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Meteorological and Oceanographic Conditions During the 1970 Bermuda Yacht Race

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ABSTRACT—Analysis of conventional data and of information provided by a number of the competing skippers yields an unusually detailed picture of environmental conditions during the Newport, R.I.–Bermuda Yacht Race in June 1970. Sea-surface temperature data indicate the presence of a warm meander of the Gulf Stream just west of the rhumb-line course, a position intermediate between that of a warm meander to the west in May disclosed by bathythermograph observations from the RMS *Franconia* and that of a warm eddy to the east in August found by a Naval Oceanographic Office survey.

The fleet was harassed by two groups of severe thundersqualls during the night of June 21–22, in the vicinity of the warm meander. Even the anomalously high sea-surface temperatures, however, were cool relative to the air in which the thunderstorms were rooted. The storms originated in the Chesapeake Bay area during the day on June 21, and they appeared, surprisingly, to gain intensity over the ocean after being cut off from their surface source of warmth and moisture. Offshore forecasts for June 21–22 took no specific account of the presence of the severe thunderstorm systems.

On June 25, part of the fleet experienced an unexpected southerly gale just northwest of Bermuda. From the yacht data, it is found that the gale was attributable to a small cyclone that formed in an old frontal cloud band and moved northeastward, remaining undetected by the conventional data network throughout its life history. Analysis of the surface wind field suggests that baroclinic effects played only a minor role in the behavior of this cyclone, which at least in some respects resembled a tropical cyclone. Study of the forecasts available at the time indicate that in neither case did small-scale convective activity have a significant direct effect upon the larger scales of motion.

1. INTRODUCTION

This account of the meteorological and oceanographic circumstances of the 1970 Newport, R.I.–Bermuda Yacht Race is given because the presence of a large number of weather-sensitive platforms in a relatively limited area offered a rare opportunity for oceanic mesoanalysis and because the meteorological events seemed to this neophyte participant to be remarkable, although I am assured by older hands that the weather was "about average." Nonetheless, a number of boats, including the author's, were disabled.

The analyses to be presented are based both on conventional data of various types and upon the replies of fellow skippers to my request for data. These replies were of varying degrees of precision and quantitativeness, but the analyses do not knowingly violate anything recounted.

It is often said that yachtsmen exaggerate. Should this be true in the present instance, the propensity for exaggeration, being subjective, should vary strongly from individual to individual. The consistency of the patterns that emerge from the yachtsmen's accounts might then be regarded as a measure of the credibility we should attach to them. We note, a priori, that only generally experienced crews are accepted as entries in this race; panic is not likely to have distorted the information provided. Navigation error is very difficult to estimate, as it depends on assiduousness of dead reckoning and availability of celestial objects for lines of position (use of Loran in the race is forbidden). We estimate that the root-mean-square position error of the yachts is between 5 and 10 n.mi.

The course of the 1970 Bermuda Yacht Race is shown in figure 1. The start was early in the afternoon of June 20. At any particular time, the fleet covered an area elongated in the direction of the rhumb line, principally because the larger boats travel faster, and extended laterally because of differing track choices of individual skippers in contending with head winds and with the need to compensate for the eastward set due to the Gulf Stream. The presence and location of meanders and eddies in the Gulf Stream are key competitive factors, of course, so most of the yachts measure sea-surface temperature at least occasionally during transit of the presumed zone of intersection of the Gulf Stream and the track.

Oceanographically, there was not much agreement between individuals about the details of the currents encountered although the majority reported help rather than hindrance by the component of current along the track. There was good agreement, however, as to the maximum sea-surface temperature observed in the Gulf Stream; no yacht found this value less than 78°F nor more than 80°F.

Meteorologically, two vigorous bands of intense thunderstorms moved across the fleet early in the evening of June 21 and again around sunrise June 22. These storms were widely regarded by the skippers as typical "Gulf

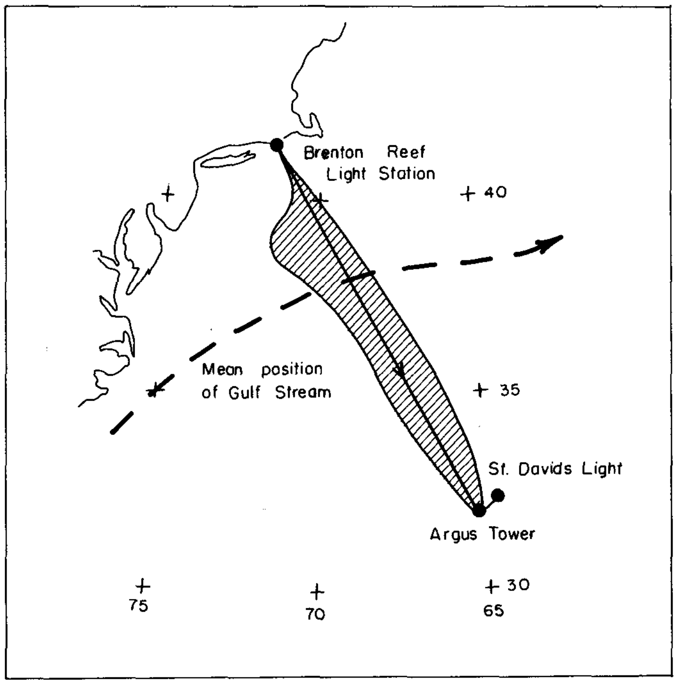

FIGURE 1.—Course of the 1970 Newport, R.I.–Bermuda Yacht Race. The start is at the Brenton Reef Light Station near Newport, and the finish is off St. David's Light, Bermuda. The Argus Tower on Plantagenet Bank southwest of Bermuda is a mark of the course and must be left to port. The hatched area represents approximately an envelope of the tracks of individual yachts.

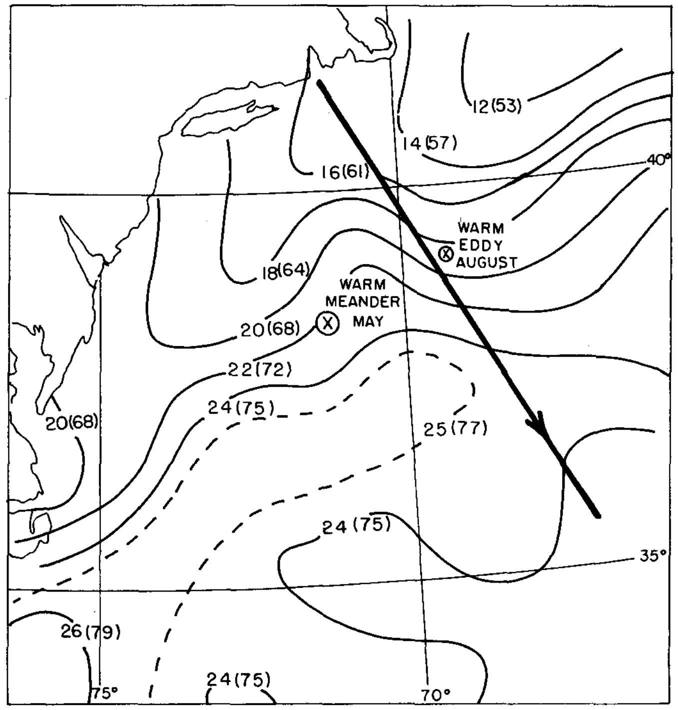

FIGURE 2.—Mean sea-surface isotherms for June 1970 at intervals of 2°C (U.S. Naval Oceanographic Office 1970) with values in °F in parentheses. The heavy solid line is the rhumb line from Brenton Reef to the Argus Tower. Circled Xs represent approximate positions of the warm meander observed in May and of the warm eddy discovered in August.

Stream weather," although we shall show that they were north of the Gulf Stream proper and that the warmth of the water played a minor role at best. Finally, on the afternoon of June 25, when all but the smallest boats had completed the race and were in harbors in Bermuda, an unexpected southerly gale harassed the remaining competitors and crippled some of them.

We will first examine the oceanographic situation in as much detail as possible and will then discuss the salient meteorological events.

2. THE GULF STREAM

The mean sea-surface temperature pattern for June 1970 is shown in figure 2. Note particularly the northward bulge of the isotherms between 70° and 71°W, north of the Gulf Stream, representing an excess warmth of about 4°F over the long-term June average. This anomaly, together with an excess coldness of 2°–3°F shown in the southward bulge of the isotherms to the east, if representative of more than a superficial contrast of surface temperatures, could account for a southeastward component of current as suggested by the accounts of most of the skippers.

Further evidence for the significance of this feature is found in the time series of bathythermograph soundings made from the RMS *Franconia* (U.S. Naval Oceanographic Office 1970) during its traverse from New York to Bermuda on May 29–30, which showed a prominent northward meander of the Gulf Stream a short distance

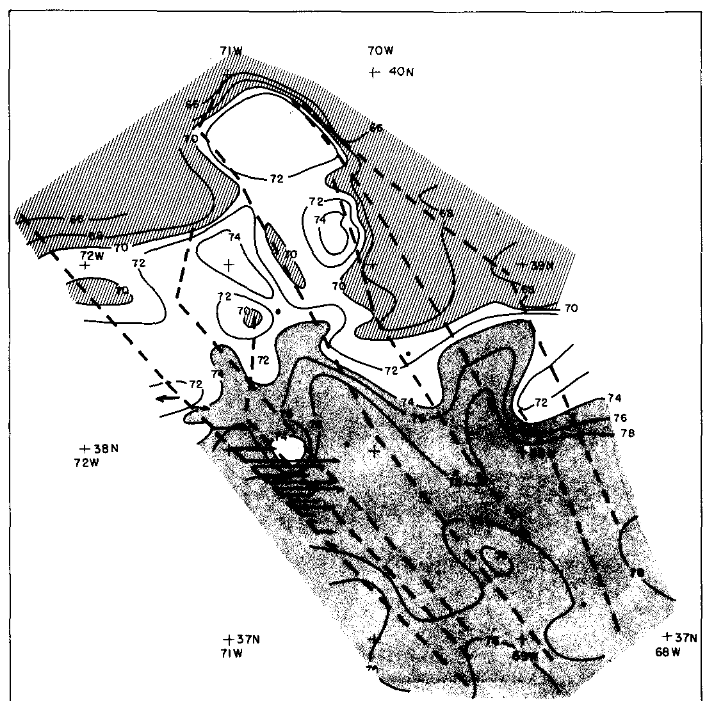

FIGURE 3.—Detailed analysis of sea-surface temperature in the vicinity of the Gulf Stream on June 21–22, 1970. Tracks of vessels recording continuously or observing at frequent intervals are shown by heavy dashed lines. Locations of other more isolated observations are shown by heavy dots. The leftmost track is that of the RMS *Franconia*, along which the arrows represent an estimate of the current profile of the Gulf Stream.

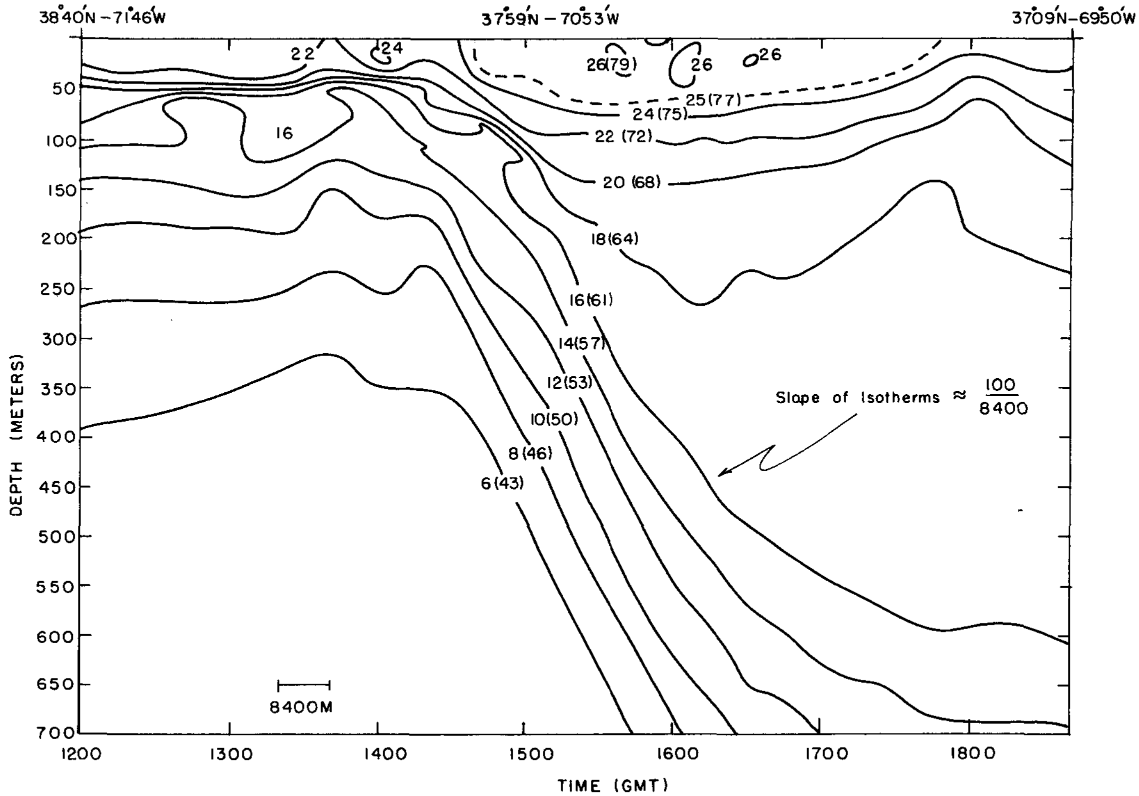

FIGURE 4.—Time-section of bathythermograph temperature soundings from the RMS *Franconia* on June 21, 1970. Latitude and longitude are shown at top of the diagram for selected times. Isotherms are labeled in °C with approximate Fahrenheit values in parentheses.

west of the mean June 1970 position of the warm bulge. Finally, a prominent anticyclonic eddy was discovered in late August moving northeastward near 39°N, 69.4°W (U.S. Naval Oceanographic Office 1971). Thus, it seems likely that the meander or eddy produced an anomalous southward current during the race, which most aided those yachts near or a short distance west of the rhumb line.

Further detail appears in figure 3, which is based on temperatures observed by 12 yachts on June 21–22 and also by the RMS *Franconia*, which passed southeastward a short distance west of the fleet on the 21st. The latitude at which the yachts first encountered the 78°F isotherm, probably representing the approximate position of the north wall of the Gulf Stream, varied only from 37°55′ to 38°25′N. The north–south oscillations of this isotherm, with a wavelength of about 40 n.mi. (65 km) and an amplitude of substantial size, do not seem to be attributable to errors in the ship thermometers or positions. Whether or not they were associated with significant current systems is impossible to say.

The warm bulge seen in the mean June pattern is very prominent in this analysis as well and lies very close to its location in the mean pattern. In figure 3, however, there is great detail, the significance of which is unknown. Nevertheless, all six yachts reporting in the vicinity of the bulge found at least one pronounced maximum of warmth, with temperatures ranging between 70° and 75°F, well to the north of the isotherms associated with the Gulf Stream proper.

The fortuitous passage of the RMS *Franconia* just west of the fleet on June 21 afforded a detailed view of the water structure at depth, shown in figure 4. Development of the seasonal thermocline obscures the temperature gradients associated with the Gulf Stream in the first 50 m, but below this depth, the north wall is plainly visible inclining toward the south with a slope of about 1:85. To obtain an idea of surface currents, we calculated the vertical average of temperature for each sounding over the layer from 15 to 705 m, the greatest depth consistently reached. Horizontal gradients of these averaged temperatures are indicated in figure 3 by arrows emanating from the track of the ship with length proportional to the intensity of the gradient and with direction along the expected geostrophic surface current. The precision of a quantitative calculation is limited principally by the lack of information on salinity. Nevertheless, we tried. From Gulf Stream cross-sections shown by Neumann and Pierson (1966, p. 132), it appears that the differences in density anomaly across the Gulf Stream are determined principally by differences in temperature and that the opposing effect of salinity differences is about 40 percent of the effect due solely to temperature. On this basis, neglecting pressure effects upon specific volume anomalies and with the further assumptions that the current vanishes at 705 m and is strictly zonal, we find a maximum current of about 5.3 kt between 37°59′ and 37°57′N. For the Gulf Stream as a whole, we obtain an average current of about 2.7 kt between 38°12′ and 37°42′N. If, as is likely the case, the current does not vanish at 705 m, then our estimate is too small, whereas, if the current is from

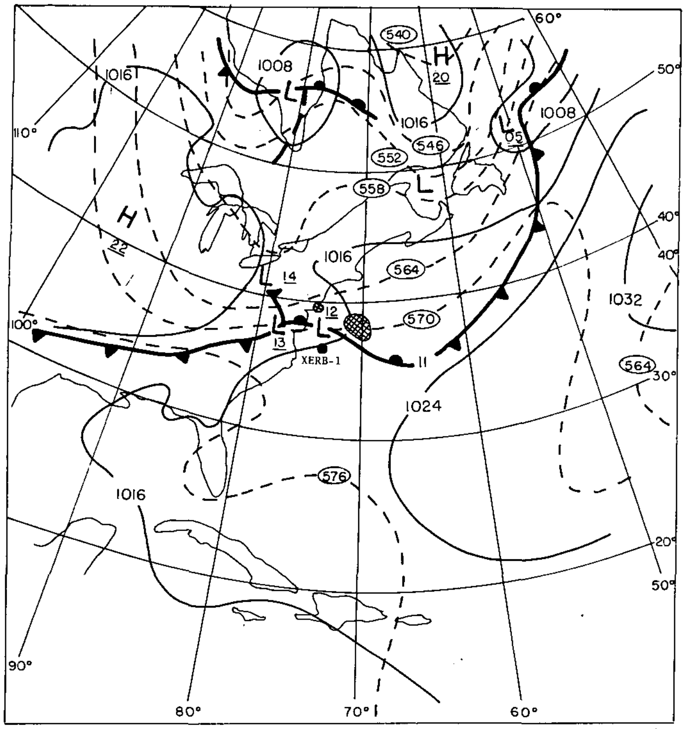

FIGURE 5.—NMC analysis for 0000 GMT on June 22, 1970. Solid lines are sea-level isobars at intervals of 8 mb and dashed lines are isopleths of thickness of the layer from 1000 to 500 mb, at intervals of 6 dekameters. The hatched area represents the approximate envelope of the racing fleet at this time. The circled X denotes the location of Atlantic City (ACY).

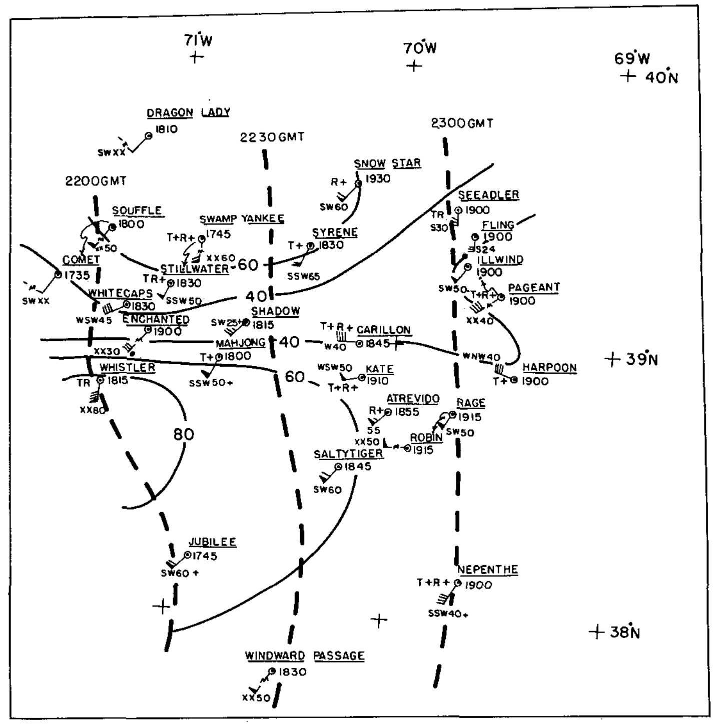

FIGURE 6.—Peak gust in the first series of squalls on June 21. Solid lines are isotachs at intervals of 20 kt. Dashed lines are isochrones of the peak gust at intervals of 30 min. Peak velocities reported by each yacht are plotted in the conventional manner. The reported time of squalls (EDT) is at the upper right of the station circle. Reports of thunder or rain (+ indicating heavy intensity) from each yacht are plotted to the left of the station circle as T or R, respectively.

southwest to northeast (also likely), our estimate is then too large. Thus, we may hope for cancellation of errors.

The presence of the Gulf Stream so far to the south of the maximum anomalous warmth reported by the yachtsmen suggests that the meander may have been cut off by this time. The reported surface temperatures in the meander or eddy were about 4°F lower than those in the Gulf Stream from which this water came. Perhaps this cooling represents a change toward the equilibrium temperature appropriate to the geographical location and time of year once systematic advection of warm water has been interrupted.

The meandering process that produced the warm eddy also yielded a cold eddy observed by the RMS *Franconia* on June 8 near 36°N, 69°W. Subsequent passages failed to show any trace of this feature, nor were appropriate current or temperature effects reported by the yachts. Thus, it seems likely that this feature moved toward the southwest where a temperature minimum is indicated (fig. 2).

3. THE THUNDERSTORMS OF JUNE 21–22

The squalls of June 21–22 were associated with a weak, nondeveloping wave cyclone, as analyzed by the National Meteorological Center (NMC). From the innocuous appearance of the map shown in figure 5, one would hardly guess that violent squalls had swept through the fleet about 1½ hr earlier (fig. 6) and would again about 9 hr later (fig. 7).

The reports of the yachts in figure 6 form a reasonable pattern as to peak windspeed, about which some subjectivity would be expected. There appears to have been a weak spot in the line of squalls from roughly 39°N, 72°W to 39.5°N, 69.5°W, since the yachts *Comet*, *Enchanted*, *Shadow*, *Seeadler*, and *Fling* (the only ones reporting less than 40 kt) all lay along this zone. Many yachts, including the author's, experienced a sharp shift in wind direction from southeasterly to southwesterly during the period of squalls. The reported times, about which one might expect objectivity, do not form a consistent pattern, probably because the request for information was not sufficiently specific concerning what event was to be timed: the beginning, peak, or end of the squall, or the windshift. Nevertheless, it seems unlikely that the peak gust moved through the fleet at a speed much less than that indicated by the analyzed isochrones, which is about 70 kt. By analogy with experience in severe convective storms over land, this speed of advance lends credibility to the reported gusts in the range from 50 to 80 kt.

The second group of squalls (fig. 7) was experienced by relatively few yachts because it was of rather small meridional extent and the larger yachts had sped on far toward the southeast, driven by brisk but steady southwesterly winds. The northern boundary of the region of strong gusts was extraordinarily sharp. Note that *Snow Star* observed heavy rain and thunder but no wind at a location only about 30 n.mi. from gusts of near-hurricane force. The reported times of this second set of squalls showed

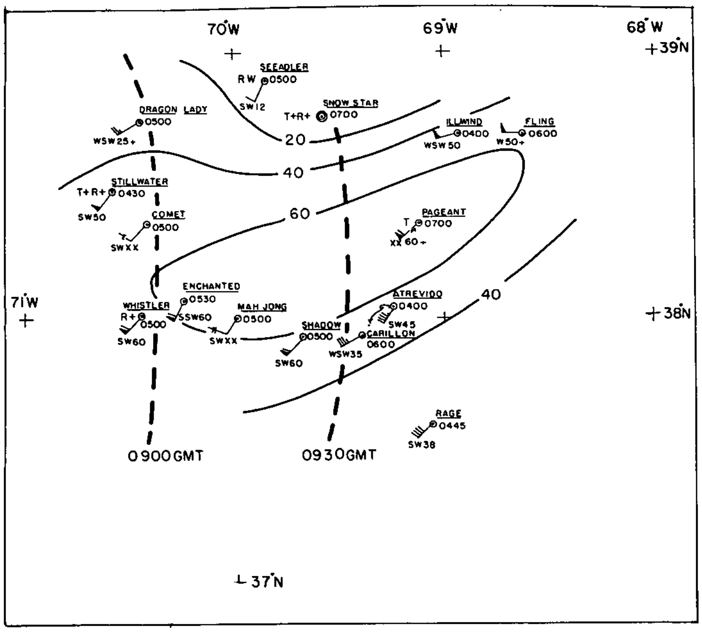

FIGURE 7.—Same as figure 6 for the second series of squalls on June 22.

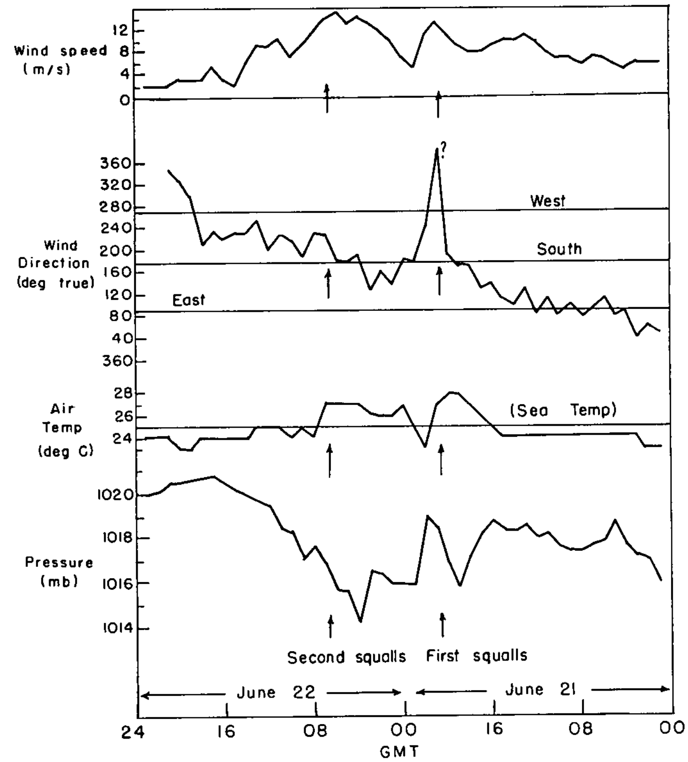

FIGURE 8.—Time-series of hourly observations from the XERB–1 buoy at 36.5°N, 73.5°W on June 21–22, 1970.

considerable scatter about any reasonably smooth progression. However, the average time of peak gust for the westernmost seven yachts was 0900 GMT and for the easternmost seven it was 0935 GMT, indicating an extremely rapid progression.

What was the origin of these violent storms? It seems natural to attribute them either to the Gulf Stream proper or to the warm meander, which brought unusually high sea-surface temperatures far to the north of the usual position of the Gulf Stream. First, we examine the time series of hourly observations at the XERB–1 buoy, moored at 36.5°N, 73.5°W on the northwestern edge of the Gulf Stream. This location (fig. 5) is about 200 n.mi. upwind from the position of the fleet. In this time series, shown in figure 8, the two periods of squalls are apparent in peak windspeeds, veering wind directions, pressure rises, and temperature falls to levels lower than the local sea temperature, due undoubtedly to cold downdrafts from cumulonimbus cloud systems. The two periods of squalls occurred at about 2030 GMT on June 21 and 0630 GMT on June 22, in each instance 2 or 3 hr before they were experienced by the fleet, confirming the great speed of advance implied by the yacht data.

Hourly surface observations at all reporting stations in and immediately west of the Chesapeake Bay area also show two distinct periods of showers or thunderstorms, separated as at XERB–1 by about 10 hr. When these observations are plotted on a representation of the plan position indicator (PPI) scope of the WSR–57 radar at Atlantic City, N.J., a striking picture emerges. A series of these mesoanalyses at 3-hr intervals is presented in figure 9. The following locations are shown in the figure for orientation: John F. Kennedy Airport, New York, N.Y. (JFK), the XERB–1 buoy, Hatteras, N.C. (HAT), Norfolk (ORF) and Charlottesville (CHO), Va., Martinsburg, W. Va. (MRB), and Washington National Airport, Washington, D.C. (DCA).

A meso-Low just west of Washington, D.C., at 1500 GMT (fig. 9), produced a great mass of convective echoes associated with thunderstorms and severe surface winds 3 hr later. In the surface air over eastern Virginia that fed these storms, temperatures were in the upper 80s and dew points in the 70s. Numerous radar echo tops were reported in excess of 40,000 ft elevation. Deaths, injuries, and extensive damage to vehicles, buildings, and trees were reported by the Environmental Science Services Administration (1970). The most severe conditions (including tornadoes and waterspouts) were observed in the elongated cold frontlike line of radar echoes in the southern part of the display. Between 1800 and 2100 GMT, the line became extremely solid and powerful in appearance, even at distances more than 100 n.mi. from the radar site. During this time, the leading edge of the echoes moved at a speed of about 50 kt. This value is intermediate between the somewhat slower rate of advance of the line of peak surface gusts over land and the somewhat faster rate required to bring the line over the ocean to the fleet at the reported time of peak wind.

The origin of the second group of squalls is seen between 2100 and 0000 GMT. Once again a meso-Low formed just west of Washington, in response to which a new group of echoes quickly appeared, again in the region just east of the Low. The surface air feeding these storms had approximately the same thermodynamic characteristics as the air involved in the first storms. This group of storms, however, appeared on radar to be more scattered and of more limited north–south extent. Again, the rate of ad-

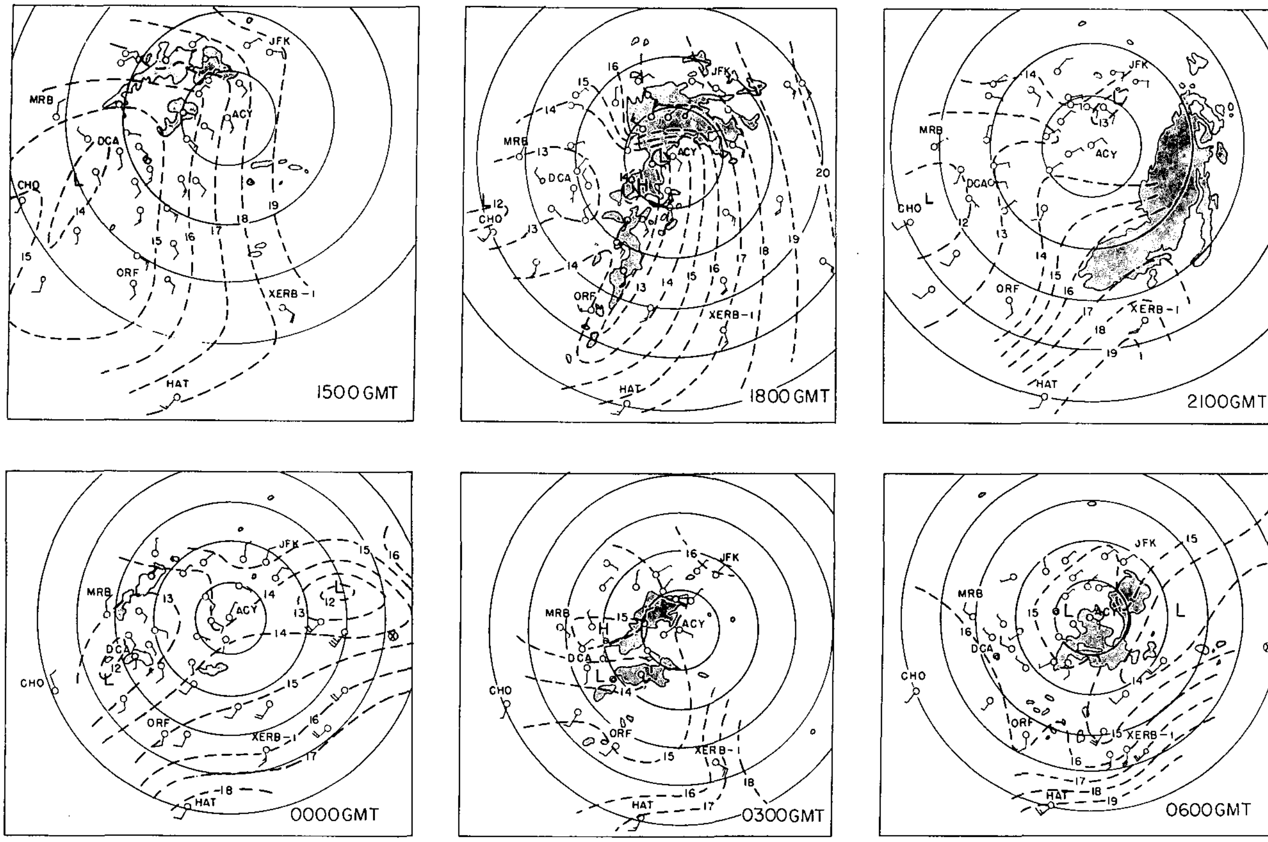

FIGURE 9.—Mesoanalyses of sea-level pressure at 3-hr intervals on June 21–22, 1970, superposed on echoes observed by the WSR–57 radar at Atlantic City (ACY). The PPI scope photograph nearest the nominal time of the 3-hourly surface observations was used. Thin solid lines are range circles at intervals of 50 n. mi. Dashed lines are sea-level isobars at intervals of 1 mb. Circled Xs show approximate centroid of positions of yachts reporting squalls.

vance of the envelope of echoes from 0300 to 0600 GMT was about 50 kt, the speed required for arrival of the storms in the fleet area at about 0900 GMT. Finally, the small meridional extent of the storms agrees well with limited north–south extent of strong squalls reported by the yachts.

Synoptic analyses of later conditions at sea (not shown) indicate that both groups of squalls subsequently slowed and weakened but that the first was still producing thunderstorms at 1200 GMT on June 22.

It is clear that neither set of thunderstorms originated over the Gulf Stream. Rather, they developed in extremely warm and moist air over land during the daytime hours. The air was sufficiently warm in its lower levels that passage over the Gulf Stream itself, to say nothing of the warm meander or eddy to the north, would have produced surface cooling and stabilization. Evidently, the charge received by the air over land was sufficient to maintain severe convective storms for 12–18 hr after the removal of the source of surface heating and moistening. The first group of storms clearly displayed its greatest radar intensity (fig. 9) after it passed offshore, and the highest cumulonimbus towers of each group were still visible on radar at a distance of almost 250 n.mi. seaward. Comparable persistence of convection above surface stability is often observed with severe nocturnal storms in the eastern portion of the Great Plains States. Perhaps, as suggested by Kessler and Bumgarner (1971), surface stabilization tends to promote the organization of convective activity into large, hence severe, elements.

The initiation of each group of storms immediately after the formation of a mesoscale Low and immediately downwind (in the upper flow) from the Low is not likely a coincidence. The Lows formed in a region of synoptic scale ascent associated with a shortwave upper trough, in a region downwind from the crests of the Appalachian Mountains (thus favorable for orographic cyclogenesis) and in a region of strong, localized diurnal heating (thus favorable for thermal cyclogenesis). The thunderstorms formed in a region where we might reasonably expect locally enhanced warm advection, because of the presumed quasi-geostrophic character of the flow associated with the mesoscale Lows, and in a region where we might expect pronounced frictional boundary-layer convergence because of enhanced low-level vorticity associated with the mesoscale Low. Thus, the air rising in the cumulonimbus towers might be associated either with moisture convergence brought about by large-scale motions above the surface boundary layer or with such convergence produced within the layer as suggested by Charney and Eliassen (1964) or both, In short, there was every qualitative reason to anticipate development of thunderstorms.

In the problem of forecasting severe convection, the suggestion by Fawbush et al. (1951) that strong vertical wind shear and convective instability are necessary ingredients has become generally accepted. These aspects are

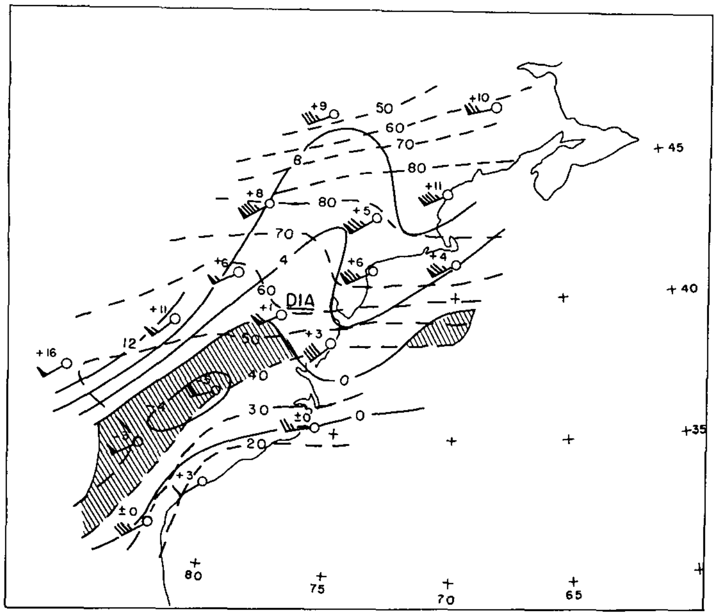

FIGURE 10.—Showalter stability index at intervals of 4°C (solid lines) and isotachs of wind shear for the layer from 850 to 200 mb at intervals of 10 kt (dashed lines), for 0000 GMT on June 22, 1970. The observed index value is plotted above and to the left of the station circle; the wind shear vector is plotted in the conventional manner. DIA is Dulles International Airport.

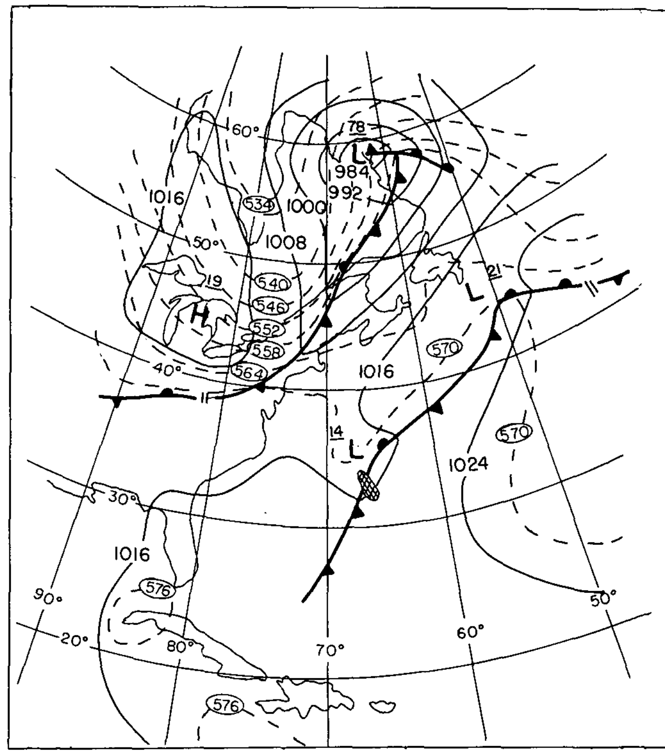

FIGURE 11.—NMC surface analysis for 1200 GMT on June 25, 1970. Format is the same as in figure 5. The hatched area is the approximate envelope of the racing fleet at this time.

displayed for 0000 GMT in figure 10. Stability is represented by the Showalter index (ambient 500-mb temperature minus the temperature of the 850-mb parcel lifted dry adiabatically to its condensation level then moist adiabatically to 500 mb), while wind shear is shown for the layer from 850 mb, in the lower part of the clouds, to 200 mb, near the level of maximum wind. Generally speaking, the region of strong shear lies to the north of the region of instability. Over central and western Virginia and North Carolina, however, we find negative Showalter index together with shear greater than 40 kt (hatched area in fig. 10). At this time, the second group of squalls was just becoming organized, with radar echoes in the vicinity of Dulles International Airport and thunder reported at nearby stations to the south and west within the hatched area. Twelve hours earlier, Dulles was the only station east of the Appalachian Mountains meeting the above shear and stability criteria; the first group of squalls became organized in this area a few hours after this time. As nearly as can be judged, both groups of squalls advanced at speeds somewhat faster than the speed of the large-scale tropospheric mean flow.

4. THE GALE OF JUNE 25

The gale of June 25 was of quite different character. None of the yachts mentioned thunder and only a few reported rain. The NMC surface analysis for 1200 GMT (fig. 11) shows a weak frontal wave with a Low center near 36°N, 67°W. The paucity of thickness lines in the vicinity of this system suggests horizontal temperature gradients in the lower and middle troposphere of less than 0.5°C/100 km. The only indication of more than gentle zephyrs is the 25-kt geostrophic wind implied by the spacing of isobars east of the front between 30° and 35°N. Nevertheless, a Nimbus satellite view about 8 hr before the time of the map (fig. 12A) shows abundant cloudiness alined along the analyzed frontal position. Another view about 4 hr after the time of the map (fig. 12B) shows dissipation of much of the cloudiness south of 30°N and a more chaotic pattern to the north. Nothing suggests the presence of a gale.

Thirteen yachts provided accounts of their experiences on this date in various formats. For each of them, however, it was possible to construct a time history of latitude, longitude, and wind. From these and from the surface observations at Kindley Field, Bermuda, a series of detailed analyses at 3-hr intervals were constructed. These are shown in figure 13. We see clearly the northeastward passage of a cyclone through the fleet at a rate of about 23 kt, being about 85 n.mi. northwest of Bermuda at its closest approach. Between the island and the Low center lay a narrow zone of gale-force winds never more than 50 n.mi. wide that blasted some of the yachts but left others, farther to the northwest, with either a good sailing breeze or with light air. The position of the Low on the 1200 GMT NMC map was evidently in error by some 300 n.mi. or so.

The difference in wind speeds between the southeast and northwest sides of the cyclone was about 40 kt. If we imagine the cyclone as an axisymmetric vortex superposed upon a uniform basic current, then the advection of relative vorticity (we can neglect the advection of earth vorticity for a system this small) would indicate a rate of advance of half the speed difference, or 20 kt.

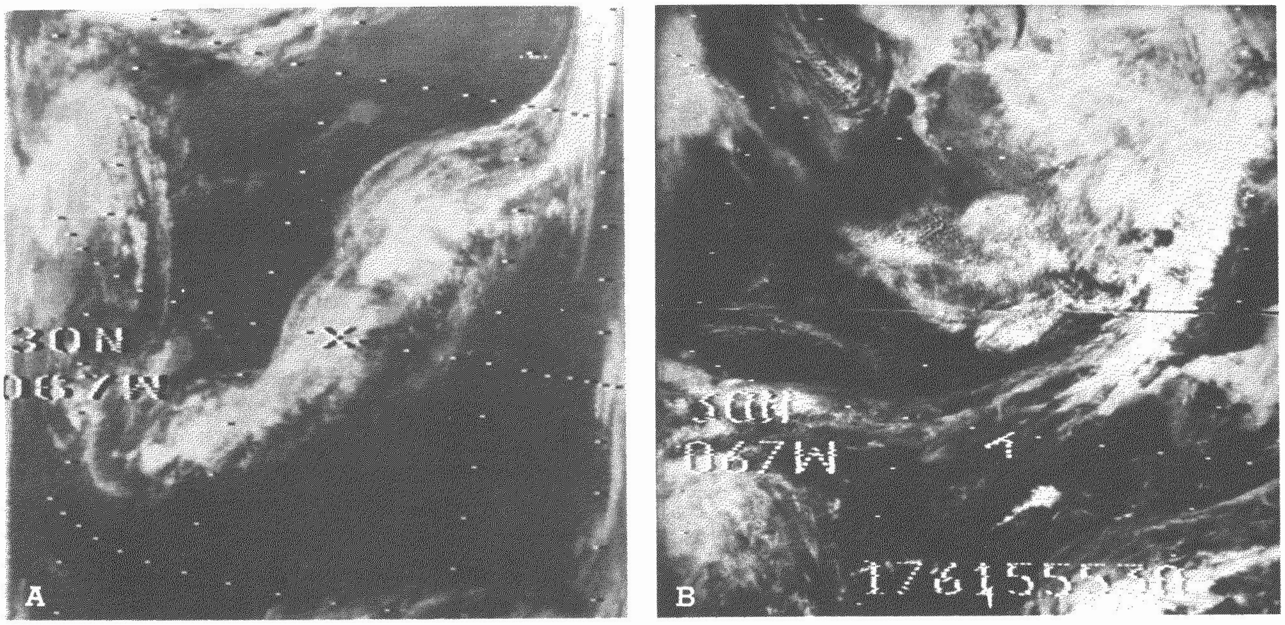

FIGURE 12.—Nimbus satellite (A) high resolution infrared radiometer picture at about 0400 GMT and (B) TV picture at about 1600 GMT on June 25, 1970. Grid dots represent latitude and longitude at intervals of 2°. The fiducial mark is at 30°N, 67°W in both pictures.

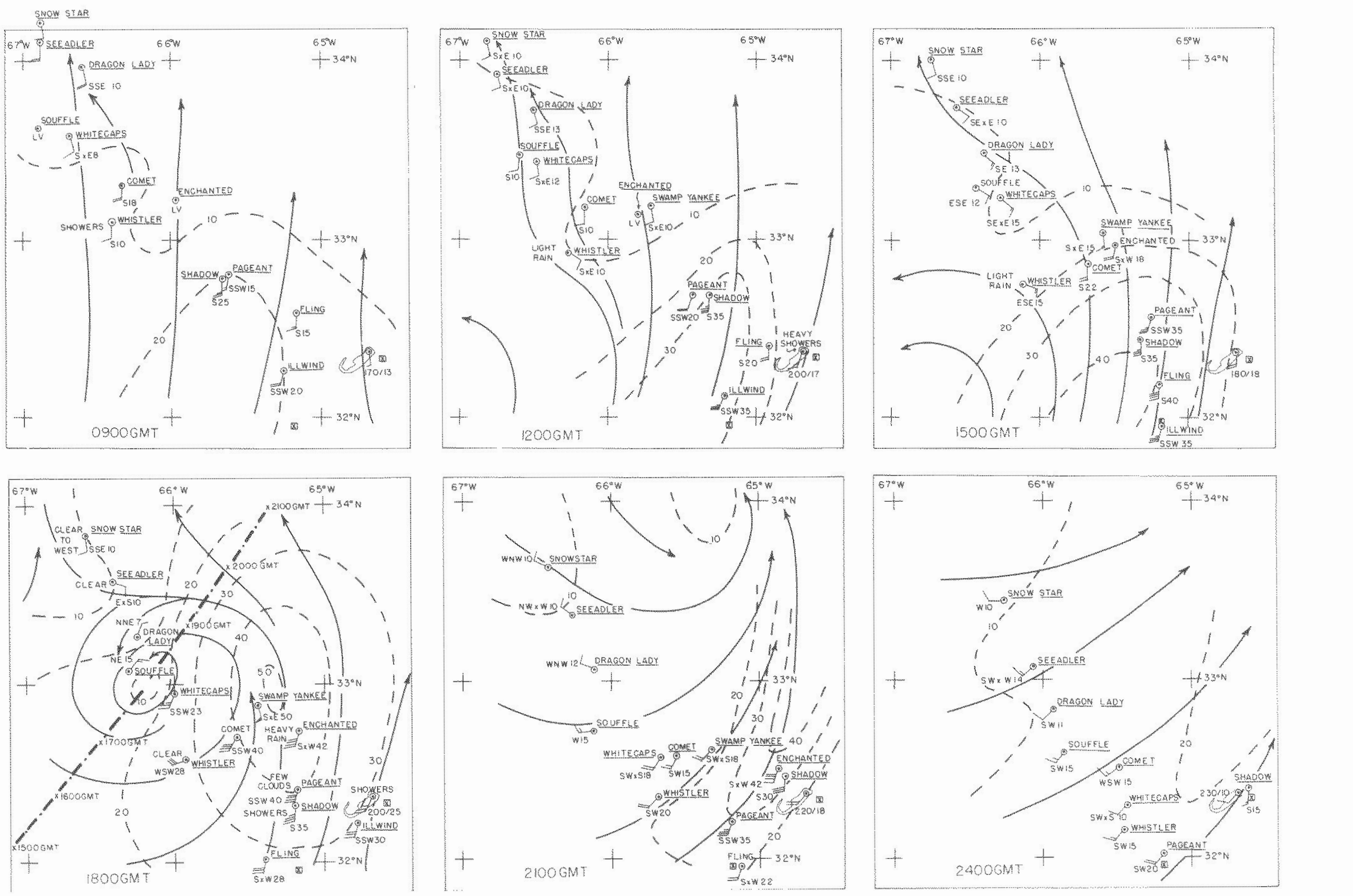

FIGURE 13.—Detailed surface analyses at 3-hr intervals from 0900 to 2400 GMT on June 25. Wind is plotted for all yachts and for Kindley Field, Bermuda, with annotations where available concerning sky conditions and precipitation. Analyses include streamlines of wind flow (solid lines), isotachs at intervals of 10 kt (dashed lines), and the estimated track of the cyclone with hourly positions indicated (heavy dot-dash line).

Since the actual speed is only slightly faster, we can conclude that convergence and divergence effects associated with baroclinicity, the predominant mechanism in the motion of most extratropical cyclones, were quite unimportant in this case and that the cyclone moved rather in the manner of a tropical storm.

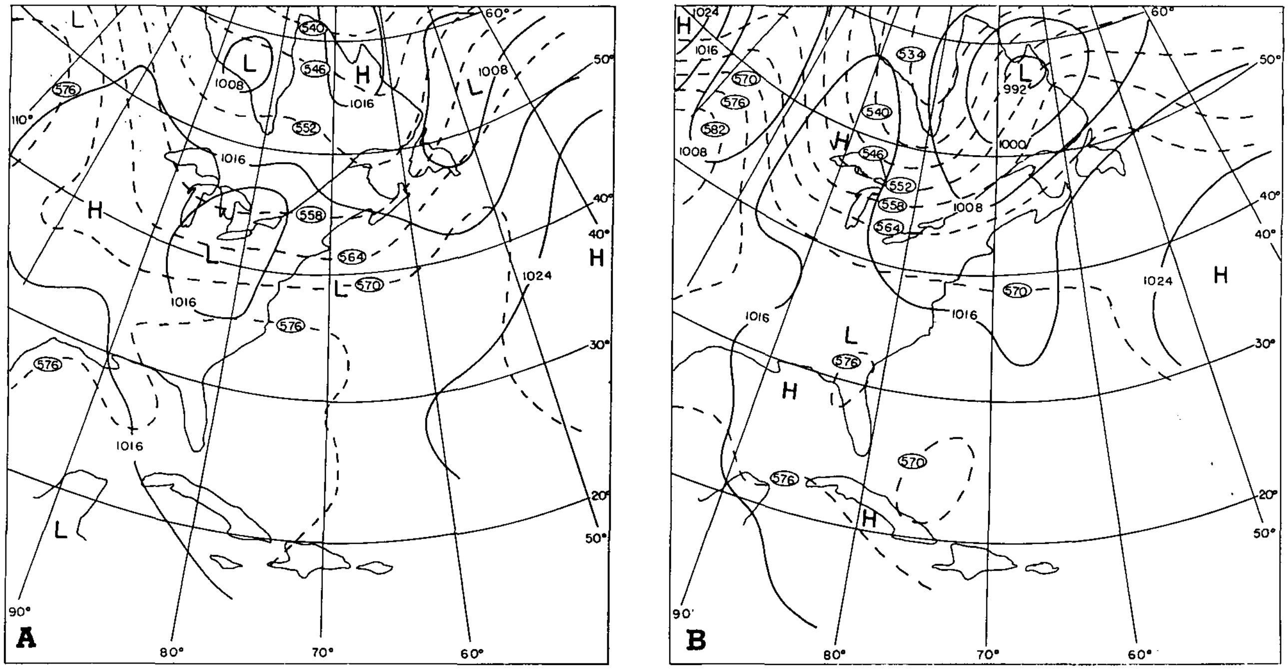

FIGURE 14.—Twenty-four hr forecast sea-level isobars and thickness lines for the layer from 1000 to 500 mb, derived from the PE model for (A) 0000 GMT, June 22, and (B) 1200 GMT on June 25, 1970. Format is the same as in figure 5.

It is difficult to argue that the cyclone was maintained by latent heat release as tropical cyclones are, since precipitation was sparse. The only heavy rainfall reported was in the bright cloudband on the eastern periphery of the gale, shown in figure 12B, from which Kindley Field received 0.60 in. of rain in showers. It is possible, however, that the storm was dissipating at the time it passed through the fleet, for later NMC maps omitted the weak Low and frontal system altogether. However the storm was initiated, its origin was doubtless within the massive cloud system shown in figure 12A. We, therefore, tentatively conclude that the storm was principally tropical in character, with weak baroclinic characteristics; and we wonder how many similarly small and short-lived systems go unobserved across the expanses of the global ocean. Careful study of an ATS 3 film loop for June 25 does, in fact, disclose rotation of cloud around a small central hub that can be identified with the small bright cloud area near 33°N, 67°W in the Nimbus photograph in figure 12B, but no identifiable cloud targets gave a hint of maximum strength of the surface winds.

5. THE FORECASTS

Two questions occur concerning the forecasts for June 22 and 25. First, what effect did the convective storms have on the predictions for the larger synoptic scales of motion? Relevant 24-hr predictions of the patterns of sea-level pressure and of thickness of the layer from 1000 to 500 mb, derived from the NMC primitive-equation (PE) model (Shuman and Hovermale 1968), are displayed in figure 14. Comparison of figure 14A with figure 5 indicates that the actual position of the complex low-pressure system along the mid-Atlantic coast was east of the predicted position. It does not seem reasonable to blame this discrepancy on the convective storms, however, because virtually all the Highs and Lows shared this prognostic defect whether or not they were associated with cumulus activity. The slowness of predicted eastward displacement of mobile Highs and Lows is a generally recognized bias in the PE forecasts. Comparison of figures 14B and 11 shows that the forecast in the vicinity of Bermuda on June 25 was as good as the analysis. The paucity of observations conspired with the sparsity of computational gridpoints to conceal the existence of the gale before, during, and after the fact. In neither case was there evidence that the tropospheric mean temperature, as measured by the thickness, was significantly influenced on the large scale by the release of latent heat in the cumulus. Nor, in either case, was there predicted or observed intensification of the relevant synoptic scale features subsequent to the verification times shown in figure 14. We conclude then that, important as the small-scale storms were to the participants in the race, they were (so far as immediate and direct effects were concerned) mere embroidery on the large-scale fabric of meteorological events.

The second question is how well the all-important smaller features were predicted in the forecasts available to the racing crews. We have no documentation concerning the forecasts around Bermuda on June 25. For the thunderstorms on June 21–22, however, we can refer to the National Weather Service West Central North Atlantic Offshore Forecast for the area between 35° and 41°N and west of 65°W, the product probably most widely used by the crews at this time. This forecast is issued at 0400 GMT each day and at 6-hr intervals thereafter.

The forecast issued at 1000 GMT on June 21 (12 hr before the first squalls struck the fleet) stated that "a low [in] western Indiana will move . . . to northeastern Pennsylvania by Monday [June 22] morning." This

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projection reflected the slowness of the PE forecast described above and did not entirely compensate for it. "Winds will veer on Sunday [June 21] becoming generally southeast 5 to 15 knots over the southwest portion and northeast to east 5 to 15 knots elsewhere by Sunday afternoon." Rain was forecast over the southwest portion, but there was no mention of thunderstorms in the vicinity of the fleet.

The forecast issued at 1600 GMT (6 hr before the arrival of squalls and at the time of initial thunderstorm formation in the vicinity of Washington) refers to "low pressure over the Middle West [moving] eastward 20 knots to southeastern New York by Monday morning." The revised forecast position of the Low was an improvement. Another change was the introduction of a warm front crossing the rhumb line at 36°N and predicted to move northward to 39°N by 1200 GMT. "South of and near warm front winds south to southwest 15 to 25 knots though locally stronger in gusts near thunderstorms through Monday morning."

The forecast issued at 2200 GMT (as the first squalls struck) described a "complex low with several centers from the upper Ohio Valley to Delaware Bay [that will] become better organized in vicinity of Nantucket by daybreak. . . ." Again there was an eastward shift of the low-pressure system. The warm front again served as the basis for describing the weather; thus "south of frontal system winds mostly southwest 15 to 25 knots but briefly higher in thundersqualls."

The forecast issued at 0400 GMT on June 22 (between the two squall episodes in the fleet) spoke of a "complex low over middle Atlantic states with several centers . . . [becoming] better organized during the night and [moving] to 41N 67W by 8am [1200 GMT]." This was the final eastward modification of the predicted position of the Low center. Over the fleet, the forecast was for "winds southwest 15 to 25 knots but briefly higher in thundersqualls." Virtually the same language was used to describe the winds in each ensuing forecast through at least 0400 GMT on June 23.

Note that these forecasts were quite detailed and specific so far as the location and position of the low-pressure center were concerned. In contrast, the reference to the associated weather, in which the seaman is interested, was very general (i.e., "southwest 15 to 25 knots but briefly higher in thundersqualls" was used with only minor variation throughout a period of 36 hr, during which the description of the Low center changed each 6 hr). Indeed, the average weather experienced by the fleet was close to that predicted. But the important events were on the mesoscale, as is so often the case, and the land-based forecaster generally lacks the data necessary to cope with such occurrences at sea. In the present case, however, it is interesting to speculate whether, for example, the consolidation and rapid eastward motion of the echoes seen in figures 9B and 9C, with reported tops as high as 50,000 ft, might have served as the basis for a specific short-range forecast of gusts in the vicinity of 50 kt, had sufficient and timely radar information been available to the forecaster.

The focus of the forecasting effort needs to be changed from the synoptic scale to the mesoscale. The forecasts in this case were not inaccurate; they were irrelevant.

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