On the use of the parabolic wave equation to model the electromagnetic propagation in maritime environment

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Abstract: Modeling the long-range propagation in a maritime environment is a challenging problem since many physical phenomena shall be accounted for, such as refraction, or waves. Here a model based on the parabolic wave equation solved with split-step wavelet that allows obtaining accurate simulations is proposed.

Modeling the tropospheric long-range propagation is very important for predicting the coverage of systems or optimizing the placement of antennas. In this work, we are interested in the propagation in the maritime environment, where local phenomena, such as sea waves or surface ducts, shall be accounted for.

In this context, a widely used model is the parabolic wave equation (PWE) [1]. Indeed, it allows fast computational simulations while accounting for the refraction the relief, and the ground composition. In particular, a low complexity method, i.e., split-step wavelet (SSW), has been developed [2,3] for tropospheric propagation applications. The latter has been modified to account for the sea, using a hybrid approach [4,5]. In this approach the sea spectrum is cut in half, the lowest part is used to generate random sea surface, while the highest allows computing a new roughness coefficient. We improve this method by modifying this coefficient to account for the shadowing effect of the waves, as in [6]. Using this approach, we are also able to model the propagation above polluted sea surfaces [7]. In Figures 1 and 2, we plot the propagation computed with SSW. Different models are used: a plane sea is considered with either the Ament or Miller-Brown roughness coefficient, the usual hybrid approach is used, or the shadowed hybrid approach. For the last two, which are stochastic methods, a Monte Carlo simulation is performed and the mean and 99% confidence intervals are plotted. In Figure 1 we considered a 10 m/s wind speed, while a 15 m/s wind speed is considered for 3.

As expected, the results are quite different considering the waves or not. Indeed, the extremum are not at the same position, mostly due to the effect of the relief (sea waves), in particular when higher wind speeds are considered, as expected. Also, introducing the shadowed coefficient in the hybrid approach introduced a slight modification of the maxima and minima values.

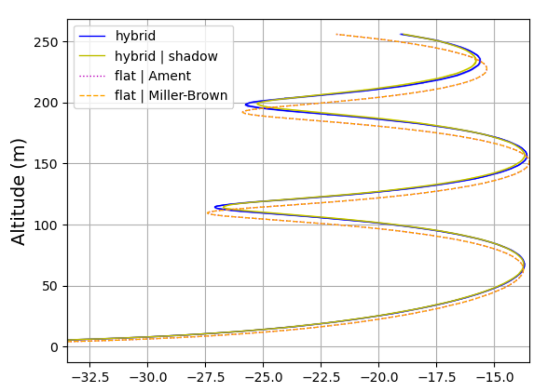

Figure 1: Field (in dB) computed with SSW with different approaches considering a wind speed of 10 m/s.

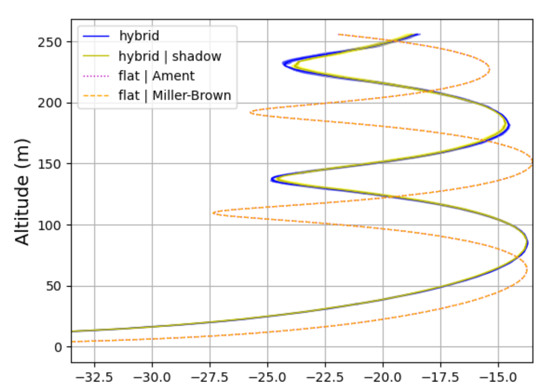

Figure 2: Field (in dB) computed with SSW with different approaches considering a wind speed of 15 m/s

In the maritime environment, we also need to consider tropospheric ducts that are very common. Among the various models available to understand evaporation ducts, the log-normal model stands out. Remarkably, it relies on just four parameters: duct height, surface parameter, roughness, and refractive index at sea level. However, accurately setting these parameters for simulation poses challenges due to inherent errors in meteorological measurements. To address this, we conduct a statistical study employing a Latin hypercube sampling and a Sobol' indices strategy, we can explore the influence of different parameter sets on the predicted field, thereby showing their respective impacts on the predicted field. In Figure 4, we plot some samples of the field computed with some set of parameters, but also the mean value and the 99% confidence interval computed over the samples. In red, we also plot the case when no error is assumed.

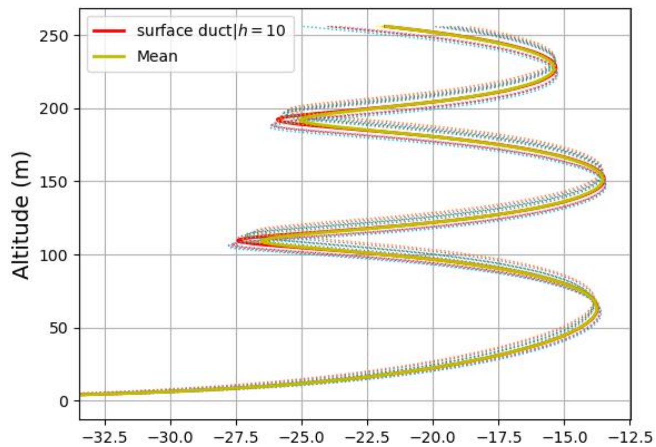

Figure 3: Statistical analysis of the parameters of log-normal model duct.

In this figure, we can see that the measurement errors influence on the result. Indeed, the position and values of maxima and minima are different. Therefore, it shall be accounted for. Furthermore, the Sobol' indices strategy has shown that the key parameters of the model are the duct height and the surface parameter. Therefore, more accuracy is needed on these two for better predictions.

In this work, we proposed a PWE/SSW method to model the propagation in the maritime environment. The propagation above the sea is considered through a shadowed hybrid approach. Furthermore, we proposed a statistical study to explore the influence of measurement error on the parameters of the log-normal model for evaporation ducts.

References

1. Levy, M. "Parabolic equation methods for electromagnetic wave propagation," IET, 2000.
2. Zhou, H., R. Douvenot, and A. Chabory, "Modeling the long-range wave propagation by a split-step wavelet method," *Journal of Computational Physics*, 402, 109042, 2020.
3. Bonnafont, T., Douvenot, R., & Chabory, A. (2021). "A local split-step wavelet method for the long range propagation simulation in 2D," *Radio science*, 56(2), 1-11.
4. Benhmammouch, O., Khenchaf, A., & Caouren, N. (2011). "Modelling roughness effects on propagation of electromagnetic waves in a maritime environment: A hybrid approach," *IET radar, sonar & navigation*, 5(9), 1018-1025.
5. Bonnafont, T., Benhmammouch, O., & Khenchaf, A. (2022). "A two-way split-step wavelet scheme for tropospheric long-range propagation in various environments," *Remote Sensing*, 14(11), 2686.
6. Pinel, N., Bourlier, C., & Saillard, J. (2007). "Forward radar propagation over oil slicks on sea surfaces using the Ament model with shadowing effect," *Progress In Electromagnetics Research*, 76, 95-126.
7. Bonnafont, T., & Khenchaf, A. (2023, June). A hybrid wavelet-based method to model the electromagnetic propagation above a polluted sea surface. In *9th International Conference on Antennas and Electromagnetic Systems, AES 2023*.