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Texas Hurricane Landfalls: A Case Study for Understanding Circular Distributions and Geographic Data

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ABSTRACT

The azimuth at which a hurricane makes landfall has important implications in evaluating potential impacts and effects. This paper develops an analysis of azimuths of Texas landfalling hurricanes to demonstrate the use of descriptive and inferential statistics for data with a circular distribution. Results indicate that hurricanes making landfall in northern Texas have a more westerly component to their azimuth then those striking southern Texas.

INTRODUCTION

Many phenomena studied in geography exhibit directional characteristics [1-2]. These characteristics include position in both the relative and absolute sense in addition to vector data such as velocity. A vector is a quantity which exhibits both size (magnitude) and direction. For example, wind velocity measures both speed (size) of the wind and the direction from which the wind is blowing. Even positional data can be considered as vectors. To quantify the location of one object relative to another requires both the distance (size) and the direction from an "origin object" of interest. Sophisticated positioning systems such as GPS compute locations in terms of distance and direction from the origin of an Earth-centered coordinate system. The familiar latitude/ longitude display is just the result of a mathematical manipulation between the GPS satellite system determined position vector and the desired output rectangular coordinate system.

An example of such directional data is the azimuth of a hurricane as it approaches and makes landfall. Numerous studies have shown the relationship between azimuth and such impacts as tornadoes, treefall, location of heavy rain, and the distribution of surface winds [3-6]. Azimuth measurements represent one of the most common types of circular measurements encountered by geographers, compass orientation. Directional data is in itself interval level with no true zero point. While azimuths may be added or subtracted, division and multiplication is proscribed. Therefore, azimuths must be transformed into their component coordinates prior to analysis. This is accomplished by considering the azimuth as a vector of unit size with direction measured from north.

This paper uses both descriptive and inferential statistics applied to data which follows a circular distribution. Hurricane landfall azimuth data are used to find the expected value for Texas landfalling hurricanes as well as to test for potential locational and storm strength differences in landfall azimuth.

DESCRIPTION OF THE DATA

The data of Table 1 consist of the set of landfall azimuths and intensities for the 36 hurricanes that struck the Texas coastline during the 20th Century. The data was obtained from the National Hurricane Center's Best Track dataset and azimuth at landfall was calculated from the two position fixes which bracketed the landfall time of the storm. Azimuths were then binned into 10° increments to match the reporting of wind speed. Hurricane intensity was measured using the Saffir-Simpson Scale, an ordinal level scale which runs from 1-5 as a function of wind speed. Hurricanes making landfall south (north) of Port O'Connor were classified as southern (northern) storms. Fifteen storms were classified as southern, 21 as northern. This data set reflects only those storms which were of hurricane intensity and made their landfall in Texas. Tropical storms or hurricanes which moved parallel to the Texas coast before making landfall in another state or in Mexico are not included.

Table1. *Landfall Azimuth of Texas Hurricanes 1900 – 1999.*

Azimuth [Degrees]	Saffir-Simpson Intensity					Total
	1	2	3	4	5	
250	1					1
260	1		1			2
280		2	2	1		5
290	1		2			3
300	1		1	1		3
310	1	3	1	1		6
320	2			1		3
330	1		1	1		3
340			1			1
350	1					1
360	4	1	1	1		7
010		1				1
Total	13	7	10	6		36

METHODS

Descriptive statistics are used as a "first look" at the data. They attempt to summarize data characteristics such as central tendency and dispersion. The calculation of central tendency for circular data is done by transforming the data into rectangular coordinates consisting of the north-south and east-west components of the original data. For data measured as compass azimuth this is accomplished by taking the trigonometric sine (cosine) of the angle for the east-west (north-south) component and multiplying that value by the magnitude (which may be considered to be one).

Once the azimuths have been transformed into their components a mean value for each component is found by summing the components and dividing by the number of azimuths. This is analogous to the classical definition of a mean, but it is performed on each of the two individual components. If we let the average north-south component be designated as v and the average east-west component as u, the mean angle (a) is:

$$a = \arctan (v/u)$$

Another other important factor in descriptive statistics is a measure of dispersion. Measures of dispersion tell us how tightly grouped about the mean are the data. The quantity:

$$r = [u^2 + v^2]^{1/2}$$

is dimensionless and varies from 0 if the data is widely dispersed to 1 if the data all has the same azimuth [7]. Using this, a circular standard deviation or angular deviation may be defined as:

$$s = 180/\pi \ [-2 \ln r]^{1/2}$$

in units of degrees.

Inferential statistics are used to draw conclusions about a population using data derived from a sample. Geographers most commonly ask questions such as could this sample have come from a population with a particular mean or did these samples come from the same population? The first question asks if the data are randomly distributed or clustered around a hypothesized population mean value μ. This hypothesis can be tested using a V-test [8].

$$V = [2n]^{1/2}\, r \cos(a - \mu)$$

If the calculated value of V equals or exceeds the critical value, the null hypothesis of a random distribution is rejected.

The Watson-Williams test [9] is used to test if two sample means belong to the same population. The test statistic is:

$$F = g(N - 2)\, [(R_1 + R_2 - R) / (N - R_1 - R_2)]$$

where: N = total number of samples = $n_1 + n_2$

R = resultant length for both samples combined

R_1 = resultant length for first sample

R_2 = resultant length for second sample

g = bias correction factor tabulated in [8]

If the calculated value of F exceeds the critical value, the null hypothesis that both samples came from the same population is rejected.

RESULTS AND DISCUSSION

Hurricanes made landfall along the Texas cost at an average azimuth of 315° or trending northwest. There was little variability in this azimuth with the angular deviation being 33°. For those hurricanes making landfall in southern Texas (south of Port O'Connor), the average azimuth was 330° +/- 28° while northern landfalls occurred at an average azimuth of 305° +/- 33°. This was likely a result of the geography of the Texas coastline. The coast line begins to turn north-east-ward as you move north from Port O'Connor. So storms making landfall in the northern part of the state may encounter the coast prior to full recurvature. This is similar to the geography of the Outer Banks of North Carolina. Storms making landfall in southern Texas tend to be well into recurvature and may have entered the Gulf of Mexico further south. Additional research is indicated to elucidate this potential connection between storm history and landfalling azimuth.

To determine if there is a statistically significant difference between these two sections of the coast, a Watson-Williams test was performed on the two mean landfall azimuth angels. Results show a statistically significant difference in landfalling azimuth ($F_{1,34}$ = 4.60; 0.05 > p > 0.025) and the difference in landfall azimuth between the two sections of the coast is confirmed.

Another Watson-Williams test was performed to determine if there was a statistically significant difference in azimuth depending on the Saffir-Simpson Scale intensity measurement of the hurricane. Results of this test ($F_{1,34}$ = 0.89; p > 0.25) were not significant. Moderate hurricanes (Saffir-Simpson Scale 1 or 2) made landfall at an azimuth or 310° +/- 36° while the more severe storms (Category 3 or 4) struck with an azimuth of 322° +/- 29°.

Conclusion

This paper has used azimuths of landfalling Texas hurricanes to demonstrate the use of circular statistical analysis for geographers. Measures of central tendency and variability were presented along with inferential techniques for determining if two samples came from the same population. These techniques are superior to simple linear (rectangular) presentations for circularly distributed data because they remove the bias of an imposed zero point on the measurement scale.

Application of these techniques shows that Texas hurricanes make landfall with a mean azimuth angle of 315° and an angular deviation of 33°. There is no statistically significant difference in landfall azimuth between moderate and severe hurricanes. But, landfall location along the Texas cost does impact azimuth. Hurricanes making landfall in northern Texas have a more westerly component to their azimuth than those landfalling in southern Texas.

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