Near-Earth Radio Frequency Propagation

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Introduction: The Near-Earth Propagation (NEP) program at NRL is investigating the unique radio frequency (RF) phenomena that occur within one meter of the Earth's surface. In the past, researchers have generally focused their propagation analysis on signals that propagate significantly above the Earth's surface.[1] However, with tomorrow's distributed and integrated micro-sensors, long-range, medium-altitude communication will not necessarily be the norm.

This article discusses some of the physical phenomena associated with near-Earth propagation. When radiating near the Earth, a communications link is subjected to a number of physical impairments, including Fresnel region encroachment and multipath reflections. The NEP program collected a variety of RF propagation observations in a controlled anechoic chamber at NRL, and in the open atmosphere in a variety of environmental conditions at Marine Corps Base Quantico, VA, and White Sands Missile Range, NM. The signal variation was measured in the 400 MHz, 1.78 GHz, and 2.4 GHz RF spectral regions with monopole and horn antennas at several heights above the surface and as a function of antenna-receiver separation. In this way we observed the influences of surface roughness, heating, and cooling on changes in the radiation pattern of the emitted RF signal.

Temperature and Moisture Gradients: The near-Earth atmosphere is characterized by heat and moisture exchanges that result in strong temperature and humidity gradients that vary locally and diurnally. At the Earth's surface, gradients are strongest and turbulent effects dominate, as defined by Garratt.[2] Traditional propagation analysis and models do not generally account for these rapidly varying micro-climate perturbations—rather they use a stochastic model of near-surface flux. Our near-Earth propagation observations include the detailed characterization of the turbulent mixing regime immediately adjacent to the Earth's surface. The turbulent exchange results in small air parcels of varying temperature and humidity, termed micro air parcels, with length scales similar to the wavelengths of the RF signals studied here. These varying micro-air parcels translate to varying index of refraction parcels, which in turn cause dynamic ray bending, resulting in scattering of the original signal (Fig. 6).

Refractivity and Refractive Index: In the standard atmosphere, refraction causes RF energy propagating in the forward direction to bend downward. Depending on frequency, the bending allows the radio horizon to propagate well beyond the traditional line of sight. Only minor changes in refractive index are necessary to cause a significant change in energy propagation. Near the Earth's surface the refractive index values range from 1.000250 to 1.000400 as described by Goldhirsh and Dockery.[3] This refractive index value typically decreases with height but may decrease quickly or increase with height if local weather anomalies occur. By using the relationship between refractivity and the refractive index, the refractive index is derived in terms of total pressure, temperature, and water vapor concentration, as shown in Eq. (1). Variations of temperature and moisture in the propagation path cause local refraction of the signal, resulting in signal loss and increase of noise.

$$n = 77.6 \times 10^{-6}\left(\frac{P}{T}\right) - 5.6 \times 10^{-8}(\rho) + 1.7305 \times 10^{-3}\left(\frac{\rho}{T}\right) + 1 \qquad (1)$$

n : index of refraction
T : temperature (Kelvin)
P : localized atmospheric pressure (mb)
ρ : water vapor concentration (g/cm^3)

Distributed Sensor Setup: During multiple experiments, distributed autonomous nodes were placed in a field to measure inter-node signal loss. The field was prepared grass cut to a height of approximately 4 cm. The terrain between the nodes was primarily flat. Nodes were placed and tested with new batteries that were characterized under similar conditions. The monopole antennas were placed perpendicular to the surface of the Earth and at a height of 7 cm measured at the base. The controller node autonomously polled each of the sensor nodes sequentially. After receiving the polling request, the sensor nodes transmitted data packets back to the controller node for thirty seconds. While receiving the data packets the controller node packaged the radio signal strength indicator (RSSI) information as seen by the controller node and forwarded it to the recording node. The recording node was placed at a height of 91 cm and connected to a laptop to record this RSSI data. While the information was transmitting from one of the sensor nodes to the controller node, the recording node monitored the transmission and recorded the RSSI as seen by the recording node. The controller node polled each sensor node independently, once per hour, for 48 hours. In addition to the RSSI data, meteorological data was also collected and time stamped to examine the correlation between surface temperature, flux, and propagation path signal strength loss.

Distributed Sensor Analysis: The node data were collected over a period of 48 hours. As expected, the data demonstrates that the greater the distance between the receiving and transmitting nodes, the lower the power received. In addition, as the temperature and heat flux increase, the overall signal strength decreases. Thirty seconds of data was collected for each node every hour. Further analysis of the data reveals that during the 30-second collection period the signal strength varies rapidly when insolation is at its peak, but minimally during the early morning hours. Of particular interest, the slant path was observed to exhibit higher short-term variability than the flat near-Earth link. Signal strength was much lower for both paths when compared to a link several wavelengths above the Earth (see Fig. 7 for results from a separate experiment). Additionally, both paths exhibited increased diurnal cycle fluctuations compared to paths at standard propagation heights.

Summary: Several experiments were conducted of the propagation environment within one meter of the Earth's surface using distributed nodes, horn antennas, and monopole antennas with high-fidelity data collection. The experiments recorded both rapid perturbations and diurnal changes in the propagation signal strength over short periods of time with stationary antennas and no moving reflectors in range of the equipment. The microclimate of the near-Earth atmospheric boundary layer is a contributing factor to the signal strength changes.

[Sponsored by NRL]

References

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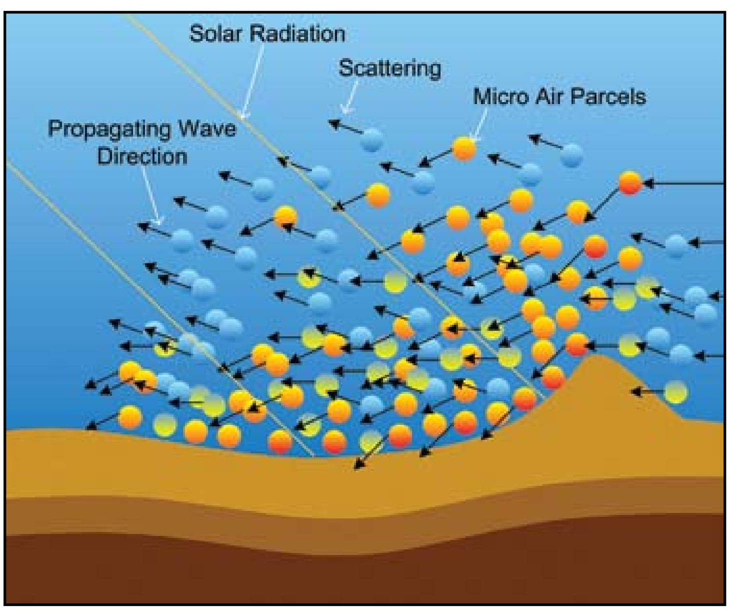

FIGURE 6
Micro air parcel concept: temperature and moisture gradients in the near-Earth environment result in a turbulent mix of micro air parcels. The micro air parcels with varying indexes of refraction cause turbulent wave bending.

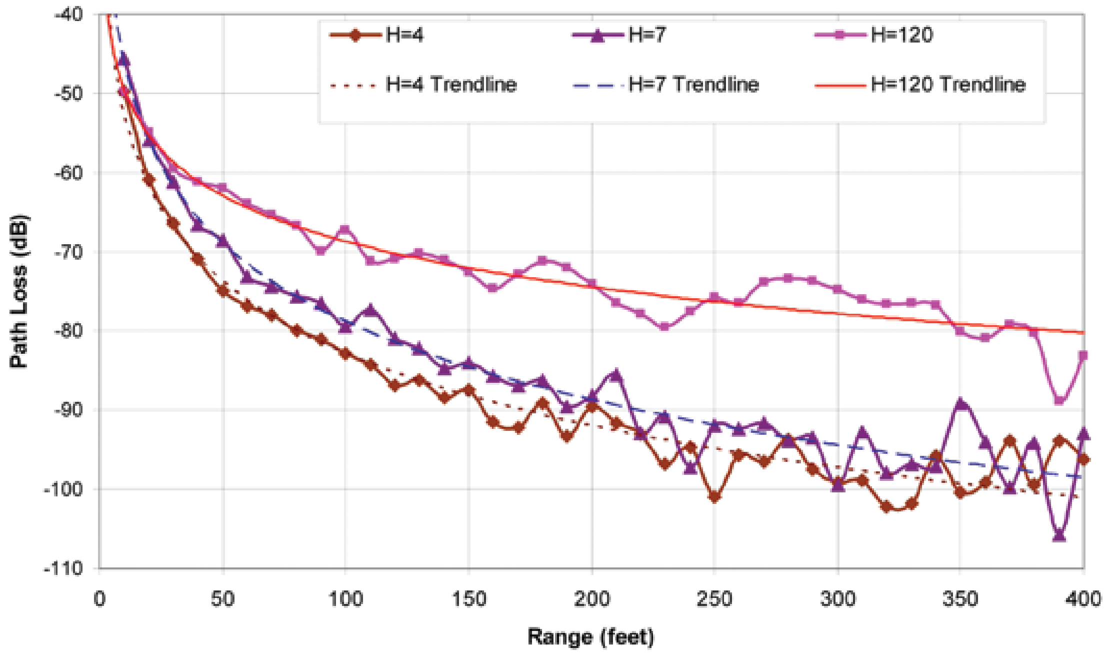

FIGURE 7
RF pathloss graph. This graph depicts RF pathloss observed from a monopole transmitter and corner reflector receiver. The three collection heights were 4 inch, 7 inch, and 120 inch.