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Tropical Cyclone Report

Hurricane Isabel

6 - 19 September 2003

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National Hurricane Center

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Hurricane Isabel was a long-lived Cape Verde hurricane that reached Category 5 status on the Saffir-Simpson Hurricane Scale. It made landfall near Drum Inlet on the Outer Banks of North Carolina as a Category 2 hurricane. Isabel is considered to be one of the most significant tropical cyclones to affect portions of northeastern North Carolina and east-central Virginia since Hurricane Hazel in 1954 and the Chesapeake-Potomac Hurricane of 1933.

a. Synoptic History

Isabel formed from a tropical wave that moved westward from the coast of Africa on 1 September. Over the next several days, the wave moved slowly westward and gradually became better organized. By 0000 UTC 5 September, there was sufficient organized convection for satellite-based Dvorak intensity estimates to begin. Development continued, and it is estimated that a tropical depression formed at 0000 UTC 6 September, with the depression becoming Tropical Storm Isabel six hours later. The "best track" chart of Isabel is given in Figure 1, with the wind and pressure histories shown in Figure 2 and Figure 3, respectively. The best track positions and intensities are listed in Table 1.

Isabel turned west-northwestward on 7 September and intensified into a hurricane. Strengthening continued for the next two days while Isabel moved between west-northwest and northwest. Isabel turned westward on 10 September and maintained this motion until 13 September on the south side of the Azores-Bermuda High. Isabel strengthened to a Category 5 hurricane

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on 11 September with maximum sustained winds estimated at 145 kt at 1800 UTC that day. After this peak, the maximum winds remained in the 130-140 kt range until 15 September. During this time, Isabel displayed a persistent 35-45 n mi diameter eye.

Isabel approached a weakness in the western portion of the Azores-Bermuda High, which allowed the hurricane to turn west-northwestward on 13 September, northwestward on 15, September, and north-northwestward on 16 September. The latter motion would continue for the rest of Isabel's life as a tropical cyclone.

Increased vertical wind shear on 15 September caused Isabel to gradually weaken. The system weakened below major hurricane status (96 kt or Category 3 on the Saffir-Simpson Hurricane Scale) on 16 September. It maintained Category 2 status with 85-90 kt maximum winds for the next two days while the overall size of the hurricane increased. Isabel made landfall near Drum Inlet, North Carolina near 1700 UTC 18 September as a Category 2 hurricane, then weakened as it moved across eastern North Carolina. It weakened to a tropical storm over southern Virginia, then lost tropical characteristics as it moved across western Pennsylvania on 19 September. Extratropical Isabel moved northward into Canada and was absorbed into a larger baroclinic system moving eastward across south central Canada early the next day.

b. Meteorological Statistics

Observations in Isabel (Figure 2 and Figure 3) include satellite-based Dvorak technique intensity estimates from the Tropical Analysis and Forecast Branch (TAFB), the Satellite Analysis Branch (SAB) and the U. S. Air Force Weather Agency (AFWA). Also included are flight-level and dropwindsonde observations from flights by the 53rd Weather Reconnaissance Squadron of the U. S. Air Force Reserve Command, the NOAA Aircraft Operations Center, and a Canadian research aircraft. Observations from ships (Table 2), land stations, and data buoys (Table 3) are included where appropriate. Microwave satellite imagery from the National Aeronautics and Space Administration (NASA) Tropical Rainfall Measuring Mission (TRMM), the NASA Quikscat, and the Defense Meteorological Satellite Program (DMSP) satellites were also useful in tracking Isabel.

The Air Force Reserve Hurricane Hunters made 39 center fixes during Isabel. The NOAA Hurricane Hunters made two formal center fixes and flew seven research missions into the storm. The highest winds measured by the aircraft were 158 kt (Air Force at 700 mb) and 157 kt (NOAA at 8400 ft) between 1700-1730 UTC 13 September. A 156-kt flight-level wind (700 mb) was also observed at 1719 UTC 12 September. Stronger winds were observed on eyewall dropsondes, with a maximum of 203 kt reported at 806 mb (4500 ft) at 1753 UTC 13 September. This is the strongest wind ever observed in an Atlantic hurricane, although it likely does not represent a 1-min average.

Comparison of the aircraft and satellite data makes the peak intensity of Isabel somewhat speculative. Aircraft data on 12 September indicate that Isabel had winds near 140 kt. However, the maximum intensity based on

satellite imagery was reached on 11 September before the first reconnaissance mission, and the satellite signature was weaker at the time of the first mission. The maximum intensity estimate of 145 kt on 11 September is based on the aircraft data of 12 September and the stronger satellite signature on the previous day. The minimum central pressure of 915 mb on 11 September has a similar basis.

Isabel's intensity is also somewhat uncertain during 16-18 September. During this time, a large outer eyewall formed, which disrupted the inner core wind structure. Dropsonde data indicated that the usual 90% reduction for 700 mb winds to the surface in the eyewall was not valid, with the actual reductions being closer to 70-75%. Both Air Force and NOAA aircraft measured 118-kt flight-level winds in the northeast eyewall just as Isabel was making landfall, which using the 90% reduction would support 105 kt sustained surface winds. However, using a 75% reduction gives a sustained surface wind of near 90 kt, which is in better agreement with maximum surface winds estimated by a dropsonde (83 kt) and the Stepped Frequency Microwave Radiometer on the NOAA aircraft (90 kt) near the same time. Based on this, the best estimate of the landfall intensity is 90 kt.

Isabel brought hurricane conditions to portions of eastern North Carolina and southeastern Virginia. The highest observed wind on land (Table 3) was sustained at 69 kt with a gust to 85 kt at an instrumented tower near Cape Hatteras, North Carolina at 1622 UTC 18 September. Another tower in Elizabeth City, North Carolina reported 64-kt sustained winds with a gust to 84 kt at 1853 UTC that day. The National Ocean Service (NOS) station at Cape Hatteras reported 68-kt sustained winds with a gust to 83 kt before contact was lost. The Coastal Marine Automated Stations (C-MAN) at Chesapeake Light, Virginia and Duck, North Carolina reported similar winds. Elsewhere in Virginia, Gloucester Point reported 60-kt sustained winds with a gust to 79 kt at 2200 UTC 18 September, while the Norfolk Naval Air Station reported 50-kt sustained winds with a gust to 72 kt at 2100 UTC that day. Unofficial reports from the affected area include a gust of 102 kt at Kitty Hawk, North Carolina, a gust of 93 kt from Gwynns Island, Virginia, a gust of 91 kt at Ocracoke, North Carolina, and a gust of 88 kt at New Bern, North Carolina. The wind record from the most seriously affected areas is incomplete, as several observing stations were either destroyed or lost power as Isabel passed.

Isabel brought tropical-storm conditions to a large area from eastern North Carolina northward to the eastern Great Lakes and western New England. The C-MAN station at Thomas Point, Maryland reported 42 kt sustained winds with a gust to 58 kt at 0850 UTC 19 September. Reagan National Airport in Washington, DC reported 39-kt sustained winds with a gust to 50 kt at 0139 UTC that day. Sustained tropical storm-force winds were reported at Kennedy and LaGuardia Airports in New York City, while a gust of 52 kt was reported in Middletown, Pennsylvania. Extratropical Isabel brought gale-force winds to portions of the eastern Great Lakes and southeastern Canada.

Shipping for the most part avoided Isabel. The most significant ship report was from the **ZIPR7** (name unknown), which reported 52-kt winds at 1200 UTC 17 September (Table 2). Additionally, NOAA buoy 41002 reported a 10-min average wind of 52 kt with a gust to 70 kt at 0540 UTC 18

September. Two NOAA data buoys broke loose as the storm passed and had to be replaced.

The lowest pressure observed by reconnaissance aircraft was 920 mb at 1712 and 1901 UTC 12 September. The lowest pressures observed on land were unofficial reports of 957 mb at Arrowhead Beach, North Carolina, and 958 mb from a storm chaser in Hobucken, North Carolina. The lowest pressures from official observation sites were 962.8 mb from an instrumented tower in Atlantic Beach, North Carolina at 1645 UTC 18 September, and 963.5 mb at Washington, North Carolina at 1944 UTC that day.

Isabel produced storm surges of 6-8 ft above normal tide levels near the point of landfall along the Atlantic coast of North Carolina. Farther north, storm surge values ranged from 4-6 ft along the Virginia coast, 2-4 ft along the Maryland, Delaware and New Jersey shorelines, and 1-2 ft along the coast of Long Island and in the Long Island sound.

In the North Carolina estuaries, storm surge values were generally 4-6 ft above normal tide levels over the eastern portions of the Pamlico Sound and most of the Albemarle Sound. Values of 6-10 ft above normal tide levels were observed in the western end of the Pamlico Sound with a maximum value of 10.5 ft reported on the Neuse River in Craven County (Table 3).

Storm surges of 3-5 ft above normal tide levels were observed over the central portions of the Chesapeake Bay and 5-6 ft over the southern portion of the Bay in the vicinity of Hampton Roads, Virginia. Surge values of 6-8 ft above normal levels were observed in the upper reaches of the Chesapeake Bay near Annapolis and Baltimore, Maryland and in most of the main stem rivers draining into the Chesapeake Bay. Even higher surges occurred at the heads of the rivers, with values of 8.5 ft above normal levels at the Richmond City locks along the James River in Virginia and nearly 8 ft along the Potomac River in Washington, D.C. Water levels exceeded previous record levels established in the Chesapeake-Potomac Hurricane of 1933 in Washington, D.C., Baltimore and Annapolis.

Storm surges in Delaware Bay were generally 3-4 ft at the mouth of the bay and 5-6.5 ft at the head of the bay and along the Delaware River in the vicinity of Philadelphia, Pennsylvania.

Rainfall from Hurricane Isabel averaged 4-7 in over large portions of eastern North Carolina, east-central Virginia and Maryland. Rainfall totals of 8-12 in with locally higher amounts occurred in the Shenandoah valley in northern Virginia. Upper Sherando, Virginia, reported a storm total of 20.20 in (Table 4). Lesser amounts in the 2-4 in range occurred elsewhere over eastern Virginia and the Delmarva Peninsula.

One tornado occurred in association with Hurricane Isabel. It touched down in the Ocean View section of Norfolk, Virginia at approximately 2200 UTC 18 September and was verified only by visual confirmation from law enforcement officials. No Fujita scale rating has been assigned to the tornado since its damage could not be distinguished from the extensive hurricane-related wind damage in the area.

c. Casualty and Damage Statistics

Isabel is directly responsible for 16 deaths: 10 in Virginia, and 1 each in North Carolina, Maryland, New Jersey, New York, Rhode Island, and Florida. The deaths in Florida and Rhode Island were drownings in high surf generated by Isabel. Isabel was indirectly responsible for 34 deaths: 22 in Virginia, 6 in Maryland, 2 in North Carolina and Pennsylvania, and 1 each in New Jersey and the District of Columbia.

Isabel caused widespread wind and storm surge damage in coastal eastern North Carolina and southeastern Virginia. Storm surge damage also occurred along Chesapeake Bay and the associated river estuaries, while wind damage occurred over portions of the remaining area from southern Virginia northward to New York. The current estimate for insured property damage is \$1.685 billion - \$925 million in Virginia, \$410 million in Maryland, \$170 million in North Carolina, \$80 million in Pennsylvania, \$45 million in New York, \$25 million in New Jersey, \$20 million in Delaware, and \$10 million in West Virginia. The total damage for Isabel is estimated to be about twice that of the insured damage, or \$3.37 billion.

d. Forecast and Warning Critique

The track of Isabel was in general well forecast. Average official track errors (with the number of cases in parentheses) for Hurricane Isabel were 22 (51), 39 (49), 52 (47), 60 (45), 80 (41), 104 (37), and 146 (33) n mi for the 12, 24, 36, 48, 72, 96, and 120 h forecasts, respectively¹. These errors are much lower than the average official track errors for the 10-yr period 1993-2002² (45, 81, 116, 150, 225, 282, and 374 n mi, respectively) (Table 5) - 50-65 % smaller than the average forecast errors at all times. The track forecasts also showed tremendous skill when compared to the errors of the Climatology-Persistence (CLP5) model (32, 68, 109, 148, 231, 350, and 537 n mi for the 12, 24, 36, 48, 72, 96, and 120 h forecasts, respectively) - including an almost 75% improvement at 120 h. Overall, the official track forecasts had smaller errors than the dynamical models. However, three ensemble methods that combine the forecasts of the dynamical models (GUNS, GUNA, and FSSE) had smaller errors than the official forecasts.

There appear to be three primary reasons for the excellent track forecasts. First, Isabel was a large and strong hurricane, and this type of tropical cyclone is generally easier to forecast.

Second, Isabel moved slowly through the central and eastern Atlantic in a relatively predictable steering pattern. While an initial northwestward motion was not as well forecast as other parts of the track, the forecasts did correctly anticipate that Isabel would turn westward and maintain that course for several days.

Third, when Isabel reached the western Atlantic, synoptic surveillance missions began using both the NOAA Gulfstream-IV jet and Air Force Reserve aircraft. These mission helped resolve a complex steering flow pattern around Isabel. Preliminary estimates from the Hurricane Research Division indicate that the synoptic surveillance data improved the track forecasts of the NWS Global Forecast System model (AVNO in Table 5) by

as much as 40% at 120 h. Qualitative examination of forecasts from the NOGAPS (NGPS) and UKMET models (UKM) also suggest forecast track improvement due to the data.

The landfall forecasts were exceptionally accurate. The track forecast errors verifying at 1800 UTC 18 September (1 h after landfall) had errors of 6, 12, 6, 16, 31, 86, and 118 n mi for the 12, 24, 36, 48, 72, 96, and 120 h forecasts, respectively.

The intensity forecasts were less accurate than the track forecasts. Average official intensity errors were 7, 11, 14, 17, 22, 25, and 27 kt for the 12, 24, 36, 48, 72, 96, and 120 h forecasts, respectively, which are larger than the average official intensity errors over the 10-yr period 1993-2002 (6, 10, 13, 15, 19, 21, and 22 kt, respectively). However, the intensity forecasts showed skill when compared to intensity climatology and persistence, which had errors of 8, 13, 18, 23, 29, 32, and 35 kt for the 12, 24, 36, 48, 72, 96, and 120 h forecasts, respectively. The greatest contributors to the intensity forecast errors included 1) underforecasting how quickly Isabel would intensify over the eastern Atlantic, and 2) overforecasting how strong Isabel would remain as it reached a less favorable environment in the western Atlantic.

Table 6 lists the watches and warnings associated with Hurricane Isabel. The accurate track forecasts and the large size of Isabel led to longer than normal watch and warning lead times. A hurricane watch was issued for the landfall area 50 h before the center made landfall. A hurricane warning was issued 38 h before landfall.

Acknowledgements

Much of the data from the affected areas were provided by the NWS Weather Forecast Offices at Wilmington, Morehead City, and Raleigh, North Carolina, Wakefield, Sterling, and Blacksburg, Virginia, Mount Holly, New Jersey, Upton, New York, and Pittsburgh and State College, Pennsylvania. NOAA buoy and C-MAN data were provided by the National Data Buoy Center. NOS data were provided by the NOAA National Ocean Service. Remote Automated Weather Stations (RAWS) data were provided by the National Interagency Fire Center. USGS data were provided by the NWISWeb web site. Other data were provided by the Weather Underground web site.

¹All forecast verifications in this report include the depression stage of the cyclone. National Hurricane Center verifications presented in these reports prior to 2003 did not include the depression stage.

²Errors given for the 96 and 120 h periods are averages over the two-year period 2001-2002.

Table 1: Best track for Hurricane Isabel, 6-19 September 2003.

Date/Time (UTC)	Position		Pressure (mb)	Wind Speed (kt)	Stage
	Lat.	Lon.			

	(°N)	(°W)			
06 / 0000	13.8	31.4	1009	30	tropical depression
06 / 0600	13.9	32.7	1005	35	tropical storm
06 / 1200	13.6	33.9	1003	40	"
06 / 1800	13.4	34.9	1000	45	"
07 / 0000	13.5	35.8	994	55	"
07 / 0600	13.9	36.5	991	60	"
07 / 1200	14.4	37.3	987	65	hurricane
07 / 1800	15.2	38.5	984	70	"
08 / 0000	15.8	39.7	976	80	"
08 / 0600	16.5	40.9	966	95	"
08 / 1200	17.1	42.0	952	110	"
08 / 1800	17.6	43.1	952	110	"
09 / 0000	18.2	44.1	948	115	"
09 / 0600	18.9	45.2	948	115	"
09 / 1200	19.4	46.3	948	115	"
09 / 1800	20.0	47.3	948	115	"
10 / 0000	20.5	48.3	952	110	"
10 / 0600	20.9	49.4	952	110	"
10 / 1200	21.1	50.4	948	115	"
10 / 1800	21.1	51.4	942	120	"
11 / 0000	21.2	52.3	935	125	"
11 / 0600	21.3	53.2	935	125	"
11 / 1200	21.4	54.0	925	135	"
11 / 1800	21.5	54.8	915	145	"
12 / 0000	21.6	55.7	920	140	"
12 / 0600	21.7	56.6	920	140	"
12 / 1200	21.6	57.4	920	140	"
12 / 1800	21.7	58.2	920	140	"
13 / 0000	21.8	59.1	925	135	"
13 / 0600	21.9	60.1	935	130	"
13 / 1200	22.1	61.0	935	135	"
13 / 1800	22.5	62.1	932	140	"
14 / 0000	22.9	63.3	935	135	"
14 / 0600	23.2	64.6	939	135	"
14 / 1200	23.5	65.8	935	135	"
14 / 1800	23.9	67.0	933	140	"
15 / 0000	24.3	67.9	937	130	"
15 / 0600	24.5	68.8	940	125	"
15 / 1200	24.8	69.4	946	120	"
15 / 1800	25.3	69.8	949	115	"
16 / 0000	25.7	70.2	952	105	"
16 / 0600	26.3	70.5	955	100	"
16 / 1200	26.8	70.9	959	95	"
16 / 1800	27.4	71.2	959	95	"
17 / 0000	28.1	71.5	957	95	"

17 / 0600	28.9	71.9	957	95	"
17 / 1200	29.7	72.5	957	90	"
17 / 1800	30.6	73.0	955	90	"
18 / 0000	31.5	73.5	953	90	"
18 / 0600	32.5	74.3	956	90	"
18 / 1200	33.7	75.2	956	90	"
18 / 1800	35.1	76.4	958	85	"
19 / 0000	36.7	77.7	969	65	"
19 / 0600	38.6	78.9	988	50	tropical storm
19 / 1200	40.9	80.3	997	35	extratropical
19 / 1800	43.9	80.9	1000	30	"
20 / 0000	48.0	81.0	1000	25	"
20 / 0600					absorbed by extratropical low
11 / 1800	21.5	54.8	915	145	minimum pressure
18 / 1700	34.9	76.2	957	90	landfall at Drum Inlet, North Carolina

Table 2: Selected ship reports with winds of at least 34 kt for Hurricane Isabel, 6-19 September 2003.

Ship Name or Call Sign	Date/Time (UTC)	Lat. (°N)	Lon. (°W)	Wind dir/speed (deg/kt)	Pressure (mb)
Duncan Island	17/ 0300	27.4	68.7	160/42	1007.5
Duncan Island	17/ 0900	29.1	67.9	160/45	1010.0
ZIPR7	17/ 0900	32.0	68.3	110/45	1010.7
ZIPR7	17/ 1200	30.2	67.4	150/52	1011.6
Sealand Hawaii	17/ 1800	31.0	68.5	130/40	1010.2
Galveston Bay	17/ 1800	33.4	76.7	020/37	1010.8
Oriental Bay	19/ 0000	35.5	73.1	140/37	1010.6
P&O Ned Lloyd Pegasus	19/ 0300	34.7	74.8	190/37	1010.5
P&ONed Lloyd Piraeus	19/ 0600	38.9	72.9	160/45	1015.3
James R. Barker	19/ 1200	42.2	81.1	060/42	1001.0

Table 3: Selected surface observations for Hurricane Isabel, 6-19 September 2003.

Location	Minimum Sea-level Pressure		Maximum Surface Wind Speed (kt)					
	Date/Time (UTC)	Press. (mb)	Date/Time ^a (UTC)	Sust. Wind ^b (kts)	Peak Gust (kts)	Storm Surge ^c (ft)	Storm Tide ^d (ft)	Rain (storm total) (in)
South Carolina								
Springmaid Pier			18/1545	24	39			
North Carolina								
Alligator River NWR RAWS			18/1900	50				3.75
Atlantic Beach								

(Clemson/UF Tower)	18/1645	962.8	18/1558	55	67			
Back Island RAWS			18/1813		53			1.65
Beaufort RAWS			18/1815		64			5.64
Beaufort (NOS)						5.8	2.5	
Burlington (KBUY)					48			
Cape Hatteras (Clemson/UF Tower)	18/1644	968.2	18/1622	69	85			
Cape Hatteras Pier NOS [†]	18/1518	974.0	18/1518	68	83	7.7	5.6	
Caswell Gamelands RAWS			18/2017		46			1.95
Cherry Point (KNKT)	18/1840	968.2	18/1818		62			5.24
Clinton (KCTZ)					40			
Craven Co. (Neuse river)							10.5	
Duke Forest RAWS			18/1907		53			1.70
Duck Corps of Engineers Pier NOS [°]	18/1918	984.0	18/2100	55	72	7.8	4.7	4.72
Elizabeth City (KECG)			18/1543	51 [°]	64 [°]			2.72
Elizabeth City (Clemson/UF Tower)	18/1940	981.9	18/1852	64	84			
Elizabethtown			18/2320	22	43			2.26
Erwin-Dunn (KHRJ)					38			
Fayetteville (KFAY)				35	50			
Fort Bragg (KFBG)					52			
Fort Bragg RAWS			18/2007		48			1.33
Franklinton (KLHZ)					39			
Goldsboro (KGSB)				35	51			
Greensboro (KGSO)					40			
Greens Cross RAWS			18/1708		50 [°]			6.29
Greenville (KPGV)			18/1855	34	44			5.75
Henderson (KHNZ)					39			
Hoffman Forest RAWS			18/1509		50			2.35
Laurinburg (KMEB)					35			
Lumberton (KLBT)			18/1921	32	45			3.39
Manteo (KMQL)	18/1743	982.4	18/1843	44	68			
Nature Conservancy RAWS			18/1658		54			1.91
New Bern (KEWN)			18/1608		50 [°]			
New River (KNCA)	18/1756	981.7	18/1556	39	56			2.02
Newport (KMHX)	18/1730	968.9	18/1800		46			5.87

Oregon Inlet Marina NOS						5.4	4.7	
Pocosin Lake NWR RAWS			18/1823		64			5.94
Raleigh (KRDU)					39			
Rocky Mount (KRWI)				35	54			
Rocky Mount RAWS			18/2113		52°			4.20
Roanoke Rapids° (KRZZ)			18/2147	38	55			
Sanford (KTTA)					43			
Smithfield (KJNX)					34			
Sunny Point RAWS			18/2158		51			2.09
Turnbull Creek RAWS			18/2313		41			2.19
Washington (KOCW)	18/1944	963.5	18/1803	37	49			
Wilmington (KILM)	18/1843	990.5	18/2143	39	51			1.98
Wilmington (Clemson/UF Tower)	18/1730	990.8	18/1315		43			
Virginia								
Back Bay NWR RAWS			18/1935	38	53			4.12
Blacksburg (WFO)			19/0120		34			
Chesapeake Bay Bridge Tunnel NOS	18/2154	992.4	18/2048	52	64	7.5	4.8	
Colonial Beach NOS°						5.4	3.7 (6.5) ^h	
Culpeper (KCJR)	19/0303	995.0						
Danville (KDAN)			18/1922		45			
Dulles Airport (KIAD)	19/0359	997.6	19/0122	32	42			1.96
Fort Belvoir (KDAA)								2.32
Fredericksburg (KEZF)								2.79
Gloucester Point NOSe						8.3	6.4	
Gloucester Point (VIMS)			18/2200	60	79			
Great Dismal Swamp RAWS			18/1945		39			
Kingsmill NOS°						6.6	4.3	
Kiptopeake NOS			18/2342	39	60	6.5		
Langley AFB (KLFI)	18/2348	991.9	18/1808	46	66			2.67
Leesburg (KJYO)			19/0444		42			
Lewisetta NOSe	19/0012	997.3	19/0100	46	59	3.7	3.0	
Manassas (KHEF)	19/0335	997.0						
Melfa (KMFV)	18/2102	1000.0						
Money Point NOS			18/2318	38	52	8.3	5.7	

Newport News ^o (KPHF)	18/2237	990.2	18/1756	38	57			3.16
Norfolk Airport ^o (KORF)	18/2151	990.2	18/2049	41	64			2.50
Norfolk N.A.S. (KNGU)			18/2110	50	72			4.21
Oceana N.A.S. (KNTU)	18/2056	990.9	18/2056	48	60			
Portsmouth	18/2225	987.2						
Quantico (KNYG)	19/0355	996.8	19/0322	47	67			
Roanoke (KRNK)			18/2143		38			
Rappahannock Light NOS	18/2354	995.4	18/2318		60			
Richmond (KRIC)			19/0013	33	63			4.32
Scotland NOS ^o						6.8	4.8	
Sewells Point NOS	18/2130	991.4	18/1642	50	64	7.9	5.6	
Wakefield (KAKQ)								5.76
Wallops Island (KWAL)	19/0012	1003.1	18/1747	43	54			0.80
Wachapreague NOS ^o	18/2300	1001.8				5.5	2.5	
Wakefield WFO								5.66
Washington Reagan Airport (KDCA)	19/0359	999.3	19/0139	39	50			2.31
Windmill Point NOS						3.8		
District of Columbia								
National Academy of Science (DCNet)				19/ N/A	62			
Washington NOS						7.9		
West Virginia								
Martinsburg	19/0654	997.3	19/0318	26	40			
Petersburg (W99)	19/0537	995.0						
Maryland								
Andrews AFB (KADW)			18/2051	33	60			
Annapolis NOS						7.2	6.3	
Baltimore NOS						8.2	7.3	
Baltimore (KBWI)	19/0358	1001.4	19/0211	38	48			3.21
Black NWR RAWS			18/2227		40			1.42
Cambridge NOS ^o	19/0154	1003.0	18/2054	37	49	6.2	5.2	2.20
Chesapeake City NOS						5.7	4.9	
Frederick			19/0543		43			
Hagerstown (KHGR)	19/0548	998.6	18/2328	34	45			
Maryland Science Center(KDMH)	19/0301	1002.4						
Ocean City (KOXB)	18/2257	1006.1	18/2252	36	46	6.5		1.97
Patuxent River (KNHK)	19/0355	999.0	19/0355	48	60			

Salisbury (KSBY)	19/0331	1005.1	18/2009	32	44			2.08
Silver Springs (DCNet)			19/ N/A		72			
Solomons Island NOS ^e	19/0018	1000.7	19/0106	45	56			
Tolchester Beach NOS	19/0354	1003.2	19/0124		38	7.9	6.9	
Delaware								
Brandywine Shoal NOS	19/0424	1007.3	19/0742		54			
Delaware City NOS	19/0630	1005.6	19/0606	34	47	8.62	5.42	
Dover AFB (KDOV)			19/0419		53			
Georgetown (KGED)			19/0613		52			1.74
Lewes NOS	19/0336	1006.6	18/2024	46	54	6.51	3.07	
Prime Hook NWR RAWS			18/2127		44			1.06
Reedy Point NOS						8.66	5.00	
Wilmington (KILG)			19/0720		46			1.46
New Jersey								
Atlantic City (KACY)			19/0034		42			
Atlantic City USGS	19/0300	1011.9	19/0100		46			
Barnegat Light USGS	19/0500	1014.6	19/1930		39			
Burlington NOS	19/0706	1010.4				10.6	6.5	
Cape May NOS	19/0500	1008.1	18/2124		47	6.5	3.1	
Cape May USGS	19/0100	1005.2	18/2100	34	53			
Forsythe NWR RAWS			19/0827		34			0.31
Keansburg USGS	19/0600	1014.6	19/0100		45			
Millville (KMIV)			19/0046		48			
Newark (KEWR)	19/0757	1013.9	19/0619	28	38			0.66
Point Pleasant USGS	19/0500	1014.6	19/0100		40			
Sandy Hook NOS	19/0736	1014.2	19/0142		39			
Ship John Shoal NOS	19/0518	1007.1	19/0206	47	62	8.0	4.7	
Tacony-Palmyra Bridge NOS						9.9	5.8	
Trenton (KTNT)			19/0304		38			
Wildwood (KWWD)			19/0835		41			1.30
Wrightstown			19/0337		47			
Pennsylvania								
Allentown (KABE)			19/0907		41			
Altoona (KAOO)	19/0804	998.7	19/0429		37			
Capital City	19/0513	1003.0	19/0530		50			
Clearfield (KFIG)	19/0926	1000.3	19/0604		35			
Hazleton (KFET)								
Lancaster (KLNS)	19/0634	1004.4	19/0637		46			

Middletown	19/0509	1003.0	19/0517		52			
Mt Pocono (KMPO)					40			
Philadelphia (KPHL)			19/0747		43			1.14
Philadelphia NOS	19/0530	1010.6	18/2312		37	9.5	5.4	
Reading (KRDG)			19/0735		43			
Scranton Wilkes-Barre (KAVP)					35			
Sherburne RAWS			19/1808		41			
Williamsport (KIPT)	19/0843	1003.0	19/0841		45			
York (KTHV)	19/0603	1002.7	19/0601		38			
New York								
Binghamton (KBGM)					39			
Buffalo (KBUF)			19/2012		35			
Farmingdale (KFMG)	19/0902	1016.3	19/0725	28	36			0.00
Monticello (KMSV)					38			
New York Kennedy Airport (KJFK)	19/0815	1015.2	19/0802	35	43			0.16
New York LaGuardia Airport (KLGA)	19/0827	1014.9	19/0736	35	44			0.26
Saranac Lake (KSLK)			19/1827		38			
Shinnecock Inlet			18/2330	30	45			
Syracuse (KSYR)					35			
Utica (KUCA)					37			
Watertown (KART)			19/1605		35			
Wellsville (KELZ)			19/0958		35			
Vermont								
Burlington (KBTV)			19/1940		40			
Rutland (KRUT)			19/1535		35			
Canada								
Burlington					39			
Hamilton					36			
Long Point				37	42			
Point Petre					43			
Port Colborne				35	44			
Toronto Island					43			
Toronto Pearson Airport (CYYZ)			19/1350		39			
Buoy/CMAN								
NOAA Buoy 41001	18/0900	997.7	18/0150	40 ^a	51			
NOAA Buoy 41002	18/0800	978.8	18/0540	52 ^a	70			
NOAA Buoy 44004			18/2331		35			
NOAA Buoy 44009	19/0000	1006.6	19/2200	38	51			
NOAA Buoy 44014	18/1900	995.5	18/1250	43 ^a	60			
NOAA Buoy 44017	19/0900	1018.5	18/2300	29	36			

NOAA Buoy 44025	19/0800	1015.0	19/0100	30	38			
NOAA Buoy 45005	19/1300	1002.6	19/2100	27 ^g	35			
NOAA Buoy 45008	19/1700	1002.6	20/0030	28	34			
NOAA Buoy 45012	19/1700	1004.2	19/1220	32 ^g	41			
Canadian Buoy 45135				34	42			
Canadian Buoy 45139				32	40			
Canadian Buoy 45160				32	40			
Ambrose Tower (ALSN7)	19/0700	1014.1	19/2350	44 ^g	52			
Chesapeake Light (CHLV2)	18/2100	990.6	18/2140	65 ^g	83			
Cape Lookout (CKLN7)	18/1600	964.9	18/1530	60 ^g	79			
Dunkirk (DBLN6)	19/1500	1000.3	19/1900	31	39			
Diamond Shoals Light (DSLN7)	18/1600	970.5						
Duck (DUCN7)	18/1900	984.4	18/1930	66 ^{>g}	82			
Frying Pan Shoals (FPSN7)	18/1700	993.4	18/1610	63 ^g	77			
Lake St Clair (LSCM4)	19/1400	1004.1	19/2100	31	36			
South Bass Island (SBO11)	19/1400	1003.8	19/2050	32 ^g	36			
Thomas Point Light (TPLM2)	19/0500	1001.1	19/0850	42 ^g	58			
Unofficial Observations:								
South Carolina								
Little River			18/1723		36			
Loris EMS			18/1742		37			1.34
Myrtle Beach Pavilion			18/1638		34			
Pawleys Island			18/1624		35			
North Carolina								
Arrowhead Beach	18/2030	957.0						
Atlantic Beach (Sudduth)	18/1644	967.5	18/1531	48	59			
Battleship					43			
Cape Lookout ^e			18/1415		71			
Carolina Beach			18/1405		45			
Cary (Weather Underground)	18/2209	988.0	18/2149		43			1.22
Cedar Island			18/1440		75			
Clayton (Weather Underground)	19/0102	990.4	18/1752		40			
Edenton							7.0	
Elizabeth City							5.0	
Harkers Island Bridge			18/1430		85			

Hobucken (Leonard)	18/1750	958.0						
Holly Shelter			18/2020		53			
Isabelle Homes Bridge (Cape Fear River)			18/1330		50			
Kitty Hawk	18/1925	984.5	18/ N/A		102			
Kure Beach Pier			18/1605		41			
Kyre Beach La Que Center			18/1300		48			
Lillington (Weather Underground)			18/1808		37			
New Bern (Weather Underground)	18/1912	970.1	18/1327	80	88			
Ocean Isle			18/1600		50			
Ocracoke			18/1545		91			
Plymouth			18/1805		83			
Southport NC State Pilot			18/2334		56			
Southport Elementary School					46			
Southport Brunswick County Airport			18/1600		44			1.95
Sunny Point Military Ocean Terminal			18/2020		45			
Surf City (Weather Underground)	18/1846	991.8	18/1206	44	75			
Topsail Beach			18/1430		50			
Trenton			18/1912		70			
Whiteville Chamber of Commerce					43			4.51
Wilmington (NC State Port)			18/1400		57			
Wilmington (Weather Underground)	18/1730	994.1	18/1800		36			
Wilmington (WECT TV)					46			2.24
Wilson (Weather Underground)	18/2110	976.5	18/1955		47			
Wrightsville Beach Police			18/1500		39			
Wrightsville Beach FD			18/1230		52			
Wrightsville Beach Oceanic Pier			18/2128		49			
Virginia								
Boone			18/2241		40			
Chase City			18/2010		46			
Chesapeake Bay Bridge			18/2125	62	76			

Chincoteague			18/2315		41			
Chincoteague CGS					62			
Chincoteague (Weather Underground)	18/2311	1004.3	18/2231	36	40			
Dublin			19/0220		49			
Dunnsville							6.0	
Five Forks					70			
Gwynns Island			19/0042		93			
Hampton			18/2130	58	80			
Hillsville			19/0240		37			
Hopewell							8.0	
Hot Springs			19/0020		38			
Jefferson			19/0220		35			
Norfolk Fred Heutte Center			18/1944		61			4.88
Oak Hall					50			
Onley					54			
Parksley					57			
Portsmouth (WRS)			18/1944		48			
Reedville					87			
Richmond (WWBT- TV)					55			
Richmond County				42 ^j	57 ^j			
Smith Island					72			
Smithfield						10.75 ^j	8.0 ^j	
Tappahannock							5.5	
West Point							9.0 ^j	
White Stone (NNWS) ^e			18/ N/A		55			
Williamsburg (Weather Underground)	18/2247	993.5	18/1917		50			
Yorktown (Weather Underground) ^e			18/1820		41			
Maryland								
Frederick (Weather Underground)	19/0705	1001.2	18/ N/A		42			
Hagerstown (Weather Underground)			19/0500		55			2.89
Hurlock					54			
Millersville (Weather Underground)	19/ N/A	1001.3	18/ N/A		41			2.14
Montgomery Village (Weather Underground)	19/0344	1000.3	19/0300		43			2.30
Ocean Pines					52			
Perry Hall (Weather Underground)	19/0430	1000.9	19/0350		37			0.68

Pocomoke				43			
New Jersey							
Berlin (Weather Underground)	19/0525	1010.0	19/0540	42			
Buena (Weather Underground)			19/0030	42			
Oceanport (Weather Underground)	19/0649	1013.8	18/2209	39			
Toms River (Weather Underground)	19/0700	1015.5	18/2200	37			
Williamstown (Weather Underground)			19/0740	53			
Pennsylvania							
Aston (Weather Underground)	19/0615	1010.0	19/0030	34			
Elk Lake				40			
Exeter				37			
Gettysburg			19/0701	50			
Jermyn				40			
Kinzer (Weather Underground) ^e			19/0600	39			
Lancaster (Weather Underground)			19/0800	40			
Lancaster (WGAL)			19/0608	63			
Millersville (University)			19/0800	44			
Moscow				41			
New Holland			19/0742	47			
Perkasie (Weather Underground)			19/0845	35			
Plymouth				34			
Rock Spring			19/0723	40			
Saylorsburg (Weather Underground)			19/0744	34			
Shiremanstown			19/0645	59			
New York							
Hornell				39			
Liverpool				38			
Lowville (Weather Underground)	19/1916	1008.4	19/1847	37			
Madison				38			
Marathan				36			
Rochester (Weather Underground)	19/1602	1003.3	19/1446	34			
Romulus				35			
Vermont							
Cambridge			19/1720	45			

Lincoln (Weather Underground)		19/1231	44			
Mt Mansfield		19/1805	72			
Pleasant Valley		19/1728	48			
Salisbury		19/1620	43			
^a Date/time is for sustained wind when both sustained and gust are listed. ^b Except as noted, sustained wind averaging periods for C-MAN and land-based ASOS reports are 2 min; buoy averaging periods are 8 min; NOS stations averaging periods are 6 min; RAWS stations report 10 min average sustained winds. ^c Storm surge is water height above normal astronomical tide level. ^d Storm tide is water height above National Geodetic Vertical Datum (1929 mean sea level). ^e Incomplete record - more extreme values may have occurred ^f Station destroyed - more extreme values may have occurred ^g 10-min average ^h Subsequent Survey Storm Surge value ⁱ 15-min average ^j Estimated						

Table 4: Selected storm rainfalls (in) from Hurricane Isabel, 6-19 September 2003.

Station	Storm-total Rainfall (in)
Virginia	
Amelia (Amelia)	5.50
Apple Orchard Mountain (Botetourt)	8.76
Ash RAWS	4.33
Ashland (Hanover)	5.20
Bent Gap (Nelson)	6.68
Big Meadows (Madison)	8.60
Big Meadows (Page)	11.10
Blackstone (Nottoway)	7.00
Bowling Green (Caroline)	4.22
Bumpass (Louisa)	5.45
Carson (Dinwiddie)	6.20
Cartersville (Goochland)	4.91
Charles City (Charles City)	4.90
Chester (Chesterfield)	5.50
Chesterfield (Chesterfield)	5.80
Craigsville (Augusta)	3.44
Crewe (Nottoway)	5.10
Dale Enterprise (Rockingham)	4.17
Devils Knob (Nelson)	10.70
Emporia (Greenville)	6.41
Farmville (Prince Edward)	5.00
Glen Allen (Henrico)	5.50
Green Bay (Prince Edward)	4.76
Grottoes (Rockingham)	6.25
Hogback Mountain (Warren)	7.55
Homeville (Sussex)	7.10
Hood (Madison)	4.00

Hopewell	6.00
Ida (Page)	8.59
Irish Gap (Rockbridge)	6.96
James River NWR RAWS	5.42
Jordan's Point (Prince George)	5.67
Lewis Mountain (Page)	6.82
Linden (Warren)	4.23
Long Run (Rockingham)	7.08
Lynnwood (Rockingham)	5.48
Madison/Green Line (Madison)	4.36
Madison (Madison)	4.10
Mathews Arm (Page)	8.40
McDowell (Highland)	4.76
Mechanicsville (Hanover)	4.50
Mills Creek Dam (Augusta)	9.16
Montebello 1SSE (Nelson)	6.10
Monterey (Highland)	4.24
Montpelier	4.00
Mustoe (Highland)	3.20
Nethers (Madison)	4.23
Newland (Richmond)	3.50
New Market (Shenandoah)	4.50
Newport News	3.70
Orange (Orange)	3.42
Paineville (Amelia)	4.17
Petersberg	5.59
Portsmouth	4.04
Powhatan (Powhatan)	5.00
Prince George (Prince George)	6.00
Richmond (WBBT TV)	6.88
Richmond (WTVR-TV)	4.01
Robinson Hollow (Augusta)	7.24
Ruther Glen (Caroline)	4.22
Sandston (Henrico)	5.08
Sherando (Augusta)	8.32
Short Pump (Henrico)	3.78
Skyland (Page)	9.54
Somerset (Orange)	4.73
Sperryville (Rappahannock)	3.62
Stuarts Draft (Augusta)	6.50
Suffolk	4.79
Swift Run (Rockingham)	6.90
The Plains (Fauquier)	3.45
Toano (James City)	10.60
Toms Branch (Augusta)	7.12
Upper Sherando (Augusta)	20.20

Urbanna (Middlesex)	7.00
Watkins Landing (Powhatan)	4.00
Waynesboro (Augusta)	6.11
West Point (King William)	3.86
Williamsburg	4.50
Woodstock (Shenandoah)	3.50

Table 5: Preliminary forecast evaluation (heterogeneous sample) for Hurricane Isabel, 6-19 September 2003. Forecast errors (n mi) are followed by the number of forecasts in parentheses. Errors smaller than the NHC official forecast are shown in bold-face type. Verification includes the depression stage, but does not include the extratropical stage, if any.

Forecast Technique	Period (hours)						
	12	24	36	48	72	96	120
CLP5	32 (52)	68 (50)	109 (48)	148 (46)	231 (42)	350 (38)	537 (34)
A90E	29 (52)	60 (50)	93 (48)	144 (46)	235 (42)	373 (38)	503 (34)
A98E	29 (52)	59 (50)	92 (48)	142 (46)	238 (42)	384 (38)	492 (34)
A9UK	28 (24)	52 (23)	70 (22)	99 (21)	151 (19)		
LBAR	26 (51)	49 (49)	75 (47)	104 (45)	163 (41)	205 (37)	227 (33)
BAMD	26 (52)	43 (50)	66 (48)	93 (46)	156 (42)	190 (38)	236 (34)
BAMM	29 (52)	52 (50)	79 (48)	110 (46)	169 (42)	190 (38)	223 (34)
BAMS	41 (52)	72 (50)	101 (48)	130 (46)	201 (42)	254 (38)	300 (34)
COAI	20 (27)	35 (25)	50 (23)	65 (21)	100 (17)		
COAL*	31 (14)	38 (13)	52 (12)	60 (11)	95 (9)		
COEI	20 (14)	42 (14)	65 (14)	75 (12)			
COCE*	22 (8)	33 (8)	53 (7)	71 (6)			
AF1I	31 (47)	51 (45)	78 (43)	103 (41)	157 (37)		
AFW1*	56 (24)	75 (23)	83 (22)	105 (21)	144 (19)		
GFNI	21 (44)	35 (42)	45 (40)	63 (38)	109 (34)		
GFDN*	24 (23)	36 (22)	46 (21)	52 (20)	97 (18)		
GFDI	26 (51)	45 (49)	60 (47)	69 (43)	97 (39)	117 (35)	149 (31)
GFDL*	22 (50)	39 (48)	54 (46)	67 (44)	95 (40)	111 (36)	143 (32)
UKMI	23 (49)	41 (47)	57 (45)	67 (43)	88 (39)	111 (35)	154 (31)
UKM*	31 (25)	47 (24)	60 (23)	73 (22)	94 (20)	119 (18)	145 (16)
NGPI	21 (52)	39 (50)	58 (48)	78 (46)	129 (42)	192 (37)	250 (33)
NGPS*	25 (51)	36 (49)	50 (47)	63 (45)	105 (41)	159 (37)	215 (33)
AVNI	25 (49)	41 (47)	58 (45)	79 (43)	123 (39)	155 (35)	204 (31)
AVNO*	29 (50)	43 (48)	57 (46)	75 (44)	123 (40)	154 (36)	191 (32)
AEMI	15 (8)	39 (8)	73 (7)	112 (6)	202 (3)		
AEMN*	16 (8)	32 (7)	49 (6)	84 (5)	160 (3)	205 (1)	
GUNS	18 (49)	32 (47)	45 (45)	52 (43)	72 (39)	86 (34)	93 (30)
GUNA	19 (49)	32 (47)	43 (45)	53 (43)	75 (39)	97 (34)	114 (30)
FSSE	18 (24)	32 (23)	44 (22)	51 (21)	72 (19)		
OFCI	24 (50)	42 (48)	54 (46)	64 (44)	85 (40)	108 (36)	157 (32)
OFCL	22 (51)	39 (49)	52 (47)	60 (45)	80 (41)	104 (37)	146 (33)
NHC Official (1993-2002)	45	81	116	150	225	282	374

mean)	(2985)	(2726)	(2481)	(2230)	(1819)	(265)	(216)
*Output from these models was unavailable at forecast time.							

Table 6: Watch and warning summary for Hurricane Isabel, 6-19 September 2003.

Date/Time	Action	Location
16/1500	Hurricane Watch Issued	Little River Inlet, S.C. Chincoteague Virginia including Albemarle and Pamlico Sounds, the lower Chesapeake Bay south of North Beach Maryland, and the tidal Potomac.
16/1500	Tropical Storm Watch Issued	South Santee River SC to Little River Inlet, SC
16/2100	Tropical Storm Watch Issued	North of Chincoteague, VA to Little Egg Inlet, NJ including Delaware Bay.
17/0300	Hurricane Warning Issued	Cape Fear North Carolina to the North Carolina-Virginia border including Albemarle and Pamlico sounds.
17/0300	Tropical Storm Warning Issued	Little River Inlet, SC to Cape Fear, NC
17/0900	Hurricane Warning extended northward	North Carolina-Virginia border to Chincoteague including the Chesapeake Bay south of Smith Point.
17/0900	Tropical Storm Watch extended northward	Little Egg Inlet, NJ to Sandy Hook, NJ
17/1500	Hurricane Watch changed to Tropical Storm warning	South Santee River, SC to Cape Fear, NC and Chincoteague, VA to Sandy Hook, NJ including Delaware Bay and Chesapeake Bay north of Smith Point including the tidal Potomac.
18/0900	Tropical Storm warning extended eastward	Sandy Hook, NJ to Moriches Inlet, NY
18/2100	Hurricane Warning changed to Tropical Storm warning	Cape Fear, NC to Surf City, NC
18/2100	Tropical Storm warning discontinued	South Santee River, SC to Cape Fear, NC
19/0100	Hurricane Warning changed to Tropical Storm warning	Surf City, NC to Chincoteague, VA including Albemarle and Pamlico sounds and Chesapeake Bay south of Smith Point.
19/0300	Tropical Storm warning discontinued	Surf City, NC to Currituck Beach Light, NC including the Albemarle and Pamlico sounds.
19/0900	Tropical Storm warning discontinued	Currituck Beach Light, NC to Chincoteague, VA including the Chesapeake Bay south of Smith Point
19/1500	All coastal warnings discontinued	

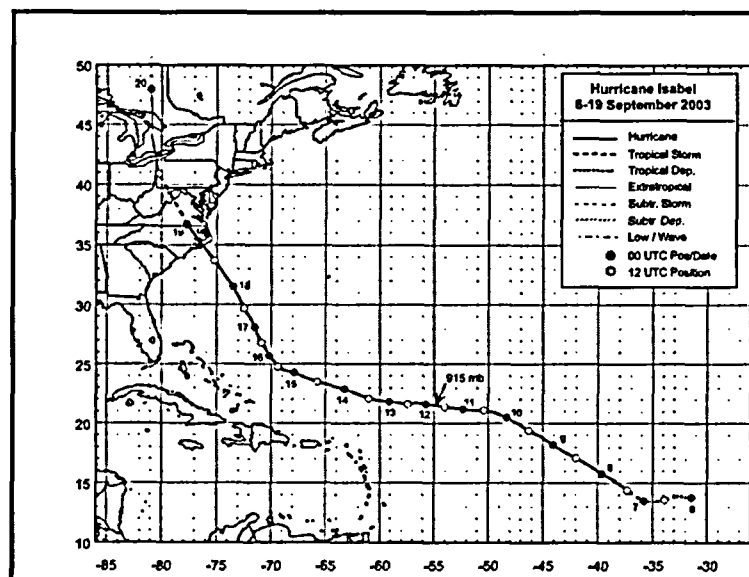


Figure 1: Best track positions for Hurricane Isabel, 6-19 September 2003.

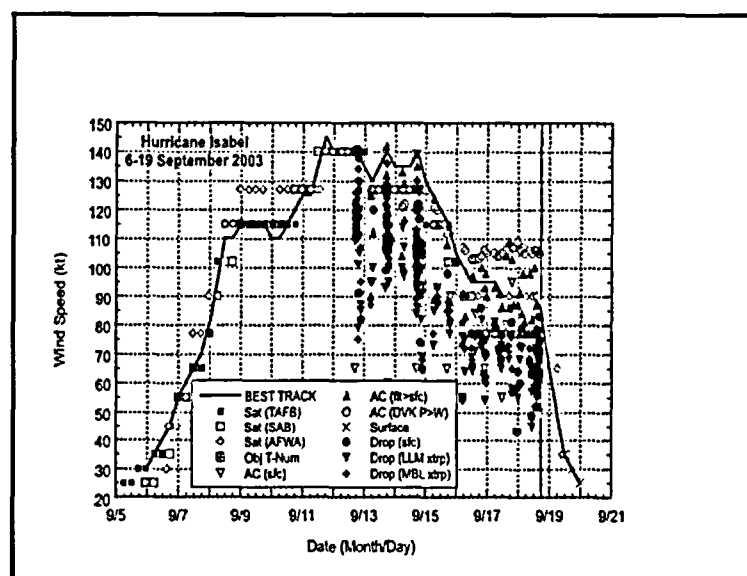
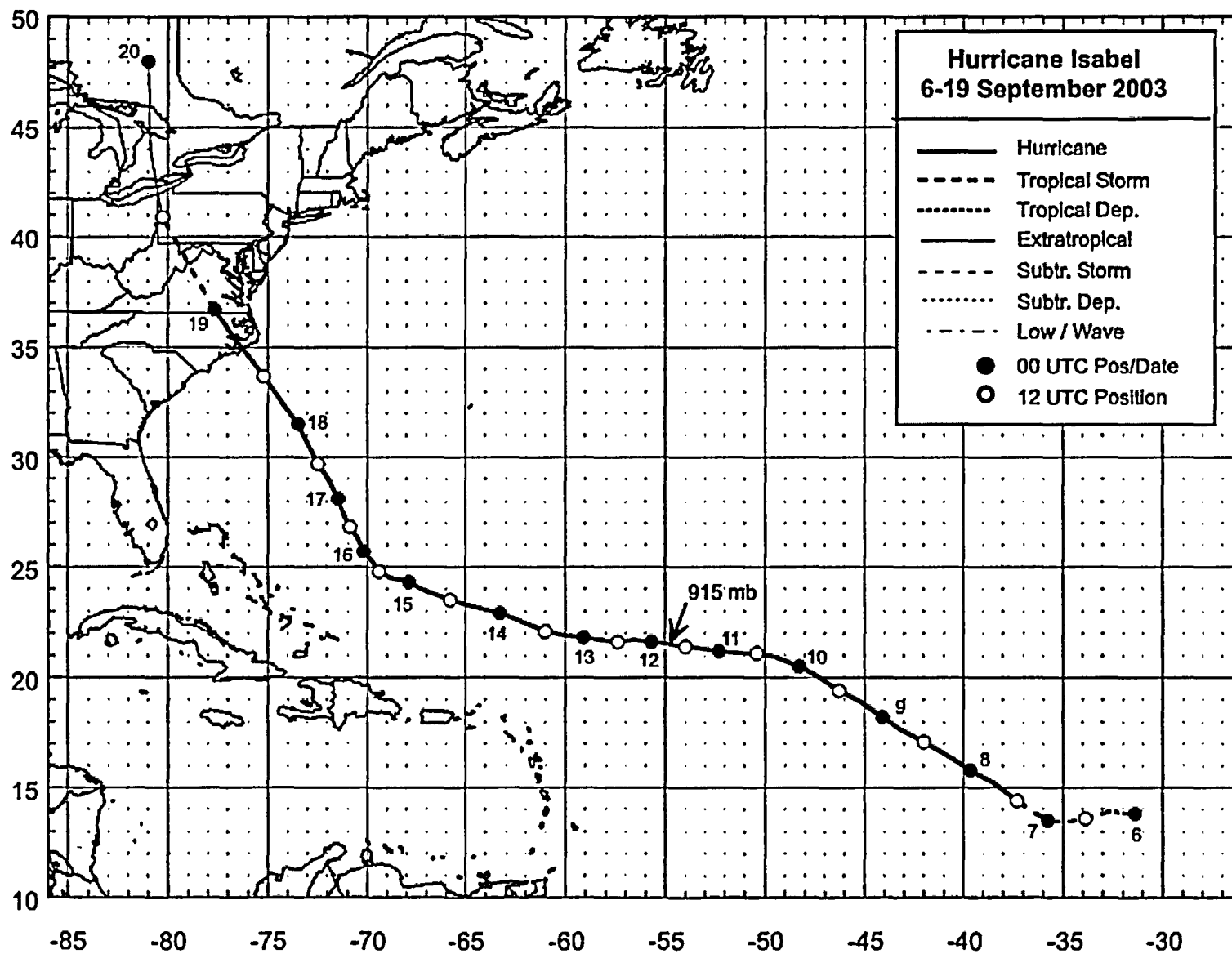
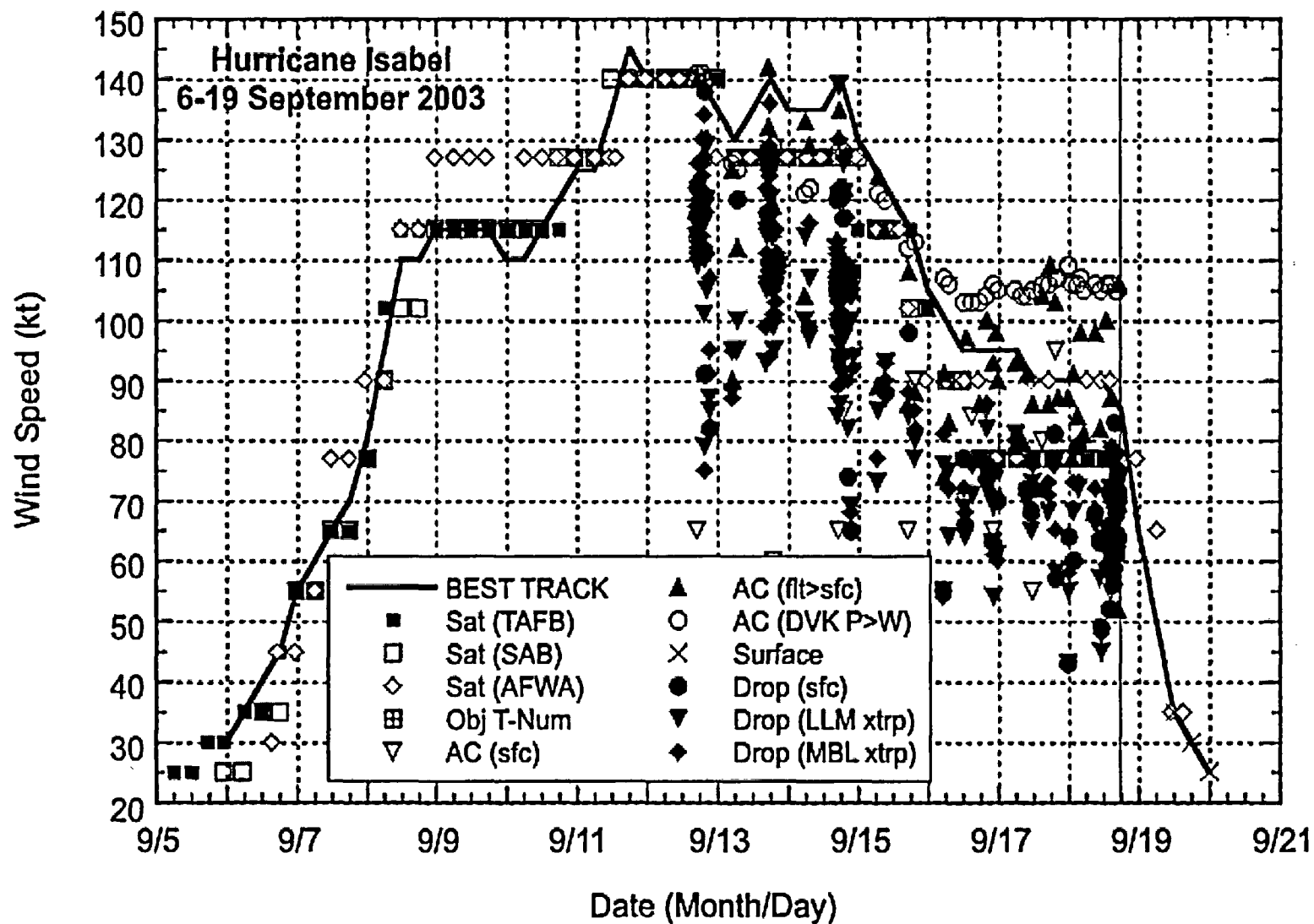


Figure 2: Selected wind estimates/observations and best track maximum sustained surface wind speed curve for Hurricane Isabel, 6-19 September 2003. Aircraft observations have been adjusted for elevation using 90% and 80% reduction factors for observations from 700 mb and 850 mb respectively. Dropwindsonde observations include actual 10 m winds (sfc), as well as surface estimates derived from the mean wind over the lowest 150 m of the wind sounding (LLM), and from the sounding boundary layer mean (MBL).





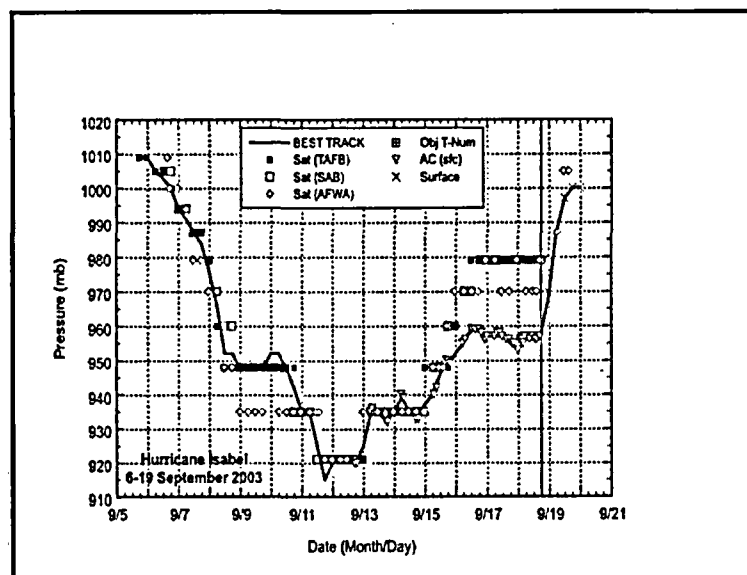


Figure 3: Selected pressure estimates/observations and best track minimum central pressure curve for Hurricane Isabel, 6-19 September 2003.

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