

Preliminary Report
Hurricane Edouard
19 August - 3 September 1996

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Edouard, the strongest tropical cyclone of the 1996 Atlantic season, was a prototypical Cape Verde hurricane. It had a very long track, and maintained category three or greater intensity on the Saffir/Simpson Hurricane Scale for nearly eight days. Edouard brushed southeastern New England as it recurved out to sea.

a. Synoptic History

Edouard originated from a tropical wave that was already well-marked by a spiral-shaped mass of convective clouds while moving across western Africa on 17-18 August. The wave crossed the west coast of Africa early on the 19th, accompanied by a 45-knot mid-tropospheric jet seen in rawinsonde data. Observations from Dakar and nearby stations showed thunderstorms and squalls, along with 24-hour surface pressure falls on the order of 3 to 4 mb as the wave passed. Soon after entering the eastern tropical Atlantic, ship reports showed the presence of a large surface circulation. It is estimated that a tropical depression formed around 1800 UTC on 19 August, centered about 300 n mi southeast of the Cape Verde Islands, as shown in the post-analysis "best track" in Table 1 and Fig. 1. This was the first in a series of four tropical cyclones that would form over the eastern Atlantic from waves that moved off the west coast of Africa during a two-week span in late August and early September of 1996. Three of these systems (Edouard, Fran, and Hortense) eventually became category three (or stronger) hurricanes.

Initially, it appeared that the westward-moving tropical cyclone would soon take a northwestward turn in response to a weakness in the subtropical ridge over the eastern Atlantic. However, the subtropical ridge remained strong enough to the north of the system to keep it on a generally westward track into the central tropical Atlantic. Higher-level winds favored intensification of the cyclone, as an upper-tropospheric anticyclone became well established over the area. The system became Tropical Storm Edouard early on 22 August, and strengthened into a hurricane around

1200 UTC the following day, when a banding-type eye was noted in satellite pictures.

When the hurricane neared 45° W longitude on the 24th, a deep-layer cyclone to the east of Bermuda began to create a weakness in the subtropical ridge. In response to this, Edouard's direction of motion changed from westward to west-northwestward. Meanwhile, intensification continued, and Edouard's winds strengthened to 100 knots on the 24th and to 125 knots on the 25th, making it a category four hurricane. The latter wind speed was the maximum intensity, and a similar wind speed is estimated on the 26th and also around 0000 UTC on the 28th. From the 26th to the 28th, some fluctuations in intensity were noted, apparently as the result of eyewall replacement cycles and occasional doses of stronger vertical shear over the area. Nonetheless, Edouard maintained 115 knot or greater winds throughout the above period. The final deepening episode in Edouard was observed late on 29-30 August. During that event, *three* concentric eyewalls were indicated by aerial reconnaissance observations. Overall, Edouard remained a powerful, 100-knot or stronger hurricane for a very long time - from 24 August until early on 1 September.

Edouard moved relentlessly towards the west-northwest, at around 12 knots, until the 29th of August. This track kept the hurricane well to the northeast and north of the islands of the northeastern Caribbean Sea. On the 29th, a mid-tropospheric trough became established near the U.S. east coast, creating a more northward steering component for Edouard. Slowing its forward speed slightly, the hurricane turned northwestward, and then northward, while gradually weakening. The cyclone passed about midway between Cape Hatteras and Bermuda on 1 September, and then started moving slightly east of north. Late on the 1st, the hurricane wobbled toward the north, in the general direction of southeastern New England. However, early on the 2nd, Edouard veered sharply toward the northeast, and the center of the hurricane passed about 75 n mi southeast of Nantucket island around 0900 UTC, the closest point of approach to the United States. Maximum winds had diminished to near 70 knots by that time.

Edouard weakened to a tropical storm near 0000 UTC on the 3rd, and became extratropical shortly thereafter. The storm's motion became east-northeastward, keeping the center south of Nova Scotia, and, later, well offshore of Newfoundland. Edouard's remnant low was drawn around and into the circulation of a larger extratropical cyclone on the 6th, and was absorbed by this bigger system by 0000

UTC 7 September.

b. Meteorological Statistics

Figures 2 and 3 depict the curves of minimum central sea-level pressure and maximum one-minute average "surface" (10 meters above ground level) wind speed, respectively, as a function of time. Also plotted are the observations on which the curves are based, consisting of aircraft reconnaissance data, Dvorak-technique estimates using satellite imagery, and fixes from synoptic analyses.

Most of the aircraft reconnaissance flights into Edouard were accomplished by the "Hurricane Hunters" of the U.S. Air Force Reserves. The Hurricane Hunters flew 15 missions, and made 66 center fixes. NOAA aircraft provided four additional fixes. The highest wind speed reported was 140 knots (at 700 mb) at 0003 UTC 28 August. Lowest central pressure reported was 934 mb at 1727 UTC 30 August. However, the highest wind reported by aircraft around that time was 134 knots. Subjective and objective Dvorak intensity estimates indicate that Edouard was stronger on 25-26 August, and also at 0000 UTC 28 August, than it was at the time of the minimum aircraft-reported pressure. At the latter time, the hurricane appeared considerably less well-organized on satellite images than on the earlier days.

Since Edouard crossed over the New York shipping channels, there was a large number of encounters by vessels at sea with this hurricane. Table 2 lists ship reports of tropical storm force or greater wind speeds associated with Edouard.

The hurricane came close enough to New England to produce sustained winds of tropical storm force at Nantucket Island and the Cape Cod area. Wind gusts to hurricane force were reported at Nantucket. Table 3 lists selected surface observations from Massachusetts, New Hampshire and Maine. In addition, there were unofficial reports of wind gusts to 90 mph at Nantucket, 80 mph at Martha's Vineyard, and 77 mph on Cape Cod.

Large swells, minor beach erosion, and some coastal flooding, presumably minor as well, occurred along the coast from North Carolina northward through Maine.

c. Casualty and Damage Statistics

Two deaths have been directly attributed to Edouard. A 71-year old man died

when his boat capsized in heavy surf in Great Egg Harbor Inlet, south of Atlantic City, New Jersey. A 28-year old man drowned while surfing at Lavallette, northeast of Tom's River, New Jersey. Additionally, a 44-year old man suffered a broken neck (but survived) while surfing near Atlantic City. Overall, the effects of Edouard on land were apparently minor. Most of the damage was to boats at Martha's Vineyard and Nantucket.

d. Forecast and Warning Critique

In general, the track forecasts for Edouard were excellent. This may be attributable to the objective guidance, which was quite accurate in most cases. Table 4 lists the average track model and official forecast errors for Edouard. One can see that the average official forecast errors are spectacularly low, in comparison to the most recent ten-year averages. The same can be said for the most oft-used objective track forecast techniques, viz the GFDL, BAMD, and A90E (NHC90). The U.K. Met. Office model, UKMI, also had rather low average track forecast errors.

NHC advisories had large underforecasts of intensity, up to 65 knots at 72 hours, during the early stages of Edouard. Intensity was significantly overforecast, on the order of 25 to 45 knots in 48 to 72 hours, on 30-31 August. Otherwise, the intensity predictions were good.

Since the official forecast tracks were bringing Edouard close to the U.S. east coast, and there was the usual uncertainty in these forecasts, watches and warnings were required from the mid-Atlantic states northward. Table 5 summarizes these watches and warnings. A hurricane warning was posted for portions of Rhode Island and Massachusetts at 0900 UTC 1 September. Although sustained hurricane force winds did not occur in these areas, sustained tropical storm force winds, with gusts to hurricane force, were observed in the eastern end of the hurricane warning area 18 to 24 hours after the issuance of the warning. At 0900 UTC on the 2nd, the hurricane warning was changed to a tropical storm warning over southeastern New England, even though it was clear that Edouard was bypassing the area. The reason for downgrading the warning (as opposed to lowering all warnings) was that Edouard was slow to exit, and strong winds were likely to continue lashing the coast in the vicinity of Cape Cod during the day. All U.S. warnings were dropped at 0000 UTC 3 September, by which time Edouard was nearing Nova Scotia.

Table 1. Best track, Hurricane Edouard, 19 August - 3 September, 1996

Date/Time (UTC)	Position		Pressure (mb)	Wind Speed (kt)	Stage
	Lat. (°N)	Lon. (°W)			
19/1800	12.4	19.9	1007	25	tropical depression
20/0000	12.4	20.7	1007	25	“
0600	12.4	21.6	1007	25	“
1200	12.5	22.6	1007	25	“
1800	12.6	23.8	1007	25	“
21/0000	12.6	25.3	1007	25	“
0600	12.8	26.7	1007	25	“
1200	12.9	27.9	1007	25	“
1800	13.0	29.2	1006	25	“
22/0000	13.1	30.3	1006	30	“
0600	13.2	31.6	1005	35	tropical storm
1200	13.4	32.9	1003	40	“
1800	13.5	34.4	1002	40	“
23/0000	13.7	35.8	1000	45	“
0600	13.8	37.0	996	50	“
1200	13.9	38.3	988	65	hurricane
1800	14.0	39.8	986	65	“
24/0000	14.1	41.1	983	70	“
0600	14.1	42.4	980	75	“
1200	14.4	43.6	970	90	“
1800	14.6	44.7	960	100	“
25/0000	15.0	45.8	942	120	“
0600	15.4	47.0	933	125	“
1200	15.9	48.3	934	125	“
1800	16.5	49.6	935	125	“
26/0000	17.0	50.9	936	125	“
0600	17.5	52.0	936	125	“
1200	17.9	53.2	937	125	“
1800	18.4	54.5	938	125	“
27/0000	18.9	55.6	942	125	“
0600	19.5	56.9	948	120	“
1200	20.0	58.1	952	115	“
1800	20.4	59.3	951	115	“
28/0000	20.9	60.4	944	125	“
0600	21.3	61.7	952	115	“
1200	21.9	63.2	960	110	“
1800	22.3	64.6	956	110	“

Table 1 (continued). Best track, Hurricane Edouard, 19 August - 3 September, 1996

29/0000	22.9	65.9	957	110	“
0600	23.4	67.1	961	110	“
1200	24.0	68.1	950	115	“
1800	24.7	69.0	948	120	“
30/0000	25.5	69.5	941	120	“
0600	26.4	69.9	939	120	“
1200	27.4	70.2	938	120	“
1800	28.5	70.5	934	120	“
31/0000	29.5	70.5	944	110	“
0600	30.4	70.6	950	105	“
1200	31.6	70.3	952	105	“
1800	32.7	70.1	953	100	“
01/0000	34.0	70.1	959	100	“
0600	35.2	70.1	958	100	“
1200	36.5	70.2	958	95	“
1800	37.5	70.0	960	85	“
02/0000	38.7	69.5	964	80	“
0600	39.8	69.4	961	70	“
1200	40.5	68.3	962	70	“
1800	41.3	67.3	972	65	“
03/0000	42.0	66.8	978	60	tropical storm
0600	42.2	66.0	985	55	extratropical
1200	42.5	65.0	992	50	“
1800	42.7	63.0	995	50	“
04/0000	43.2	59.8	997	50	“
0600	43.3	57.5	994	50	“
1200	43.4	55.5	994	50	“
1800	43.5	53.5	995	50	“
05/0000	43.5	51.5	995	50	“
0600	43.5	50.0	994	45	“
1200	43.5	48.5	994	45	“
1800	43.7	47.5	995	45	“
06/0000	44.5	46.0	995	40	“
0600	46.0	44.0	994	40	“
1200	48.0	43.0	992	40	“
1800	50.0	41.0	990	40	“
07/0000					absorbed by larger low

25/0600	15.4	47.0	933	125	minimum pressure
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Table 2. Ship reports of 34 knots or higher wind speed associated with Hurricane Edouard, August/September 1996.

date/time (UTC)	ship call sign	latitude (°N)	longitude (°W)	wind dir/ speed(knots)	pressure (mb)
26/0600	DHEE	11.5	53.5	210/44	1012.0
30/1800	OZBL2	29.8	69.1	090/64	1010.0
31/0000	WZJF	33.2	73.7	050/35	1011.0
31/0600	OZBL2	32.1	71.1	090/60	1010.0
31/1200	9VGL	29.8	67.3	150/36	1009.0
31/1800	DDQS	29.2	67.7	190/37	1010.9
01/0000	SHIP	27.8	70.1	270/41	1010.3
01/0000	9VGL	32.2	66.6	150/34	1009.0
01/0600	WXKM	33.1	66.0	150/35	1012.0
01/0600	ZCBC3	35.0	68.0	180/37	1001.4
01/0600	9VGL	33.4	66.5	150/36	1009.0
01/0900	PGAF	36.0	65.3	120/35	1010.0
01/1200	KMJL	38.7	69.5	060/58	1005.9
01/1200	PJJU	36.8	66.0	130/40	1007.0
01/1200	ZCBC3	36.3	67.3	140/37	1001.6
01/1200	9VGL	34.6	66.5	150/38	1007.8
01/1500	KMJL	38.7	69.1	060/68	1000.8
01/1500	PEBP	36.4	73.4	010/41	1007.2
01/1500	PGAF	35.2	65.3	150/35	1010.8
01/1800	KMJL	38.7	68.9	110/40	999.1
01/1800	LXWB	35.9	64.5	160/34	1014.5
01/1800	PEBP	36.1	73.6	360/39	1009.0
01/1800	PGAF	34.7	65.3	140/35	1012.2
01/1800	SHIP	35.4	74.8	360/58	-
01/1800	V2MF	39.5	66.6	120/40	1010.0
01/1800	ZCBC3	37.0	68.0	180/44	1006.4
01/1800	9VGL	35.3	67.3	190/40	1006.0
01/2100	DV2MFB	39.4	66.5	140/45	1006.2
01/2100	KMJL	38.7	68.4	130/60	995.8
01/2100	ZCBC3	36.5	68.0	180/37	996.5
02/0000	C6MZ8	40.4	70.3	050/40	1003.2

Table 2 (cont.). Ship reports of 34 knots or higher wind speed associated with Hurricane Edouard, August/ September 1996.

date/time (UTC)	ship call sign	latitude (°N)	longitude (°W)	wind dir/ speed(knots)	pressure (mb)
02/0000	KMJL	38.8	68.0	140/70	994.0
02/0000	LXWB	36.2	65.6	160/40	1011.2
02/0000	SKOZ	40.5	71.1	040/37	1003.2
02/0000	ZCBC3	36.5	68.1	180/37	997.4
02/0000	9VGL	36.0	68.1	210/42	994.2
02/0300	KMJL	38.8	67.7	150/70	995.1
02/0300	SKOZ	40.2	72.1	030/37	1003.5
02/0300	4XGR	39.7	66.0	130/34	1003.0
02/0600	KMJL	38.7	67.5	190/70	997.5
02/0600	LXWB	36.5	66.7	220/43	1009.2
02/0600	NFMK	41.9	70.2	040/35	1006.5
02/0600	NJPJ	41.6	70.4	040/40	1013.5
02/0600	SKOZ	40.0	72.4	360/37	1003.5
02/0600	VCRJ	36.8	64.1	180/40	1013.3
02/0600	V2MF	39.1	66.0	180/45	1001.5
02/0600	4XGR	39.4	66.0	160/50	1001.5
02/0600	9VGL	36.5	68.7	250/36	1004.5
02/0900	KMJL	38.5	67.2	210/45	999.9
02/0900	V2MF	39.0	66.0	210/49	1000.0
02/0900	4XGR	39.0	65.9	160/45	1001.0
02/1200	C6MZ8	38.7	70.5	320/55	1002.1
02/1200	KMJL	38.3	66.9	200/45	1003.9
02/1200	LXWB	36.8	67.3	230/39	1010.7
02/1200	NFMK	41.9	70.3	010/42	1002.5
02/1200	V2MF	39.0	66.1	180/48	1000.0
02/1200	ZCBC3	38.0	69.4	250/37	1005.4
02/1200	4XGR	39.2	66.6	200/45	997.5
02/1200	9VGL	37.1	69.3	290/39	1008.0
02/1500	KMJL	38.1	67.0	220/45	1005.0
02/1500	V2MF	38.7	66.0	180/47	1001.0
02/1500	4XGR	39.5	67.2	220/54	993.0

Table 2 (cont.). Ship reports of 34 knots or higher wind speed associated with Hurricane Edouard, August/September 1996.

date/time (UTC)	ship call sign	latitude (°N)	longitude (°W)	wind dir/ speed(knots)	pressure (mb)
02/1800	C6MZ8	38.4	69.3	310/37	1005.5
02/1800	LXWB	36.9	68.2	280/34	1011.2
02/1800	NJPJ	42.0	70.4	010/40	1004.1
02/1800	VYQJ	44.6	66.4	040/35	1009.0
02/1800	V2MF	38.5	65.8	200/47	1002.0
02/1800	ZCBC3	39.0	70.4	330/37	1007.4
02/1800	4XGR	39.6	68.0	270/45	996.0
02/1800	9VGL	37.5	69.7	300/44	1010.0
02/2100	VYQJ	44.0	66.7	030/39	1003.5
02/2100	V2MF	38.2	65.5	230/45	1005.0
03/0000	C6MZ8	38.7	67.8	290/47	1000.6
03/0000	ELRZ8	36.8	65.8	240/40	1011.0
03/0000	KMJL	38.2	67.7	280/40	1008.0
03/0000	VCRJ	41.2	65.6	200/46	994.3
03/0000	VCRZ	43.1	70.3	330/35	1009.5
03/0000	VYQJ	43.5	66.3	060/38	996.0
03/0000	V2MF	37.7	65.1	230/41	1007.0
03/0000	3ETG9	41.3	69.4	020/35	1023.0

Table 3. Hurricane Edouard selected surface observations, September, 1996.

Location	Press. (mb)	Date/ time (UTC)	Sustained wind (kts) ^a	Peak gust (kts)	Date /time (UTC) ^b	Storm surge (ft) ^c	Storm tide (ft) ^d	total rain (in)
Massachusetts								
Brant Point Coast Guard			50	69	02/1900			
Buzzards Bay buoy (44028)			39	54	02/1500			
Chatham upper air site				62	02/1117			
Falmouth	1001.7	02/1021						4.97
Georges Bank buoy (44011)	986.8	02/1700	39	50	02/1700			
Hyannis	1001.0	02/1039						5.20
Martha's Vineyard	1000.0	02/0945		47				
Menemsha Coast Guard			55		02/1500			
Nantucket buoy (44008)	979.9	02/0500	39	50	02/0500			
Nantucket Island						2.1	5.6	
Nantucket tower (ACK)	995.9	02/0945	45	65	02/0945			
New Bedford ASOS			35	46	02/1029			
Pocasset								4.70
West Dennis								6.37
West Yarmouth								4.75
New Hampshire								
Portsmouth								1.00
Maine								
Eastport								1.23
Eliot								1.17
Matinicus Rock C-MAN			35	41	02/1900			
Mt. Desert Rock C-MAN			41	47	02/2000			
Westbrook								1.16

^aNWS standard averaging period is 1 min; ASOS and C-MAN are 2 min; buoys are 8 min.

^bDate/time is for sustained wind when both sustained and gust are listed.

^cStorm surge is water height above normal astronomical tide level.

^dStorm tide is water height above NGVD.

Table 4

**Preliminary forecast evaluation of Hurricane Edouard
Heterogeneous sample**

(Errors in nautical miles for tropical storm
and hurricane stages with number
of forecasts in parenthesis)

Technique	Period (hours)				
	12	24	36	48	72
CLIP	26 (46)	50 (44)	81 (42)	114 (40)	168 (36)
GFDI	32 (46)	51 (44)	66 (42)	80 (40)	147 (36)
GFDL*	30 (23)	51 (22)	67 (21)	78 (20)	111 (18)
VBAR	23 (41)	40 (39)	58 (37)	84 (35)	189 (31)
LBAR	25 (46)	43 (44)	65 (42)	87 (40)	156 (36)
AVNI	43 (44)	84 (42)	130 (41)	176 (39)	279 (36)
BAMD	27 (36)	47 (44)	67 (42)	88 (40)	151 (36)
BAMM	35 (46)	70 (44)	111 (42)	155 (40)	228 (36)
BAMS	53 (46)	109 (44)	168 (42)	219 (40)	293 (36)
A90E	26 (46)	46 (44)	73 (42)	99 (40)	180 (36)
NGPI	55 (18)	123 (16)	215 (14)	330 (12)	552 (8)
UKMI	44 (28)	66 (28)	71 (26)	96 (24)	171 (21)
NHC OFFICIAL	25 (46)	46 (44)	66 (42)	84 (40)	118 (46)
NHC OFFICIAL 1986-1995 10-year average	49 (1670)	93 (1484)	136 (1314)	181 (1155)	273 (882)

* GFDL output not available until after forecast issued. VBAR output sometimes not available until after forecast issued.

Table 5. Watch and warning summary, Hurricane Edouard, August/September 1996.

Date/time (UTC)	Action	Location
30/2100	hurricane watch and tropical storm warning issued	Cape Lookout, North Carolina northward to Cape Henlopen, Delaware including the Pamlico and Albermarle Sounds
31/2100	hurricane watch extended northward	north of Cape Henlopen, Delaware to Plymouth, Massachusetts
31/2100	hurricane watch and tropical storm warning discontinued	south of Cape Charles, Virginia
1/0300	hurricane watch extended northward	north of Plymouth, Massachusetts to Merrimack River, Massachusetts
1/0900	hurricane warning issued	Watch Hill, Rhode Island to Merrimack River, Massachusetts
1/0900	hurricane watch extended northward	north of Merrimack River, Massachusetts to Eastport, Maine
1/0900	tropical storm warning issued	Fire Island Inlet, Long Island, New York to Watch Hill, Rhode Island including Long Island Sound east of Port Jefferson Harbor
1/0900	all watches and warnings discontinued	south of Brigantine New Jersey
1/1500	tropical storm warning issued	Merrimack River , Massachusetts to Eastport, Maine
1/2100	hurricane watch discontinued	New Jersey Coast and Long Island west of Fire Island Inlet

Table 5 (cont.). Watch and warning summary, Hurricane Edouard, August/September 1996.

2/0300	hurricane watch discontinued	Long Island, Long Island Sound and the coast of New England west of Watch Hill, Rhode Island
2/0900	hurricane warning changed to tropical storm warning	Watch Hill, Rhode Island to Woods Hole, Massachusetts and from Plymouth, Massachusetts to Merrimack River, Massachusetts
2/0900	hurricane watch discontinued	north of Merrimack River, Massachusetts
2/1500	hurricane warning changed to tropical storm warning	Woods Hole, Massachusetts to Plymouth, Massachusetts
2/1500	watches and warnings discontinued	west of Woods Hole, Massachusetts and north of Plymouth Massachusetts
3/0000	tropical storm warning discontinued	Woods Hole, Massachusetts to Plymouth, Massachusetts

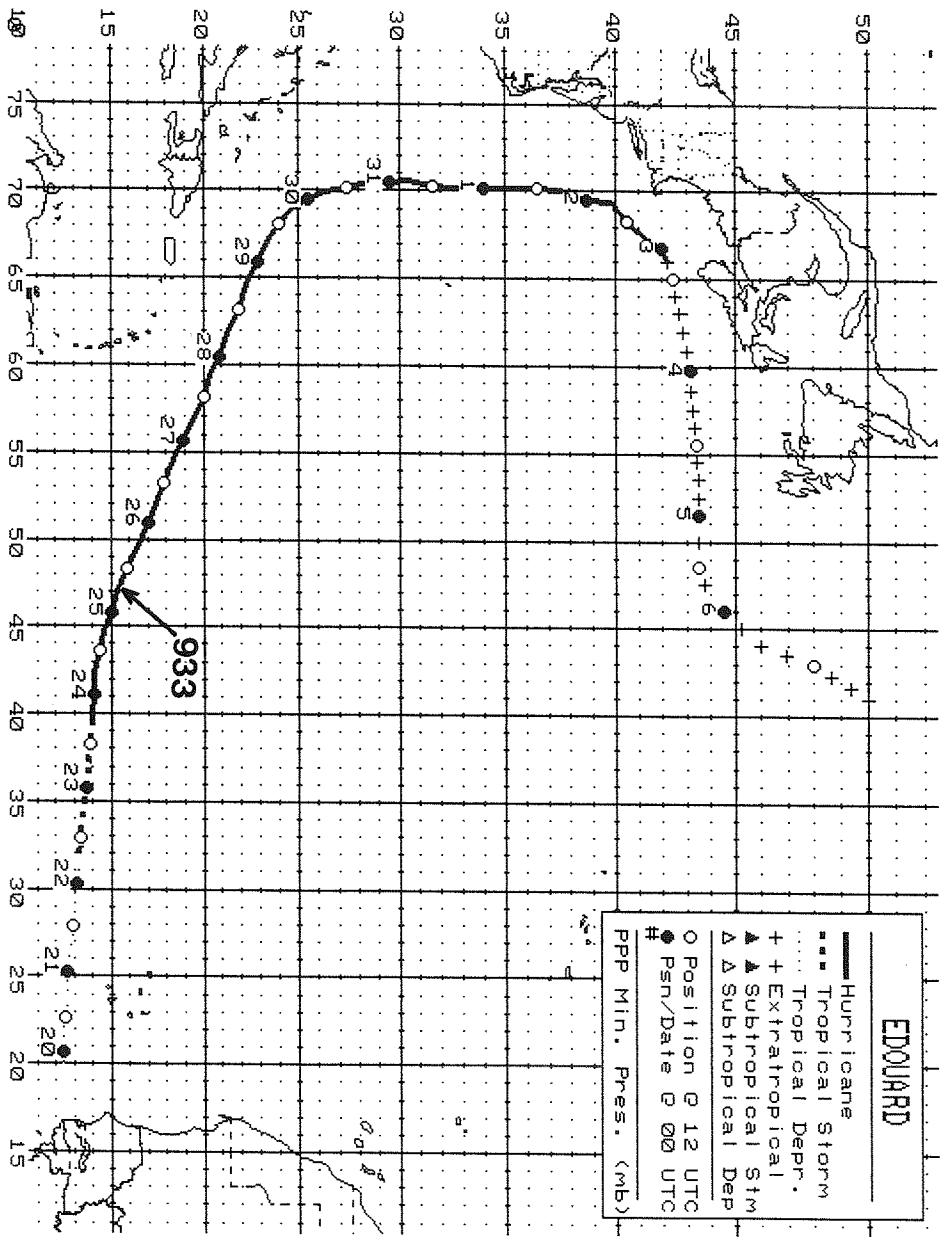


Figure 1. Best track positions for Hurricane Edouard, August/September 1996.

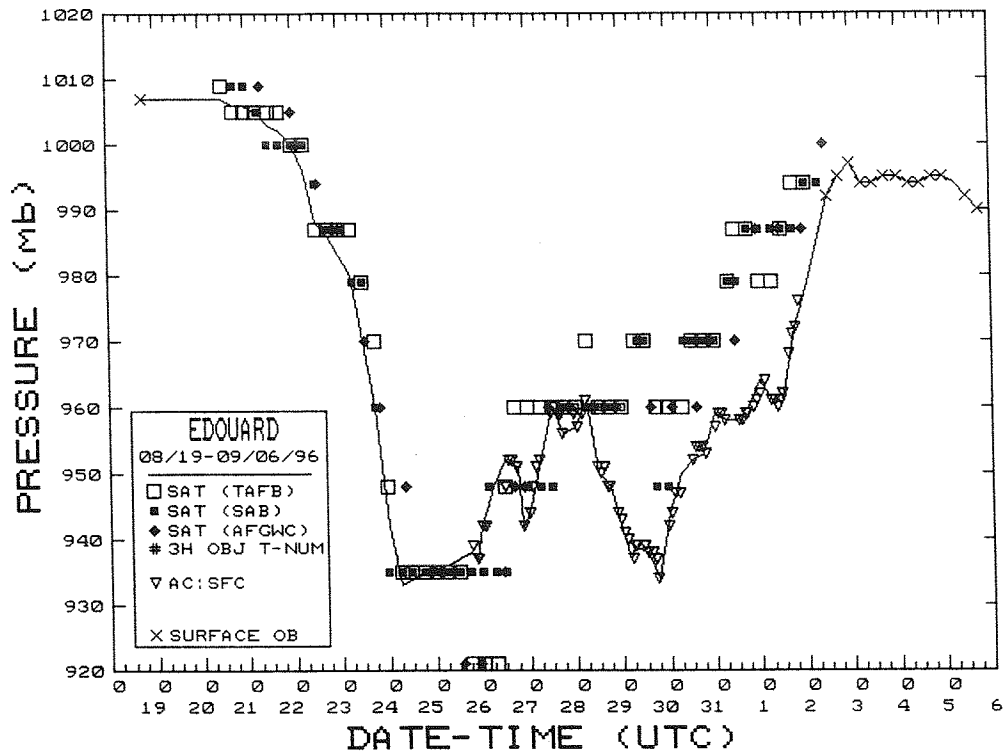


Figure 2. Best track central pressure curve for Hurricane Edouard, August/September

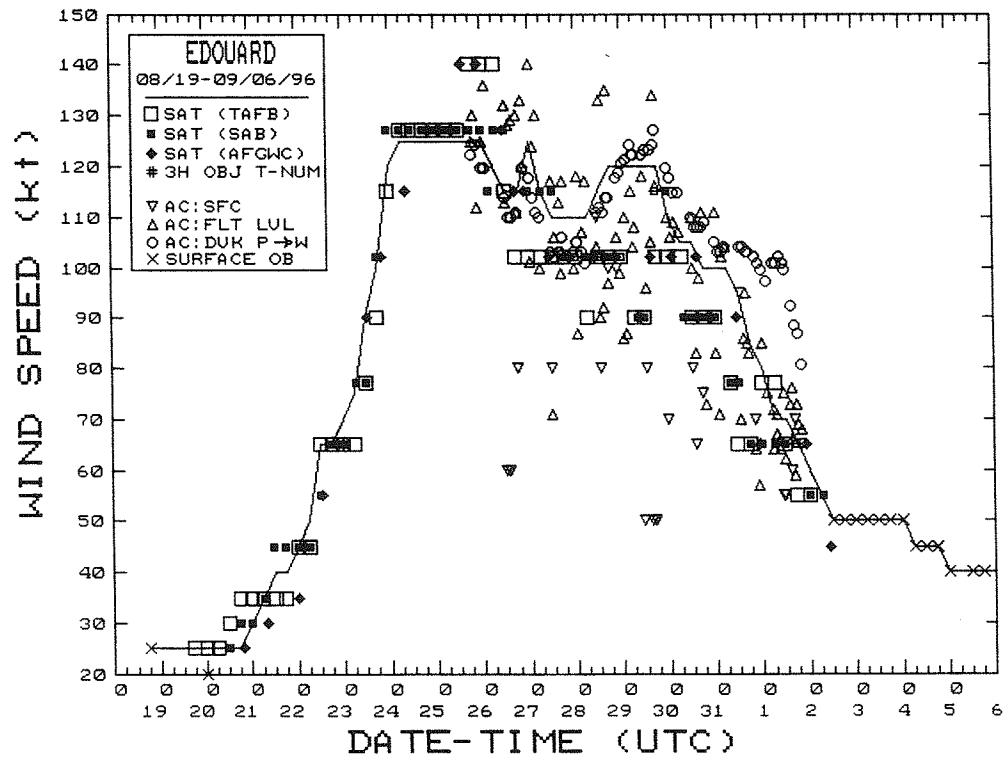


Figure 3. Best track maximum one-minute wind speed curve for Hurricane Edouard, August/September 1996.