



Supplement of

Combining hazard, exposure and vulnerability data to predict historical United States hurricane losses

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Risk Variable	Acronym	Description	Reference
Historical Loss	NOAA Billion Dollar Loss Record	Historical hurricane loss estimates collected by NOAA	NOAA (2025)
	EMDAT Loss History	Historical hurricane loss estimates collected by EMDAT	Delforge et al. (2025)
	Muller et al. (2025)	Historical hurricane loss estimates collected by Muller et al.	Muller et al. (2025)
	Grinsted et al. (2025)	Historical hurricane loss estimates collected by Grinsted et al.	Grinsted et al. (2025)
	Weinkle et al. (2025)	Historical hurricane loss estimates collected by Weinkle et al.	Weinkle et al. (2025)
Hazard	IBTrACS	International Best Track Archive for Climate Stewardship (IBTrACS) project global tropical cyclones data collection	Gahtan et al. (2025)
	HURDAT	NOAA Hurricane Research Division detailed List of Continental United States Hurricane Impacts/Landfalls	Hurricane Research Division. (2025)
	NOAA Rainfall	Tropical cyclone rainfall footprint figures, indicating maximum rainfall accumulation	NOAA (2025b)
	MSWEP Rainfall	Sub-daily precipitation dataset with full global coverage at 0.1° resolution	Beck et al. (2019)
	ERA5 Storm Surge	Global gridded time series of global sea level related variables including tides, storm surges and sea level rise from 1950 to 2050 based on hydrodynamic modelling	Copernicus Climate Change Service (2022)
	Gori et al. (2023) (<i>Size & Storm Surge Reconstructions</i>)	Reconstructed TC sizes for North Atlantic storms from 1950-present using reanalysis data and a physics-based TC wind model	Gori et al. (2023)
Exposure	GHSL: Building Density	Global gridded dataset of the distribution of built-up surface area	Pesaresi and Politis (2023)
	WorldPOP (Population Density)	Global gridded dataset of the distribution of population	WorldPOP (2018)
	ACS: Housing Unit Density	2019-2023 data from the American Community Survey (ACS) about housing units by year built by tenure	U.S. Census Bureau (2024)
	LitPOP: Exposure Value	Global gridded dataset developed by ETH Zurich to estimate the economic value of assets	Eberenz et al. (2020)
	FEMA: Exposure Value	FEMA National Risk Index is an online mapping tool that identifies U.S. communities most at risk from natural hazards, including data on exposure value per USA county	FEMA (2024)
Vulnerability	GDP	USA State Gross Domestic Product	U.S. Bureau of Economic Analysis (2025)
	ACS: Mean Building Year	2019-2023 data from the American Community Survey (ACS) about housing units by year built by tenure	U.S. Census Bureau (2024)
	FEMA: Historical Loss Ratio (HLR)	FEMA National Risk Index is an online mapping tool that identifies U.S. communities most at risk from natural hazards, including data on historical loss ratios per USA county	FEMA (2024)
	FEMA: Risk Value	FEMA National Risk Index is an online mapping tool that identifies U.S. communities most at risk from natural hazards, including data on risk score based on social vulnerability and community resilience per USA county	FEMA (2024)
	FEMA: Building Resilience	FEMA's Building Code Adoption Tracking (BCAT) System	FEMA (2025)
	Mean Damageability: Emanuel (2021) Vulnerability	Wind-damage function equation that produces positive values only for winds speeds more than a specified threshold	Emanuel (2021)
Exposure & Vulnerability	LitPOP Damaged	LitPOP gridded exposure value multiplied by % damage coefficients derived from Emanuel (2021), given hurricane characteristics	NA
	GHSL Damaged	GHSL gridded building density value multiplied by % damage coefficients derived from Emanuel (2021), given hurricane characteristics	NA

Table S1. Descriptions and references for all hurricane loss, hazard, exposure and vulnerability datasets used in this study.

Hurricane Katrina (2005)
Max. Storm Surge Residual +/- 24 hours
within 500km of Storm Centre (29/08/2005 12UTC)

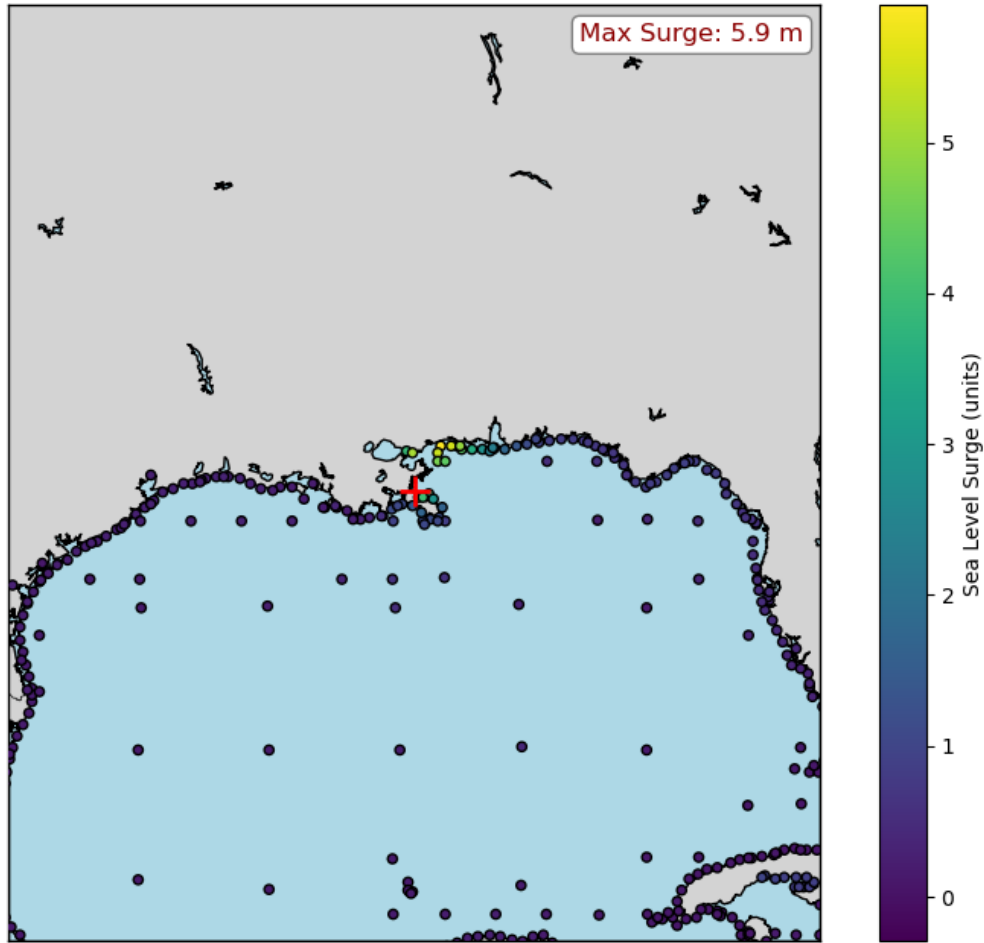


Figure S1. Example ERA5-derived storm surge residual reconstruction for Hurricane Katrina (2005), which made landfall on the 28th August 2005, defined as maxima within 500km of the cyclone centre and ± 24 hours of landfall. Unit is metres above reference height.

AL122005 (2005_KATRINA) (MSWEP)

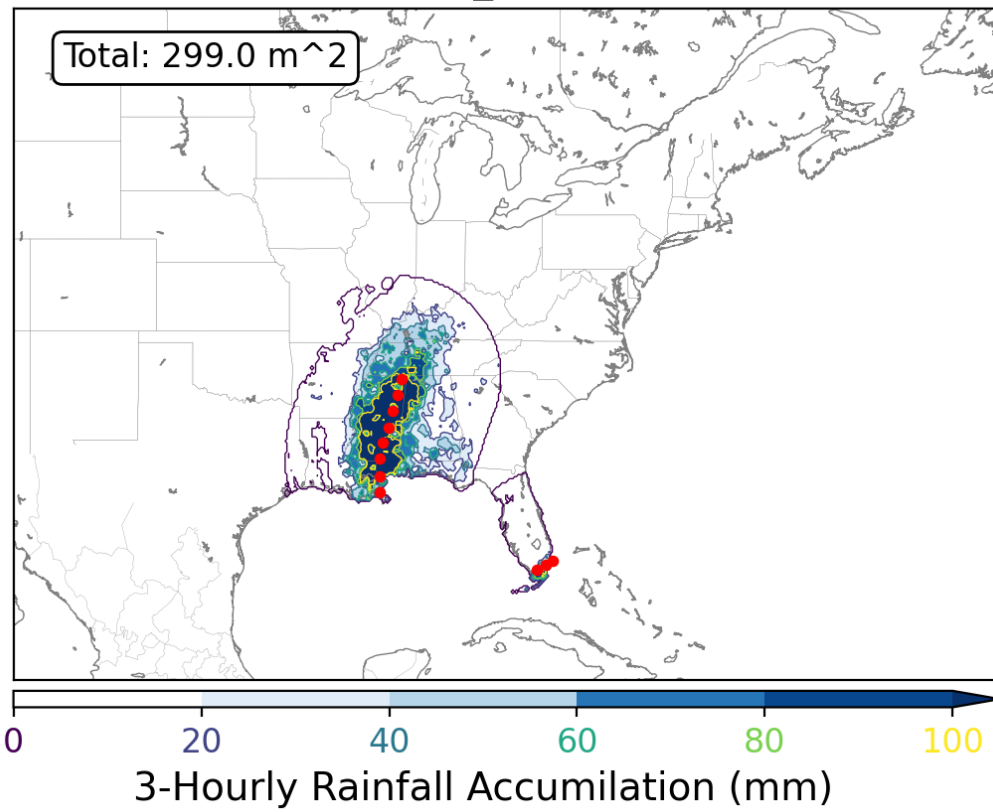


Figure S2. Example rainfall footprint for Hurricane Katrina (2005), determined by accumulating three-hourly MSWEP data along the track following landfall.

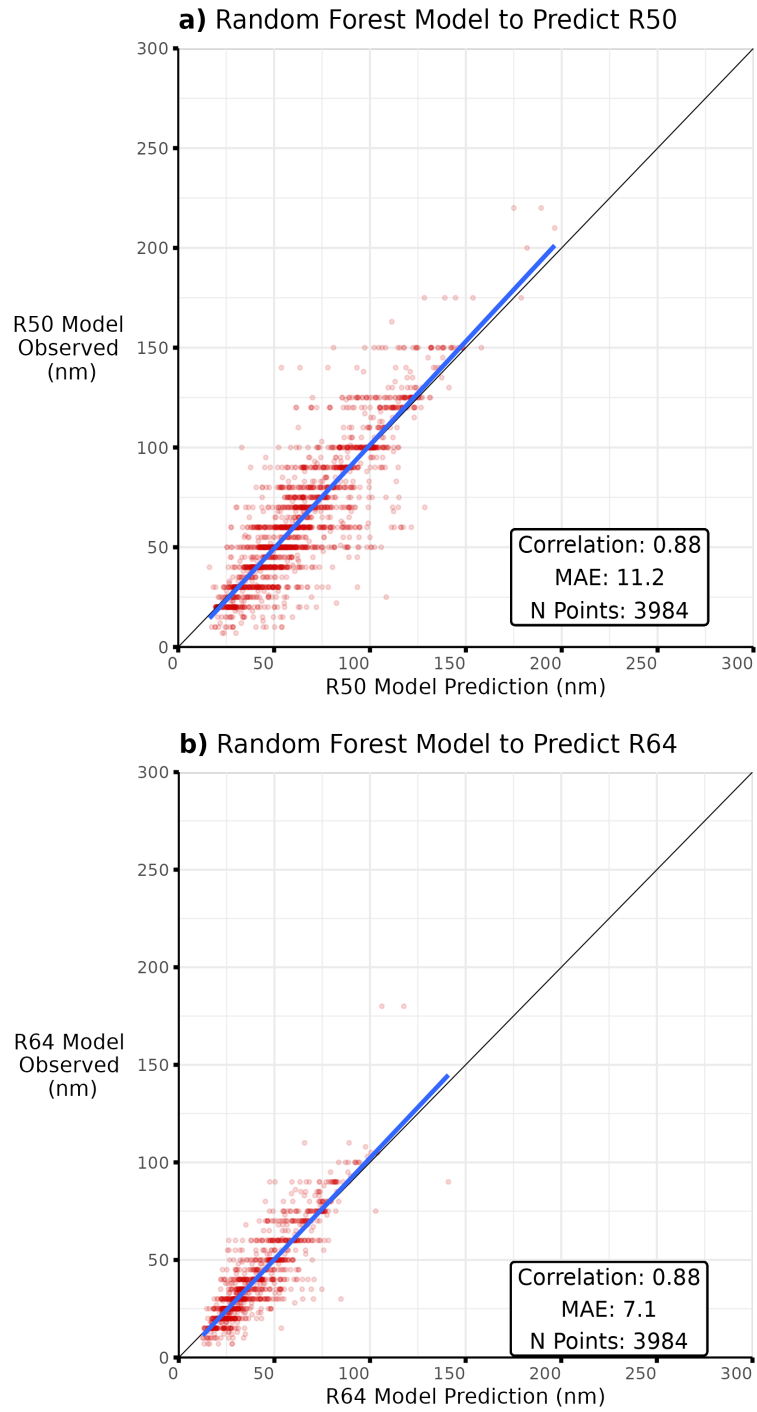


Figure S3. Comparison of estimated and observed hurricane **a) R50** and **b) R64** from 1979–2023, using a random forest statistical model based on v_{\max} , RMW, c_p and latitude as predictors.

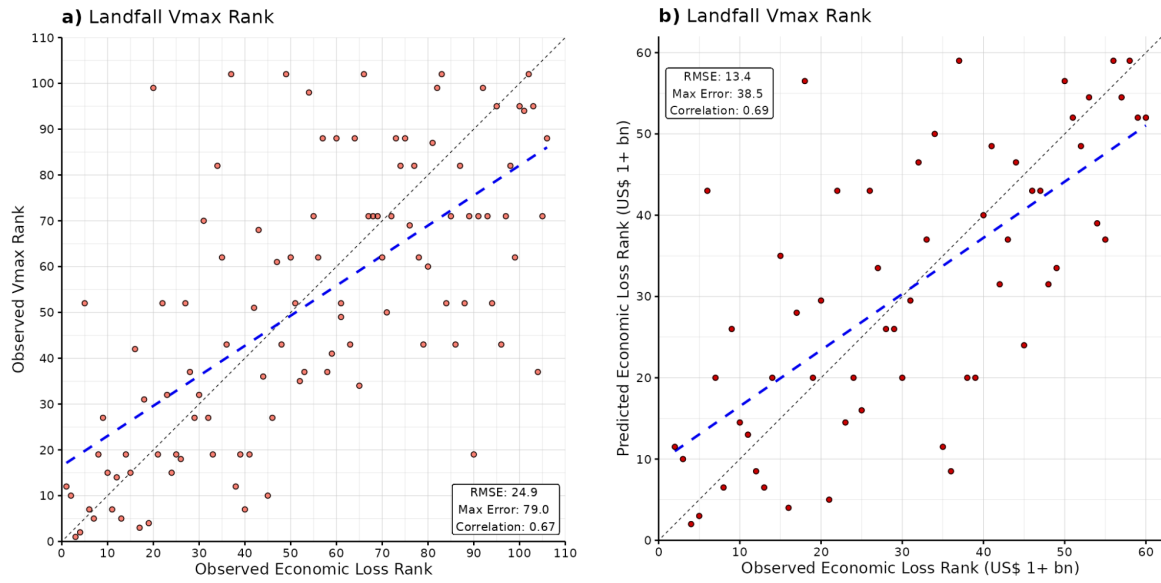


Figure S4. Leave-one-out evaluation using a generalised linear-prediction model to predict historical hurricane loss rank using landfall v_{max} for a) all hurricanes for which all landfall variables could be derived ($n = 106$) and b) hurricanes that caused $\geq \$1$ bn normalised economic damage ($n = 60$). Rank 1 denotes the most intense hurricane at landfall and the highest normalised loss.

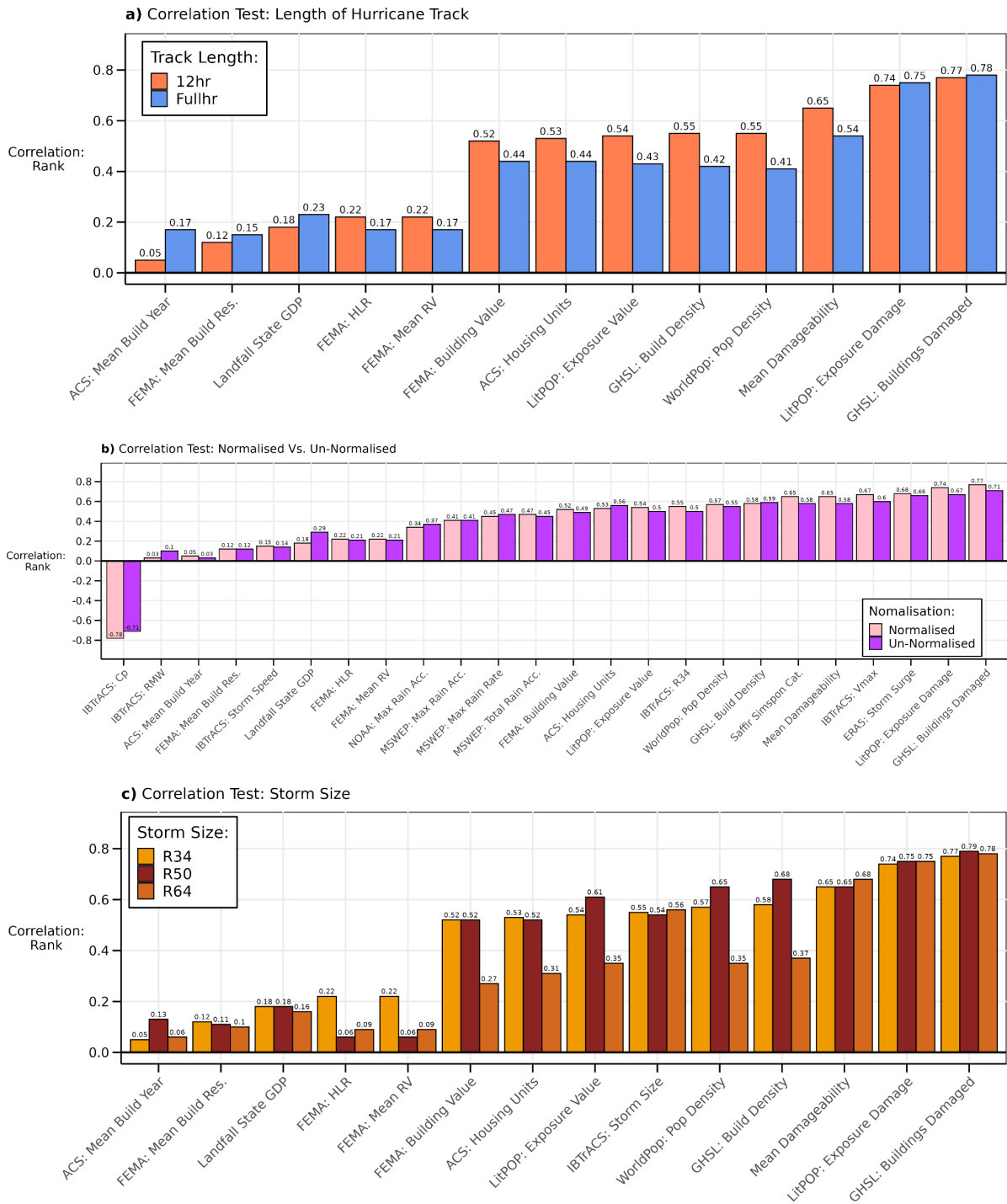


Figure S5. Uncertainty in Spearman coefficient for correlation with economic loss estimates when (a) different track lengths are used to calculate exposure and vulnerability footprints (using 12 hours post-landfall versus the full track), (b) using un-normalised and normalised economic loss, and (c) using R34, R50 and R64 to define the hurricane exposure and vulnerability impact footprint radii. If un-normalised, past building density, population density and housing unit footprint data are used; if normalised, present-day building density, population density and housing unit footprint data are used for all historical storms.

Saffir–Simpson category	Percentage of historical U.S. landfalling hurricanes	Saffir–Simson scale v_{max} threshold (kts)	c_p threshold (hPa)	Loss (U.S.\$ bn)
Cat 1	55.4%	<64	<962.0	<5.3
Cat 2	25.6%	64 - 83	962.0 - 946.4	5.3 - 24.9
Cat 3	9.2%	83 - 96	946.4 - 937.8	24.9 - 48.2
Cat 4	9.2%	96 - 114	937.8 - 923.3	48.2 - 150.7
Cat 5	1.5%	114 - 136	923.3+	150.7+

Table S2. Historical U.S. landfalling hurricanes (1979–2023) per Saffir–Simpson category and the thresholds in landfalling c_p and loss rank required to reclassify historical hurricanes in our HLPS scale, maintaining the same proportions of events per category.