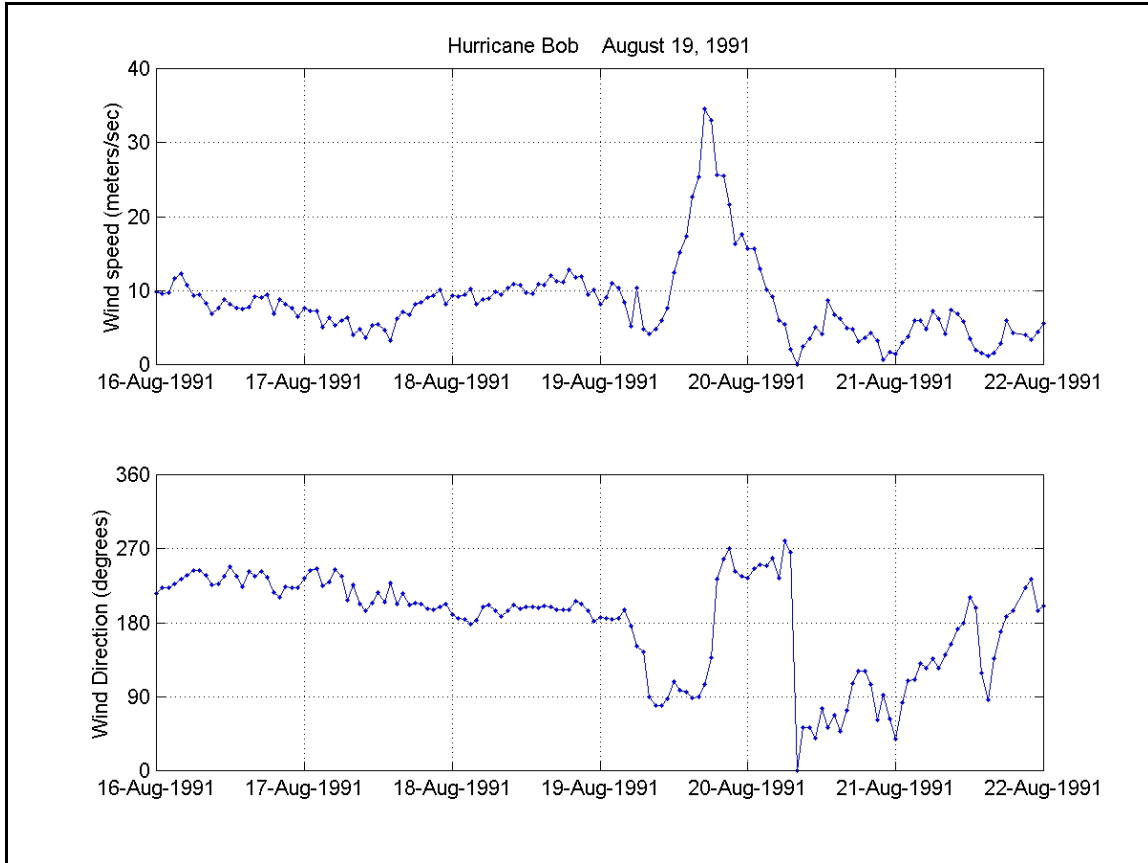


## **APPENDIX A**

### **SPECIFICATION OF A WORST-CASE STORM EVENT IN LONG ISLAND/BLOCK ISLAND SOUND**

# Specification of a Worst Case Storm Event in Long Island/Block Island Sound



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**July 2001**

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## Introduction

This report presents an analysis of historical wind data to identify a ‘worst-case’ storm event in Long Island Sound (LIS) and Block Island Sound (BIS). ‘Worst-case’ storm event was defined in terms of energy influencing sediment transport at proposed dredged-material disposal sites. Results included statistical analyses to document storm frequency as well as the wind magnitude, direction, and duration for storm events.

Wind energy applied to the sea surface of LIS and BIS enhances bottom sediment transport in several ways: direct wind-forced water motions, wave-induced bottom motions, and effects of non-locally generated wind motions (such as wind-induced motions on the continental shelf which propagate into the Sound). Wind effects influence sediment transport patterns by providing aperiodic enhancements to the principal bottom currents dominated by tides and density-induced flow.

There may not be a direct correlation between strongest wind speeds and ‘worst-case’ storm influence on sediment transport processes. For example, in western LIS it has been noted that west winds generate a current along the seabed directed opposite the wind direction (toward the west). This wind-induced countercurrent will enhance sediment transport processes only if added to prevailing density-driven flow, thus the combination of westward wind- and density-induced currents result in maximum bottom speeds. Eastward winds, such as those generated by extratropical storms (northeast storms), create eastward bottom currents that oppose prevailing westward density-driven currents, thus minimizing the overall bottom current. Hurricanes were found to possess the highest wind speeds, but rapid passage of these storm systems plus rotation of wind direction during the event limit hurricane wind impact to bottom currents. Wind data obtained for this study were analyzed in light of these physical processes to determine the ‘worst-case’ storm conditions for specific areas where proposed dredged-material disposal sites may be located.

This report reviews historical wind data from several locations in and around LIS. All data were obtained from government organizations, and were of good quality. However, measurements from these locations were not directly comparable due to potential differences in observation elevation, averaging intervals, and inland versus sea station locations; these differences resulted with different wind observations for the same event. Hence, some stations exhibit higher speeds, on average, than other stations within similar geographic regions. Sea-based stations, specifically the NOAA C-Man buoy stations, appeared to have higher wind speeds than those located inshore (such as at airports). In general, data from sea-based (versus inland) stations were utilized for this analysis because these data were considered to more closely resemble wind stress applied to the surface of Long Island Sound.

An empirical screening procedure was developed to identify wind directions that affect sediment transport at each disposal location. These identified events were then sorted by peak speed and event duration, creating a census of storms originating from a specified direction. From this census, two or three events were presented to characterize ‘worst case’ storms.

## **Bottom Currents in Long Island Sound: Effects of Winds**

Wind forcing plays a secondary role in LIS near-bottom circulation. Bottom currents in LIS are dominated by tides, accounting for most of the total current variance. Bottom tidal currents are strongest in the eastern region of LIS, with peak bottom velocities of order 60 to 70 cm/sec during spring tides, and weaken toward the west to 18 to 21 cm/sec (Signell et al., 2000). Other physical processes that contribute to bottom circulation are winds and horizontal density differences.

Horizontal density gradients through LIS are present for much of the year, resulting in net eastward surface flow and net westward bottom flow of approximately 5 to 10 cm/sec (Gordon and Pillbeam, 1975). This horizontal density gradient results from input of significant volumes of fresh water from river sources along the northern shore of LIS. The upper layer of relatively fresher water is advected eastward by prevailing winds (predominantly from the west), inducing a bottom counterflow towards the west. This density-induced westward bottom flow is important, as it controls the influence storms can provide to bottom currents.

Wind-driven bottom flow is much weaker than tidal currents. However, strong wind events provide additional energy that, when combined with tidal and density-induced currents, can exceed thresholds required for re-suspension and transport of sediments. Wind-driven bottom currents are manifest in several forms. Direct wind stress forcing in shallow water can drive surface water in the direction of the wind. Near-bottom currents can flow opposite the direction of wind in response to sea surface slopes resulting from wind set-up or set-down, or water ‘piling up’ along a shoreline boundary. Non-local wind-driven currents (generated on the shelf) can propagate into the estuary and affect the local flow regime at subtidal time scales. Further, orbital velocities along the bottom due to surface gravity waves can be a significant source of sediment transport, especially in waters shallow enough to be affected by relatively short period wind waves. Longer period ocean swells also can affect sediment transport in estuarine areas exposed to the open ocean, specifically areas in eastern LIS.

Recent research suggests winds affect bottom currents in deeper areas of western LIS. Schmalz (1993) presented numerical model results of Long Island Sound, noting an eastward wind produced significant net westward flow along the bottom. Other work suggests fluctuations in bottom currents in the deep central basin are strongly correlated with along-Sound wind. Signell et al. (2000), analyzing near-bottom current measurements obtained in the axial depression of western LIS, reported that 62% of the subtidal along-Sound currents could be explained by wind stress variations at a station in 45 m of water and 5 m above the bed. He developed an approximate transfer function of 1 cm/sec of current per 1 m/sec of wind; a 10 m/sec wind therefore corresponded to a 10 cm/sec bottom current.

However, results from these recent numerical models contradict historic literature that suggested winds have little effect on bottom currents in the central basin of LIS. Bokuniewicz and Gordon (1980) proposed wind effects are negligible below about 18 meters. Analyzing multiple current meter records, they noted only one occasion (Hurricane Belle in 1976) when wind effects were observed in near-bottom current records; by their calculation, wind effects were observed on the bottom about 0.009% of the time. Gordon and Pillbeam (1975) also reported no correlation between wind and bottom current measurements. Snooks and Jacobsen

(1979), analyzing 11-months of current meter data in Block Island Sound, also concluded there was little correlation between near-bottom currents and wind events.

The effects of winds in Long Island Sound can be explained as the combination of density-induced circulation and wind forcing. Similar to circulation in a long lake, LIS responds most strongly to along-axis winds. These axial winds produce a downwind flow in shallow regions (where depths are less than the average depth), and an upwind countercurrent in regions deeper than the average depth (Csanady, 1973). In western regions of LIS, where the bathymetric axial depression is well defined, there exists a strong deep flow opposite the wind direction (Signell et al., 2000). If bathymetry gradients are mild, such as in the central and eastern areas, this deep bottom flow is quite weak.

In LIS, there is a net westward flow along the bottom due to persistent horizontal density gradients. During west wind events (winds from the west, the predominant wind direction), a westward bottom flow occurs, opposite the wind, which strengthens the westward density-driven flow. Bottom wind-driven currents of 6 to 8 cm/sec were reported (Signell et al., 2000) for a 10 m/sec west wind. East winds, such as those generated by passing extratropical storms, result in an eastward bottom current response, opposite the westward density-driven flow, serving to weaken the overall bottom currents.

What about other areas of the Sounds, specifically, areas where proposed disposal sites are considered? What conditions determine a 'Worst case' storm for these areas? These areas are discussed in the following sections.

### Western Long Island Sound

Proposed disposal sites in western LIS are located within the deeper axial depression affected by accelerated bottom velocities during west wind events. Bottom flow, and by extension sediment transport, would be maximized during strong west wind events. Strong east winds would result in flow opposite density-induced bottom flow, weaker generally than bottom flow during west wind events. Specification of 'worst-case' storms for proposed disposal sites in western LIS thus would be limited to wind events from the west.

Proposed monitoring sites in western LIS have approximate water depths of 23 m (Station 2) and 34 m (Station 3), hence, they are likely immune from effects due to surface gravity waves. Wave effects may be greatest during northeast storms, as the fetch to the east is greatest, creating waves of height 1.5 to 2.0 m and 4 to 6 sec periods (Signell et al., 2000). Waves of this magnitude were predicted to generate bottom currents less than 5 cm/sec in water depths greater than 20 m.

### Central Long Island Sound

Proposed monitoring sites in central LIS are found in the broadest portion of the basin on a plain of relatively smooth bathymetry. These monitoring locations are not within the deeper axial depression discussed in the previous section, hence west wind-induced countercurrents along the bottom were significantly weaker, approximately 0 to 4 cm/sec (Signell et al., 2000). By comparison, density-induced currents in central LIS were westward approximately 2 to 6

cm/sec for this region. Strong winds from the west, albeit weaker on average than winds during northeast storms, likely cause stronger bottom currents at these locations than east winds. The counterflow along the bottom in response to west winds adds to the westward density-driven flow.

Water depths range from 21 to 30 m; wave-orbital velocities during strong storms are expected to be less than 5 cm/sec.

### Eastern Long Island Sound

Proposed monitoring locations in eastern LIS are found along the southern Connecticut shore between Niantic Bay and Avery Point, near New London. This region is near the terminus of the basin, potentially influenced by outflow from the Thames River, as well as strong tidal rips through The Race and Fishers Island Sound. The highly-variable bathymetry in these areas strongly modifies local circulation characteristics.

Because these eastern locations are found at the terminus of the basin, influenced strongly by shoreline boundaries, it is difficult to predict how winds may affect bottom currents. The USGS circulation model (Signell et al., 2000) shows wind-driven bottom currents (approximately 2 to 6 cm/sec) induced by strong west winds are weakest in eastern Long Island Sound (strongest in western LIS). Density-induced westward currents along the bottom, greatest in deeper parts of the Sound, are also weak at the proposed near-shore monitoring locations in eastern LIS.

These proposed monitoring stations are in relatively shallow water (Station 8: Fishers Island Sound is in 14 meters depth, Stations 6 and 7 in 17m and 20m, respectively), hence winds may have a more direct impact on these sites relative to those in deeper water. Wave-orbital velocities will have greater influence on bottom currents in relatively shallow water. The sites are in the lee of the mainland during strong northeast storms, but have the longest fetch for winds from the west and south. Thus, winds from the western and southern quadrants may be assumed most important to gauge effects of waves on bottom currents at these sites.

### Block Island Sound

Two proposed monitoring sites in northeastern BIS are located in relatively deeper water (30 and 45 m) within the principal tidal exchange pathway between The Race and Rhode Island Sound. These proposed monitoring locations appear more exposed to winds than those in LIS. Open fetches exist to the west, south, and east, with partial sheltering afforded by Fishers, Long, and Block Islands. The morainal ridges that define Block Island Sound provide some hydrodynamic impedance to tidal currents and open ocean swell (Driscoll, 1996).

There is little data available to analyze the effects of wind on bottom circulation in this region. BIS is not as enclosed by shoreline boundaries as LIS; therefore, it is unclear how wind stress on the surface will affect bottom currents. While tidal currents contribute most of the bottom current variance, other processes may enhance net transport of sediments. Snooks and Jacobsen (1979) suggested that subtidal variations of near-bottom currents, obtained in the passage between Block Island and Point Judith, RI, were not closely correlated to wind events.

Instead, near-bottom currents possessed a more stable net flow towards the west. This net westward drift of bottom currents in northern BIS was consistent with Lagrangian drifter studies by Hollman and Sandberg (1972). Observations suggest that subtidal circulation processes other than direct wind forcing, potentially density-driven processes similar to those occurring in LIS, are responsible for near-bottom flow.

These results suggest that wind influence in Block Island Sound may be similar to those for LIS; that is, impacts will be greatest when they enhance net westward bottom flow, and weakest when they oppose net westward flow. Until more is known about how wind affects bottom currents in BIS, it will be difficult to assess which storms have the greatest impact. Thus, west, south, and east winds were reviewed to determine worst-case conditions.

### **Data Sources and Quality**

Wind speed and direction data sets were obtained from multiple sources. These source locations are shown on Figure 1:

- NOAA C-Man buoy located in Buzzards Bay, Massachusetts average winds over 8 minutes for the time period 1985-1994, 1997-2001 (12 years). These data were obtained from NOAA and have passed the agency's quality control screening.
- Brookhaven National Laboratory: wind speeds and directions sampled hourly for two height levels (11 and 108 meters) were obtained from a third party, and cover the time period 1960 through 1989 (29 years). Observations at 108 m chosen for analysis since this station is inland, where near-surface measurements may be influenced more significantly by boundary layer effects (surface roughness).
- Data were obtained from the Groton, CT airport for time periods 1943, 1951-1954, 1973-2000 (31 years), sampled at 3.0 m above sea level and averaged over 2 minutes every hour. These data were purchased from the National Climatic Data Center (NCDC) and have passed quality control guidelines.
- Data obtained from the observatory 33.5 m above sea level at Block Island, RI spanned 1976-2000 (27 years). Hourly samples result from 2-minute averages. These data were also purchased from NCDC.

Overall, the data quality appears good. Wind speed obtained at Groton, Block Island, Brookhaven (355 feet), and Buzzards Bay are plotted graphically in Figure 2. Data gaps appear in the record due to missing data from the original source or because some data were considered suspect and removed from the records. Data removal due to suspected poor quality occurred only for an approximate 7-month time span in late 1979 for the Block Island station. In general, observed wind speeds were typically less than 20 m/sec. Longer records show clear seasonal variability; stronger winds prevailed in winter and milder winds during summer. Figure 3 presents rose diagrams for the Groton, Block Island, Brookhaven, and Buzzards Bay locations. These figures illustrate the differences in wind speed between land-based (Groton, Block Island, Brookhaven) and sea-based stations (Buzzards Bay).

Wind speed data are typically normalized to correct for potential differences in observation elevation, averaging duration, and inland versus sea station locations. Wind directions are unaffected by station location and sampling differences. Rigorous quantitative

comparisons of wind speed data measured at different sites can only be accomplished if the data are normalized. Many of the existing correction procedures to normalize different data characteristics are listed in the Shore Protection Manual (USACE, 1984). However, these corrections are based on empirical estimates, and are not necessarily capable of refining more accurately wind speeds for the more qualitative approach of this study. Therefore, this study elected not to apply the corrections to each site, rather choose to present observations for each location 'as is'. Normalization of the data should be applied if true magnitudes are required for input to numerical models or other quantitative analyses.

In most cases, data obtained from the Buzzards Bay C-Man station were used to present the worst-case storms. This station was sea-based versus inland, less affected by frictional attenuation of wind speeds over land, and thought more representative of actual wind stress applied to the sea surface of Long Island Sound. Data from other locations were not ignored for selected storms, rather used verify storm wind speed magnitudes/directions at other LIS/BIS locations. When data from Buzzards Bay were not available (pre-1985), storm data from other locations were assessed.

### **Statistical Analysis of Wind Data**

A simple screening procedure was developed to evaluate 'worst case' storms. For many of the proposed monitoring sites, strong winds from the west appear to impact bottom currents most significantly. Other sites, such as those in eastern LIS, may also be impacted by south winds. In addition, BIS sites may be affected by winds from the east. Because of this directional spread, three cases were developed in this evaluation procedure: storms from the west, south, and east. For each case, one or several 'typical' storms were identified and presented.

Initially, winds were converted from speed and direction to vector components in the axial along-Sound and cross-Sound directions. Winds from the east and north were signed positive (i.e., winds from the west and south would be negative); the axis of the Sound was estimated to be along the magnetic east-west compass axis (about 15° CCW from the grid axis). The algorithm then screened data according to the following criteria:

1. Average wind speeds greater than 15 m/sec in the principal component (roughly west, south, or east) were included; all other winds were discarded. All data points exceeding this threshold were retained with associated time/date and analyzed in more detail.
2. For the event to be labeled 'significant', wind speeds had to be sustained for at least three hours from a steady direction.
3. These significant events were then sorted by peak speed and duration, yielding several potential examples of 'worst-case' conditions.

Tables 1, 2, and 3 describe statistical results of the screening procedure. The column headings are percentage of samples that exceed the given threshold; for example, >5 m/s represents the percentage of samples where western component winds exceeded 5 m/sec.

To manage the results of the screening procedure, all winds exceeding 15 m/s (for land-based stations) for at least three (3) hours were analyzed. Due to large number of qualifying

storms, all winds exceeding 20 m/s for at least three hours at the Buzzards Bay station were analyzed. The results of this screening are presented in the next section.

<b>Table 1. Percent Exceedence for West winds</b>					
<b>Location</b>	<b>No. of Years</b>	<b>&gt;5 m/s</b>	<b>&gt;10 m/s</b>	<b>&gt;15 m/s</b>	<b>&gt;20 m/s</b>
Groton	31	12%	0.4%	0.01%	<0.005%
Block Island	27	19%	1.5%	0.04%	<0.005%
Brookhaven (108m)	29	25%	1.7%	0.07%	<0.005%
Buzzards Bay	12	32%	7.0%	1.05%	0.05%

<b>Table 2. Percent Exceedence for South winds</b>					
<b>Location</b>	<b>No. of Years</b>	<b>&gt;5 m/s</b>	<b>&gt;10 m/s</b>	<b>&gt;15 m/s</b>	<b>&gt;20 m/s</b>
Groton	31	5%	0.3%	0.04%	0.007%
Block Island	27	11%	0.4%	0.01%	0.001%
Brookhaven (108m)	29	15%	1.3%	0.09%	0.002%
Buzzards Bay	12	25%	4.3%	0.40%	0.035%

<b>Table 3. Percent Exceedence for East winds</b>					
<b>Location</b>	<b>No. of Years</b>	<b>&gt;5 m/s</b>	<b>&gt;10 m/s</b>	<b>&gt;15 m/s</b>	<b>&gt;20 m/s</b>
Groton	31	5%	0.2%	0.01%	0.003%
Block Island	27	5%	0.3%	0.01%	0.002%
Brookhaven (108m)	29	6%	0.4%	0.03%	0.001%
Buzzards Bay	12	11%	1.9%	0.28%	0.034%

## **Storm Census**

### West Winds

Winds from the west occur most frequently in this region, with winter winds predominantly from the northwest and summer winds from the southwest (Williams, 1969). The screening procedure described above identified several wind events featuring strong winds from the west. These events are important since west wind events are typically longer in duration than those associated with other events, such as hurricanes or extratropical storms (northeast storms).

Figures 4A and 4B show two events for the periods November 17-25, 1989 and November 8-16, 1990. These figures present the genesis of the event, the event itself, as well as the decay. Although only the Buzzards Bay data is shown, the 1989 event was detected at all four stations; the 1990 event was detected at Buzzards Bay, Groton, and Block Island. These two events represent the strongest west wind events in the data records in terms of peak speeds and event duration, and were chosen to portray characteristics of a 'worst-case' west wind.

These two events featured 15 to 20 m/sec winds steadily from the west persisting for several days. During the 1989 event (Figure 4A), winds blew from the west at speeds of 5 to 10 m/s for several days before strengthening to peak conditions. Peak winds of 23 m/s were measured at the Buzzards Bay location; inland locations measured peak speeds of 17 m/s. The event persisted about 5 days before winds weakened. The 1990 event (Figure 4B) was slightly different; weak southeast winds rotated abruptly toward the west and wind speeds increased sharply to 15 to 20 m/s. The acceleration of wind speeds occurred over a 24-hour period. Winds built to peak speeds of 20 to 25 m/s, sustaining these levels for about two days until decaying gradually. During this event, wind speeds were greater than 15 m/s and steady from the west for about three days.

### South Winds

Most of the strong south wind events occurred during the winter months, and were generally weaker than western wind events. The strong southerly winds were likely manifest by the track of extratropical storms (northeast storms), whose paths dictated a prolonged period of southerly winds in the region. The strongest south wind events generally had peak speeds of 20 m/s; however, the event durations were quite rapid (less than a day) due to rotation of winds during the storm. This rotation suggests the passage of a low pressure system.

Two events are presented, both occurring within a few days of one another in February of 1981 measured at the Brookhaven, NY station. The first event (Figure 5A), occurring on February 2, began with northwest winds around 10 m/s, which weakened and turned south. These southerly winds strengthened to 20 m/s, remaining steady from the south for about 24 hours, then rotated west and weakened. Wind speeds exceeded 15 m/s for about 16 hours. The second event (Figure 5B), a week later on February 11, 1981, featured slightly higher peak speeds (21 m/s). These winds were not steady from a single direction, rather rotated clockwise. Wind speeds exceeded 15 m/s for about 24 hours; however, during this time winds shifted from the east to the southwest.

### East Winds

Strong east wind events normally correlate with strong winter northeast storms that originate as low pressure systems in the Gulf of Mexico and progress northerly along the eastern seaboard. Some of the more powerful storms to have reached New England are the Blizzard of 1978 and the Perfect Storm (or Halloween Storm of 1991). Unfortunately, some of these events did not pass the screening procedures for strong east wind events and do not qualify as 'worst-case' storms.

Such events are plentiful in the records, with two strong east wind events standing out. Northeast storms occurring on October 31, 1991 and December 11, 1992 are presented. Each of these events feature winds that began blowing from the east then rotate from the northeast. Peak speeds reach 25 m/s and the events persist for several days. The Halloween Storm of 1991 (Figure 6A) persisted for four days, with winds exceeding 15 m/s for much of the storm. The December 11 storm (Figure 6B) featured steady winds greater than 15 m/s for three full days and greater than 20 m/s for 36 hours.

These northeast storms, while appearing in the records as the longest duration events (relative to south or west winds) with winds of high magnitude, the limited fetch of the proposed dredged-material disposal sites to the northeast direction may limit the influence such winds have on sediment transport at the seabed. The one exception may be the western-most site in BIS, whose exposure to the northeast is greater than other sites.

### Hurricanes

Hurricane winds, the strongest winds to affect the region in terms of magnitude, tend to rotate in direction, hence do not sustain strong winds from a consistent direction long enough to develop wind-forced motions along the seabed (Driscoll, 1996; Bokuniewicz and Gordon, 1980). Figures 7A, 7B, and 7C show wind speed and direction histories for three hurricanes: Gloria in September 1985, Bob in 1991, and Floyd in 1999. These wind data were obtained from the Buzzards Bay C-Man station.

With the exception of Hurricane Bob, whose eye passed directly over Block Island, these hurricanes were characterized by rapid increase in wind speed and a steady rotation of winds throughout the event. Gloria winds exceeded 15 m/s for about 12 hours before weakening (Figure 7A) and rotated clockwise through east, south, and west. Peak speeds during Gloria, as measured by the NOAA buoy at Buzzards Bay, were 30 m/s. Hurricane Floyd (Figure 7C, September 17, 1999) winds exceeded 15 m/s for about 24 hours, but peak speeds were relatively lower than other hurricanes (24 m/sec). The steady clockwise rotation during the storm may limit the influence winds can impart on bottom sediment transport. Hurricane Bob (Figure 7B) attained peak speeds of 35 m/s, however the acceleration of these winds was quite rapid. Speeds exceeded 15 m/s for about 12 hours during the storm. This storm was unlike others in that wind direction remained steady from the south prior to the storm, then turned east and weakened. Winds accelerated rapidly as the eye passed the region, turning west as speeds peaked. Winds weakened rapidly and turned back towards the east.

### **Summary and Conclusions**

Wind events influence sediment transport patterns by enhancing the principal tidal and density-induced bottom currents in Long Island Sound. The net bottom current in LIS and BIS has been identified as westward; this circulation results from horizontal density gradients between fresher western areas and more-saline eastern areas nearer to the continental shelf. In deeper regions of LIS, bottom currents respond most strongly to along-axis winds from the west, which produce a westward countercurrent. In shallower areas, bottom currents parallel the direction of wind stress.

Analysis of historical data from four locations surrounding LIS shows winds have a strong westward component about 32% of the time. West wind events with speeds exceeding 15 m/s were sustained for three to five days, persisting typically for longer periods of time than wind events from other directions. Although northeast (extratropical) storms have been noted to produce significant sediment transport on the U.S. Atlantic Coast, LIS is fetch limited from the northeast and somewhat removed from the influence of such winds. Northeast storms, containing a strong east wind component, may produce an eastward countercurrent that impedes the net westward bottom currents in LIS. The rapid change in direction of winds produced

during hurricanes appears to limit their impact on bottom currents and sediment transport in the Sound.

Westward bottom currents in the deep basin of western and central Long Island Sound result from the combination of density-induced currents and west winds driving westward flow. In the axial depression, the combined bottom currents locally increase sediment transport and winnow fine-grained sediment from the depression (Signell et al., 2000). Sediment transport in the shallow coastal margins (i.e., eastern Long Island Sound) is primarily affected by wave-induced bottom currents as a result of west and occasionally south winds.

The exposure of Block Island Sound to the Atlantic Ocean increases the complexity of sediment transport processes. The hydrodynamics of BIS are influenced by tidal exchange, irregular bathymetry, and shelf processes. Although insufficient data exists to assess the ‘worst-case’ storm direction for BIS, significant wind events from the west, south, and east have potential to enhance sediment transport.

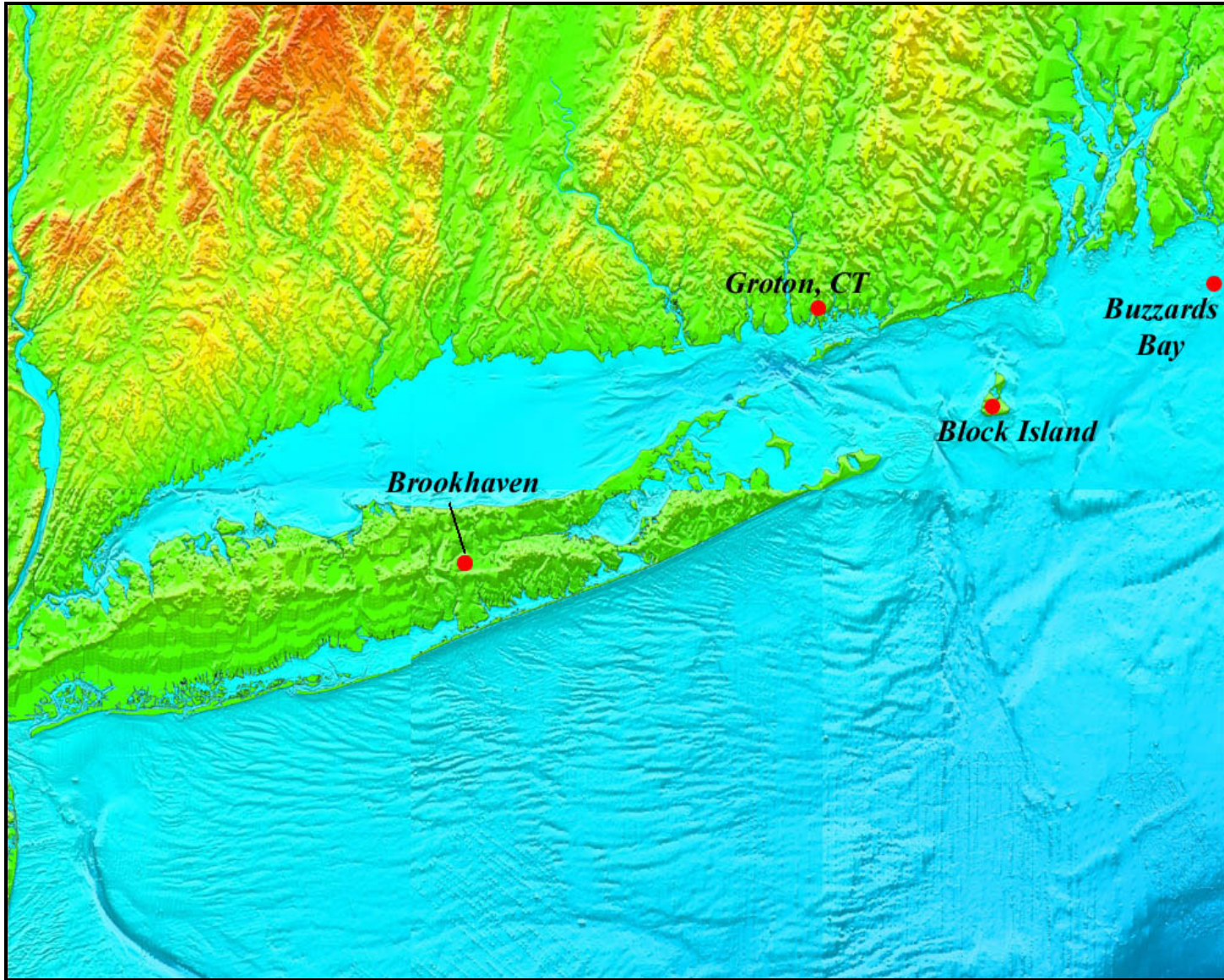


Figure 1. Map of Long Island and Block Island Sounds showing the locations of wind data sources.

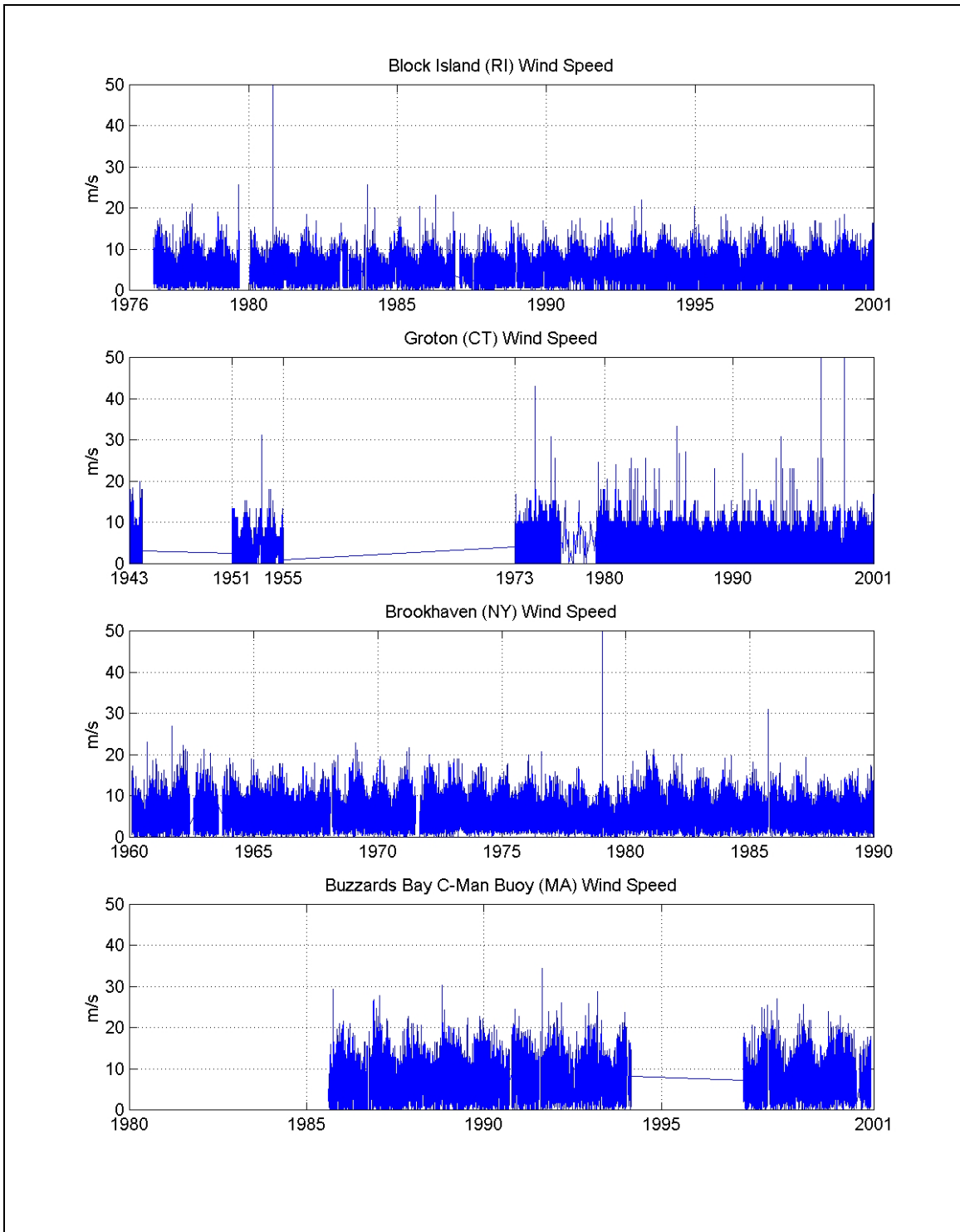


Figure 2. Wind time series showing data coverage at four locations in the vicinity of Long Island and Block Island Sounds. Note differences in time axis.

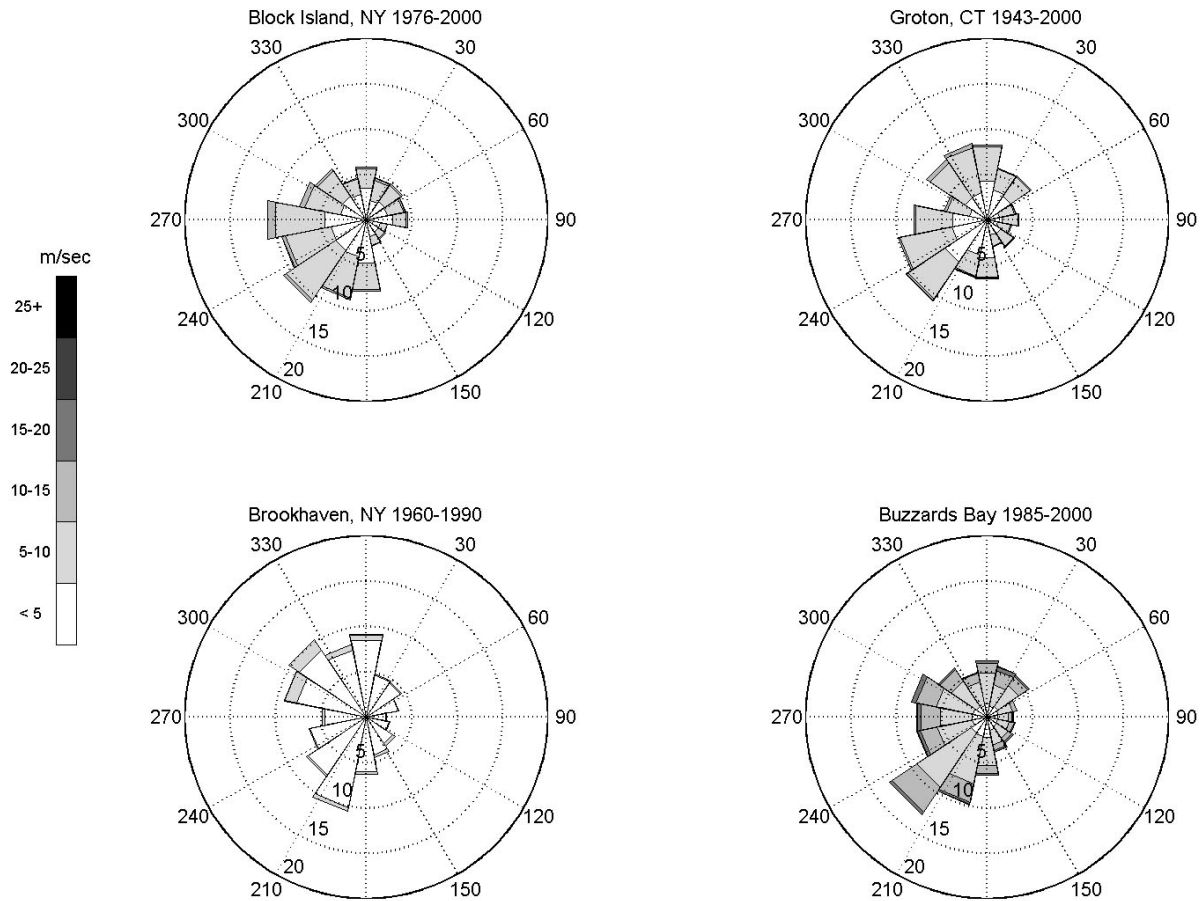


Figure 3. Rose diagrams depicting wind observations for Block Island, Groton, Brookhaven, and Buzzards Bay. The annulus radii represent the frequency of occurrence (dotted radial lines are labeled 5%, 10%, 15% and 20 % occurrence). Shading indicates the magnitude of the wind speed. For example, the Buzzards Bay site shows that winds were from the southwest about 13% of the time; about 8% of winds were SW between 5 and 10 m/sec, and about 4% of winds were between 10 and 15 m/sec. The Groton and Buzzards Bay data contains gaps within the time period displayed in the titles.

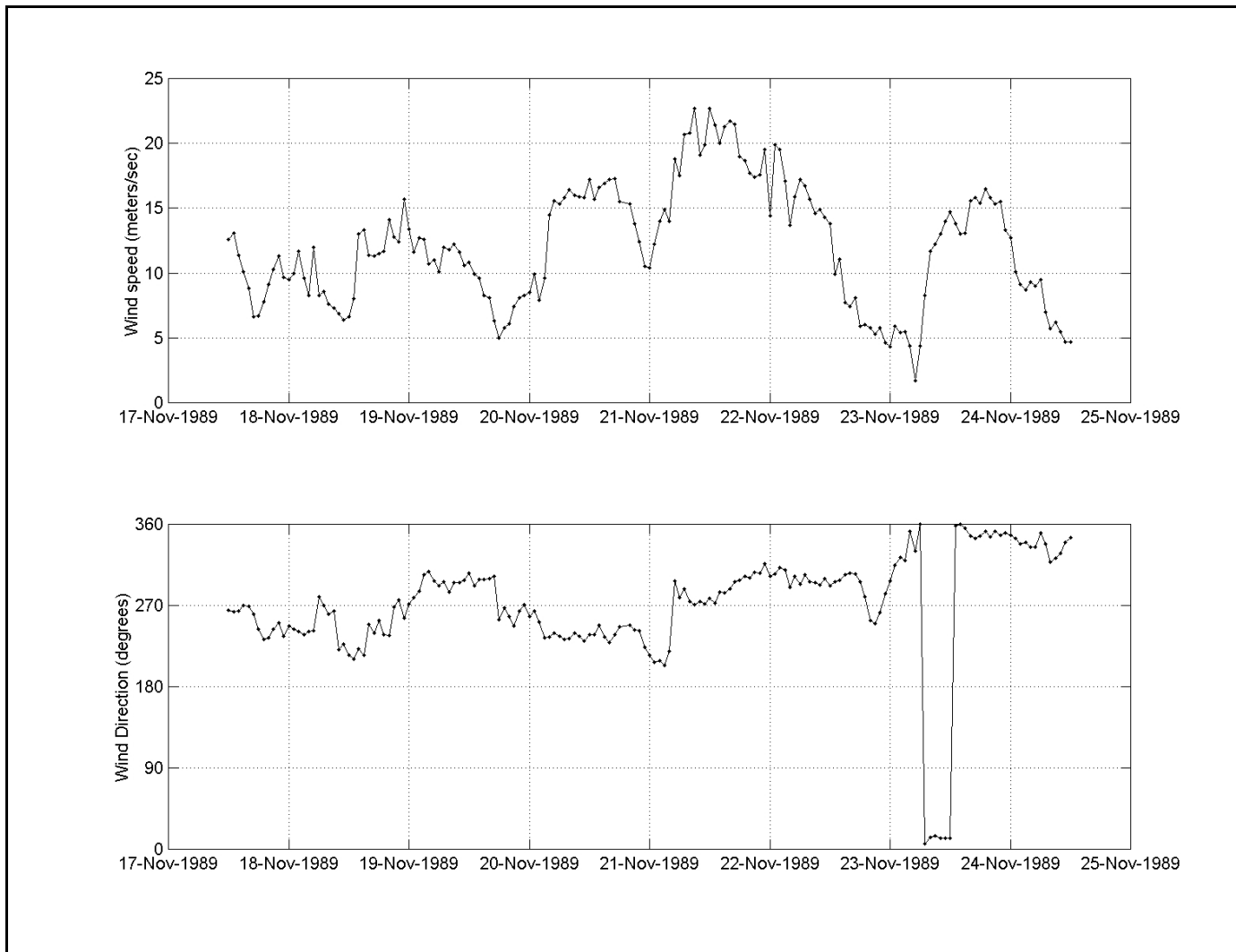


Figure 4A. Strong west wind event measured at the Buzzards Bay buoy in November 1989. Winds were steady from the west for several days prior to peak conditions, and remained westerly during peak speeds of 23 m/sec.

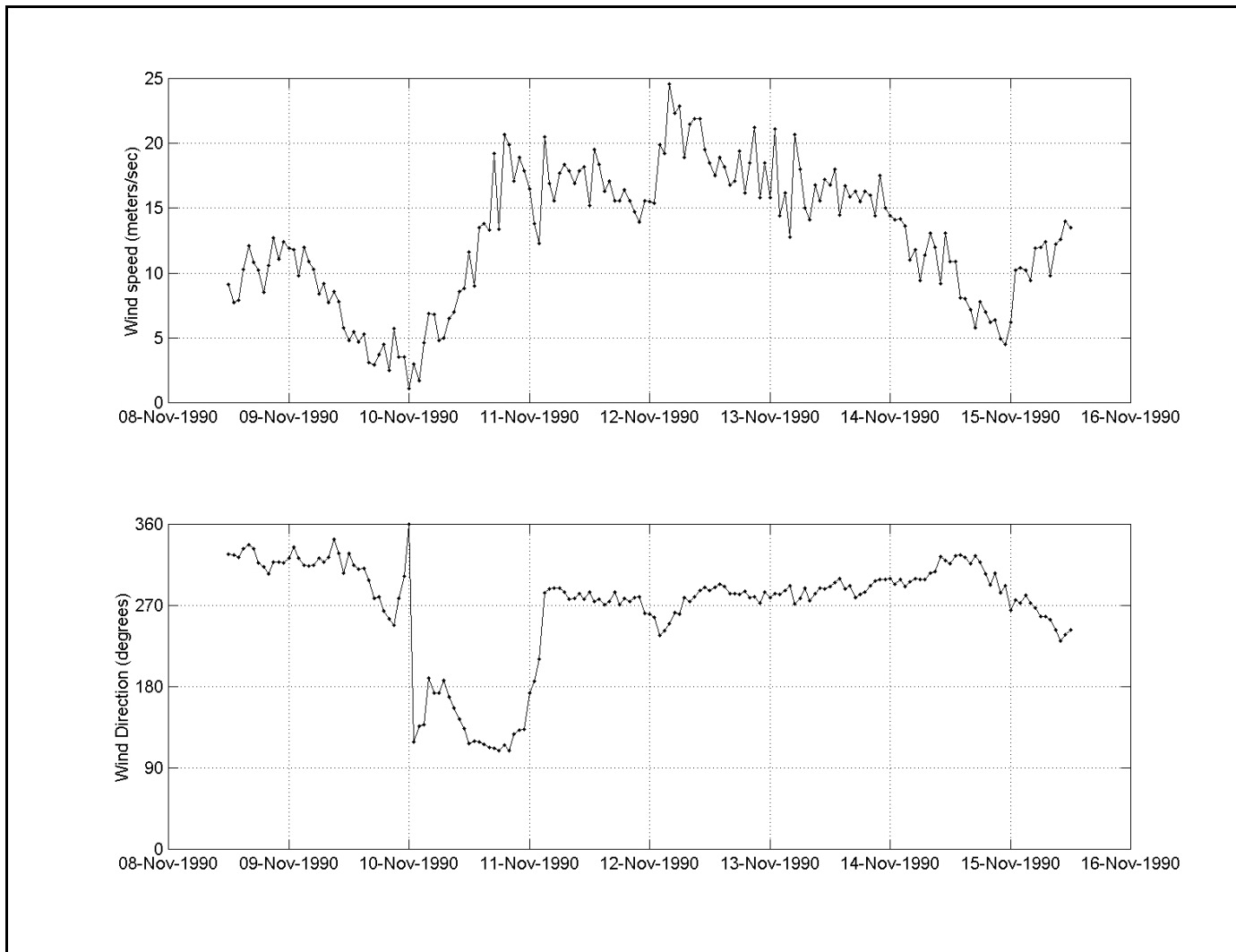


Figure 4B. A similar westerly event occurring in November 1990 measured at the Buzzards Bay buoy. Winds were steady from the west for about four days; peak speeds were nearly 25 m/sec.

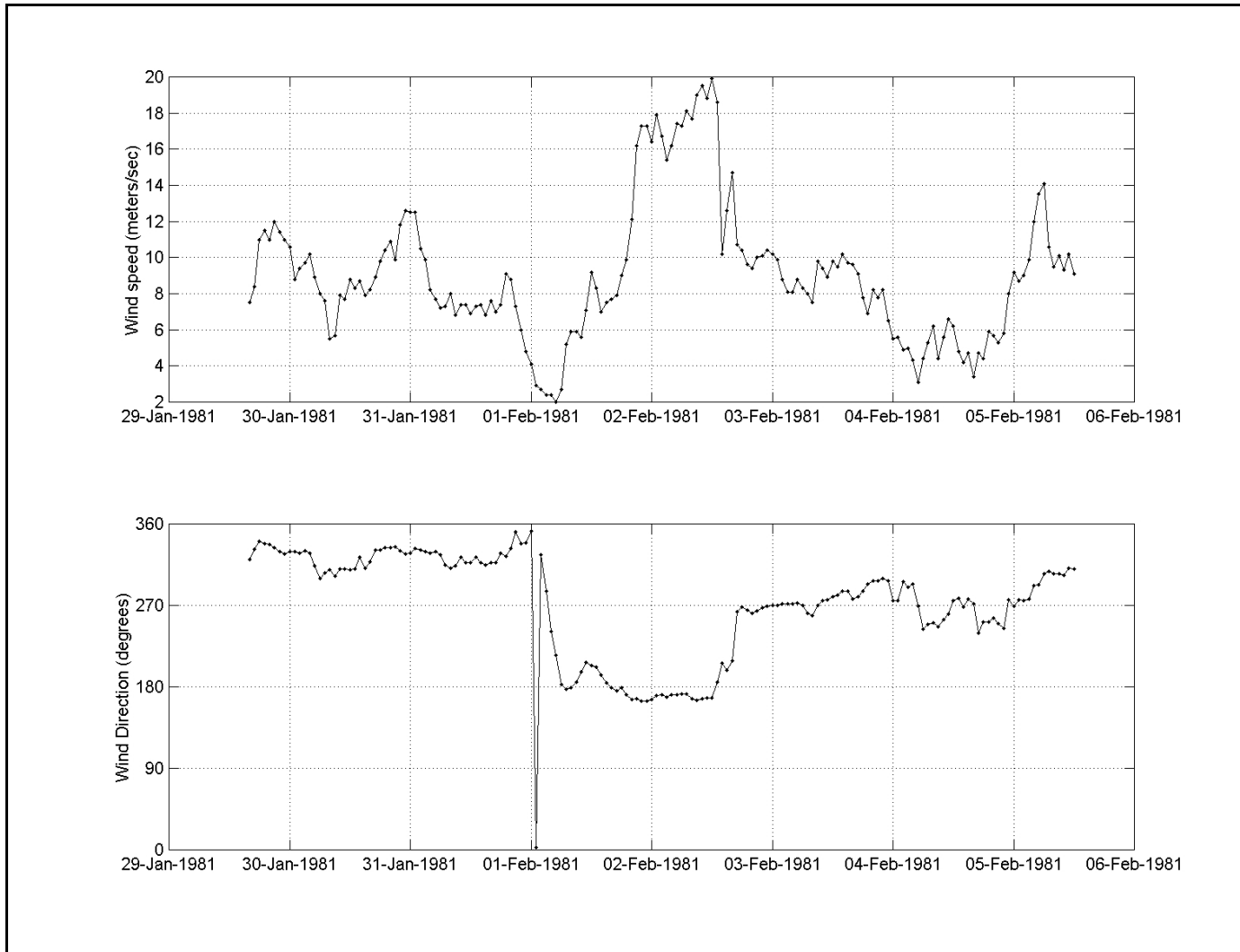


Figure 5A. South wind event occurring February 02, 1981 measured at the Brookhaven, NY station. Winds rotated clockwise during the storm, reaching a peak speed of 20 m/s from the south. South winds persisted for about 24 hours; winds were greater than 15 m/s for approximately 16 hour before weakening and rotating west.

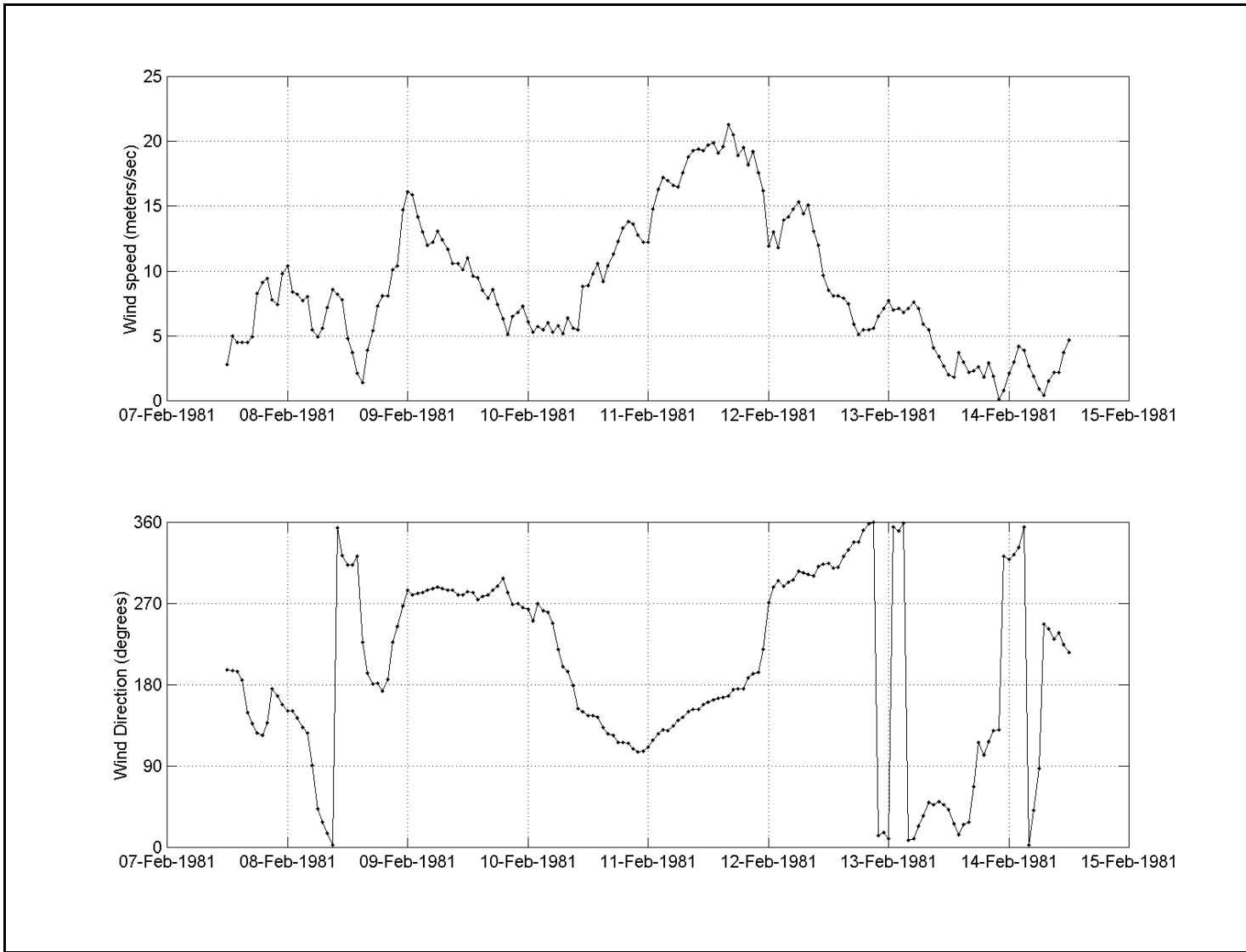


Figure 5B. South wind event occurring February 11, 1981 measured at the Brookhaven, NY station. Winds rotated clockwise during the storm, reaching a peak speed of 21 m/s from the south. The period of persistent south winds was relatively short.

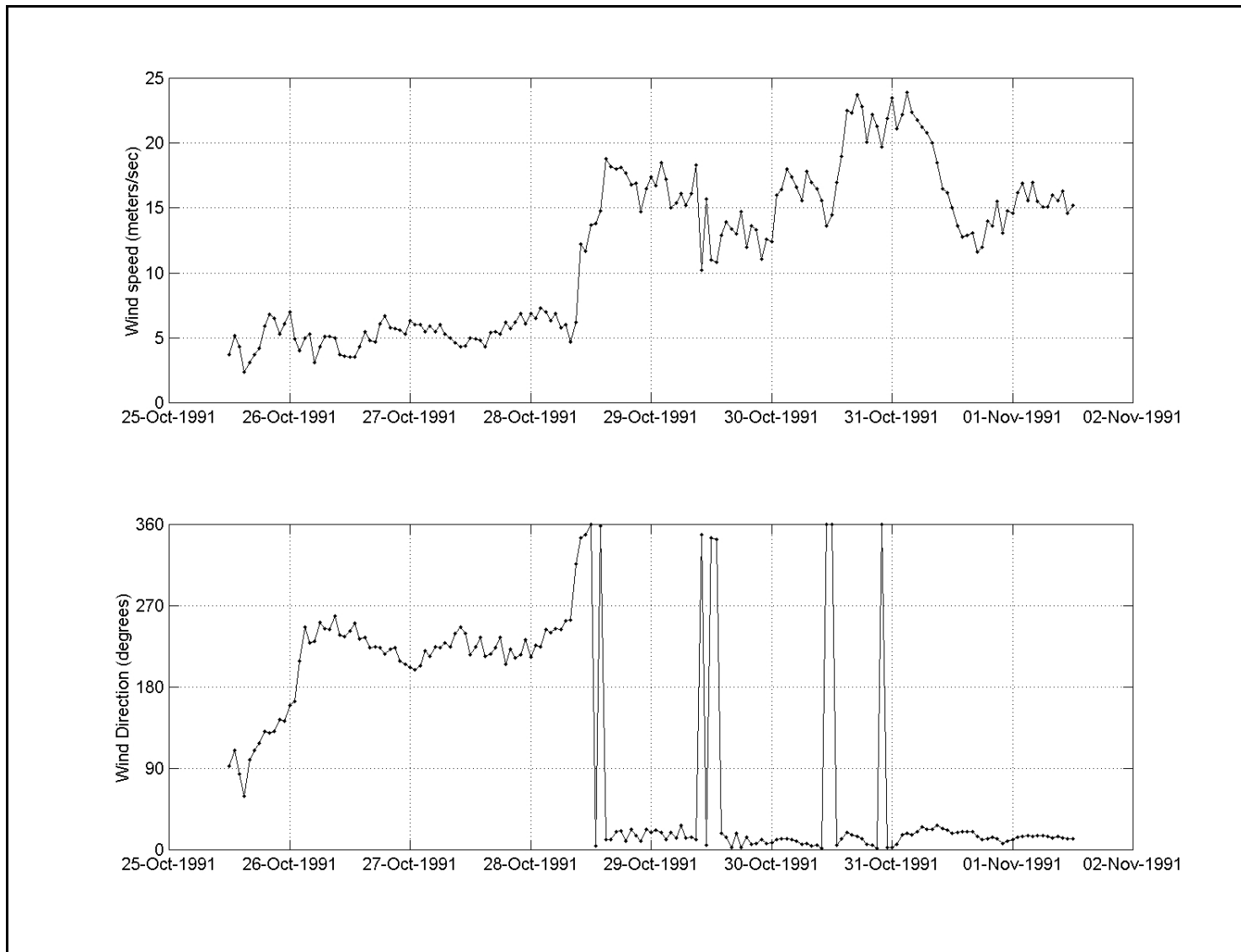


Figure 6A. ‘The Perfect Storm’ occurring Halloween of 1991 recorded at Buzzards Bay. Winds were steady from the north for four days, and peak speeds neared 25 m/s.

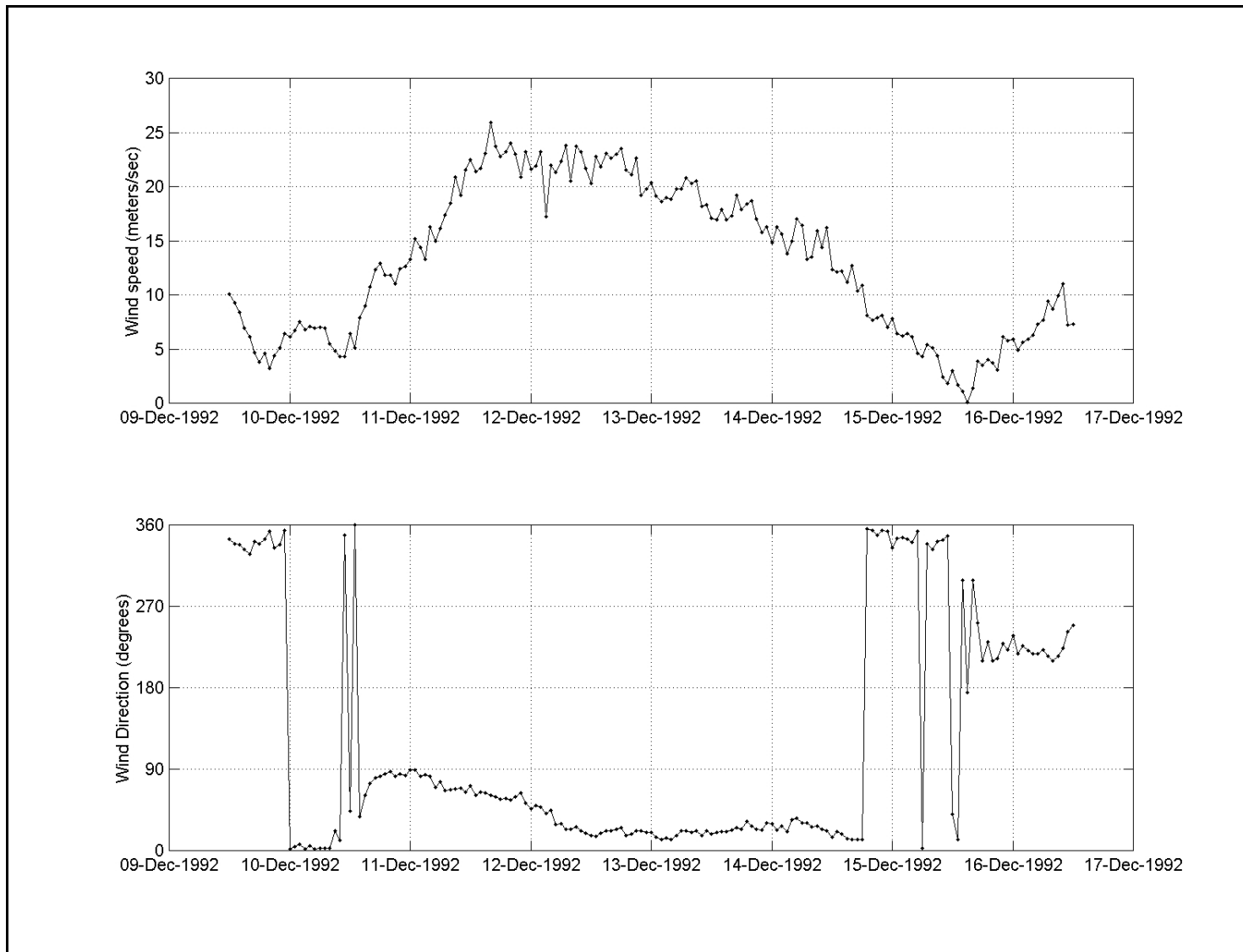


Figure 6B. Strong northeast storm on December 11, 1992. Winds exceeded 15 m/s for approximately 3 days. Peak speeds at the Buzzards Bay buoy were measured at 26 m/s.

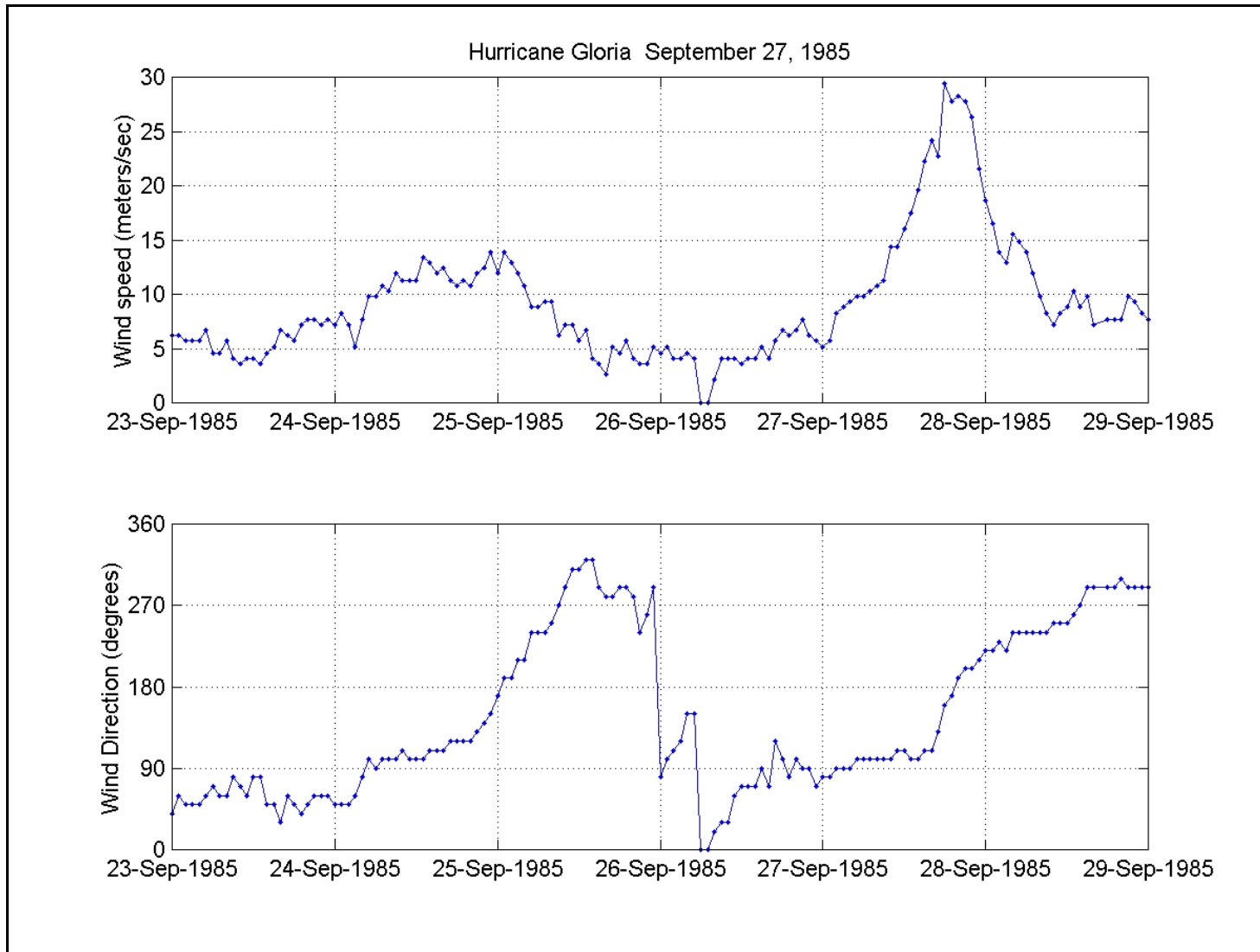


Figure 7A. Hurricane Gloria occurring September 27, 1985. Winds accelerated rapidly during the events while rotating from east to west (in a clockwise sense). Winds exceeded 15 m/s for about 16 hours.

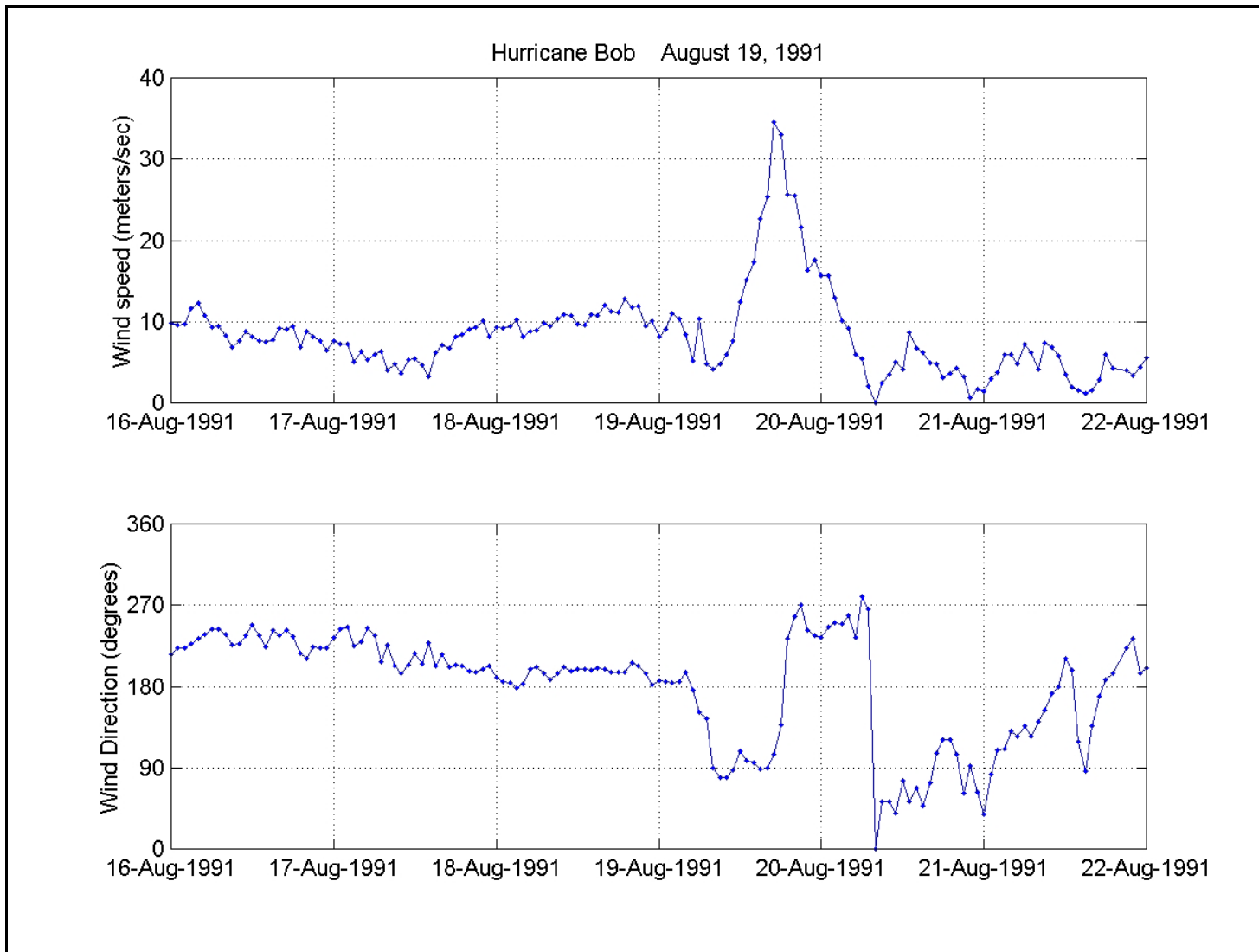


Figure 7B. Hurricane Bob occurring August 19, 1991. The eye of the storm passed over Block Island, shown in the record as the rapid acceleration of wind speed during the event, and also the sharp transition from east winds to west winds. Peak speeds reached 35 m/sec.

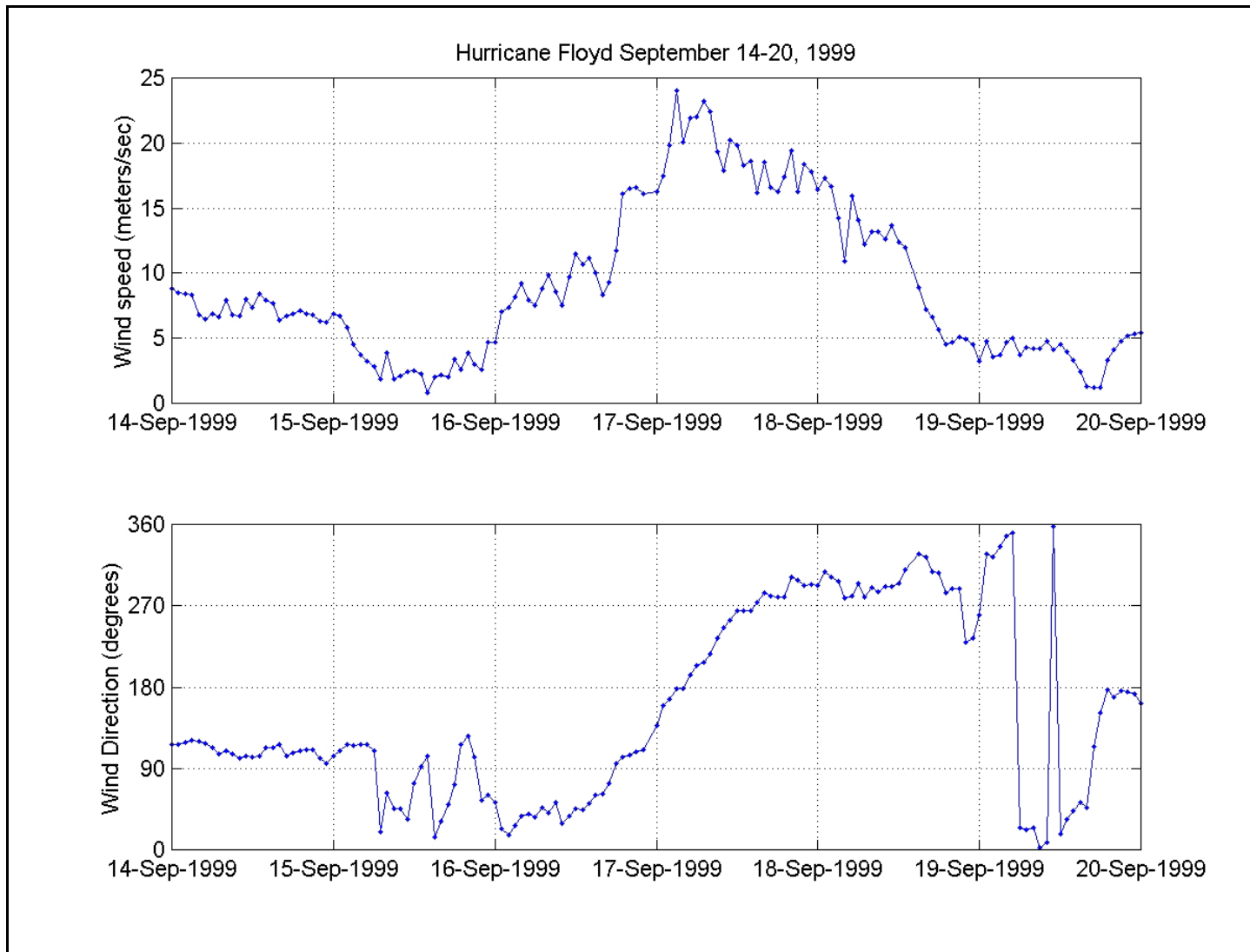


Figure 7C. Hurricane Floyd occurring September 17, 1999. Peak speeds only reached 25 m/s however, winds exceeded 15 m/s for approximately 36 hours. This persistent of strong winds was unusual for a hurricane, which typically travel quickly through the region (such as Gloria or Bob).

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