MMW Propagation in Warm Water Evaporation Ducts

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Atmospheric radio refractivity $N \equiv (n-1)10^6$, with n is the index of refraction, is conventionally expressed (e.g. B. Bean and E. Dutton, *Radio Meteorology*, Dover, 1968) as a function of the atmospheric thermodynamic parameters of pressure p (mbar), temperature T (°K) and water vapor pressure e (mbar) as $N = 77.6(p/T + 4807e/T^2)$. To account for propagation over a spherical earth, the modified refractivity profile $M(z) = N(z) + 0.157z$ is employed, where z is the vertical coordinate in meters. Over water bodies, there can be substantial near-surface vertical gradients in the water vapor pressure $e(z)$, going from a high value at the air-water interface to a lower value at higher altitudes. This causes a positive curvature region in the M-profile: ($M'' = \frac{d^2M(z)}{dz^2} > 0$) at some altitude $z = Z_d$, separating a negative M-gradient ($M' < 0$) region for $0 < z < Z_d$ from a positive M-gradient region ($M' > 0$) for $z > Z_d$. The part of the M-profile between $0 < z < Z_d$ is termed an *evaporation duct*. Using bulk flux models for the temperature and humidity fluxes and Monin Obhukov stability theory (MOST), a commonly used analytic evaporation duct M-profile model is the ln-linear form: $M(z) = M_0 + g[z - (Z_d + z_o)\ln(Z_d/z_o + 1)]$, where M_0 is the surface modified refractivity, g is a gradient and z_o is the aerodynamic roughness length. The significant parameters of the evaporation duct are the duct height Z_d and the M-deficit $\Delta M = M_0 - M(Z_d)$.

The evaporation duct acts like a leaky waveguide, and can trap or duct energy to substantial distances. Being a wave phenomena, the ducting characteristics depend upon the number of "trapped" modes m_t supported for a given wavenumber $k_0 = 2\pi/\lambda$, with effective propagation occurring if $m_t >> 1$ and ineffective if $m_t < 1$. Estimates of the number of trapped modes m_t can be derived from quantum mechanical methods via the phase integral J where $J = 0.001k_0\sqrt{2}\int_0^{Z_d}\sqrt{M_0 - M(z)}\,dz = \pi(m_t - 1/4)$. For trapping to exist, the evaporation duct phase integral $J/\pi \geq 3/4$ and this in turn determines the minimum frequency that can propagate in the duct.

This talk will focus on Ka-band (35 GHz) propagation in maritime evaporation ducts using M-profiles derived from high resolution radiosonde observations from locations with warm sea surface temperature (> 25°C) and large M-deficits ($\Delta M >$ 60 M-units), and the equivalent ln-linear model fits to the radiosonde M-profiles. The measured radiosonde M-profiles have evaporation ducts that are more closely approximated by a bi-linear model rather than the typical ln-linear model. Using a parabolic wave equation propagation model, the resulting differences in ducted path loss coverage diagrams will be examined and related to the curvature properties of the M-profile near the duct height. The poor fit of the ln-linear model to measured M-profiles results in substantial differences in the RF propagation.