Energy and Population Elasticity of Tornado Casualties

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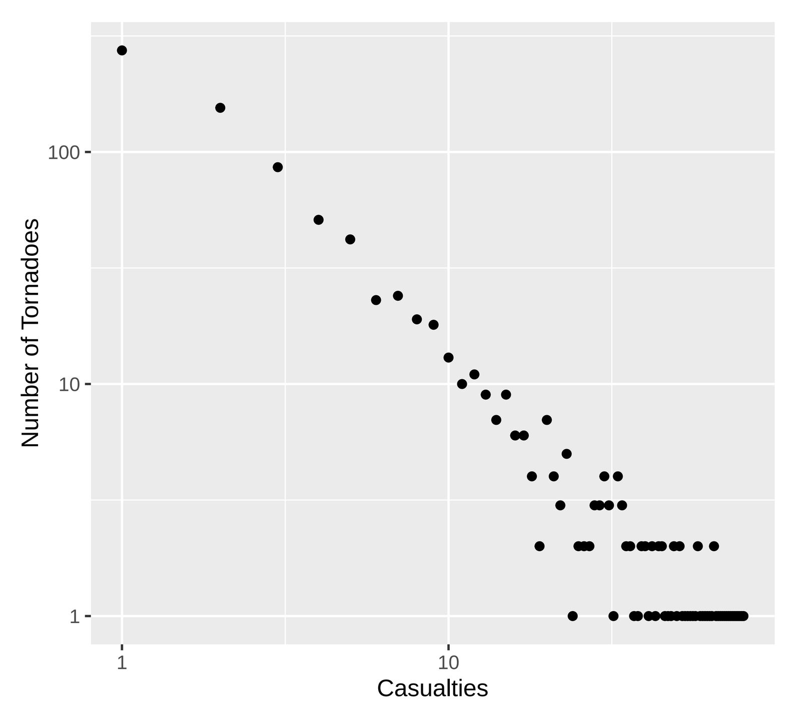
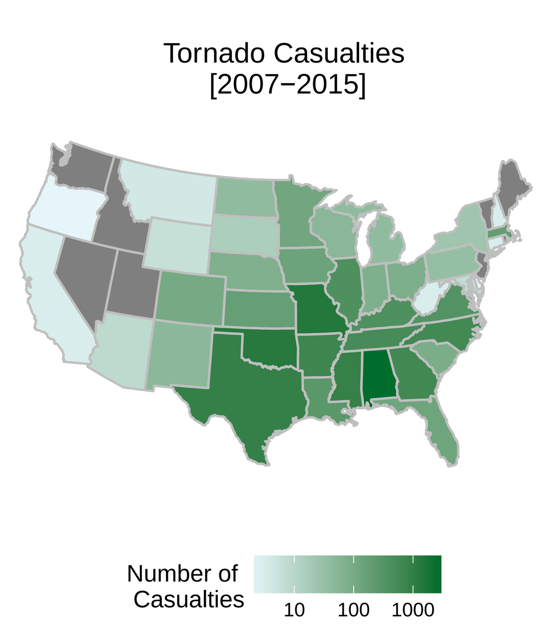
Why Did We Do This?

Tornadoes have the potential to cause mass casualties and to severely disrupt economic productivity. Whether that potential is realized depends on the number of people and extent of the property in harm's way. Population growth implies a greater potential for casualties. Recent research suggests that as population increases, so does the chance that a tornado impacts developed land, resulting in more damage and a higher numbers of casualties. This concept, known as the expanding bull's-eye effect (Ashley et al. 2014), explains changes in tornado destruction using housing units and households. But other factors beyond population changes might play a role in the potential for future losses.

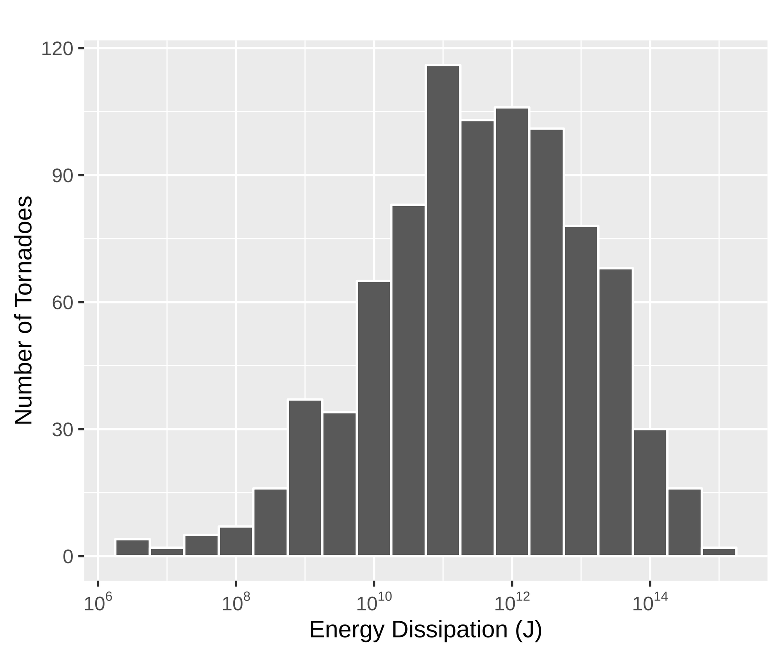
The goal of this study is to better understand the relationship between energy, population, and tornado casualties. The objective is to establish statistical estimates (and margins of error) on how sensitive casualties are to changes in population and on how sensitive casualties are to changes in tornado strength. This study uses the economic concept of 'elasticity' to quantify these changes for the first time. Quantification is done at the tornado level over the period 2007 through 2015.

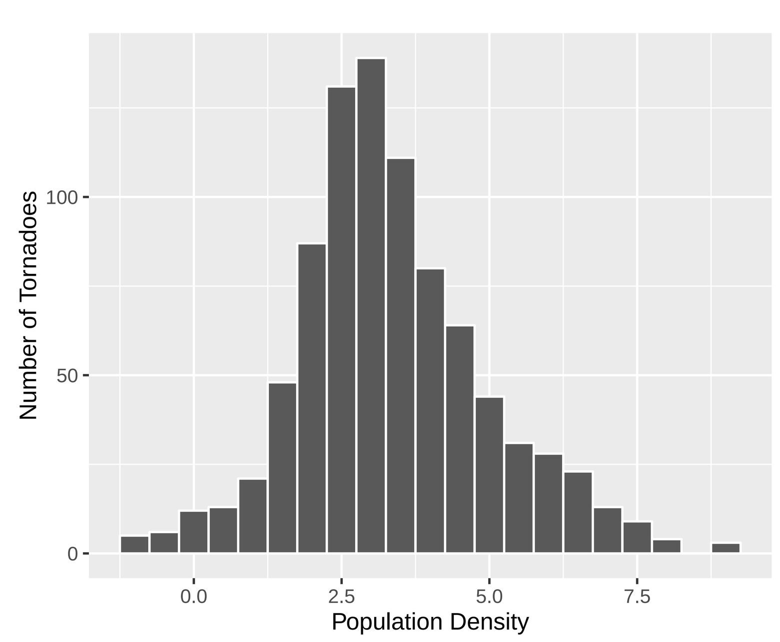
Casualties





Energy and Population





How Do We Get Tornado Energy?

Building off of Schielicke and Névir (2011), the equation for energy dissipation (atmosphere moment) is

$$E = \frac{1}{2} A_v l \bar{\rho} \sum_{j=0}^{J} w_j v_j^2, \quad (1)$$

where A_v is the area of the vortex (πR^2), l is the path length, $\bar{\rho}$ is air density, v_j is the midpoint wind speed for each rating, and w_j is the corresponding fraction of path area. With no upper bound on the EF5 wind speeds, the midpoint wind speed is set at 97 m s^{-1} (7.5 m s^{-1} above the threshold wind speed consistent with the EF4 midpoint speed relative to its threshold). Since fractions of path area by EF rating are not available in the much larger Storm Prediction Center (SPC) database, the U.S. Nuclear Regulatory Commission (NRC) model for the fractions can be used (see Fricker and Elsner 2015).

Energy and Population Elasticity

Energy dissipation and population data are examined in relationship with tornado casualties using the economic concept of 'elasticity'. This is an efficient way to explain the changes in casualties by focusing on the ratios of the percentage changes in population and energy to the percentage change in casualties.

We employ a multiplicative model for casualties expressed as

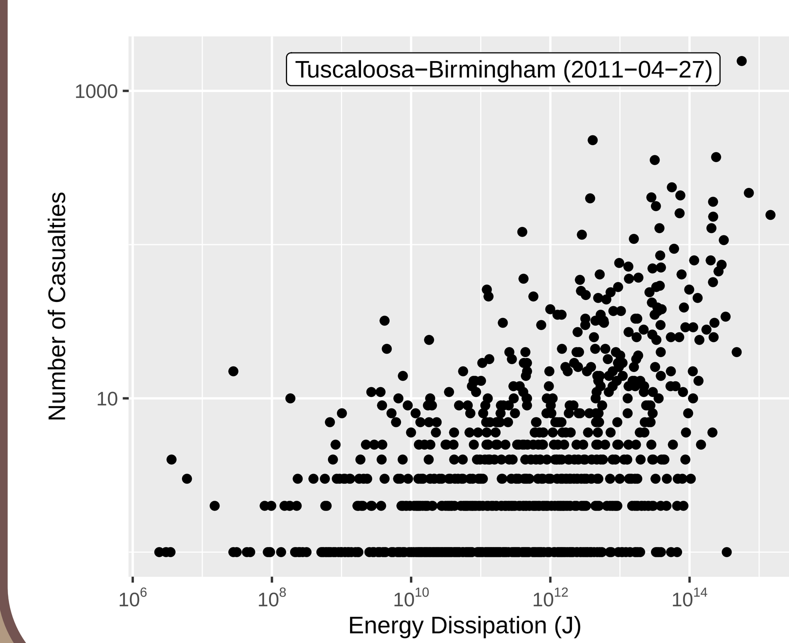
$$C \sim E^{\alpha} \cdot P^{\beta}, \quad (2)$$

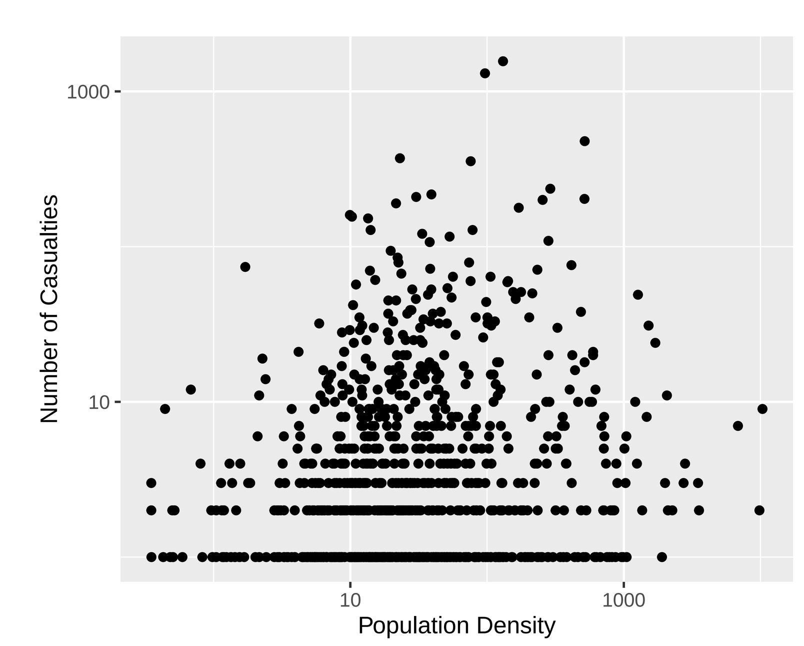
where C is the number of casualties, E is energy dissipation in joules, and P is the population density in persons per square km. Taking logarithms and writing the relationship statistically, we have

$$\log(\hat{C}) = \hat{\alpha} \cdot \log(E) + \hat{\beta} \cdot \log(P), \quad (3)$$

where $\hat{C}$ is the predicted number casualties and the coefficient $\hat{\alpha}$ is the energy elasticity and $\hat{\beta}$ is the population elasticity.

Casualties, Energy Dissipation, and Population





Multiplicative Regression Model

The data are fit to the model (Eq. 3) using ordinary least squares. The R^2 is .31 indicating that energy dissipation and population explains 31% of the casualties. Population and energy dissipation are both significant factors in explaining the number of casualties as expected.

Coefficient	Estimate	Std. Error	t value	Pr(> |t|)
$\hat{\alpha}$	.206	.011	18.907	< 0.0001
$\hat{\beta}$	.223	.022	9.484	< 0.0001

How Sensitive Is the Model?

Years	EF Range	Months	Energy elasticity	Population elasticity
2007-2015	EF0+	1-12	15%([14%, 17%])	17%([14%, 20%])
1998-2006	EF0+	1-12	13%([11%, 14%])	9%([7%, 12%])
1989-1997	EF0+	1-12	11%([10%, 12%])	10%([7%, 12%])
1980-1988	EF0+	1-12	11%([10%, 13%])	8%([6%, 10%])
2007-2015	**EF1+**	1-12	17%([15%, 18%])	18%([14%, 21%])
2007-2015	**EF2+**	1-12	19%([17%, 22%])	26%([21%, 30%])
2007-2015	**EF3+**	1-12	29%([23%, 34%])	43%([34%, 52%])
2007-2015	EF0+	**4-6**	15%([11%, 18%])	19%([12%, 27%])
2007-2015	EF0+	**12-2**	17%([9%, 26%])	17%([0%, 35%])

Conclusions

Here, we quantify the expanding bull's-eye effect, along with energy dissipation to understand the relationship between tornado casualties, tornado strength, and population. Results show that a doubling in energy dissipation leads to a 15% increase in the number of casualties, while a doubling in population leads to a 17% increase in the number of casualties. This indicates that energy dissipation is as important as the expanding bull's-eye effect in explaining tornado casualties at the individual tornado level.

References

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