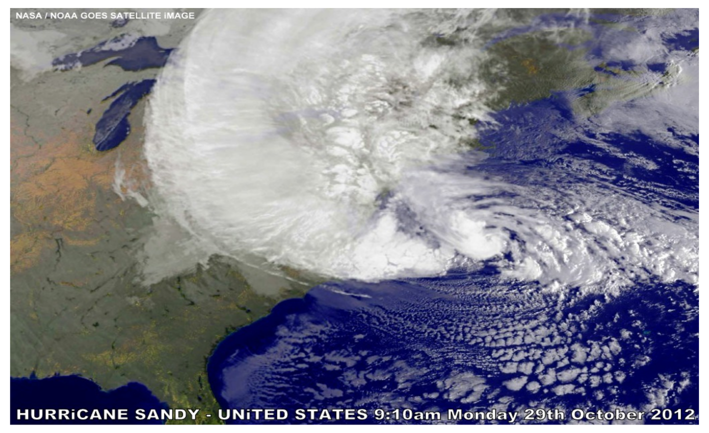

Dependency of U.S. Hurricane Economic Loss on Maximum Wind Speed and Storm Size

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Motivation

Many empirical hurricane economic loss (L) models consider only maximum wind speed (V_{max}) and neglect storm size (R) (e.g, Emanuel 2011; Murnane and Elsner 2012; Nordhaus 2010). These models may be inadequate in predicting the losses of super-sized storms, such as Hurricane Sandy in 2012.

- Hurricane Sandy (2012)
  Category 1, V_{max} = 75 mph, L = $51.21 Billion
- Hurricane Andrew (1992)
  Category 5, V_{max} = 170 mph, L = $53.77 Billion

Enormous Size of Hurricane Sandy (2012)

At its peak size, 20 hours before the landfall, Sandy's tropical-storm force winds spanned 1100 miles, about 1/5 of the area of the entire United States. At landfall, it covered almost 900 miles across, 3 times larger than the size of Hurricane Andrew (1992).

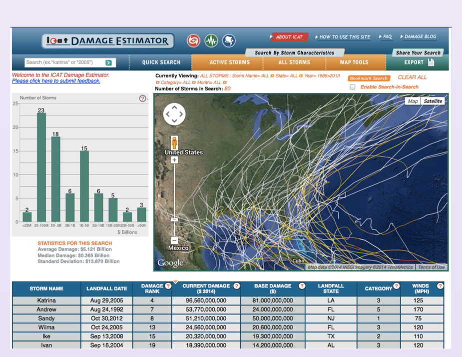
Is hurricane loss affected by storm size? If so, by how much?

Objective

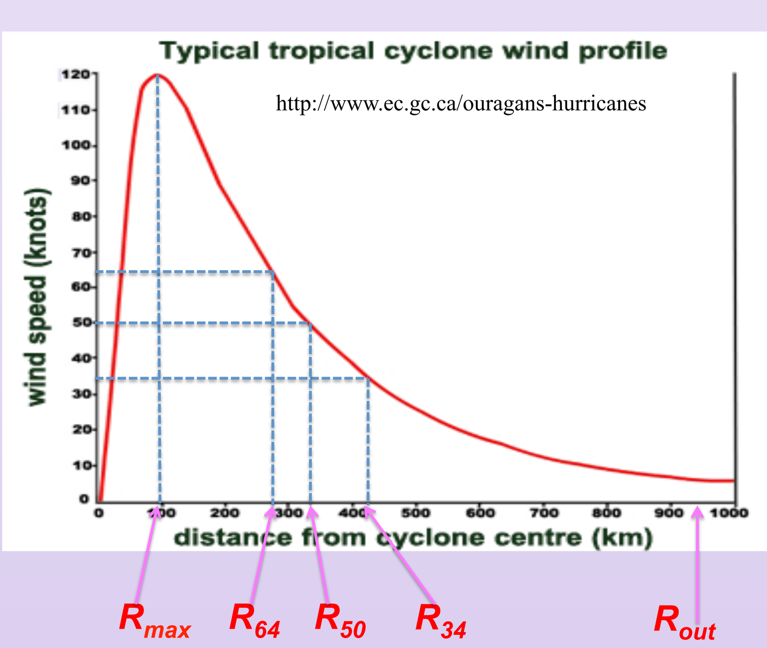
- Quantify the dependency of hurricane economic loss (L) on maximum wind speed (V_{max}) and size (R)
- Construct an empirical loss model using both V_{max} and R as predictors
- Compare the relative roles of V_{max} and R in determining Hurricane Sandy's loss

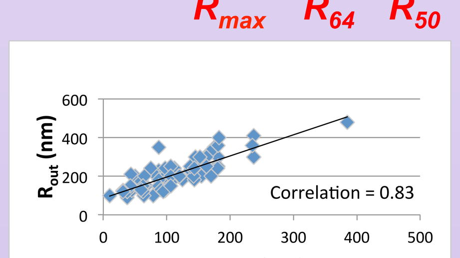
Data

- **Normalized Loss (Pielke et al. 2008) in 2013 US dollars** considering inflation, wealth and population differences between the years that landfalling hurricanes occurred
  From ICAT Damage Estimator
  http://www.icatdamageestimator.com/viewdata
- **Maximum Wind Speed at Landfall**
  From ICAT Damage Estimator
  http://www.icatdamageestimator.com/viewdata



- **Size**: R_{max}, R34, R50, R64, R_{out}, from the Extended Best Track data at the National Hurricane Center
  ftp://ftp.nhc.noaa.gov/atcf/archive/





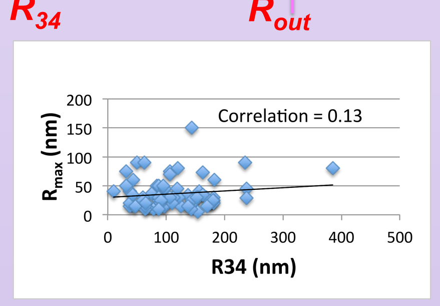


Figure 1. *R34* is highly correlated with *R50*, *R64* and R_{out}, but has little correlation with R_{max}. We use *R34* as the measure of storm size.

Relationship Between Loss and Maximum Wind Speed

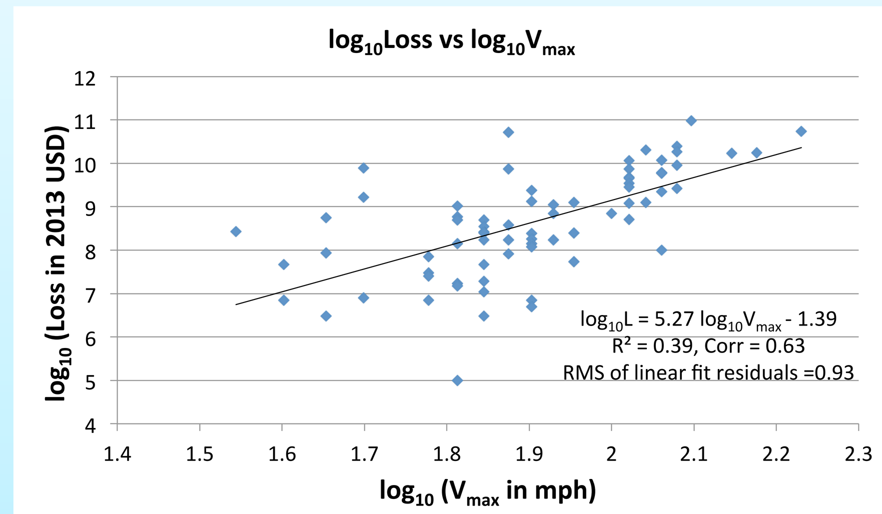


Figure 2. Normalized loss follows an approximate power-law relation with maximum wind speed, $L = 10^{-1.39}V_{max}^{5.27}$. The correlation between $log_{10}L$ and $log_{10}V_{max}$ is 0.63 and the explained variance is 39%. The root-mean-square (RMS) of the linear fit residuals for $log_{10}L$ is 0.93.

Relationship Between Loss and Size

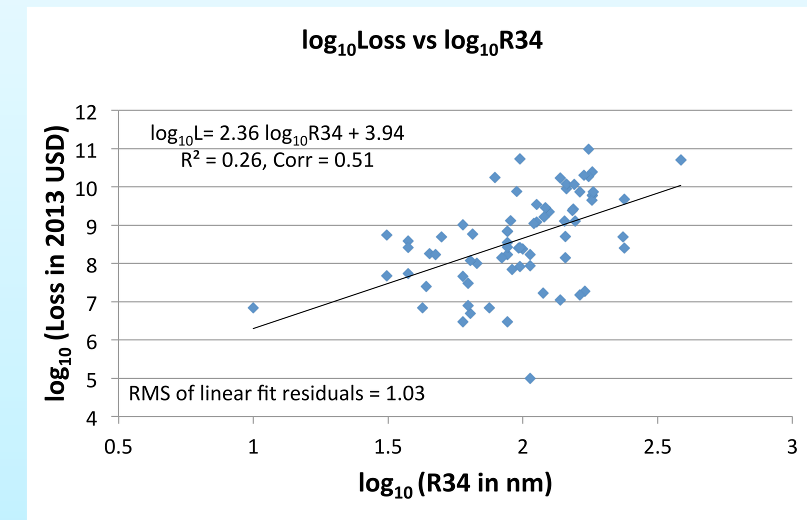


Figure 3. Normalized loss follows an approximate power-law relation with storm size, $L = 10^{3.94}R34^{2.36}$. The correlation between $log_{10}L$ and $log_{10}R34$ is 0.51 and the explained variance is 26%. The RMS of the linear fit residuals for $log_{10}L$ is 1.03.

Dependency of Loss on Maximum Wind Speed and Size

$$L = 10^c V_{max}^a R34^b$$

$$\log_{10} L = c + a \log_{10} V_{max} + b \log_{10} R34$$

Threshold V_{max}	Sample Size	R^2	a	b	c	R^2 (V_{max} only)	a (V_{max} only, b=0)	R^2 (R34 only)	b (R34 only, a=0)
>=35	73	0.45	4.19	1.25	-1.83	0.39	5.27	0.26	2.36
>=60	64	0.58	6.78	1.43	-7.31	0.52	7.77	0.23	2.57
>=65	60	0.55	6.92	1.44	-7.62	0.48	7.69	0.18	2.32
>=70	53	0.62	6.29	1.82	-7.11	0.49	7.60	0.31	2.75
>=75	43	0.69	4.98	2.66	-6.22	0.40	7.11	0.51	3.36
>=80	38	0.75	6.53	2.61	-9.30	0.57	9.01	0.51	3.92
>=85	30	0.75	6.82	2.48	-9.64	0.50	8.07	0.41	3.10
>=90	27	0.74	7.80	2.59	-11.90	0.44	8.42	0.37	2.85
>=100	24	0.64	8.82	3.13	-15.17	0.30	6.73	0.16	2.09
>=110	15	0.75	11.97	4.44	-24.62	0.23	6.54	0.16	2.17
>=115	13	0.80	12.11	4.34	-24.72	0.25	6.92	0.20	2.31

Table 1. The coefficients (*a*, *b*, *c*) from the multi-variate regressions and the explained variance (R^2) vary for the sub-samples of storms defined by the maximum wind speed.

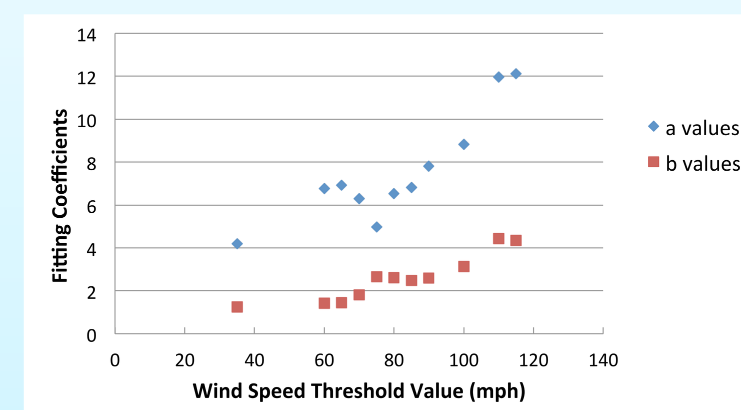


Figure 4. When hurricane intensity increases, the dependencies of loss on maximum wind speed and size become stronger.

- The explained variance (R^2), dependencies on maximum wind speed (*a*) and size (*b*) increase when maximum wind speed threshold increase.
- The explained variance (R^2), for bi-variate regressions are greater than those for the corresponding single-variate regressions.
- When V_{max} < 100 mph, a and b from bi-variate regressions are smaller than those from single-variate regressions.
- When V_{max} ≥ 100 mph, a and b from bi-variate regressions are greater than those from single-variate regressions.

Weighted Regression

W is the weighting function, set y-intercept to zero in tri-variate regressions to fit $W(log_{10}L)$ using $W(log_{10}V_{max})$, $W(log_{10}R34)$ and *W* as predictors

$$W \log_{10} L = aW \log_{10} V_{max} + bW \log_{10} R34 + cW$$

$$L = 10^c V_{max}^a R34^b$$

	a	b	c	RMS of log10(L)
All storms (V_{max} >= 35 mph), unweighted	4.18	1.25	-0.83	0.89
All storms (V_{max} >= 35 mph), weighted by loss	4.28	2.52	-3.77	1.21
All storms (V_{max} >= 35 mph), weighted by sqrt(loss)	3.18	1.96	-0.45	1.24
Hurricanes (V_{max} >= 75 mph), unweighted	4.98	2.66	-6.22	0.56
Hurricanes (V_{max} >= 75 mph), weighted by loss	7.88	4.61	-15.98	0.79
Hurricanes (V_{max} >= 75 mph), weighted by sqrt(loss)	5.90	3.42	-9.34	0.64

Table 2: The weighted regressions yield stronger dependencies on maximum wind speed (*a*) and size (*b*) than the unweighted regressions. The fitting residuals for $log_{10}(L)$ become larger in weighted regressions, but the biases of losses (*L*) are smaller at large losses (see Figure 5).

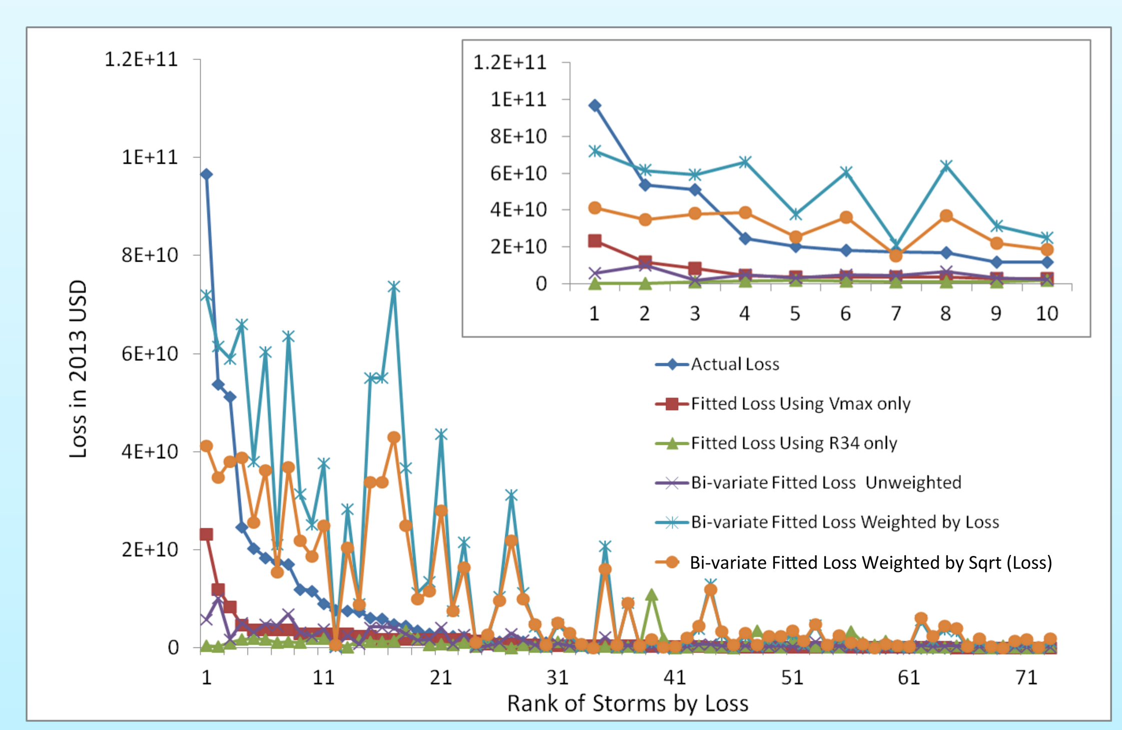
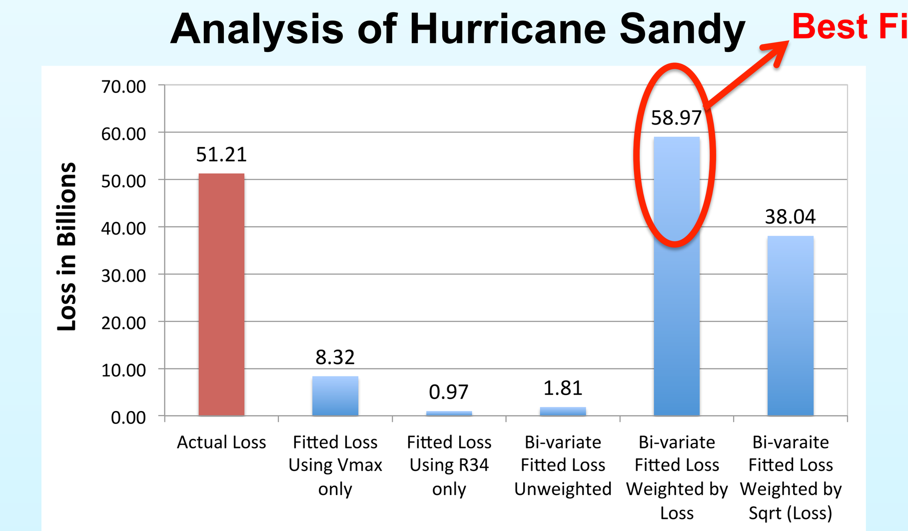
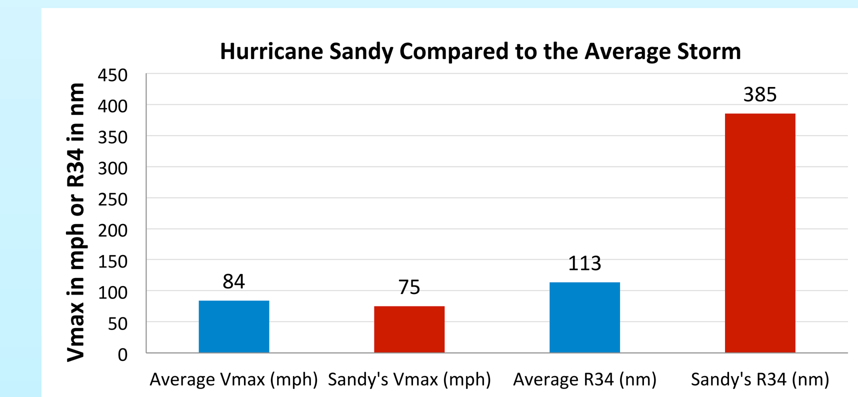
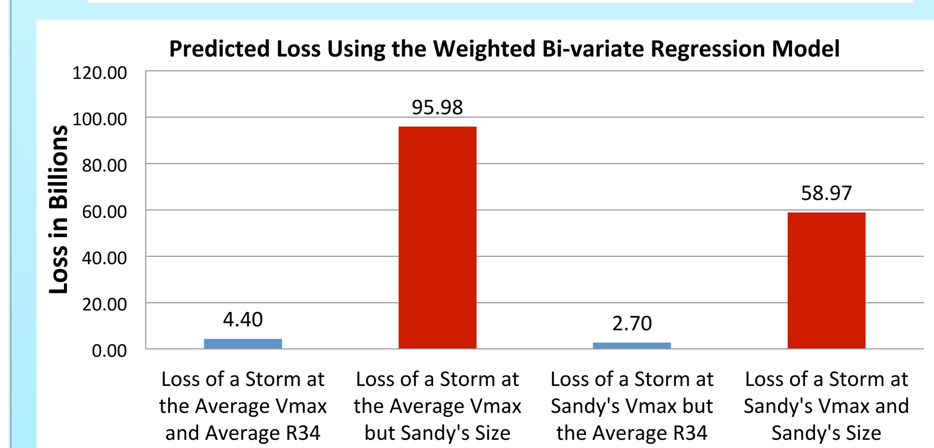


Figure 5. Predicted losses using various regression models. At large losses (for example, the top 10 losses shown in the inset), the weighted regressions produce close fittings to the actual losses, while the unweighted regressions are significantly biased low.

Analysis of Hurricane Sandy







Conclusion and Discussions

- Hurricane loss approximately follows a power-law relation with maximum wind speed and storm size, i.e., $L = 10^c V_{max}^a R34^b$, with ***a*** being 4-12 and ***b*** being 2-4.
- Both ***a*** and ***b*** tend to increase with stronger wind speed.
- The regression models using both wind speed and size as predictors capture more variance of the losses than the models using either wind speed or size alone.
- Single-variate regression models need to be revised.
- Hurricane Sandy's size was 3.4 times of the average storm size. The best fit model, $L = 10^{-3.77} V_{max}^{4.28} R34^{2.52}$, suggests that the loss of Sandy would be about 21 times smaller if its size were of the average storm size, given the maximum wind speed unchanged.
- The best fit bi-variate regression model based on the historical data provides a basis for developing more comprehensive hurricane loss models.

Large size plays a predominant role in the economic loss of Hurricane Sandy.

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