Measurements of Atmospheric Turbulent Refractivity in Coastal Zone and Microwave Propagation

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This paper discusses high-resolution meteorological measurements made in the coastal zone by tethersonde and kitesonde instruments and their inclusion in a parabolic wave equation (PWE) model to study RF propagation in a turbulent medium. The meteorological measurements were conducted off Duck, NC and Virginia Beach, VA during Spring-Summer 2016 and were used to create snapshots of turbulent radio refractivity $\tilde{N}$. The vertical extent of the sounding measurements was $\leq$ 150 m and spanned the surf zone. The raw sounding measurements were filtered and spatially smoothed to estimate mean refractivity vertical profiles and ingested by a high-resolution PWE model which also contained a 3D spatial turbulence model.

Atmospheric microwave propagation in the presence of turbulence can have significant differences from normal propagation, due to the mean (background) radio refractivity $\bar{N}(\vec{r})$, because turbulence modifies the instantaneous refractivity and produces small scale spatial gradients which affect EM wave propagation. This paper discusses methods to create 3D spatial realizations of turbulent refractivity fields, $N_t(\vec{r})$, which are then used in a parabolic wave equation (PWE) model to propagate EM waves beyond-line-of-sight (BLOS). The turbulent refractivity N_t is based on a modified 3D von Kármán spectrum that is scaled by the local structure constant C_N^2 profile computed from high-resolution radiosonde measurements.

The microwave refractivity $\tilde{N} \equiv 10^6(n-1)$ can be expressed in terms of mean $\bar{N}$ and random N_t components: $\tilde{N} = \bar{N} + N_t$, where the ensemble average $< N >= \bar{N}$ and $< N_t >= 0$. To propagate an EM field through $\tilde{N}$, a sub-wavelength 3D spatial realization N_t is computed and used by the PWE model. The stochastic N_t is computed by 2D convolution of a spatial, white zero-mean Gaussian field with the modified von Kármán wavenumber spectrum:

$$S(k_r, k_z) = \frac{0.0555 C_N^2}{[K^2 + L_o^{-2}]^{4/3}} e^{-K^2/K_m^2}, \quad K^2 = k_r^2 + k_z^2, \quad K_m = 4.6/L_i$$

Here the inner (L_i) and outer (L_o) spectral scales specify the equilibrium turbulence region. The refractivity turbulence structure constant C_N^2 provides a scaling parameterization for N_t and is computed from the large scale ($> L_o$) atmospheric properties. A turbulence threshold is computed from the mean (background) atmosphere, based on a critical Richardson number R_c, such that turbulence is only present when the Richardson number $Ri < R_c$.

Examples of PWE propagation in the presence of turbulence will be shown for X/Ka-band frequencies in coastal environments.