

Assessing Current and Future Freshwater Flood Risk from North Atlantic Tropical Cyclones via Insurance Claims

Associated Supplemental Material – December 6, 2016

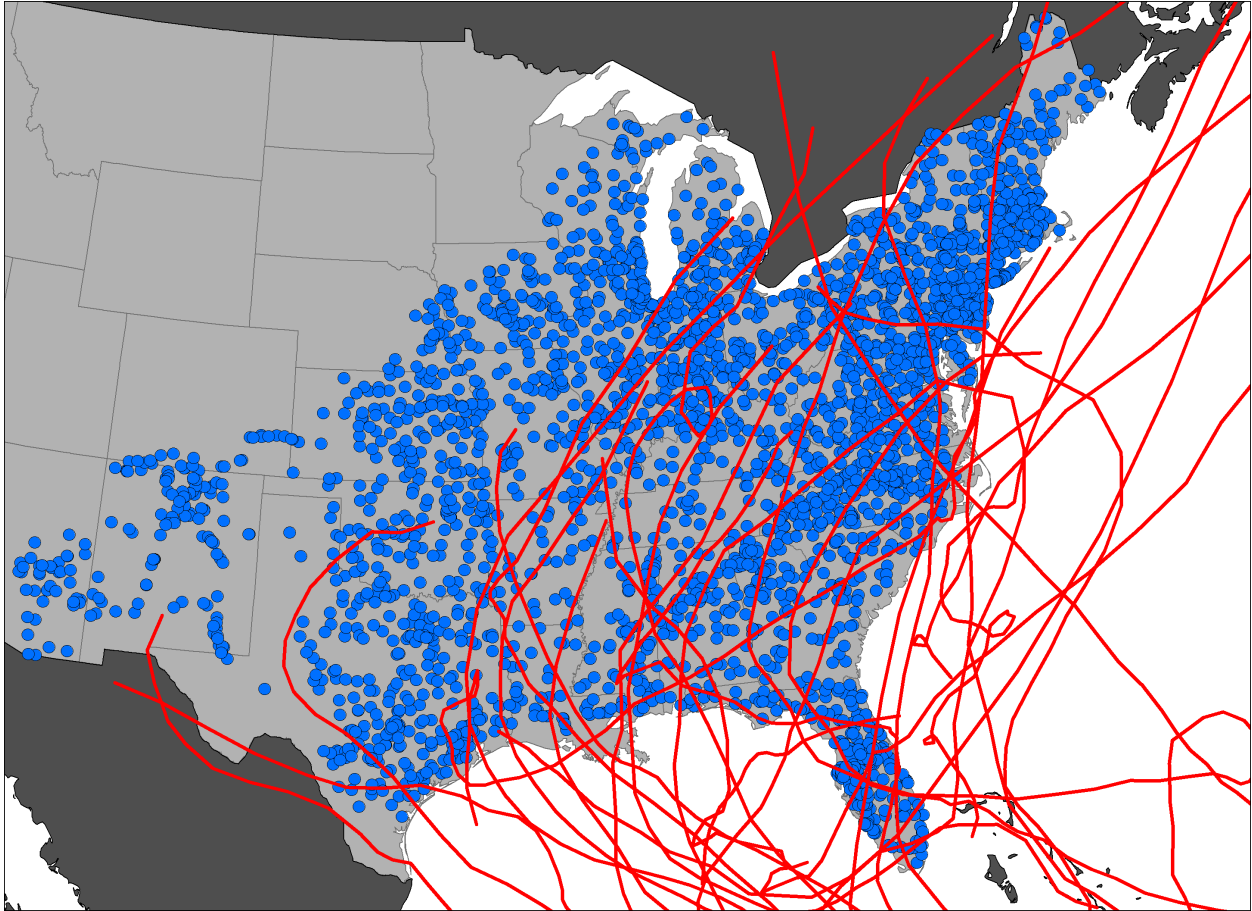
JEFFREY CZAJKOWSKI^{1,2}, GABRIELE VILLARINI³, MARILYN MONTGOMERY¹, ERWANN MICHEL-KERJAN¹ AND RADOSLAW GOSKA³

¹The Wharton School, University of Pennsylvania, 3730 Walnut Street, Philadelphia, PA 19104, USA

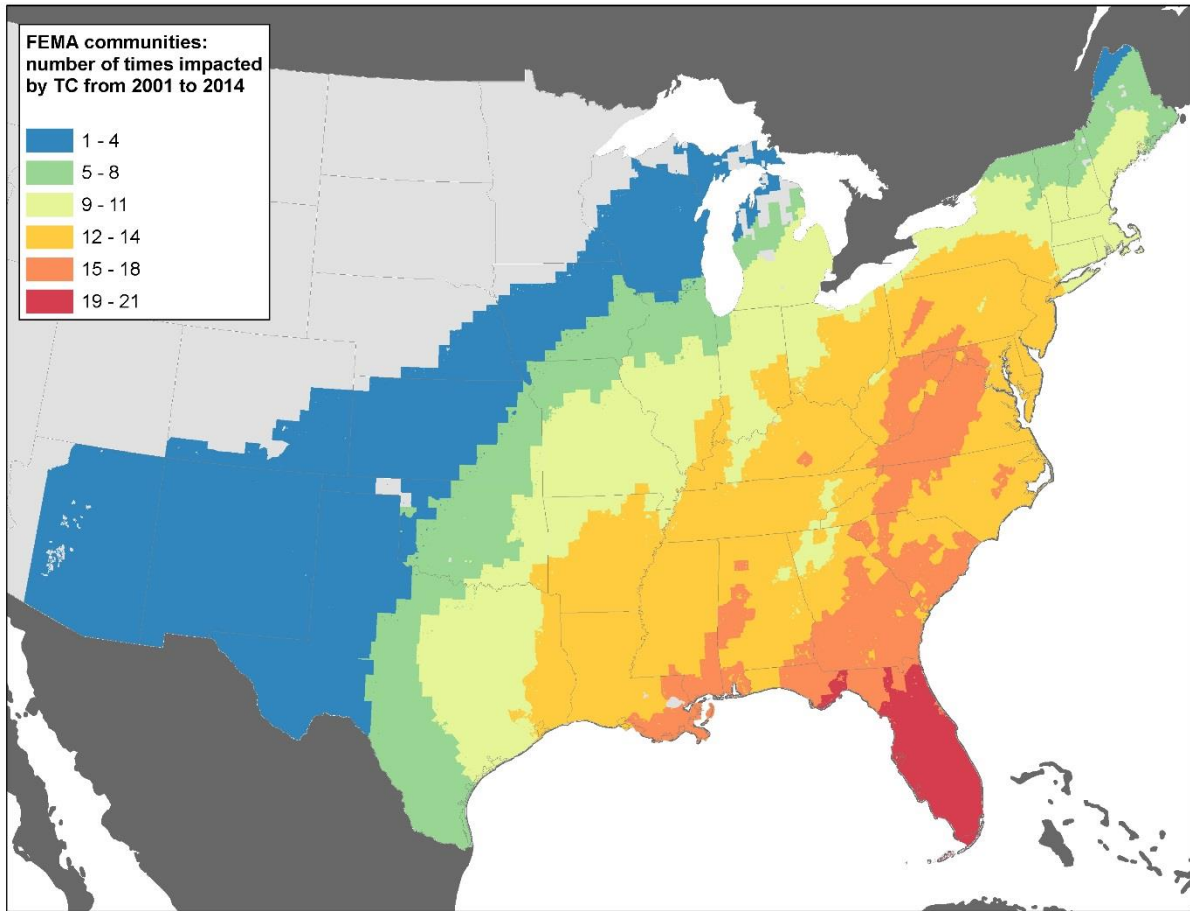
²Willis Research Network, 51 Lime Street, London EC3M 7DQ, UK

³IIHR-Hydrosience & Engineering, The University of Iowa, 100 C Maxwell3 Stanley Hydraulics Laboratory, Iowa City, IA 52242, USA

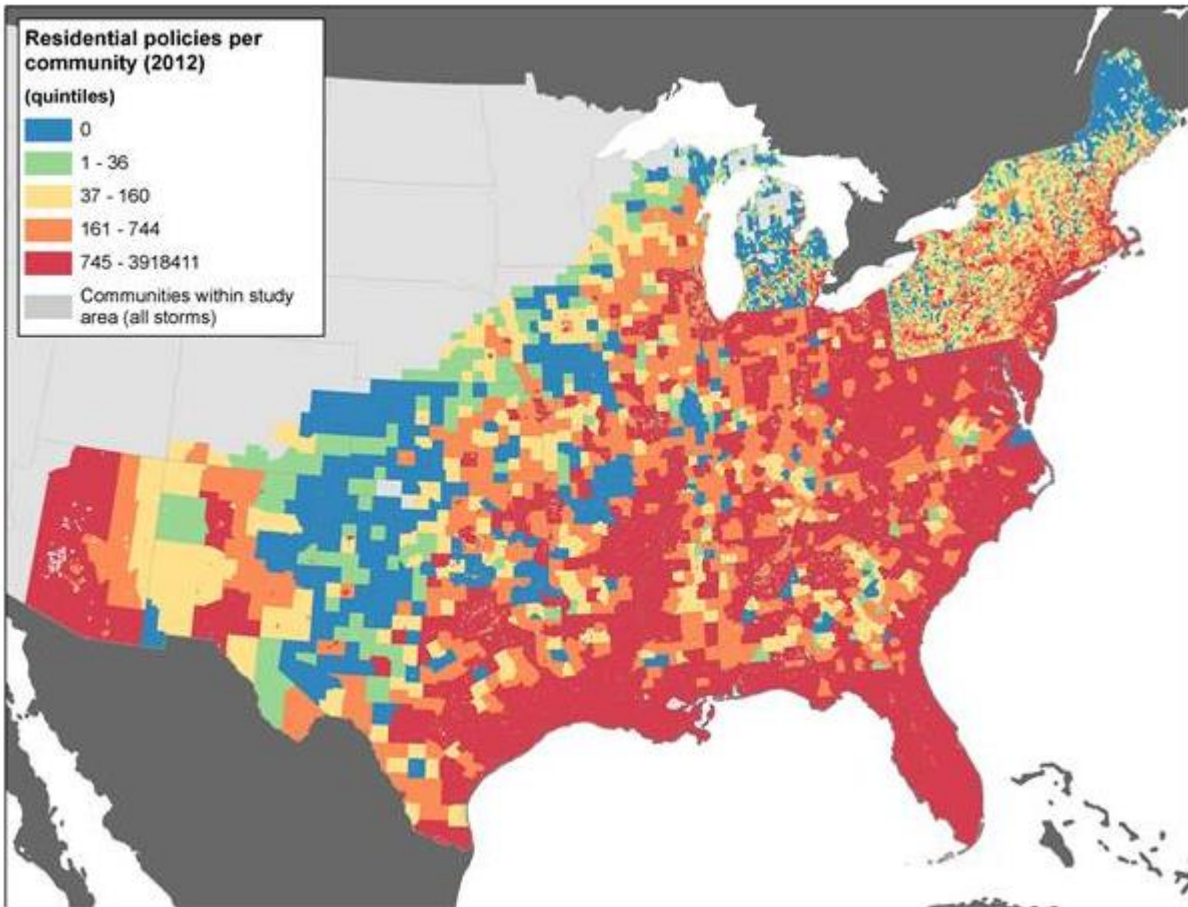
Corresponding author: Jeffrey Czajkowski, The Wharton School, University of Pennsylvania, Huntsman Hall, Suite 500, 3730 Walnut Street, Philadelphia, PA, 19104, USA; jczaj@wharton.upenn.edu; +(1) 215 898-8047



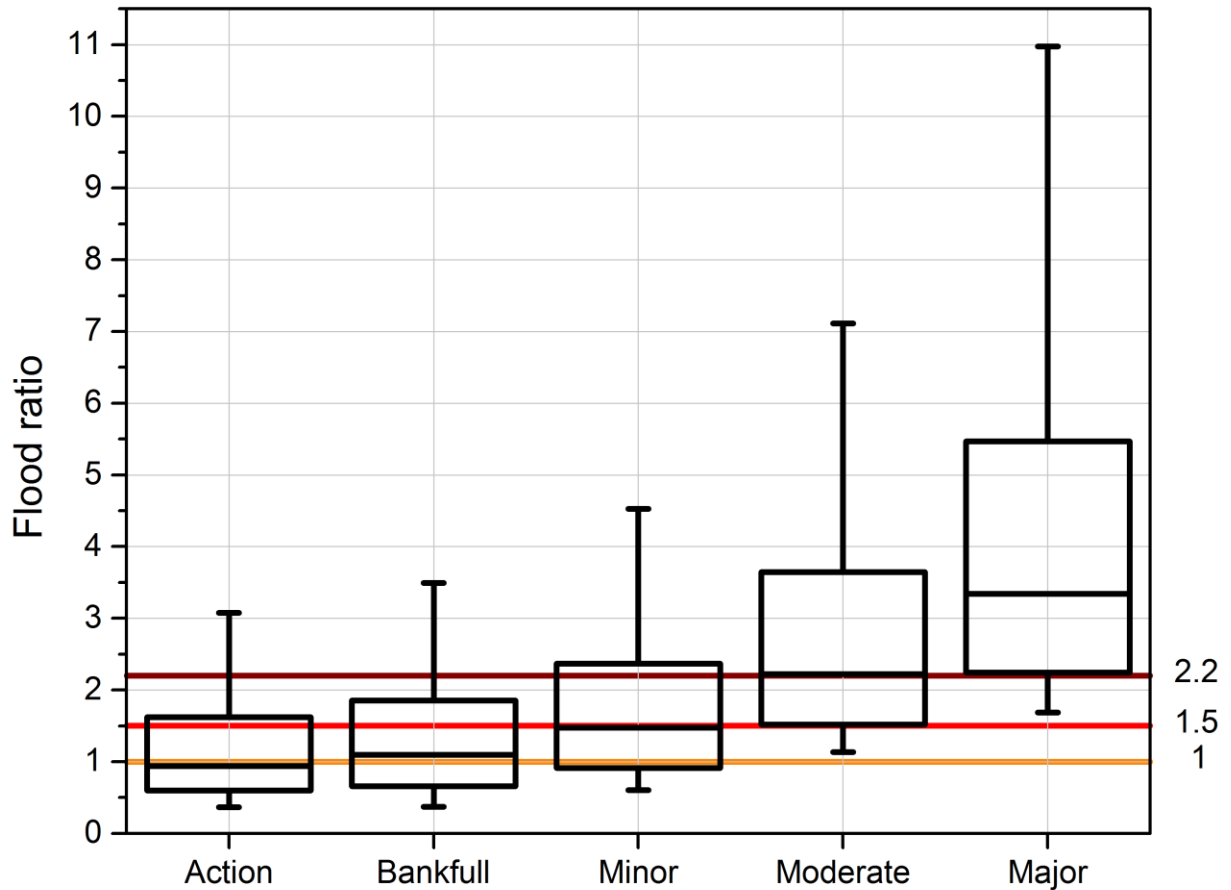
SUPPLEMENTARY FIGURE 1. Map showing the location of the 3035 U.S. Geological Survey (USGS) stream gages (blue circles) within 500 km of at least one the 28 tropical cyclones (TCs; red lines) considered in this study. Maps were created in ESRI ArcGIS version 10.2.2 (<http://www.esri.com/software/arcgis/arcgis-for-desktop>).



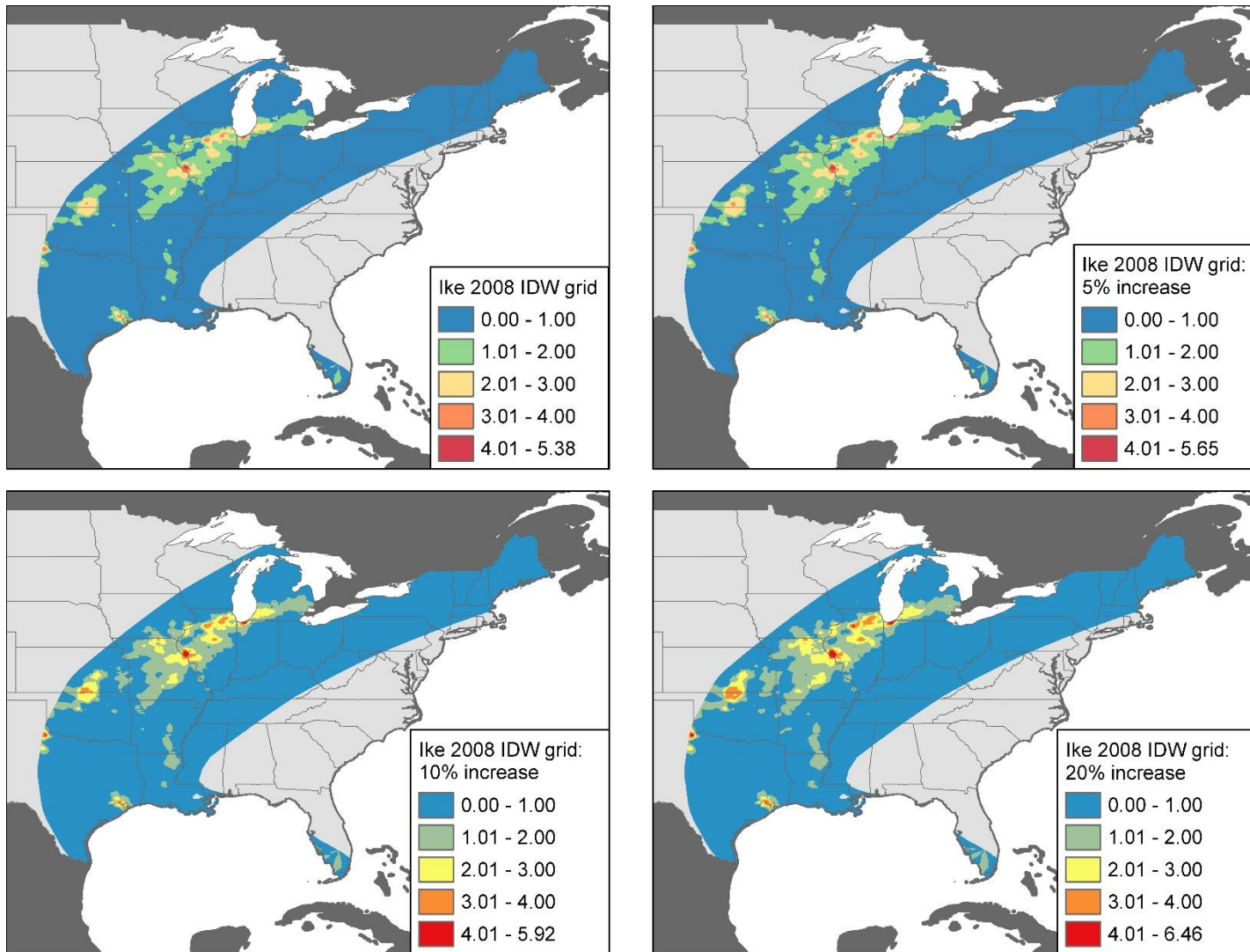
SUPPLEMENTARY FIGURE 2. FEMA's NFIP communities affected by TCs. This figure shows the number of times any one FEMA defined community was affected by any of the 28 TCs considered in this study. Maps were created in ESRI ArcGIS version 10.2.2 (<http://www.esri.com/software/arcgis/arcgis-for-desktop>).



SUPPLEMENTARY FIGURE 3. NFIP total residential flood insurance policies in-force per community as per 2012. Maps were created in ESRI ArcGIS version 10.2.2 (<http://www.esri.com/software/arcgis/arcgis-for-desktop>).



SUPPLEMENTARY FIGURE 4. Relating the flood ratio to flood status classification. This figure shows the relationship between flood ratio values and flood status classification according to the National Weather Service (Action, Bankfull, Minor, Moderate and Major Flooding) for all the stations in our domain. In each boxplot, the limits of the whiskers represent the 0.1-0.9 quantiles, the limits of the box the 0.25 and 0.75 quantiles, while the line in the middle of the box the median (0.5 quantile). The colored horizontal lines represent the limits of the three categories in which we have stratified the flood ratios: a flood ratio below 1 is for bankfull conditions; a flood ratio between 1 and 1.5 represents minor flooding conditions, while values between 1.5 and 2.2 and larger than 2.2 are indicative of moderate and major flooding, respectively.



SUPPLEMENTARY FIGURE 5. Increasing the observed Hurricane Ike TC flood ratios by 1, 5, 10, and 20 percent at every USGS location. Maps were created in ESRI ArcGIS version 10.2.2 (<http://www.esri.com/software/arcgis/arcgis-for-desktop>).

SUPPLEMENTARY TABLE 1. Summary of the 28 TCs considered in this study. The information about the radius at landfall is based on the Extended Best Track data.

#	Year	Storm	Wind speed at landfall (knots)	Category	Radius at landfall (nm)
1	2001	ALLISON	45	TS	120
2	2001	BARRY	60	TS	175
3	2001	GABRIELLE	60	TS	180
4	2002	ISIDORE	55	TS	360
5	2002	LILI	80	CAT1	200
6	2003	CLAUDETTE	80	CAT1	180
7	2003	ISABEL	90	CAT2	300
8	2004	ALEX*	85	CAT2	150
9	2004	CHARLEY	130	CAT4	100
10	2004	FRANCES	90	CAT2	200
11	2004	IVAN	105	CAT3	240
12	2004	JEANNE	105	CAT3	200
13	2005	DENNIS	105	CAT3	300
14	2005	KATRINA	110	CAT3	325 [#]
15	2005	OPHELIA**	75	CAT1	200
16	2005	RITA	100	CAT3	300
17	2005	WILMA	105	CAT3	300
18	2006	ALBERTO	40	TS	175
19	2006	ERNESTO	40	TS	125
20	2007	ERIN	30	TD	150
21	2008	DOLLY	75	CAT1	180
22	2008	FAY	55	TS	200
23	2008	GUSTAV	90	CAT2	232.5 [#]
24	2008	IKE	95	CAT2	325
25	2011	IRENE	75	CAT1	400
26	2012	DEBBY	65	CAT1	300
27	2012	ISAAC	70	CAT1	275
28	2012	SANDY	70	CAT1	512.5 [#]

* For Hurricane Alex we used the location off of the Carolinas Coast (2004/08/03, 1200) as the closest landfall point.

**For Hurricane Ophelia we used the location off of the Carolinas Coast (2005/09/14, 1800) rather than the landfall location in Florida

[#] Average value between two time steps.

SUPPLEMENTARY TABLE 2A. Statistical modeling of the number of SFHA freshwater flood insurance claims (329,301 total claims) using a zero-inflated negative binomial model. (SFHA: special flood hazard areas, defined by FEMA as high risk zones). Predictors are same as those in Table 1.

	Estimate	Robust Standard Error	[95% Confidence Intervals]
Minor flooding	0.950***	0.121	[0.713; 1.188]
Moderate flooding	1.478***	0.136	[1.212; 1.745]
Major flooding	2.322***	0.133	[2.062; 2.582]
LnResPol	0.920***	0.044	[0.833; 1.007]
LnHousing	-0.183***	0.041	[-0.265; -0.102]
PropLowRisk	-0.217	0.348	[-0.9; 0.465]
PropMedRisk	0.302	0.354	[-0.392; 0.997]
PropHighRisk	0.687**	0.342	[0.017; 1.358]
YrDummy2002	-0.654***	0.241	[-1.128; -0.182]
YrDummy2003	0.418	0.476	[-0.515; 1.352]
YrDummy2004	-3.851***	0.227	[-4.296; -3.406]
YrDummy2005	-3.035***	0.240	[-3.506; -2.564]
YrDummy2006	-2.735***	0.422	[-3.562; -1.909]
YrDummy2007	-3.158***	0.375	[-3.893; -2.423]
YrDummy2008	-1.454***	0.171	[-1.791; -1.118]
YrDummy2011	-1.181***	0.202	[-1.577; -0.786]
YrDummy2012	-0.037	0.212	[-0.452; 0.378]
TS	-2.529***	0.147	[-2.818; -2.241]
MajorHurr	2.164***	0.129	[1.911; 2.417]
CoastalState	-0.249***	0.089	[-0.424; -0.076]
Impervious	0.500**	0.207	[0.094; 0.906]
Miles25-100	-0.596***	0.102	[-0.796; -0.397]
Miles100-500	-0.523***	0.110	[-0.738; -0.309]
Miles500+	-1.304***	0.423	[-2.133; -0.476]
Intercept	-1.295***	0.415	[-2.109; -0.481]

Inflate	Estimate	Robust Standard Error	[95% Confidence Intervals]
MaxFR	-1.375***	0.033	[-1.439; -1.311]
LnResPol	-0.168***	0.011	[-0.191; -0.146]
Intercept	2.780***	0.071	[2.641; 2.919]

	Estimate	Robust Standard Error	[95% Confidence Intervals]
Ln(Dispersion α)	1.661***	0.041	[1.58; 1.742]
Dispersion α	5.264***	0.218	[4.854; 5.709]

SUPPLEMENTARY TABLE 2B. Statistical modeling of the number of Non-SFHA freshwater flood insurance claims (114,183 total claims) using a zero-inflated negative binomial model. (SFHA: special flood hazard areas, defined by FEMA as high risk zones). Predictors are same as those in Table 1.

	Estimate	Robust Standard Error	[95% Confidence Intervals]
Minor flooding	0.513***	0.114	[0.29; 0.736]
Moderate flooding	1.271***	0.125	[1.026; 1.517]
Major flooding	1.913***	0.127	[1.664; 2.162]
LnResPol	0.787***	0.041	[0.707; 0.868]
LnHousing	-0.047	0.038	[-0.122; 0.027]
PropLowRisk	-0.242	0.654	[-1.525; 1.039]
PropMedRisk	-0.229	0.658	[-1.519; 1.061]
PropHighRisk	0.484	0.655	[-0.8; 1.769]
YrDummy2002	-1.472***	0.195	[-1.855; -1.089]
YrDummy2003	-1.497***	0.256	[-2; -0.995]
YrDummy2004	-3.738***	0.212	[-4.153; -3.322]
YrDummy2005	-3.047***	0.246	[-3.528; -2.565]
YrDummy2006	-2.673***	0.437	[-3.529; -1.817]
YrDummy2007	-1.877***	0.301	[-2.467; -1.287]
YrDummy2008	-1.182***	0.170	[-1.516; -0.849]
YrDummy2011	-1.242***	0.195	[-1.625; -0.859]
YrDummy2012	-0.815***	0.197	[-1.203; -0.429]
TS	-1.878***	0.158	[-2.187; -1.568]
MajorHurr	2.086***	0.119	[1.853; 2.32]
CoastalState	0.244***	0.076	[0.095; 0.393]
Impervious	0.881***	0.186	[0.518; 1.246]
Miles25-100	-0.330***	0.078	[-0.484; -0.178]
Miles100-500	-0.526***	0.095	[-0.714; -0.34]
Miles500+	-1.788***	0.407	[-2.586; -0.99]
Intercept	-2.473***	0.702	[-3.849; -1.096]

Inflate	Estimate	Robust Standard Error	[95% Confidence Intervals]
MaxFR	-1.300***	0.036	[-1.371; -1.229]
LnResPol	-0.066***	0.010	[-0.087; -0.046]
Intercept	2.215***	0.080	[2.059; 2.372]

	Estimate	Robust Standard Error	[95% Confidence Intervals]
Ln(Dispersion α)	1.366***	0.042	[1.284; 1.447]
Dispersion α	3.918***	0.163	[3.612; 4.251]

SUPPLEMENTARY TABLE 2C. Statistical modeling of the number of freshwater flood insurance claims for Single-Family residential properties only (374,306 total claims) using a zero-inflated negative binomial model. Predictors are same as those in Table 1.

	Estimate	Robust Standard Error	[95% Confidence Intervals]
Minor flooding	0.886***	0.103	[0.685; 1.088]
Moderate flooding	1.545***	0.118	[1.313; 1.777]
Major flooding	2.473***	0.123	[2.231; 2.714]
LnResPol	0.885***	0.046	[0.796; 0.975]
LnHousing	-0.145***	0.043	[-0.23; -0.062]
PropLowRisk	-0.239	0.353	[-0.931; 0.453]
PropMedRisk	0.035	0.357	[-0.664; 0.736]
PropHighRisk	0.530	0.348	[-0.151; 1.212]
YrDummy2002	-1.138***	0.195	[-1.52; -0.756]
YrDummy2003	-0.388	0.365	[-1.103; 0.326]
YrDummy2004	-4.090***	0.210	[-4.502; -3.679]
YrDummy2005	-3.363***	0.219	[-3.792; -2.934]
YrDummy2006	-2.854***	0.316	[-3.473; -2.235]
YrDummy2007	-2.415***	0.302	[-3.007; -1.823]
YrDummy2008	-1.426***	0.169	[-1.757; -1.095]
YrDummy2011	-1.391***	0.190	[-1.762; -1.019]
YrDummy2012	-.4757**	0.193	[-0.855; -0.097]
TS	-2.409***	0.146	[-2.696; -2.123]
MajorHurr	2.306***	0.114	[2.083; 2.529]
CoastalState	0.018	0.081	[-0.14; 0.178]
Impervious	0.369**	0.182	[0.012; 0.726]
Miles25-100	-0.569***	0.096	[-0.758; -0.381]
Miles100-500	-0.6436***	0.102	[-0.844; -0.444]
Miles500+	-1.384***	0.374	[-2.116; -0.651]
Intercept	-1.144***	0.414	[-1.954; -0.333]

Inflate	Estimate	Robust Standard Error	[95% Confidence Intervals]
MaxFR	-1.437***	0.032	[-1.501; -1.373]
LnResPol	-0.119***	0.010	[-0.140; -0.100]
Intercept	2.432***	0.065	[2.304; 2.559]

	Estimate	Robust Standard Error	[95% Confidence Intervals]
Ln(Dispersion α)	1.515***	0.041	[1.434; 1.597]
Dispersion α	4.551***	0.189	[4.196; 4.936]

SUPPLEMENTARY TABLE 3. Cross Validation Goodness-of-Fit Pseudo R Squared Statistics

<u>(k-1) Training</u> <u>Estimate</u>	<u>k=20</u>	<u>k=30</u>
est1	0.04	0.01
est2	0.10	0.01
est3	0.15	0.01
est4	0.07	0.09
est5	0.06	0.03
est6	0.10	0.02
est7	0.02	0.07
est8	0.09	0.39
est9	0.02	0.03
est10	0.06	0.04
est11	0.20	0.30
est12	0.13	0.26
est13	0.01	0.10
est14	0.04	0.34
est15	0.00	0.14
est16	0.01	0.02
est17	0.02	0.52
est18	0.02	0.01
est19	0.23	0.02
est20	0.02	0.15
est21		0.43
est22		0.06
est23		0.01
est24		0.45
est25		0.05
est26		0.04
est27		0.02
est28		0.03
est29		0.05
est30		0.02
mean pseudo-R2	0.07	0.13