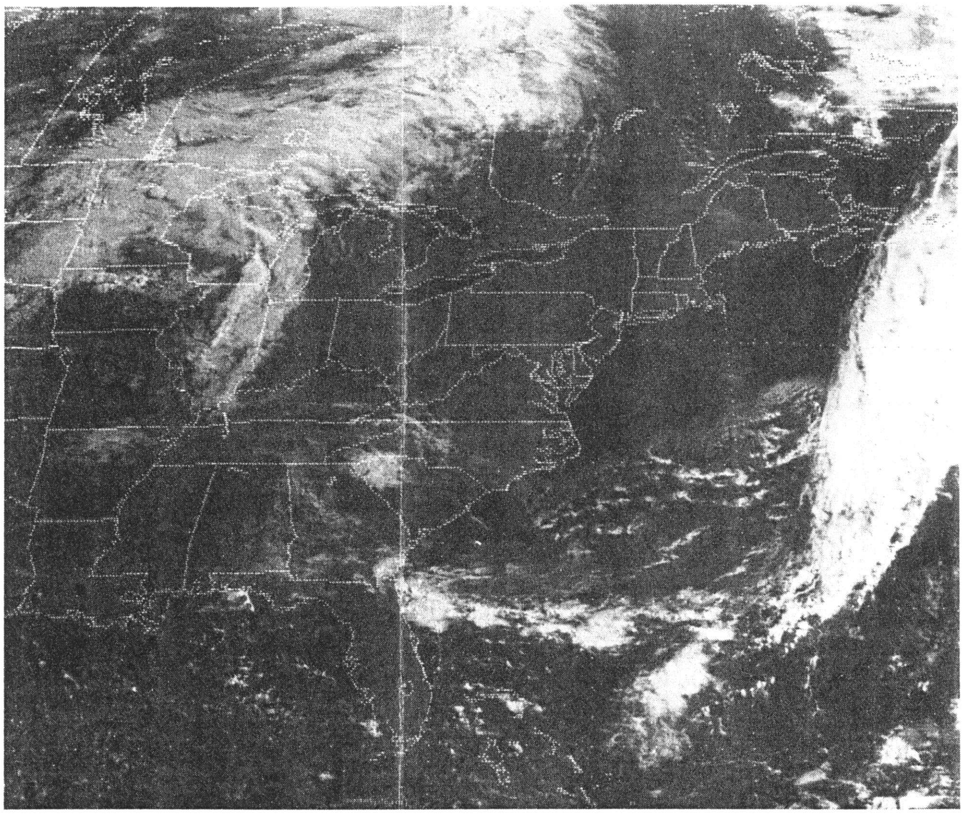

FIG. 4. Same as Fig. 2, except for 1230 GMT 28 June.

500 mb temperature of −12°C, whereas an ambient linear temperature profile with a thickness of 559 dam between 1000 mb and 500 mb indicates an environmental temperature of −16°C at the latter level. The 4°C excess in the hypothetical undilute cloud supports the inference that intense deep convection was occurring just northeast of the center of the cold pool.

The LFM initial analysis for 1200 GMT (Fig. 5b) finally showed a pressure minimum of the correct depth, but the position was grossly in error. It is difficult to see from the ship data in Fig. 5a why this error occurred. The forecasts in Figs. 5c and 5d, however, were oblivious of the development, as before.

The west-central North Atlantic forecast, issued at 6 h intervals, contained a gale warning for the first time at 1539 GMT (1139 EDT). "Gale center 1008 mb near 37°N, 63°W will remain nearly stationary through Tuesday [30 June]." West of 70°W, northeast winds were to diminish "to 10 to 15 kt (7.7 $m \cdot s^{-1}$) tonight becoming southwest 10 to 15 kt (5.2–7.7 $m \cdot s^{-1}$) near the coast on Tuesday," as the high in the eastern United States moved slowly eastward. Apparently, too few ship observations had been received to make the westward retrogression evident in the absence of adequate numerical guidance.

5. 30 June

In any event, substantial retrogression (about 15 kt (7.7 $m \cdot s^{-1}$)) had occurred by the next day, as seen in Fig. 7a. Most important, however, was the development of a very small but intense vortex at the center of the cyclone. The earliest hint of this vortex was a report from the yacht *Invictus* of 60 kt northeasterly winds at 0300 GMT, not received, unfortunately, until several days later. According to the captain,[2] the yacht subsequently experienced a brief lull, with pressure about 1000 mb and stars abundantly visible, then renewed easterly winds at less extreme speeds. Hence, the storm appeared fully developed at this time. A vortex in the infrared satellite imagery could be identified continuously after 0400 GMT, and hindsight enabled detection of some sporadic attempts at vortex development in both infrared and visible imagery as far back as 1530 GMT on the 29th. Development occurred on the eastern edge of the warm-front cloud mass, discussed earlier, at least 50 n.mi. west of the synoptic-scale pressure minimum. There was no ambiguity, however, in the first visible imagery on the 30th (Fig. 8). The presence of a small eye

[2] F. Schweitzer, personal communication.

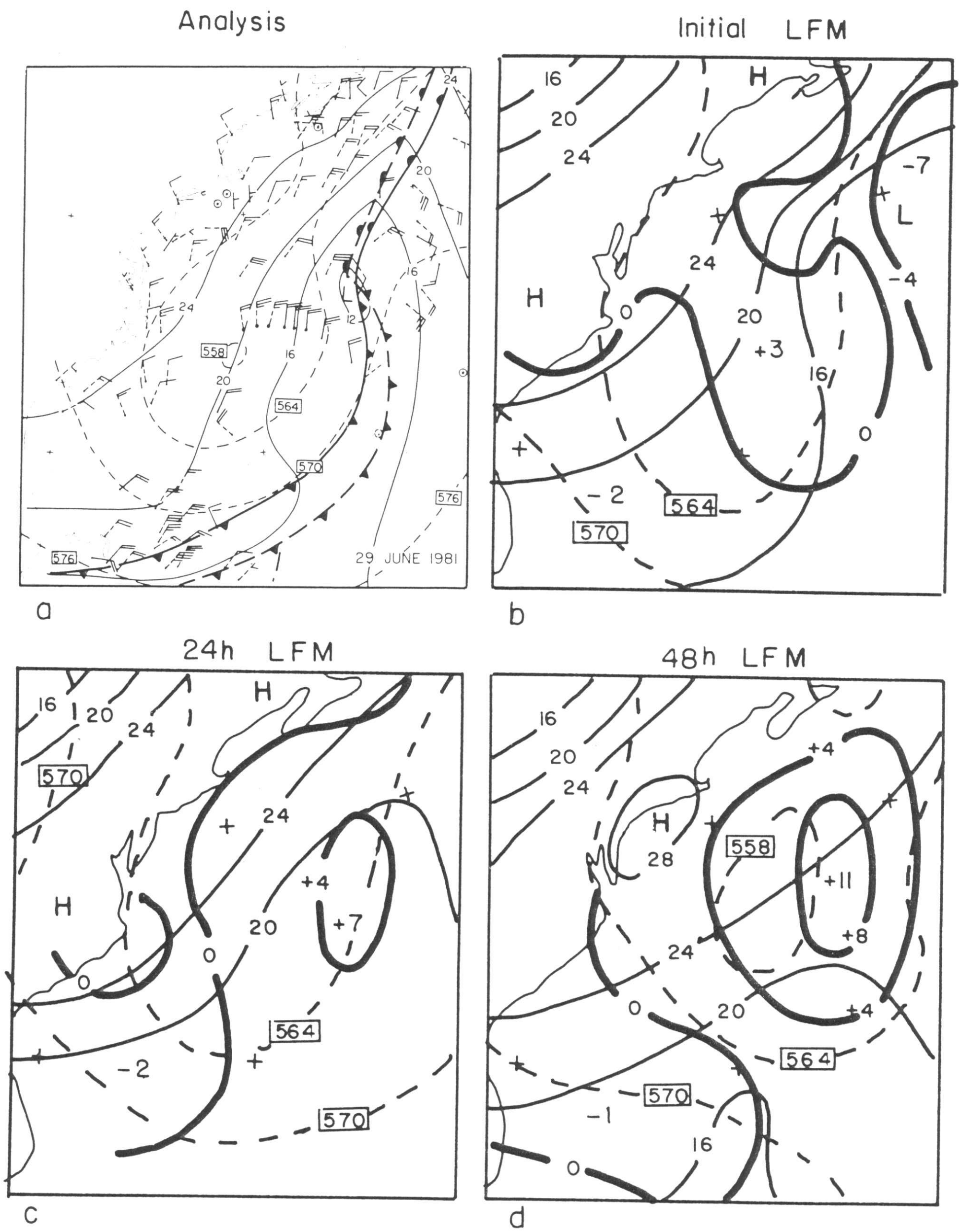

FIG. 5. Same as Fig. 1, except for 1200 GMT 29 June. Fig. 5c is a 12 h forecast generated from data at 0000 GMT, for reasons explained earlier.

enclosed by a tightly wrapped cloud band prompted the dispatch of a reconnaissance flight, which found a central pressure of 997 mb and maximum surface winds of 65 kt (33.5 $m \cdot s^{-1}$) at 2100 GMT. Shortly afterward, the vortex was denoted Tropical Storm Bret.

Aside from this development, Figs. 7a and 8 show dissipation of the frontal structure, except in the far southeastern periphery of the circulation. Large pressure rises occurred in the entire eastern third of the map as an anticyclone developed and moved westward from the central Atlantic. The cold pool warmed and moved slowly toward the west-southwest (nearly counter to the low-level flow), but continued to be accompanied by extensive deep convection.

On encountering near gale conditions and backing winds at about 0000 GMT on the 30th, *Valiant Lady* altered course toward the southwest in the interest of crew comfort and to escape from possibly hazardous conditions. This strategy paid off, as the wind diminished substantially (Fig. 7a) and eventually shifted to southwest in response to the westward passage of the storm. The windshift was quite abrupt, as sup-

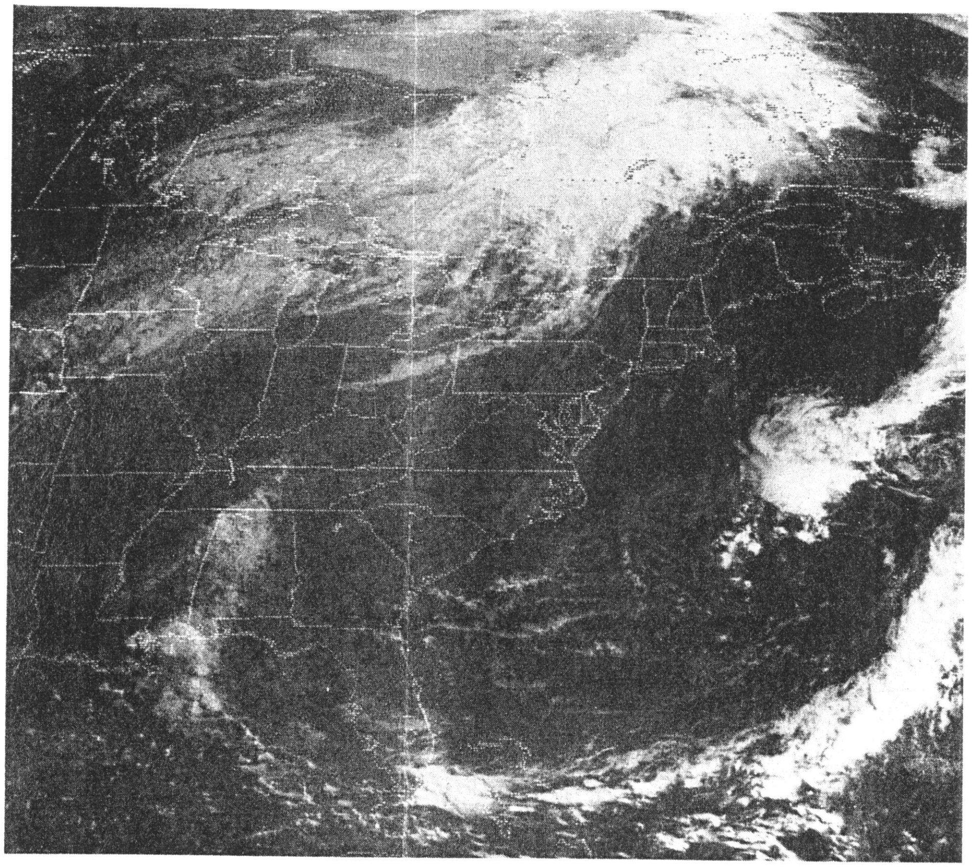

FIG. 6. Same as Fig. 2, except for 1230 GMT 29 June.

ported by observations near 32°N, 75°W in Fig. 7a, indicating a long sharp trough connecting the storm center and the cold pool in the thickness pattern.

The LFM initial analysis (Fig. 7b) for 1200 GMT was reasonably accurate, except for the understandable absence of the small intense vortex. The forecasts for this time, however, still failed to appreciate the gravity of even the synoptic-scale situation (Figs. 7c and 7d). Similar error patterns are seen, with no cyclonic circulation of consequence. Even when a definite center of low pressure was present in the initial data for 1200 GMT of the 29th (Fig. 5b), the 24 h forecast (Fig. 7c) insisted on filling it by 9 mb and perhaps splitting it in two. A further persistent error was a substantial underestimate of pressures over the northeastern third of the map area.

The west-central North Atlantic forecast for 1539 GMT (1139 EDT) placed the gale center at 36°N, 72°W and was the first to speak of definite westward motion rather than a slow drift at unspecified speed. Winds were stated to be 20–35 kt (10.3–18.0 $m \cdot s^{-1}$), accurate except for a very small, as yet undetected, region around the center. There was no mention of the weakening of winds, which had characterized most earlier forecasts. The forecasters had clearly bitten the bullet.

6. 1 July

Conditions ameliorated substantially on 1 July (Fig. 9a) as Bret weakened and moved inland over southern Chesapeake Bay. The cruiser USS *Spruance* experienced 45 kt (23.2 $m \cdot s^{-1}$) north-northeast winds with the passage of the dying center at about 0000 GMT, while peak northwesterly winds of 33 kt (17.0 $m \cdot s^{-1}$) were observed at the Chesapeake Light Station (near 36.8°N, 75.9°W) three hours later. Pressure continued to rise over the northeastern portion of the map area, producing an extensive region of anomalous southeasterly flow from Bermuda to the mid-Atlantic states and the Canadian Maritimes.

The western edge of this southeasterly current was quite marked near the track of *Valiant Lady*, now heading northwestward. The post-Bret southwesterly breeze gave way to a light south-southeasterly at about 0900 GMT. Three hours later, near 35.2°N, 74.1°W, we observed a thin ropelike waterspout just east of our position, extending from the base of a cumulus congestus cloud in an innocuous line that is visible in the satellite imagery (Fig. 10) oriented north-northwest to south-southeast. No precipitation was observed at the time

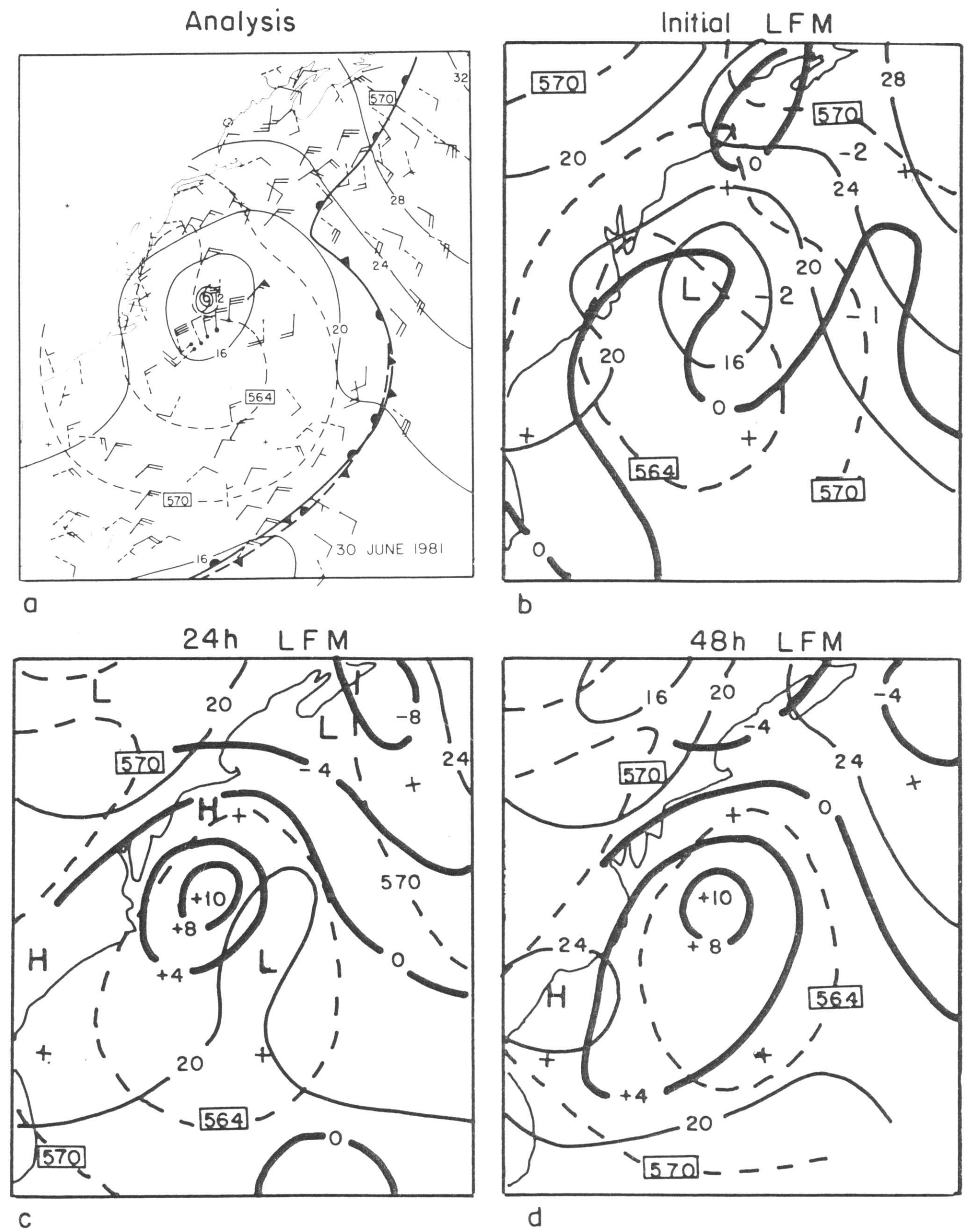

FIG. 7. Same as Fig. 1, except for 1200 GMT 30 June. Fig. 5d is a 36 h forecast generated from data at 0000 GMT 29 June, for reasons explained earlier. The observation near 36°N, 70°W is from the yacht *Invictus* at 0300 GMT.

of the spout, which persisted for about 10 min, but a number of rain shafts developed thereafter as the line developed cumulonimbus and overtook us on its way westward to the coast.

Elsewhere in Figs. 9a and 10 the frontal structure had dissipated, although substantial deep cloudiness persisted in and around the eastern and southern peripheries of the slowly weakening and retrograding cold pool. The patch of bright cloudiness in Virginia is the remnant of Bret.

With the inland dissipation of the tropical storm, the LFM analysis in Fig. 9b could not be faulted. Both the 24 and 48 h forecasts, however (Figs. 9c and 9d), failed to indicate sufficient easterly flow over the entire map area and predicted

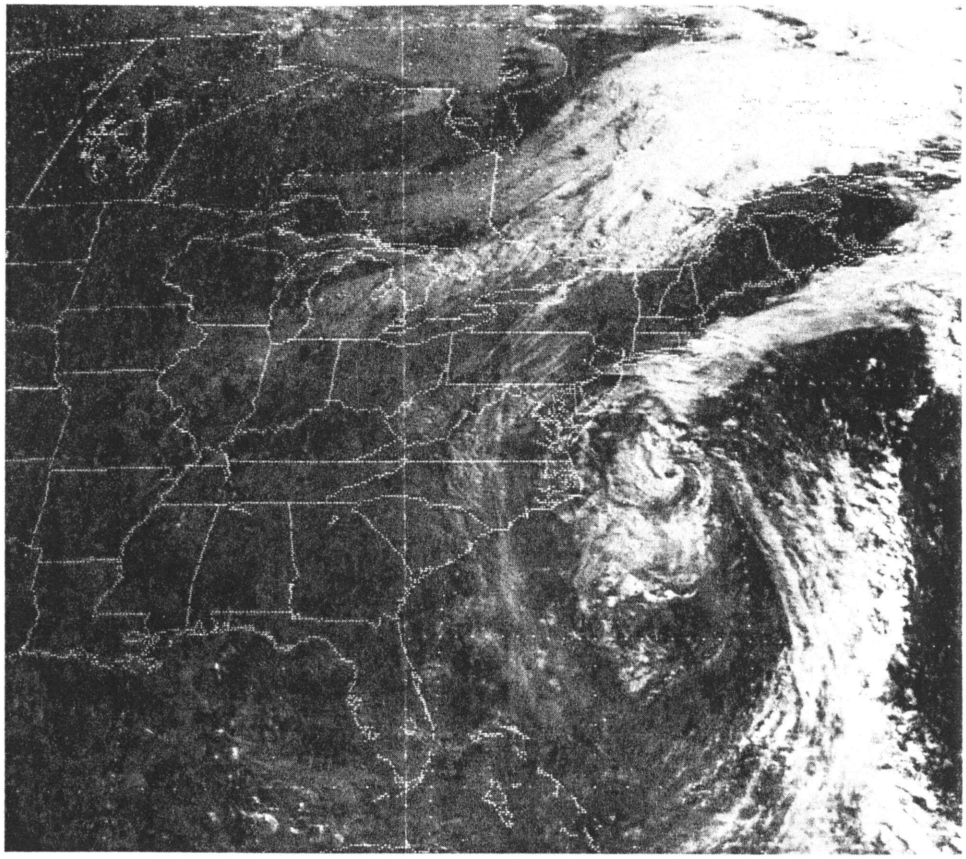

FIG. 8. Same as Fig. 2, except for 1230 GMT 30 June.

pressures that were much too low in the north and somewhat too high in the south. This large-scale error also was evident in the forecasts for 30 June and was responsible for the forecasters' failure to move the upper-level center and the associated cold pool sufficiently far to the west, as seen in Figs. 7c, 7d, 9c, and 9d.

7. Concluding discussion

The series of forecasts for the period 27 June–1 July 1981 failed on three scales: meso, synoptic, and planetary.

The diameter of the intense inner core of high wind was not more than 100 km, to judge from information received from the National Hurricane Center.[3] This mesoscale substructure within the larger cyclone could be neither analyzed nor predicted, given the relatively coarse mesh length of the LFM model.

The parent cyclonic circulation, to judge from the pressure maps, displayed a zonal scale size of perhaps 2000 km, while the meridional scale was larger. Repeated failure of the model to predict the development of this synoptic-scale cyclone, and to handle it properly once formed, cannot be attributed to an excessively large mesh length, nor to the vagaries of the data at some particular initial time. Qualitatively, the cyclogenesis occurred east of a pronounced thermal trough, where Sutcliffe's (1947) "thermal development" effect, expressed in terms of the advection by the thermal wind of its own vorticity, would suggest low-level convergence and vorticity generation. A close examination of the analyses (Figs. 3a and 5a), however, shows that the thermal vorticity advection was slight over the low-pressure center and at a maximum well to the west or southwest of it. (This circumstance may have aided retrogression by promoting continuous regeneration of cyclonic vorticity west of the center.)

Quantitatively, the observed synoptic-scale deepening is hard to explain. In terms of Gyakum's (1980) modification of Sanders's (1971) diagnostic model, the basic large-scale horizontal temperature gradient and perturbation, estimated from the thickness patterns in Figs. 3a and 5a, were about $0.4°C\ (100\ km)^{-1}$ and 2°C, respectively. With no surface friction, neutral stability, and placement of the cyclone over the strongest thermal vorticity advection, the computed deepening rate would be $14\ mb \cdot day^{-1}$. With more plausible stability and observed placement of the surface cyclone near the thermal ridge, the inviscid rate would be about $3\ mb \cdot day^{-1}$. This development, like the more explosive cases during the winter season, appears to represent a very large response to minimal baroclinic forcing.

[3] R. Sheets, National Hurricane Center, personal communication.

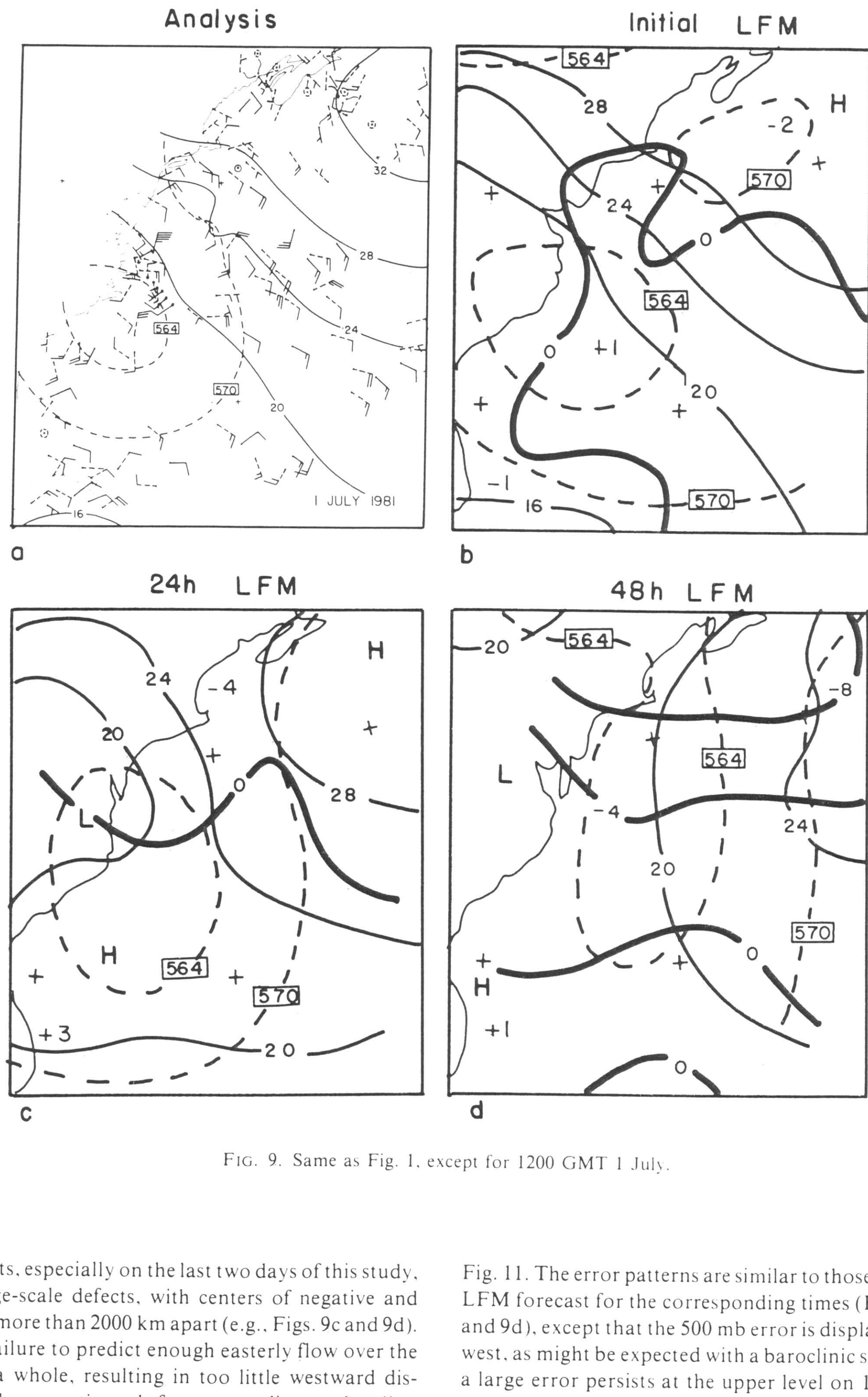

FIG. 9. Same as Fig. 1, except for 1200 GMT 1 July.

The forecasts, especially on the last two days of this study, displayed large-scale defects, with centers of negative and positive error more than 2000 km apart (e.g., Figs. 9c and 9d). There was a failure to predict enough easterly flow over the map area as a whole, resulting in too little westward displacement of the synoptic-scale features, as discussed earlier.

Since this error might be attributable to the Global Spectral Model forecast, which provides boundary conditions for the limited-area model heretofore examined, and since the performance of this model is interesting in itself, the 48 h forecasts for 1200 GMT 28 June through 1 July were consulted. These, with their associated error patterns, appear in Fig. 11. The error patterns are similar to those seen in the 48 h LFM forecast for the corresponding times (Figs. 3d, 5d, 7d, and 9d), except that the 500 mb error is displaced toward the west, as might be expected with a baroclinic system. Further, a large error persists at the upper level on 1 July, after the tropical storm has moved inland and dissipated at the surface, thus eliminating the large error there.

Thus, the failure at synoptic and larger scales was common to both operational models at the National Meteorological center, and likely is attributable to incompleteness of the model physics, as well as to inadequacy of initial data.

In cursory examinations of the forecasts (not shown) pro-

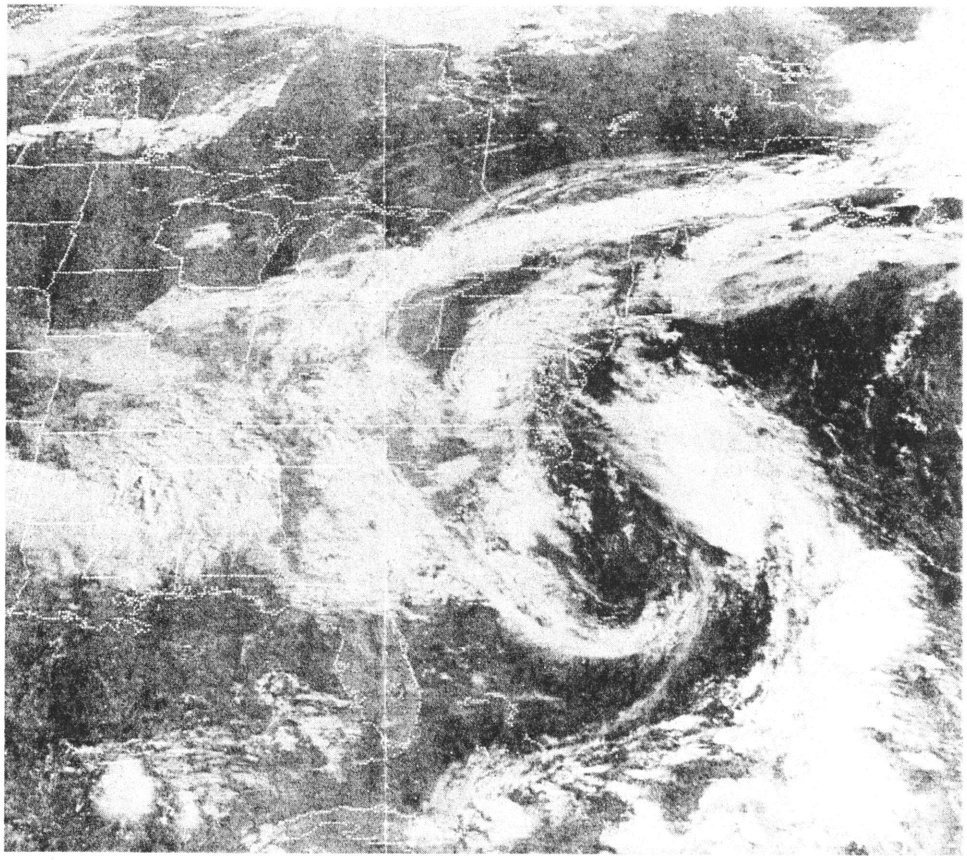

FIG. 10. Same as Fig. 2 except for 1230 GMT 1 July. The observations near 37°N, 74°W are from the USS *Spruance* at 2300 GMT 30 June and one hour later.

duced by the Primitive Equation Model of the U.S. Navy Fleet Numerical Oceanography Center (FNOC), it appeared that the 500 mb patterns were similar to those produced by the Global Spectral Model, aside from insufficient eastward displacement of the trough in the former early in the period under study. This similarity notwithstanding, the FNOC model, initialized on 27 and 28 June, developed substantial cyclonic circulation at the surface, unlike LFM. The FNOC forecast on the 29th, on the other hand, weakened an initially strong circulation even in the first 24 h, as did LFM. The differences between certain FNOC and LFM surface forecasts, despite similar 500 mb forecasts, suggests that differences in model physics may have an important effect on predicted oceanic cyclogenesis. A vigorous program of research and development is needed to elucidate these effects and to achieve the goal of adequate prediction of oceanic storms.

Some questions and comments are prompted by this study. First, should Bret be regarded as a tropical storm? Baroclinic processes appear to have been important, although the quantitatively adequate explanation eludes us. It did not form in a region of minimal wind shear, suggested by Gray (1968) as a necessary ingredient for genuinely tropical storms. Figs. 5a and 7a show that the small intense vortex that prompted the naming developed in a large-scale vertical wind shear of 35 kt (18 $m \cdot s^{-1}$) in the layer from 1000 mb to 500 mb, closer to the largest than to the smallest value available in the area. The storm was similar to the more severe and more conventionally oriented case at 40–45°N studied by Gyakum (1980), and doubtless to countless of others at higher latitudes during the colder half of the year, wherein a small, intense, warm-core vortex forms within a region of substantial large-scale horizontal temperature gradient. Where should we draw the line?

Second, should we rush toward automation of synoptic-scale forecasting over the oceans, as we seem to be doing over land? Until there is a substantial improvement in the ability of operational numerical models to deal with oceanic storm development, it seems well to rely on intensive analysis of the observations by skilled and experienced forecasters.

Finally, if automation were taken to its logical extreme, if all those wind barbs on all those ship observations were withheld from view and all we saw were the LFM initializations and forecasts such as those seen in Figs. 1, 3, 5, 7, and 9, then the analyses would be as oblivious of what actually occurred out there as the forecasts, and the contrary accounts of mariners would be relegated to the realm of mythology.

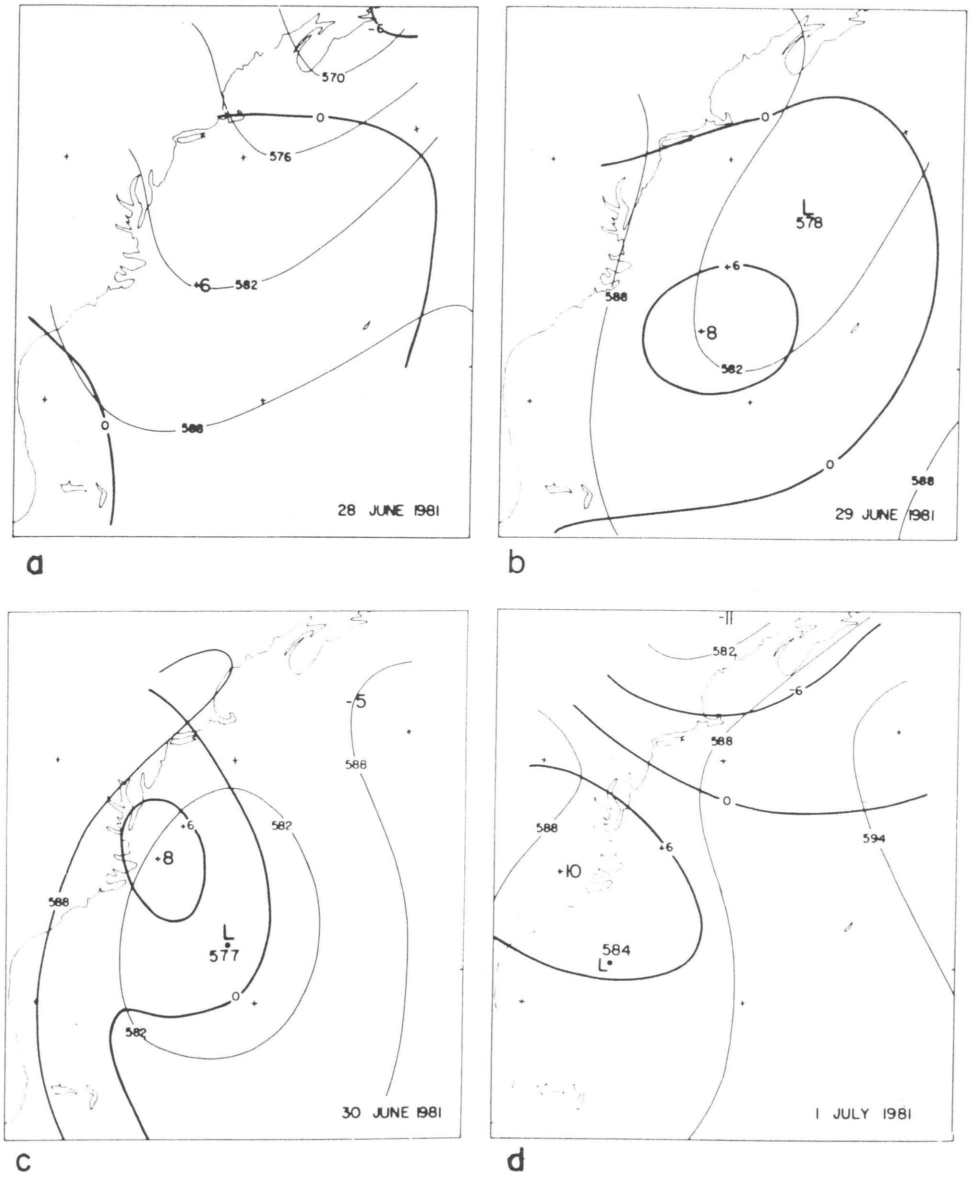

FIG. 11. Forty-eight hour Global Spectral Model forecasts for the 500 mb level at 1200 GMT on a) 28 June, b) 29 June, c) 30 June, and d) 1 July. Thin solid lines are predicted height contours and heavy lines and numbers represent errors. Numerical values are in dam.

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