# Casualty Actuarial Society
# E-Forum, Summer 2019

# The CAS *E-Forum*, Summer 2019

The Summer 2019 edition of the CAS *E-Forum* is a cooperative effort between the CAS *E-Forum* Committee and various CAS committees, task forces, working parties and special interest sections. This *E-Forum* contains one report from the CAS Insurance On Demand Working Party and one independent research paper.

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# CAS *E-Forum*, Summer 2019

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# IS THERE A DEMAND FOR INSURANCE ON DEMAND?

BY STEPHANIE GOULD RABIN
IN COLLABORATION WITH JIM WEISS, SCOTT SWANAY, & THE CAS INSURANCE ON DEMAND WORKING PARTY

According to a survey of over 1,000 consumers, consumers:

- Have only a **MODERATE UNDERSTANDING** of insurance pricing and coverage.
- Are more **TRANSACTIONAL** in their review of insurance need.
- **HAVE NEVER HEARD** of the current insurance on demand companies (95% of survey takers).

With this information at hand, one critical question comes to mind: Is there a demand for insurance on demand?

A Working Party on Insurance On Demand, sponsored by the Casualty Actuarial Society (CAS), issued a survey in December 2017 to over 1,000 consumers (demographics are available at the conclusion of this article) to answer some questions around awareness / readiness of the consumer and potential design features for on-demand insurance in the property & casualty realm. Three key aspects of product development were explored in this survey:

**PEOPLE:** First and foremost, we need to know what the consumer wants and can bear before we build any solutions. How much do our consumers know and understand about their insurance? How do consumers want to interact with their insurance carriers? What kind of insurance do they care most about?

**PRODUCT:** Today's technology and economy open up the door to more coverages needed by the average consumer. What coverage features should an on-demand product include? Should any of the coverages be unbundled from the rest? Should coverage be tailor made? How long should policies be?

**PRICE:** Technology allows us to try to reflect or capture the core risk drivers of insurance. And the potential changes in coverage features affords a whole new way to envision pricing for an on-demand product. So, what pricing features would a consumer be willing to have?

This article will look at a number of responses to this consumer survey to help provide more understanding from the consumer point of view.

## DEFINITION

Having an understanding of what represents insurance on demand (IOD) is a critical first building block for any research. The actual definition of Insurance On Demand has seen several variations from very narrow to very broad in scope. Based on insurance industry experiences and upon review of the current IOD companies operating today, the CAS IOD Working party agreed to the following definition:

> **"Insurance On Demand is Insurance where the product exhibits client-focus through nontraditional modifications to coverages, pricing, and/or administration.**
>
> **These modifications, which are often achieved by leveraging modern-day technology, aim to facilitate the purchase of insurance or offer changes in terms that are desired by the policyholder relative to traditional insurance coverages."**
>
> *- CAS Insurance On Demand Working Party*

This definition is still quite broad but encompasses two key pillars: nontraditional features and modernized insurance technology.

## CURRENT STATE OF INSURANCE: CONSUMERS SPEAK OUT

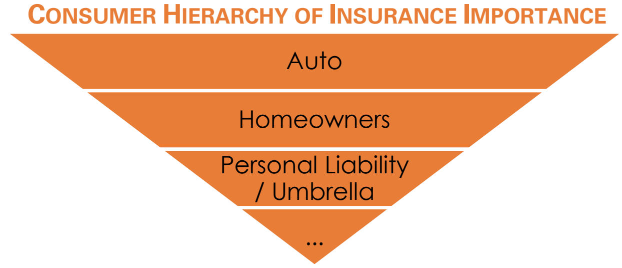
Before understanding what consumers want, it's critical to understand the current state of insurance from the consumers' perspective: What is top of mind? What is important? What do they know?

> **"On-demand insurance is attractive to people penalized by traditional insurance products, that is, consumers with low usage that would otherwise have to pay for more coverage than they need."**
>
> *-Matteo Carbone, IoT Insurance Observatory*
> *(interview with Josh Taub, FCAS)*

Those of us in the insurance sector have a rich understanding of the business of insurance and can make many of our insurance decisions with relative ease. What the average consumer knows and understands is critical to determining what their insurance product should look like in terms of access, price, and coverage. The less knowledge, experience, and practice a consumer has, the more likely they will need to put effort into setting up their insurance. And with more effort required, behavioral economic theory notes they will need a prevailing reason to change, which is consistent what has been noted by Matteo Carbone.

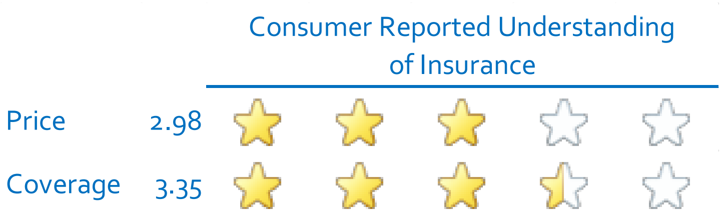
In a survey question asking consumers to rate the level of importance of each listed line of business, top of mind for the majority of consumers is automobile and homeowners insurance (property and casualty lines only). While other lines were noted, consumers, regardless of industry, age or gender, prioritized these key lines of business. Consumers also noted Life and Health as top lines (despite the study being focused on Property & Casualty). With Homeowners, Auto, as well as Life and Health, consumer responses are often centered on more traditional U.S. insurance lines of business.

**CONSUMER HIERARCHY OF INSURANCE IMPORTANCE**



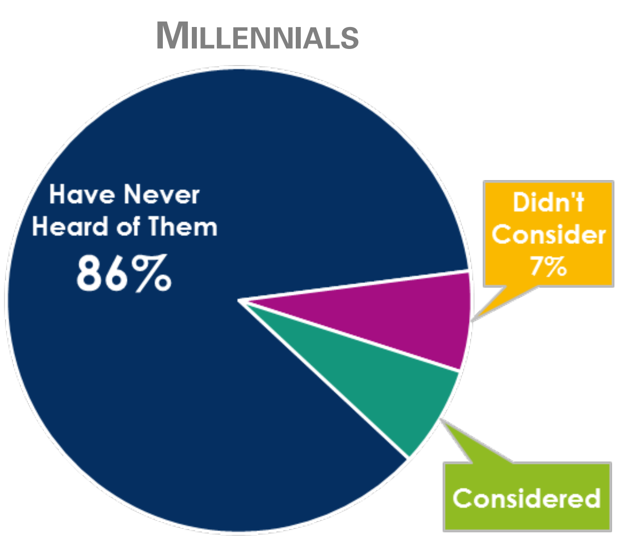
Central to exploring consumer readiness for insurance on demand is the frequency with which consumers review their insurance needs. Consumers in this survey were asked how often they reviewed their insurance policy. Nearly 20% of consumers will only review their insurance policies and coverage when reminded. So, one-fifth of consumers likely renew insurance passively by not reviewing terms or price. In fact, only 15% of consumers review their insurance policies and coverage off cycle (i.e., quarterly or monthly). With such limited review, the purchase of insurance today is largely transactional in nature (dealt with at specific periods of time rather than continuously), limiting access points for something like an on-demand structure.

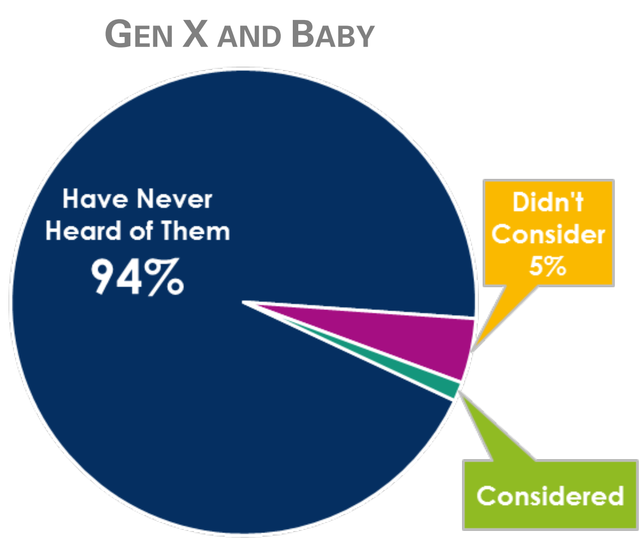
In an interview with Josh Taub, FCAS, a member of the CAS Insurance On Demand Working Party, Scott Walchek from Trōv (an intermediary using an on-demand approach to insurance for personal items) noted that "…consumers are leaving coverage on for much longer than expected, even months at a time."




Consumers self-reported that they had only a moderate understanding of insurance pricing and coverage. With a moderate understanding, combined with a transactional approach to reviewing insurance needs, the challenge of attracting people to something like an on-demand insurance product becomes much greater.

Consumers were asked whether they had considered purchasing insurance from Airsurety, Cuvva, Lemonade, Metromile, Slice, Sure, Swyfft, Trōv, or Verifly. In fact, consumers have barely heard of the current leading players in the on-demand insurance space. This may be partly due to



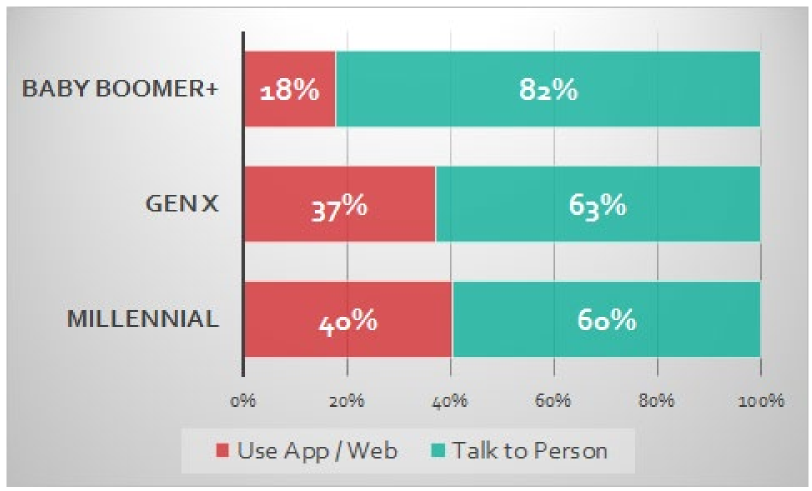




marketing challenges as the internet of things grows and typical advertisement techniques become less relevant. Millennials have a slightly better awareness of the current available on-demand insurance solutions. That said, it is still an overwhelming percentage of even Millennials who are unaware of the additional options available. And of those who have heard of the newer companies, several still have not considered moving to these companies; cited reasons include relationships built with their existing carriers, limited track record, and need for additional information.

With all of the above painting quite a grim picture for insurance on demand, what could help to move the dial? Certainly more awareness and access could help. But, what is that prevailing reason for change? The majority of those few who considered the new On-Demand players commented that they did so due to PRICE OF INSURANCE. This is consistent with the majority of consumer responses to a more generalized question on requested improvements in the industry.

## PEOPLE: HOW DO WE REACH THEM?

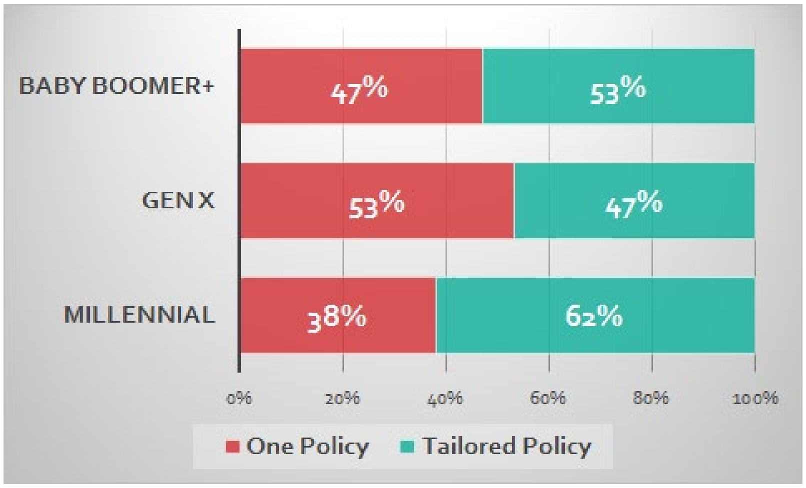
One of the largest hurdles for the On-Demand Insurance arena is access to consumers. As noted above, consumers have barely heard of the current players in the market. And right now, approximately 63% of consumers are using insurance agents to access their insurance (based on a survey question asking how insurance was purchased). Some online purchasing was noted by consumers, but that alone did not preclude the use of agents with an online platform.




The insurance agent has historically been the source of knowledge and understanding of insurance and risk management needs. In a forced choice question, consumers had to choose their preference when setting up insurance of either speaking to a person or using an App/Web. Consumers largely preferred to speak to a person versus leveraging the web or an application. So, combining this response with behavioral economics principles, easier transference of knowledge and understanding of individual risk management is likely the key to unlock consumers' willingness to leverage technology to access alternative options for insurance. This would require having technology that could replace what people value in their agent today.

## PRODUCT: BUILDING SOMETHING TO RESPOND TO NEEDS

While consumers seem to be more transactional in nature for their insurance needs, there was a larger portion who desired a tailored policy over more of an all-inclusive single policy…. even more so for the Millennial generation. This interest in a less traditional product (recalling consumers have homeowners, auto, and health insurance at top of mind) may reflect a true need for some specific protections that may or may not be currently available. Additional consumer research would be necessary to assess the reason.




In fact, this could partly play into perception of price…*if I can tailor make my policy, then I pay only for what I need*. Recall that price does matter most in helping to drive a consumer to change insurance carriers.

Consumers were asked if they would unbundle their current coverages and only ***42% OF CONSUMERS WERE WILLING TO SPLIT COVERAGES*** out from their current policies. Interestingly, 60% of Business owners, who also self-reported a slightly higher understanding of coverage and price, were willing to unbundle their coverage. Aspects of coverage that consumers were willing to split out include (in order of popularity):

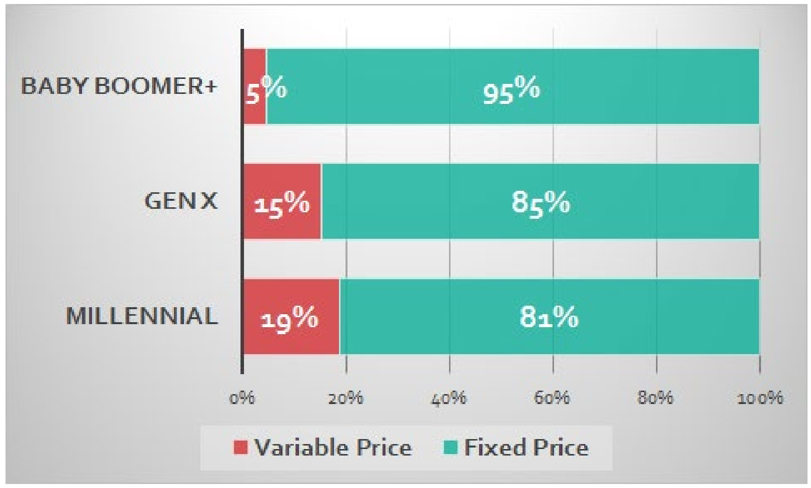
1. Accidents
2. Personal Liability
3. Car Rentals
4. Weather-related perils (Flood, Hurricane, Earthquake, Tornado/Hail)
5. Specific Items in a home or business

> **"I don't know if I understand insurance to answer this question"**
>
> *-Consumer Survey Response when asked "What coverage(s) would you like to see split out as a separate policy from your current policies?"*

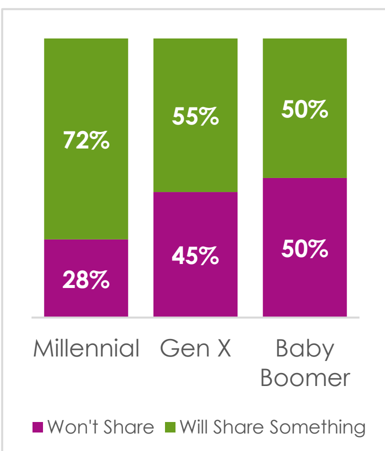
While unbundling may be a solution attractive to some consumers, the insurance sector should consider both the role of the insurance sector in making people whole again and the awareness of risk need by the consumer. Should an unbundled approach (where consumers pick and choose what they want to pay for) create gaps in coverage, the consumer would ultimately be the one to suffer.

## PRICE: THE PREVAILING REASON FOR CHANGE

As noted in the current state of the market, Consumers cited price as one of the prevalent factors in driving them to change insurance carriers. With the growth in ready access to more data and the enhanced abilities for machine learning, predictive analytics, telematics and more, insurance technology could help to drive changes in pricing to more accurately capture the risk being covered.




Consumers overwhelmingly indicate that they prefer a fixed price over a per use price that may fluctuate. This desire is quite consistent with the timing with which consumers review their policies. If they are not looking at their insurance regularly, having variation in price throughout the insurance term would be less preferable.




While variable pricing may not be a desired solution by consumers, there is a growing trend among consumers in their willingness to share information in support of pricing and/or coverage support. In fact, Millennials are much more willing to share information than the older generations. Information Millennials were willing to share included: Location, Driving Behaviors, Exercise, Languages, Body Temperature, and Sleep Activity.

While this willingness to share exists, those not willing to share consistently noted the same reason in their comments: concern over data privacy. So, should the alternative pricing solution include a sufficient level of comfort on privacy, a large portion of those unwilling may become more willing to share information for using in more nonstandard pricing and coverage support.

## WHAT'S NEXT?

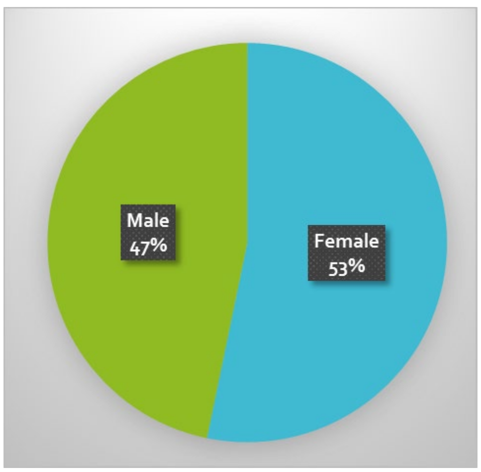
The consumer responses open up many more questions than answers. And in an age where information flows quickly, many of these responses may shift over time.

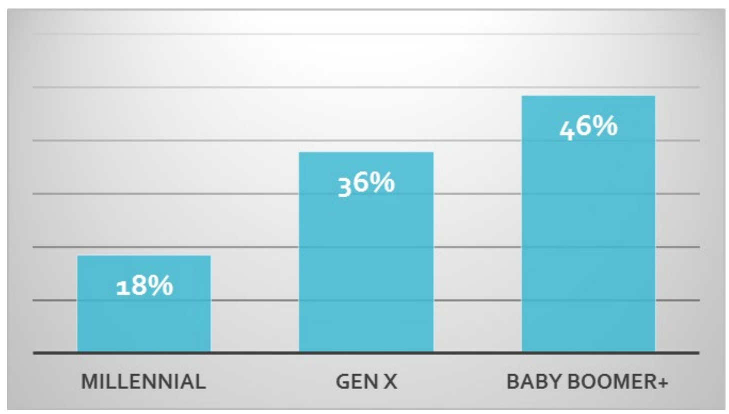
Further, while a majority of responses to the survey demonstrated statistically significant difference among the generations, broadening the analysis both longitudinally (over time) and via number of consumers for better breakouts, may help to highlight if there is a trend on the horizon versus a difference purely due to experience.

In the meantime, there are certainly some signs of demand for insurance on demand, and organizations that best address consumer needs may own a valuable call option on the future.

## DEMOGRAPHICS

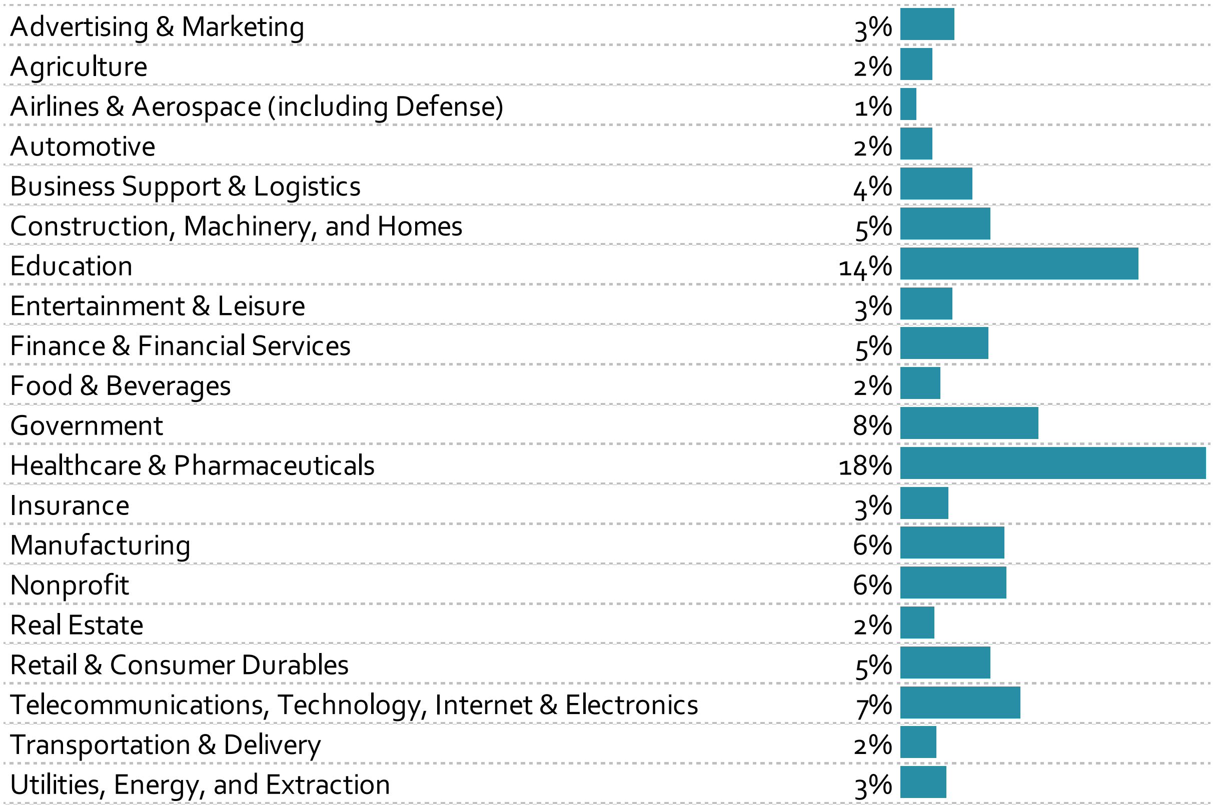
The following provide some detailed demographics for this survey.

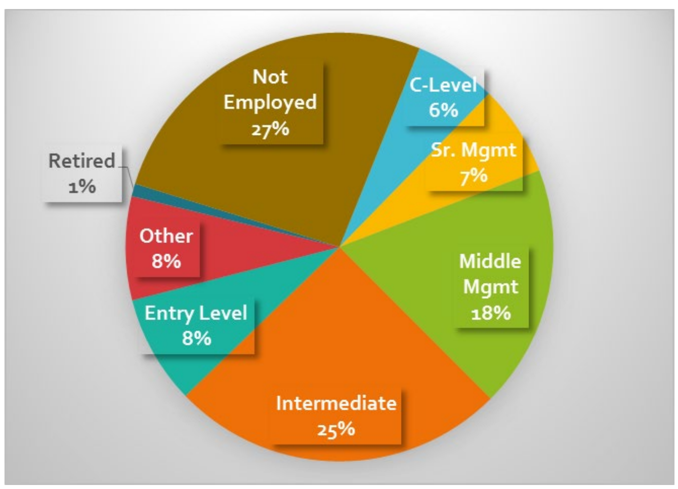



**Region of United States**

| | |
|---|---|
| East North Central | 18% |
| East South Central | 5% |
| Middle Atlantic | 14% |
| Mountain | 8% |
| New England | 7% |
| Pacific | 10% |
| South Atlantic | 21% |
| West North Central | 8% |
| West South Central | 8% |
| N/A | 1% |


Advertising & Marketing 3%
Agriculture 2%
Airlines & Aerospace (including Defense) 1%
Automotive 2%
Business Support & Logistics 4%
Construction, Machinery, and Homes 5%
Education 14%
Entertainment & Leisure 3%
Finance & Financial Services 5%
Food & Beverages 2%
Government 8%
Healthcare & Pharmaceuticals 18%
Insurance 3%
Manufacturing 6%
Nonprofit 6%
Real Estate 2%
Retail & Consumer Durables 5%
Telecommunications, Technology, Internet & Electronics 7%
Transportation & Delivery 2%
Utilities, Energy, and Extraction 3%


Not Employed 27%
C-Level 6%
Sr. Mgmt 7%
Middle Mgmt 18%
Intermediate 25%
Entry Level 8%
Other 8%
Retired 1%

# Atlantic Windstorm Distributions

R. Stephen Pulis, ACAS, MAAA

**Abstract:** The following paper is a study of Atlantic windstorms. It reveals that the shape of the distribution of maximum wind speeds is both trending higher and changing its skewed shape. Current estimates of the maximum storm strength in 100 years, etc. are understated as there is an increase in the frequency of more severe wind speeds.

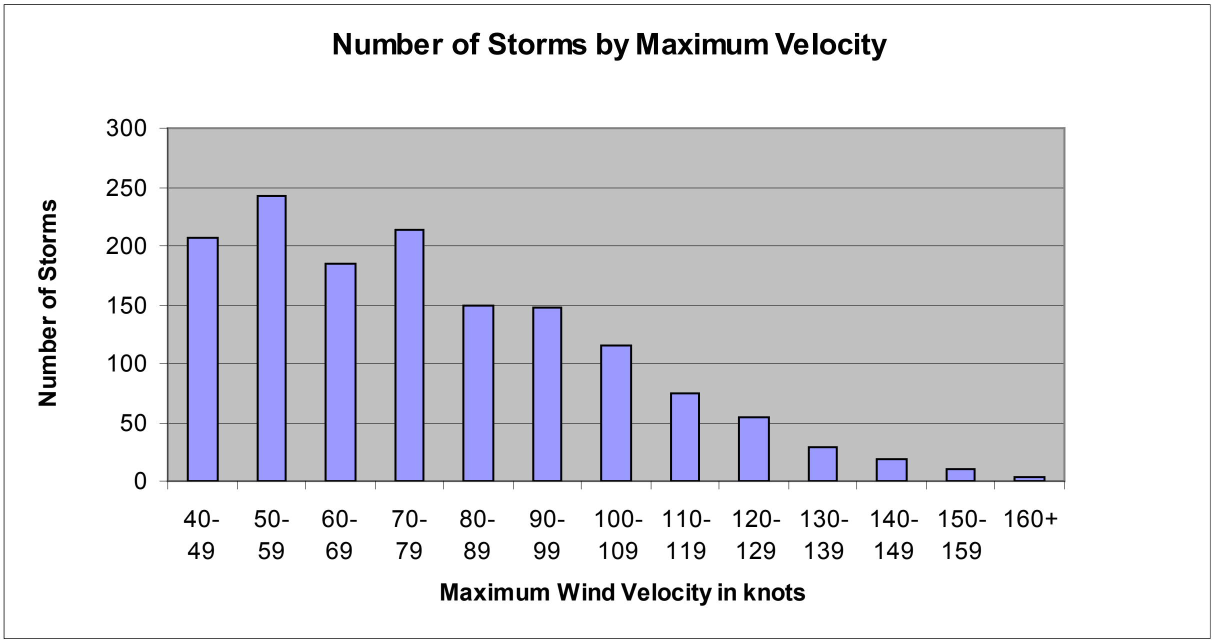
**Keywords:** Windstorm; Hazard Distribution; Skewness; Weibull modeling.

## INTRODUCTION

The recent catastrophic storms raise questions as to the reasonable probability of a 100-year, 500-year or 1,000-year storm. A normal distribution indicates that the value at 2.433 standard deviations above the mean includes 99% below this value or represents the equivalent of 1 in 100. Insurance claims, however, do not have negative claims, and therefore the distributions are skewed to the positive side. The hypothesis of this paper is that the distribution of storm frequency and severity has changed over time and these shifts are not uniform.

In this paper, the windstorms in the North Atlantic are investigated. There is a wealth of data available, but, as always, the actuary wishes there was more complete and consistent data. The National Hurricane Center (NHC) is part of the National Oceanic & Atmospheric Administration (NOAA). The NHC has published detailed Atlantic windstorm data[1] since 1851 and is the source of the experience reviewed in this paper.

Experience is selected based on the maximum wind speed measured in 5 knots increments (one knot is approximately 1.15 mph). The reported storms are suspected to be understated for lower wind speeds for older years. From inception, storms with a maximum wind speed of 40 knots or more were reported. Storms with a maximum wind speed of 35 knot storms were not included until 1887, and lesser storms are not included until 1968. This paper only includes storms with at least 40 knot winds. The following graph is for years 1858 through 2017.


Number of Storms by Maximum Velocity
Number of Storms
300
250
200
150
100
50
0
40-49
50-59
60-69
70-79
80-89
90-99
100-109
110-119
120-129
130-139
140-149
150-159
160+
Maximum Wind Velocity in knots

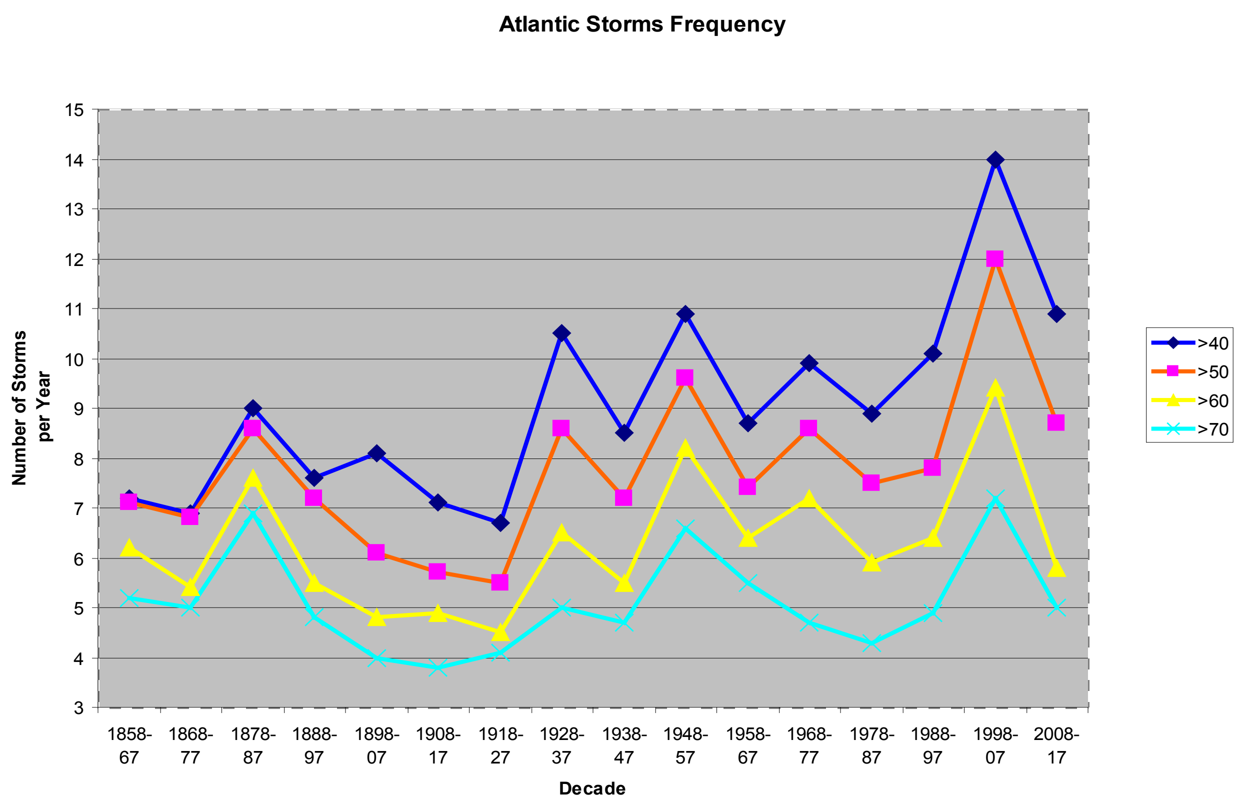
The experience is aggregated into 10-year intervals ending with 2008-2017. This results in an average of 51 (38 to 72) major storms (70+ knots) per decade. Higher average storm counts per decade exist for lower minimum wind speeds: 91 for 40+, 78 for 50+, and 63 for 60+.

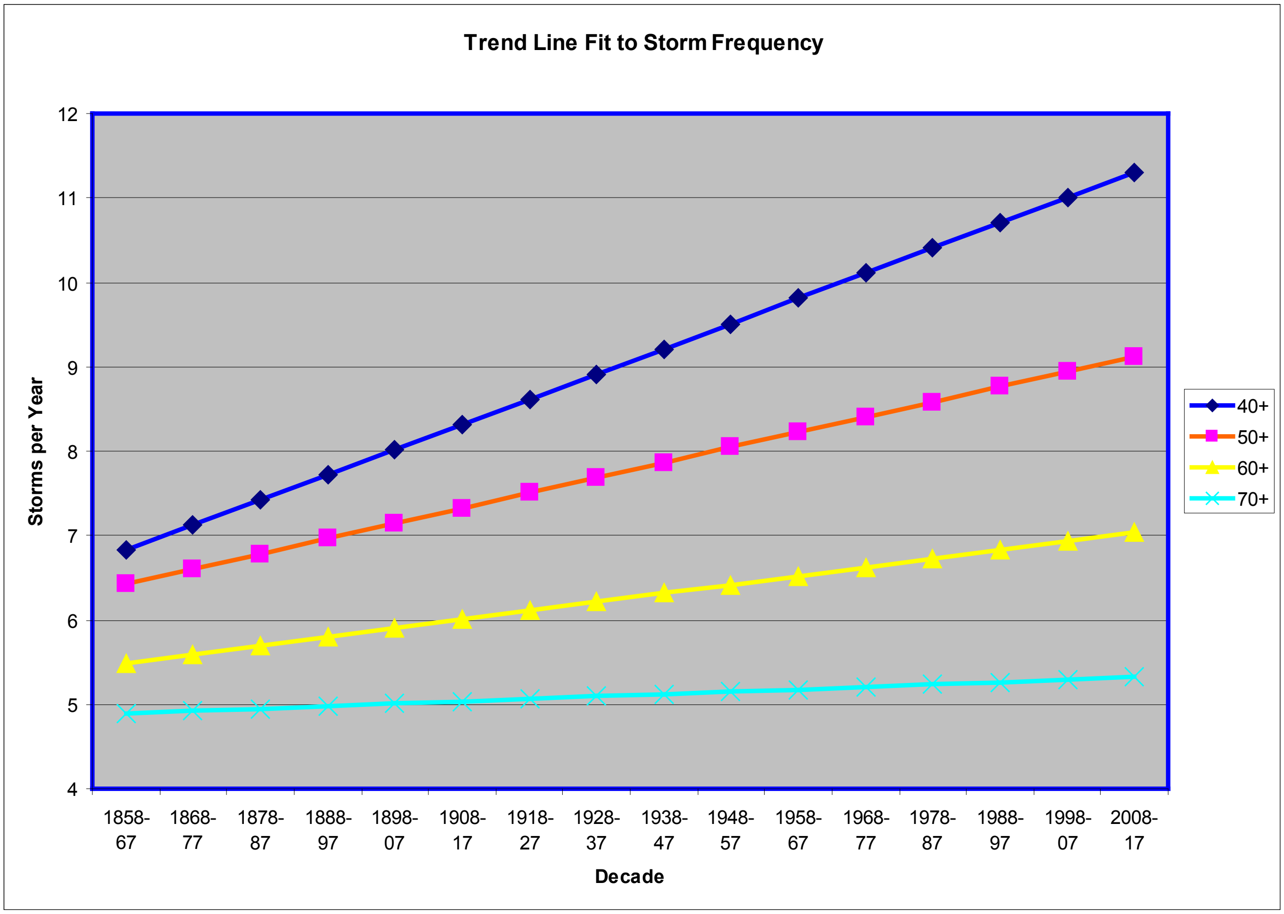
**National Hurricane Center Data Atlantic Windstorm Counts**

| | **Years from/to** | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Max Knots** | **1858 1867** | **1868 1877** | **1878 1887** | **1888 1897** | **1898 1907** | **1908 1917** | **1918 1927** | **1928 1937** | **1938 1947** | **1948 1957** | **1958 1967** | **1968 1977** | **1978 1987** | **1988 1997** | **1998 2007** | **2008 2017** |
| 30 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 36 | 57 | 23 | 17 | 8 |
| 35 | 0 | 0 | 1 | 3 | 2 | 1 | 4 | 6 | 6 | 3 | 3 | 0 | 2 | 5 | 10 | 5 |
| 40 | 1 | 1 | 3 | 1 | 6 | 5 | 8 | 10 | 3 | 5 | 3 | 4 | 2 | 10 | 5 | 10 |
| 45 | 0 | 0 | 1 | 3 | 14 | 9 | 4 | 9 | 10 | 8 | 10 | 9 | 12 | 13 | 16 | 12 |
| 50 | 9 | 14 | 10 | 15 | 11 | 7 | 7 | 13 | 10 | 11 | 9 | 5 | 10 | 7 | 19 | 12 |
| 55 | 0 | 0 | 0 | 2 | 2 | 1 | 3 | 8 | 7 | 3 | 1 | 9 | 6 | 7 | 8 | 17 |
| 60 | 10 | 4 | 7 | 3 | 8 | 6 | 2 | 10 | 7 | 13 | 5 | 17 | 8 | 7 | 13 | 6 |
| 65 | 0 | 0 | 0 | 4 | 0 | 5 | 2 | 5 | 1 | 3 | 4 | 9 | 8 | 9 | 10 | 2 |
| 70 | 18 | 20 | 18 | 6 | 13 | 3 | 8 | 6 | 11 | 10 | 7 | 7 | 7 | 8 | 7 | 5 |
| 75 | 0 | 0 | 3 | 2 | 2 | 2 | 3 | 3 | 0 | 1 | 5 | 8 | 8 | 8 | 7 | 9 |
| 80 | 4 | 4 | 11 | 3 | 3 | 2 | 4 | 6 | 3 | 4 | 5 | 5 | 4 | 0 | 7 | 4 |
| 85 | 0 | 0 | 7 | 16 | 5 | 7 | 2 | 6 | 11 | 4 | 4 | 0 | 4 | 4 | 5 | 5 |
| 90 | 26 | 15 | 13 | 2 | 4 | 3 | 4 | 5 | 2 | 4 | 1 | 7 | 4 | 3 | 6 | 3 |
| 95 | 0 | 0 | 0 | 4 | 3 | 4 | 5 | 3 | 4 | 7 | 3 | 3 | 0 | 5 | 2 | 2 |
| 100 | 0 | 10 | 4 | 3 | 0 | 3 | 1 | 1 | 2 | 6 | 4 | 6 | 3 | 7 | 4 | 3 |
| 105 | 0 | 0 | 3 | 6 | 6 | 9 | 5 | 1 | 5 | 8 | 2 | 2 | 2 | 2 | 5 | 3 |
| 110 | 3 | 1 | 5 | 4 | 0 | 0 | 2 | 3 | 1 | 6 | 6 | 4 | 2 | 1 | 3 | 3 |
| 115 | 0 | 0 | 0 | 2 | 2 | 1 | 1 | 2 | 2 | 6 | 3 | 0 | 5 | 1 | 1 | 4 |
| 120 | 1 | 0 | 3 | 0 | 0 | 0 | 2 | 4 | 2 | 2 | 2 | 1 | 1 | 3 | 4 | 3 |
| 125 | 0 | 0 | 0 | 0 | 1 | 2 | 0 | 1 | 3 | 3 | 3 | 0 | 1 | 4 | 6 | 3 |
| 130 | 0 | 0 | 2 | 0 | 1 | 2 | 3 | 1 | 0 | 2 | 2 | 1 | 0 | 1 | 3 | 0 |
| 135 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 1 | 2 | 0 | 0 | 0 | 3 | 3 |
| 140 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 1 | 1 | 5 | 1 | 0 | 1 | 1 | 0 |
| 145 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 0 |
| 150 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 2 | 1 | 1 | 3 | 0 |
| 155 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 |
| 160 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 |
| 165 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| **Total** | **72** | **69** | **91** | **79** | **83** | **72** | **71** | **111** | **91** | **112** | **90** | **136** | **148** | **131** | **170** | **122** |

| 10 Year Period | Storms per Year | | | | Average Maximum Wind Speed | | | |
|---|---|---|---|---|---|---|---|---|
| | 40+ | 50+ | 60+ | 70+ | 40+ | 50+ | 60+ | 70+ |
| 1858-67 | 7.2 | 7.1 | 6.2 | 5.2 | 75.8 | 76.3 | 80.2 | 84.0 |
| 1868-77 | 6.9 | 6.8 | 5.4 | 5.0 | 74.8 | 75.3 | 81.9 | 83.6 |
| 1878-87 | 9.0 | 8.6 | 7.6 | 6.9 | 78.9 | 80.6 | 84.7 | 87.2 |
| 1888-97 | 7.6 | 7.2 | 5.5 | 4.8 | 76.4 | 78.2 | 86.7 | 90.2 |
| 1898-07 | 8.1 | 6.1 | 4.8 | 4.0 | 67.8 | 75.8 | 82.6 | 87.1 |
| 1908-17 | 7.1 | 5.7 | 4.9 | 3.8 | 75.1 | 82.9 | 88.2 | 95.7 |
| 1918-27 | 6.7 | 5.5 | 4.5 | 4.1 | 76.3 | 83.8 | 91.0 | 93.8 |
| 1928-37 | 10.5 | 8.6 | 6.5 | 5.0 | 74.6 | 81.7 | 91.3 | 100.2 |
| 1938-47 | 8.5 | 7.2 | 5.5 | 4.7 | 73.7 | 79.1 | 87.5 | 92.0 |
| 1948-57 | 10.9 | 9.6 | 8.2 | 6.6 | 80.7 | 85.8 | 91.8 | 99.2 |
| 1958-67 | 8.7 | 7.4 | 6.4 | 5.5 | 83.0 | 89.9 | 96.1 | 101.6 |
| 1968-77 | 9.9 | 8.6 | 7.2 | 4.7 | 72.7 | 77.2 | 81.8 | 92.4 |
| 1978-87 | 8.9 | 7.5 | 5.9 | 4.3 | 72.2 | 77.4 | 84.3 | 92.4 |
| 1988-97 | 10.1 | 7.8 | 6.4 | 4.9 | 73.4 | 82.4 | 88.9 | 96.9 |
| 1998-07 | 14.0 | 12.0 | 9.4 | 7.2 | 78.9 | 84.8 | 93.9 | 103.7 |
| 2008-17 | 10.9 | 8.7 | 5.8 | 5.0 | 71.0 | 78.2 | 90.8 | 95.5 |
| Average | | | | | | | | |
| 1858-2017 | 9.1 | 7.8 | 6.3 | 5.1 | 75.3 | 80.6 | 87.6 | 93.5 |
| 1938-2017 | 10.2 | 8.6 | 6.9 | 5.4 | 75.7 | 81.8 | 89.4 | 96.7 |

The count of storms as far back as 1851 is expected to be reasonably accurate up to 70+ knots. There is a general increase in storm frequencies for each higher level of storm severity. The greatest increases are for the lower level maximum winds. Page 4 displays a straight line fit to storm frequency (Y=A+BX).






**10-Year Change in Number of Storms per Year**

| Group | A | B | R | Change | % Ch. |
|---|---|---|---|---|---|
| 40+ | 6.4800 | 0.3082 | 0.735 | 0.308 | 2.78% |
| 50+ | 6.2075 | 0.1881 | 0.544 | 0.188 | 2.08% |
| 60+ | 5.3500 | 0.1103 | 0.394 | 0.110 | 1.57% |
| 70+ | 4.8525 | 0.0306 | 0.145 | 0.031 | 0.58% |

**Average Maximum Wind Velocity**

| Group | A | B | R | Change | % Ch. |
|---|---|---|---|---|---|
| 40+ | 75.7818 | -0.0587 | 0.074 | -0.059 | -0.08% |
| 50+ | 78.0371 | 0.2924 | 0.339 | 0.292 | 0.35% |
| 60+ | 83.0113 | 0.5303 | 0.536 | 0.530 | 0.58% |
| 70+ | 85.5732 | 0.9263 | 0.729 | 0.926 | 0.93% |

The lack of sophisticated equipment to measure extreme maximum wind speeds raises questions as to the accuracy of the maximum winds for the early years. The advent of modern aircraft and the high level of military interest in the measuring and tracking North Atlantic weather for ships and planes during WWII is taken as assurance that data since 1938 is reasonable accurate. Therefore, statistics on average speed, its standard deviation and skewness is calculated from 1938 through 2017. Because of the volatility of the experience, rolling 20-year periods are analyzed.

For each of the four selected minimum wind speeds (40+, 50+, 60+ & 70+), four measures are calculated: a) average storms per year, b) average maximum wind speed, c) standard deviation of the average maximum wind speed, and d) skewness of the average maximum wind speed.

| 20 Year Period | Storms per Year | | | | Average Maximum Wind Speed | | | |
|---|---|---|---|---|---|---|---|---|
| | 40+ | 50+ | 60+ | 70+ | 40+ | 50+ | 60+ | 70+ |
| 1938-57 | 9.7 | 8.4 | 6.9 | 5.7 | 77.65 | 82.95 | 90.04 | 96.24 |
| 1948-67 | 9.8 | 8.5 | 7.3 | 6.1 | 81.76 | 87.62 | 93.66 | 100.33 |
| 1958-77 | 9.3 | 8.0 | 6.8 | 5.1 | 77.55 | 83.06 | 88.53 | 97.40 |
| 1968-87 | 9.4 | 8.1 | 6.6 | 4.5 | 72.47 | 77.27 | 82.94 | 92.44 |
| 1978-97 | 9.5 | 7.7 | 6.2 | 4.6 | 72.82 | 79.93 | 86.71 | 94.84 |
| 1988-07 | 12.1 | 9.9 | 7.9 | 6.1 | 76.58 | 83.81 | 91.90 | 100.95 |
| 1998-17 | 14.1 | 11.5 | 8.5 | 7.0 | 75.66 | 83.03 | 93.76 | 100.90 |

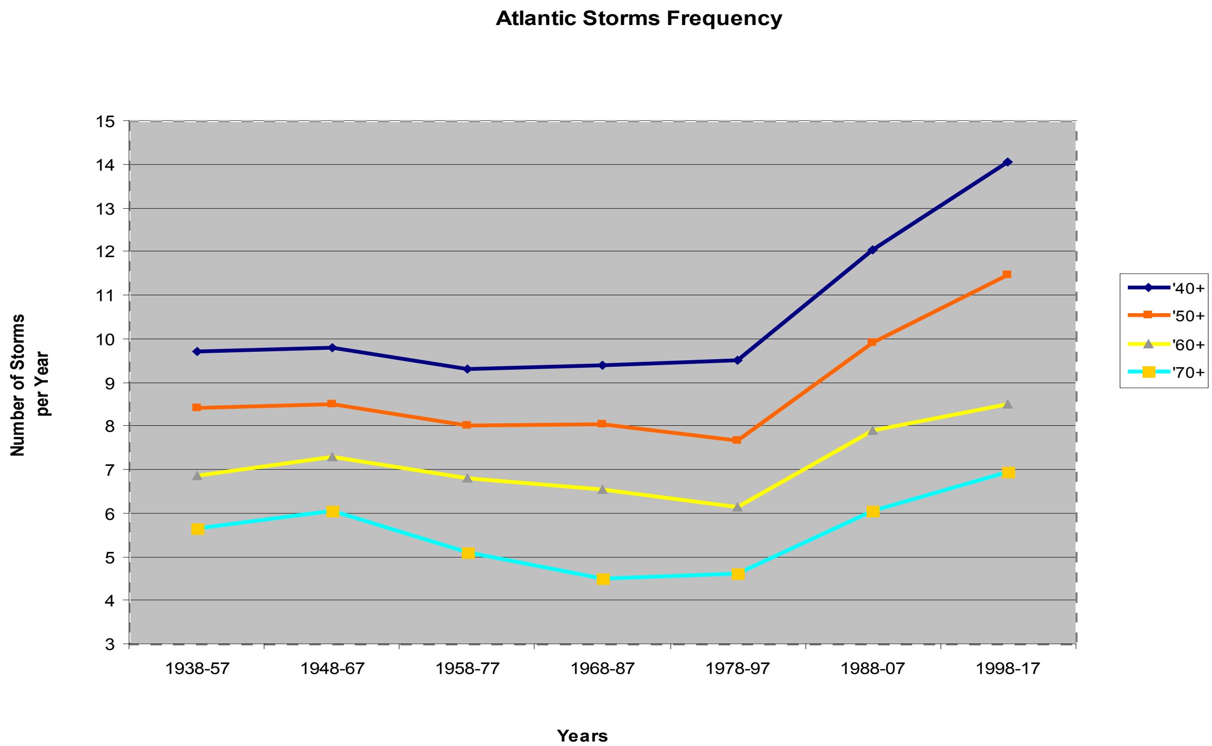
| 20 Year Period | Standard Deviation | | | | Skewness | | | |
|---|---|---|---|---|---|---|---|---|
| | 40+ | 50+ | 60+ | 70+ | 40+ | 50+ | 60+ | 70+ |
| 1938-57 | 26.8 | 24.9 | 22.1 | 19.3 | 0.433 | 0.383 | 0.335 | 0.364 |
| 1948-67 | 29.4 | 27.1 | 24.5 | 21.5 | 0.362 | 0.307 | 0.294 | 0.272 |
| 1958-77 | 28.2 | 26.5 | 25.0 | 22.8 | 0.754 | 0.760 | 0.736 | 0.620 |
| 1968-87 | 24.8 | 23.6 | 22.6 | 21.2 | 1.130 | 1.215 | 1.244 | 1.194 |
| 1978-97 | 27.1 | 25.5 | 23.9 | 22.4 | 0.994 | 1.001 | 1.022 | 0.966 |
| 1988-07 | 30.7 | 29.2 | 27.2 | 24.8 | 0.847 | 0.768 | 0.681 | 0.561 |
| 1998-17 | 30.8 | 29.5 | 26.9 | 24.6 | 0.853 | 0.737 | 0.587 | 0.545 |

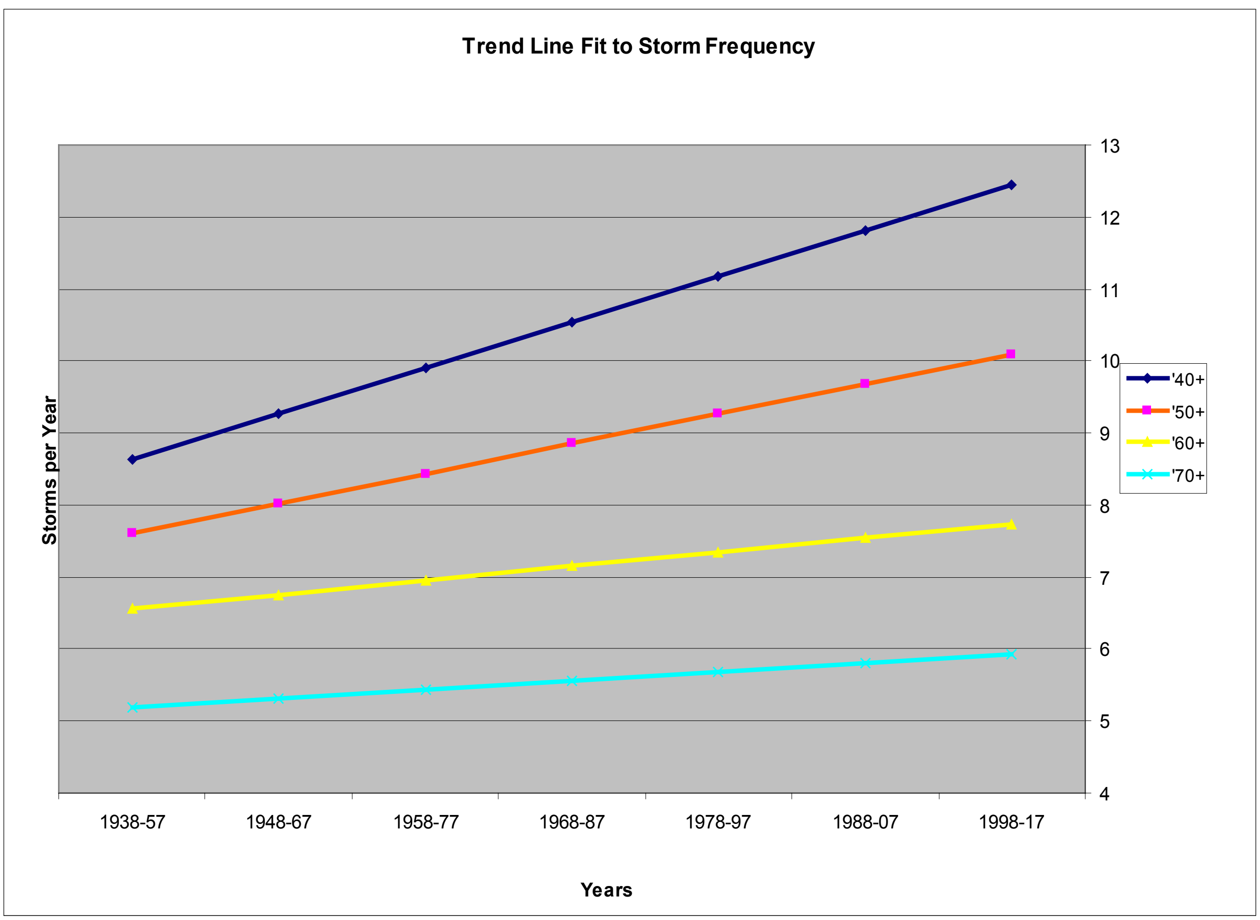
On page 6, the graph of average storm counts per year displays the fluctuations from period to period. Immediately following it, is a graph displaying the trend line fitted to each storm group. The storm frequency increases for each group with the largest increase at the lower velocities and increasing at lesser amounts for each higher velocity group. This phenomenon is the result of there being larger numbers of storms with lesser velocities that trend up just enough to pierce the next higher velocity level. The last 80 years helps to show the leverage (ratio of number of storms in lower level to next higher level) that a skewed distribution has. If a uniform increase is assumed, a greater relative increase in storm counts is experienced at the lower velocity layers than it is at the higher velocity layers.

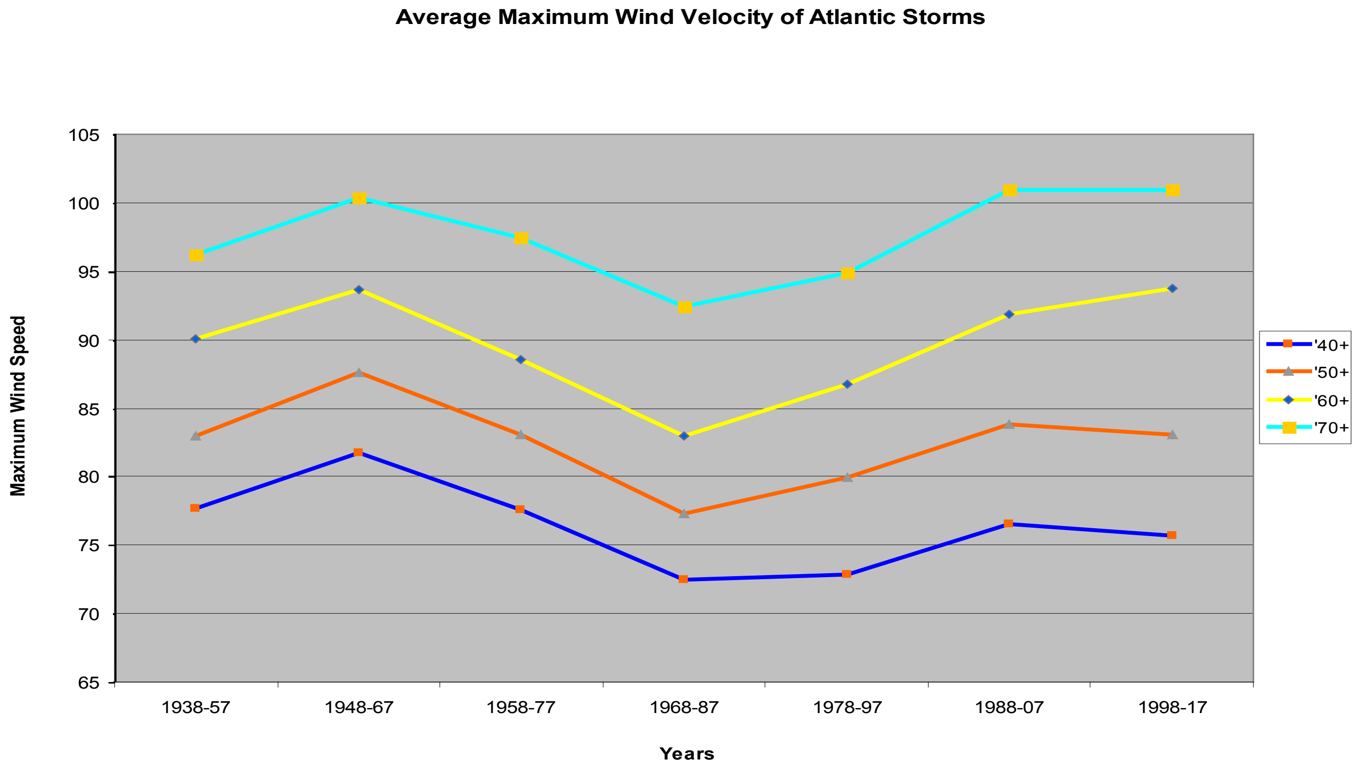
| Wind Velocity From | to | Number of storms | Leverage |
|---|---|---|---|
| 30 | 39 | 175 | 1.33 |
| 40 | 49 | 132 | 0.94 |
| 50 | 59 | 141 | 1.16 |
| 59 | 69 | 122 | 1.13 |
| 70 | 79 | 108 | |

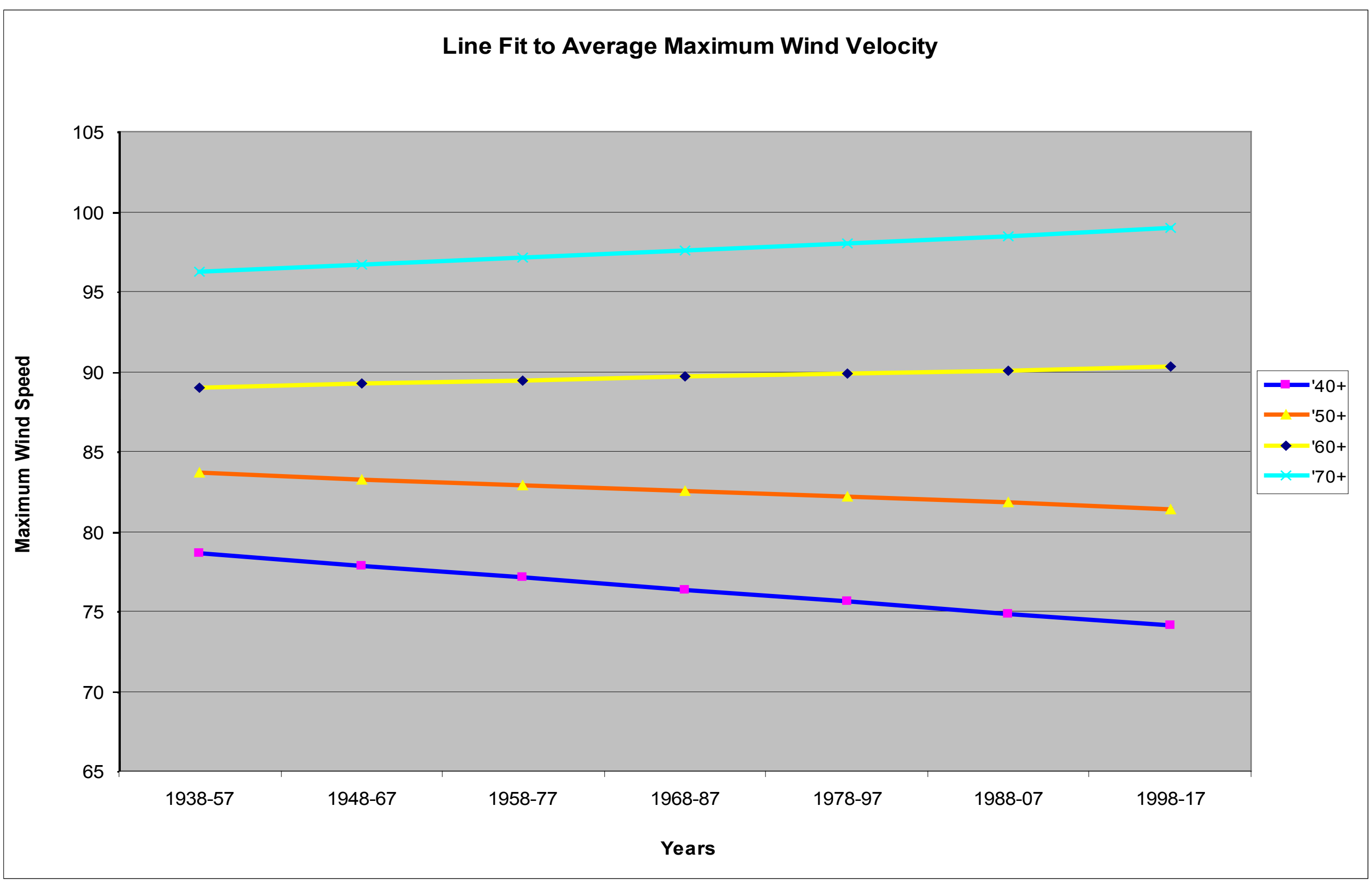
Within each period, the average wind velocity is calculated. Page 6 displays the average maximum wind speed over the 7 periods. Trend lines in the average maximum wind velocity are displayed in the graph immediately following. There is an increasing trend in the average maximum wind speed with the greatest increases for the higher wind velocity categories. The exception to this is for the layer of storms with the lowest wind speeds of 40 or more. It is the increase of minimal wind speeds that brings down the average slightly.

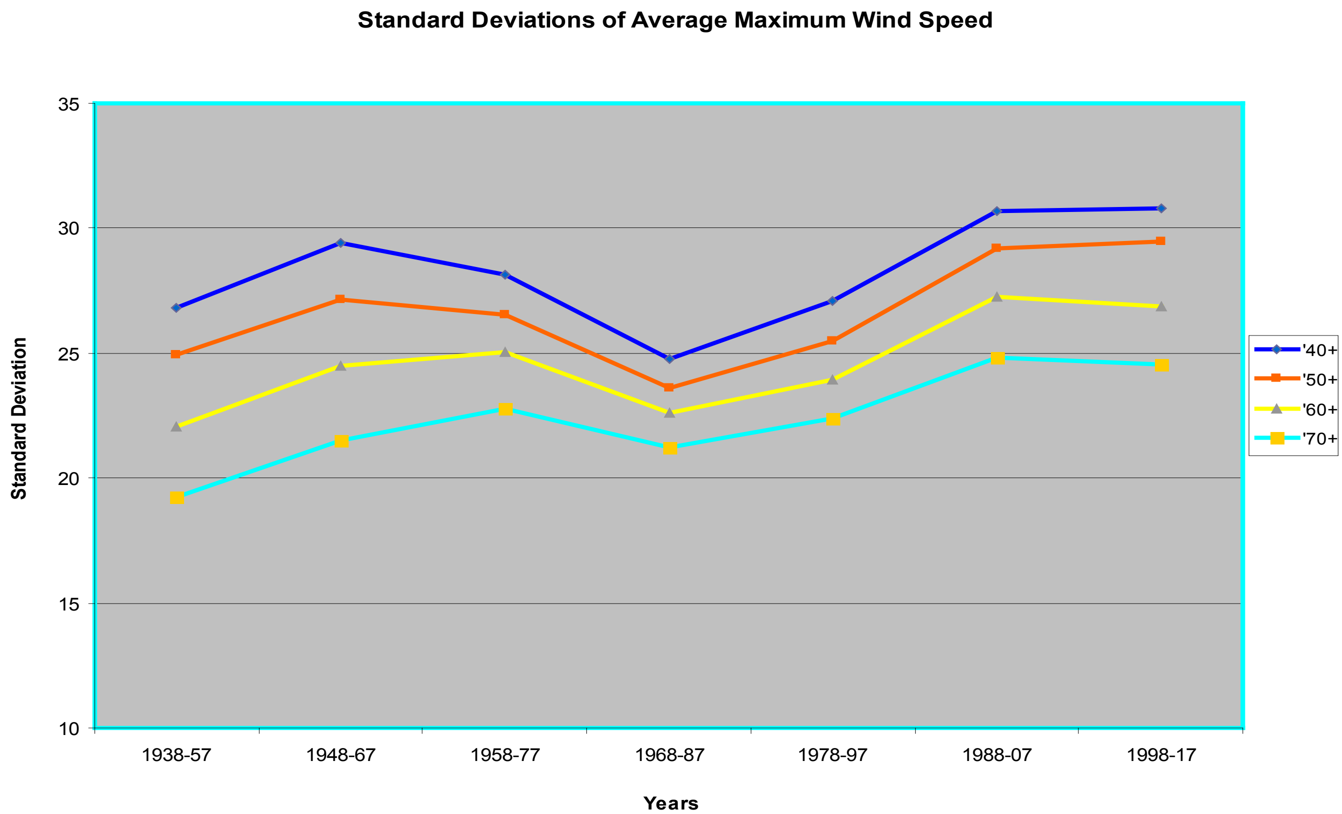
Is the distribution of storms simply a transfer of the shape of the distribution to an increased mean for more recent years? The standard deviation is calculated within each period. Page 8 displays the graph of the standard deviations. As the range of velocities is tightened, the standard deviation is reduced, but they generally move in the same upward direction. The graph of the trend lines fit to the standard deviations shows increasing trends that are almost parallel lines, with the higher wind groups at lower standard deviations as the wind speed increases.


Atlantic Storms Frequency
Number of Storms per Year
15
14
13
12
11
10
9
8
7
6
5
4
3
1938-57
1948-67
1958-77
1968-87
1978-97
1988-07
1998-17
Years
'40+
'50+
'60+
'70+

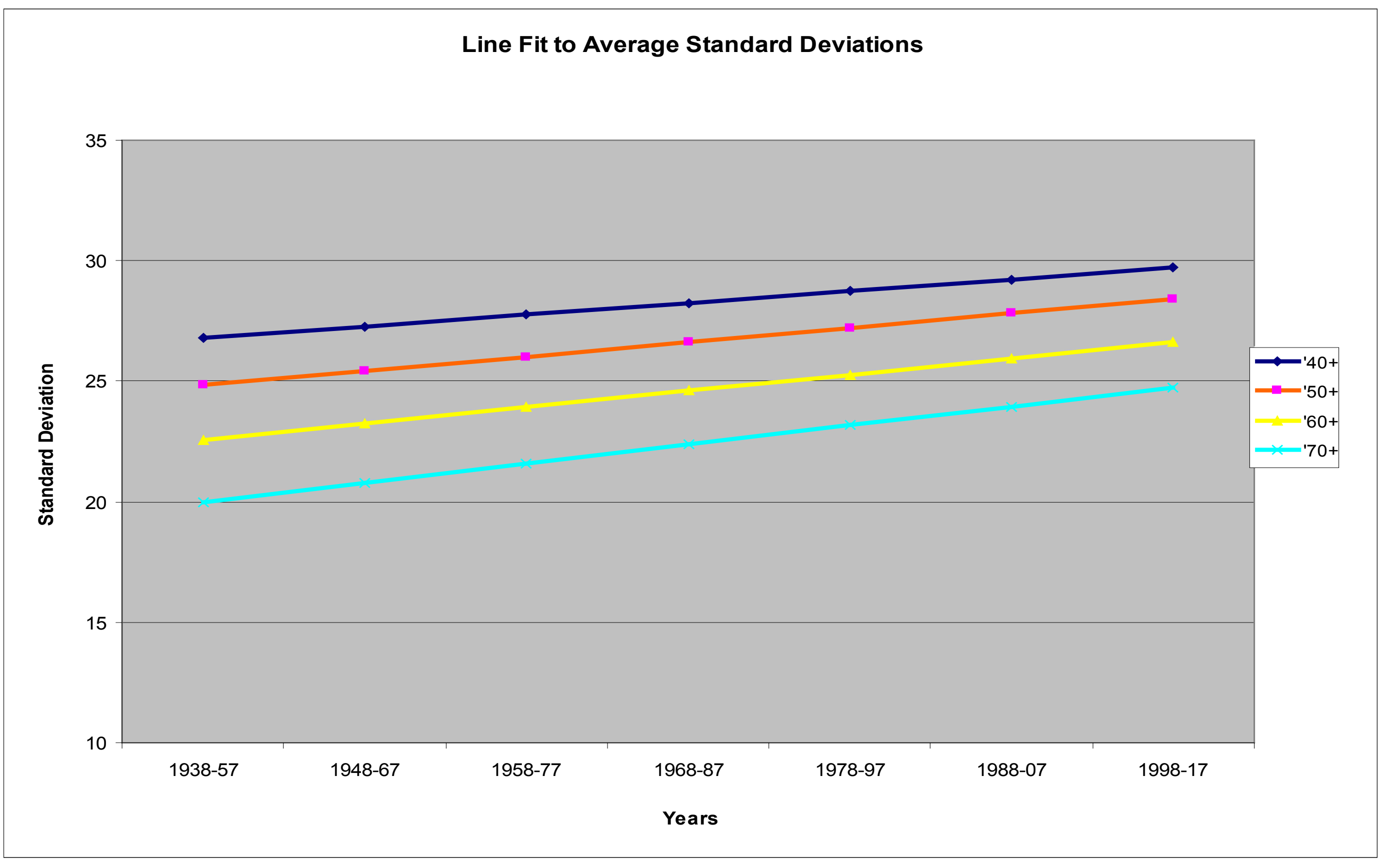

Trend Line Fit to Storm Frequency
Storms per Year
13
12
11
10
9
8
7
6
5
4
1938-57
1948-67
1958-77
1968-87
1978-97
1988-07
1998-17
Years
'40+
'50+
'60+
'70+


Average Maximum Wind Velocity of Atlantic Storms
Maximum Wind Speed
105
100
95
90
85
80
75
70
65
1938-57
1948-67
1958-77
1968-87
1978-97
1988-07
1998-17
Years
'40+
'50+
'60+
'70+

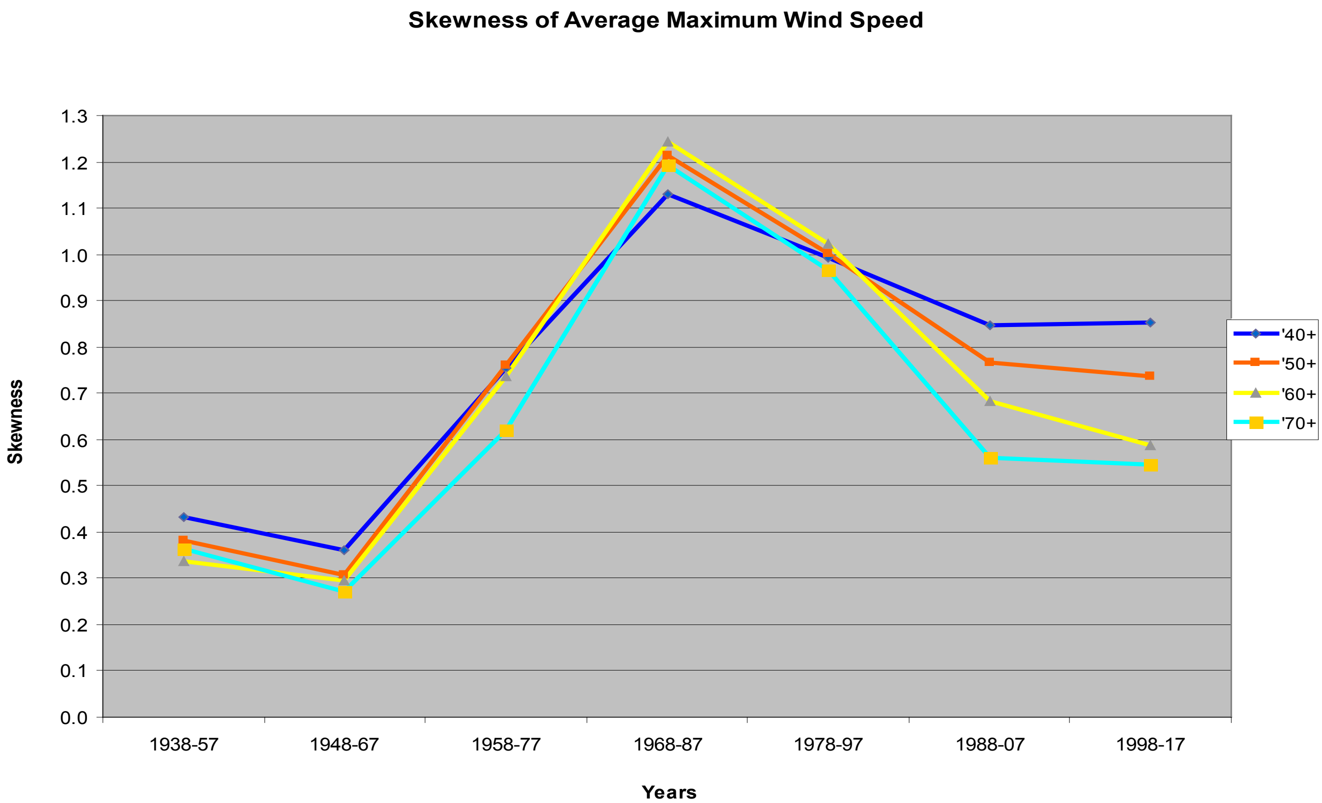

Line Fit to Average Maximum Wind Velocity
Maximum Wind Speed
105
100
95
90
85
80
75
70
65
1938-57
1948-67
1958-77
1968-87
1978-97
1988-07
1998-17
Years
'40+
'50+
'60+
'70+

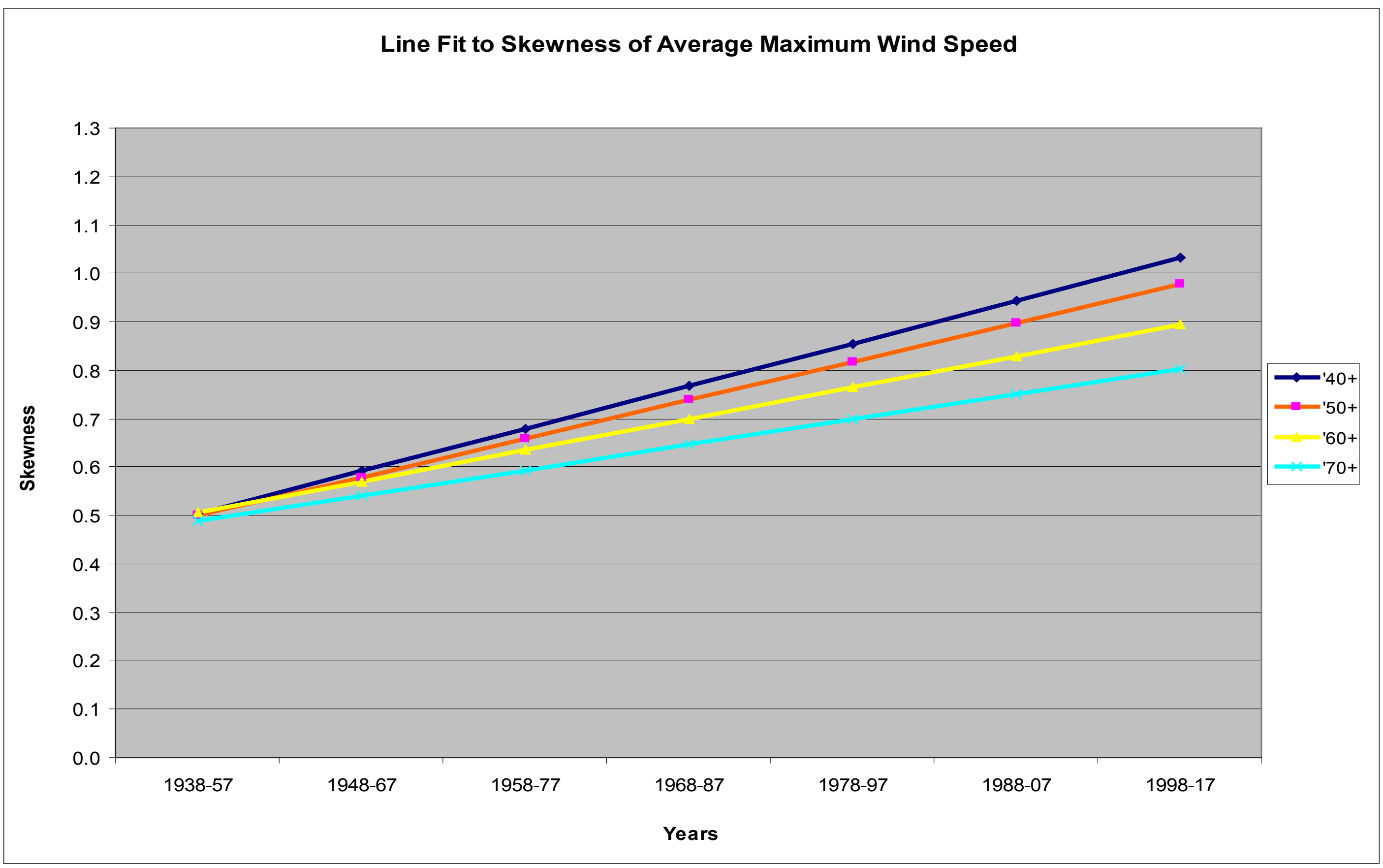


Standard Deviations of Average Maximum Wind Speed
35
30
25
20
15
10
Standard Deviation
1938-57
1948-67
1958-77
1968-87
1978-97
1988-07
1998-17
Years
'40+
'50+
'60+
'70+

Line Fit to Average Standard Deviations
35
30
25
20
15
10
Standard Deviation
1938-57
1948-67
1958-77
1968-87
1978-97
1988-07
1998-17
Years
'40+
'50+
'60+
'70+


Skewness of Average Maximum Wind Speed
Skewness
Years
1938-57
1948-67
1958-77
1968-87
1978-97
1988-07
1998-17
'40+
'50+
'60+
'70+


Line Fit to Skewness of Average Maximum Wind Speed
Skewness
Years
1938-57
1948-67
1958-77
1968-87
1978-97
1988-07
1998-17
'40+
'50+
'60+
'70+

A Wikipedia article,[3] "Air Pressure and Wind," says the Net Force of a wind is determined by five factors: Net Force = PGF +G +Co +F +Ce.

1. PGF = Pressure Gradient Force, which is based on the distance and the difference between pressure levels.
2. G = Gravity.
3. Co = Coriolis Force, which causes greater turning forces as the distance from the equator increases.
4. F = Friction, which is caused by the winds interaction with the earth's surface.
5. Ce = Centrifugal Force.

**Comparison of Barometric Pressure with Wind Velocity**

| Barometric Pressure | Number Storms | Maximum Velocity | Barometric Pressure | Number Storms | Maximum Velocity | Barometric Pressure | Number Storms | Maximum Velocity |
|---|---|---|---|---|---|---|---|---|
| 882 | 1 | 160.0 | 944 | 4 | 106.3 | 979 | 14 | 83.2 |
| 888 | 1 | 160.0 | 945 | 5 | 111.0 | 980 | 18 | 74.7 |
| 897 | 1 | 150.0 | 946 | 6 | 111.7 | 981 | 10 | 81.5 |
| 899 | 1 | 165.0 | 947 | 1 | 115.0 | 982 | 10 | 73.5 |
| 900 | 1 | 150.0 | 948 | 4 | 123.8 | 983 | 6 | 70.8 |
| 905 | 3 | 150.0 | 949 | 3 | 110.0 | 984 | 9 | 75.6 |
| 908 | 1 | 150.0 | 950 | 10 | 111.5 | 985 | 19 | 70.5 |
| 910 | 1 | 145.0 | 951 | 1 | 105.0 | 986 | 16 | 65.9 |
| 914 | 2 | 155.0 | 952 | 3 | 110.0 | 987 | 13 | 67.3 |
| 915 | 1 | 145.0 | 953 | 3 | 115.0 | 988 | 6 | 67.5 |
| 916 | 1 | 130.0 | 954 | 4 | 106.3 | 989 | 12 | 63.8 |
| 918 | 1 | 140.0 | 955 | 6 | 107.5 | 990 | 22 | 62.3 |
| 920 | 2 | 132.5 | 956 | 4 | 108.8 | 991 | 5 | 63.0 |
| 921 | 1 | 135.0 | 957 | 3 | 101.7 | 992 | 14 | 55.4 |
| 922 | 1 | 150.0 | 958 | 8 | 102.5 | 993 | 15 | 63.3 |
| 923 | 1 | 140.0 | 959 | 3 | 103.3 | 994 | 24 | 55.0 |
| 924 | 2 | 142.5 | 960 | 10 | 98.5 | 995 | 13 | 63.8 |
| 926 | 1 | 150.0 | 961 | 2 | 100.0 | 996 | 15 | 54.7 |
| 927 | 2 | 125.0 | 962 | 8 | 99.4 | 997 | 22 | 53.4 |
| 928 | 1 | 130.0 | 963 | 6 | 93.3 | 998 | 18 | 60.0 |
| 929 | 5 | 134.0 | 964 | 8 | 100.0 | 999 | 19 | 50.8 |
| 930 | 2 | 130.0 | 965 | 13 | 85.0 | 1000 | 31 | 51.1 |
| 931 | 2 | 142.5 | 966 | 5 | 84.0 | 1001 | 21 | 50.0 |
| 932 | 2 | 132.5 | 967 | 4 | 95.0 | 1002 | 21 | 46.7 |
| 933 | 2 | 130.0 | 968 | 9 | 88.3 | 1003 | 11 | 46.8 |
| 934 | 5 | 124.0 | 969 | 7 | 91.4 | 1004 | 18 | 46.4 |
| 935 | 6 | 120.8 | 970 | 11 | 91.4 | 1005 | 21 | 46.4 |
| 936 | 1 | 125.0 | 971 | 4 | 90.0 | 1006 | 12 | 45.8 |
| 937 | 2 | 130.0 | 972 | 5 | 84.0 | 1007 | 12 | 47.1 |
| 938 | 7 | 122.1 | 973 | 10 | 83.5 | 1008 | 1 | 45.0 |
| 939 | 3 | 121.7 | 974 | 9 | 84.4 | 1009 | 3 | 65.0 |
| 940 | 7 | 120.0 | 975 | 10 | 86.0 | 1011 | 1 | 40.0 |
| 941 | 4 | 132.5 | 976 | 8 | 79.4 | | | |
| 942 | 5 | 115.0 | 977 | 12 | 78.8 | **# Storms** | 750 | |
| 943 | 4 | 122.5 | 978 | 6 | 77.5 | | | |

The record barometric pressures[4] are: 870 mb from a Pacific typhoon TIP on 10/17/1979, and 1084 mb in Siberia on 12/31/1968. A straight line fit between the measured barometric pressure and the average maximum wind velocity produced the following coefficients and correlation:

| **Coefficients** | **Pressure** | | **Pressure** | **Projected Wind** |
|---|---|---|---|---|
| a | 1177.880 | | 1000 | 53 |
| b | -1.125 | | 950 | 109 |
| **Correlation** | -0.924 | | 900 | 165 |

The change in barometric pressure causes a trivial change in sea level[3]; a decrease of 1 hPa results in a sea level rise of 1 cm. The shift between pressure levels is the most significant contributor to severe wind velocities. The longer the wind continues, the greater the impact on creation of waves.

Much of the damage resulting from windstorms are causes by the water surge. A Wikipedia article[6], "Wind Wave," identifies 5 elements that influence the height of waves.

1. Wind speed relative to wave speed.
2. Uninterrupted distance of open water.
3. Width of area affected by fetch.
4. Wind duration, and
5. Water depth.

Given open ocean water conditions, the article indicates the height of the waves (trough to crest) that can develop based on continuous wind velocity are:

| **Wind Velocity in Knots** | **Hours Duration** | **Wave Height in Feet** |
|---|---|---|
| 30 | 23 | 13 |
| 40 | 42 | 28 |
| 50 | 69 | 49 |

The table on page 12 shows the number of storms and their maximum velocity by the duration in days that the storm was tracked. The maximum winds were not maintained for this whole time, but high wind velocities are correlated with the duration of the storm. Generally, the longer the storm endures, the greater the waves size.

**Line Fit to Wind Velocity from Days of Duration**

| Coefficients | # Days | - | Days | Projected Wind |
|---|---|---|---|---|
| a | 43.412 | | 5 | 63 |
| b | 3.906 | | 10 | 82 |
| | | | 15 | 102 |
| Correlation | 0.582 | | 20 | 122 |

The impact on shore, however, is a combination of the initial wave size and the structure of the shoreline. Waves break when the wave height exceeds 80% of the water depth.

A missing hazard from this analysis is the amount of rain produced by windstorms. It seems a priori that longer duration storms will produce greater levels of rain, and subsequent resulting damages.

| | Maximum Wind Velocity | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Duration in Days** | **40-49** | **50-59** | **60-69** | **70-79** | **80-89** | **90-99** | **100-109** | **110-119** | **120-129** | **130+** | **Number Storms** | **Average Velocity** |
| 2 | 6 | 6 | 2 | | | | | | | | 14 | 50.0 |
| 3 | 20 | 15 | 16 | 4 | 2 | | | | | | 57 | 54.0 |
| 4 | 39 | 35 | 16 | 11 | | 1 | | | | 1 | 103 | 53.3 |
| 5 | 16 | 29 | 9 | 17 | 6 | 4 | 2 | 1 | 1 | | 85 | 62.2 |
| 6 | 17 | 23 | 15 | 20 | 10 | 4 | 4 | 5 | 1 | 2 | 101 | 68.0 |
| 7 | 12 | 14 | 10 | 9 | 9 | 7 | 5 | 4 | 1 | 2 | 73 | 72.0 |
| 8 | 12 | 7 | 16 | 16 | 9 | 5 | 5 | 7 | 4 | 1 | 82 | 75.2 |
| 9 | 8 | 4 | 10 | 5 | 7 | 6 | 9 | 5 | 3 | 4 | 61 | 84.0 |
| 10 | 5 | 7 | 7 | 10 | 6 | 7 | 10 | 3 | 2 | 2 | 59 | 81.1 |
| 11 | 2 | 1 | 8 | 4 | 2 | 6 | 7 | 5 | 1 | 4 | 40 | 89.6 |
| 12 | 1 | 1 | 5 | 3 | 3 | 4 | 3 | 4 | 1 | 6 | 31 | 97.1 |
| 13 | 2 | 1 | 3 | 2 | 8 | 1 | 6 | 1 | 9 | 6 | 39 | 99.4 |
| 14 | 1 | 1 | 2 | 4 | 1 | 1 | 4 | 6 | 5 | 3 | 28 | 101.6 |
| 15 | 1 | 1 | 2 | | 3 | 5 | 4 | | 4 | 5 | 25 | 101.8 |
| 16 | | | | 4 | 1 | 4 | 5 | 2 | 1 | 2 | 19 | 98.4 |
| 17 | | | | | 2 | 2 | 2 | 1 | 3 | 3 | 13 | 111.5 |
| 18 | | | | 2 | | | 1 | 2 | 4 | 3 | 12 | 115.0 |
| 19 | | | | | | | | 1 | 1 | 1 | 3 | 130.0 |
| 20 | | | 1 | | | | 1 | 1 | 1 | | 4 | 100.0 |
| 21 | | | 1 | | | | | | | 1 | 2 | 97.5 |
| 23 | | | | 1 | | | | 1 | | 2 | 4 | 116.3 |
| 25 | | | | | 1 | | | | | | 1 | 80.0 |
| 30 | | | | | | 1 | | | | | 1 | 95.0 |
| Total | 142 | 145 | 123 | 112 | 70 | 58 | 68 | 49 | 42 | 48 | 857 | 75.8 |
| Ave # Days | 5.6 | 5.6 | 7.3 | 7.9 | 9.3 | 10.4 | 11.0 | 11.0 | 13.0 | 13.1 | | |

Knowing that the basic distribution is skewed to the right, how has its skewness changed? The skewness (3rd moment divided by the cubed standard deviation) is calculated for each storm group within each period. The graph on page 9 shows a degree of volatility by group, but with a definite increasing trend. There is generally movement in the same direction and magnitude for each wind group for each period. The higher wind speed groups have lower skewness. The trend lines on page 9 show increases with larger increases for lower wind speed groups. This result is due to the disproportional increase in the smaller storms.

The distribution of storm severity closely fits a Weibull distribution. The Weibull model has desirable characteristics for modeling windstorms:

1. It is a continuous function.
2. It is a right tailed distribution.
3. Has a zero value for x<=0.
4. As x increases, the probability density function is asymptotic to the x axis.

Range 0<= X <=+ infinity

Scale parameter b>0, Shape parameter c>0 a smaller c, extends the density distribution

Mean: $b*\Gamma[(c+1)/c]$

Distribution function: $1-\exp[-(x/b)^c]$

Probability density function: $(cx^{c-1}/b^c) \exp[-(x/b)^c]$

Hazard function: $cx^{c-1}/b$. The Appendix gives an expanded description[7] of the Weibull Distribution.

To verify the shift in the distribution, Weibull curves are fit to the storm severity distributions for four periods: 1938-1967, 1968-1997, 1998-2017 and the total 1858-2017 (see pages 14 thru 17). The Weibull distribution is a continuous distribution, but the windstorm data is discrete, so pages 14 thru 17 include a range +or -.5 around each x value to recognize this difference. The coefficient of correlation R is at least 0.997 for the Distribution Functions for each period. Since the Weibull distribution extends to infinity, there is always the possibility for larger values, thus a correlation of R=1.0 for sample data to a Weibull is not possible except due to rounding.

| Weilbell | Parameters | | | | | Correlation Coefficient R | |
|---|---|---|---|---|---|---|---|
| Years | C | B | Mean | Std. Dev. | Variance | Density | Distribution |
| 1858-2017 | 1.407 | 5.117 | 0.925 | 1.212 | 1.470 | 0.986 | 0.998 |
| 1938-1967 | 1.338 | 6.172 | 1.075 | 1.410 | 1.987 | 0.954 | 0.999 |
| 1968-1997 | 1.480 | 4.100 | 0.767 | 1.006 | 1.012 | 0.951 | 0.998 |
| 1998-2017 | 1.186 | 4.181 | 0.662 | 0.868 | 0.753 | 0.948 | 0.997 |

It is interesting to note the number of storms with 130 of higher winds; 1938-1967 had 14 over 30 years; 1968-1997 had 10 over its 30 years, and 1998-2017 had 18 in only 20 years. The Weibull distribution for 1968-1997 indicates 1% of the storms will have winds or 145 knots or higher (11.5 table index). The Weibull distribution of 1998-2017 indicates 3.41% of the storms will have 145 knots or higher wind speeds. The Weibull distribution for 1998-2017 experience indicates 1% of the storms will reach 188 knots.

This study has considered storm frequency, maximum wind velocity, barometric pressure, and duration and wave propagation. An expanded study should include:

1. Width of the storm with decreasing wind velocities as distance increases from the center.
2. Length of the path traveled.
3. Location of storm, such as sea depth and water temperature, and
4. Precipitation.

To price windstorm/hurricane insurance, the exposure measure has to be based on current information. The number of structures continues to increase the exposure. The values of properties and construction costs have changed. Local regulations may have required improved structural standards. Ideally, a pricing structure will recognize the level of damage a structure can endure before damage occurs and the likelihood of levels of those winds.

## CONCLUSION

In conclusion, the experience displays long-term upward trends in the occurrence of significant windstorms in the Atlantic. There is also a shift in the shape of the distribution that warrants consideration in predicting the likelihood of the maximum windstorm within a defined probability. Although precipitation experience is not considered, wave surge will increase with increasing winds. The greatest increases in storm frequencies is for the lesser severities but increases in severe storms make the likelihood that recognition of the 100-year storm is currently being understated and the potential damages under appreciated.

| | | | |
|---|---|---|---|
| Data = | 1858-2017 | | Weibull |
| Mean = | 73.372 | mean = | 0.925 |
| Variance = | 4264.000 | variance = | 1.470 |
| Std Dev = | 65.299 | std dev = | 1.212 |
| # Points = | 13 | C (shape)= | 1.407 |
| | | B (scale)= | 5.117 |

| | | Probability Density | | Weibull | | |
|---|---|---|---|---|---|---|
| Speed | X= | Counts | Percentage | X-.5 | Curve | X+.5 |
| 40 | 1 | 207 | 0.142 | 0.103 | 0.128 | 0.140 |
| 50 | 2 | 243 | 0.167 | 0.140 | 0.144 | 0.143 |
| 60 | 3 | 188 | 0.129 | 0.143 | 0.138 | 0.131 |
| 70 | 4 | 215 | 0.148 | 0.131 | 0.123 | 0.113 |
| 80 | 5 | 149 | 0.102 | 0.113 | 0.103 | 0.094 |
| 90 | 6 | 147 | 0.101 | 0.094 | 0.084 | 0.075 |
| 100 | 7 | 116 | 0.080 | 0.075 | 0.066 | 0.058 |
| 110 | 8 | 74 | 0.051 | 0.058 | 0.051 | 0.044 |
| 120 | 9 | 55 | 0.038 | 0.044 | 0.038 | 0.032 |
| 130 | 10 | 29 | 0.020 | 0.032 | 0.028 | 0.024 |
| 140 | 11 | 18 | 0.012 | 0.024 | 0.020 | 0.017 |
| 150 | 12 | 11 | 0.008 | 0.017 | 0.014 | 0.012 |
| 160 | 13 | 4 | 0.003 | 0.012 | 0.010 | 0.008 |
| Total | | 1456 | | | | |

Distribution Functions

| Speed | X= | Cum Counts | Cum Percentage | X-.5 | Weibull Curve | X+.5 |
|---|---|---|---|---|---|---|
| 40 | 1 | 207 | 0.142 | 0.037 | 0.096 | 0.163 |
| 50 | 2 | 450 | 0.309 | 0.163 | 0.234 | 0.306 |
| 60 | 3 | 638 | 0.438 | 0.306 | 0.376 | 0.443 |
| 70 | 4 | 853 | 0.586 | 0.443 | 0.507 | 0.566 |
| 80 | 5 | 1002 | 0.688 | 0.566 | 0.620 | 0.669 |
| 90 | 6 | 1149 | 0.789 | 0.669 | 0.714 | 0.753 |
| 100 | 7 | 1265 | 0.869 | 0.753 | 0.789 | 0.820 |
| 110 | 8 | 1339 | 0.920 | 0.820 | 0.847 | 0.870 |
| 120 | 9 | 1394 | 0.957 | 0.870 | 0.891 | 0.908 |
| 130 | 10 | 1423 | 0.977 | 0.908 | 0.923 | 0.936 |
| 140 | 11 | 1441 | 0.990 | 0.936 | 0.947 | 0.956 |
| 150 | 12 | 1452 | 0.997 | 0.956 | 0.964 | 0.970 |
| 160 | 13 | 1456 | 1.000 | 0.970 | 0.976 | 0.980 |

| | | |
|---|---|---|
| Coefficient of | Density | 0.986 |
| Correlation R | Distribution | 0.998 |

| | Data | | Weibull |
|---|---|---|---|
| Data = | 1938-1967 | | Weibull |
| Mean = | 77.117 | mean = | 1.075 |
| Variance = | 2421.762 | variance = | 1.987 |
| Std Dev = | 49.211 | std dev = | 1.410 |
| # Points = | 12 | C (shape)= | 1.3383 |
| | | B (scale)= | 6.1715 |

| | | Probability Density | | | Weibull | |
|---|---|---|---|---|---|---|
| Speed | X= | Counts | Percentage | X-.5 | Curve | X+.5 |
| 40 | 1 | 39 | 0.139 | 0.090 | 0.107 | 0.116 |
| 50 | 2 | 41 | 0.146 | 0.116 | 0.119 | 0.119 |
| 60 | 3 | 33 | 0.117 | 0.119 | 0.116 | 0.112 |
| 70 | 4 | 34 | 0.121 | 0.112 | 0.107 | 0.101 |
| 80 | 5 | 31 | 0.110 | 0.101 | 0.095 | 0.089 |
| 90 | 6 | 21 | 0.075 | 0.089 | 0.082 | 0.076 |
| 100 | 7 | 27 | 0.096 | 0.076 | 0.069 | 0.063 |
| 110 | 8 | 24 | 0.085 | 0.063 | 0.057 | 0.052 |
| 120 | 9 | 15 | 0.053 | 0.052 | 0.047 | 0.042 |
| 130 | 10 | 7 | 0.025 | 0.042 | 0.038 | 0.034 |
| 140 | 11 | 7 | 0.025 | 0.034 | 0.030 | 0.027 |
| 150 | 12 | 2 | 0.007 | 0.027 | 0.024 | 0.021 |
| 160 | | | | 0.021 | 0.019 | 0.016 |
| Total | | 281 | | | | |

| | | Distribution Functions | | | Weibull | |
|---|---|---|---|---|---|---|
| Speed | X= | Cum Counts | Cum Percentage | X-.5 | Curve | X+.5 |
| 40 | 1 | 39 | 0.139 | 0.034 | 0.084 | 0.140 |
| 50 | 2 | 80 | 0.285 | 0.140 | 0.199 | 0.258 |
| 60 | 3 | 113 | 0.402 | 0.258 | 0.317 | 0.374 |
| 70 | 4 | 147 | 0.523 | 0.374 | 0.429 | 0.481 |
| 80 | 5 | 178 | 0.633 | 0.481 | 0.530 | 0.576 |
| 90 | 6 | 199 | 0.708 | 0.576 | 0.618 | 0.658 |
| 100 | 7 | 226 | 0.804 | 0.658 | 0.694 | 0.727 |
| 110 | 8 | 250 | 0.890 | 0.727 | 0.757 | 0.785 |
| 120 | 9 | 265 | 0.943 | 0.785 | 0.809 | 0.832 |
| 130 | 10 | 272 | 0.968 | 0.832 | 0.852 | 0.870 |
| 140 | 11 | 279 | 0.993 | 0.870 | 0.886 | 0.900 |
| 150 | 12 | 281 | 1.000 | 0.900 | 0.912 | 0.924 |
| 160 | | | | 0.924 | 0.933 | 0.942 |
| Coefficient of Correlation R | | | | Density | 0.962 | |
| | | | | Distribution | 0.998 | |

| | Data | | Weibull |
|---|---|---|---|
| Data = | 1968-1997 | | Weibull |
| Mean = | 70.308 | mean = | 0.767 |
| Variance = | 2487.625 | variance = | 1.012 |
| Std Dev = | 49.876 | std dev = | 1.006 |
| # Points = | 13 | C (shape)= | 1.48 |
| | | B (scale)= | 4.1 |

| | | Probability Density | | Weibull | | |
|---|---|---|---|---|---|---|
| Speed | X= | Counts | Percentage | X-.5 | Curve | X+.5 |
| 40 | 1 | 50 | 0.171 | 0.126 | 0.162 | 0.178 |
| 50 | 2 | 44 | 0.151 | 0.178 | 0.181 | 0.176 |
| 60 | 3 | 58 | 0.199 | 0.176 | 0.166 | 0.152 |
| 70 | 4 | 46 | 0.158 | 0.152 | 0.136 | 0.120 |
| 80 | 5 | 17 | 0.058 | 0.120 | 0.104 | 0.089 |
| 90 | 6 | 22 | 0.075 | 0.089 | 0.075 | 0.062 |
| 100 | 7 | 22 | 0.075 | 0.062 | 0.051 | 0.042 |
| 110 | 8 | 13 | 0.045 | 0.042 | 0.034 | 0.027 |
| 120 | 9 | 10 | 0.034 | 0.027 | 0.021 | 0.017 |
| 130 | 10 | 2 | 0.007 | 0.017 | 0.013 | 0.010 |
| 140 | 11 | 2 | 0.007 | 0.010 | 0.008 | 0.006 |
| 150 | 12 | 4 | 0.014 | 0.006 | 0.004 | 0.003 |
| 160 | 13 | 2 | 0.007 | 0.003 | 0.003 | 0.002 |
| Total | | 292 | | | | |

| | | Distribution Functions | | | | |
|---|---|---|---|---|---|---|
| | | Cum | Cum | | Weibull | |
| Speed | X= | Counts | Percentage | X-.5 | Curve | X+.5 |
| 40 | 1 | 50 | 0.171 | 0.043 | 0.117 | 0.202 |
| 50 | 2 | 94 | 0.322 | 0.202 | 0.292 | 0.382 |
| 60 | 3 | 152 | 0.521 | 0.382 | 0.467 | 0.547 |
| 70 | 4 | 198 | 0.678 | 0.547 | 0.619 | 0.683 |
| 80 | 5 | 215 | 0.736 | 0.683 | 0.739 | 0.787 |
| 90 | 6 | 237 | 0.812 | 0.787 | 0.827 | 0.862 |
| 100 | 7 | 259 | 0.887 | 0.862 | 0.890 | 0.913 |
| 110 | 8 | 272 | 0.932 | 0.913 | 0.932 | 0.947 |
| 120 | 9 | 282 | 0.966 | 0.947 | 0.959 | 0.969 |
| 130 | 10 | 284 | 0.973 | 0.969 | 0.976 | 0.982 |
| 140 | 11 | 286 | 0.979 | 0.982 | 0.987 | 0.990 |
| 150 | 12 | 290 | 0.993 | 0.990 | 0.993 | 0.995 |
| 160 | 13 | 292 | 1.000 | 0.995 | 0.996 | 0.997 |

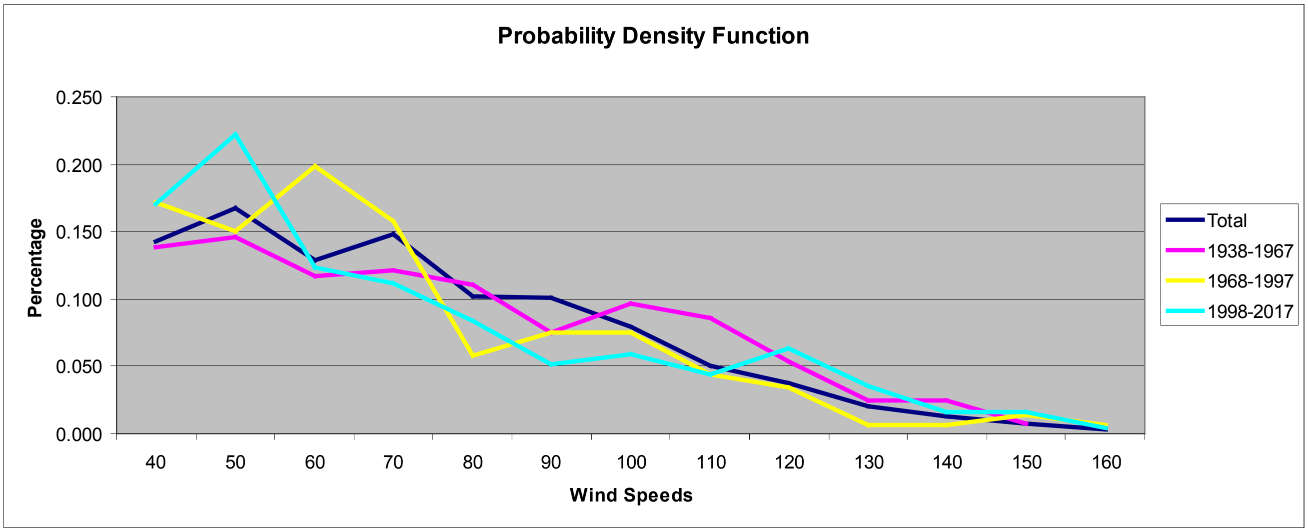
| | | |
|---|---|---|
| Coefficient of Correlation R | Density | 0.951 |
| | Distribution | 0.998 |

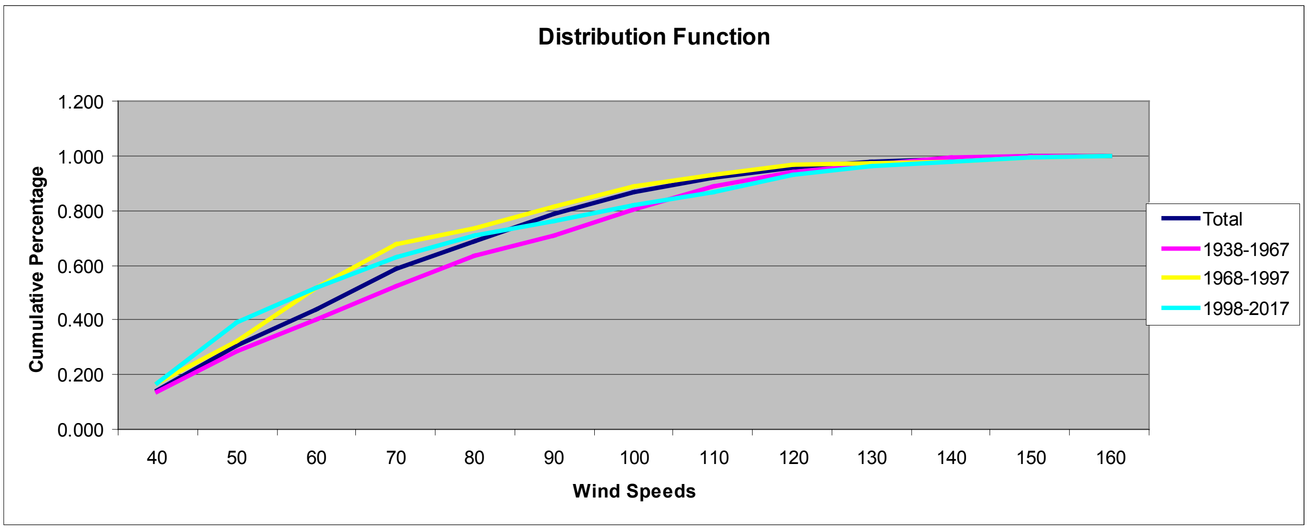
| | | | |
|---|---|---|---|
| Data = | 1998-2017 | | Weibull |
| Mean = | 72.659 | mean = | 0.662 |
| Variance = | 2544.542 | variance = | 0.753 |
| Std Dev = | 50.443 | std dev = | 0.868 |
| # Points = | 13 | C (shape)= | 1.186 |
| | | B (scale)= | 4.181 |

| | | Probability Density | | | Weibull | |
|---|---|---|---|---|---|---|
| Speed | X= | Counts | Percentage | X-.5 | Curve | X+.5 |
| 40 | 1 | 43 | 0.171 | 0.176 | 0.181 | 0.174 |
| 50 | 2 | 56 | 0.222 | 0.174 | 0.163 | 0.150 |
| 60 | 3 | 31 | 0.123 | 0.150 | 0.136 | 0.122 |
| 70 | 4 | 28 | 0.111 | 0.122 | 0.109 | 0.097 |
| 80 | 5 | 21 | 0.083 | 0.097 | 0.085 | 0.075 |
| 90 | 6 | 13 | 0.052 | 0.075 | 0.065 | 0.057 |
| 100 | 7 | 15 | 0.060 | 0.057 | 0.049 | 0.043 |
| 110 | 8 | 11 | 0.044 | 0.043 | 0.037 | 0.032 |
| 120 | 9 | 16 | 0.063 | 0.032 | 0.027 | 0.023 |
| 130 | 10 | 9 | 0.036 | 0.023 | 0.020 | 0.017 |
| 140 | 11 | 4 | 0.016 | 0.017 | 0.015 | 0.012 |
| 150 | 12 | 4 | 0.016 | 0.012 | 0.011 | 0.009 |
| 160 | 13 | 1 | 0.004 | 0.009 | 0.008 | 0.006 |
| Total | | 252 | | | | |

| | | Distribution Functions | | | | |
|---|---|---|---|---|---|---|
| | | Cum | Cum | | Weibull | |
| Speed | X= | Counts | Percentage | X-.5 | Curve | X+.5 |
| 40 | 1 | 43 | 0.171 | 0.077 | 0.167 | 0.257 |
| 50 | 2 | 99 | 0.393 | 0.257 | 0.341 | 0.419 |
| 60 | 3 | 130 | 0.516 | 0.419 | 0.491 | 0.555 |
| 70 | 4 | 158 | 0.627 | 0.555 | 0.613 | 0.664 |
| 80 | 5 | 179 | 0.710 | 0.664 | 0.710 | 0.750 |
| 90 | 6 | 192 | 0.762 | 0.750 | 0.784 | 0.815 |
| 100 | 7 | 207 | 0.821 | 0.815 | 0.842 | 0.865 |
| 110 | 8 | 218 | 0.865 | 0.865 | 0.885 | 0.902 |
| 120 | 9 | 234 | 0.929 | 0.902 | 0.916 | 0.929 |
| 130 | 10 | 243 | 0.964 | 0.929 | 0.940 | 0.949 |
| 140 | 11 | 247 | 0.980 | 0.949 | 0.957 | 0.964 |
| 150 | 12 | 251 | 0.996 | 0.964 | 0.970 | 0.974 |
| 160 | 13 | 252 | 1.000 | 0.974 | 0.979 | 0.982 |

| | | |
|---|---|---|
| Coefficient of | Density | 0.948 |
| Correlation R | Distribution | 0.997 |




## APPENDIX

The Weibull can be defined with 1, 2 or 3 parameters. The 3-parameters probability density function is:

$PDF(x) = [\ C(x-A)^{C-1} / B^{C}\ ] \exp\{-[(x-A)/B]^{C}\}$ where the A parameter adjusts the location ($\pm$ infinity).

Setting A=0 produces the 2-parameter probability density function (PDF) used in this paper and described[7] below:

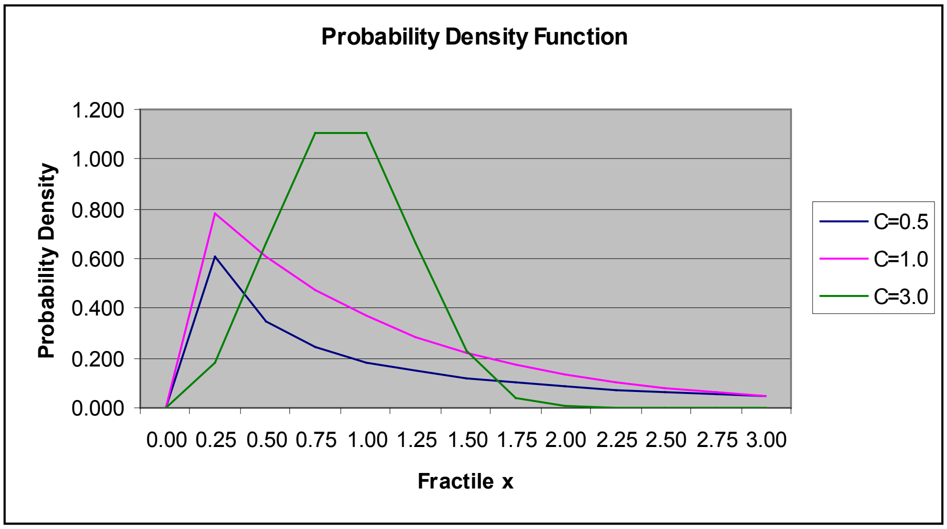
$PDF(x) = (Cx^{C-1} / B^{C}) \exp[-(x/B)^{C}]$

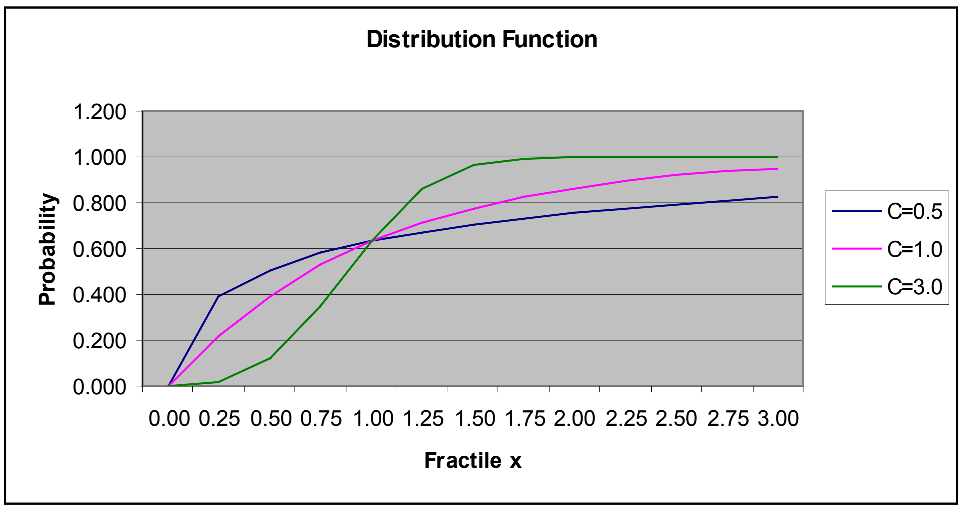
The distribution function (DF) is: $DF(x) = 1 - \exp[-(x/B)^{C}]$

$\text{Variance} = B^{2}\ (\ \Gamma[(C+2)/C] - \{\Gamma[(C+1)/C]\}^{2})$

$\text{Mode} = B\ (1-1/C)^{1/C}$ for $C \geq 1$ and $= 0$ for $C \leq 1$

C is the shape parameter (C>0). A Weibull distribution with C=1 produces the exponential distribution with mean B. A C value slightly below 3.0 looks somewhat like a normal distribution with a slight tail. The scale parameter(B), adjusts the length of the distribution. The following graphs uses Excel's function, WEIBULL(x,C,B=1, 0 & 1), to illustrate the shift in the distributions by adjusting its shape parameter (C):

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Credit for the statistics and calculations used for this paper go to:


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