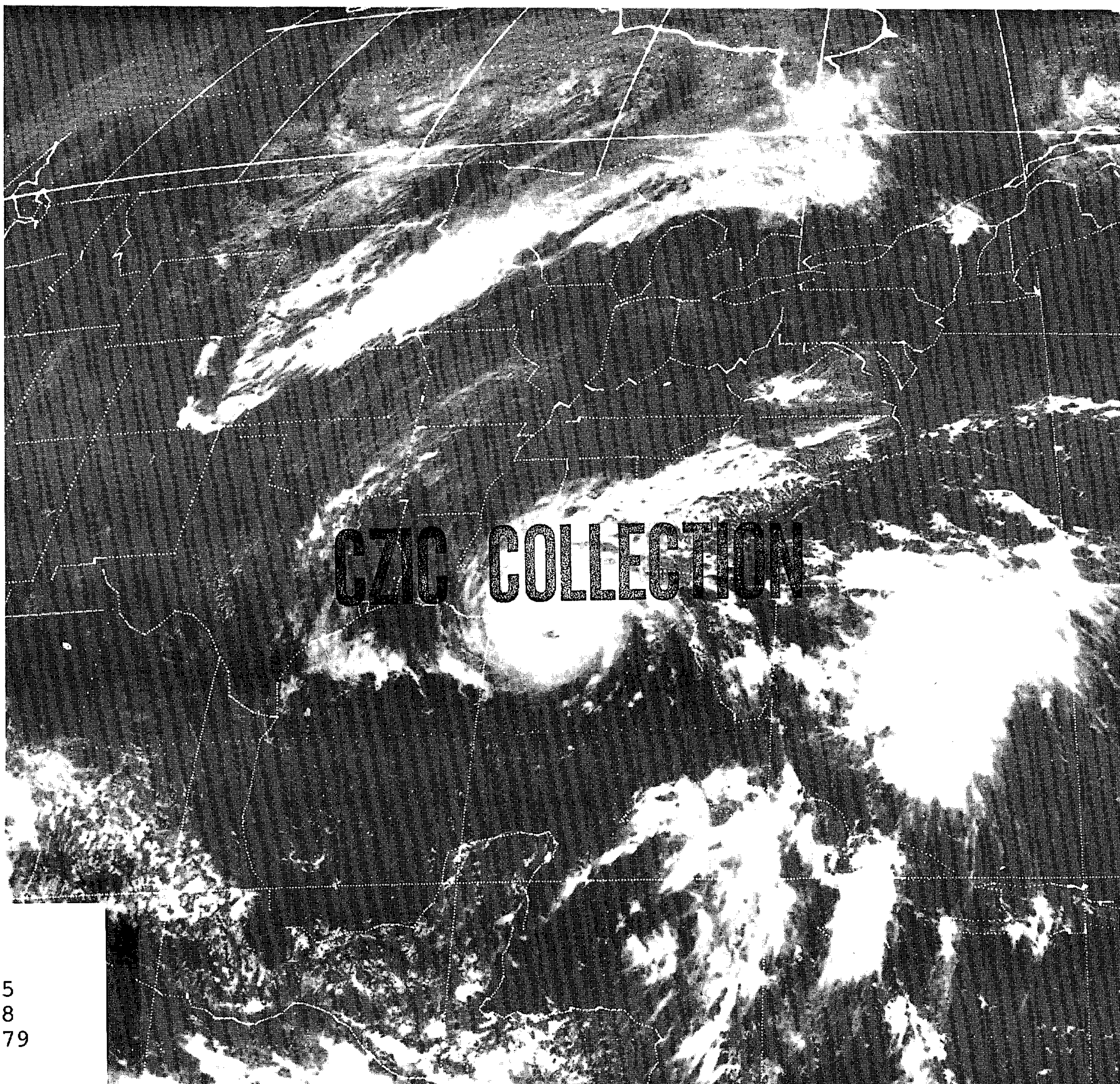
Natural Disaster Survey Report

Hurricane Frederic
Aug 29 - Sept 13, 1979

U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Weather Service, Silver Spring, Maryland



FOREWARD

Hurricane Frederic, one of the most severe hurricanes to strike the U.S. in the past decade, caused enormous damage to parts of Alabama, Florida, and Mississippi as it came ashore on Wednesday, September 12, 1979. An estimated quarter of a million people heeded the warnings from NOAA's National Weather Service offices and the advice of state officials. The extremely low death toll is due to the diligence of many officials, agencies, volunteers, and governments working in a coordinated and unified way.

NOAA sends a survey team into an area after a major natural disaster occurs. Their objective is to determine how the warning system performed. This report has several findings and recommendations. It is gratifying that most are relatively minor and it is heartwarming to find that so many of the actions taken undoubtedly saved hundreds of lives.

Richard E. Hallgren
Director, National Weather Service

Cover: This NOAA satellite view shows Hurricane Frederic at 11:00 a.m. CDT on September 12, 1979, when the center was about 180 miles south of Mobile, Alabama.

PREFACE

The NOAA survey team included:

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Stanley Spivey, Meteorological Services Division, NWS Southern Region
Doyle Cook, Meteorologist in Charge, WSFO, Charleston, W. Va.
Joseph Bird, Research and Development, NOAA
Dane Clark, Satellite Operations, NESS
Herbert Lieb, Consultant, Disaster Preparedness and Public Affairs

From September 18-21, 1979, the team visited the five counties where the worse damage occurred -- Mobile and Baldwin Counties, AL; Escambia County, FL; Jackson and Harrison Counties, MS.

In addition to interviewing NWS personnel at the WSO's at Mobile, AL, and Pensacola, FL, the NHC and WSFO, New Orleans, the team visited mayors, civil defense directors, county commissioners, television and radio executives, and newspaper editors and reporters in the five counties.

The team is grateful for their time, patience, and invaluable insights.

GLOSSARY

NOAA: National Oceanic and Atmospheric Administration
NWS: National Weather Service, NOAA
NHC: National Hurricane Center, NWS
NMC: National Meteorological Center, NWS
WSFO: Weather Service Forecast Office, NWS
WSO: Weather Service Office, NWS
MIC: Meteorologist in Charge, NWS
NESS: National Environmental Satellite Center, NOAA

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EXECUTIVE SUMMARY

Hurricane Frederic, with winds reaching 145 mph, moved over Dauphin Island (near the mouth of Mobile Bay) and inlane just west of Mobile, Alabama, between 10 a.m. and 11 p.m. CDT on Wednesday, September 12, 1979. Storm tides of 8 to 12 feet above normal were reported from Pascagoula, Mississippi to western Santa Rosa Island, Alabama. The damage estimate of $2.3 billion makes Frederic the costiliest hurricane ever to hit the United States, exceeding the $2.1 billion attributed to the widespread floods from Hurricane Agnes in 1972. Based on information from preparedness officials, 250,000 persons were safely evacuated in advance of Frederic. It was the first hurricane to strike Mobile directly since 1926. It was the most intense hurricane of this century for the area from Mobile, Alabama, to Pascagoula, Mississippi.*

That only five deaths have been directly attributed to Frederic in the U.S. is testimony to the high level of preparedness in the state, county, and city governments along the coast. The survey team received the highest praise for the NWS's forecasts and warnings during Frederic.

The team's findings and recommendations follow:

- Finding 1

The combination of extremely good forecasts and warnings and excellent hurricane preparedness resulted in a very low death toll. Major credit must be given to several key Southern Region employees and local emergency preparedness officials.

<u>Recommendation 1</u>

Awards and/or other recognition should be given to appropriate individuals. (This recommendation was carried out at a special ceremony in Mobile, Alabama, on December 13, 1979.)

- Finding 2

NOAA Weather Radio transmissions were lost at Gulfport, Mississippi (after 6:30 p.m.); Mobile, Alabama (around 6:30 p.m.); Pensacola, Florida (6-7 p.m.); and Panama City (7 p.m.). All outages due to loss of electrical power at the transmitter site and throughout the respective cities were due to storm damage. NWR at Panama City was also struck by lightning. NWR is classified as the sole Government-operated radio system to provide direct warnings into private homes for both natural disasters and nuclear attacks.

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* Paul J. Hebert, National Hurricane Center, NWS, Atlantic Hurricane Season of 1979, Monthly Weather Review, July 1980.

Recommendation 2

Emergency power must be provided for NWR transmitters, particularly in vulnerable areas. Measures to provide lightning protection should also be pursued.

- Finding 3

Tide gage data was lost early at both Mobile and Pensacola. In Mobile the data was lost due to phone line outages. In Pensacola the high tide destroyed the well and made the system inoperable. These are critical losses which inevitably seem to occur during every hurricane when the data is needed most.

Recommendation 3

Some form of backup or emergency system needs to be developed and implemented to guarantee access to data.

- Finding 4

While shaky at times, communications between the Weather Service, local officials, and the news media never failed. However, reliable back-up communication systems to local officials and the media are lacking. Amateur radio groups played a crucial role in providing emergency communications. Emergency power kept WSO's Mobile and Pensacola in operation.

Recommendation 4

Providing reliable back-up communications to insure continuing contact with the many vital action agencies is crucial, yet technically difficult and costly. Time after time, amateur radio groups, both Ham and CB, have effectively filled the need by operating out of the WSFO or WSO. We should adopt this approach as a matter of official policy and encourage the establishment of such arrangements in appropriate areas of the country where they do not exist now. It is an effective, economical, and practical solution.

- Finding 5

Information on Hurricane Frederic reached Pensacola-area public officials from several sources including the Naval Air station, Pensacola, the Governor of Florida, and from one or more radio stations with drops on the Florida NAWAS circuit. Radio and television were outstanding in broadcasting the latest forecasts, warnings, and advice until they were knocked out as the storm approached the coast. There was some evidence of "editorializing" by some broadcast personnel that led to misinformation. However, the survey team found that it was not a significant problem.

Recommentation 5

Information about the hurricane should reach the public through a single coordinated source. Multiple sources of information lead to confusion and can have dire effects. A review should be made of the dissemination of hurricane information in Florida to see whether any changes are needed. With the media on NAWAS, it is no longer a "private line" used by the decision-making action teams. If this represents a new FEMA policy, other means of having "hot-line" communications between NWS offices, Civil Defense, law enforcement and other local action agencies must be found.

- Finding 6

The MIC, WSO Mobile, believed it would have been more effective if he had had control of the NWR transmitter in southeastern Mississippi which covers part of his warning area.

Recommendation 6

Transferring control of the McHenry NWR transmitter to Mobile WSO as the MIC requested has much merit in a warning situation. The staff of the Mobile WSO would, however, be hard-pressed to handle another transmitter with its current manpower. The possible transfer should be explored.

- Finding 7

A local university meteorologist volunteered his services and stayed at the Mobile Emergency Operating Center (EOC) throughout the storm as a staff consultant to the Director of Civil Defense and the County Commissioners. He helped them to interpret and reconcile information they were receiving from WSO Mobile and other sources (e.g., reports from state police patrol cars) as Frederic was moving onshore. The meteorologist's assistance was highly touted as contributing significantly to the feeling that local officials were on top of the situation.

Recommendation 7

The feasibility of detailing meteorologists to the EOC's at the center of the action should be explored.

- Finding 8

The high state of readiness in Alabama and Florida as Frederic hit reflected a lot of hard work over a long period. Both the Pensacola and Mobile MIC's are spending their own time and money to get the preparedness job done. Their travel budget is inadequate to cover their actual expenses and the demands on their time at the office are such that they often have to use their own time to go out and make contacts. The need for a principal assistant was also raised by both MIC's.

Recommendation 8

We must provide more support to our MIC's and their staffs to do the preparedness job.

- Finding 9

Although the majority of the satellite support was extremely effective, two deficiencies were revealed which should be remedied. Both of these were ongoing problems and not solely related to the operations during Hurricane Frederic. Nevertheless, these deficiencies did affect the overall performance of the meteorological warning system. The first involved a complaint by the National Hurricane Center. This involved NESS's recent change from producing photographic prints from negatives to an automatic picture display using UNIFAX machinery. Since the switchover, NHC feels dissatisfied with the quality of their satellite data. The second deficiency is the communication system NESS and NWS use to pass satellite-derived rainfall estimates from satellite meteorologists to NWS meteorologists and hydrologists. The present phone relay system is deficient because often these estimates fail to reach all NWS offices that could use this data. The River Forecast Centers at New Orleans and Atlanta did not receive these estimates during Hurricane Frederic.

Recommendation 9

The possibility of improving the quality of satellite imagery available at NHC should be explored.

- Finding 10

The three aircraft in NOAA are not enough to sustain operations for high density/accuracy data. An additional five aircraft with this capability are needed for the Western Atlantic/ Caribbean/Gulf of Mexico area. This is a mutual NOAA/DoD requirement.

Recommendation 10

NOAA must support the U.S. Air Force plan for an Improved Weather Reconnaissance System to the maximum extent possible.

- Finding 11

The single side-band NWS inter-office emergency communications equipment at both Mobile and Pensacola went down during Frederic while conventional systems, for the most part, stayed in operation.

Recommendation 11

The inter-office emergency communications program should be reviewed. If the single side-band system is to be maintained at coastal offices, review of ways in which its survivability can be increased should be considered.

CHAPTER I

HURRICANE FREDERIC - A BRIEF HISTORY

Hurricane Frederic's history spanned more than 2 weeks beginning in the Eastern Atlantic.

The system that gave birth to Frederic was detected by satellite south of the Cape Verde Islands. Ship and satellite data showed the formation of a depression on August 29. It reached tropical storm strength on August 30 -- the same day that Hurricane David was passing close to Puerto Rico and a day before David devastated the Dominican Republic. David killed more than 1,200 in the Dominican Republic. The history of David and the news attention it received in the U.S. during its Caribbean passage was a vital factor in encouraging public response along the Gulf Coast as Frederic moved inland. The NOAA National Disaster Survey Report, Hurricanes David and Frederic as They Concerned Puerto Rico and the Virgin Islands, August 26 - September 5, 1979, prepared by the NWS's Southern Region details and compares the two storms and their impact in the Caribbean.

Paul Hebert's article, cited earlier, also shows the meteorological connection between Frederic and David.

On September 1, satellite photographs showed that Frederic reached hurricane strength about 400 miles east of the Lesser Antilles but David's influence weakened Frederic to a tropical storm on September 2. From then until September 9 it moved generally westward, decellerated, and weakened more.

Frederic turned toward the northwest during the next 48 hours. On Sunday, September 9, forecasters at the National Hurricane Center indicated that Frederic was over Cuba, regaining strength, and posed a threat to the U.S. On the 10th, Frederic was upgraded to a hurricane and was located 150 miles southwest of Key West over the western end of Cuba.

Based on the NHC advisories, the Pensacola and Mobile MIC's alerted and began formal contacts with the Civil Defense directors and others early on Monday, September 10, more than 2 full days before hurricane conditions occurred in coastal areas. A hurricane warning was issued by the National Hurricane Center in a special advisory at 9:30 p.m. Tuesday, September 11, approximately 22 hours ahead of observed hurricane conditions. It read in part, "Hurricane warnings are being issued tonight in order to alert local governments of the need for quick action early Wednesday." This warning was quickly distributed by the WSO's. Several interviewees stated that it was fortunate that the National Weather Service did not wait until Wednesday morning to issue the warning. It would have made successful evacuation much more difficult -- or perhaps impossible. Subsequent advices from both the National Hurricane Center and the WSO's kept all concerned current on the progress of the storm. Local action statements by the WSO's, particularly with respect to specific evacuation recommendations, were generally very well done and closely coordinated with local officials.

A hurricane watch was issued for Panama City, Florida, to Vermillion Bay, Louisiana, at 6 p.m. Tuesday, September 11. The storm was moving slowly northwest at this point and was 450 miles southeast of New Orleans. At 9:30 p.m. a hurricane warning was issued for Panama City, Florida, to Grand Isle, Louisiana, in a special advisory.

Wednesday, September 12, an estimated 250,000 people evacuated coastal areas during the day. The center of Frederic moved over Dauphin Island, Alabama, and inland just west of Mobile, Alabama, between 10 and 11 p.m. Landfall was at the midpoint of the area placed under a Hurricane Warning earlier. The maximum storm surge, usually the big killer, was observed at 12 feet right near the middle of the forecast range of 10 to 15 feet. Highest observed winds were approximately 145 miles per hour at Dauphin Island.

Thursday, September 13, the storm weakened quickly as it moved inland.

CHAPTER II

<u>THE WARNING CHAIN</u> - Preparedness - Dissemination - Coordination - Public Response

There was a high level of hurricane preparedness in the county/city governments along the coast. This undoubtedly was a key factor in the low death toll for a strong hurricane -- one which almost completely destroyed, or very heavily damaged, several communities along the coast and caused over $2 billion in property damage. The counties had good evacuation plans and used them effectively in close coordination with the National Weather Service and the news media. In fact, Mobile County issued an updated and strengthened plan less than one month prior to being hit by Frederic.

Certainly, the fact that Hurricane Camille (1969) and Eloise (1975) had affected the same general section of the Gulf within the last decade and that Hurricane David had killed so many in the Caribbean less than 2 weeks earlier helped motivate people to evacuate. However, the major credit for the preparedness effort must be given to the NWS's preparedness program and to the efforts of Southern Region officials, particularly Neil Frank (Director, National Hurricane Center, Miami), David Barnes (Meteorologist in Charge, WSFO New Orleans), Raymond Barnes (MIC, WSO Mobile), and Phyllis Polland (MIC, WSO Pensacola), in cooperation with local Civil Defense directors, the news media and others.

Almost unanimously the Civil Defense directors attributed the success achieved in Frederic to the year after year preseason education and awareness programs and drills; to the close alliance between Civil Defense and the NWS at the state-county-city levels; and to the total cooperation and support of the news media.

The NWS considers its preparedness and coordination activities indispensible to the total warning program. Ever since Camille in 1969 struck viciously at the Mississippi coastline a "team" of dedicated people from the states from Texas to Florida have poured all their energies into a heightened public awareness campaign as well as the exercising of disaster and evacuation plans. The "team" consisted of NWS employees, civil defense directors, law enforcement officials, the news media, Red Cross workers, volunteer amateur radio operators, educators and others.

Hurricane Eloise's impact along Florida's coastline near where Frederic came in proved the value of such preparedness efforts and even intensified those coordinated efforts.

The NWS, together with all county/city officials responsible for public safety, hold conferences before the hurricane season together with news directors of radio and television and newspaper editors and reporters. The purpose is to update disaster plans, coordinate communications systems and enlist the help of the news media in a continuing education venture.

Those type meetings were held in every area where Frederic hit and have taken place annually since Camille hit a decade before.

The role of radio and television before and during Frederic's onslaught -- and afterwards, was superb. Their dedication to hurricane awareness and education before the season, along with newspapers carrying safety information and advice, were largely responsible for the wise and orderly public actions.

The NWS's dissemination channels, NOAA Weather Radio (NWR), the NOAA Weather Wire Service (NWWS), and the use of FEMA's National Warning System (NAWAS), worked well throughout the storm until the NWR's at Gulfport, Pensacola, Mobile, and Panama City lost commercial power. Communications between the WSO's Pensacola and Mobile, the public officials, and the media never completely failed.

The Mobile County Civil Defense had also installed a Plectron radio system throughout Mobile County. This system is used to distribute emergency information without dependence on land lines. It links the Mobile County Emergency Operations Center, the National Weather Service, and radio and TV stations and certain other offices. The system produces a recorded message at the receiving end and was used quite effectively during Frederic. However, it was also partially out during the height of the storm. The recipients included the local Emergency Broadcast System (CPCS-1) station, WABB. The WABB chief engineer, Mr. Rene Stiegler, felt that there should be a backup system to link his station with WSO Mobile as a precautionary measure.

In accordance with a prearranged plan, an amateur radio group set up an operation at WSO Pensacola early Wednesday afternoon and maintained a communications link with the Emergency Operations Center and the shelters until Thursday afternoon. This was very helpful to all concerned. A similar arrangement was placed in operation at WSO Mobile. Mr. Prentiss Baughman, Civil Defense Director of Baldwin County, said that the amateur group was his only link with WSO Mobile after his phones went out late Wednesday afternoon. He considered their contributions invaluable.

CHAPTER III

EVALUATION OF OFFICIAL FORECASTS, OBJECTIVE FORECASTS, AND NMC GUIDANCE

A. National Hurricane Center (NHC) Evaluation

1. Introduction

Seven objective techniques are available to the hurricane forecaster preparing an advisory. Forecasts through 72 hours are based on the four synoptic times of 0000, 0600, 1200, and 1800 GMT. The statistical techniques, NHC67, NHC72, HURRAN, and CLIPER[1] are available every 6 hours (the HURRAN occasionally does not have enough cases), and are received in time for the forecaster to use them for the advisory based on the synoptic time for which they were run. This means that the forecaster can use the forecast positions from these techniques for the same valid times as his 12, 24, 48, and 72 hour forecasts.

The three dynamic techniques - NHC73, SANBAR, and MFM (NMC Movable Fine Mesh model 1) - require upper air data and are not received until 6 to 9 hours after the 0000 or 1200 GMT synoptic times on which they are based. This does not allow them to be used as guidance for the advisory based on the synoptic time for which these techniques are run, and requires the forecaster to interpolate or extrapolate to obtain forecast positions compatible with the advisory being prepared when they become available. In essence, this requires 36 and 48 hour forecasts based on dynamic techniques to be as accurate as 24 and interpolated 36 hour official forecasts if one considers such guidance in the most critical application - the issuance of hurricane watches and warnings.

These considerations together with the impact of directional or speed biases should be remembered in evaluating the following tables and comments.

2. Verification

The following tables give various comparisons of the official and objective forecast technique errors based on the official best track given in the included preliminary report on Hurricane Frederic. Table 1 gives the verification for all forecasts for the official and objective techniques for the periods when Frederic was of tropical storm or hurricane intensity. Table 2 gives the verification of the six cases available for all forecasts when Frederic was in the Gulf of Mexico.

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[1] Attachment 1 gives a brief description of the various objective techniques.

A significant consideration in evaluating the utility of the various forecasts is the forecast errors during critical forecast periods. Table 3 gives the average forecast errors for two periods. The first is from 9/2/0000 GMT to 9/4/0000 GMT when Frederic was approaching Puerto Rico and the Virgin Islands. The second is the period from 9/10/0000 GMT to 9/12/1800 GMT when Frederic was in the Gulf of Mexico approaching the U.S. mainland. It is not known in advance which forecasts will be exactly the critical ones for issuing hurricane watches and warnings, because the forecasts have such large differences in projected landfall times. However, a post-analysis can be made from the best track based on actual time of landfall backwards to the forecasts actually available to the forecaster 24 and 36 hours before landfall. These, of course, are the truly critical individual forecasts upon which hurricane warnings and watches are nominally issued. Table 4 gives these forecasts with those for a watch circled and a warning boxed.

3. Discussion

In Table 1, results for the MFM are unrealistic for comparison with the other techniques, the seven cases comprising less than 20% of the official forecasts, and all occurring in the Gulf of Mexico where data is plentiful. Table 2 gives a homogeneous sample for the 6 cases in the Gulf of Mexico for which the MFM and all other techniques were available. In this comparison the MFM has the poorest verification at 12 hours and second poorest at 24 hours. However, it becomes the best at 48 hours. The statistical techniques show the reverse with the official and other dynamic techniques somewhere in between. Similar results have been noted previously in larger samples.

Excluding the MFM, Table 1 shows the official forecasts with the minimum forecast errors for all time periods except the 72 hour NHC73 which was slightly better.

While detailed directional and speed bias analysis is not available for this evaluation, the following comments can be made with particular emphasis on forecasts in the Gulf of Mexico:

a) Official forecasts showed a slight bias to the right of the observed track during early forecasts, especially for the extended periods, but were generally on track as the center approached the coast. Forecasters tend to forecast the center a few tenths of a degree of latitude beyond that expected (faster) to take into account the onset of hurricane conditions several hours before the center makes landfall.

b) The NHC67 forecasts showed biases similar to the official forecasts early in the period, but were very good as the center approached the coast. The NHC72 is so affected by the changes in analysis at NMC in recent years that forecasters place little credence in it beyond 24 hours at present. Relatively good verification for time periods of 12 and 24 hours is a result of the large contribution of persistence-available from several other techniques. After the NHC73, the NHC72 used to be one of the forecasters' best guidance tools! Guidance from the HURRAN technique was good to excellent out to 72 hours as Frederic approached the northern Leeward Islands and very good out to 24 hours from the time Frederic left Cuba to its U.S. mainland approach. The CLIPER forecasts were not so good approaching the Leeward Islands and Puerto Rico but verified well approaching the mainland. However, they suffered from a strong bias to the right (east), while the HURRAN had a slight bias to the left (west).

c) The NHC73 forecast verification appears good to excellent throughout 72 hours both approaching the Leeward Islands and the U.S. mainland. However, forecasts in the Gulf of Mexico were all to the right (east) of the observed track and too slow. This illustrates the importance of verifying the speed and direction bias and landfall accuracy implications in terms of watch and warning areas, based on the availability of the techniques and their critical time frame forecasts. As mentioned earlier, in the case of the dynamic techniques - MFM, SANBAR, NHC73 - the 36 hour and 48 hour forecasts are those available for 24 hour warning and 36 hour watch decisions! SANBAR forecasts were erratic approaching the Leeward Islands and Puerto Rico. In the Gulf of Mexico they were slow but pretty much along the observed track. The MFM model appears to have developed a quirk whereby the forecast (vortex) goes west of the observed initial motion for 12 to 24 hours and then recurves and accelerates to cross the observed track by 48 hours. This contributed to a slow bias for all forecasts.

4. Summary of Forecast Evaluation

A study by Neumann of NHC has shown the tendency of the statistical techniques to do better in the shorter time frames and the dynamic techniques in the longer time frames. However, it is very difficult for the operational forecaster to "hook-up" the positive aspects of the different objective guidance when the dynamic techniques have strong initial directional and speed biases. For westward and northward moving storms/hurricanes threatening land, official forecasts try to stay ahead of the center and slightly to the left as a "least regret" philosophy because of the obvious disastrous consequences of predicting a landfall too late or out of the hurricane warning area. The tendency for most objective techniques to have a right bias and be slow in critical situations can have a compromising effect on the forecaster's thinking and consequently the official forecast.

While Tables 1 through 4 are for a single storm with a relatively small number of cases, they are quite representative in almost all cases of typical distributions of forecast errors for the various types of forecasts for various samples and time periods. As always, at the time of each individual forecast the forecaster does not know which technique (even his own) will turn out to be the best choice.

5. NMC Numerical Prog Guidance

The numerical prog charts Limited-area Fine Mesh. (LFM), Primitive Equation (PE), Barotropic, were examined for the period 9/10/1200 GMT to 9/12/1200 GMT which coincides with the second critical period considered previously for the official and objective techniques. The guidance from these prog charts was evaluated from two points of view. The first is to use the low centers or vorticity maxima to track the hurricane itself, and the second to use the prevailing synoptic scale featuers other than the hurricane itself to make subjective estimates of their effect on the hurricane.

In the case of Frederic, the numerical guidance for the first aforementioned purpose contributed little directly to the forecast. By 24 hours, the P.E. and Barotropic models showed no evidence of the hurricane low which was present in the initial analysis for any of the five forecast packages! The LFM surface low always went west and southwest during the 48 hour period, the 700 mb low too far west and too slow, and the 500 mb low disappeared with the vorticity maximum making landfall only twice, and well east of the observed track. The 700 mb and 500 mb hurricane vortex appeared to merge with a cold low near the Texas coast during latter forecast times as the cold low moved east and northeast. Earlier prog packages showed the low remaining stationary near the central Texas coast but it came eastward as a stronger than forecast low during latter forecast periods. Not surprisingly, the MFM and LFM appear to have similar problems in the early portions of the forecast period.

The forecasters were able to make the more general use of the NMC prog guidance by noting the presence of the long wave troughs and ridges, and, to a lesser extent, the influence of the short waves in the westerlies as they interacted with the hurricane. In this case, the guidance precluded to a high degree of confidence a turn of Frederic to the west, and to a lesser degree, a critical landfall in the New Orleans area.

6. Storm Surge Guidance

The SPLASH objective storm surge models were run at 0800 GMT on September 12 to obtain guidance for the storm surge values to be used in the 1000 GMT advisory on Frederic. The SPLASH I was run for a landfall 45 miles east of Gulfport, Mississippi, or just west of Mobile Bay with an expected central pressure of 940 millibars moving northnorthwest at 11 knots.

The accuracy of these forecast parameters determines the accuracy of the storm surge profile along the coast. In this case the landfall forecast was very good with the central pressure 946 millibars and the other parameters about as used. The model gave a peak surge of 11.5 feet above MSL on the open coast south of Mobile. The advisory forecast tides of 10 to 15 feet above normal near and to 100 miles east of where the center makes landfall. The wording of this statement is to allow for higher tides at the heads of bays and estuaries and to allow for forecast error and also not specify the landfall point too far in advance. The highest tides reported thus far in the Mobile area range from 8 to 12 feet above MSL.

An interesting note is that this hurricane with the same parameters would result in a model forecast of 19 feet above MSL near Bay St. Louis if the center made landfall just east of New Orleans.

The guidance furnished by SPLASH I in this instance was excellent.

TABLE 1. Initial position errors are displacement errors in nautical miles for all forecasts of Frederic while it was of tropical storm or hurricane intensity. Number of cases are in parentheses.

	INITIAL POSITION	12-HR	24-HR	36-HR	48-HR	72-HR
OFFICIAL	20 (48)	37 (43)	71 (43)	 (0)	147 (33)	217 (28)
NHC67	19 (44)	47 (42)	97 (39)	141 (35)	172 (31)	283 (26)
NHC72	20 (49)	44 (47)	87 (44)	152 (40)	261 (36)	347 (31)
HURRAN	20 (43)	39 (42)	89 (41)	127 (38)	185 (35)	223 (28)
CLIPER	20 (49)	37 (47)	81 (44)	119 (40)	157 (36)	225 (31)
NHC 73	19 (21)	37 (20)	88 (19)	135 (17)	151 (15)	201 (14)
SANBAR	19 (23)	42 (22)	80 (21)	117 (19)	184 (17)	344 (15)
MFM	11 (7)	35 (7)	66 (7)	91 (7)	127 (7)	

TABLE 2. Initial position errors and displacement errors in nautical miles for the 6 cases on Frederic in the Gulf of Mexico available for all forecasts.

	INITIAL POSITION	12-HR	24-HR	36-HR	48-HR	72-HR
OFFICIAL	12	29	55		160	
NHC67	12	20	29		142	
NHC72	12	18	57		252	
HURRAN	12	23	66		225	
CLIPER	12	20	59		202	
NHC73	12	20	51		164	
SANBAR	12	29	58		217	
MFM	12	36	65		142	

TABLE 3 Individual initial position errors and displacement errors in nautical miles for critical forecasts as Frederic approached 1) Puerto Rico and 2) the United States mainland. Forecasts which would be used for a hurricane watch are circled and for a gale or hurricane warning are boxed.

1. PUERTO RICO

	DATE/TIME (GMT)	INITIAL POSITION	24-HR	36-HR	48-HR
OFFICIAL	9/3/00	66	(58)	INTERPOLATED	(180)
	9/3/06	12	44		199
	9/3/12	17	[72]		259
NHC67	9/3/00	66	128	(183)	238
	9/3/06	12	93	162	229
	9/3/12	17	[121]	252	497
NHC72	9/3/00	66	90	(194)	186
	9/3/06	12	33	103	157
	9/3/12	17	[47]	152	187
HURRAN	9/3/00	66	97	(162)	252
	9/3/06	12	82	128	226
	9/3/12	17	[85]	138	244
CLIPER	9/3/00	66	150	(251)	369
	9/3/06	12	76	144	258
	9/3/12	17	[72]	140	243
NHC73	9/2/12	6	33	41	(48)
	9/3/00	66	67	[110]	87
SANBAR	9/2/12	6	48	108	(174)
	9/3/00	66	141	[265]	249

2. UNITED STATES

	DATE/TIME (GMT)	INITIAL POSITION	24-HR	36-HR	48-HR
OFFICIAL	9/11/12	5	(63)	INTERPOLATED	(175)
	9/11/18	13	84		259
	9/12/00	5	[47]		143
	9/12/06	5	24		204
NHC67	9/11/12	5	6	(48)	58
	9/11/18	13	41	99	140
	9/12/00	5	[24]	79	114
	9/12/06	5	32	49	123
NHC72	9/11/12	5	38	(103)	264
	9/11/18	13	61	133	258
	9/12/00	5	[87]	179	334
	9/12/06	5	73	192	403

TABLE 4 Average initial position errors and displacement errors in nautical miles for critical forecasts as Frederic approaches Puerto Rico and[2] the United States mainland. Number of cases are in parentheses.

1 Leeward Islands, Virgin Islands, Puerto Rico

	INITIAL POSITION	12-HR	24-HR	36-HR	48-HR	72-HR
OFFICIAL	24 (9)	36 (9)	72 (9)	- (0)	188 (9)	289 (7)
NHC67	24 (9)	45 (9)	108(9)	166(9)	204 (9)	353 (7)
NHC72	24 (9)	44 (9)	71 (9)	139(9)	165 (9)	190 (7)
HURRAN	24 (9)	38 (9)	76 (9)	120(9)	165 (9)	224 (7)
CLIPER	24 (9)	42 (9)	95 (9)	166(9)	227 (9)	320 (7)
NHC73	23 (5)	31 (5)	71 (5)	111(5)	109 (5)	64 (4)
SANBAR	23 (5)	30 (5)	75 (5)	143(5)	211 (5)	312 (4)

2 United States

	INITIAL POSITION	12-HR	24-HR	36-HR	48-HR	72-HR
OFFICIAL	13 (12)	23 (12)	49 (12)	(0)	152 (11)	233 (7)
NHC67	13 (12)	33 (12)	77 (12)	77 (12)	125 (11)	274 (7)
NHC72	13 (12)	24 (12)	59 (12)	119(12)	230 (11)	323 (7)
HURRAN	13 (11)	28 (11)	72 (11)	137(11)	137 (11)	306 (6)
CLIPER	13 (12)	28 (12)	71 (12)	135(12)	209 (11)	336 (7)
NHC73	15 (6)	20 (6)	48 (6)	105(6)	159 (6)	230 (4)
SANBAR	15 (6)	32 (6)	61 (6)	123(6)	234 (6)	471 (4)
MFM	12 (7)	38 (6)	70 (6)	88(6)	120 (6)	(0)

TABLE 4 CONTINUED.
UNITED STATES

	DATE/TIME (GMT)	INITIAL POSITION	24-HR	36-HR	48-HR
HURRAN	9/11/12	5	61	131	217
	9/11/18	13	69	146	297
	9/12/00	5	78	156	267
	9/12/06	5	78	195	336
CLIPER	9/11/12	5	53	126	198
	9/11/18	13	85	151	236
	9/12/00	5	88	150	196
	9/12/06	5	78	152	249
NHC73	9/11/00	18	28	105	124
	9/11/12	5	54	129	176
SANBAR	9/11/00	18	68	130	221
	9/11/12	5	68	134	212
MFM	9/11/00	18	121	129	115
	9/11/12	5	39	72	118

Objective Forecast Techniques

The following tropical cyclone prediction models were used at the National Hurricane Center for forecasting motion on an operational basis:

1. NHC-67 (Miller, Hill, Chase, 1968). A stepwise screening regressing model using predictors derived from the current and 24-hour old 1000, 700, and 500 mb data, and includes persistence during the early forecast periods.

2. SANBAR (Sanders and Burpee, 1968). A filtered barotropic model using input data derived from the 1000 to 100 mb pressure weighted winds. The model requires the use of "bogus" data in data-void areas. The system was modified by Pike (1972) so that the initial wind field near the storm would conform to the current storm motion.

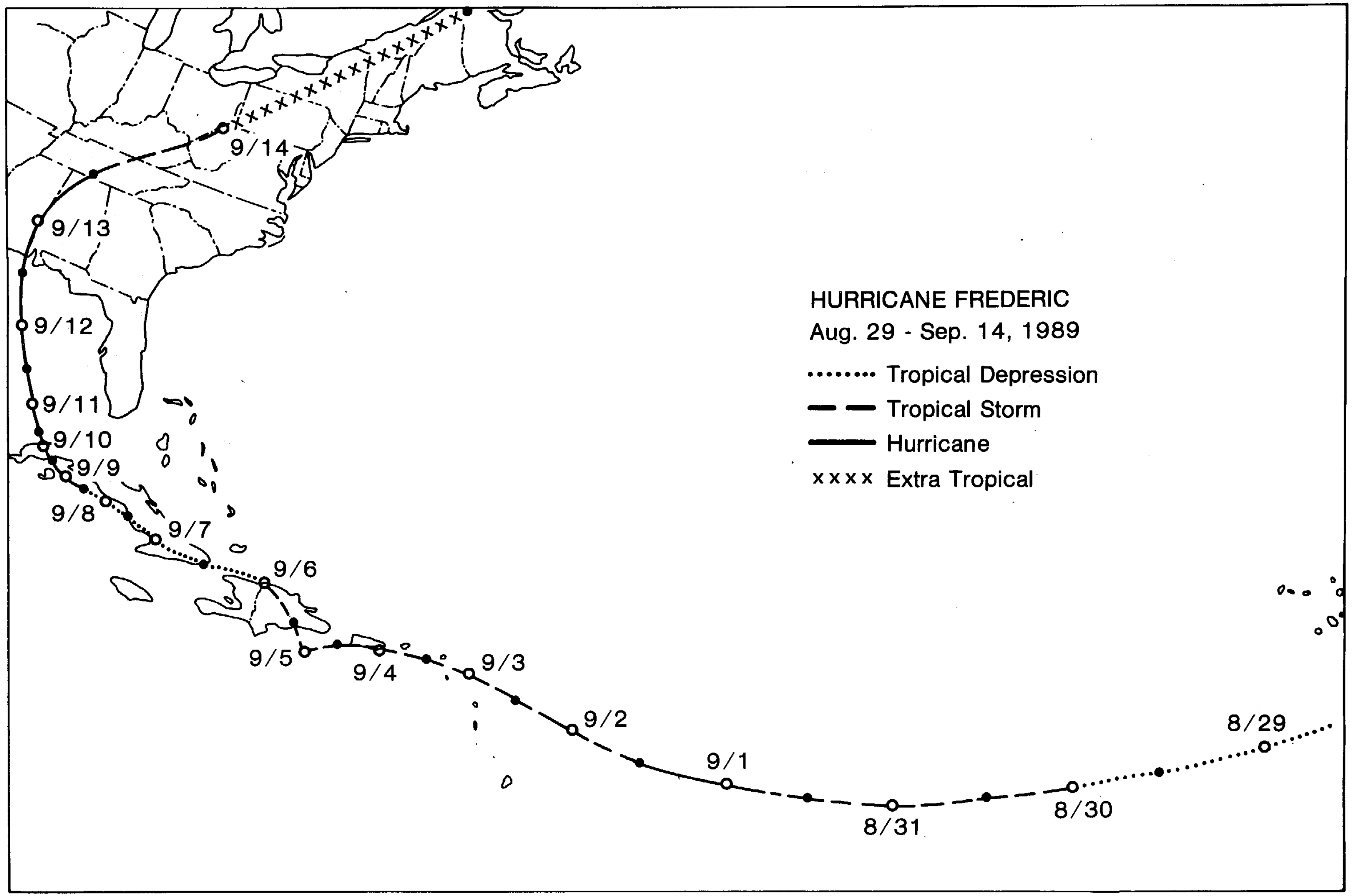
3. HURRAN (Hope and Neumann, 1970). An analog system using as a data base the tracks of all Atlantic tropical storms and hurricanes dating back to 1886.

4. CLIPER (Neumann, 1972). Stepwise multiple screening regression using the predictors derived from climatology and persistence.

5. NHC-72 (Neumann, Hope, Miller, 1972). A modified stepwise multiple screening regression system which combines the NHC-67 concept and the CLIPER system into a single model.

6. NHC-73 (Neumann and Lawrence, 1973). Similar in concept to the NHC-72 except it also used the "perfect prog" and MOS (model output statistics) methods to introduce NMC (National Meteorological Center) numerical prognostic data into the prediction equations.

7. NMC MFM MODEL (Hovermale, 1975). A ten-level baroclinic model which uses a moving fine mesh (MFM) grid nested within the coarser NMC fixed grid primitive equation (PE) model. It is capable of predicting both track and intensity changes.


HURRICANE FREDERIC
Aug. 29 - Sep. 14, 1989
Tropical Depression
Tropical Storm
Hurricane
xxxx Extra Tropical
8/29
8/30
8/31
9/1
9/2
9/3
9/4
9/5
9/6
9/7
9/8
9/9
9/10
9/11
9/12
9/13
9/14

B. NMC Quantitative Precipitation Forecasts

The swath of heaviest rainfall was to the left of the observed track of Frederic's circulation center, in contrast to David where the heaviest rainfall occurred to the right of its track.

Frederic's rainfall maximum of 8" - 10" over southeast Mississippi tapered off to 5" - 6" as the decaying storm center moved northward west of the Appalachians.

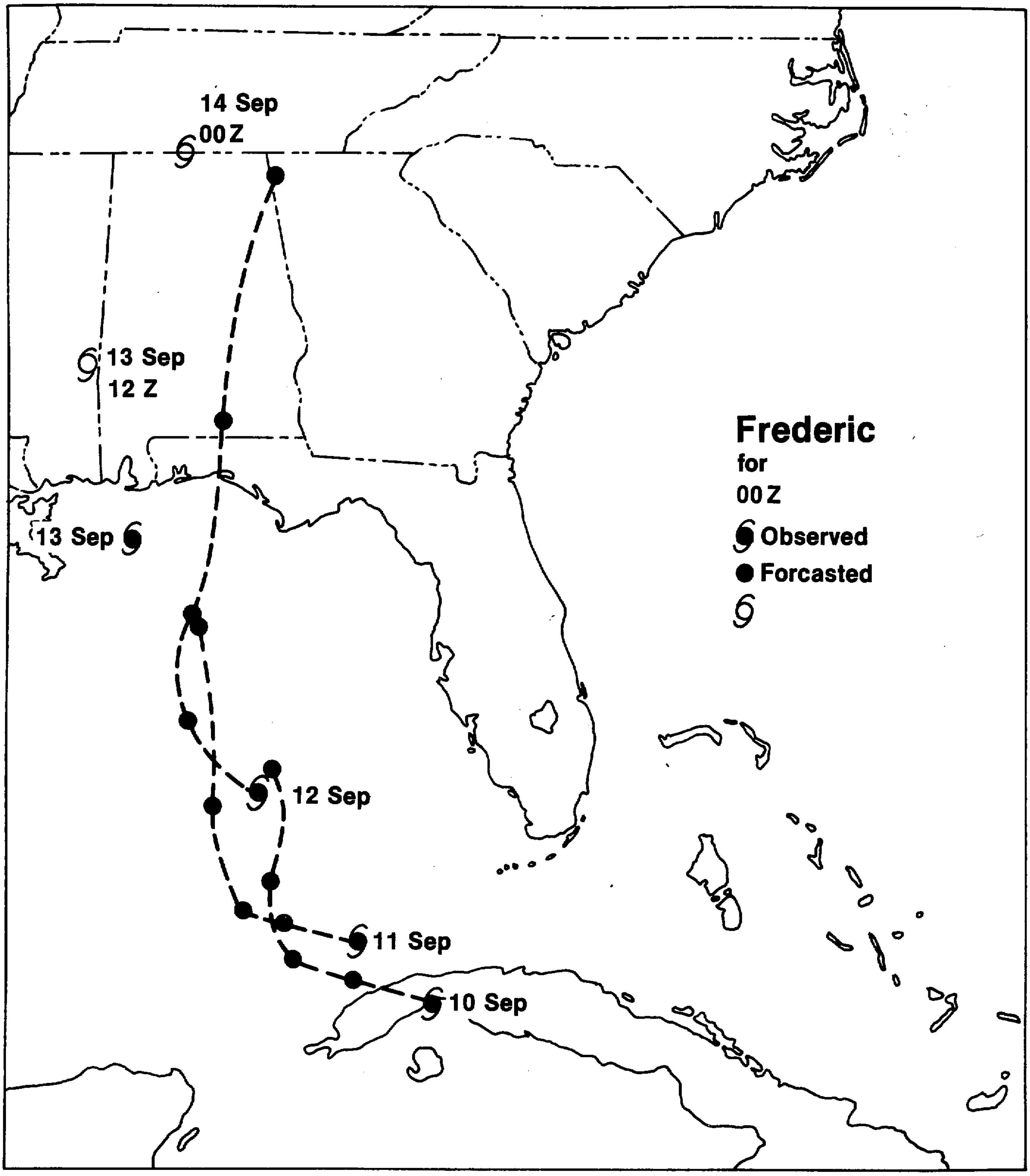
All numerical precipitation guidance was available throughout the storm. The areal extent of 1" rainfall was fairly well forecast by the Limited Fine Mesh (LFM) but was unable to indicate either the magnitude of the steep gradient of the rainfall. The MOS probability of precipitation amount (POPA) guidance largely resembled the explicit solutions, with the exception that it added substantially sized areas of spurious and erroneous 1" - 2" rainfall. The MFM precipitation forecasts showed larger amounts than the LFM (in fact, at times too large) but overall were not very good at predicting either speed of the maximum or the axis of heaviest rainfall.

NMC's subjective QPF's were by far the best guidance issued for rainfall amounts. These forecasts correctly indicated 8" or more associated with landfall and consistently showed a 5" - 6" forecast along and slightly to the left of the predicted track. Early forecasts of the northward extension of the rains were slow, corresponding to the slowness of the forecast movement of Frederic. Frederic was forecast slightly too far to the east in the Appalachians, which helped cause a corresponding small error in the placement of the relatively narrow maximum rainfall.

Excessive rainfall potential forecasts from Forecast Division were timely and accurate, adjusting quickly to expected deviations from the forecast track. For example, the 0730Z scheduled outlook indicated possible rainfall in excess of 5" from Meridian, Mississippi, to central West Virginia in an area about 90 miles wide, completely consistent with the predicted track of Frederic. At 1430Z the expected axis of maximum rainfall was correctly shifted west about 70 miles. Maximum indicated rainfall of 5" - 8" was correct. Later that evening an adjustment for speed was indicated which correctly brought excessive rainfall into western New York by 12Z the following morning.

Coordination calls were held with most of the affected WSFO's concerning expected rainfall. The quality, credibility and timeliness of the scheduled forecasts and specials undoubtedly significantly reduced the possible number of calls.

In summary, the LFM provided perhaps the best numerical guidance for the extent of 1" - 2" rainfall. Scheduled 24-hour period QPF's were consistent with the official forecast track and correctly indicated the rainfall amounts, although typically were a little to the east and a little slow. Excessive rainfall potential forecasts -- both scheduled and unscheduled -- showed the flexibility desired in adapting to errors in circulation forecasts by being able to modify the important aspects of earlier forecasts.


14 Sep
00 Z
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Frederic
for
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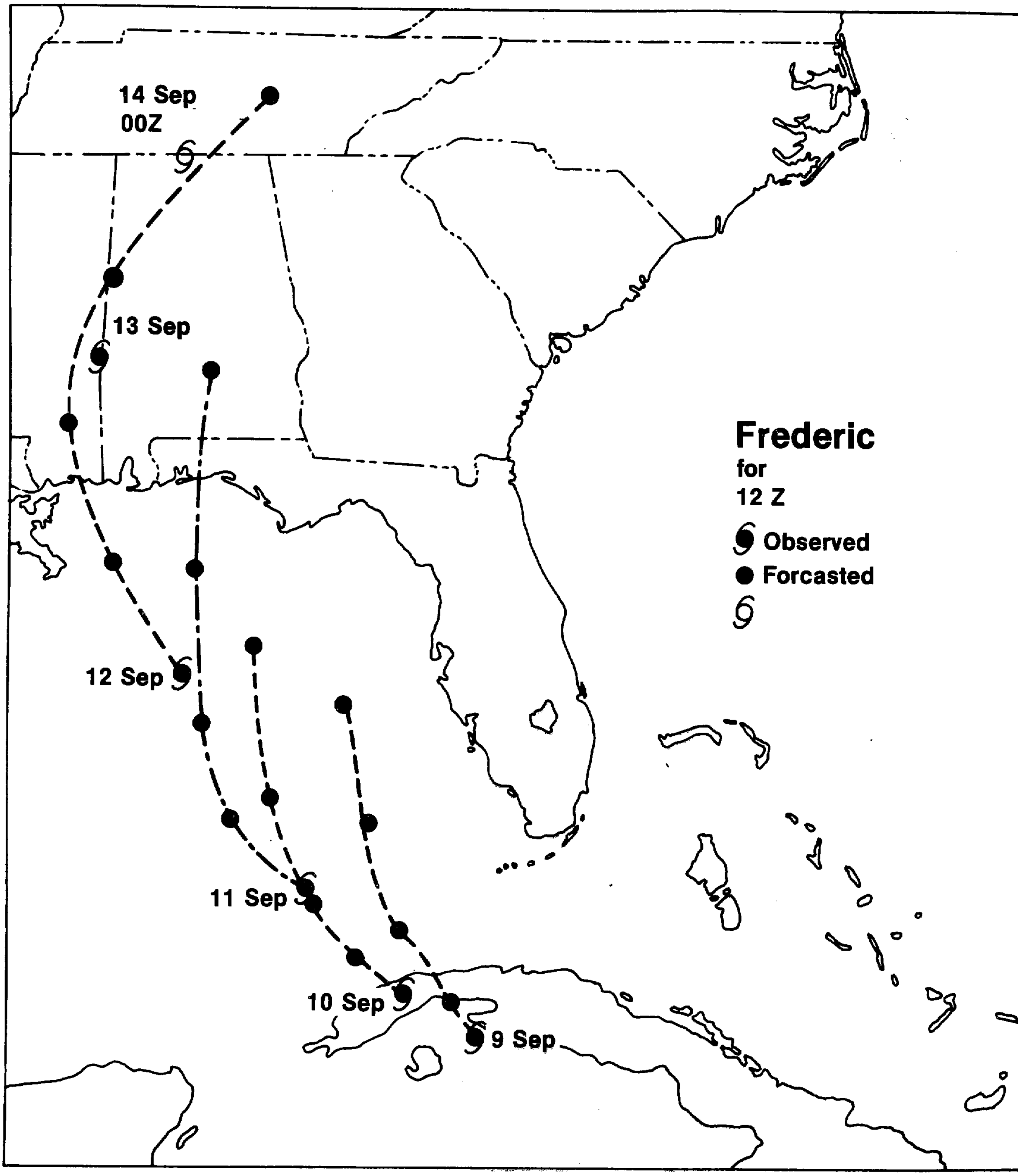
Observed
Forcasted


14 Sep
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Frederic
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CHAPTER IV

MONITORING

A. Aerial Reconnaissance

The National Hurricane Operations Plan states that the "Department of Defense (DoD) will attempt to fulfill all Department of Commerce (DoC) requirements; however, based on stated DoC needs, DoD will normally be prepared to generate up to five reconnaissance aircraft sorties per day. Requirements exceeding this capability will be executed on a resource permitting basis. Research aircraft of NOAA's Research Facilities Center (RFC) may be diverted to fulfill urgent operational requirements." The Director of the National Hurricane Center is responsible for identifying the total operational requirements for hurricane reconnaissance in the Atlantic, Caribbean, Gulf of Mexico, Eastern Pacific, and Central Pacific. He is responsible for advising the Chief, Aerial Reconnaissance Coordination, All Hurricanes, (CARCAH) of these requiements. The CARCAH is responsible for coordination and the final preparation of the Tropical Cyclone Plan of the Day (TCPOD) and for scheduling of aircraft required to meet the provisions of the Plan. The CARCAH will coordinate the TCPOD with NHC, Keesler Weather Reconnaissance Coordination Center and the RFC before publication. The RFC may be requested to:

(1) Augment the U.S. Air Force (USAF) for operational aircraft reconnaissance with high-density/accuracy data, when storms are within 24 hours of landfall of the continental United States.

(2) Augment capabilities for USAF aircraft reconnaissance when DoC needs exceed the capabilities of DoD resources.

(3) Assume responsibility for hurricane reconnaissance over foreign airspace that may be restricted for military operations.

(4) RFC may also conduct research flights which assume an operational responsibility to the hurricane forecast centers. As is apparent all of this requires extensive effort on the part of CARCAH to insure that operational requirements are fully met, recognizing problems of maintenance, logistics, communications, and in the case of Frederic, evacuation of an operational base (Keesler).

A review of the aerial reconnaissance activity, based upon the records retained by CARCAH, reveals that 49 scheduled fixes were requested by NHC for Frederic and all were obtained on time. An additional 18 extra fixes were obtained. To accomplish this 28 missions were flown with a total of 273 hours. The 920th Weather Reconnaissance Group (WRG) flew 15 missions; the 53rd Weather Reconnaissance Squadron (WRC) flew 8 missions; and the RFC flew 5 missions.

This outstanding record resulted from hard work and fine cooperation by all individuals and units involved. CARCAH coordinated activities to meet the reconnaissance requirements of NHC and on several occasions was able to maintain the continuous support required by exchanging reconnaissance commitments among the various participating units.

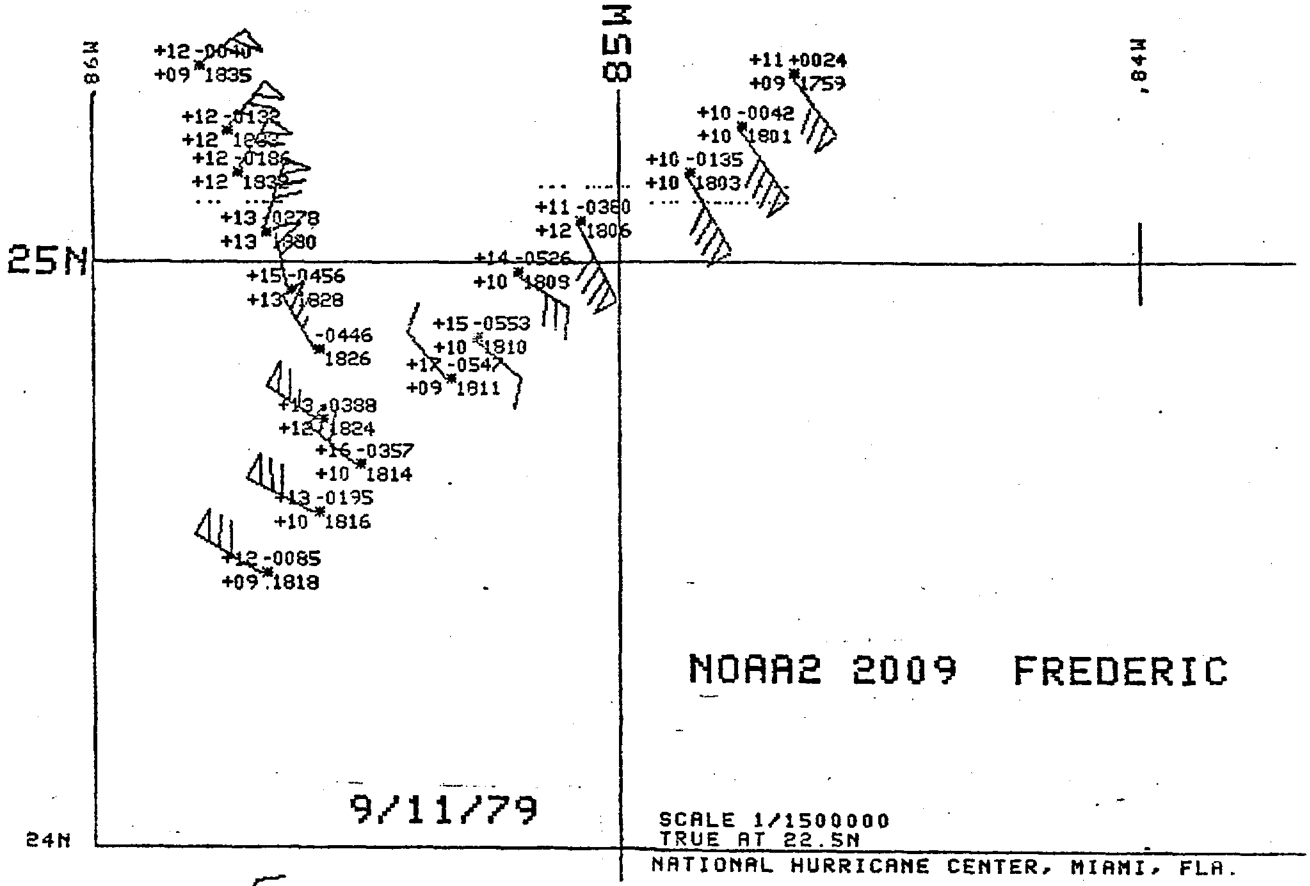
The first scheduled reconnaissance mission on Frederic was flown by the 53rd WRS on September 2, 1979, with the 1200Z position at 15:37N and 57:13W. Lowest sea level presure was 996 mb with a maximum surface wind of 70 knots. The 53rd flew the next two missions.

The 920th WRG flew the next two missions with the storm decreasing in intensity as it moved over Puerto Rico. The storm continued to move in its weakened condition with aerial reconnaissance maintained at six hourly intervals. The track was over Hispanola and the length of Cuba. Finally it freed itself from Cuba later on September 10th. Mission 19 on Frederic was flown by the 920th with the surface pressure 985 mb and surface winds of 45 knots. By September 11 at 1210Z the storm had quickly intensified to hurricane force with 980 mb surface pressure and surface winds of 95 knots. This was the first Frederic mission flown by the RFC.

The RFC flew five missions among the last nine that were flown on Hurricane Frederic. The high density data from the research aircraft are extremely useful, especially in the 24 hours prior to landfall. The high density and precision information on location, wind speed, and direction at flight level are needed for input to newly developed numerical prediction models. These new models use grid spacings of about 30 Km and produce significant improvements in predictions of both storm path and intensity. An example of the data which are routinely available to the NHC from NOAA's aircraft is shown in Figure 1. These data are transmitted from the aircraft via satellite to Wallops Island, Virginia, and then via landline through the National Environmental Satellite Service (NESS) computer in Washington, D.C., and on to NHC. At NHC the data are plotted by an on-line computer. This system allows for a rapid visual display of this information.

It is essential that some of the USAF aircraft that reconnoiter storms be equipped to provide more precise and detailed data similar to the data available on the RFC aircraft. At this time the maximum winds reported by USAF aircraft are estimated since the observed winds are an average over about a ten minute time interval. The winds in a storm can make some significant changes in ten minutes.

For example, in NOAA flight 2709 on Frederic 9/13/79 (Figure 1) from 02107 to 02207 the wind increased from 25 knots to 95 knots then decreased to 65 knots. This would be observed


86W
85W
84W
25N
24N
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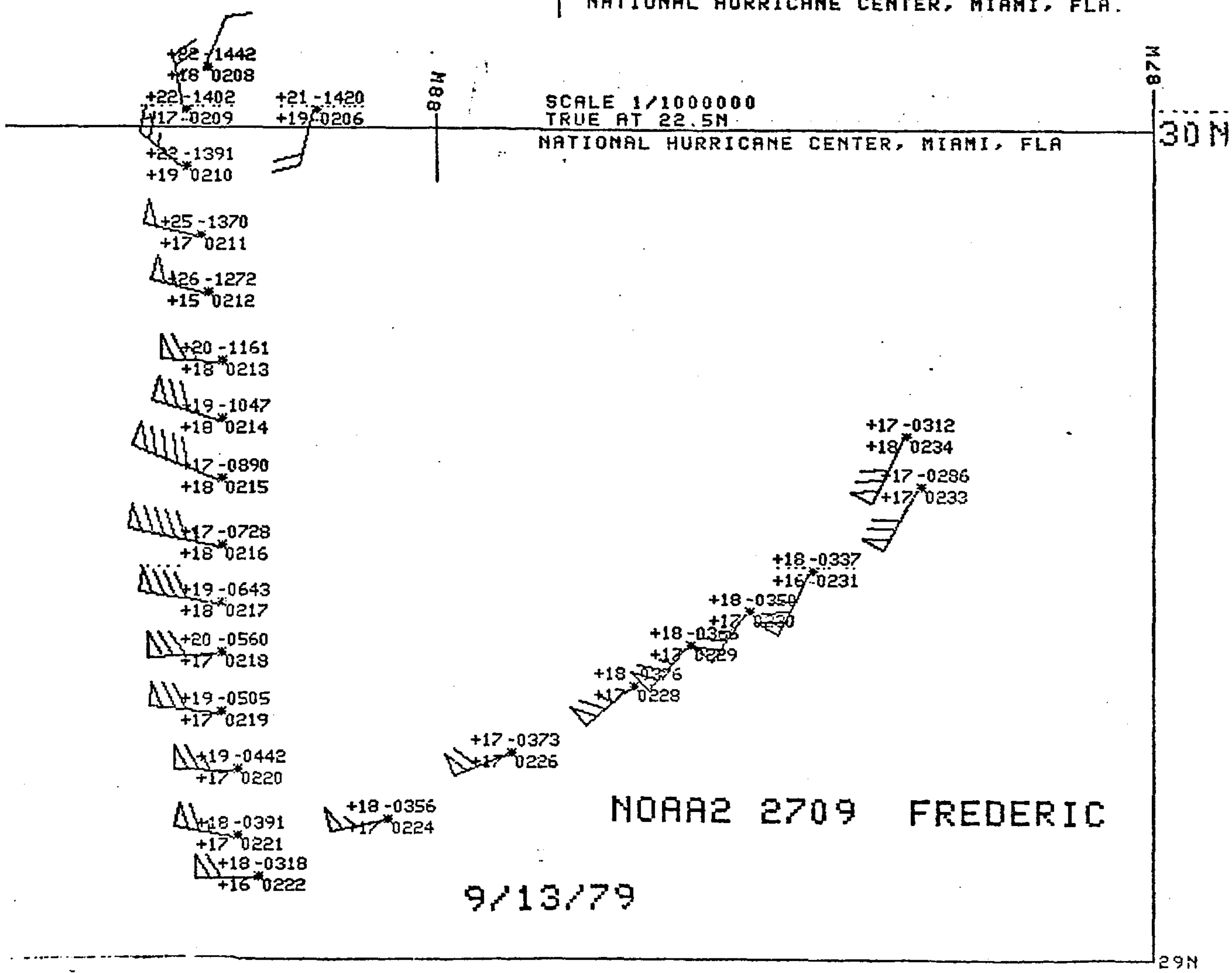
NOAA2 2009 FREDERIC
9/11/79
SCALE 1/1500000
TRUE AT 22.5N
NATIONAL HURRICANE CENTER, MIAMI, FLA.


88W
87W
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NATIONAL HURRICANE CENTER, MIAMI, FLA
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+17 -0286
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+18 0234
NOAA2 2709 FREDERIC
9/13/79

by USAF reconnaissance aircraft as 68 knots and the maximum wind estimated to be something higher than that. But the detailed wind speed distribution within that 10 minutes (or about 55 miles) is lost. This is important information to the forecasting model as well as the analysts at NHC.

Some areas along the coast cannot evacuate in such a timely manner as did Mobile citizens. Many places require more than 24 hours for such an orderly evacuation. This requires high density and accurate information while the storm is still 36 to 48 hours from landfall. This cannot be accomplished with only the three NOAA aircraft. Only with dedication and good luck was RFC able to generate the five missions in two days for Hurricane Frederic. USAF must also be equipped to provide this data for the longer time needed for specific and more advanced warnings required for these areas.

B. Evaluation of Satellite Systems

The National Environmental Satellite Service (NESS) provided continuous and comprehensive support to the National Weather Service during Hurricane Frederic. Geostationary Operational Environmental Satellite (GOES) data displays and communication networks performed effectively at all NESS and NWS field offices. Gridding accuracy was quite acceptable with only minor difficulties.

I. NWS Support

(1) The Kansas City Satellite Field Service Station (SFSS) and the Gulf Support Unit provided Weather Service Forecast Offices with detailed information prior to and after landfall. Satellite Interpretation Messages (SIMS) and numerous telephone coordination calls provided guidance for marine forecasts, local forecasts, and special weather statements issued by forecast offices.

The Gulf of Mexico SIMS, issued every 6 hours included information about position, movement, and intensity of Hurricane Frederic. Satellite meteorologists carefully described atmospheric conditions surrounding the hurricane to provide forecasters important information over sparse data regions. SIMS also included high-level and low-level cloud motion vectors prepared by the Interactive Processing Group (IPG) of NESS. The Gulf Support Unit provided telephone coordination calls to the New Orleans WSFO which supplemented SIMS messages and kept forecasters aware of the latest satellite indicated trends.

(2) The Miami SFSS provided the National Hurricane Center (NHC) with timely and detailed analysis of Hurricane Frederic from August 29 to September 13, 1979. GOES data were utilized to determine storm location, intensity and movement. Hurricane forecasters were briefed routinely, and constantly were informed of the latest changes. SFSS meteorologists also provided input

parameters, calculations, and interpretation for the NHEML rainfall estimate model. This model produced rainfall potential guidance for NHC.

Examination of maximum wind information available to NWS forecasters revealed several noteworthy facts. Figure 1 shows maximum wind information from reconnaissance and satellite analysis during the 15 hour period preceding landfall. Even though NHC maintained 115 kts in the official advisories, reconnaissance and satellite information depicted the extreme variability experienced as the storm approached the coastline.

The Miami SFSS used the current Dvorak Satellite Tropical Cyclone Classification System during Frederic. The final product of this classification system produced an intensity (CI) number or maximum wind estimate (Figure 1). This maximum wind estimate, passed to NHC, relates closely with the official advisories. But since reconnaissance information is usually considered "ground truth," the CI number did not accurately represent the short term variability of the storm. (In fairness to the system, the CI number concept was not designed to define the short term variability of tropical cyclones).

Another part of the Dvorak classification system did correlate positively with aircraft wind measurements (Figure 1). This relatively new phase of the classification system utilizes enhanced infrared (EIR) imagery and a quasi-objective decision ladder. There is also some evidence that trends in these EIR intensity measurements actually preceded similar trends in maximum wind strength as measured by reconnaissance aircraft.

(3) The Synoptic Analysis Branch (SAB) together with the Kansas City SFSS supplied timely and extremely accurate satellite-derived rainfall estimates to the NWS (Figure 2.a). Rainfall estimates were especially useful for NWS forecasters because hurricane conditions substantially reduced the effectiveness of the rainfall reporting network. WSFO's used these estimates, together with radar data, to issue Flash Flood Warnings. The maximum satellite estimate of 12 inches was used directly in a Flash Flood Warning issued by the Jackson WSFO. This figure was used to represent a maximum potential and to update the 5 to 10 inch rainfall forecast carried in the Hurricane Advisories. Post-analysis of the maximum rainfall area indicated an 11 inch gage near Pascagoula, Mississippi, had overflowed during the hurricane (Figure 2.b).

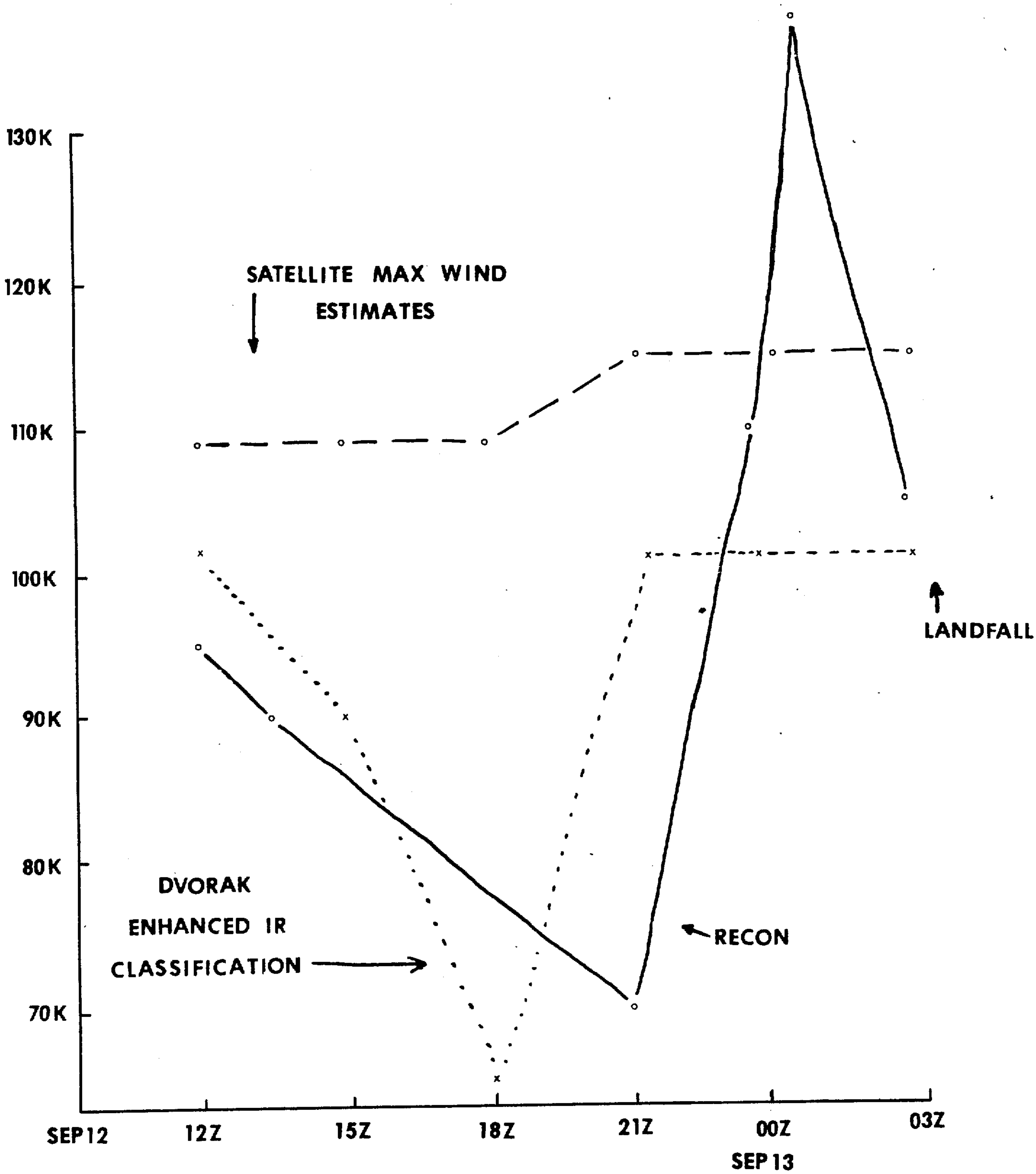
II. Media Support

The Miami SFSS supplied special prints to the UPI and the SAB periodically prepared special prints of Hurricane Frederic for the AP. A short descriptive text accompanied these prints. Local and national television stations along with local newspapers utilized this special product.

SAB and the Washington SFSS also cooperated with local news media. They provided use of the image analyzer for the "live" television broadcasts as Frederic approached and made landfall. Satellite meteorologists were also interviewed "live" to help interpret the iamgery for TV audiences.

Kansas City SFSS and Miami SFSS also cooperated with the news media providing extra pictures and professional interpretation of the data.

Fig. 1 Maximum winds of Hurricane Frederic: A comparison of Reconnaissance data with satellite derived wind and intensity estimates



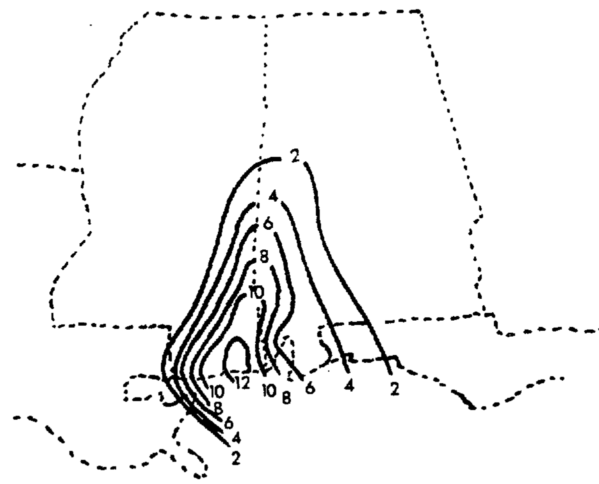


Fig. 2a Satellite derived rainfall estimates
(2130Z Sep 12 to 1100Z Sep 13)

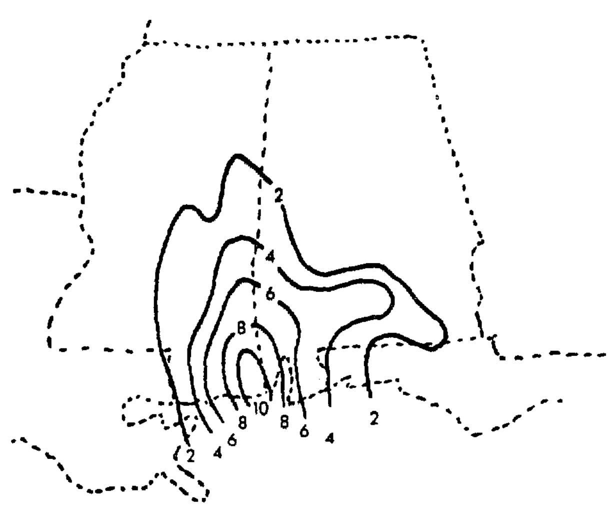


Fig. 2b Observed 24-hour rainfall
(1200Z Sep 12 to 1200Z Sep 13)