Tropical Cyclone Wind Field Analysis for Ocean Response Modeling: Hurricane Harvey (2017)

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Hurricane Harvey (2017) made landfall near San Jose Island on the Texas coast as a Category 4 storm on the Saffir-Simpson scale with one-minute winds of 115-120 knots. The storm devastated the coastal towns of Rockport and Fulton and dumped over 50 inches of rain in the Houston area. In order to critically assess wind, wave and surge damage both offshore and on the coast, a detailed analysis of the wind and pressure fields in Harvey were required for application in ocean response models. Detailed here is an analysis of the winds and application of a tropical boundary layer model for incorporation into a synoptic scale wind/pressure field.

The Tropical Analyst's WorkStation (TAWS, see Cox and Cardone, 2007) is applied to reanalyze the temporal evolution of Harvey over the period of storm history. TAWS allows for the description of the radial pressure distribution in the boundary layer using a single or a double exponential analytical formulation and allows the analyst to iterate the Tropical Planetary Boundary Layer (TropPBL, Cardone et al. 1992, Cardone et al. 1994, Thompson and Cardone, 1996 & MORPHOS, 2009) model against available wind and pressure measurements.

The basic storm parameters of track and intensity (expressed as sea level pressure (SLP) or derived from a wind-pressure algorithm) are taken from real-time or historical archives (HURDAT, IBTracs, etc.) as developed by the national tropical centers and are subject to revision if required. Track positions are typically six-hourly and are evaluated using available center fix data from satellites, radar, aircraft and insitu stations to include addition detail and time steps. Figure 1 depicts a portion of Harvey (2017) while in the Gulf of Mexico (GOM) with available fix data from the Tropical Prediction Center (TPC). Additional model inputs including far-field pressure and ambient synoptic flow are derived from atmospheric model output using a methodology described in Knaff and Zehr, 2007.

The shape of the radial pressure and resultant wind profile is controlled in the model by the Holland's B (related to the peakedness of the wind profile, see Holland 1980) and scale pressure radius (Rad1, related to the radius of maximum wind (RMW)) model inputs. Initially, a climatological relationship is used to estimate B1 and Rad1 and the model is run using a single-exponential formulation for comparison to the maximum wind and RMW or radius of 34/50/64 knot winds as analyzed by the national centers. The B1/Rad1 inputs are then scaled to match the wind maxima and radii. The resultant "TropGen" fit can be applied directly in modeling and is commonly applied in both forecast and global hindcast ocean response modeling. In detailed tropical storm analysis, it represents the first step in an analyst-interactive approach.

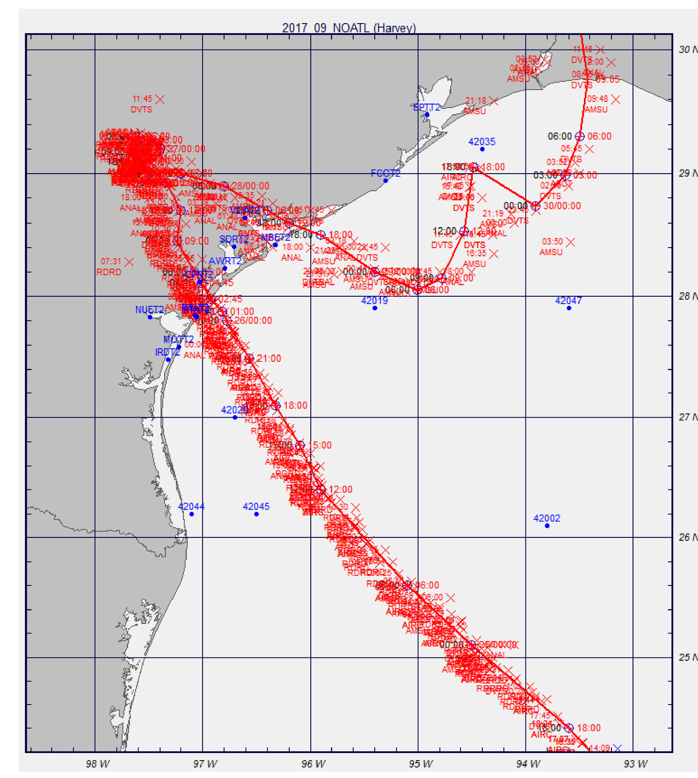

Figure 1. Reanalyzed storm track in the GOM during Hurricane Harvey (2017) with fix location data derived from satellite, radar and aircraft.

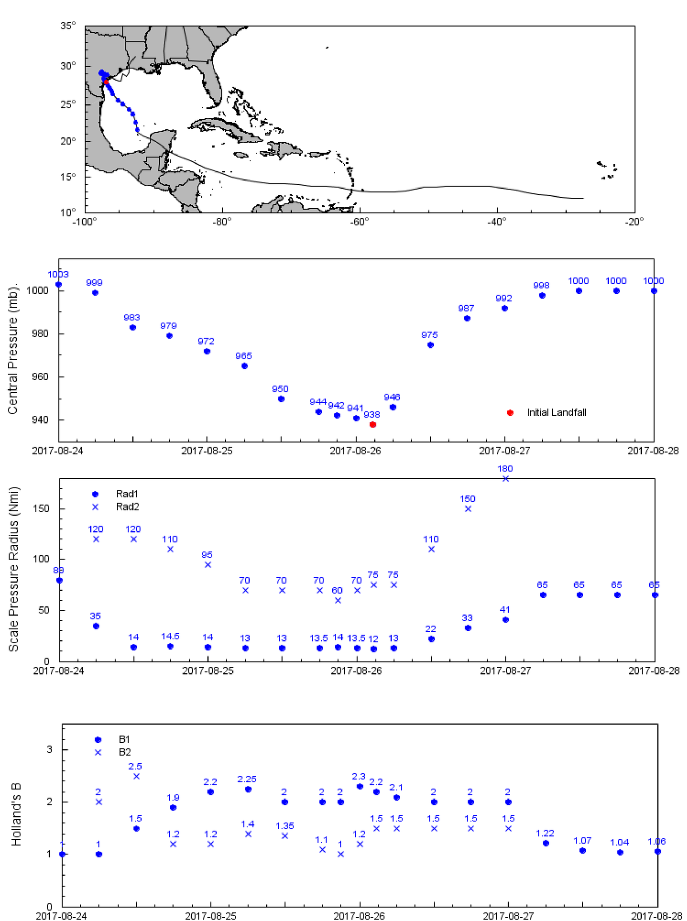

Figure 2. Track (top) and TropPBL inputs of sea level pressure (mb), scale pressure radius (Nmi) and B during Harvey from Aug 24-28 2017

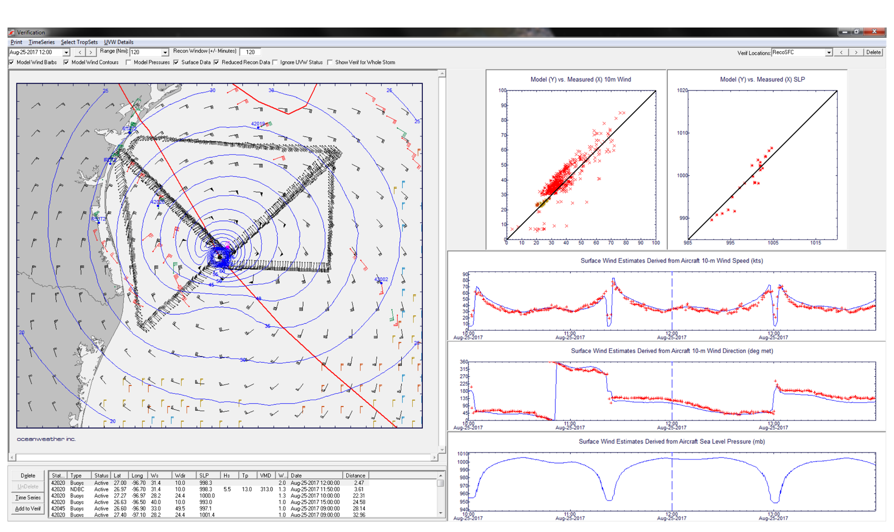

Figure 4. Time series comparison of aircraft stepped frequency microwave radiometer surface winds and TropPBL winds (kts, 30-minute average)

The double exponential model requires three additional storm parameters to define the storm structure. The added complexity is necessary since many well documented hurricanes exhibit a more complicated structure, most commonly a "shelf" to the wind profile that extends well past the RMW (Cox, 2017). Cardone and Cox (2009) discusses the importance of accurately describing the entire wind field when applying ocean response models.

Depicted in Figure 2 are the time series of sea level pressure (SLP, mb), scale pressure radii (Rad1/2, Nmi) and Holland's B parameters analyzed while Harvey was in the GOM. The radial distribution of aircraft and surface data are shown for selected snap shot times in the panels in Figure 3. The analysis applies a cost function described by Willoughby and Rahn (2004) to minimize the difference between the model and data at flight level (heights and winds) and the surface (pressure). The resultant 30-minute average surface winds produced by the model are then compared in radial form in the bottom right panels of Figure 3 or in time series form as shown in Figure 4. Snapshots are first developed independently, then reevaluated using time continuity.

On Aug-24th 12:00 UTC (Figure 3, top), Harvey depicts a classic double-maxima radial structure with an inner RMW of ~13 Nmi and secondary maxima 80-90 Nmi from the center. As the storm continues to deepen, the radial profile takes on a "shelf" profile by Aug-25 06:00 UTC (Figure 3, 2nd from top) in which a secondary wind maxima is not as apparent but the winds from 60-120 Nmi from the center show little decrease. Rad2 has decreased from 120 to 70 Nmi, and more importantly B2, which controls the peakedness of the secondary wind maxima, has decreased from 2.5 to 1.4 which results in the flatter wind profile. Inner RMW is in the 11-13 Nmi range and Harvey continues this wind profile form as it deepens to 938 mb attaining Category 4 status at landfall. After landfall (Figure 3, bottom) the storm has weakened to 987 mb and the Rad1 has expanded to 30 Nmi. Fits after Aug 27 06:00 UTC apply the simpler single-exponential structure with increased Rad1.

The Grid Interpolation in Space and Time (GIST) program is applied to interpolate and overlay storm-centered tropical wind and pressure fields with synoptic scale atmospheric products. To minimize positional errors, the storm pressure center is identified in the atmospheric model output and both wind and pressures are morphed to the analyzed position. Figure 5 depicts the miss-located center (left panel) with the morphed winds/pressures at the correct location of Harvey (middle panel).

Application of morphed background winds/pressures greatly reduced artifacts in the overlay and blending of TAWS output into the final wind/pressure field. A per time-step or manually set scale radius is then determined for overlay/blending. Typically, TAWS tropical output is overlaid directly at the target timestep/resolution within the core of the storm and a blending function applied to smoothly transition into the synoptic field. The right panel of Figure 5 shows the resultant wind/pressure field after morphing and overlay.

After GIST morphing/overlay, the resultant wind and pressure fields can be applied directly in an ocean response model or subject to manual kinematic analysis using the Interactive Objective Kinematic Analysis (IOKA, Cox et al., 1995) system. IOKA analysis can include wind features not well resolved by the TropPBL model and can direct assimilate insitu, satellite and aircraft data into the final fields.

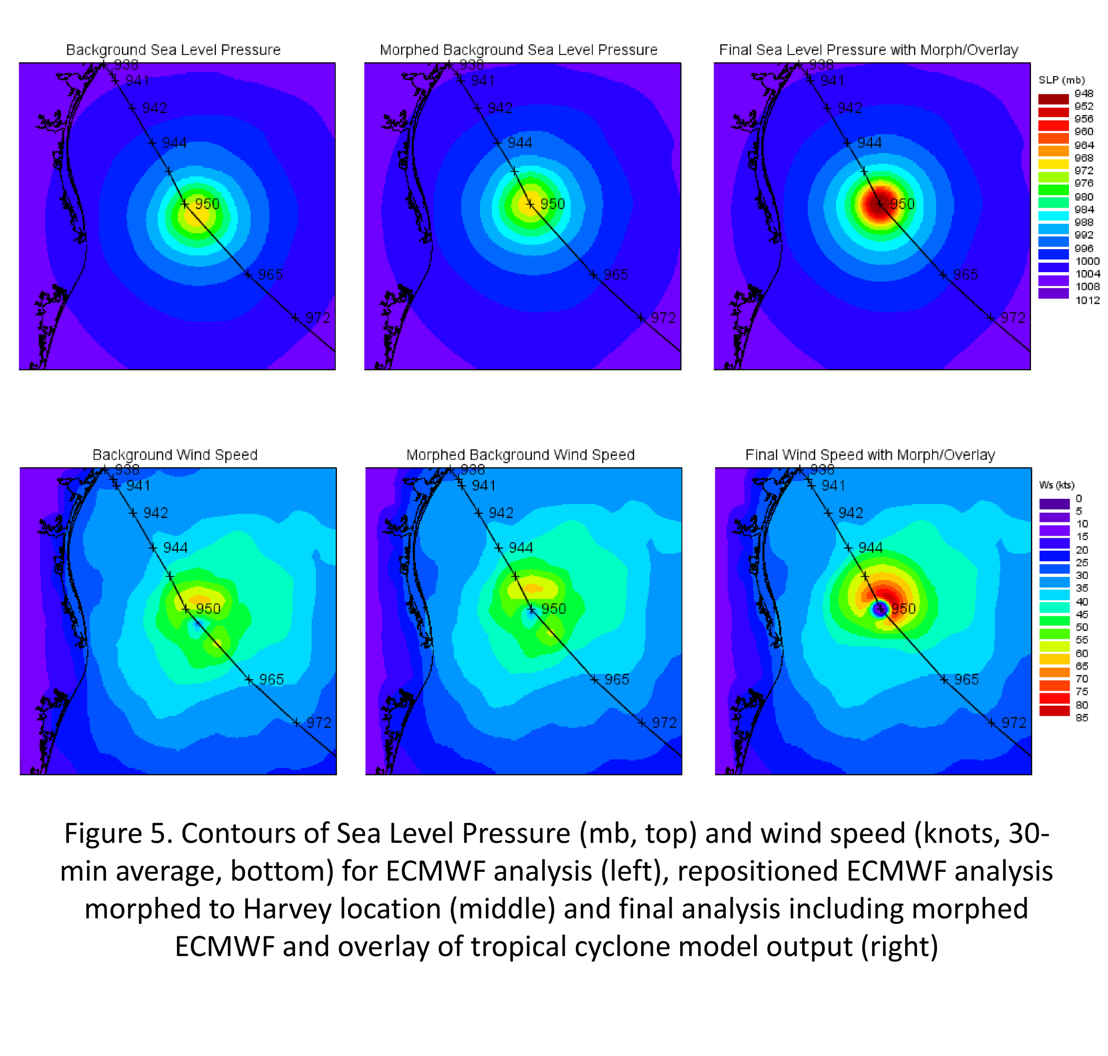

Figure 5. Contours of Sea Level Pressure (mb, top) and wind speed (knots, 30-min average, bottom) for ECMWF analysis (left), repositioned ECMWF analysis morphed to Harvey location (middle) and final analysis including morphed ECMWF and overlay of tropical cyclone model output (right)

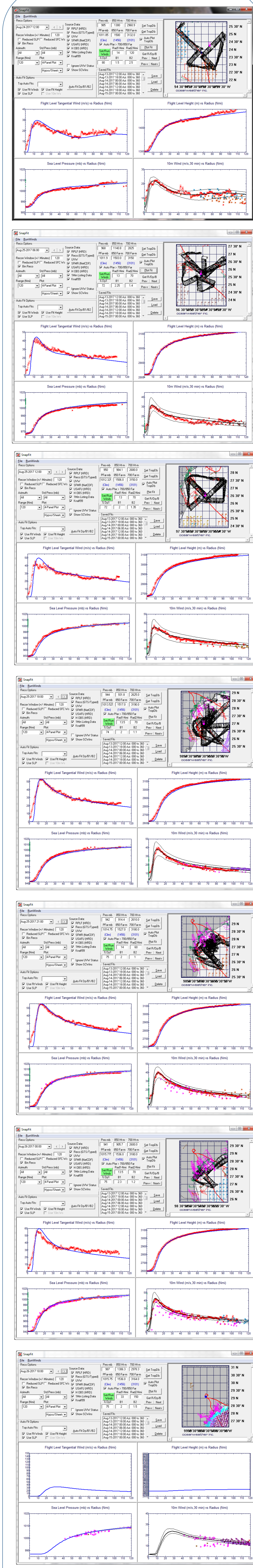

Figure 3. Radial pressure and wind profile fits from Aug-24-2017 12:00 to Aug-26 18:00 as shown in the TAWS SnapFit interface

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