U.S. DEPARTMENT OF COMMERCE • ENVIRONMENTAL SCIENCE SERVICES ADMINISTRATION
Weather Bureau

TECHNICAL NOTE 11-T

TECHNICAL NOTE 11- TDL -2

Hurricane Cindy
Galveston Bay Tides

BASIC KNOWLEDGE
TECHNIQUES DEVELOPMENT LABORATORY
OPERATING PROCEDURES

TECHNIQUES DEVELOPMENT LABORATORY REPORT NO.2

WASHINGTON, D.C.
September 1965

WEATHER BUREAU TECHNICAL NOTES

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ENVIRONMENTAL SCIENCE SERVICES ADMINISTRATION
Robert M. White, Administrator

Weather Bureau

TECHNICAL NOTE 11-TDL 2

Hurricane Cindy Galveston Bay Tides

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WASHINGTON, D.C.
September 1965

HURRICANE CINDY GALVESTON BAY TIDES

by

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ABSTRACT

Hurricane Cindy of September 1963 probably produced the most completely recorded set of tide data in a bay of any United States hurricane. Hydrographs showing the water levels in Galveston Bay along with pertinent meteorological data are presented.

INTRODUCTION

Hurricane Cindy of September 1963, although not much of a storm as hurricanes go, probably has the distinction of producing the most completely recorded storm tide in a bay of any United States storm. The U. S. Army Corps of Engineers had installed a dense network of tide gages in Galveston Bay for the verification of a Galveston Bay - Houston Ship Channel model study made by the Corps of Engineers Waterways Experiment Station at Vicksburg, Miss. This network along with two regularly operated Coast and Geodetic Survey gages was in operation during the passage of Cindy. Other reports [1, 3, 4] have also been made on this storm. The purpose of this report is simply to document this unique set of tide recordings.

METEOROLOGICAL DATA

Cindy formed on September 16 about 150-200 mi. off the Texas coast and moved northward at an average speed of 8 m.p.h. After it reached hurricane force the storm stopped intensifying. It crossed the coast near High Island, Tex. on September 17, then became nearly stationary. Dunn [1] reported highest sustained winds over the Gulf as estimated at 80 m.p.h. with highest gusts on the coast being 80 m.p.h. measured near the eastern end of Galveston Island. Cindy diminished in strength and on the 19th moved southwestward and southward over Texas. Figure 1 shows a portion of the track of the storm as indicated by the Galveston radar. The insert of the figure, taken from Dunn [1], shows the general track of the storm and the stages of development and dissipation. Four selected synoptic surface charts are shown in Figure 2. Hourly observations from Weather Bureau Local Climatological Data [5] are shown in Figure 3 for Galveston and Port Arthur.

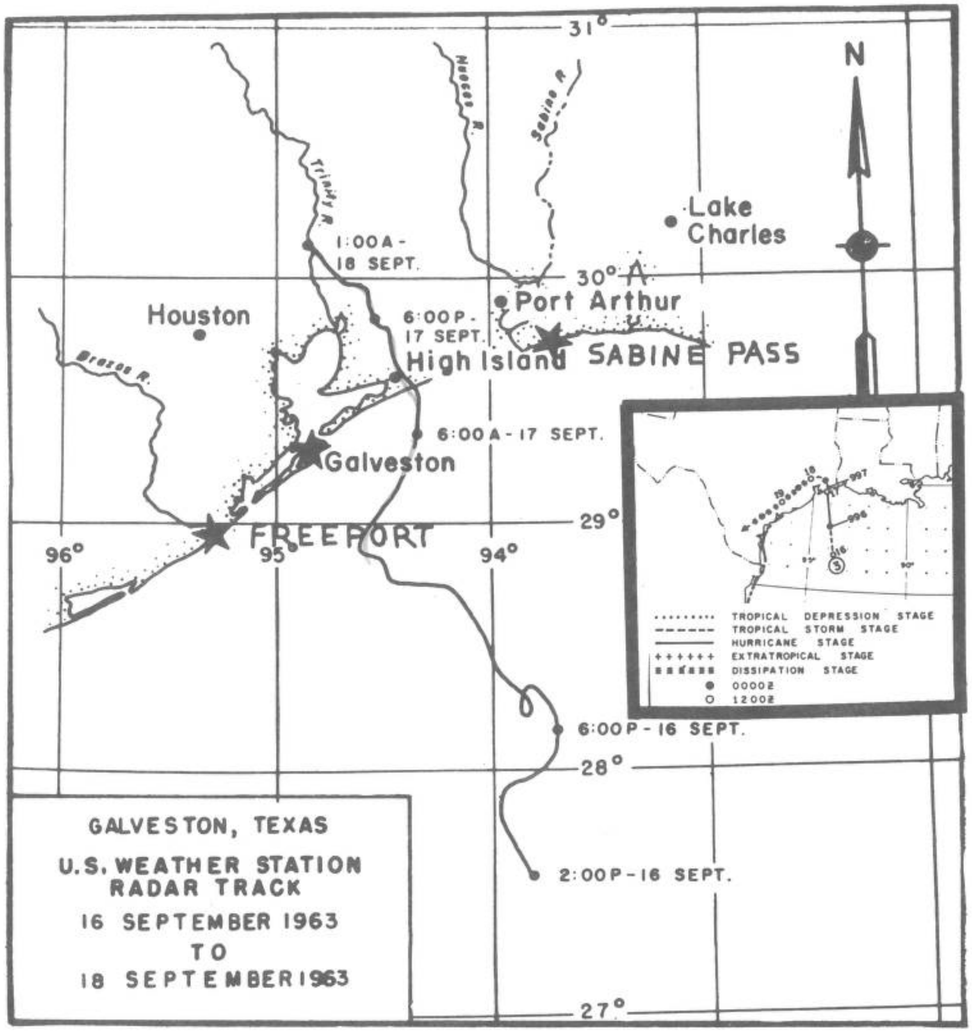

Figure 1. - Path of hurricane Cindy, September 16-18, 1963 as indicated by radar. The insert shows the general path of the storm from September 16-19 and indicates the stages of development and dissipation (from [1]).

THE TIDE DATA

The tides produced by Cindy were not exceptionally high for hurricane conditions. Figure 4 shows the storm surge for three coastal stations near the landfall of the storm. For these curves, based on hourly values of storm surge, the plotted date is at the noon position (CST). The locations of these stations are shown by stars in figure 1. The storm surge is defined as the algebraic difference between the observed tide and the normal tide and is considered to be the effect of the storm on sea level. The normal tide is the approximation of the tide which would have occurred in the absence of the storm. Following the procedure of Harris [2], the normal tide is the predicted astronomical tide corrected for the seasonal anomaly and the

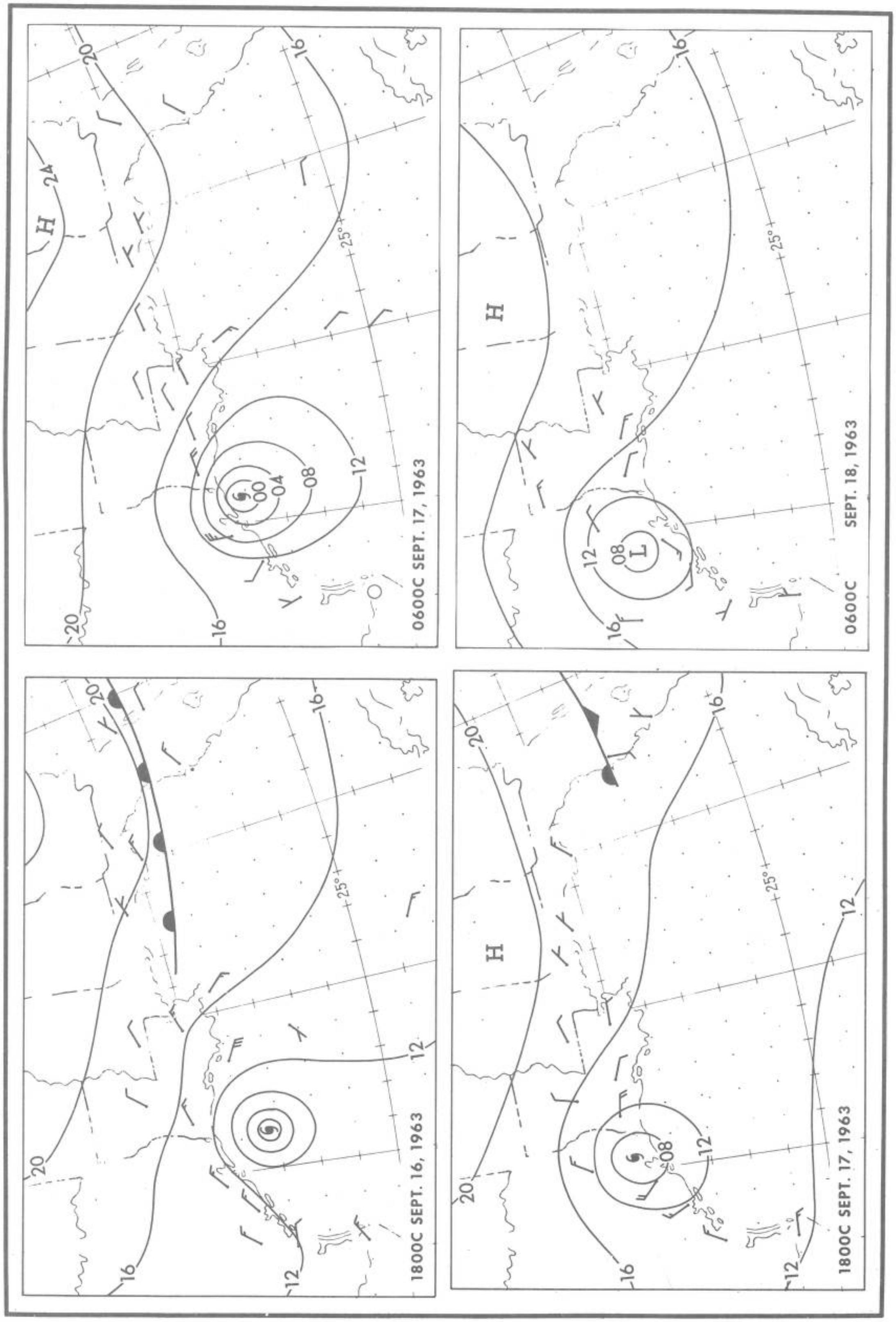

Figure 2. - Selected surface charts showing wind and pressure distributions around hurricane Cindy from September 16 to 18, 1963.

GALVESTON, TEXAS
MUNICIPAL AIRPORT
SEPTEMBER 1963

DAY: 16

Hour	Sky cover (tenths)	Sky condition	Ceiling (hnds. of ft.)	Visibility whole miles	Visibility 16th mi	W1	W2	W3	W4	W5	W6	O1	O2	Station press. (in.)	Dry bulb (°F)	Wet bulb (°F)	Rel. hum. (%)	Dew pt. (°F)	Wind dir.	Wind speed (knots)
00		22	UNL	12										29.93	77	75	91	74	NE	6
01		25	20	12										29.91	78	75	88	74	ESE	15
02		28	CIR	7		1	4							29.92	75	73	90	72	SE	12
03		28	CIR	10										29.91	77	74	88	73	E	7
04		22	UNL	12										29.90	77	74	88	73	NE	5
05		28	CIR	12			4							29.91	77	73	82	71	E	8
06	10	58	10	10			4							29.94	76	74	91	73	ESE	9
07	10	8	10	4			4							29.94	76	73	87	72	ESE	7
08	10	28	100	7			4							29.95	76	75	94	74	ENE	10
09	10	28	100	3			4							29.97	75	74	94	73	NE	3
10	10	58	8	10										29.98	77	75	91	74	NNE	14
11	10	58	8	6			4							29.98	76	75	94	74	NE	10
12	10	58	10	7			4							29.96	77	75	91	74	ENE	10
13	10	58	10	7			4							29.94	76	75	94	74	NE	13
14	10	228	25	5			4							29.89	77	75	91	74	NE	12
15	10	28	25	7										29.88	75	74	97	74	NE	22
16	10	258	10	8			4							29.87	75	74	94	73	NE	19
17	10	8	10	4			4							29.88	75	74	94	73	NE	20
18	10	8	13	4			4							29.88	74	73	97	73	NE	19
19	10	58	15	4			5							29.88	73	71	90	70	NNE	26
20	10	58	10	2	8		5							29.89	73	71	90	70	NNE	21
21	10	8	10	1	8		5							29.88	73	72	93	71	N	33
22	10	8	10	1	4		5							29.84	74	73	93	72	NNE	35
23	10	8	8	3			4							29.82	74	73	94	72	NNE	35

DAY: 17

Hour	Sky cover (tenths)	Sky condition	Ceiling (hnds. of ft.)	Visibility whole miles	Visibility 16th mi	W1	W2	W3	W4	W5	W6	O1	O2	Station press. (in.)	Dry bulb (°F)	Wet bulb (°F)	Rel. hum. (%)	Dew pt. (°F)	Wind dir.	Wind speed (knots)
00	10	8	10	8			4							29.79	75	73	90	72	NNE	26
01	10	8	12	8										29.71	75	73	90	72	N	35
02	10	58	8	8			1							29.64	76	73	85	71	N	45
03	10	X	0	0		1	6							29.59	74	73	97	73	N	48
04	10	8	8	0	8	1	5							29.59	75	73	90	72	N	35
05	10	8	12	7										29.59	75	73	90	72	NNW	40
06	10	58	6	6			4							29.59	76	74	91	73	NNW	33
07	10	8	6	2			4							29.63	75	74	94	73	N	30
08	10	8	8	2			4							29.67	74	73	94	72	NNW	9
09	10	8	8	1			4					1		29.68	74	73	94	72	W	27
10	10	8	9	1			4					1		29.71	74	73	94	72	W	29
11	10	8	8	1			4					1		29.72	75	73	90	72	W	19
12	10	8	10	3			1					1		29.73	75	73	90	72	WNW	24
13	10	8	10	3			1					1		29.73	75	73	90	72	W	16
14	10	8	10	5			1					1		29.73	76	74	91	73	SW	23
15	10	8	10	7										29.73	76	74	90	73	SW	10
16	10	58	10	7										29.73	76	73	87	72	SW	20
17	10	28	14	3								1		29.73	76	74	91	73	WNW	19
18	10	28	14	3								1		29.74	76	74	91	73	W	19
19	10	8	13	8										29.74	76	73	87	72	WSW	15
20	10	8	14	8										29.76	76	73	87	72	WSW	14
21	10	8	11	7			1							29.78	75	73	90	72	WSW	14
22		8	20	7			1							29.79	75	73	90	72	WSW	13
23		8	20	7			1							29.80	75	73	90	72	WSW	13

DAY: 18

Hour	Sky cover (tenths)	Sky condition	Ceiling (hnds. of ft.)	Visibility whole miles	Visibility 16th mi	W1	W2	W3	W4	W5	W6	O1	O2	Station press. (in.)	Dry bulb (°F)	Wet bulb (°F)	Rel. hum. (%)	Dew pt. (°F)	Wind dir.	Wind speed (knots)
00		8	24	7										29.81	74	72	90	71	WSW	10
01		8	25	7										29.82	74	73	94	72	WSW	10
02		8	25	7										29.84	74	73	94	72	WSW	10
03		8	20	7										29.84	74	72	90	71	SW	10
04		8	20	7										29.84	74	72	90	71	SW	8
05		28	20	7										29.84	74	72	90	71	SW	8
06	10	28	20	10										29.86	74	72	90	71	SSW	12
07	10	28	25	10										29.86	74	72	90	71	SSW	13
08	10	28	30	10										29.87	74	72	90	71	SSW	12
09	10	28	30	10										29.89	74	72	90	71	SSW	13
10	10	28	35	10										29.90	75	73	90	72	SSW	10
11	10	58	15	10										29.89	75	72	87	71	SSW	9
12	10	28	25	10										29.88	76	73	85	71	SSW	12
13	10	8	18	10										29.88	77	73	82	71	SSW	10
14	10	8	18	10										29.87	77	73	82	71	SSW	11
15	10	8	22	10										29.86	77	73	82	71	SSW	11
16	10	8	21	10										29.86	78	73	79	71	SSW	6
17	10	8	20	10										29.85	78	74	82	72	SSW	3
18	10	28	25	10										29.86	76	73	87	72	SW	2
19	10	28	25	10										29.87	77	74	85	72	SSW	1
20	10	28	25	10										29.88	77	74	85	72	S	5
21	10	28	25	10										29.90	77	74	88	73	SE	7
22		28	25	10										29.90	78	75	88	74	SE	7
23		28	30	10										29.90	79	75	82	73	SE	10

PORT ARTHUR, TEXAS
JEFFERSON COUNTY AIRPORT
SEPTEMBER 1963

DAY: 16

Hour	Sky cover (tenths)	Sky condition	Ceiling (hnds. of ft.)	Visibility whole miles	Visibility 16th mi	W1	W2	W3	W4	W5	W6	O1	O2	Station press. (in.)	Dry bulb (°F)	Wet bulb (°F)	Rel. hum. (%)	Dew pt. (°F)	Wind dir.	Wind speed (knots)
00	5	222	UNL	12										29.93	76	74	91	73	ENE	8
01	10	28	CIR	10										29.92	76	73	87	72	E	13
02	10	28	CIR	10										29.92	76	73	87	72	E	14
03	10	558	11	10										29.91	76	74	91	73	E	10
04	10	2558	12	10										29.93	76	74	91	73	E	12
05	10	258	11	10			4							29.92	75	74	94	73	E	10
06	10	28	11	7										29.93	74	73	94	72	E	12
07	10	8	6	7			1							29.95	74	73	94	72	ENE	10
08	10	8	6	7			1							29.96	75	74	94	73	ENE	10
09	10	-8	6	2	8		1					1		29.99	75	74	94	73	E	12
10	10	-58	6	1	8		2					1		29.99	74	73	97	73	E	10
11	10	-58	7	2			2					1		29.99	74	73	97	73	E	10
12	10	-8	7	4			2					1		29.97	75	74	94	73	E	12
13	10	8	7	6			1					1		29.95	75	74	97	74	E	14
14	10	8	9	7			1							29.96	76	75	94	74	ENE	12
15	10	8	10	7			1							29.91	75	74	94	73	ENE	10
16	10	8	5	5			1							29.90	75	74	94	73	ENE	12
17	10	58	8	6			1							29.89	75	74	94	73	ENE	14
18	10	28	9	5			1					1		29.90	74	73	94	72	ENE	15
19	10	8	9	5			2					1		29.91	74	73	94	72	ENE	14
20	10	8	9	5			2					1		29.90	74	73	94	72	ENE	16
21	10	8	10	6			1							29.91	74	73	94	72	ENE	16
22	10	28	10	10			1							29.89	74	73	94	72	NE	16
23	10	28	12	10			1							29.87	74	73	94	72	ENE	20

DAY: 17

Hour	Sky cover (tenths)	Sky condition	Ceiling (hnds. of ft.)	Visibility whole miles	Visibility 16th mi	W1	W2	W3	W4	W5	W6	O1	O2	Station press. (in.)	Dry bulb (°F)	Wet bulb (°F)	Rel. hum. (%)	Dew pt. (°F)	Wind dir.	Wind speed (knots)
00	10	28	9	7			2							29.86	74	72	90	71	ENE	14
01	10	28	9	7			1							29.83	74	72	90	71	ENE	19
02	10	28	9	7			2							29.80	74	72	90	71	ENE	17
03	10	28	8	7			1							29.78	74	72	90	71	ENE	19
04	10	8	5	1			3							29.74	75	73	90	72	ENE	24
05	10	X	2	0	12		3							29.73	75	73	90	72	ENE	22
06	10	X	1	0	6		3							29.73	76	75	94	74	E	19
07	10	58	8	0	12		2							29.73	76	74	91	73	E	23
08	10	58	8	0	12		4					1		29.71	77	75	91	74	E	20
09	10	58	9	4			4					1		29.72	78	76	91	75	E	20
10	10	58	5	0	12		6							29.72	78	75	88	74	SE	22
11	10	58	5	2			5							29.72	78	75	88	74	ESE	24
12	10	58	5	2			5							29.71	78	75	88	74	ESE	26
13	10	58	5	1			5							29.70	78	75	88	74	SE	25
14	10	8	7	1			6							29.68	77	75	91	74	SE	27
15	10	58	5	1			6							29.68	77	75	91	74	SE	19
16	10	58	5	1			5							29.68	77	74	88	73	SE	19
17	10	58	5	1			6							29.67	77	75	91	74	SE	20
18	10	58	5	1			6							29.67	78	75	88	74	SE	21
19	10	8	6	2			6							29.68	77	75	91	74	SE	19
20	10	X	6	1			6							29.69	77	75	91	74	SSE	19
21	10	8	6	4			4							29.72	77	75	91	74	SSE	20
22	10	X	6	1			6							29.74	77	75	91	74	SSE	22
23	10	X	5	2			6							29.77	77	74	88	73	SSE	21

DAY: 18

Hour	Sky cover (tenths)	Sky condition	Ceiling (hnds. of ft.)	Visibility whole miles	Visibility 16th mi	W1	W2	W3	W4	W5	W6	O1	O2	Station press. (in.)	Dry bulb (°F)	Wet bulb (°F)	Rel. hum. (%)	Dew pt. (°F)	Wind dir.	Wind speed (knots)
00	10	X	5	2			6							29.78	78	75	88	74	SSE	15
01	10	X	5	2			6							29.80	78	74	85	73	SSE	18
02	10	X	5	0	12		6							29.81	77	74	88	73	SSE	17
03	10	X	5	2			6							29.81	77	74	88	73	SSE	15
04	10	8	7	4			6							29.81	76	74	91	73	S	10
05	10	8	7	8			4							29.82	76	74	91	73	S	8
06	10	258	15	8			4							29.84	76	74	91	73	S	6
07	10	258	15	8			4							29.86	76	74	91	73	SSE	6
08	10	558	9	8			4							29.87	77	75	91	74	SE	6
09	10	258	17	8			4							29.89	78	75	88	74	SSE	4
10	10	58	7	8			4							29.89	78	75	88	74	ESE	9
11	9	255	15	10										29.89	82	78	82	76	SE	9
12	10	58	7	10			4							29.89	80	77	88	76	ESE	12
13	10	558	7	10										29.88	80	76	85	75	SE	11
14	10	258	12	10										29.86	82	78	82	76	SE	10
15	10	258	12	10										29.86	80	77	88	76	SE	11
16	10	2258	20	10										29.85	81	77	85	76	SE	10
17	10	28	20	10										29.85	80	76	85	75	ESE	7
18	9	255	17	10										29.86	79	76	88	75	ESE	8
19	9	225	80	10										29.87	79	76	88	75	ESE	12
20	8	225	80	10										29.88	79	76	88	75	ESE	12
21	10	X	2	4			6							29.91	79	76	88	75	ESE	8
22	10	258	20	7										29.91	79	76	88	75	ESE	9
23	10	258	13	7										29.89	79	75	85	74	ESE	12

Figure 3. - Hourly weather observations for Galveston and Port Arthur during hurricane Cindy (from [5]).

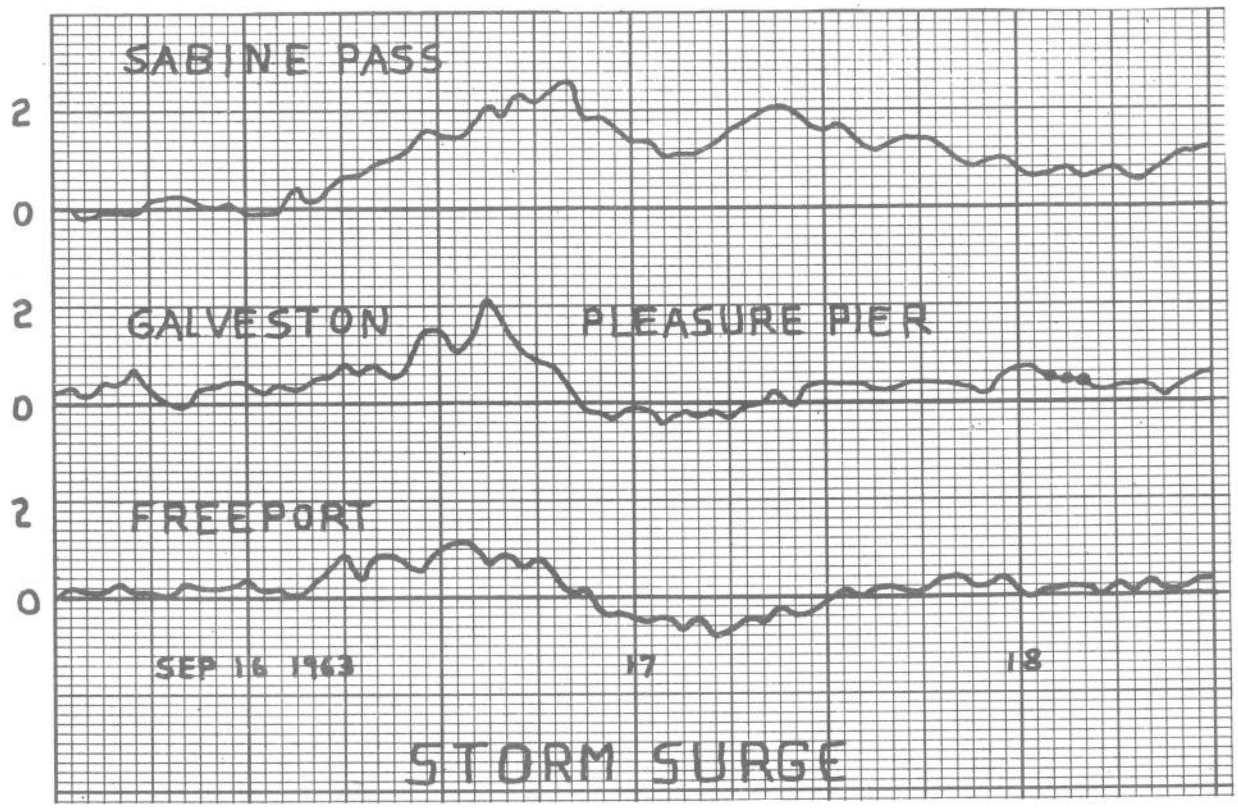

Figure 4. - Storm surge curves for three selected stations. The vertical scale is in feet. On the abscissa the date is plotted at the noon position (CST) of each day. The three stations are shown by stars in figure 1.

changing trend in sea level. Figure 4 shows storm surge values of about 2.6, 2.1, and 1.1 ft. respectively for Sabine Pass, Galveston, and Freeport on September 17.

Figure 5 shows the locations of the tide gages in the Galveston Bay area where suitable tide records were made and the curve of tide height for each gage. These curves were made by extracting hourly values of the tide height from the rolls of tide gage records. The original tide records indicate some slight timing errors at the end of the recorded periods but these are of no significance on the time scale used in figure 5. The zero value on the vertical scales of the two Galveston curves is mean sea level, whereas the zero value on the vertical scales of all the other tide curves is 1.4 ft. above mean sea level. For comparison the storm surge curves for the two Galveston gages are shown in the lower left insert of figure 5.

DISCUSSION

As Cindy approached the Texas coast late on the 16th the northerly wind components over Galveston Bay began to move the water southward. Northerly winds were quite strong during the morning of the 17th resulting in

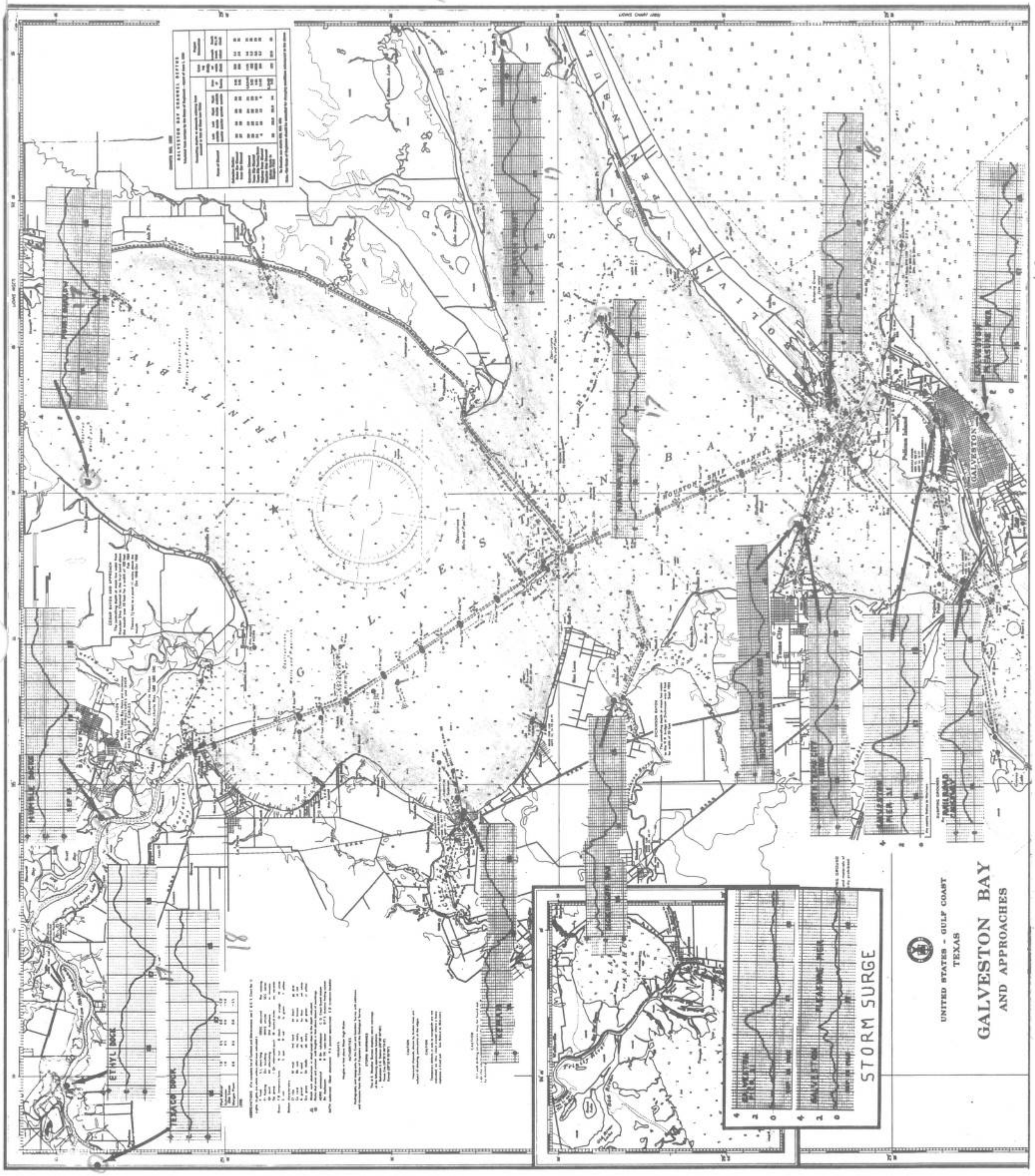

Figure 5. - Hydrographs showing the actual water level in Galveston Bay during hurricane Cindy. The units of the vertical scale are feet. The date for each day is shown on the noon position (CST). Hydrographs of storm surge for the two Galveston gages are shown in the insert.

significant drops in the water level in the northern portion of the Bay and significant rises in the southern end of the Bay. The resulting highest tides in the Galveston area occurred about the time of the normal high tide.

The pile-up of water in the southern portion resulted in a significant slope of the water surface. For example at 0500 on September 17, the tide curves in figure 5 show about 2.8 ft. MSL at Port Bolivar on Bolivar Peninsula and -2.3 ft. MSL at Point Barrow in the northern portion. This height difference of 5.1 ft. occurred in the distance of about 22 n. mi.

As the wind became more westerly and southwesterly after mid-morning on the 17th the pile-up of water began to move back north, resulting in highest water levels at the northern stations on the 18th.

SUMMARY

We have attempted to extract the tide data from the individual tide records and present them in concise form so that they may be readily compared with some of the pertinent meteorological data.

ACKNOWLEDGMENTS

We wish to express our appreciation to the U. S. Army Engineer District, Corps of Engineers, Galveston, Tex. for the numerous rolls of tide recordings they had duplicated for our use and to the Coast and Geodetic Survey for the tide data from their two recorders at Galveston.

REFERENCES

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2. D. L. Harris, "Characteristics of the Hurricane Storm Surge," U. S. Weather Bureau, Technical Paper No. 48, Washington, D. C., 1963, 139 pp.

3. U. S. Army, Final Report on Hurricane Cindy, 16 - 20 September 1963, U. S. Army Engineering District, Corps of Engineers, Galveston, Tex. Apr. 1964, 8 pp.

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5. U. S. Weather Bureau, Local Climatological Data (Supplement), Port Arthur, Tex. and Galveston, Tex., September 1963.