# Examining Constants in the Paulus-Jeske Evaporation Duct Model

*N.G. Grimes and E.E. Hackett*
*Coastal Carolina University, School of Coastal and Marine Systems Science, Conway, SC, USA*

The propagation of electromagnetic waves in the environment can be subjected to anomalies due to the structure of the index of refraction in the atmosphere. In the marine environment, one of the most common anomalies results from evaporation ducts, which are due to moisture gradients in the surface layer that extend a few tens of meters above the air-sea interface. The Paulus-Jeske evaporation duct model (PJ) (Paulus, 1990) is frequently used for representing evaporation ducts in propagation simulations. This logarithmic model is considered a single parameter model, where the free parameter is the duct height, which is determined from bulk measurements of atmospheric and oceanic conditions near the sea surface and utilizes Monin-Obukhov similarity theory. While much work has been performed over the years evaluating and improving estimates of the duct height from atmospheric measurements (e.g., Babin et al. 1997; Fairall et al. 1996, Pasricha et al., 2002, Ivanov et al. 2007), discrepancies between measured and predicted propagation remain (e.g., Gunashekar et al. 2007). To address these shortcomings, recent efforts have begun utilizing inverse problem approaches to invert for the refractivity profile based on measured sea clutter and forward propagation models (Gerstoft et al. 2003; Karimain et. al 2011; Xiaofeng and Sixun 2012). Many of these "refractivity-from-clutter" studies also use the PJ model to invert for parameters that will adequately describe the refractivity profile for evaporation ducts. These implementations also consider the PJ model as a one-parameter model. In addition to the duct height, two constant values (fixed parameters) appear in the PJ model formulation, which represent the aerodynamic roughness ($z_0$ = $1.5x10^{-4}$ m) and the critical potential refractivity gradient ($c_0$=-0.125 M-units/m) (Paulus, 1990). A number of assumptions go into fixing these constants, and although atmospheric and oceanic conditions often do not adhere to these assumptions, the PJ model is frequently used to represent evaporation ducts in all types of conditions.

In this study, we examine 33 different sonde data sets collected during conditions when an evaporation duct was present. These data sets (that measure atmospheric refractivity) are fit to the PJ model using a genetic algorithm inverse problem technique. The fits are examined to evaluate how well the PJ model can match the evaporation ducts when using the constant $z_0$ and $c_0$ values, as well as when these constants are allowed to vary (i.e., making them free parameters). For the latter, we examine the distribution of the best-fit parameters and compare them to the fixed values. Results to-date show that the PJ model is able to fit the evaporation duct profiles with high accuracy, but only when all the parameters are permitted to vary; thus, fixing $z_0$ and $c_0$ results in a poorer representation of the evaporation duct even when the duct height is accurate. The aerodynamic roughness parameter can modify the M-gradient below the duct and the M-deficit, while adjustment of $c_0$ can change the M-gradient both above and below the duct as well as the M-deficit. Thus, allowing these parameters to vary greatly improves the model's ability to accurately represent evaporation ducts because the curvature surrounding the duct can be better matched. The quality of the fit depends on the altitude range; thus, coupling the PJ model with a linear function above the duct, similar to that done by Gerstoft et al. (2003), further improves the fit because the radius of curvature can be small at the duct while still matching the linear profile above the duct. The results of this study are important for inversion techniques that seek to determine refractivity profiles from clutter (Gerstoft et al., 2003; Karimain et al., 2011) because permitting all PJ model parameters to vary can result in better inverse solutions, which has not been done in prior refractivity-from-clutter studies.