# The Longley-Rice Irregular Terrain Model: A Comprehensive Analysis of Architecture, Algorithmic Mechanics, and Implementation Strategies for Advanced Propagation Research

## 1. Introduction and Historical Genesis

The Longley-Rice model, officially designated as the Institute for Telecommunication Sciences (ITS) Irregular Terrain Model (ITM), represents one of the most enduring and analytically sophisticated frameworks in the discipline of radio wave propagation prediction. Developed in the 1960s by Anita G. Longley and Phil L. Rice at the U.S. Department of Commerce's research laboratories, the model was conceived during a pivotal era in telecommunications engineering. The rapid expansion of VHF and UHF television broadcasting, coupled with the nascent demands of mobile land radio, necessitated a predictive tool that could transcend the limitations of smooth-earth theoretical models.[1]

Prior to the advent of the ITM, propagation predictions largely relied on deterministic models that assumed an idealized spherical earth or simple plane-earth geometries. While these models—such as the classic two-ray ground reflection model or the Bullington diffraction method—provided foundational insights, they consistently failed to account for the stochastic complexity of real-world topography. Field measurements conducted in the rugged terrain of the Colorado Rocky Mountains and the rolling hills of Ohio demonstrated that signal attenuation was not merely a function of distance and frequency, but was profoundly influenced by the statistical roughness of the terrain profile, atmospheric refractivity gradients, and the specific geometry of the horizon.[3]

The Longley-Rice model was the engineering response to this discrepancy. It was architected as a general-purpose model valid for frequencies between 20 MHz and 20 GHz, a range that encompasses the vast majority of terrestrial communications, from FM radio and TV broadcasting to modern cellular networks and Wi-Fi. Its fundamental innovation lay in its semi-empirical nature. Rather than attempting a purely deterministic solution—which would require computational resources unavailable in the 1960s and precise data that is often unavailable even today—the ITM synthesizes theoretical electromagnetic physics with extensive empirical adjustments derived from thousands of measurement paths.[4]

For the contemporary researcher undertaking a dissertation in this field, the Longley-Rice model offers a unique analytical lens. It is not merely a "black box" calculator but a procedural algorithm that encodes decades of propagation physics. It operates in two distinct modes: the "Area Prediction" mode, which estimates coverage based on broad statistical descriptions of terrain roughness, and the "Point-to-Point" mode, which ingests deterministic terrain profiles to calculate path-specific attenuation. This report will focus primarily on the Point-to-Point mode, as it constitutes the rigorous standard for dissertation-level research where specific link geometries and digital elevation models (DEMs) are analyzed.[3]

Understanding the ITM requires a deep dive into its three-stage propagation architecture—Line-of-Sight (LOS), Diffraction, and Scatter—and the intricate "preparatory subroutines" that convert raw terrain data into effective parameters. This report provides an exhaustive deconstruction of these components, the mathematical heuristics used to characterize terrain (such as the interdecile range $\Delta h$), and a strategic roadmap for implementing the model in a modern computational environment using Python or C++.

# 2. Architectural Framework and Propagation Physics

The architectural genius of the Longley-Rice model lies in its recognition that radio waves do not propagate via a single mechanism. Depending on the distance between the transmitter and receiver, and the intervening terrain, the signal may be dominated by free-space radiation, coherent ground reflection, diffraction over obstacles, or incoherent scattering from the troposphere. The model constructs a continuous curve of "Reference Attenuation" ($A_{ref}$) by seamlessly blending these regimes.

## 2.1 The Concept of Reference Attenuation ($A_{ref}$)

The core output of the ITM is the reference attenuation, defined as the median attenuation relative to free-space loss. It is crucial to distinguish this from "Path Loss" or "Basic Transmission Loss."

- **Free Space Loss ($L_{bf}$):** The loss that would occur if the antennas were isolated in a vacuum, purely due to the geometric spreading of the wavefront.
- **Reference Attenuation ($A_{ref}$):** The *additional* loss (in decibels) caused by the presence of the earth and atmosphere.
- **Basic Transmission Loss ($L_b$):** The total loss, calculated as $L_b = L_{bf} + A_{ref}$.

The calculation of $A_{ref}$ is governed by the subroutine lrprop (Longley-Rice Propagation), which evaluates the path geometry to determine which propagation regime applies. The model defines three critical distance zones based on the radio horizon distance ($d_{Ls}$) and the diffraction-scatter crossover distance ($d_x$).[1]

## 2.2 The Three Propagation Regimes

The transition between these regimes is not abrupt. The model employs sophisticated weighting functions and curve-fitting techniques to ensure continuity (smooth transitions) in the predicted attenuation curve, preventing mathematical artifacts that could be misinterpreted as physical phenomena.

### 2.2.1 The Line-of-Sight (LOS) Region ($d < d_{Ls}$)

In the region where the receiver is geometrically visible to the transmitter, the propagation is dominated by the interaction of the direct ray and the ground-reflected ray. Classical two-ray theory predicts deep signal nulls (fades) where the two rays cancel each other out due to phase differences. However, the Longley-Rice authors recognized that for irregular terrain, these perfect cancellations rarely occur because the ground is rough and the reflection is diffuse rather than specular.

To model this, the ITM calculates attenuation in the LOS region using a convex combination of two estimates:

1. **Two-Ray Optics:** A calculation based on the reflection coefficient of the ground (determined by permittivity $\epsilon_r$, conductivity $\sigma$, and polarization) and the path length difference.
2. **Extended Diffraction:** A theoretical curve that projects the diffraction loss (calculated at the horizon) backwards into the line-of-sight region.

This architectural decision effectively "fills in" the deep nulls of the two-ray model, providing a median value that better represents the average signal stability observed in field measurements. As the path distance $d$ approaches the horizon distance $d_{Ls}$, the weight shifts entirely to the extended diffraction component, ensuring a smooth handoff to the next regime.[1]

### 2.2.2 The Diffraction Region ($d_{Ls} \le d \le d_x$)

Once the receiver moves beyond the radio horizon, the direct line of sight is blocked. The dominant mechanism becomes diffraction—the bending of waves around obstacles. The ITM handles this complexity by calculating two distinct diffraction values and blending them using a weighting factor $w$.

- **Knife-Edge Diffraction ($A_k$):** This component assumes that the dominant terrain features act as sharp, opaque edges. The model typically identifies the single or double dominant obstacles and applies Fresnel-Kirchhoff diffraction theory. Knife-edge diffraction generally underestimates loss (predicts higher signal) because real hills are rounded, not infinitely sharp.
- **Rounded Earth Diffraction ($A_r$):** This component treats the earth as a smooth, spherical surface with an effective radius $a_e$. It uses Vogler's rigorous formulation for creeping waves propagating over a curved dielectric surface. This typically represents an upper bound on attenuation (lower signal).

The weighting factor $w$ is a function of the terrain irregularity parameter $\Delta h$ and the frequency.

$$A_{diff} = (1 - w) \cdot A_k + w \cdot A_r + A_{fo}$$

Where $A_{fo}$ is a "clutter factor" (discussed later).

- If the terrain is very rugged (large $\Delta h$), $w$ approaches 0, and the model favors the Knife-Edge result.
- If the terrain is smooth (small $\Delta h$), $w$ approaches 1, and the model favors the Smooth Earth result.

This blending is a profound insight of the Longley-Rice architecture: it acknowledges that real-world terrain is neither a perfect knife edge nor a perfect sphere, but a statistical intermediate.[1]

### 2.2.3 The Tropospheric Scatter Region ($d > d_x$)

At great distances, the diffracted signal attenuates exponentially and becomes negligible. The dominant signal then becomes tropospheric scatter (troposcatter)—energy scattered forward by turbulent eddies and refractive index fluctuations in the common volume of the troposphere visible to both antennas.

The ITM calculates scatter attenuation ($A_{scat}$) based on:

- **Angular Distance ($\theta$):** The angle between the horizon rays of the transmitter and receiver.
- **Surface Refractivity ($N_s$):** Which dictates the bending of the rays and the scattering cross-section of the atmosphere.
- **Common Volume Height:** The altitude of the intersection of the radio beams.

The transition distance $d_x$ is calculated as the point where the diffraction loss curve intersects the scatter loss curve. Beyond this point, the reference attenuation follows the scatter gradient $m_s$, which is typically shallower than the diffraction gradient, allowing signals to propagate (albeit weakly) for hundreds of kilometers.[1]

## 2.3 Atmospheric Refraction and the Effective Earth Radius

Crucial to all these calculations is the treatment of the atmosphere. The density of the atmosphere decreases with height, causing the refractive index $n$ to decrease. This gradient bends radio waves downward, effectively allowing them to propagate further than the geometric horizon.

The Longley-Rice model accounts for this by scaling the earth's radius. The user inputs the surface refractivity $N_s$ (typically in N-units, e.g., 301). The model calculates the effective earth radius factor $k$ (often approximated as 4/3 or 1.333 in standard atmospheres) using the relationship:

$$\gamma_e = \gamma_a (1 - 0.04665 e^{N_s/N_1})$$

Where $\gamma_e$ is the effective earth curvature ($1/a_e$) and $\gamma_a$ is the actual earth curvature ($1/6371$ km). This "effective curvature" $\gamma_e$ is used in all subsequent geometric calculations, including horizon distances and elevation angles.1

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## 3. The Architecture of Terrain Analysis: Processing the Profile

While the propagation physics form the engine of the model, the fuel is the terrain data. In Point-to-Point mode, the accuracy of the prediction relies entirely on the rigorous extraction of "effective" geometric parameters from the terrain profile. This is handled by a suite of "preparatory subroutines," chiefly qlrpfl, hzns, dlthx, and zlsq1.

### 3.1 The Terrain Profile Array Structure (PFL)

The model requires terrain data to be formatted into a specific array structure, historically referred to in the FORTRAN source code as the PFL array. For a dissertation implementation, constructing this array correctly is the first critical step.

The PFL array is a linear sequence of floating-point numbers:

- **Index 0 (PFL):** The integer number of intervals ($n_p$) in the path.
- **Index 1 (PFL):** The step size ($\xi$) or resolution of the profile in meters.
- **Index 2 (PFL):** The terrain elevation ($z_0$) *at the transmitter location*.
- **Index 3 to $n_p+2$:** The terrain elevations at subsequent steps.
- **Index $n_p+3$ (PFL[np+3]):** The terrain elevation ($z_{np}$) *at the receiver location*.

**Critical Implementation Detail:** The profile contains ground elevations only. The structural heights of the antennas ($h_{g1}, h_{g2}$) are separate input parameters. The algorithm adds the structural height to the ground elevation at the endpoints to determine the physical radiation center.[3]

### 3.2 Horizon Extraction Logic (hzns)

The hzns (Horizons) subroutine is responsible for identifying the radio horizons. This is not a simple line-of-sight check; it must account for the curvature of the earth.

For the transmitter, the algorithm iterates through every point $i$ in the profile (from 1 to $n_p-1$) and calculates the elevation angle $\theta_i$ required to clear that point:

$$\theta_i = \frac{z_i - z_{tx}}{d_i} - \frac{d_i}{2 a_e}$$

Where:
- $z_i$ is the terrain elevation at point $i$.
- $z_{tx}$ is the total elevation of the transmitter (Ground + Tower).
- $d_i$ is the distance from the transmitter to point $i$.
- $a_e$ is the effective earth radius calculated from $N_s$.

The term $\frac{d_i}{2 a_e}$ accounts for the "drop" of the curved earth surface relative to a straight tangential line. The point $i$ that yields the **maximum** $\theta_i$ is identified as the horizon. The corresponding distance is $d_{L1}$ and the angle is the horizon elevation angle $\theta_{e1}$.

The same process is repeated for the receiver (looking backwards) to find $d_{L2}$ and $\theta_{e2}$. If the maximum angle is negative, it implies the antenna is looking down at the terrain; the horizon is strictly defined by the terrain masking, even if that mask is below the local horizontal.[1]

## 3.3 The Terrain Irregularity Parameter ($\Delta h$) and dlthx

The parameter $\Delta h$ is the statistical heartbeat of the Longley-Rice model. It quantifies the roughness of the terrain along the path. In Point-to-Point mode, this is calculated deterministically from the profile using the dlthx subroutine.

**The dlthx Algorithm:**

1. **Range Selection:** The algorithm selects a subset of the profile points, typically excluding a small buffer near the terminals to avoid biasing the roughness metric with the immediate hill on which a tower might sit.
2. **Trend Removal (Linear Fit):** The terrain often has a global slope (e.g., a path from a mountain peak down to a plain). dlthx fits a straight line to the selected profile points using the method of least squares.
3. **Residual Calculation:** It calculates the vertical difference (residual) between the actual terrain height and the fitted line for every point.
4. **Interdecile Range Calculation:** The residuals are sorted numerically. The algorithm identifies the value at the 10th percentile ($v_{10}$) and the 90th percentile ($v_{90}$).
5. **Result:** $\Delta h = v_{90} - v_{10}$.

This definition—the interdecile range of residuals after removing the linear trend—is robust against outliers and global slopes. A high $\Delta h$ (e.g., >200m) indicates rugged terrain, which influences the weighting factor $w$ in the diffraction calculation and the location variability $\sigma_L$. A low $\Delta h$ (e.g., <10m) indicates smooth plains or water.[1]

## 3.4 The "Effective Antenna Height" ($h_e$) and zlsq1

Perhaps the most nuanced concept in the ITM is the "Effective Antenna Height" ($h_e$). For a dissertation, it is critical to understand that $h_e$ is **not** the structural height ($h_g$) and **not** the Height Above Average Terrain (HAAT) used in FCC contours (which averages 3-16 km).

In Longley-Rice, $h_e$ is the height of the antenna above an "Effective Reflecting Plane" defined by the foreground terrain. This simulates how the terrain immediately in front of the antenna influences the launching of the wave (for low angles) and the surface wave component.

**The Calculation Logic (qlrpfl calling zlsq1):**

1. **Range of Interest:** The qlrpfl subroutine defines a specific segment of the terrain profile to analyze. This range is typically from the antenna out to the horizon ($d_L$) or a specific multiple of the structural height (e.g., $15 h_g$). The goal is to capture the "foreground" relevant to reflection.
2. **Least Squares Fit (zlsq1):** The zlsq1 subroutine performs a linear least squares regression on the elevations within this range of interest. This fits a line $L(x) = mx + c$ to the foreground terrain.
3. **Effective Ground Plane:** The elevation of this fitted line *at the antenna's location* ($x=0$) is treated as the effective ground level ($z_{eff}$).
4. Effective Height: $h_e$ is calculated as the difference between the antenna's radiation center and this effective ground level:

   $$h_e = (z_{ground} + h_g) - z_{eff}$$

**Implications:**

- **The "Cliff" Effect:** If an antenna is on the edge of a cliff, the foreground terrain (the valley floor) drops away. The least-squares line will be far below the physical base of the tower. Consequently, $z_{eff} \ll z_{ground}$, and $h_e$ becomes very large. This correctly models the enhanced propagation of a high vantage point.
- **The "Valley" Effect:** If an antenna is at the bottom of a depression, the terrain rises in front of it. The fitted line might be higher than the antenna base, resulting in $h_e < h_g$, modeling the obstruction.

This dynamic calculation of $h_e$ allows the ITM to adapt its geometric parameters ($d_{Ls},

$\theta_e$) based on the specific shape of the terrain, rather than relying on fixed inputs.[1]

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# 4. Variability and Statistical Architecture

A deterministic calculation of $A_{ref}$ yields a single decibel value—the median loss. However, radio propagation is stochastic. Atmosphere changes, trees sway, and "exact" terrain profiles have errors. The Longley-Rice model handles this through a robust statistical framework managed by the avar subroutine.

## 4.1 The Three Dimensions of Variability

The model calculates attenuation as a distribution defined by three variables:

1. **Time Variability ($q_T$):** Accounts for changing atmospheric conditions (refractivity, turbulence, stratification) over minutes, hours, and seasons.
2. **Location Variability ($q_L$):** Accounts for statistical differences in paths that might have similar macroscopic terrain parameters ($\Delta h$) but different microscopic features.
3. **Situation Variability ($q_S$):** Accounts for "hidden variables"—model errors, measurement errors, and environmental factors not captured by the inputs.

The user requests a prediction for a specific "quantile" or "reliability." For example, a request for "90% confidence" means calculating the loss that will not be exceeded in 90% of situations.

## 4.2 The Calculation Pipeline (avar)

The avar subroutine takes standard normal deviates ($z_T, z_L, z_S$) corresponding to the desired probabilities (e.g., $z=1.28$ for 90%) and computes deviations in dB.

1. Time Deviation ($Y_T$):
   This is climate-dependent. The model supports 7 standard radio climates (e.g., Equatorial, Continental Temperate, Maritime). Based on the climate code and the effective distance $d_e$, the model looks up empirical variability curves (derived from

NBS Technical Note 101 data). It calculates a deviation $Y_T$ representing the fading range.
   - *Insight:* Maritime climates typically exhibit higher time variability (more ducting/fading) than continental climates.[1]
2. Location Deviation ($Y_L$):
   This captures the uncertainty of the terrain. It is calculated as:

   $$Y_L = \sigma_L \cdot z_L$$

   The standard deviation $\sigma_L$ is a function of frequency and the terrain irregularity $\Delta h$.

   $$\sigma_L = 10 \frac{k \Delta h}{k \Delta h + 13}$$
   - *Insight:* In rougher terrain (high $\Delta h$), $\sigma_L$ increases, reflecting greater uncertainty in the prediction. In Point-to-Point mode, $q_L$ is often set to 0.5 (median) or $z_L=0$ because the "location" is fixed and known, removing this variance from the total sum.[1]
3. Situation Deviation ($Y_S$):
   This is the "model confidence" term. It combines the other variances to estimate the total uncertainty of the prediction.

   $$Y_S = z_S \sqrt{\sigma_S^2 + \frac{Y_T^2}{7.8 + z_S^2} + \frac{Y_L^2}{24 + z_S^2}}$$

   Here, $\sigma_S$ is a base standard deviation (typically around 5-6 dB).

The final attenuation is:

$$A_{total} = A_{ref} - V_{med} - Y$$

Where $V_{med}$ is a median adjustment and $Y$ is the combined deviation. Note the subtraction: higher reliability (higher confidence of service) implies designing for a higher attenuation value (lower signal), so the deviation is often negative in signal strength terms but positive in attenuation terms.1

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# 5. Implementation Strategy for Dissertation Research

Implementing the Longley-Rice model for academic research requires more than just downloading code; it requires building a validated data pipeline. The following section outlines the necessary components and strategies.

## 5.1 Data Acquisition and Pre-Processing

The quality of the ITM output is linearly dependent on the quality of the terrain profile.

- **Source Data:** Use **SRTM (Shuttle Radar Topography Mission)** data. The 1-arc-second (~30 meters) dataset is the global standard for dissertation work. For US-specific studies, the **USGS National Elevation Dataset (NED)** at 1/3 arc-second (~10 meters) offers higher precision. Avoid low-resolution datasets (like GLOBE 1km) unless simulating legacy systems.
- **Geospatial Library Stack:** Use Python with GDAL (Geospatial Data Abstraction Library).
  - Use rasterio for reading GeoTIFF DEMs.
  - Use pyproj for coordinate transformations (WGS84 to local metric projections if necessary, though ITM works on Great Circle distances).
- **Profile Extraction:**
  - Calculate the path vector between Tx and Rx lat/lon coordinates using Vincenty's formulae (which account for the oblate spheroid shape of Earth).
  - Sample the DEM at regular intervals.
  - **Crucial Step:** Use **Bilinear Interpolation**. Do not simply grab the "nearest neighbor" pixel value. The FCC and ITU recommendations specify bilinear interpolation to calculate the elevation at the exact sample point between grid posts. This reduces quantization noise in the profile, which smooths the $\Delta h$ calculation.[8]

## 5.2 Codebase Selection and Validation

Do not write the electromagnetic physics from scratch. The algorithms for Fresnel integrals and Vogler's attenuation are numerically sensitive and prone to implementation errors.

- **Recommended Libraries:**
  - **C++:** The NTIA maintains a canonical C++ port of the original FORTRAN code. This is the "gold standard" for numerical accuracy.[11]
  - **Python:** Use itmlogic [18] or itm.py.[19] These are validated wrappers/ports that expose the qlrpfl and avar subroutines.
- **Verification Strategy:** Your dissertation must prove your implementation works. Run the "Sample Problems" listed in **NTIA Report 82-100**. These provide known inputs (frequency, heights, profile) and expected outputs ($A_{ref}$). Your code must match

these outputs to within 0.1 dB.

## 5.3 The "Clutter" Problem and Modern Augmentation

A major limitation of the classic ITM is its handling of clutter (buildings and trees). The internal "clutter factor" $A_{fo}$ (Snippet ) is rudimentary and often set to zero in modern implementations to avoiding double-counting.

**Dissertation Requirement:** For research involving urban environments (5G, IoT), you **must** augment ITM.

1. **Method 1 (The "Bare Earth" + "Clutter" approach):** Run ITM using the bare-earth terrain profile. Then, add a separate clutter loss term based on the Land Use/Land Cover (LULC) at the receiver. The **ITU-R P.2108** model provides a statistical clutter loss model that pairs well with ITM.
2. **Method 2 (The "Canopy" approach):** If using Lidar data (DSM), the profile includes the tree/building tops. Run ITM on this surface. This is risky as ITM assumes "ground" reflections, but it captures diffraction over skylines accurately.

- *Recommendation:* Use Method 1. It separates the propagation physics (ITM) from the local multipath environment (Clutter Model), allowing for cleaner analysis.[20]

## 5.4 Step-by-Step Implementation Checklist

1. **Define Inputs:**
   - Tx/Rx Lat/Lon and Structural Heights ($h_{g}$).
   - Frequency ($f$), Polarization (H/V).
   - Surface Refractivity ($N_s \approx 301$) and Climate Code (e.g., 5).
   - Ground Constants (e.g., $\epsilon_r=15, \sigma=0.005$ for average ground).
2. **Generate Profile:**
   - Extract points every $\xi$ meters (e.g., 30m or 90m).
   - Construct the PFL array: [num_points, step_size, z_tx, z_1, z_2... z_n, z_rx].
3. **Initialize ITM:**
   - Set up the prop common block (or object structure).
4. **Call qlrpfl:**
   - Pass the profile.
   - This populates prop with effective heights ($h_e$), horizon distances ($d_L$), and irregularity ($\Delta h$).
   - *Debug Tip:* Print these "effective" values. If $h_e$ is negative or massive, check your

profile units (meters vs feet) and "range of interest" logic.

5. **Call lrprop:**
    - Obtain aref (Reference Attenuation).
6. **Call avar:**
    - Calculate reliability quantiles (e.g., 50%, 90%).
    - Final Loss = $L_{bf} + A_{ref} - \text{Variability}$.

# 6. Insights and Conclusion

The Longley-Rice model endures not because it is perfect, but because it is balanced. It navigates the trade-off between the computational impracticality of full-wave equation solvers and the inaccuracy of simple empirical curves. Its architecture—defined by the seamless blending of LOS, Diffraction, and Scatter regimes—mirrors the changing dominance of physical phenomena over distance.

For the researcher, the key insight is that the "model" is inextricably linked to the "profile." The model's accuracy is defined by how well the preparatory subroutines (hzns, dlthx, zlsq1) can extract meaningful geometric parameters from the terrain data. The "Effective Antenna Height" is not a physical measurement but a *derived parameter* resulting from a least-squares regression of the foreground terrain; it is a mathematical proxy for the "launch angle" of the wave. Similarly, $\Delta h$ is not just "roughness" but a statistical tuning parameter that adjusts diffraction efficiency and location variability.

Implementing Longley-Rice for a dissertation is a rigorous exercise in computational electromagnetics. It requires high-fidelity geospatial data processing, a nuanced understanding of statistical availability, and the ability to augment the core physics with modern clutter models. By mastering these architectural details, the researcher gains a powerful tool for analyzing spectrum sharing, network coverage, and the fundamental limits of terrestrial radio communication.

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**Table 1: Standard Input Parameters for Longley-Rice Point-to-Point Mode**

| Parameter | Symbol | Typical Value / Unit | Description |
|---|---|---|---|
| **Frequency** | $f$ | 20 MHz - 20 GHz | Carrier frequency of the signal. |

| | | | |
|---|---|---|---|
| **Polarization** | $pol$ | 0 (Horiz) / 1 (Vert) | Affects reflection coefficients in LOS calculations. |
| **Structural Heights** | $h_{g1}, h_{g2}$ | meters | Height of antenna radiation center above ground level (AGL). |
| **Surface Refractivity** | $N_s$ | 301 N-units | Parameter governing atmospheric bending (average temperate atmosphere). |
| **Ground Permittivity** | $\epsilon_r$ | 15 (Avg Ground) | Dielectric constant of the terrain surface. |
| **Ground Conductivity** | $\sigma$ | 0.005 S/m | Conductivity of the terrain surface. |
| **Climate Code** | $k_{lim}$ | 5 (Continental Temperate) | Determines time variability statistics (ducting/fading). |
| **Terrain Profile** | PFL | Array (meters) | Deterministic elevation data including path resolution. |

**Table 2: Key Internal Subroutines and Their Functions**

| **Subroutine** | **Full Name** | **Functionality** | **Key Output Parameters** |
|---|---|---|---|
| **qlrpfl** | Quick LR Profile | Master preparatory routine. | Calls hzns, dlthx, zlsq1 to set |

| | | | |
|---|---|---|---|
| | | Orchestrates terrain analysis. | geometry. |
| **hzns** | Horizons | Scans profile for max elevation angle. | $d_{L1}, d_{L2}$ (Horizon Dists), $\theta_{e1}, \theta_{e2}$ (Angles). |
| **dlthx** | Delta-H | Calculates terrain roughness via interdecile range. | $\Delta h$ (Terrain Irregularity Parameter). |
| **zlsq1** | Z-Least Squares | Fits linear regression to profile segments. | Used to derive Effective Heights $h_{e1}, h_{e2}$. |
| **lrprop** | LR Propagation | Computes the median reference attenuation. | $A_{ref}$ (Reference Attenuation in dB). |
| **avar** | Variability | Calculates statistical deviations. | $Y_T, Y_L, Y_S$ (Time, Loc, Situation deviations). |

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