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IS A TRILLION DOLLAR HURRICANE SEASON POSSIBLE?

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The most damaging 10% of hurricane seasons, eleven in all, caused $710B in US damage normalized for inflation, population and increasing household wealth (Pielke et al 2008). This figure represents about 64% of the 1900-2008 total. Pareto distributions (e.g., Rydgaard 1990, Madelbrot 1977, pp 341-348):

$$P = \Pr\{x \geq X\} = P_0 (X_0 / X)^{\alpha},$$

are a logical choice for modeling data dominated by rare, high-impact events (Fig. 1); although log-normal, Gumbel and Fréchet distributions (e.g., Embrechts et al., 1999) also show promise. Here P_0 it the probability that cumulative damage, $x \geq X_0$, a threshold value, and P is the probability that it is greater than $X > X_0$. It is easily shown that when the Pareto exponent, α, is ≤ 1 the distribution has no well-defined mean, and that when $\alpha \leq 2$ there is no well-defined variance.

Since the normalized damage time series seems to be stationary, fitting extreme value distributions can yield estimates of the probabilities of very rare events outside the experience embodied in the 1900-2008 record. If the counts of destructive seasons in the most damaging 10% with losses $\geq$ $34.5B, are binned temporally by decades, there is no statistical justification for questioning that they obey a Poisson distribution with rate = 1 per decade, as one would expect. Only two of the eleven devastating seasons occurred during the cool phase of the Atlantic Multidecadal Oscillation (Enfield et al. 2001) when hurricane activity is generally suppressed (Goldenberg et al. 2001). This seeming bias

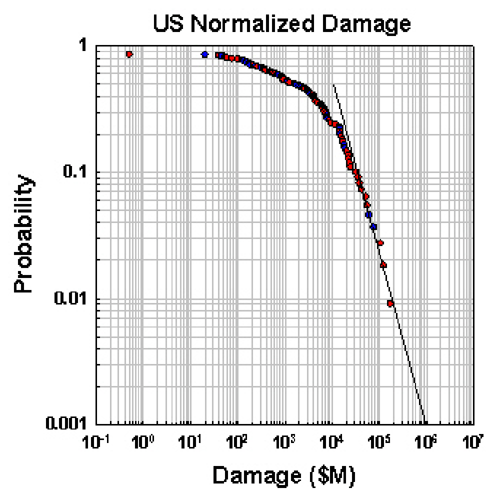

Fig. 1. A Pareto distribution fitted to the tail of the cumulative damage distribution of 1900-2008 hurricane seasons where normalized hurricane damage > $34.5B. The exponent is 1.37. This model adequately represents the most destructive 10% of hurricane seasons in the US.

is easily attributable to chance (Chi-square p = 13%).The fitted Pareto distribution extrapolates impacts with return periods of 200 yr, $304B; 500 yr, $592B; and 1000 yr, $980B. The 100 year event, $183B, is in reasonable agreement with the PI's earlier estimate based upon fitting compound log-normal distributions (Willoughby 2011).

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Nonetheless, there are reasons to question Pareto estimates. The extrapolation from 100 to 1000-yr return period extends far out on the un-sampled tail. Although the log-log plotted exceedance probability curve becomes straighter at the end, it is still subtly concave downward. Moreover, the most extreme hurricanes should not exhibit the self-similarity property that is implicit in the Pareto formulation because their maximum intensity is constrained by thermodynamic MPI (Emanuel 1999) and size by the dynamic requirement that the core Rossby number be >> 1 (e.g., Shaprio and Willoughby 1982).

Since none the three most destructive hurricanes so far (1900, 1926 and 2005) caused more than $170B in damage, unprecedented destruction would probably have to stem from multiple landfalls within the same season. For example, one might envision a repeat of 2005, where Katrina intensified east of Florida and devastated Miami and then followed the climatologically likely track to New Orleans. Then Rita destroyed Houston/Galveston, and Wilma hit Tampa Bay as a major flooding event. This scenario, whose probability can be assessed using a Bayesian tree, would result in single-season damage > $440B, the combined total from the Galveston Hurricane of 1900, the Miami Hurricane of 1926, the Havana-Tampa Hurricane of 1944 and Katrina extrapolated to 2008 coastal development and population. It is difficult to imagine a realistic scenario that would more than double this figure to $1000B. Still, examination of hypothetical future disasters in this context promises insight into the worst possible hurricane outcomes.

REFERENCES:

Emanuel, K. A., 1999: Thermodynamic control of hurricane intensity. *Nature*, **401**, 665-669.

Embrechts, P., S. I. Resnick, and G. Samorodnitsky, 1999: Extreme value theory as a risk management tool. *N. Amer. Actuarial J.*, **3**(2), 30-41.

Enfield, D.B., A.M. Mestas-Nunez, and P.J. Trimble, 2001: The Atlantic Multidecadal Oscillation and its relationship to rainfall and river flows in the continental U.S., *Geophys. Res. Lett.*, 28: 2077-2080.

Goldenberg, S. B., C. W. Landsea, A. M. Mestas-Nuñez, and W. M.Gray, 2001: The recent increase in Atlantic hurricane activity: Causes and implications. *Science*, **293**(5529), 474-479.

Mandelbrot, B., 1977: *The Fractal Geometry of Nature*, W. H. Freeman, 468 pp.

Pielke, R. A., Jr., J. Gratz, C. W. Landsea, D. Collins, M. A. Saunders, and R. Musulin, 2008: Normalized hurricane damages in the United States: 1900-2005. *Nat. Haz. Rev.*, **9**(1), 29-42.

Rydgaard, M., 1990: Estimation in the Pareto Distribution, *ASTIM Bulletin*, **20**(2), 201-216.

Shapiro, L. J. and H. E. Willoughby, 1982: Response of balanced hurricanes to local sources of heat and momentum. *J. Atmos. Sci.*, **39**, 378–394.

Willoughby, H. E., 2011: Distributions and trends of death and destruction from hurricanes in the United States, 1900-2008. *Natural. Hazards Review,* 13(1), 57-64.