Addressing Tropical Cyclone Impact Uncertainty through Multi-Model Damage Ratio Estimates

Sean S. Miller

Kinetic Analysis Corporation

Introduction

The winds, waves and rain associated with a tropical cyclone are included in most tropical cyclone forecasts; however, the damage to homes and businesses, as well as the loss of life, caused by these hazards often are of greater interest to people, insurers and emergency managers.

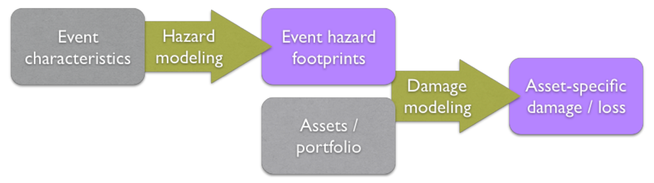
Estimating the damage and loss caused by a tropical cyclone requires three types of information: 1) the spatial variation in hazard intensity (for example, the wind speed and/or depth of inundation from coastal flooding), 2) the location and relevant attributes of each asset or insured property and, 3) damage functions that quantify the damage to each asset as a function of hazard intensity.

Kinetic Analysis Corporation (Kinanco) translates tropical cyclone forecasts into detailed, actionable data that quantifies the expected experience of the event on the ground, from direct hazards through higher-level, asset-specific impacts and consequences.

Our modeling platform supports a multi-model approach to better understand the range of reasonable results associated with forecast uncertainties. We produce a range of damage estimates based on forecasts from multiple agencies and families of damage functions to provide users a better understanding of the potential range of hazard intensities and their resultant impacts.

Damage Modeling Background

Kinanco's damage modeling translates tropical cyclone (TC) hazard information into operational intelligence specific to the assets and asset types affected by the event, based on the extent and severity of winds and waves at the location of the asset. Estimates of damage to a structure, its contents and recovery time are based on the performance of a structure (categorized in as an asset class) in response to hazard forces.



Key Points:

- Relative to hazard intensity, damage levels are *discontinuous and non-linear.* At low intensities, hazards generally cause no damage, but once a lower threshold has been exceeded, damage rates rise at a much faster rate than the increase in hazard intensity.
- *Different building types can sustain different damages at the same hazard intensity.* Wood-framed buildings, for instance, will generally sustain higher damages than masonry buildings at the same wind speeds.
- *Relative resilience of different building types varies by hazard.* For instance, in contrast to their performance under wind loads, wood-framed buildings are generally more resilient during earthquakes than are masonry buildings.
- *Many events generate multiple perils, each of which (individually and in combination) contributes to damage potential.* In tropical cyclones, surges and waves generally affect a smaller geographic area but are the most destructive hazards when present, while impacts of rainfall are generally only an issue once buildings have already been damaged by other perils.

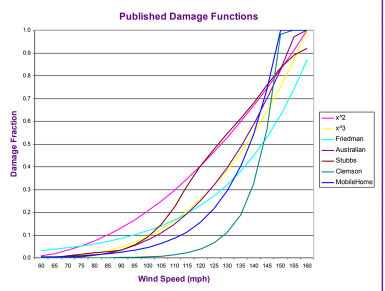
Wind Damage Functions.

Wind damage functions implemented in the damage modeling platform range from functions based on damage surveys and claims to those based on engineering judgment and theory. All functions have been normalized to generate compatible outputs. The damage function families used for calculating structural damage are discussed in a peer reviewed article by Watson and Johnson (2004) as seen below in Table 1.

Table 1. Damage ratio families

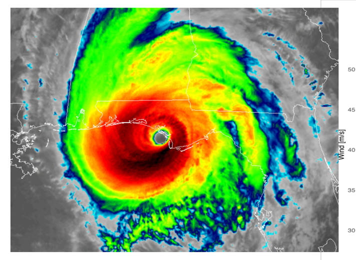
Family	Approach	Reference
Australian	Damage surveys	Leicester and Beresford, 1978
Foremost	Claims	Foremost Insurance Company, 1996
Friedman	Claims	Friedman, 1984
ProTeam	Expert judgement	FCHLPM, 2002
RTFS*	Expert judgement	Howard et al., 1972
Sill	Claims, expert judgement	Sill et al., 1997
Spark	Claims	Rosowsky et al., 1999
Stubb	Theory, expert judgement	Stubbs, 1996

* This is the default damage function family used by Kinanco.

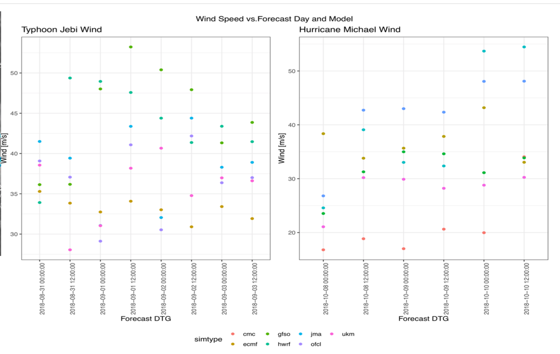


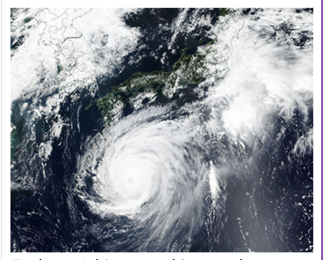
Hazard Modeling Component: Hurricane Michael and Typhoon Jebi

Given the nonlinearity in damage functions, damage estimates are highly dependent upon the extent and severity of TC hazards. Forecast uncertainty plays a greater role in the range of damage estimates for pre-landfall forecasts than uncertainty in damage modeling. To illustrate the magnitude of forecast uncertainty we show below simulated TC winds for Hurricane Michael and Typhoon Jebi that are based on forecasts available from a variety of sources. The winds are modeled using Kinanco's real-time forecasting system (RTFS) and forecast track inputs from either meteorological forecasting centers or Numerical Weather Prediction models. Simulations were configured to run at a 30 arc second resolution, approximately equivalent to a 1km horizontal grid cell.



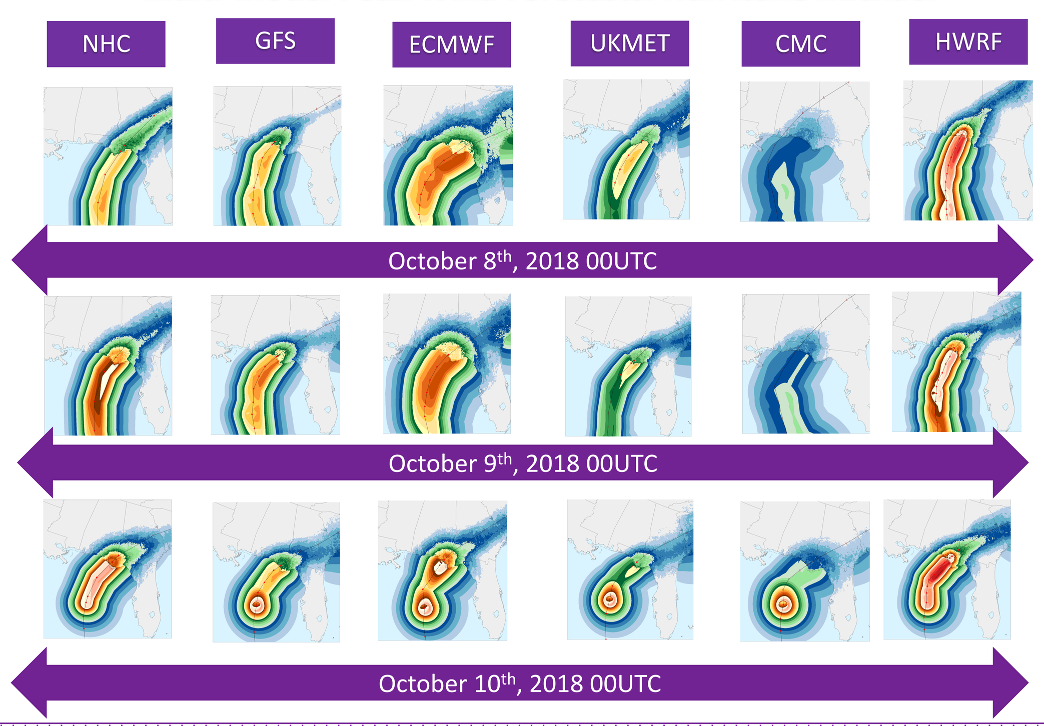
Hurricane Michael making landfall near Mexico City Beach, FL on Oct. 10th, 2018 (NOAA)



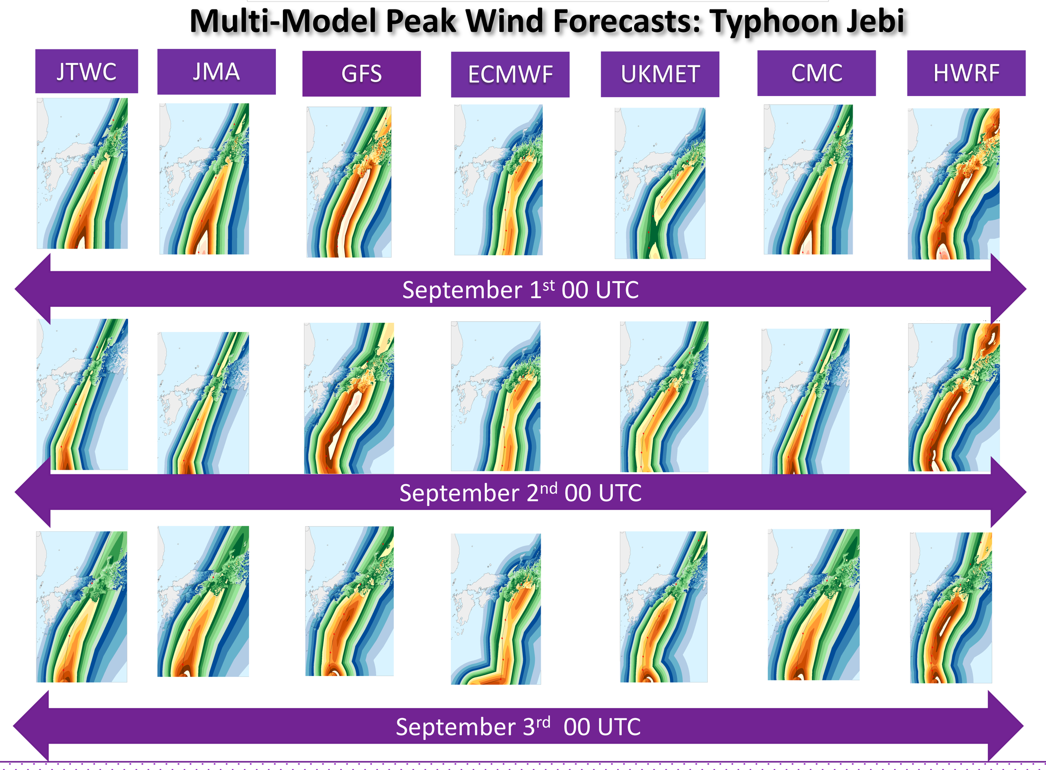


Typhoon Jebi approaching southern Japan on Sept. 3rd, 2018 (NASA/NOAA)

Multi-Model Peak Wind Forecasts: Hurricane Michael



Multi-Model Peak Wind Forecasts: Typhoon Jebi



Damage Modeling Component: Structural Damage Ratio Ensembles

Below we show boxplots for two asset-classes at georeferenced point locations. The damage ratio values update by forecast period as the simulated hazards evolve based on the input model event characteristics. The boxes show the interquartile range of the structural damage ratios for the eight families of damage functions at each forecast day and time based on the winds, waves and surges computed using official forecasts, or forecasts from other forecast centers (e.g., NHC/JTWC OFCL, GFS, UKMet, ECMWF, HWRF). The geographic location of the assets overlaid on the full storm (post-event) wind hazards are depicted in the following discussion section.

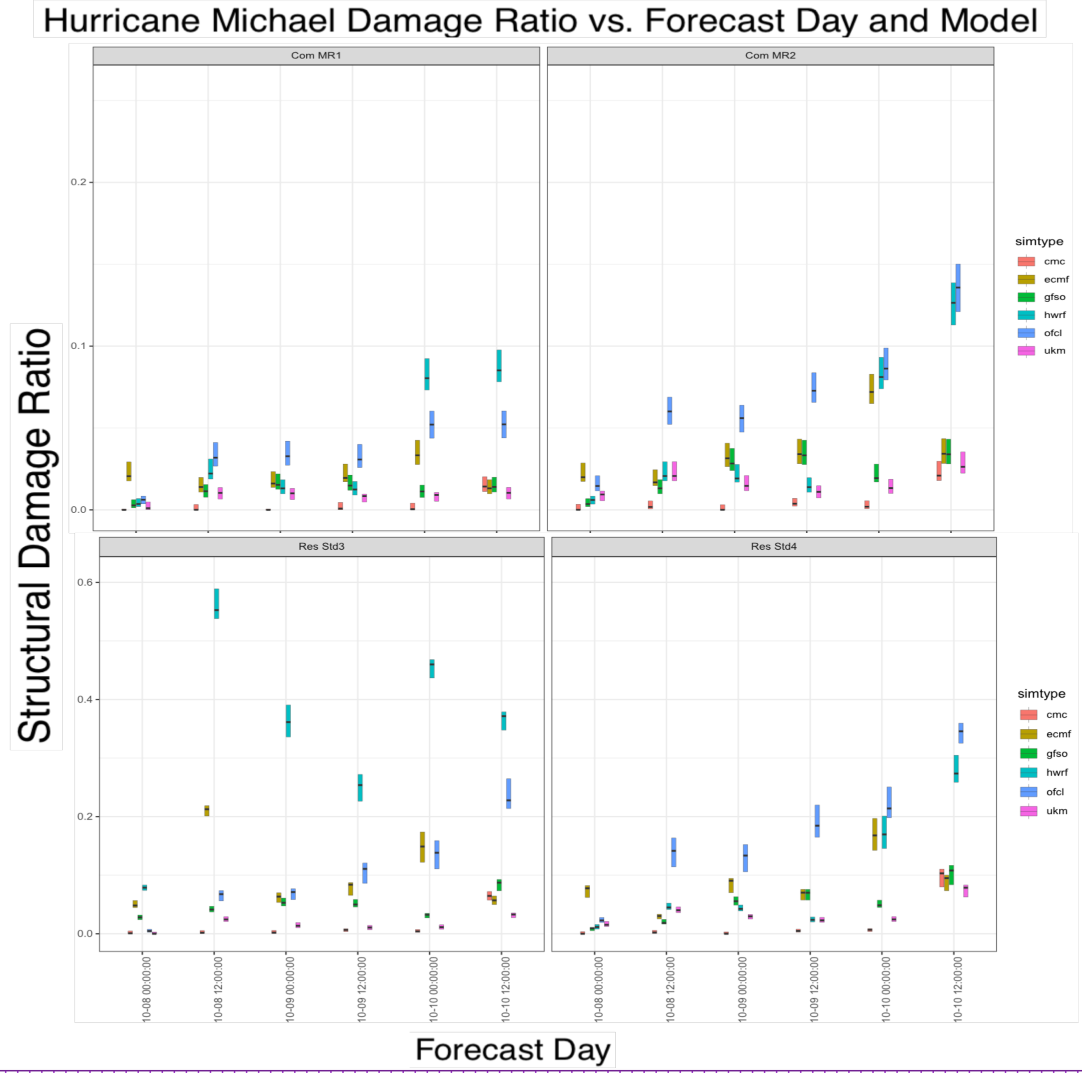
Note that the interquartile range of the forecast damage ratio is less than associated with the evolution of the forecast over time or among the different forecast sources.

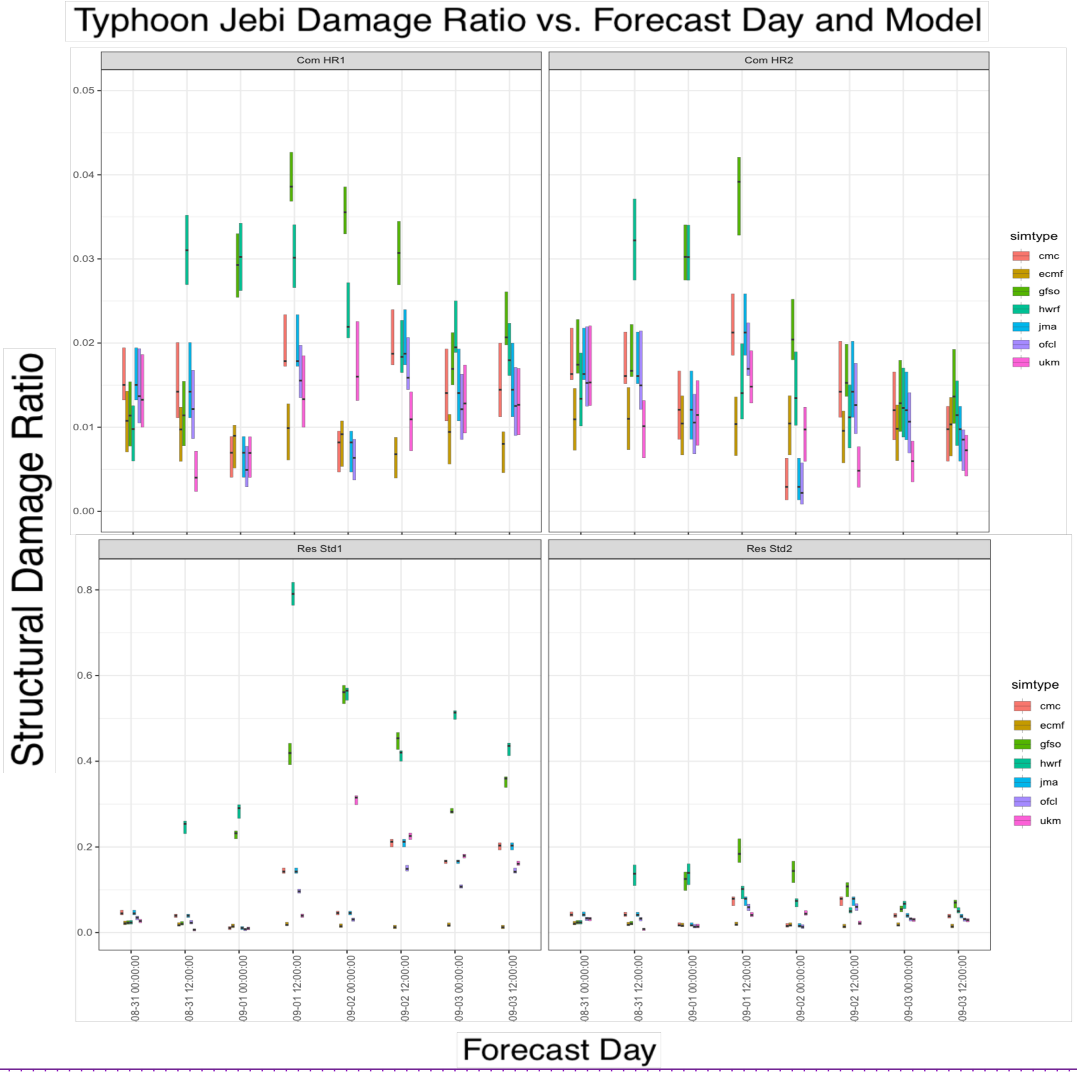
Hurricane Michael structural building damage estimates were produced for two locations and the following asset classes:

1. Standard Residential Wood Frame (Res Std3 and Res Std4)
2. Mid-rise (3-5 stories) Office/Commercial/Institutional (Com MR1 and ComMR2)

Typhoon Jebi structural building damage estimates were produced for to locations and the following asset classes:

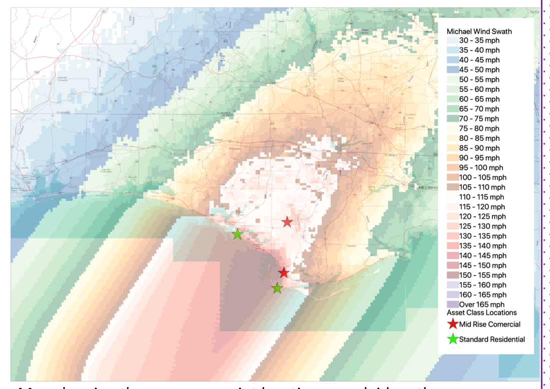
1. Standard Residential Wood Frame (Res Std1 and Res Std2)
2. High-rise (>5 stories) Office/Commercial/Institutional (Com HR1 and Com HR2)



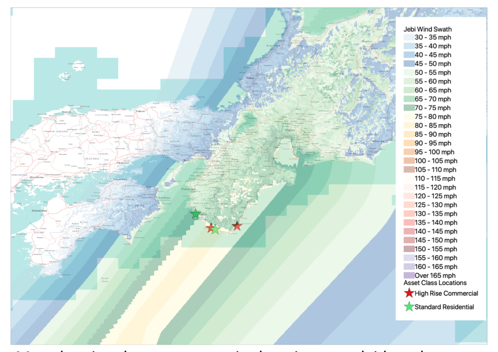


Discussion

In general, the damage ratio spread for Hurricane Michael increased as forecast lead time shortened, due to the fact that most models/forecasts poorly handled the rapid intensification of the system as it approached the Florida Panhandle. Models with a known high wind speed bias, such as HWRF, also translate to higher damage ratios values in the upper range across all forecasts. Global models that are generally good for long-lead track forecasting, but poorly resolve intensity show a low bias in the ensemble box plots. There is not a great amount of difference in the spread in the ensemble damage box plots for the exposure points for each of the asset classes, mostly since they are clustered band of most intense winds, though the coastal exposure points have the added impact of storm surge.



Map showing the exposure point locations overlaid on the RTFS-TC model generated post-storm wind field footprint for Hurricane Michael (Official NHC track initialization).



Map showing the exposure point locations overlaid on the RTFS-TC model generated post-storm wind field footprint for Typhoon Jebi (JTWC track initialization).

For Typhoon Jebi, there was a decrease in the damage ratio values as the forecast lead time shortened, since intensity estimates generally decreased as the system moved toward the landfall point in the southern Japanese Prefecture of Wakayama. The standard residential construction asset exposure point to the left (west) of the main swath of highest intensity winds when linked with the damage ratio ensemble values, illustrate that small changes in wind speed have a large impact on modeled damages due to the nonlinearity in damage functions.

Conclusions and Future Directions

The average structural damage ratios values are heavily influenced by the variation in hazards produced by the different input model and sources used to initialize the TC hazard modeling component of Kinanco's Real-Time Forecasting System (RTFS)for tropical cyclones.

Simulated damage ratios are of great value to external users who want to know the damage that might be inflicted on pre-defined asset classes without having to compromise the confidentiality of their proprietary portfolio.

The damage ratio figures illustrate the spread in the damage ratio values is a function of the variation in forecast over time and the forecast source used for the RTFS simulation.

Future work would explore how the use of the damage ratio ensemble estimates can be applied to a specific portfolios to better assess assets at risk.

Contact Information

Sean Miller
Kinetic Analysis Corporation
Email: smiller@kinanco.com
Website: www.kinanco.com
Phone: +1 (240) 821-1202

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Acknowledgements

Charles Watson Jr. of Enki Holdings, LLC
Rick Murnane, EVP and Deputy CEO, Kinetic Analysis Corporation
Steven Stichter, CEO of Kinetic Analysis Corporation