

Ray Tracing Channel Modeling

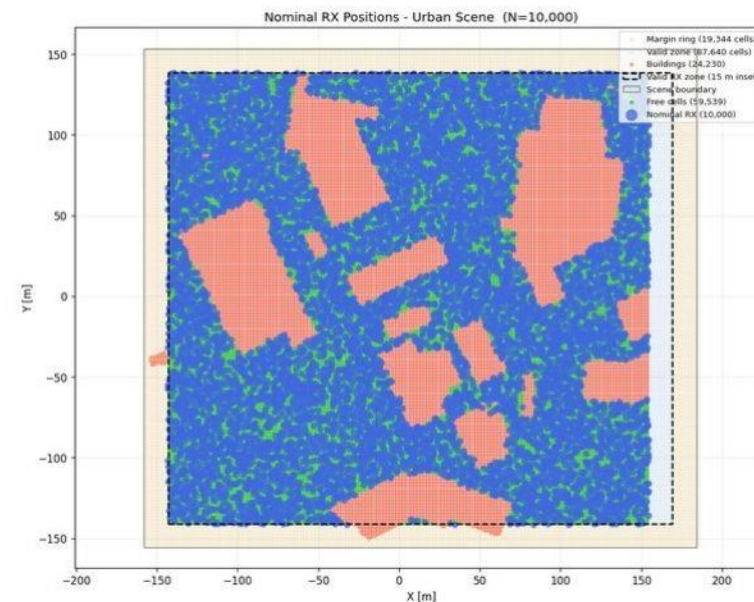
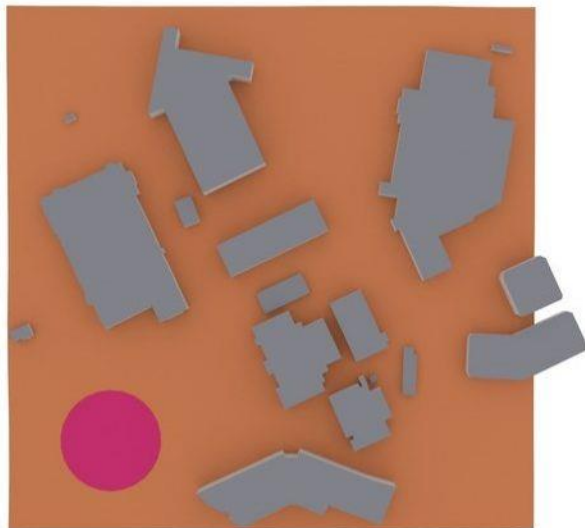
Ray Tracing Channel Modeling

SITE-SPECIFIC MODEL

Site-Specific: Three Representative Scenes

SITE-SPECIFIC

- **(Suburban)UW campus (Sieg Hall)** — 230.5 m scene radius, 17 buildings, 36 shapes, 4 materials after sanitizing
- **(Urban)San Francisco and (Dense Urban)Canary Wharf** — urban and dense-urban morphology contrasts against the same pipeline
- **10,000 UEs at 1.5 m** — drawn from a terrain-following occupancy grid, ~59.5k free cells at 1 m resolution
- **Sweep** — nine elevations, 10–90°, at 2 GHz and 20 GHz



UW campus scene, plan view (left) and the 10,000 sampled UE positions (right)

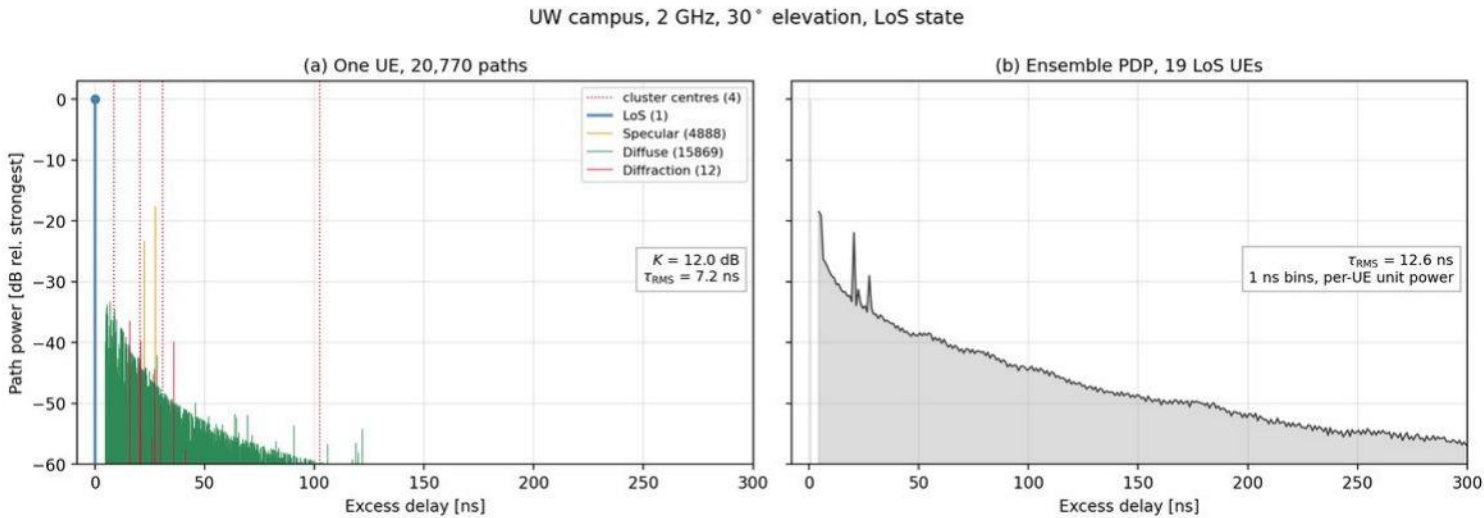
RT Configuration

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- **MAX_DEPTH = 3** — specular + diffuse + first-order UTD wedge; refraction and edge diffraction off; RHCP at both ends
- **Fixed 500 km slant range**
- **Ionosphere and troposphere disabled** — implemented, but switched off so as not to double-count TR 38.811's own link-budget terms.

Role	Material	S
Facade	itu_concrete	0.4
Roof	itu_metal	0.0
Terrain	medium_dry_ground	0.3
Water	itu_water	0.0

Roof $S = 0$ is the most consequential material choice — it biases K upward.

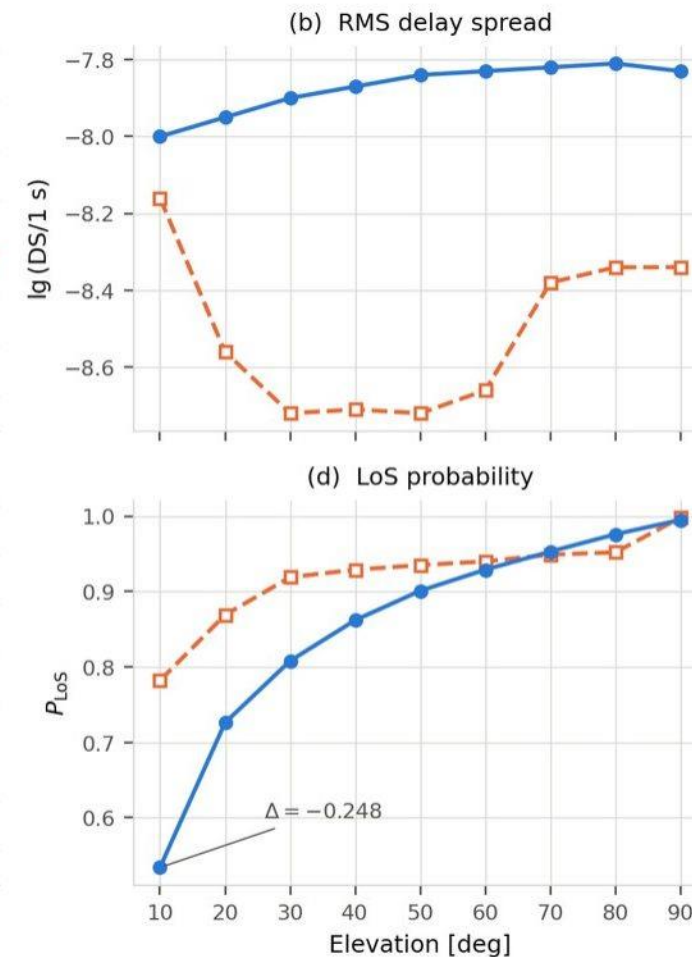
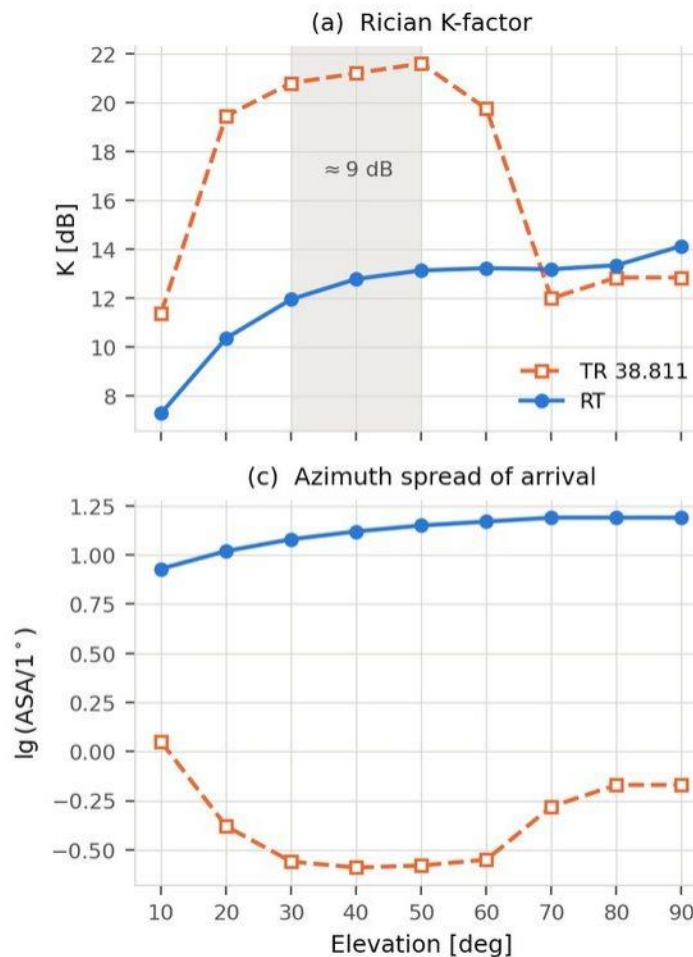


Per-UE CIR against the ensemble PDP, UW campus, 2 GHz, 30° elevation

K-Factor Trends: 3GPP Diverges from Simulation

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- **K-factor** — RT 7.30 → 14.14 dB against 11.40 → 12.85. Close at 70–90°, but ~9 dB apart at 30–50° where the table peaks at 21.6 dB
- **LoS $\Delta = -0.248$ at 10°**, converging above 60° — the campus sits between the Suburban and Urban classes rather than within Suburban

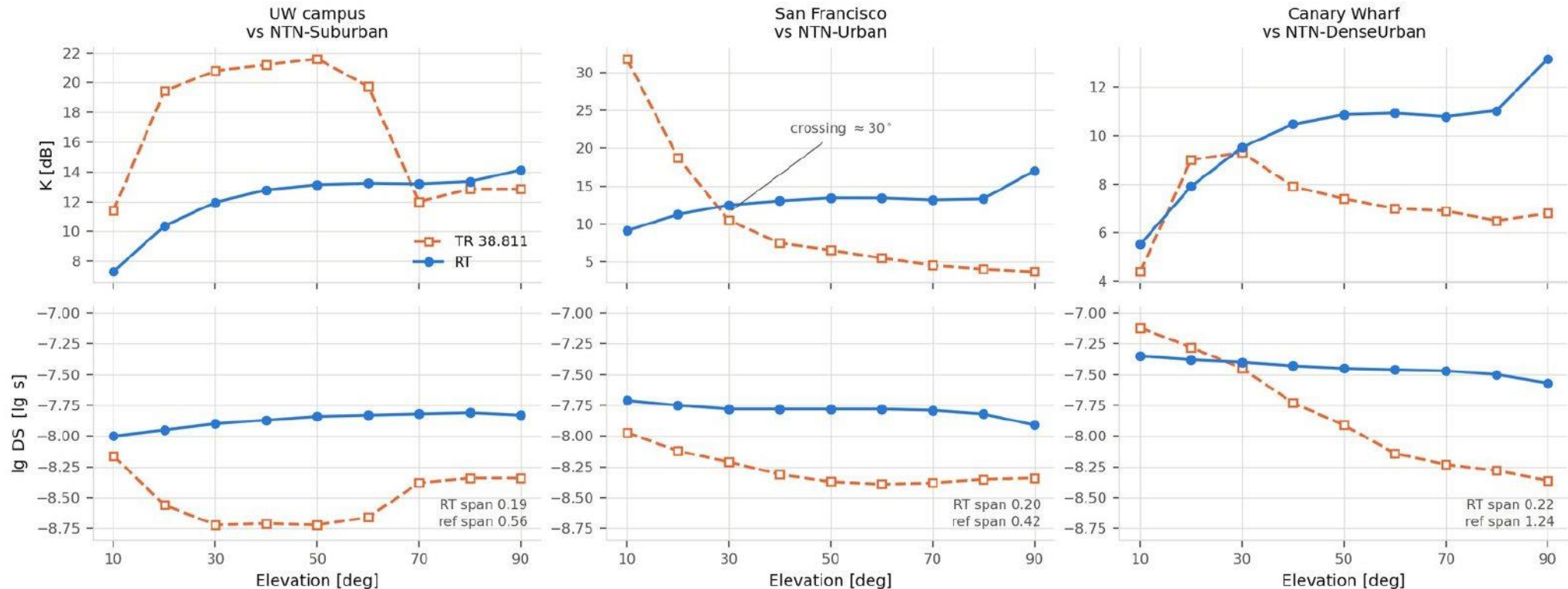


* TR 38.811 S-band 90° row duplicates 80°

Cross-scene: K Factor move, DS trends do not

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- EK-Factor Tracks within RT internally, not consistent with 3GPP
- RT delay spread is almost flat in elevation — spans of 0.19, 0.20 and 0.22 decades against 0.56, 0.42 and 1.24 for the tables: the disagreement is in shape, not level
- Only Canary Wharf changes sign — RT lgDS starts 0.23 below the reference at 10° and ends 0.79 above at 90°; UW and SF sit above throughout
- Reference defect — the TR 38.811 S-band 90° row duplicates its 80° row verbatim: eight distinct elevations, not nine



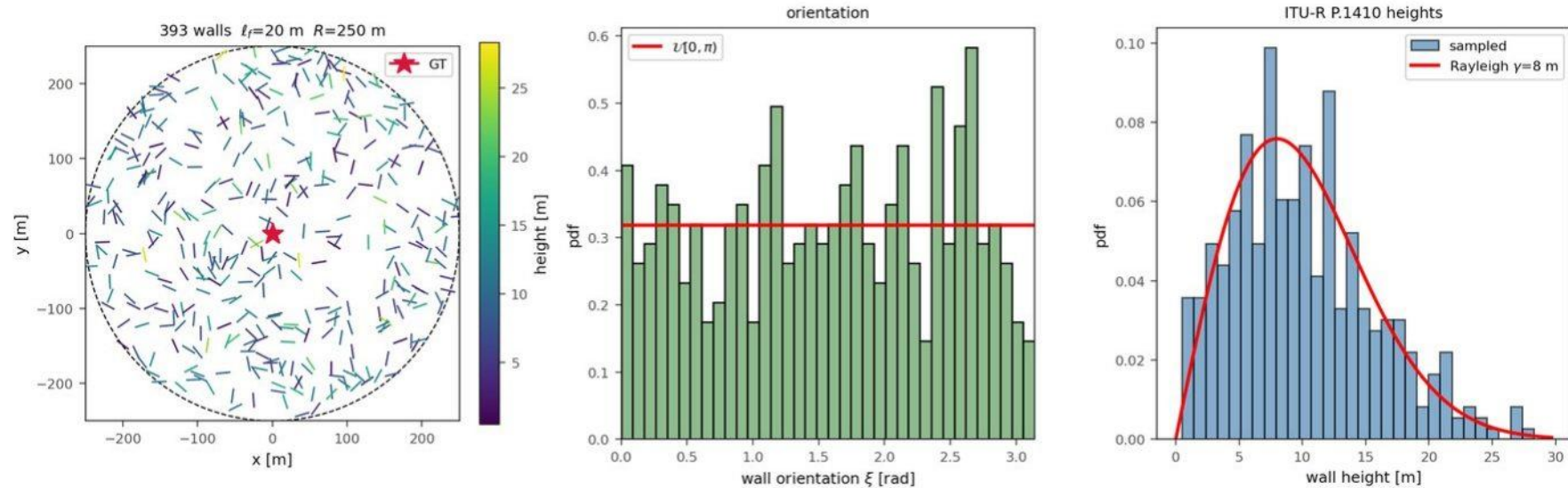
Ray-Tracing Channel modeling

STOCHASTIC MODEL

Stochastic Scene Generation

STOCHASTIC

- **Independent analytical reference** — a geometry-based delay–Doppler LEO model, validated against the same scene process the ray tracer sees
- **Wall placement** — a marked PPP of vertical wall segments: centers PPP(λ_b) in a 2 km disc, orientation $U[0,\pi)$, Rayleigh(γ) heights, fixed length ℓ_f
- **Urban** $\gamma = 8$ m, $\lambda_b = 1.96e-3$ m⁻², $\ell_f = 20$ m
- **Rural** $\gamma = 3$ m, $3.14e-3$, 10 m
- **Scene Parameters**— frequency = 2 GHz, $h_{\text{sat}} = 550$ km, $h_{\text{rx}} = 1.5$ m, MAX_DEPTH = 1, specular + UTD roof-edge only, isotropic rx
- **2000 scenes** per elevation $\times$ 8 elevations (10–80°) $\times$ 2 scenarios

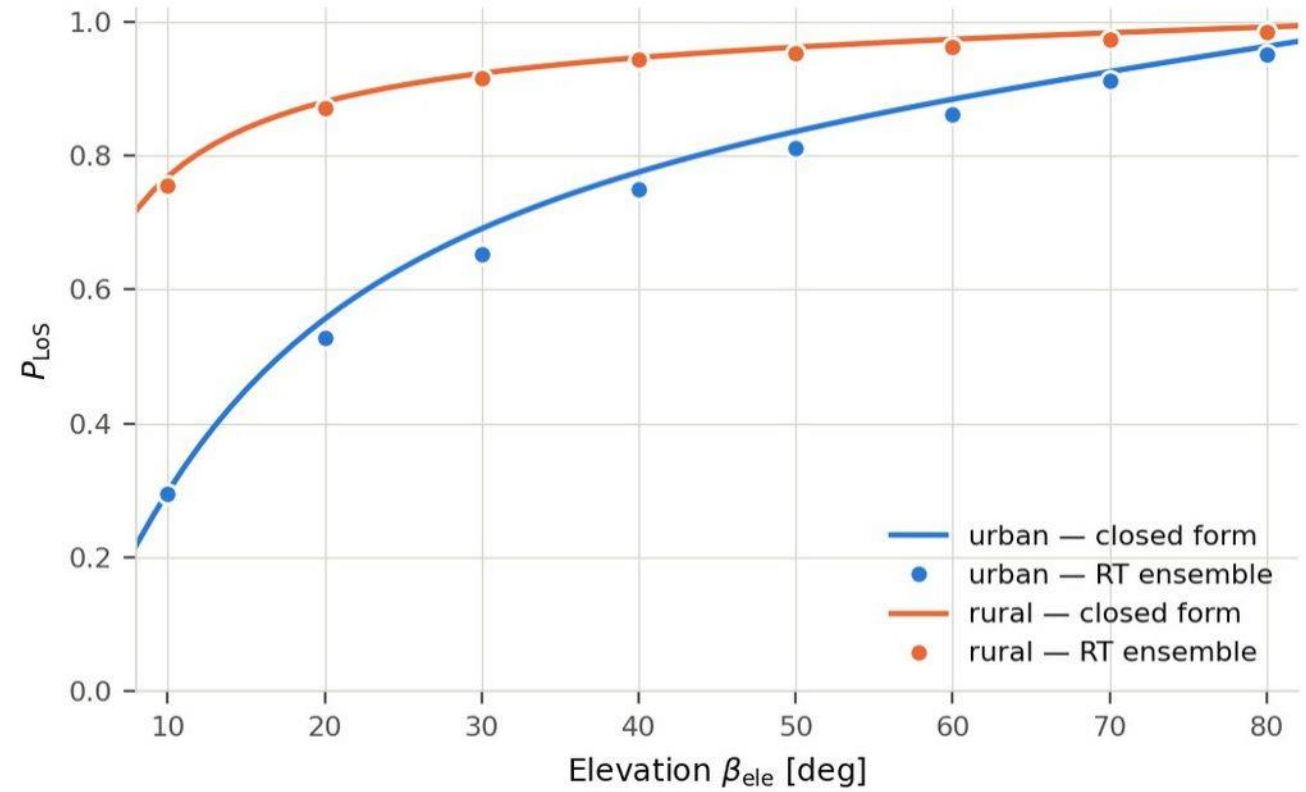


Urban wall process, seed 0 — segments coloured by height, with the $U[0,\pi)$ orientation and Rayleigh $\gamma = 8$ m height checks. Radius cut to 250 m for legibility; λ_b , γ and ℓ_f are the paper's urban values.

LoS Probability: Validated

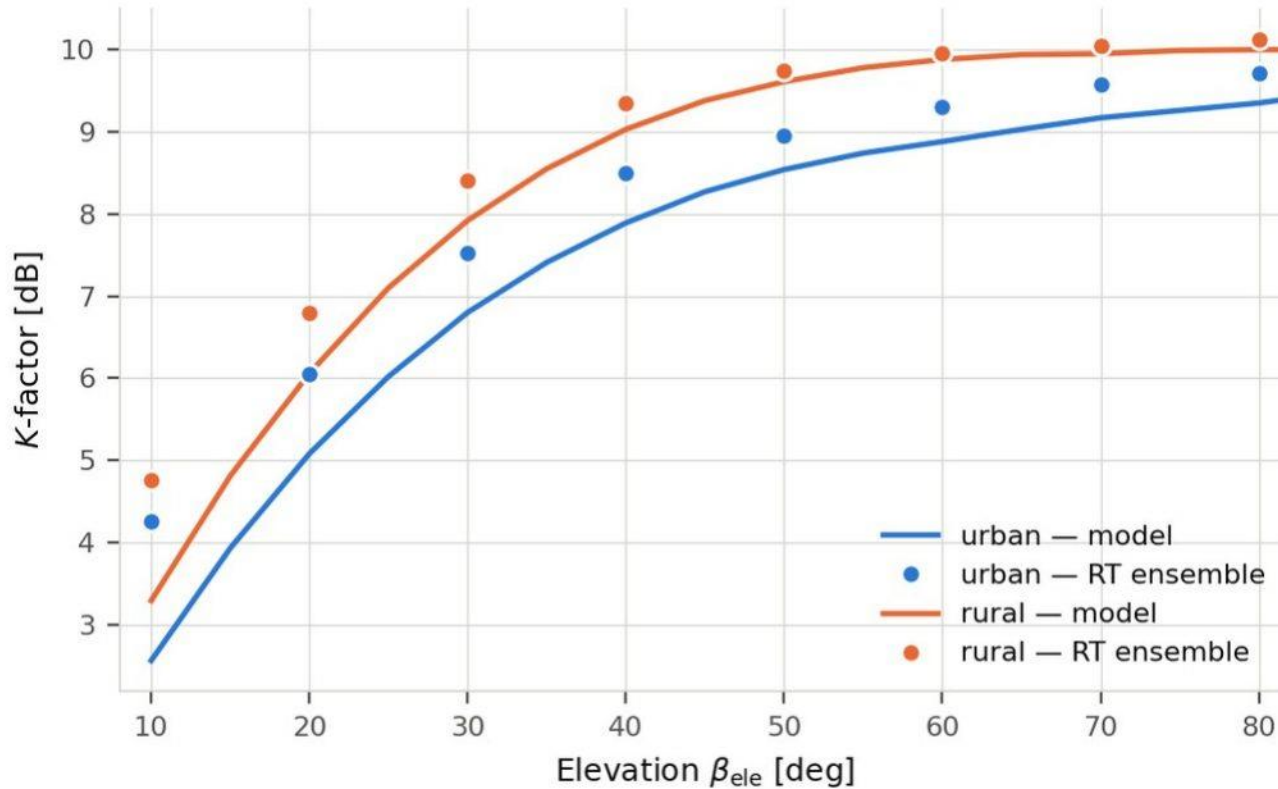
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- **Urban** 0.295 / 0.298 at 10° rising to 0.951 / 0.963 at 80° (RT / model)
- **Rural** 0.756 / 0.769 rising to 0.986 / 0.992



K-factor: agreement at zenith, RT higher at grazing

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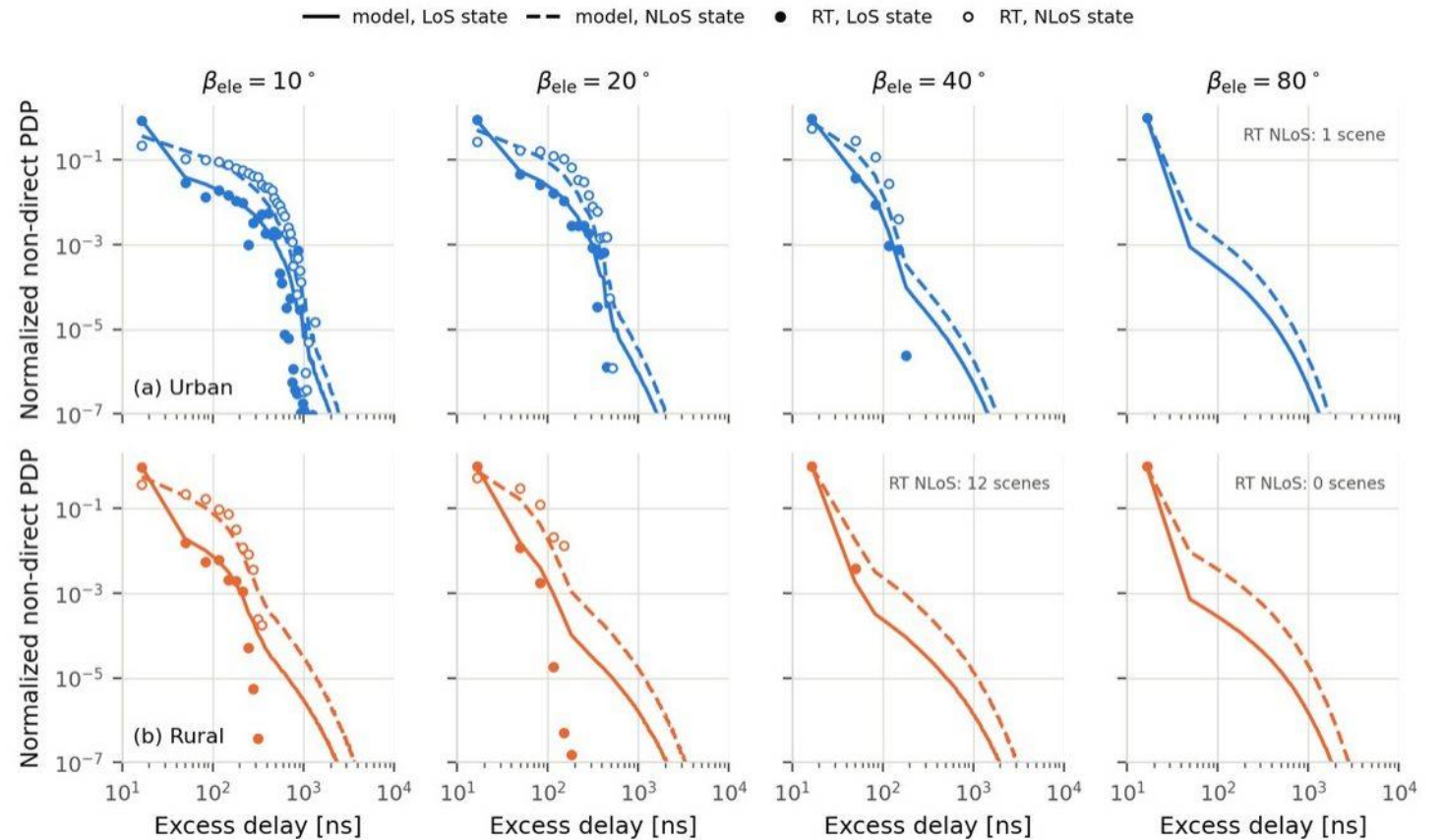


- **Urban 4.26 / 2.56 dB at 10°** (+1.70); rural 4.76 / 3.29 (+1.47)
- **Narrows quickly** — ~0.7–1.0 dB by 20°, and ~0.4 dB by 80° (urban 9.72 / 9.35)
- **Same grazing-elevation sensitivity** seen in the site-specific K comparison — consistent across both threads

Delay spread: the RT tail falls short, then ends

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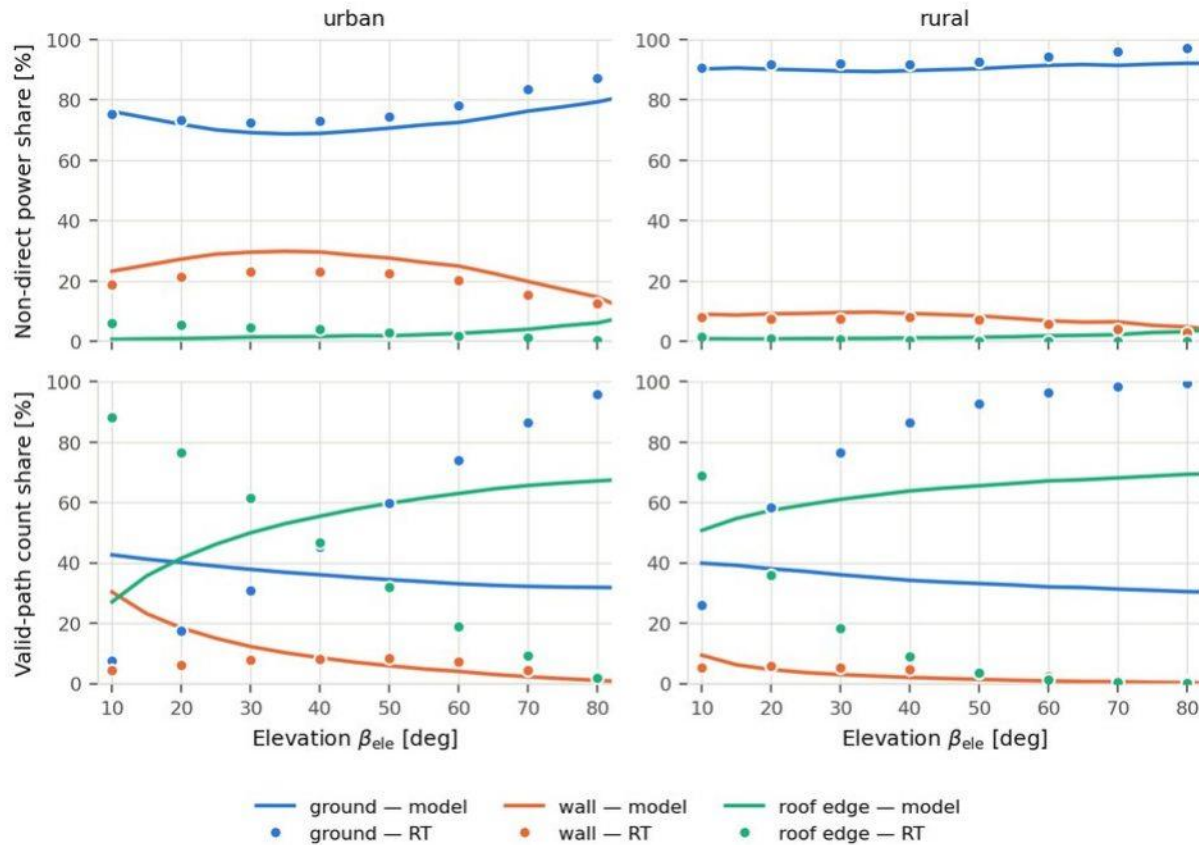
- **Urban** 40.4 / 45.0 ns at 10°, falling to 2.7 / 3.7 ns at 80°; rural 3.1 / 6.2 ns at 20°, roughly half the model (RT / model)
- **The deficit is tail power, not the LoS spike** — RT tracks the model through the first decade of excess delay, then falls below it
- **By 80° the tail is gone** — in every scene of both ensembles the longest non-direct path is the ground tap at 9.85 ns. No wall reflection and no roof-edge diffraction is returned at all



Non-direct PDP, 33 ns bins on the model's grid. Lines: model; markers: RT. Filled = LoS state, open = NLoS.

Mechanism split: Disagreement on diffraction

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- **Ground reflection dominates** the non-direct power everywhere — urban 72.4–87.2%, rural 90.5–97.2%
- **The trends run opposite** — the urban roof-edge diffraction share falls toward zenith in RT (6.1% $\rightarrow$ 0.3%) while the model's rises (0.7% $\rightarrow$ 6.1%). This is the clearest mechanism-level disagreement, and the likely source of the delay-spread deficit

Doppler spread: Tracks at lower elevation

- **Tracks at low elevation** — the Doppler spread and coherence time track at lower elevations, but deviate from the model at high elevations
- **Low Diffraction Rate** — With the thin wall PPP model uses, the RT model does not generate roof edge diffractions to a significant degree at high elevations(refer to table 28 Overleaf)
- **Fewer Ground Bounces** — Higher elevations also result in fewer ground bounces due to the geometry of the scene, contributes to under sampling of NLoS conditions at high elevations.

