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RECONSTRUCTING HISTORICAL HURRICANES IN NEW ENGLAND

Emery R. Boose*, Kristen E. Chamberlin and David R. Foster
Harvard Forest, Harvard University, Petersham, Massachusetts

1. INTRODUCTION

Hurricanes are an important natural disturbance to coastal forests in many parts of the world. This paper presents a method for reconstructing historical hurricanes and their impacts over land on a regional scale (10^2-10^3 km). Historical records provide meteorological observations and reports of wind damage for each storm. Damage reports are assessed on a town by town basis using the Fujita scale. A simple computer model reconstructs surface wind speed, direction, and damage across the region, providing informed estimates for locations lacking actual observations. Model reconstructions are tested by comparisons with actual data. Results are compiled to create regional maps of hurricane frequency and intensity, and time lines of hurricane events at particular locations. These techniques were used to reconstruct the hurricane history in New England since the first European settlers arrived in 1620.

2. METHODS

2.1 *Damage assessment*

Reports of actual wind damage to trees, buildings, and other property are collected and indexed by town to create a database for each storm. Each report is assigned an F-scale value using the classification scheme proposed by Fujita for assessing wind damage in tornadoes and hurricanes (Fujita 1971, Grazulis 1993). For this purpose it is important to identify and exclude damage resulting from storm surge and river flooding. A map of actual wind damage for each hurricane is created by using the maximum F-scale value for each town in the database.

For New England, our primary historical sources were newspapers for hurricanes since the early 1700s, and personal diaries and chronicles for earlier storms. Ludlum's work (1963) was invaluable for locating materials for hurricanes before 1871. Despite the many problems inherent in this method--e.g., variations in construction practices, more intense sampling in more populated areas, difficulties separating wind and storm surge damage in coastal towns, and reliabilty of newspaper and other accounts--the resulting damage maps were consistent with meteorological expectations, showing the greatest impacts to the right of the storm tracks and a lessening of damage as the hurricanes weakened over land.

* *Corresponding author address:* Emery R. Boose, Harvard Forest, Petersham, MA 01366-0068.; email: boose@fas.harvard.edu.

2.2 *Hurrecon model*

HURRECON is a simple meteorological model that estimates surface wind speed and direction based on the track, size, and intensity of a hurricane and the surface type (land or water; Boose *et al.* 1994). Recent improvements include: (1) The model estimates F-scale wind damage from peak wind speed, using the correlations between maximum 1/4 mile wind velocity and wind damage proposed by Fujita (1971). (2) The original wind profile equations, based on a modified Rankine vortex, were replaced with Holland's equation for the cyclostrophic wind (Holland 1980, equ. 5), which gives a more rounded wind profile and makes accurate determination of the radius of maximum wind (RMW) less critical. Because the model uses an idealized wind profile, it is not able to predict multiple wind maxima or other mesoscale features (Willoughby 1995).

Model equations are given below. Wind velocity and direction are measured relative to the Earth's surface, and angles are measured in degrees. Parameter values found to work well for New England hurricanes are given in parentheses. The sustained wind velocity (V_s) at any point P is estimated as:

$$V_s = F\,[V_m - S(1-\mathrm{Sin}\ T)V_h/2]\,[(R_m/R)^B \exp(1-(R_m/R)^B)]^{1/2} \quad (1)$$

where F = scaling parameter for effects of friction (water = 1.0, land = 0.8), V_m = maximum sustained wind velocity over water anywhere in the hurricane, S = scaling parameter for asymmetry due to forward motion of storm (1.0), T = clockwise angle between forward path of hurricane and a radial line from hurricance center to point P, V_h = forward velocity of hurricane, R_m = radius of maximum winds (50 km), R = radial distance from hurricane center to point P, and B = scaling parameter controlling shape of wind profile curve (1.3). The peak wind gust velocity (V_g) at point P is estimated from V_s as follows:

$$V_g = G\ V_s \quad (2)$$

where G = gust factor (water = 1.2, land = 1.5). The maximum 1/4 mile wind velocity (V_f) is estimated from V_s and G using Fujita's method (Fujita 1971, equ. 12). Wind direction (D) at point P is estimated as:

$$D = A_z - 90 - I \quad \text{northern hemisphere} \quad (3)$$
$$D = A_z + 90 + I \quad \text{southern hemisphere} \quad (4)$$

where A_z = azimuth from point P to hurricane center and I = cross isobar inflow angle (water = 20°, land = 40°).

Parameter values for F, G, and I were adopted from published sources (e.g., Simpson and Riehl 1981, Powell 1982); F and G were chosen so that peak gust speeds are the same over water and over land. Values for remaining parameters were determined by comparing model predictions to actual observations for recent New England hurricanes. The value $S = 2.0$ reported in the literature (i.e., peak wind on right side minus peak wind on left side = $2V_h$) was found to consistently underestimate wind speed and damage on the left side of the storm; better results were obtained with $S = 1.0$. The low value for B (1.3) yields a relatively flat wind profile that appears to be appropriate for New England hurricanes. The value $R_m = 50$ km worked reasonably well for all storms; in a few cases, where the swath of damage was particularly narrow or wide, R_m was adjusted to improve the fit between predicted and observed damage. With the model thus parameterized, the input variables for each hurricane were location of the storm center and maximum sustained wind velocity (V_m) at 6 hour intervals. Regional predictions were made at 10 x 10 km resolution.

2.3 *New England hurricanes 1620-1996*

1886-1996. During this 110 year period 36 storms were identified that possessed sustained hurricane winds (33 m/s) within 200 km of the New England coast (GTECCA 1994). Meteorological data on storm track and maximum wind speed were used directly from the GTECCA (in a very few cases maximum wind speed values were adjusted where there appeared to be sharp disagreement with observed surface winds and damage). This list of 36 storms should include all hurricanes that impacted New England since 1886.

1620-1885. During this 265 year period 26 storms were identified where the historical record showed evidence of at least F1 damage in some part of New England. Storm tracks were estimated from observed peak wind directions and regional damage patterns, after consulting previous estimates of the track (e.g., Ludlum 1963, GTECCA 1994, Fernandez-Partagas and Diaz 1995). Maximum wind speeds were estimated from regional damage (and in a few cases storm surge). This list of 26 storms should include all hurricanes that caused significant forest damage (F1+) in New England since 1700, and most or all such storms since 1620.

3. RESULTS

The methods described above, though simple, yielded results for New England hurricanes that were consistent with the available historical data. We found it helpful to begin with detailed studies of recent major storms (1938, 1944, Carol 1954, Donna 1960, Gloria 1985, Bob 1991), where we could compare actual and predicted wind speed, direction, and damage and select appropriate parameters for the model, and then work backwards in time to the earliest storms where more educated guesswork was required. For all storms there was good agreement between actual and predicted F-scale damage.

Results showed strong gradients across the region from southeast (CT, RI, and southeastern MA coastlines) to northwest (northern VT, NH, and ME) both in maximum intensity and in frequency of storms of a given intensity. These gradients resulted from the consistent direction of the storm tracks, the shape of the coastline, and the tendency for hurricanes to weaken rapidly over land or over cold ocean water. Average return intervals for F0 damage (defoliation, branch break, occasional blowdowns) ranged from 5 to 110 years; average return intervals for F1 damage (isolated blowdowns) ranged from 10 years to none in 110 years; and average return intervals for F2 damage (extensive blowdowns) ranged from 95 years to none in 375 years. Hurricanes appeared to be clustered in time, and it was not unusual for New England to be struck by 2 or even 3 hurricanes in the same year, while at other times no hurricanes occurred for several decades.

This approach can be used to study the impacts of past hurricanes in any part of the world where good historical records survive. In some areas it may be necessary to adapt or extend the Fujita scale damage specifications to account for local building practices and vegetation.

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