



Satellite image courtesy of NASA

# Hurricane Ike Meteorological Assessment and Damage Survey September 2008

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CONSULTING INC.

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## Executive Summary

From the genesis of Hurricane Ike in the Atlantic Ocean, through the aftermath of its landfall near Houston, Texas, the WeatherPredict Consulting science team worked around the clock to forecast, monitor, and evaluate the impact of the storm. This report summarizes our assessment of the impact of Ike on insurance industry exposures, as well as the conclusions drawn from our observations on the ground.

The devastation Hurricane Ike inflicted on the Houston Metropolitan Region was significant, with particularly severe losses in Galveston and its neighboring coastal communities. Wind speeds experienced in urbanized sections of Houston were less than hurricane strength, which is

corroborated by our field observations of high occurrences of low-to-moderate damage severity of residential structures. Reports of residential and commercial damage reveal some interesting aspects of this disaster. In particular:

- Older neighborhoods with established tree canopies suffered far less damage than newer neighborhoods with immature landscaping.
- The damage to large commercial buildings in downtown Houston of these types of structures indicates that overall, the damage was less than that observed when Wilma struck urbanized parts of South Florida in 2005.



Satellite image courtesy of NASA

- Galveston in particular was impacted by severe storm surge. However, actual flood levels were significantly below those initially anticipated from forecasts.

## Hurricane Ike at a Glance

- **Category 2 at Landfall**
- **Peak gusts of 110 knots**
- **Storm surge of 15 Feet**

A number of positive developments during Ike's landfall substantially reduced the wind damage on commercial and residential structures. These included: 1) the formation of an eye in the last 8-12 hours that helped to concentrate winds to the eastern side of the storm and spare metro Houston from significant downburst-type wind damage; 2) a landfall location that was further to the northeast than anticipated, keeping the strongest winds eastward of major concentrations of exposure; and 3) weaker intensity (Cat 2) at landfall than feared.

## Hurricane Ike Prior to Landfall

The formation of Ike as a tropical depression on September 1<sup>st</sup> set into motion the real-time monitoring and forecasting capabilities of our team of meteorologists and oceanographers. Operating out of our North Carolina and Rhode Island offices, we provided guidance around the clock, using both SuperEnsemble™ technology and proprietary WeatherPredict Numerical Weather Prediction (NWP) models, to forecast Ike's track and intensity up to five days ahead.

Ike was a long-lived hurricane, lasting nearly 10 days, and it followed a trajectory typical of storms originating in the Cape Verde region. Favorable upper-level atmospheric conditions led to steady intensification as Ike proceeded westward. Ike became a major hurricane as it approached the Caribbean, and impacted the southeastern Bahamas and eastern Cuba as a Category 4 storm.

A long and devastating traverse of Cuba weakened Ike from a Category 4 to a minimal Category 1 hurricane. In an unusual development, the extent of Ike's tropical storm and hurricane force winds continued to grow during its passage across

## The extraordinary breadth of Ike created storm surges over the majority of the Gulf coast.

this large island. The tropical storm force wind extent expanded from 125 nautical miles (nm) prior to the Cuban landfall, to 180 nm at the time of Ike's emergence into the open Gulf of Mexico, and eventually peaked at a remarkable 225 nm just before the storm's Texas landfall. The extraordinary breadth of Ike created storm surges over the majority of the Gulf coast. Two to four ft sea level rises were noted along the west coast of the Florida peninsula and up into the Florida panhandle. As Ike progressed toward Texas, water levels rose dramatically along the central Gulf coast, rivaling, and in some areas surpassing, the surge seen during Rita and Gustav in central to western Louisiana.



Figure 1: The track of Hurricane Ike.

The eye moved across eastern Galveston Island and straight up Galveston Bay to the eastern side of Harris County and the Houston metro area.

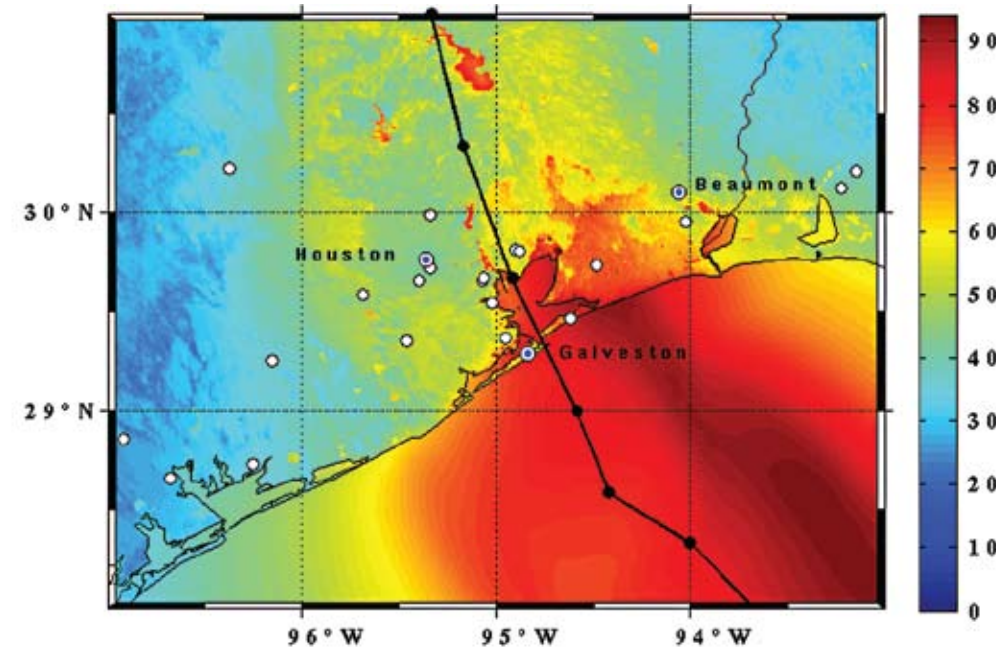
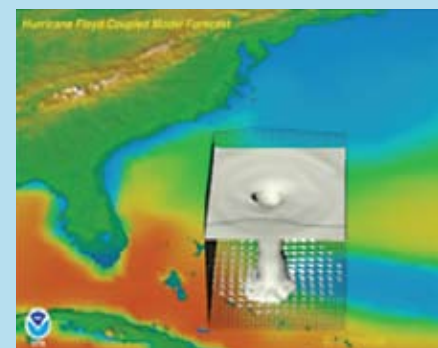


Figure 2: Wind footprint for Hurricane Ike (in knots). Observational stations are indicated with white circles.

The WeatherPredict hurricane footprint model generates a map of the maximum winds experienced at each spatial location in the impact area of the storm.

## Numerical Weather Prediction



Numerical Weather Prediction (NWP) technology uses computer models to solve the complex physical equations that govern the dynamics of the ocean and atmosphere. NWP models used by WeatherPredict take into account the coupled nature of the ocean-atmosphere system to provide skillful forecasts of hurricane track and intensity up to five days in advance. WeatherPredict's forecasting capabilities are further augmented with SuperEnsemble™ technology that synthesizes the output of multiple models into an optimal forecast.

Ike's unusual structure and a combination of northerly wind shear and lower oceanic heat content kept the inner core of the storm from consolidating, and Ike maintained a minimal Category 2 intensity for nearly 2 days during its traverse of the Gulf. During the final day prior to its landfall, early on Sept. 13<sup>th</sup>, Ike's organization improved, allowing it to strengthen by 10 knots (12 mph) to a strong Category 2. The convective structure at landfall led to an inland wind field characterized by asymmetrically broad and strong winds in the eastern and northeastern portions of the eyewall. The eye moved across eastern Galveston Island and straight up Galveston Bay to the eastern side of Harris County and the Houston metro area (see Figure 2). The tracking of Ike slightly to the east of downtown Houston and the metro areas to the west of Galveston Bay prevented more substantial impacts to these regions by placing them on the weaker, left side of the storm. The strongest convection missed the taller downtown structures, limiting the sustained winds in these areas to strong tropical storm force, with gusts above Category 1 level. As Ike moved inland, the winds gradually decreased, while broad areas were drenched with heavy, inundating rains.

## Hurricane Ike Makes Landfall

Prior to Ike's landfall, WeatherPredict wind-engineering personnel were deployed to be in position to evaluate the impact of the storm. By combining knowledge of areas of insurance industry exposures with rapid-response wind footprint information generated by WeatherPredict scientists, our ground personnel were able to promptly survey damage in critical regions and assess the severity of Ike's impact.

The WeatherPredict hurricane footprint model generates a map of the maximum winds experienced at each spatial location in the impact area of the storm. The footprint model is driven by a collection of input data that describe various features of the event: position fixes, maximum winds, radius to maximum winds, degree of asymmetry, and overall storm breadth. These parameters are derived from the advisories issued by the National Hurricane Center (NHC). The values issued in real time, however, are based on limited data and are subject to uncertainties and subsequent revisions.

The creation of a credible wind footprint is an iterative process, in which small modifications are made to the input

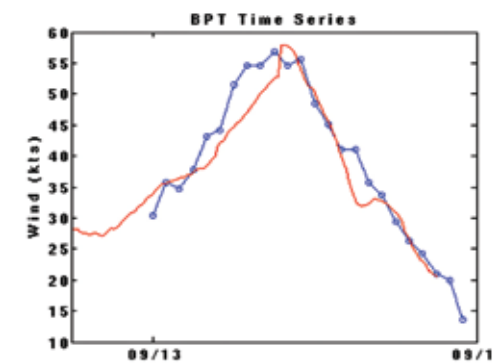
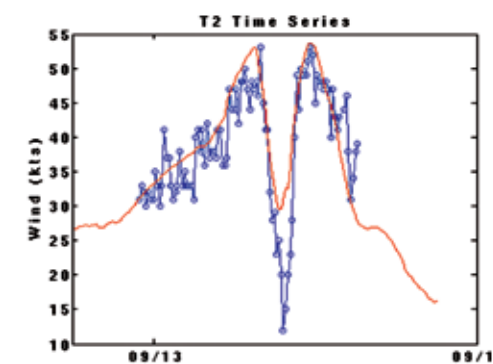


Figure 3: Wind time series comparisons at specific stations. Model results are in red, observed values in blue.

parameters and the results compared to available observational data. For Ike, these observations were comprised of readings from National Weather Service stations, mobile towers from the Florida Coastal Monitoring Program, and, for the first time, WindX™<sup>1</sup> installations. Variations in surrounding terrain, anemometer heights and wind averaging times at the observational sites were taken into account. Figure 2 shows the footprint for Ike, along with the locations of the 20 different wind observing stations that were employed to validate the footprint. Figure 3 shows some examples of time series comparisons.

## Observations of Structural Damage

Our Building Team observed Ike to be a widespread event with significant storm surge and flooding affecting many coastal areas from Louisiana through Texas. Direct wind damage, however, was not as severe as originally anticipated, and was mostly observed as sporadic wall cladding and roof cover damage. Residential communities with large and mature tree canopies experienced reduced roof cover damage, as the tree canopies provided shelter from potentially damaging wind gusts. Figure 4A is a photograph of the community of

La Port, where roof cover damage was minimal. In contrast, newly developed communities with less tree protection had more roof damage (see Figure 4B).

In addition to providing a sheltering canopy that reduced the winds, the trees in these areas have deep root systems that resisted toppling onto roofs at the wind speeds present during Ike. This is in contrast to the experience in Hurricane Fran (1996) in Raleigh N.C., where many communities also had mature tree canopies, but the shallow rooted pine trees characteristic of the area toppled onto rooftops, causing high frequency and high severity structural damage. We note that even for those canopies having mature and deep rooted systems, a critical wind speed exists where the canopy will eventually topple. For those geographic regions having lower design wind speed regimes, deep rooted mature tree canopies may reduce expected loss.

A unique feature noted for the newer Texas (and Louisiana) residential construction was the stylistic change from lower sloped roofs to much steeper roofs (see Figures 4C and 5). The damage patterns associated with the newer steep roofs were observed to occur predominantly in the roof field, which

<sup>1</sup> WindX™ is a hurricane mesonet operated by WeatherFlow Inc.



Figure 4 - A & B: Communities with mature tree canopies were observed to have less roof cover damage. Note the severe roof damage to the home visible on the far right of figure B.

Figure 4 - C: Newer construction favoring steeper roof slopes.

Figure 5: Steeper roofs display different damage patterns than traditional lower sloped roofs.

is distinctly different from typical roof-edge-focused damage patterns observed with lower pitched roofs.

These observed differences in damage patterns of the two roof slopes indicate that the wind load patterns differ, and suggest that perhaps shingles on higher sloped roofs may not seal as well as those on lower sloped roofs.

Beyond roof cover damage, damage to the tree canopy (e.g., leaves being torn from branches, tree toppling) is an excellent indicator of likely wind speeds experienced by a community. In the photo of Houston in Figure 6, we see the tree canopy is in very good shape, suggesting lower wind speeds, but that flooding initiated from inland precipitation was significant.

#### Damage to Commercial Construction

Commercial damage to the Metropolitan Houston area was observed to be minimal overall with sporadic cladding and roof edge damage. Sign damage was observed as the predominant source of flying debris, while gas station roof canopies also suffered damage (see Figure 7).

Our team also observed cladding failures associated with Exterior Insulation and Finish Systems (EIFS) construction. Damage to these systems occurs at relatively low wind speeds and tends to show up as dramatic peeling failures (see Figure 8). Compared to other cladding systems, EIFS are among the most vulnerable to failure in wind events. The EIFS failures noted in Ike were also observed following Hurricane Charley (2004)<sup>2</sup> as it went over the Orlando Metropolitan region as a tropical storm.

Damage to the high rise building stock was limited mostly to sporadic window glazing damage. The WPC team observed several high-rise structures with dramatic window glazing failures in the downtown area (see Figure 9). The root cause in glazing failures of this type is typically wind-born gravel and other debris from nearby rooftops, but we have not found unambiguous evidence in the debris field surrounding these damaged buildings to suggest this failure mode. An alternative hypothesis blames wind-generated suction forces that cause a few windows to fail by falling outwards, thereby creating a wind-born debris field that leads to a massive cascading failure of other windows on both the original and nearby buildings. Overall, commercial construction fared well in this event, owing mainly to the moderate wind speeds experienced.



Figure 6: Houston experienced moderate wind speeds, as indicated by a lack of impact on the tree canopy, but inland precipitation from Ike caused significant flood-related problems.

#### Storm Surge Effects

As Hurricane Ike approached the Texas coast, there was significant concern about the amount of storm surge that might be experienced. As we noted above, Ike made landfall as a Category 2, less than the Category 3 storm forecasted by the National Hurricane Center.

During our real-time assessment of the storm's impact on Texas, the WeatherPredict team used proprietary models to forecast the spatial distribution and height of storm surge flooding along the coast and into Galveston Bay. Figure 10A shows the maximum water level due to Hurricane Ike storm surge simulated using a WeatherPredict proprietary version of the NHC's SLOSH model. The WeatherPredict version of the SLOSH model improves the model's performance for large storms such as Ike, and also for storms that approach the shoreline at an oblique angle. Preliminary observational data suggest a 12-foot storm surge in Galveston, a 14-foot surge at the Texas-Louisiana border, and surge in excess of 15-20 feet in Galveston Bay and northeastward. These numbers are in very good agreement with the computer simulation. It is important to remember

that the cited observed and simulated storm surge levels are so-called 'still water measurements', i.e. they do not take into account hurricane-induced waves that can bring the sea water to even higher levels.

Although the 12-foot surge flooded most of Galveston, causing heavy damage, destruction of potentially much greater severity was avoided due to Galveston's 15.6-foot sea wall (the wall was built 17 feet high, but has since decreased about 2 feet). The surge was still able to flood the city from behind, but the wall prevented a head-on battering by hurricane waves.

Galveston was fortunate that Ike hit the city head-on, rather than just to the west. Ike's highest storm surge occurred about 50 miles to the northeast of Galveston, over a lightly-populated stretch of coast. Figure 10B shows a computer simulation (using the same model) of the storm surge caused by Ike as it was forecasted on September 10 (less than 2 days prior to the landfall). The forecast called for landfall about 50 miles west-south-west of the actual location with maximum winds 15 knots higher than was observed. The figure illustrates that the storm surge in this scenario would have likely overtopped the Galveston sea wall,

**Ike's highest storm surge occurred about 50 miles to the northeast of Galveston, over a lightly-populated stretch of coast.**

leading to much more severe damage. Also, southeastern Houston would have experienced storm surge in excess of 15 feet, significantly increasing the damage to this highly populated area.

Damage due to storm-related flooding was still quite significant in Galveston, affecting both commercial and residential structures. Interestingly, observation of damage here indicates that actual wind speeds were low in this area, as evidenced repeatedly by the lack of damage to building envelopes (especially roofs) above the storm surge line. Figure 11 through Figure 14 show Galveston exposures that had considerable damage due to storm surge, accompanied by little to no damage attributable to wind.

<sup>2</sup> See <http://www.weatherpredict.com/pdf-downloads/HurricaneCharleyDamageSurvey.pdf> for more information and analysis of Hurricane Charley (2004).



Figure 7: Commercial sign damage was heavy and was a significant source of debris in the Houston area.

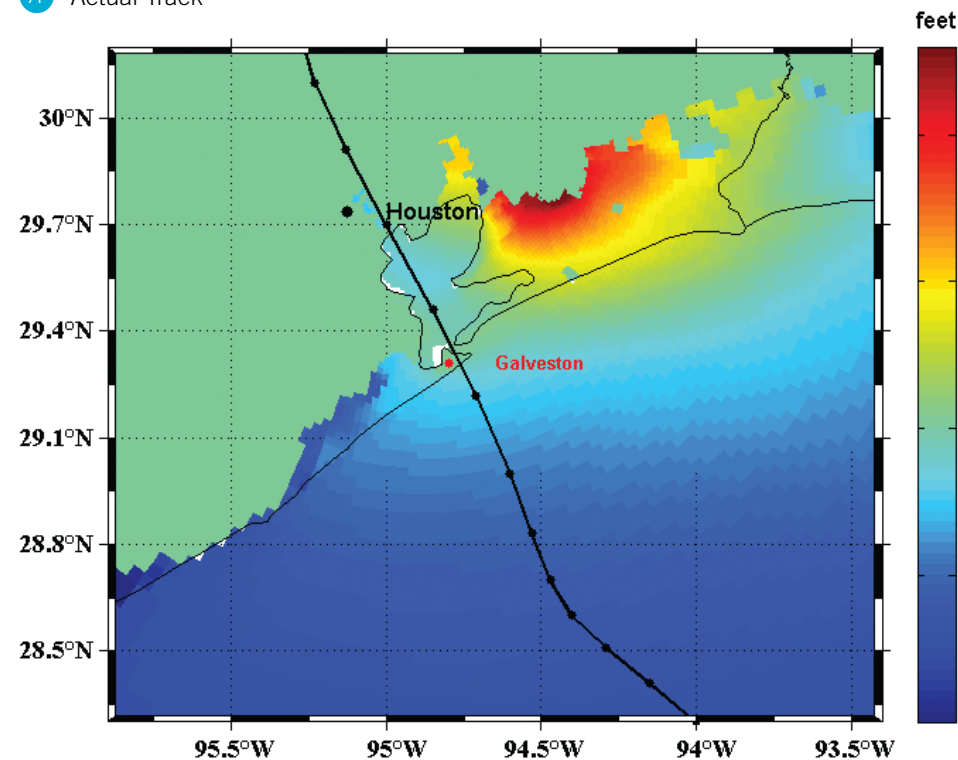


Figure 8: Cladding that employs Exterior Insulation and Finish Systems (EIFS) were particularly vulnerable to failure.



Figure 9: Commercial window cladding damage was limited to a few sporadic cases.

A Actual Track



Although the 12-foot surge flooded most of Galveston, causing heavy damage, destruction of potentially much greater severity was avoided due to Galveston's 15.6-foot sea wall...

B Forecast Track

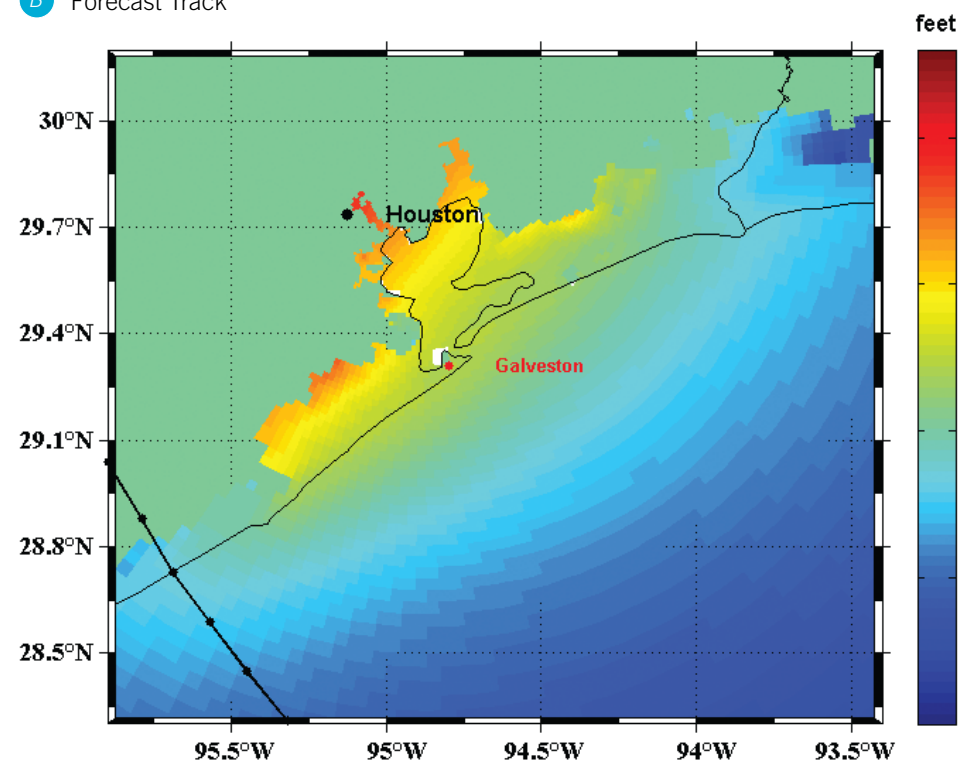


Figure 10: A & B - Computer model-simulated storm surge height for actual event (A) and the event as it was forecasted two days prior to landfall (B).



Figure 11: Galveston on the water – note lack of roof cover damage. The wind damage in Galveston was minimal.



Figure 12: The beach at Galveston Island. Storm surge was significant. Note that the roof cover has minimal damage, indicating winds speeds were lower than expected.



Figure 13: Galveston Island beach-front commercial buildings. Storm surge was significant, as evidenced by the debris line. However, the roof cover has minimal damage, indicating winds speeds were lower than expected.



Figure 14: Damage and debris on highway leading to Galveston Island. Photo shows significant storm surge and still water flooding. Note the minimal damage on the roof covers of homes in the background. These roofs are 30 feet high, (i.e., two story house on 10-15 foot piles) and the minimal roof damage again attests to the low wind speeds of Ike.

#### Beyond Texas

The remnants of Hurricane Ike interacted with a strong cold front across the U.S. mid-South and lower Ohio Valley on September 14<sup>th</sup>. As a result, widespread damaging winds were observed across much of this region. Reports from the National Weather Service cite sustained winds ranging from 25 to 50 mph, with gusts of 50 to 70 mph. These severe conditions persisted for an hour or more resulting in much damage, which was largely caused by fallen trees and power lines.

#### Conclusion

Hurricane Ike, while having a severe impact on the Houston Metropolitan region, could have been significantly more devastating had the track of the storm been more to the west or the strength of the storm been higher. Our wind speed footprints, using a combination of observational data and numerical weather prediction models, show, at most, Category 2 wind speeds along the coast northwest of Galveston and wind speeds of less than Category 1 further inland toward the Houston Central Business District. This is corroborated with visual observations on the ground by engineers

assessing damage to both residential and commercial buildings. For the most part, damage to residential and commercial buildings was limited in scope, except where the effects of Ike's storm surge and hurricane related flooding impacted structures. Given the moderate wind speeds experienced, the built environment was not tested to the wind speed demands that future hurricanes will deliver to the region.

Finally, although the storm surge heights visited upon coastal sections of the Houston Metropolitan Region were significantly lower than forecast, damage due to storm surge was widespread, especially in areas in and around Galveston, where there is a concentration of commercial and residential exposures. The WeatherPredict survey team saw repeated evidence of significant storm surge damage juxtaposed with little or no wind-related damage on the same structure.

**Given the moderate wind speeds experienced, the built environment was not tested to the wind speed demands that future hurricanes will deliver to the region.**

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