Continental Shelf Research 28 (2008) 1231–1245

Contents lists available at ScienceDirect

Continental Shelf Research

journal homepage: www.elsevier.com/locate/csr

# Northeast storms ranked by wind stress and wave-generated bottom stress observed in Massachusetts Bay, 1990–2006

Bradford Butman [a,*], Christopher R. Sherwood [a], P. Soupy Dalyander [b,1]

[a] US Geological Survey, 384 Woods Hole Road, Woods Hole, MA 02543, USA
[b] Integrated Statistics, Inc., 16 Sumner Street, Woods Hole, MA 02543, USA

ARTICLE INFO

*Article history:*
Received 16 August 2007
Received in revised form
11 February 2008
Accepted 13 February 2008
Available online 4 March 2008

*Keywords:*
Storms
Northeasters
Climatology
Bottom stress
Wind stress
Surface water waves
USA
Gulf of Maine
Massachusetts Bay

ABSTRACT

Along the coast of the northeastern United States, strong winds blowing from the northeast are often associated with storms called northeasters, coastal storms that strongly influence weather. In addition to effects caused by wind stress, the sea floor is affected by bottom stress associated with these storms. Bottom stress caused by orbital velocities associated with surface waves integrated over the duration of a storm is a metric of storm strength at the sea floor. Near-bottom wave-orbital velocities calculated by using measurements of significant wave height and dominant wave period and the parametric spectral method described in Wiberg and Sherwood [Wiberg, P.L., Sherwood, C.R. Calculating wave-generated bottom orbital velocities from surface wave parameters. Computers in Geosciences, in press] compared well with observations in Massachusetts Bay. Integrated bottom-wave stress (called IWAVES), calculated at 30 m water depth, and a companion storm-strength metric, integrated surface wind stress at 10 m (called IWINDS), are used to provide an overview of the strength, frequency, and timing of large storms in Massachusetts Bay over a 17-year period from January 1990 through December 2006. These new metrics reflect both storm duration and intensity. Northeast storms were the major cause of large waves in Massachusetts Bay because of the long fetch to the east: of the strongest 10% of storms ($n = 38$) ranked by IWAVES, 22 had vector-averaged wind stress from the northeast quadrant. The Blizzard of December 1992, the Perfect Storm of October 1991, and a December 2003 storm were the strongest three storms ranked by IWAVES and IWINDS, and all were northeasters. IWAVES integrated over the winter season (defined as October–May) ranged by about a factor of 11; the winters with the highest integrated IWAVES were 1992–1993 and 2004–2005 and the winter with the lowest integrated IWAVES was 2001–2002. May 2005 was the only month in the 17-year record that two of the nine strongest northeast storms ranked by IWINDS occurred in the same month or year; these were also the only storms of the nine strongest northeast storms to occur in the spring.



## 1. Introduction

Along the coast of the northeastern United States, strong winds blowing from the northeast are often associated with storms called "northeasters," coastal storms that strongly influence weather. These extratropical cyclones typically form off the mid-Atlantic coast and move northeastward as they strengthen. The strength and duration of winds and the surface waves associated with these storms at a particular location depend on the storm's central pressure, size, path, and speed of travel. Classification schemes and rankings for northeasters and meteorological events have been described by Dolan and Davis (1992), Zielinski (2002), and Hart and Grumm (2001). The long-term variability (Zhang et al., 2000) and characteristics of particular storms have also been investigated (see references cited in Hart and Grumm, 2001).

In addition to effects caused by the surface wind stress, which typically receive much attention, northeasters affect the sea floor. For example, observations in Massachusetts Bay and elsewhere show that the bottom stress associated with storms is a dominant cause of resuspension of bottom sediments. This paper introduces bottom stress caused by surface waves and integrated over the duration of a storm as a metric for the strength of storms at the sea floor. The paper provides motivation for use of this new storm metric and presents a companion storm metric based on integrated wind stress. The methods outlined by Wiberg and Sherwood (in press) for calculating near-bottom wave-orbital velocities and bottom-wave stress using surface-wave observations were tested using data obtained in Massachusetts Bay.

* Corresponding author. Tel.: +1 508 457 2212.
*E-mail addresses:* bbutman@usgs.gov (B. Butman), csherwood@usgs.gov (C.R. Sherwood), sdalyander@usgs.gov (P.S. Dalyander).
[1] Previously published as P. Soupy Alexander.

0278-4343/$ - see front matter © 2008 Elsevier Ltd. All rights reserved.
doi:10.1016/j.csr.2008.02.010

The surface- and bottom-stress storm metrics are used to provide an overview of the strength, frequency, and timing of large storms, particularly northeasters, in Massachusetts Bay based on wind and wave observations from January 1990 through December 2006.

## 2. Effects of northeasters

This investigation of the strength of northeasters was motivated by observations of their effects in Massachusetts Bay, a semi-enclosed embayment in the western Gulf of Maine about 50 km wide and 100 km long (Fig. 1). Long-term near-bottom observations at 30 m water depth show that bottom stress caused by surface waves is the principal cause of sediment resuspension (Butman et al., 2004, 2007), and that the largest waves are associated with northeasters because Massachusetts Bay is surrounded by land except to the east. Modeling studies of sediment transport caused by northeasters (Butman et al., 2007; Warner et al., 2008) used the ranking strategy presented here to identify the largest storms and their characteristics. These studies show that a sequence of northeast storms, modeled after the strongest to occur between 1990 and 2006, can rework a spatially uniform mixture of sediments to produce a surficial sediment distribution that is similar to the present day. They also showed that northeast storms transport sediments from Boston Harbor to the long-term depositional areas of Stellwagen Basin and Cape Cod Bay.

A second motivation for this storm ranking investigation was to place two northeast storm events in historical context. Long-term observations of the surficial sediments were made at site 3 (Fig. 1) in western Massachusetts Bay as part of a long-term USGS—Massachusetts Water Resources Authority Program to monitor the potential effects of the new ocean outfall (Bothner and Butman, 2007). The concentrations of silver, clay, and *Clostridium perfringens* spores at this site increased by a factor of two or more following the northeaster "Blizzard of December 1992"; these were the largest changes in surficial (upper 2 cm) sediment properties observed in the 17-year time-series, and they are attributed to the deposition of fine-grained contaminated sediment transported to this site during the northeaster (Bothner et al., 2007). The second event was an extensive bloom of the toxic dinoflagellate *Alexandrium fundyense* in the western Gulf of Maine in the spring of 2005, the largest bloom since 1972 (Anderson

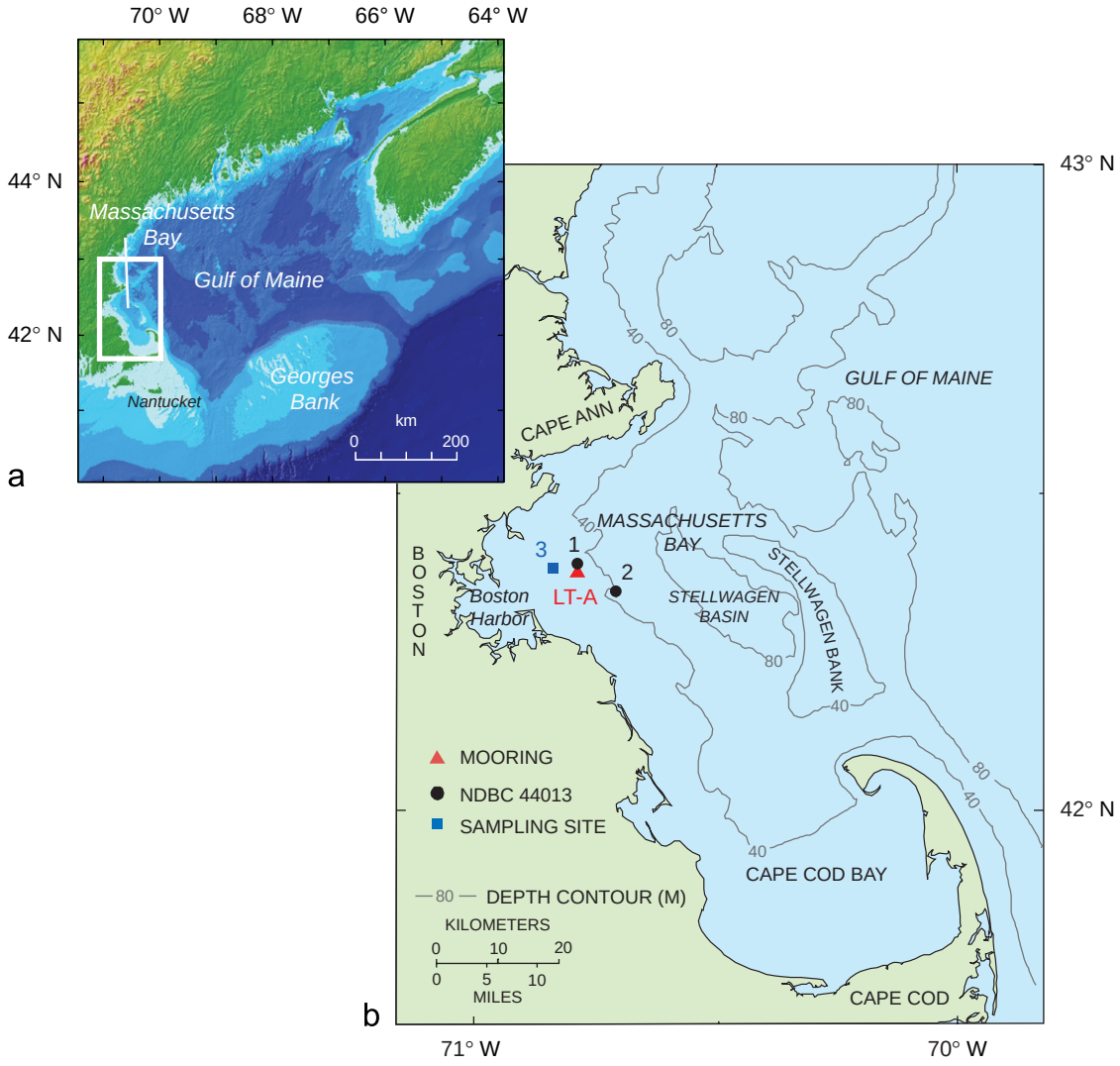


**Fig. 1.** (a) Map showing the location of Massachusetts Bay in the western Gulf of Maine (image from Roworth and Signell (1998)). (b) Map showing Massachusetts Bay. Wind and wave measurements were made at NDBC Station 44013 at site 1 (approximately 30 m water depth) from a 10 m Large Navigational Buoy from 1990 to 1993 and at site 2 (approximately 55 m water depth) from a 3 m discus buoy from 1993 to 2006. Bottom current observations were made at LT-A (32 m water depth). Long-term observations of sediment texture and contaminant concentrations were made at site 3 (Bothner et al., 2007). Contours show water depth in meters.