TERA · HFTA COMPARISON

Where HFTA Misleads: HFTA vs TERA MoM at Three Sites and 100 Stations

2026-11-06, HFTA rerun through its own DLL (first issued 2026-11-03) · 14.2 MHz with a 3-element Yagi, plus 7.1, 21.2 and 28.5 MHz in section 8, and a survey of 100 randomly drawn US stations in section 9 · 30–100 ft · average ground (εr 13, σ 0.005 S/m) · horizontal polarization

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Sites	`K6TU Tower; Mt Um Main; K6TU (sorta)`
Engines	`HFTA (YTWCore.dll) vs TERA 2-D MoM`
Source	`docs/hfta-error-budget.md`
Branch	`hfta-error-budget`

Many experienced contesters chose their antenna heights with HFTA. This report measures where HFTA's elevation patterns go wrong, by how much, and why. Each case runs HFTA and TERA's 2-D method-of-moments (MoM) solver on identical terrain, antenna and ground.

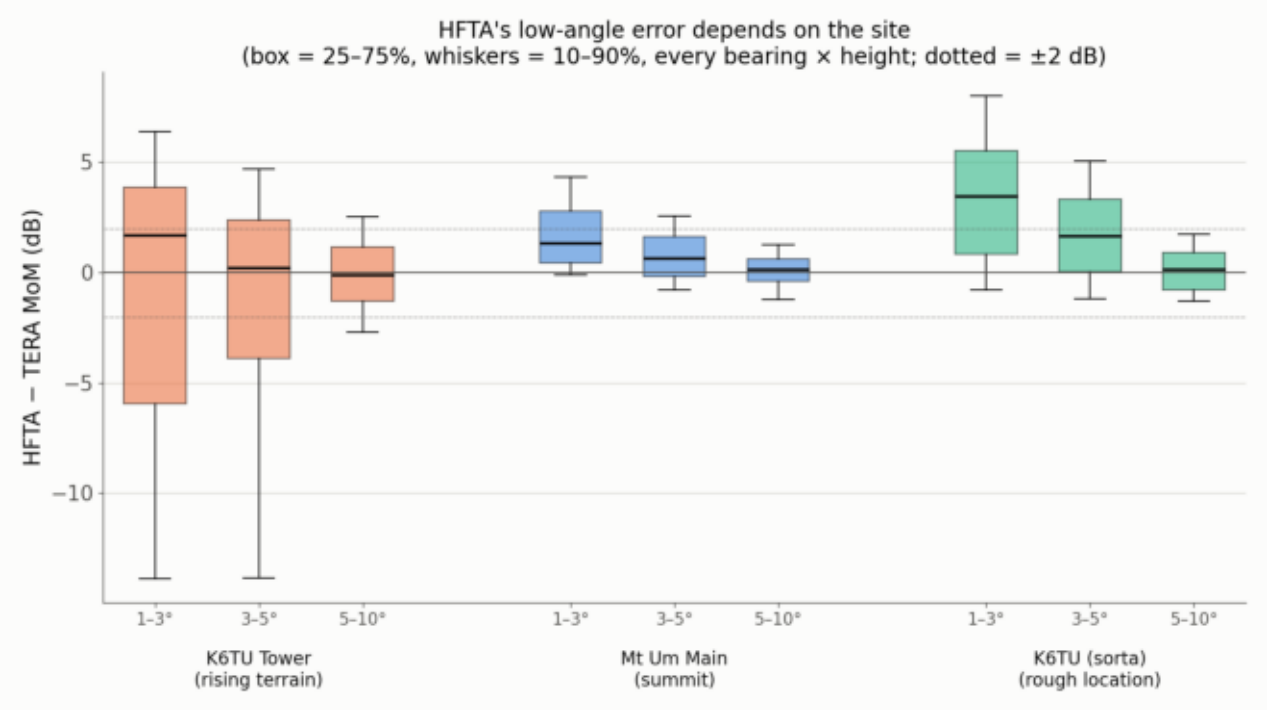
HFTA here means HFTA's own calculation engine, the YTWCore.dll that ships with it, given the same inputs HFTA.exe gives it (section 2.2). Two of the sites sit at opposite ends of the terrain spectrum, and the third falls between them:

- K6TU Tower: the terrain mostly rises away from the tower. Median true gain at 1–3° is −5.0 dBi.
- Mt Um Main: the tower is on a 1048 m summit, and the ground falls away on every bearing. Median true gain at 1–3° is +8.8 dBi.
- K6TU (sorta): a profile made earlier from rough coordinates (37.42, −122.21). From 104 m elevation, the horizon is open (−1.3°) to the north and east and rises to +1.5° to +2.0° to the south and southwest. Beyond HFTA's 4.41 km, a ridge 550–610 m higher than the site sits 7.5–9.5 km to the west and southwest. Median true gain at 1–3° on the 4.41 km profile is +1.8 dBi.

Every number comes from investigations/hfta-error-budget/analysis.py: summary_markdown() per site, and combined_tables() for the tables in section 4. Sign convention throughout: positive means HFTA reads higher than TERA.

1 Summary

HFTA's errors come almost entirely from its physics: how HFTA's ray tracer, released in 2003, handles diffraction and ground reflection. Its bookkeeping shortcuts (terrain thinning, smoothing, a simplified Yagi) cost little. How large the physics error is depends strongly on the site. From a dominant summit HFTA is a fair guide that reads a dB or two optimistic at low angles. Where terrain rises in front of the antenna it can be wrong by more than 10 dB in either direction, and it can point to the wrong antenna height. The rolling-terrain sorta site has the largest bias of the three: HFTA reads a median 3.5 dB high at 1–3°. There, a ridge HFTA's 4.41 km profile cannot see makes the real answer worse still, and HFTA ends up a median 5.1 dB high against TERA on the full 10 km profile, and as much as 22 dB high.



HFTA minus TERA by elevation window at each site

Result	K6TU Tower	Mt Um Main	K6TU (sorta)
Bearings × heights	25 × 8 = 200	24 × 8 = 192	36 × 8 = 288
Physics > 2 dB off, 1–3°	174	122	221
… of which HFTA high / low	120 / 54	122 / 0	210 / 11
Median total error, 1–3°	+1.7 dB	+1.3 dB	+3.5 dB
False lobes (> 10 dB high)	93	30	88
False shadows (no signal)	43	0	5
dB per 10 ft, TERA / HFTA	1.36 / 0.62	1.24 / 1.06	1.45 / 0.78
Wrong best height	11 of 25	9 of 24	13 of 36
Most dB lost to it	10.6	2.6	5.5
Range > 2 dB at 1–3°	82 (≤ 7.2 dB)	8 (2.6 dB)	120 (≤ 10.3 dB)
HFTA vs TERA 10 km, 1–3°	+2.5 dB	+1.6 dB	+5.1 dB

The height rows use the mean gain at 1–5°. "Range" counts cases where terrain past 4.41 km moves the 1–3° mean by more than 2 dB. The last row is the median gap between what HFTA shows and TERA's answer on the full 10 km profile: the physics error and the range error together.

Key findings:

1. Low angles are HFTA's weak spot at every site. Above 10° the two tools agree within about 1 dB.
2. False lobes: HFTA invents low-angle gain that isn't there. At K6TU 151° and 60 ft it shows +8 dBi at 1.5° where TERA has −7. At Mt Um 330° and 30 ft it overstates 1–3° by 8 dB. At sorta 250° and 60 ft it overstates 1–3° by 12 dB.
3. False shadows: looking into rising terrain, HFTA can show no signal at all below 3–6°, where the real pattern is weak but present. This is common at K6TU Tower, and at sorta it appears only in a 1° band on one bearing.
4. HFTA understates what height buys you at low angles, by about half at K6TU Tower and at sorta. At Mt Um the summit already supplies the low-angle gain, and the two tools nearly agree.
5. HFTA ignores ground-reflection loss. Over flat average ground its lobes are up to 1 dB high, even with no terrain at all.
6. The 4.41 km profile limit is a separate error, large where terrain keeps climbing past it and negligible where it falls away. At sorta it is the largest single effect on 15 of 36 bearings: a ridge 7.5–9.5 km out lowers the true 1–3° gain by up to 10 dB, and HFTA cannot see it.
7. The errors are largest on the low bands. Repeating all three sites at 7.1 MHz (2-element), 21.2 and 28.5 MHz (4-element) shows HFTA's optimism at 1–3° falling steadily with frequency, from a median of +2.5 to +7.0 dB on 40 m to between −0.2 and +1.0 dB on 15 and 10 m (section 8). The spread of large errors at K6TU Tower stays on every band. Its understatement of what height buys holds on every band at the two non-summit sites, worst on 40 m, where HFTA reports a quarter to a third of the real benefit.

8. A random survey of 100 US stations confirms both main findings on every band (section 9). HFTA reads high at 1–3° at 89, 92, 78 and 67 of 100 stations on 40, 20, 15 and 10 m (all $p < 0.001$), by a typical 5.4, 2.8, 1.4 and 0.6 dB. It understates what height buys at 92–97 of 100 stations, reporting about half the real benefit. Following HFTA's best height loses more than 2 dB on at least one bearing at 76–90% of stations. The three original sites turn out to be typical, not extreme.
9. What doesn't matter:
   - λ/8 thinning and 5-point smoothing each cost under 0.3 dB.
   - HFTA's built-in Yagi model is a uniform 1.1 dB low.
   - The DEM source or sampling is about 0.1 dB.

2 Method

2.1 Like-for-like inputs

Both tools read the same legacy terrain profiles: 148 points at 30 m spacing, out to 4.41 km. That is the limit of OpenHFTA, the reconstruction of HFTA's engine the study first ran (section 2.2): it silently keeps only the first 148 points of any longer profile, and the study's wrapper refuses longer files. HFTA.exe itself reads up to 150.

- K6TU Tower: profiles from K6TU-Tower.zip (NED). 25 bearings: every 15°, plus 151°, a bearing already known to give a false low-angle spike in ray tracing. The 10 km arm uses "K6TU Tower (TERA)", 3DEP sampled at 5 m.
- Mt Um Main: the legacy profile "Mt Um - Main Tower" (prod post 97295, at 37.153217, −121.897383) had never been run. It was regenerated on 2026-11-02 by queuing the same paas_terrain_worker job that the WordPress Generate button sends, giving result post 540001 (NED). 24 bearings at 15° steps. The 10 km arm uses "Mt Um - Main Tower (TERA)" (post 538177), NED sampled at 10 m.
- K6TU (sorta): the legacy profile "K6TU (sorta)" (prod post 519120, at 37.42, −122.21, coordinates given only to 0.01°) was regenerated on 2026-11-03 the same way, giving result post 540023. Its 360 profiles are byte-identical to a copy saved in June. 36 bearings at 10° steps. The 10 km arm uses "K6TU - sorta (TERA)", created on prod for this study on 2026-11-03 under the K6TU account at the same coordinates (request post 540024, result post 540026), NED sampled at 10 m.

Common settings:

- Heights: 30–100 ft in 10 ft steps.
- Ground: HFTA's average ground, 13 / 0.005, in both tools. TERA's own average preset is 15 / 0.005 and is not used here.
- TERA mesh: λ/10. Each bearing is one matrix factorization, with all 16 antenna × height cases solved together (mom2d.solve_pattern_multi).
- Run time: 0.3–0.7 s per bearing at 4.41 km and about 2.7 s at 10 km, so each site runs in about 15–45 s on 8 cores.

2.2 Which HFTA

The study was first run with OpenHFTA, a Fortran reconstruction of YTWCore1, the routine that does HFTA's calculation. OpenHFTA was decompiled from the YTWCore.dll that ships with HFTA, not ported from N6BV's source code. An earlier version of this report called it a port. Checked afterwards against the DLL itself, OpenHFTA did not match closely enough: with diffraction on, it was off by more than 1 dB in 12% of this study's cases, and by more than 10 dB in some. About a third of that came from the build used, an ARM build that cannot use the x87 flags OpenHFTA requires; an x86 build given the same arrays matches the DLL within 0.1 dB at the named sites. The rest is HFTA's own sensitivity to the last bit of its terrain input, which OpenHFTA's front end does not reproduce (docs/hfta-openhfta-provenance.md, "Which OpenHFTA build"). Every HFTA result in this report has therefore been rerun through the DLL itself, under Wine, with each terrain profile read the way HFTA.exe's own front end reads it. Given inputs built that way, the DLL reproduces a 360-bearing HFTA.exe sweep exactly (docs/hfta-openhfta-provenance.md on the development branch).

The rerun changed no conclusion. Most numbers moved by 0.1 dB or a few cases. The largest changes are at Mt Um: following HFTA's best height at 45° now costs 2.6 dB on 20 m, where 0.9 dB was the largest before, and its worst bearing reads 4.9 dB high instead of 5.1. In the survey, no count moved by more than two stations, and every test keeps $p < 0.001$.

Two details:

- In 10 of the 14,740 cached runs (survey stations, 15 and 10 m), the DLL returns no number (NaN) at five neighboring angles. Those angles are left out of the window means; the rest of each pattern still counts.
- The flat-ground check and figure (sections 3 and 5.4) still use OpenHFTA. On that flat profile over average ground it matches the DLL within 0.07 dB at 30, 60 and 100 ft.

2.3 The error ladder

Moving from HFTA to TERA one ingredient at a time turns each step into a line item. The like-for-like items add up exactly to the total error.

Rung	Engine	Antenna	Profile	Output stage
H0	HFTA DLL 3-Ele	HFTA cosine lobe	4.41 km	HFTA smoothing + floor
M1	TERA MoM	HFTA cosine lobe	λ/8-thinned	HFTA smoothing + floor
M2	TERA MoM	HFTA cosine lobe	4.41 km	HFTA smoothing + floor
M3	TERA MoM	HFTA cosine lobe	4.41 km	none
M4	TERA MoM	NEC 3-el Yagi	4.41 km	none (reference)
M4j	TERA MoM	NEC 3-el Yagi	10 km set, cut at 4.41 km	none
M5	TERA MoM	NEC 3-el Yagi	10 km set	none

Line item	Definition	What it measures
Ray-tracing physics	H0 − M1	Diffraction, reflection and ray handling
Terrain thinning	M1 − M2	HFTA's λ/8 decimation
Smoothing + floor	M2 − M3	5-point average, −30 dB floor
Antenna model	M3 − M4	Cosine lobe vs NEC Yagi
Total	H0 − M4	Sum of the four above
DEM sampling/source	M4 − M4j	10 km data set, cut back to 4.41 km
Range	M4j − M5	Terrain beyond 4.41 km

How the HFTA quirks were reproduced:

- Smoothing: re-derived from YTWCore1.f90 lines 1031–1049. Each output bin is a centered 5-point mean of |E|, the 0.25° and 0.5° bins are floored at −30 dB, and |E| is clamped at 1.4×10^{-4}.
- Thinning and antenna table: copied from the unmerged HFTA-comparison branch. In TERA, the HFTA lobe is zeroed behind the antenna, because HFTA launches no rays there.

The reference Yagi is a generic NEC-2 design (scripts/nec_yagi_pattern.py, PyNEC):

- 1-inch aluminum elements, 0.30λ boom.
- Element lengths searched for maximum gain, with F/B of at least 20 dB and feed resistance of at least 20 Ω.
- Result: 8.14 dBi, F/B 24.5 dB, 21.5 Ω, elevation half-power beamwidth 99.5°. For comparison, HFTA's built-in lobe is 7.0 dBi with a 97.5° beamwidth.

2.4 Statistics

- Metric: the mean signed difference in dB over each elevation window. Windows are 1–3, 3–5, 5–10, 10–20 and 20–35°, in absolute dBi. There is no whole-pattern RMS.
- 2 dB is the threshold for "matters".
- Clipping: both curves are clipped at HFTA's −30 dB floor first. Where HFTA finds no field, it outputs −77 dB; those bins are counted separately as false shadows instead of being averaged in.
- False lobe: HFTA more than 10 dB above TERA (rung M1) at any angle from 1° up.
- Best height: the height in 30–100 ft with the highest mean gain at 1–5°.

3 Checks

- Flat ground: TERA matches the exact two-ray solution, with the peak within 0.05 dB and 0.25° at 30, 60 and 100 ft.

- Perfect ground: OpenHFTA matches two-ray, mean difference within ±0.2 dB, peak exact. Over average ground it matches only once the reflection-loss term is removed (section 5.4). On flat average ground OpenHFTA and HFTA's DLL agree within 0.07 dB (section 2.2).
- Regression anchor: K6TU-151, isotropic 2.01 dBi at 18.29 m, gives −15.32 dBi at 1°. The June record is −15.52. The 0.2 dB difference comes from commit 6c8e1e3 (Aug 1), the second-kind MoM form for horizontal polarization over lossy ground, and the original run_mom.py reproduces −15.32 today.
- Order check: each item was also computed one step at a time from M4. The two orders differ by at most 0.42 dB at K6TU, 0.52 dB at Mt Um and 0.34 dB at sorta. The Mt Um figure is the thinning item, which is the smallest item and changes no conclusion.
- Ladder closure: the like-for-like items sum to the total within 10^{-14} dB.
- Tests: tests/test_hfta_quirks.py.

4 Where the error comes from

Each cell is the median over all cases, followed by [the number of cases beyond ±2 dB]. The figures show the 10th–90th percentile spread.

K6TU Tower (200 cases):

Line item	1–3°	3–5°	5–10°	10–20°	20–35°
Ray-tracing physics	+2.7 [174]	+1.4 [133]	+0.9 [77]	+0.9 [14]	+1.5 [73]
Terrain thinning (λ/8)	0.0 [0]	0.0 [0]	0.0 [0]	0.0 [0]	0.0 [2]
Smoothing + floor	+0.1 [0]	0.0 [0]	0.0 [0]	0.0 [0]	0.0 [0]
Antenna model	−1.1 [0]	−1.1 [0]	−1.1 [0]	−1.1 [0]	−1.1 [0]
Total (like-for-like)	+1.7 [151]	+0.2 [123]	−0.1 [53]	−0.3 [2]	+0.3 [40]
DEM sampling/source	+0.1 [0]	+0.1 [0]	+0.1 [0]	0.0 [0]	0.0 [0]
Range (4.41 → 10 km)	+0.7 [82]	+0.1 [40]	0.0 [0]	0.0 [0]	0.0 [0]

Mt Um Main (192 cases):

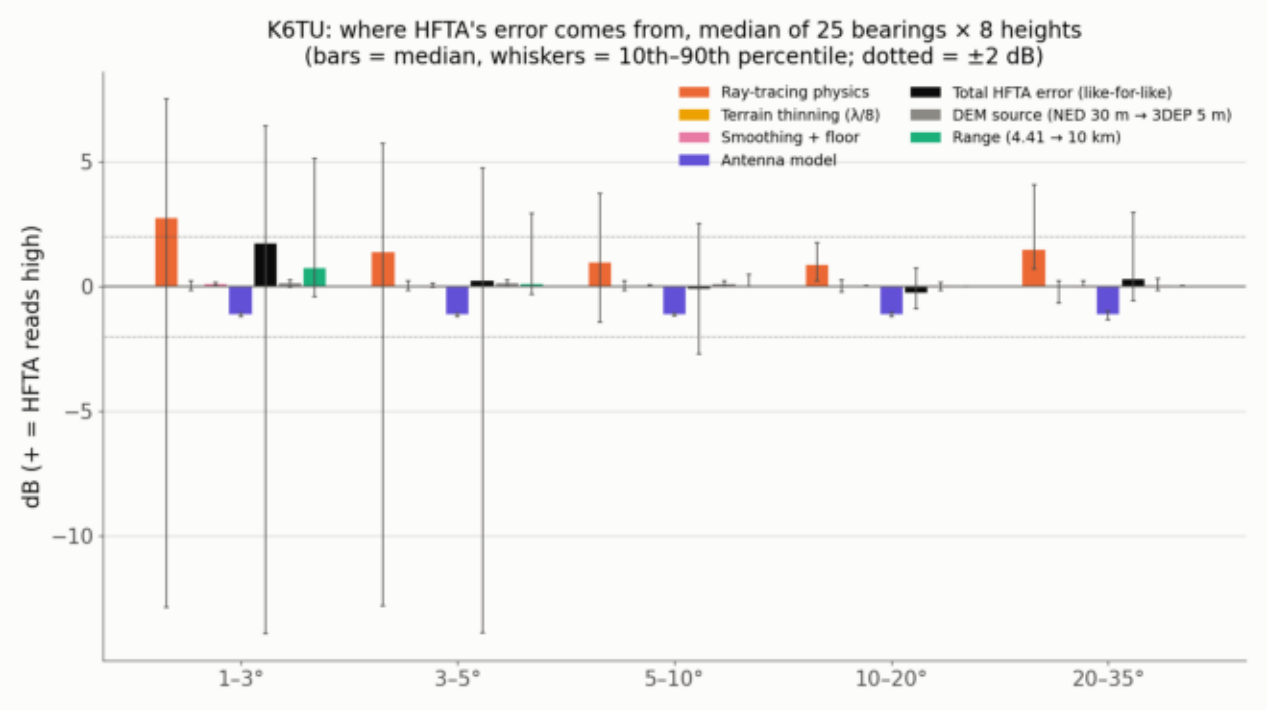
Line item	1–3°	3–5°	5–10°	10–20°	20–35°
Ray-tracing physics	+2.4 [122]	+1.7 [76]	+1.2 [26]	+1.0 [26]	+1.6 [65]
Terrain thinning (λ/8)	+0.1 [0]	+0.1 [0]	0.0 [0]	0.0 [0]	0.0 [0]
Smoothing + floor	0.0 [0]	0.0 [0]	0.0 [0]	0.0 [0]	+0.1 [0]
Antenna model	−1.2 [0]	−1.2 [0]	−1.1 [0]	−1.1 [0]	−1.1 [0]
Total (like-for-like)	+1.3 [74]	+0.7 [39]	+0.2 [14]	0.0 [8]	+0.5 [37]
DEM sampling/source	+0.1 [0]	+0.1 [0]	0.0 [0]	0.0 [0]	0.0 [0]
Range (4.41 → 10 km)	0.0 [8]	0.0 [0]	0.0 [0]	0.0 [0]	0.0 [0]

K6TU (sorta) (288 cases):

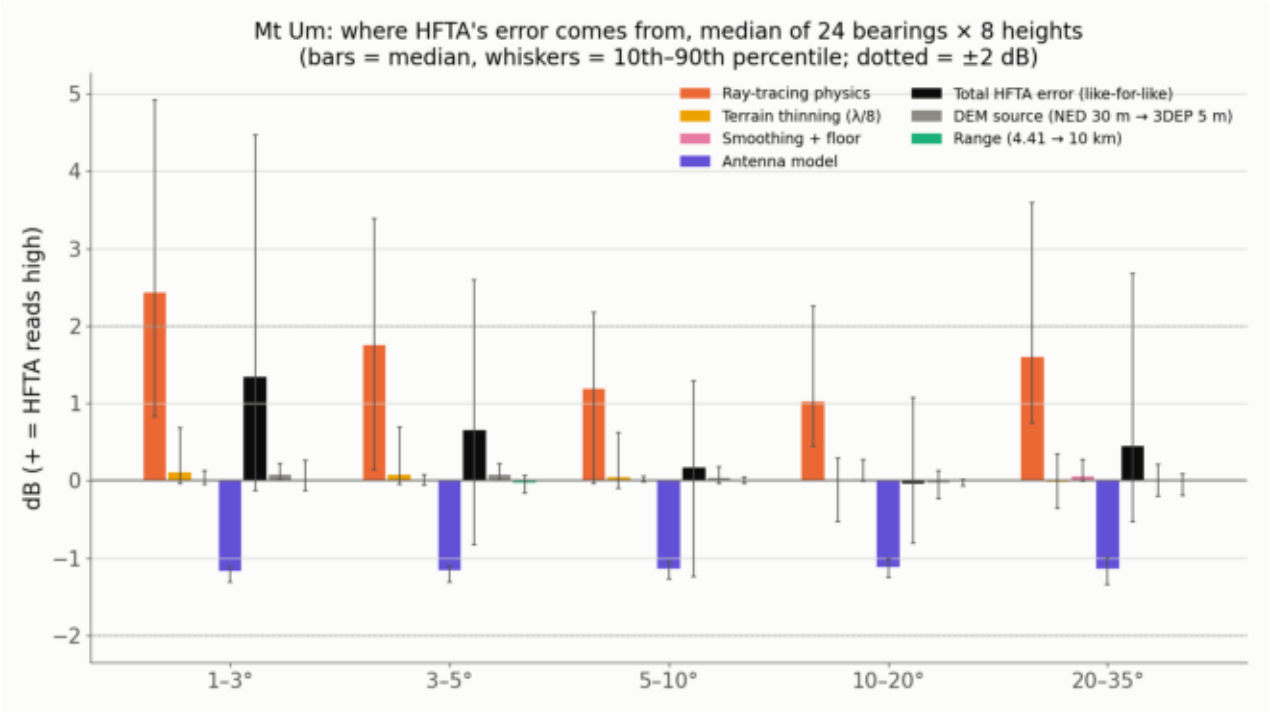
Line item	1–3°	3–5°	5–10°	10–20°	20–35°
Ray-tracing physics	+4.3 [221]	+2.5 [172]	+1.0 [55]	+1.0 [19]	+1.2 [28]
Terrain thinning (λ/8)	+0.1 [0]	+0.1 [0]	+0.1 [0]	0.0 [0]	0.0 [0]
Smoothing + floor	+0.1 [0]	0.0 [0]	0.0 [0]	0.0 [0]	0.0 [0]
Antenna model	−1.1 [0]	−1.1 [0]	−1.1 [0]	−1.1 [0]	−1.1 [0]
Total (like-for-like)	+3.5 [201]	+1.7 [139]	+0.2 [28]	−0.1 [4]	0.0 [23]
DEM sampling/source	0.0 [0]	0.0 [0]	0.0 [0]	0.0 [0]	0.0 [0]
Range (4.41 → 10 km)	+0.7 [120]	+0.1 [80]	0.0 [0]	0.0 [0]	0.0 [0]

At every site, only the physics item and the range item (at K6TU and sorta) ever exceed 2 dB. What differs between sites is the size and spread of the physics error:

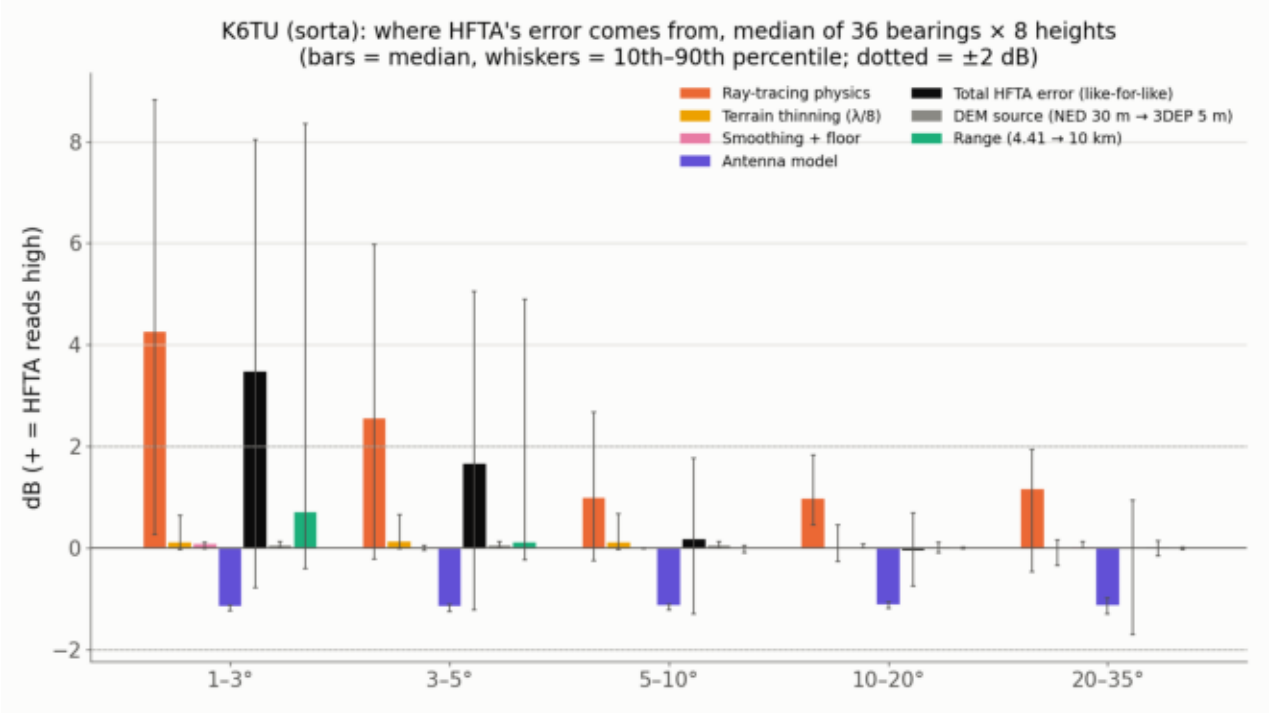
- K6TU Tower: the low-angle error runs from −14 to +6 dB across cases.
- Mt Um: it stays between 0 and +4 dB.
- Sorta: it is mostly optimistic, from −1 to +8 dB (10th–90th percentile), with the largest median of the three.



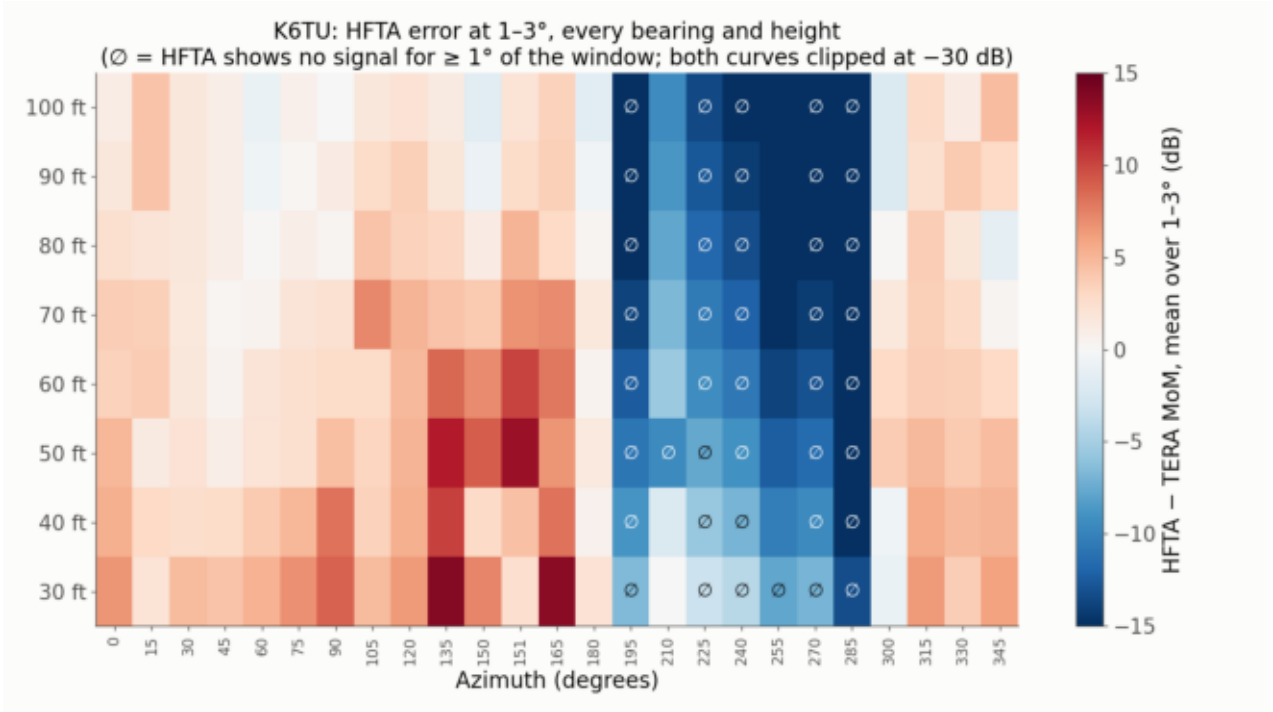
K6TU: line items by window



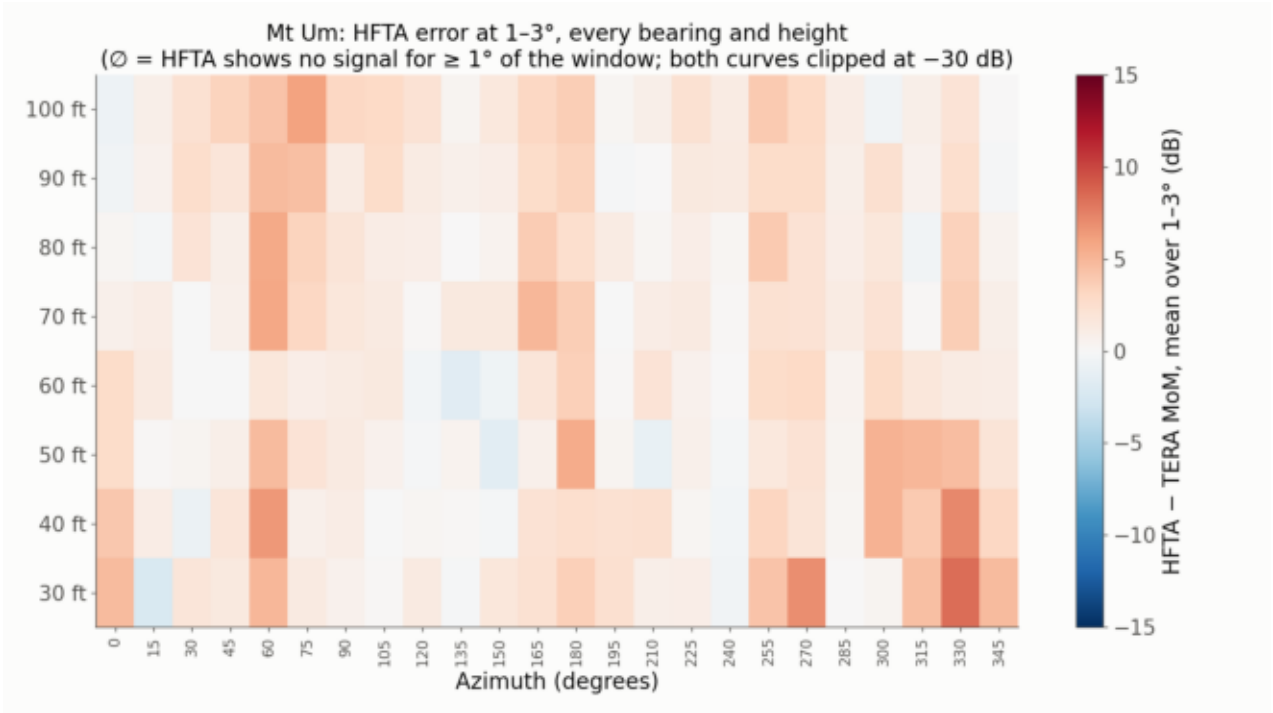
Mt Um: line items by window



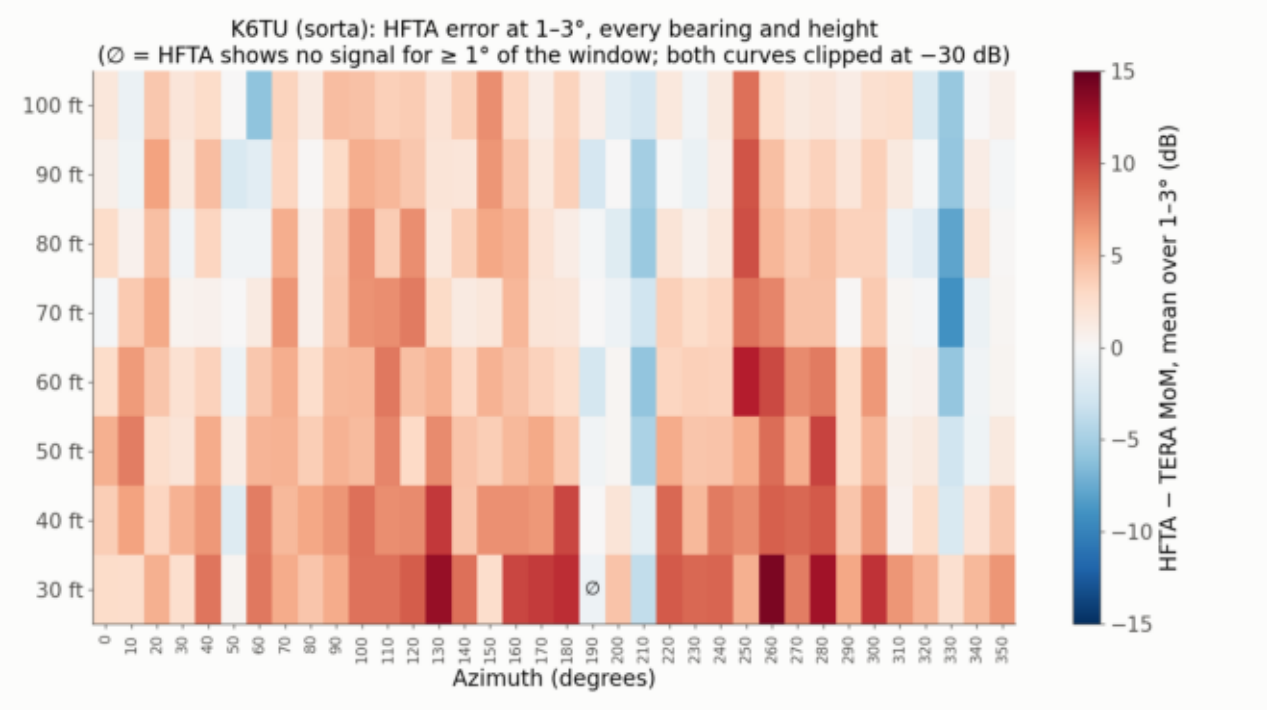
Sorta: line items by window



K6TU: error at 1–3° for every bearing and height



Mt Um: error at 1–3° for every bearing and height



Sorta: error at 1–3° for every bearing and height

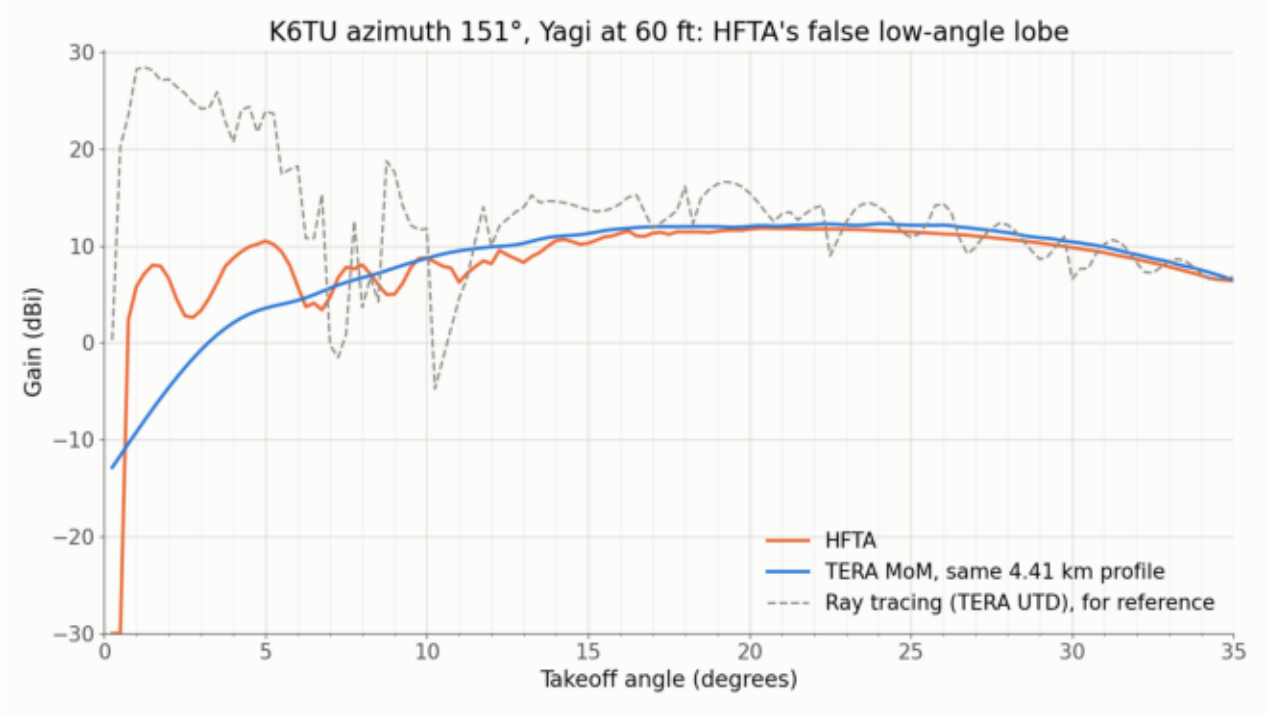
5 How HFTA goes wrong

5.1 False low-angle lobes

At K6TU 151° with the Yagi at 60 ft, HFTA shows two lobes below 6° that TERA does not. Rerunning HFTA with diffraction switched off separates them:

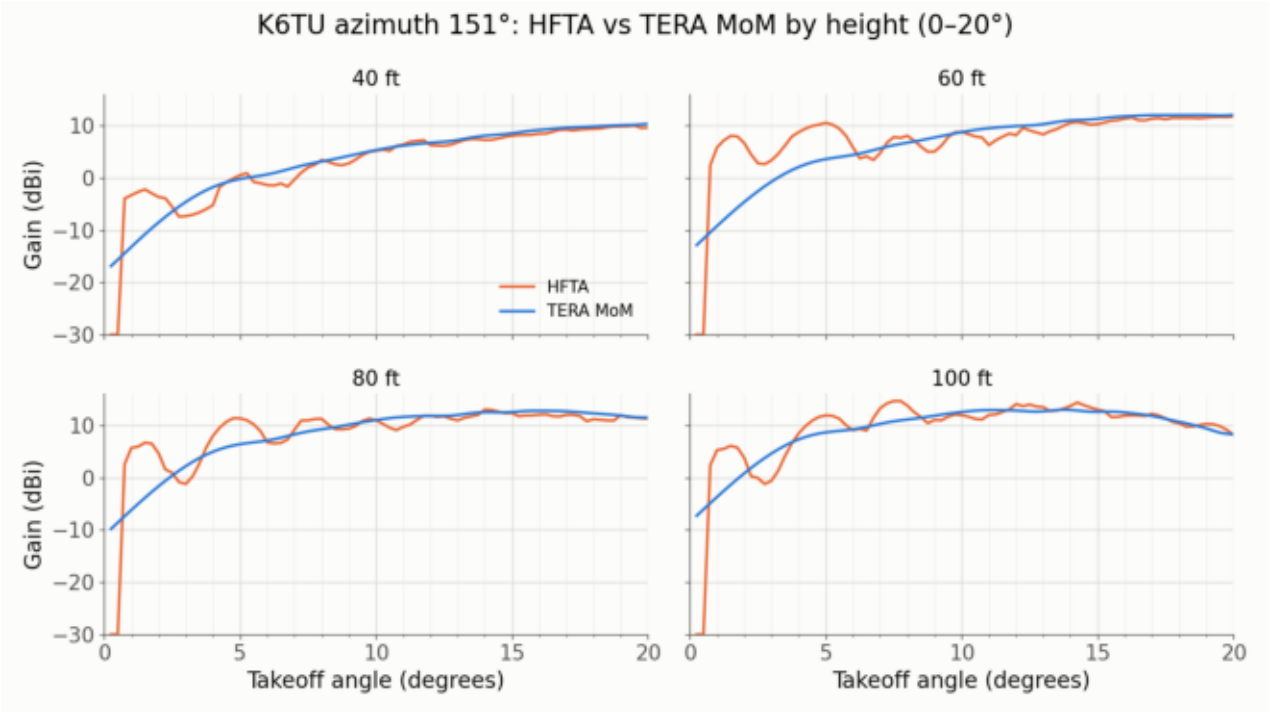
- The 1.5° lobe (+8.0 dBi) is still there at +7.0 dBi without diffraction, so it comes from HFTA's reflection sweep.
- The 5° lobe (+10.5 dBi) drops to +1.2 dBi without diffraction, so it is diffraction.

TERA's own ray tracer (UTD, the dashed curve) over-counts this terrain even worse: +28 to +31 dBi at 1° above 50 ft. That is a weakness of ray tracing at grazing incidence in general, and the reason TERA's default engine is MoM.



K6TU 151° at 60 ft

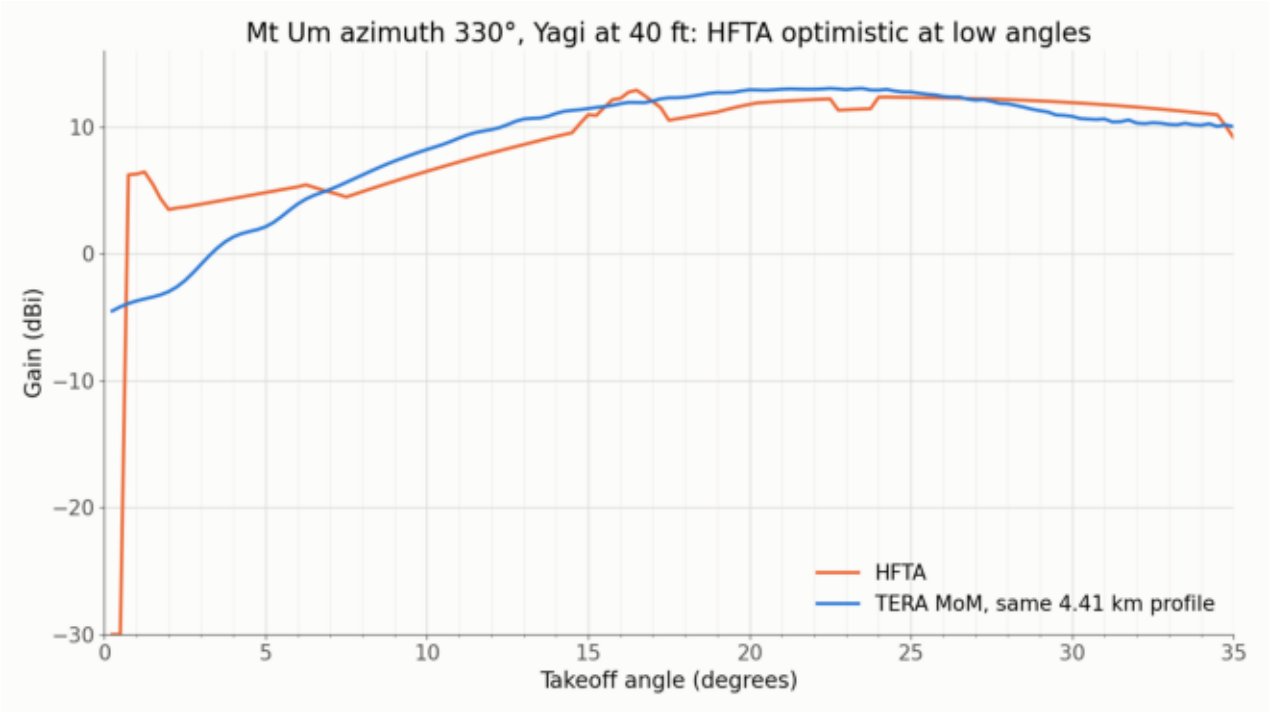
K6TU 151°	HFTA 1-3°	TERA 1-3°	TERA 10 km 1-3°	HFTA 3-5°	TERA 3-5°
30 ft	−8.9	−11.4	−14.1	−5.6	−4.7
40 ft	−4.3	−8.7	−11.4	−3.8	−2.0
50 ft	+6.4	−6.6	−9.3	+8.0	0.0
60 ft	+5.4	−4.8	−7.5	+7.9	+1.8
70 ft	+3.6	−3.2	−5.9	+6.9	+3.3
80 ft	+3.3	−1.8	−4.5	+6.5	+4.7
90 ft	+2.2	−0.5	−3.3	+6.5	+5.9
100 ft	+2.8	+0.7	−2.1	+7.1	+7.0



K6TU 151° by height

At Mt Um the same error is smaller and almost always optimistic. The worst bearing is 330°, where HFTA overstates low-height performance most:

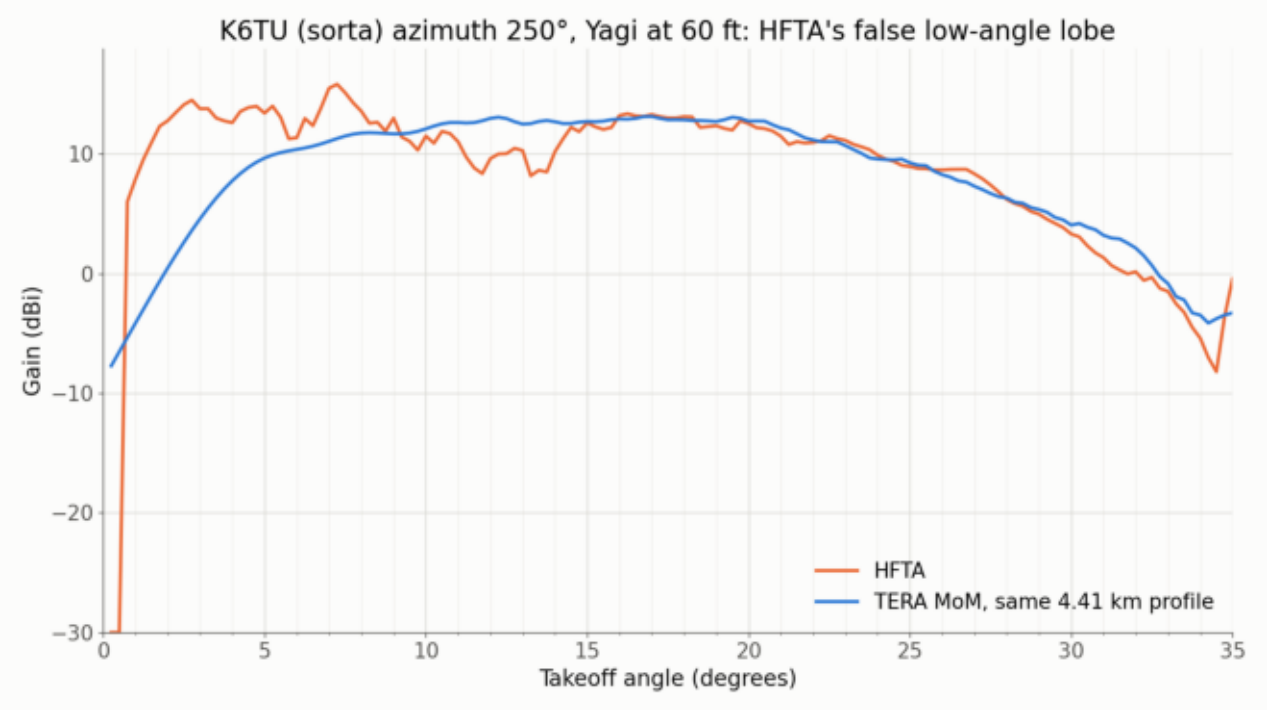
Mt Um 330°	HFTA 1–3°	TERA 1–3°	TERA 10 km 1–3°	HFTA 3–5°	TERA 3–5°
30 ft	+3.1	−5.2	−5.3	+4.0	−1.5
40 ft	+4.6	−2.7	−2.7	+4.4	+1.0
50 ft	+3.9	−0.7	−0.8	+4.7	+2.9
60 ft	+2.1	+0.8	+0.8	+4.6	+4.4
70 ft	+5.8	+2.1	+2.1	+5.8	+5.6
80 ft	+6.6	+3.2	+3.1	+6.7	+6.6
90 ft	+6.5	+4.0	+4.0	+7.9	+7.4
100 ft	+6.8	+4.8	+4.7	+8.1	+8.1



Mt Um 330° at 40 ft

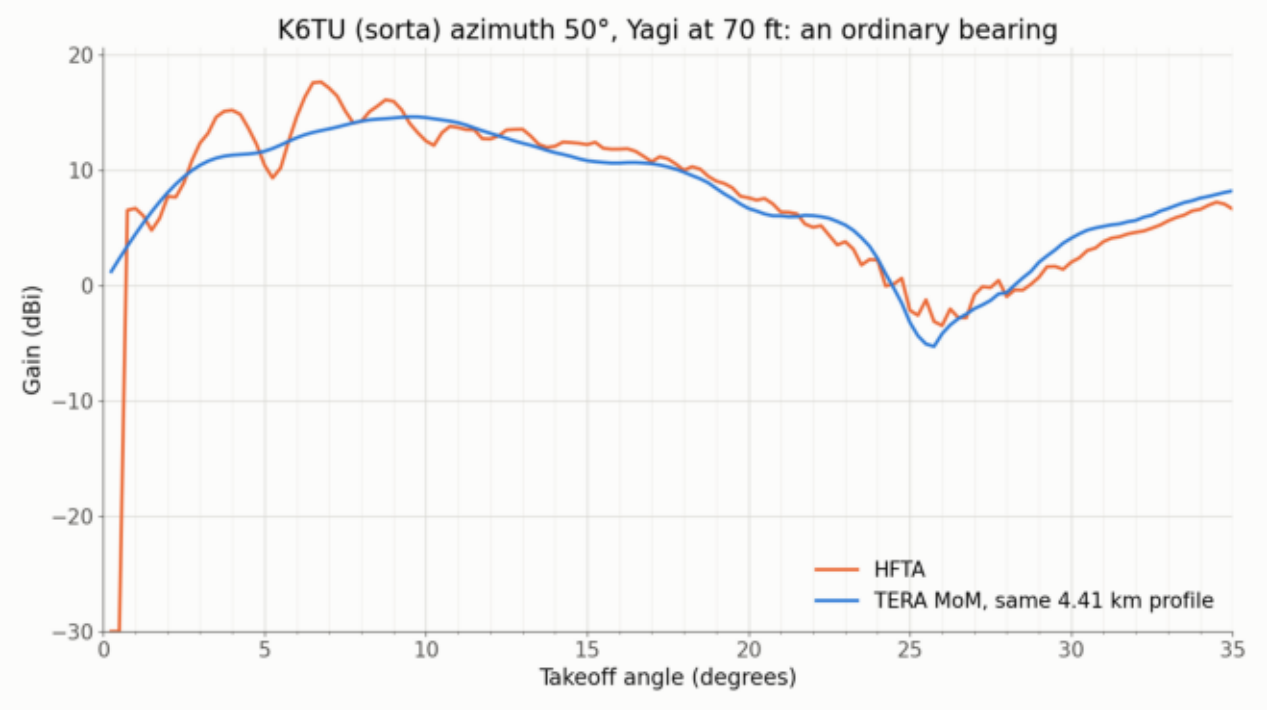
The sorta site has the strongest bias toward false lobes. HFTA's total reads high at 1–3° on 32 of its 36 bearings (median over heights), most of all at 250–260°, where the horizon is about +0.3°. At 250° and 60 ft HFTA shows +12.3 dBi at 1.75° where TERA has −0.7. Both of HFTA's mechanisms contribute there: with diffraction switched off it still reads +5.6 dBi, so about 6 dB comes from the reflection sweep and about 7 dB from diffraction.

Sorta 250°	HFTA 1-3°	TERA 1-3°	HFTA 3-5°	TERA 3-5°
30 ft	−0.4	−5.8	−2.2	+1.5
40 ft	+3.8	−3.2	+9.0	+4.0
50 ft	+4.3	−1.2	+9.8	+5.9
60 ft	+12.1	+0.4	+13.4	+7.5
70 ft	+9.8	+1.7	+11.6	+8.8
80 ft	+12.5	+2.8	+13.4	+9.8
90 ft	+13.2	+3.8	+14.8	+10.7
100 ft	+13.0	+4.7	+16.1	+11.5



Sorta 250° at 60 ft

This profile is also the one where TERA's own ray tracer (UTD) gave a low-angle spike. That spike is not confined to one bearing. With an isotropic source at 60 ft, the ray tracer reads 11 to 30 dB above MoM at 1–1.5° on every bearing tried between 30° and 70°. HFTA, by contrast, is close to TERA at 50°: within 0.1 dB at 1–3° with the Yagi at 70 ft, and with no false lobe over 10 dB at any height.

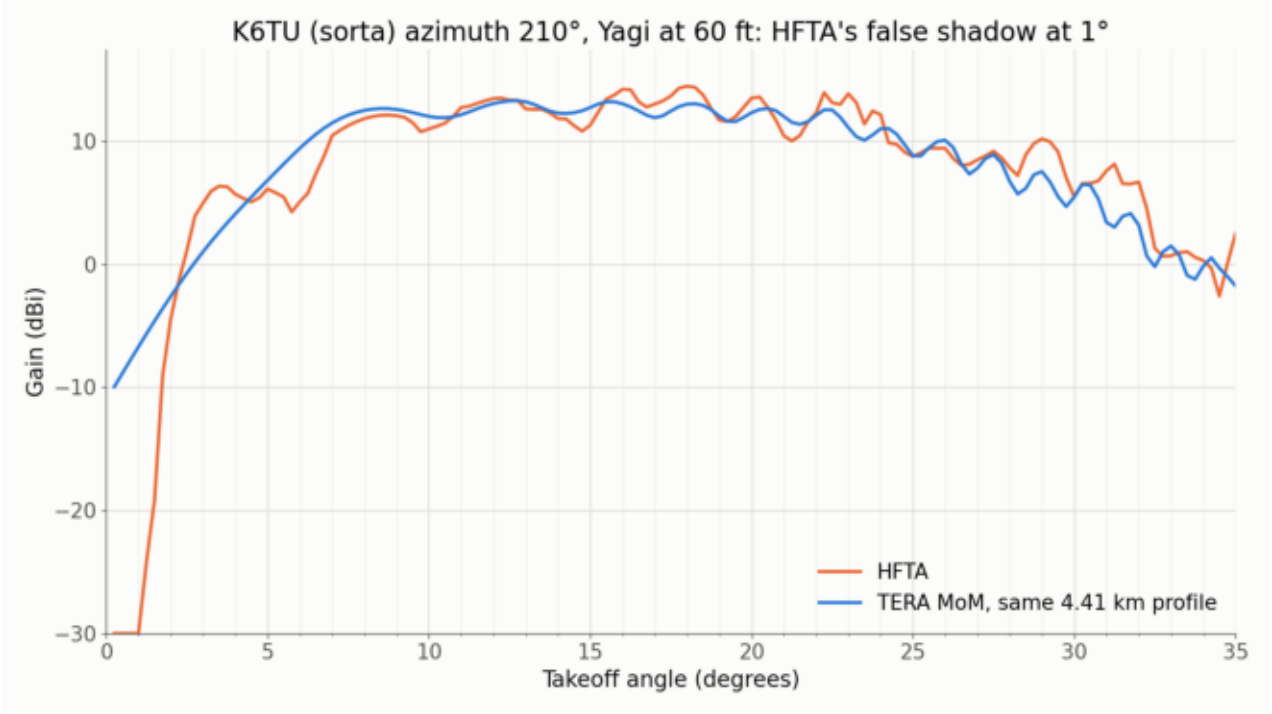


Sorta 50° at 70 ft

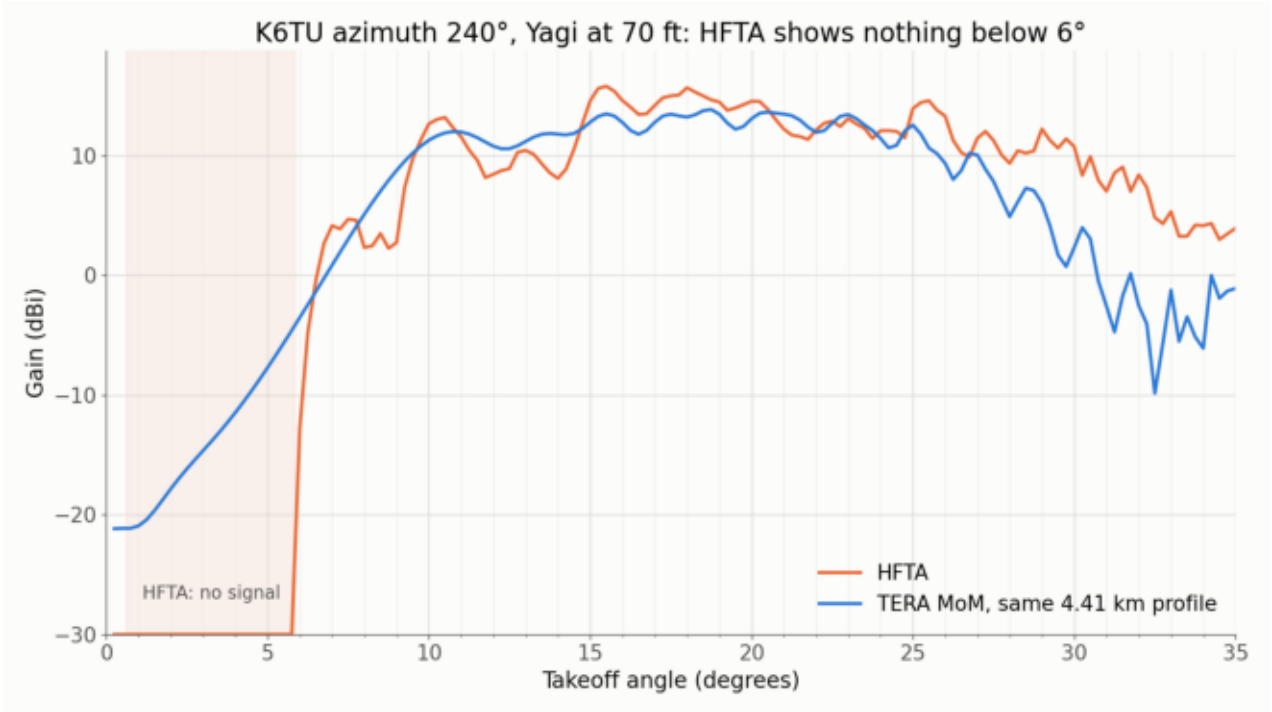
5.2 False shadows

On K6TU's western bearings, 195–285°, the antenna looks into terrain that rises to a +4° to +7° horizon. In 43 cases HFTA reports no field at all from 0.75° up to 3–6°. At 240° and 70 ft (horizon +6.4°) HFTA cuts off about 0.6° below the horizon, while TERA shows diffraction carrying signal over the ridge: −11.5 dBi at 4° and −7.7 at 5°. Both tools agree this is a poor direction. But HFTA's cliff makes height look irrelevant there, when in TERA every 10 ft still helps. Mt Um, with nothing blocking the horizon, has no false shadows.

The sorta site's horizon rises to only +2°, and HFTA finds no field at all in just 5 cases, all at 190° (30–70 ft), from 0.75° to at most 1.5°. Its next bearing, 210°, shows the same thing without a full blackout. At 60 ft (horizon +2.0°), HFTA reads −37 dBi at 1° and −19 at 1.5°, where TERA has −6.7 and −4.6. Without diffraction HFTA has no field there at all, so the little signal it shows comes only from its diffraction term.



Sorta 210° at 60 ft

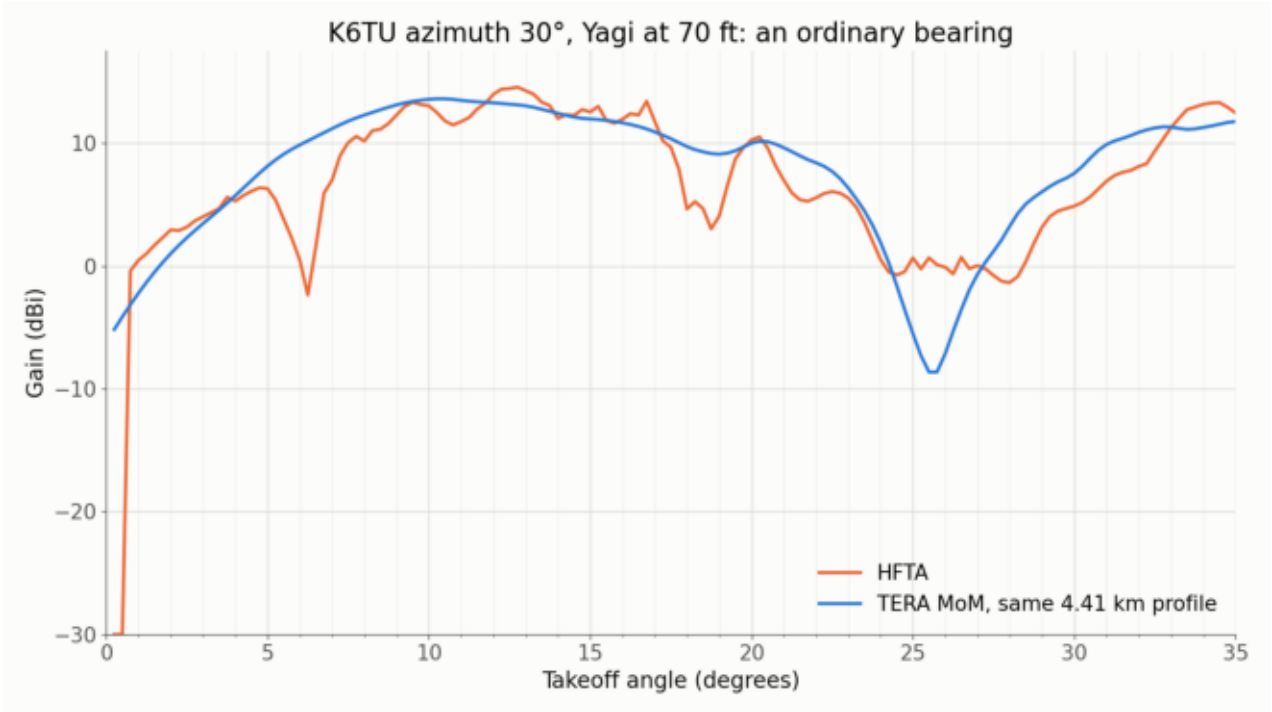


K6TU 240° at 70 ft

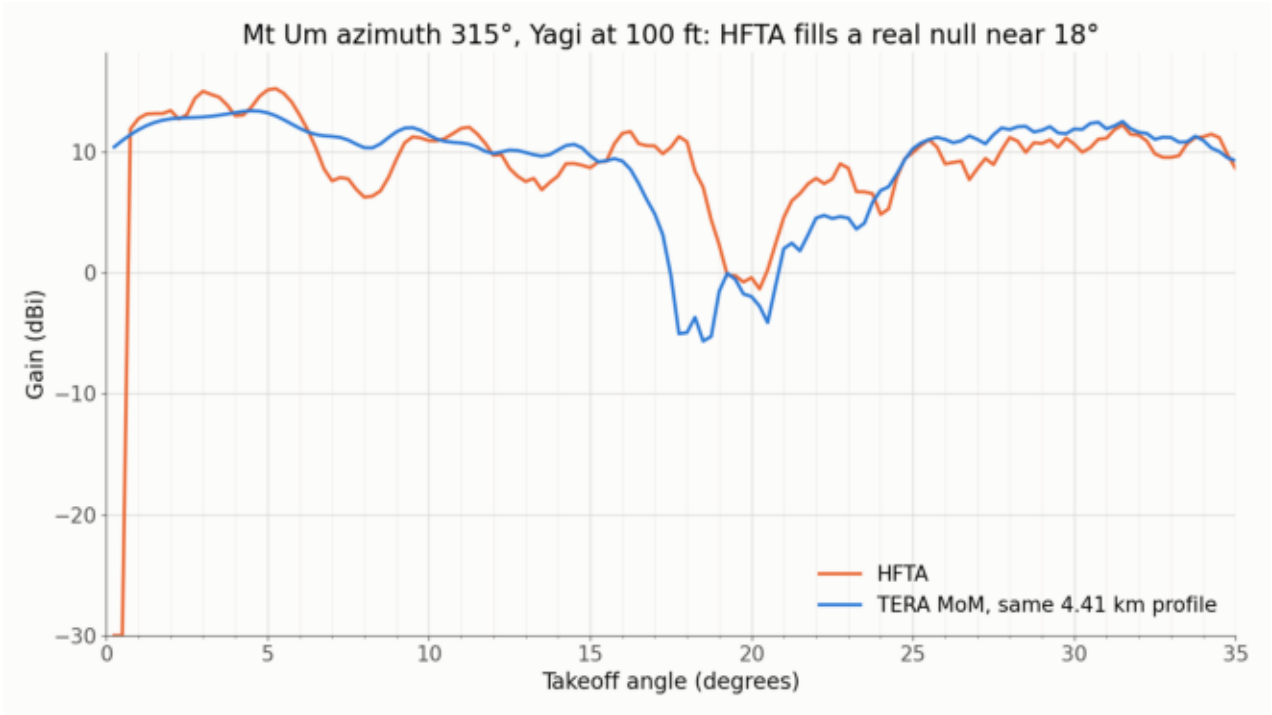
5.3 Invented and filled nulls

Away from the lowest angles, HFTA's pattern detail is unreliable even when its window averages look fine:

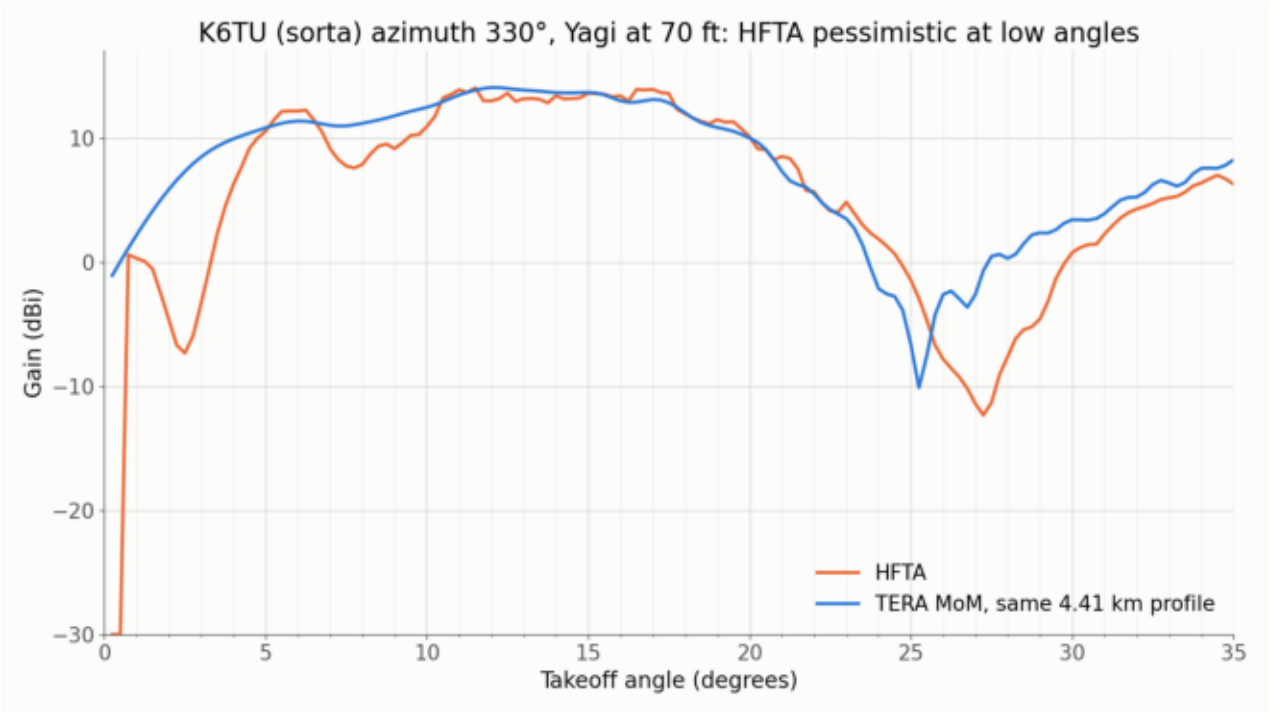
- K6TU 30° at 70 ft (open terrain): the two agree within about 1.5 dB at 1–5°. But HFTA has a false 12 dB notch at 6.25° (−2.3 dBi where TERA has +10), and it fills in the real null near 25°.
- Mt Um 315° at 100 ft: TERA has a real null between 17° and 21°, down to −5.6 dBi. HFTA reads +7 to +11 dBi across its deepest part, 17.75–18.5°, and puts its own shallower dip, to −1.3 dBi, near 20°.
- Sorta 330° at 70 ft (open horizon, −1.2°): HFTA's diffraction term invents a 15 dB notch at 2.5° (−7.3 dBi where TERA has +7.3). With diffraction off, HFTA reads +7.0 there, close to TERA. HFTA also places the real high-angle null 2° too high, at 27.25° instead of 25.25°. This is one of the few bearings at any site where HFTA is pessimistic at low angles: 1–3° reads −3.4 dBi against TERA's +5.6.



K6TU 30° at 70 ft



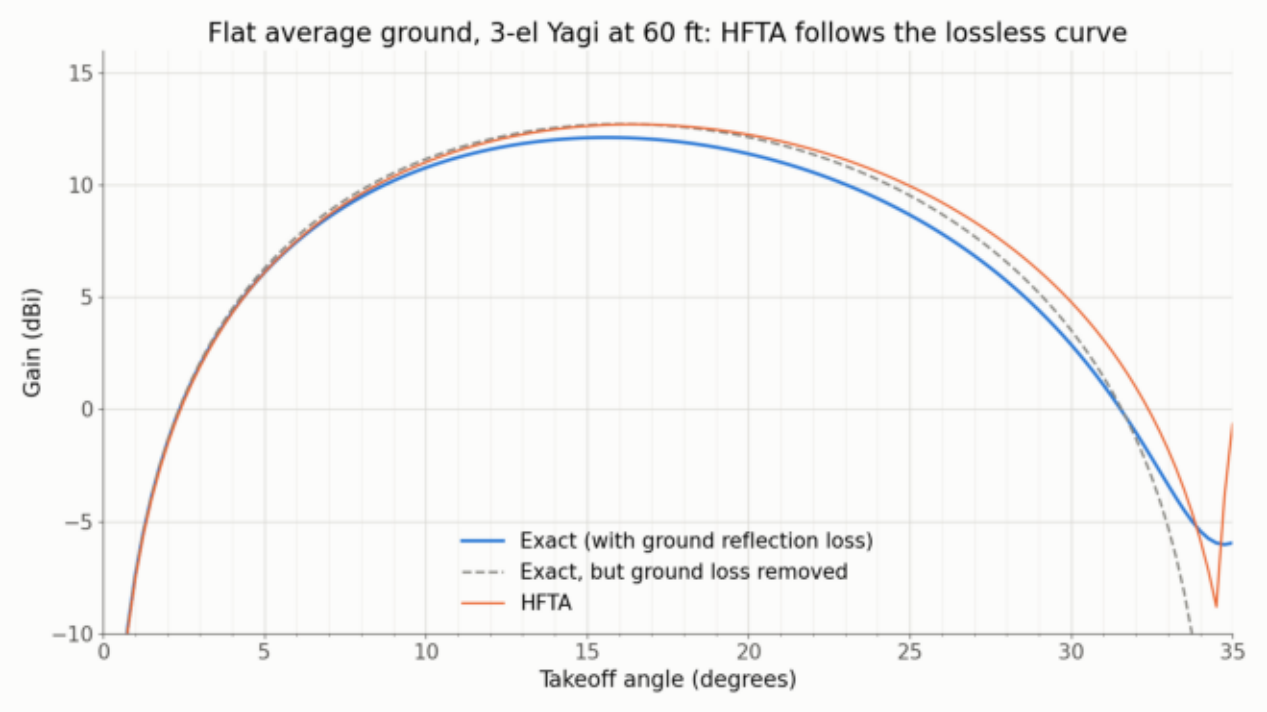
Mt Um 315° at 100 ft



Sorta 330° at 70 ft

5.4 Ground-reflection loss ignored

In its main reflection sweep, HFTA takes only the phase of the Fresnel reflection coefficient and drops its magnitude. Over perfect ground this makes no difference, and OpenHFTA matches the exact answer. Over average ground, part of every bounce is absorbed, so HFTA's lobes come out up to 1 dB high and slightly higher in angle. This bias is present at every site and accounts for much of the steady +1 to +1.6 dB physics median at 10–35°.



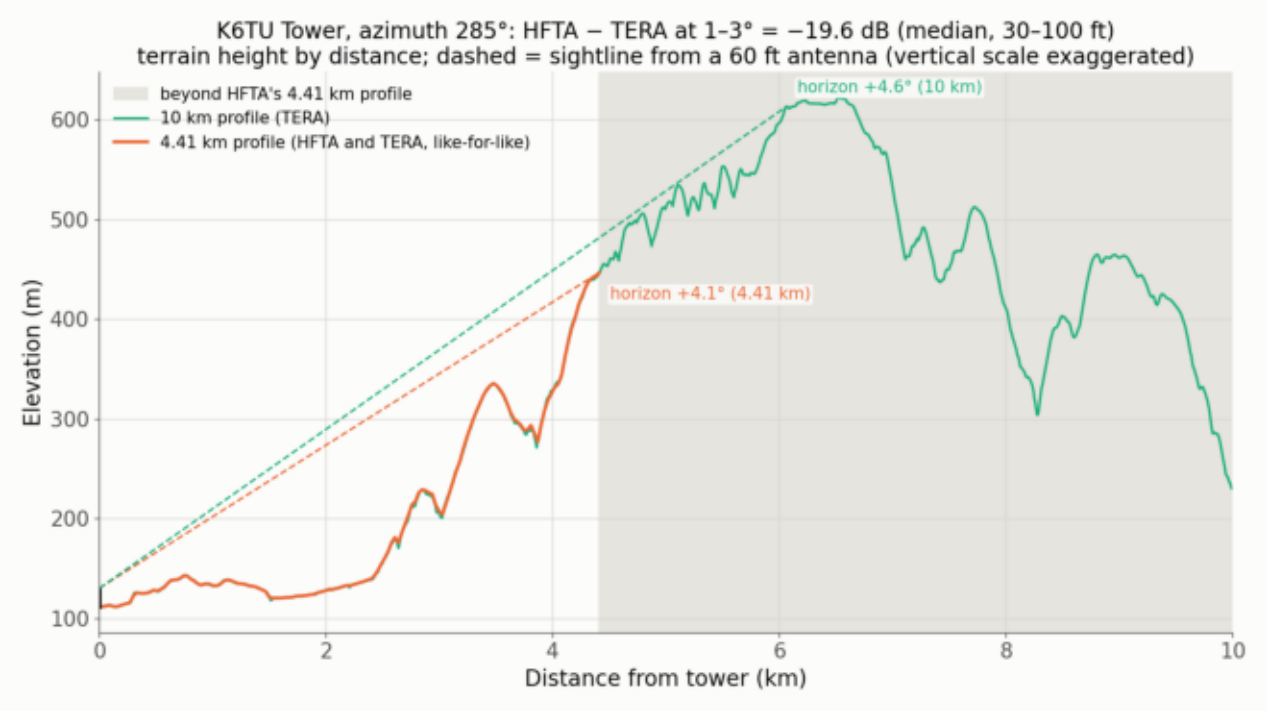
Flat average ground, 60 ft

5.5 The terrain on each site's worst bearing

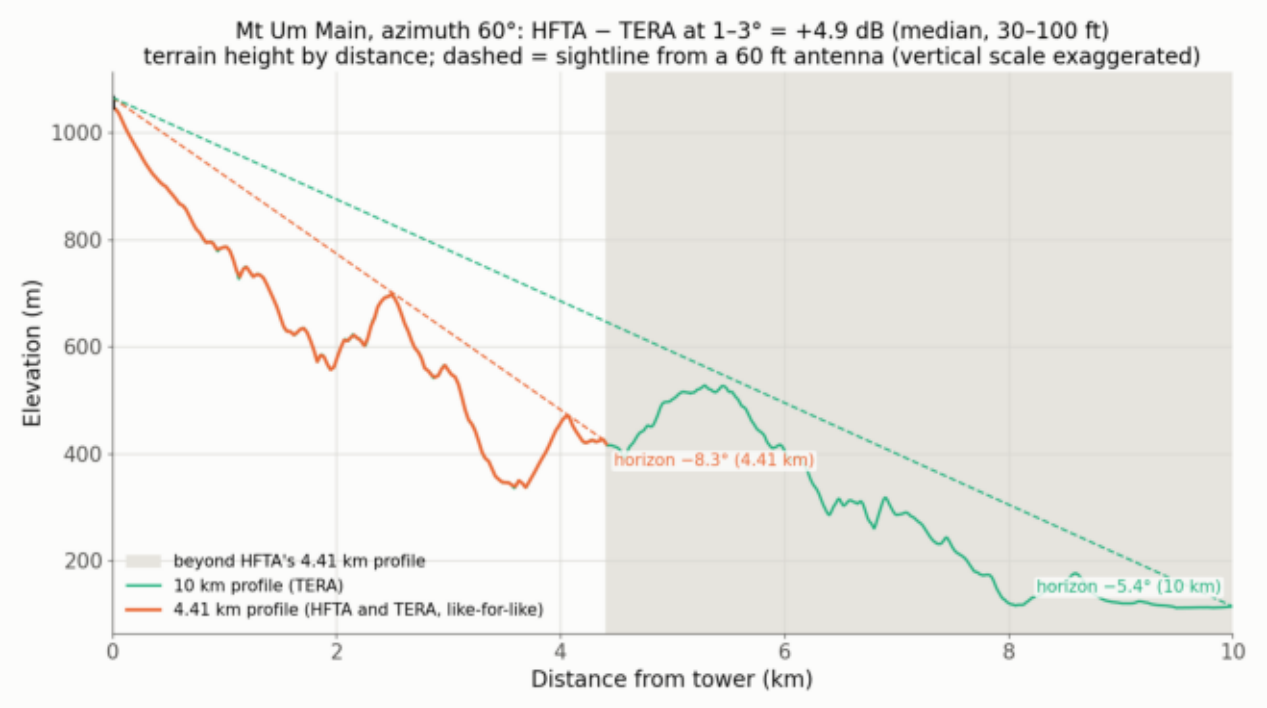
Each site's worst bearing is the one with the largest median gap between HFTA and TERA at 1–3°, over 30–100 ft, both run on the same 4.41 km profile. The plots show terrain height against distance for that bearing. The orange line is the 4.41 km profile both tools used, and the green line is the 10 km profile TERA can also use. The dashed lines are the sightlines from a 60 ft antenna to each profile's horizon. The vertical scale is exaggerated.

- K6TU Tower 285°, HFTA 19.6 dB low. The ground climbs from 112 m to 447 m at 4.41 km, a +4.1° horizon. This is a false-shadow bearing: at every height HFTA shows no field at all from 0.75° up to 2.75–3.5°, while TERA carries signal over the ridge by diffraction. Past 4.41 km the ridge keeps rising, to 623 m at 6.5 km, which lifts the true horizon to +4.6°.
- Mt Um 60°, HFTA 4.9 dB high. The ground falls away from the 1048 m summit, with a spur near 700 m at 2.5 km that sets the 4.41 km horizon at −8.3°. This is the summit site's worst case, and its error is optimistic, unlike K6TU's.

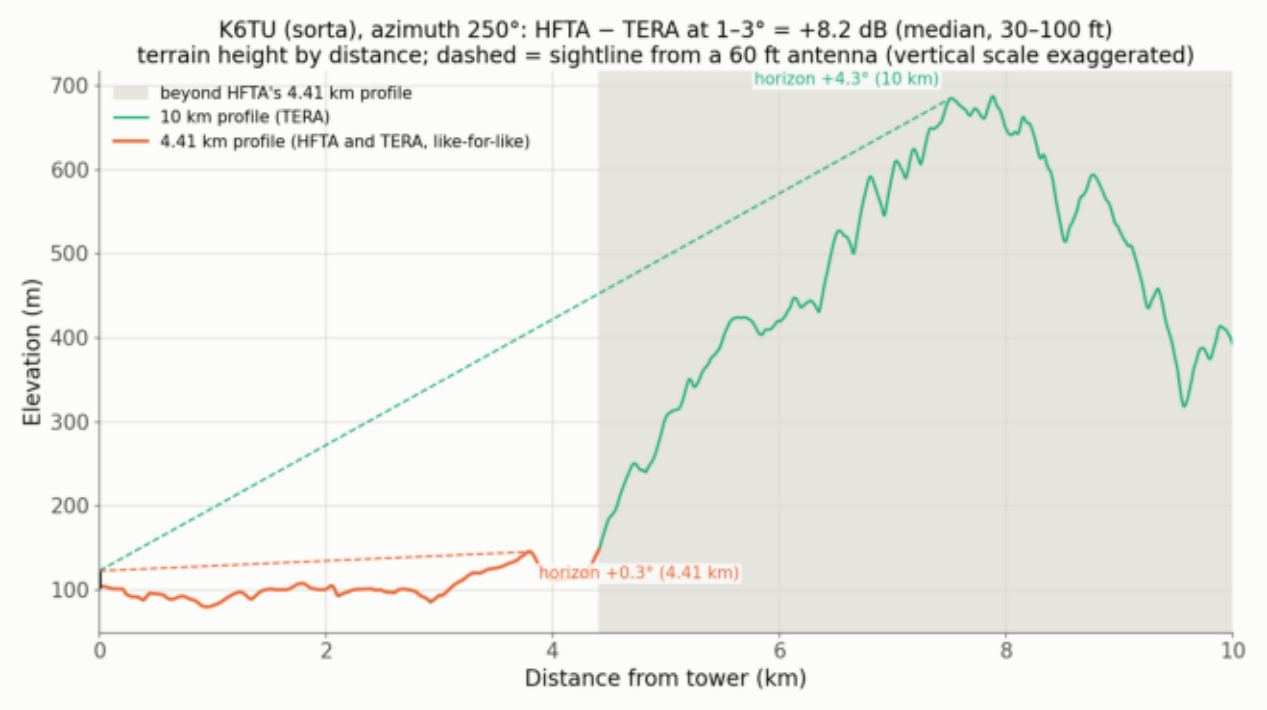
- Sorta 250°, HFTA 8.2 dB high. The first 3.5 km are nearly level, and a low rise at 3.8 km gives a horizon of only +0.3°. The ridge at 7.5–7.9 km, about 580 m above the site, is outside HFTA's profile and lifts the true horizon to +4.3°. That ridge costs a further 9.4 dB at 1–3° (median over heights) on top of HFTA's like-for-like error.



K6TU Tower 285°: terrain



Mt Um 60°: terrain



Sorta 250°: terrain

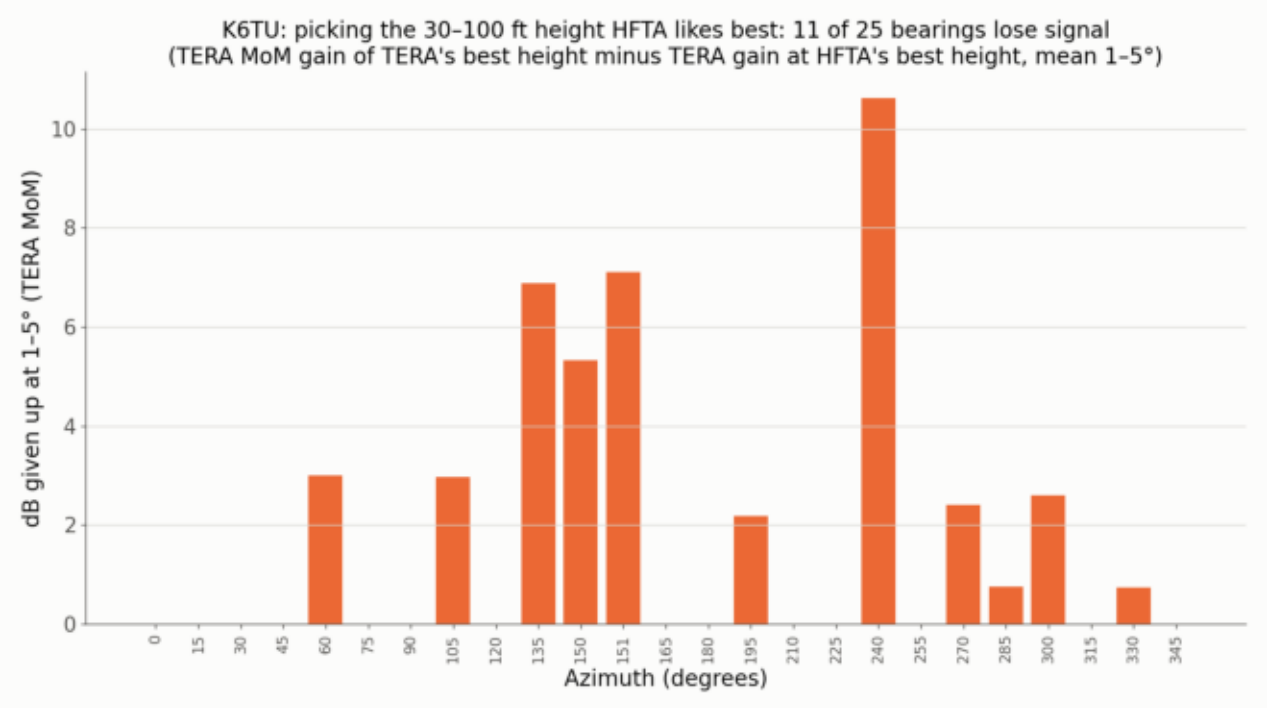
6 Height decisions

Site	HFTA dB per 10 ft (1–5°)	TERA dB per 10 ft (1–5°)
K6TU, all 25 bearings	0.62	1.36
K6TU, 17 bearings without false shadows	0.70	1.33
Mt Um, all 24 bearings	1.06	1.24
Sorta, all 36 bearings	0.78	1.45
Sorta, 35 bearings without false shadows	0.77	1.45

At K6TU, HFTA reports about half the low-angle benefit of height, and its best height differs from TERA's on 11 of 25 bearings:

K6TU azimuth	HFTA best	TERA best	dB given up
60°	60 ft	100 ft	3.0
105°	70 ft	100 ft	3.0
135°	50 ft	100 ft	6.9
150°	60 ft	100 ft	5.3
151°	50 ft	100 ft	7.1
195°	80 ft	100 ft	2.2
240°	30 ft	100 ft	10.6
270°	70 ft	100 ft	2.4
285°	90 ft	100 ft	0.8
300°	70 ft	100 ft	2.6
330°	90 ft	100 ft	0.7

The 240° entry is a false-shadow bearing, where HFTA's pick is essentially arbitrary.



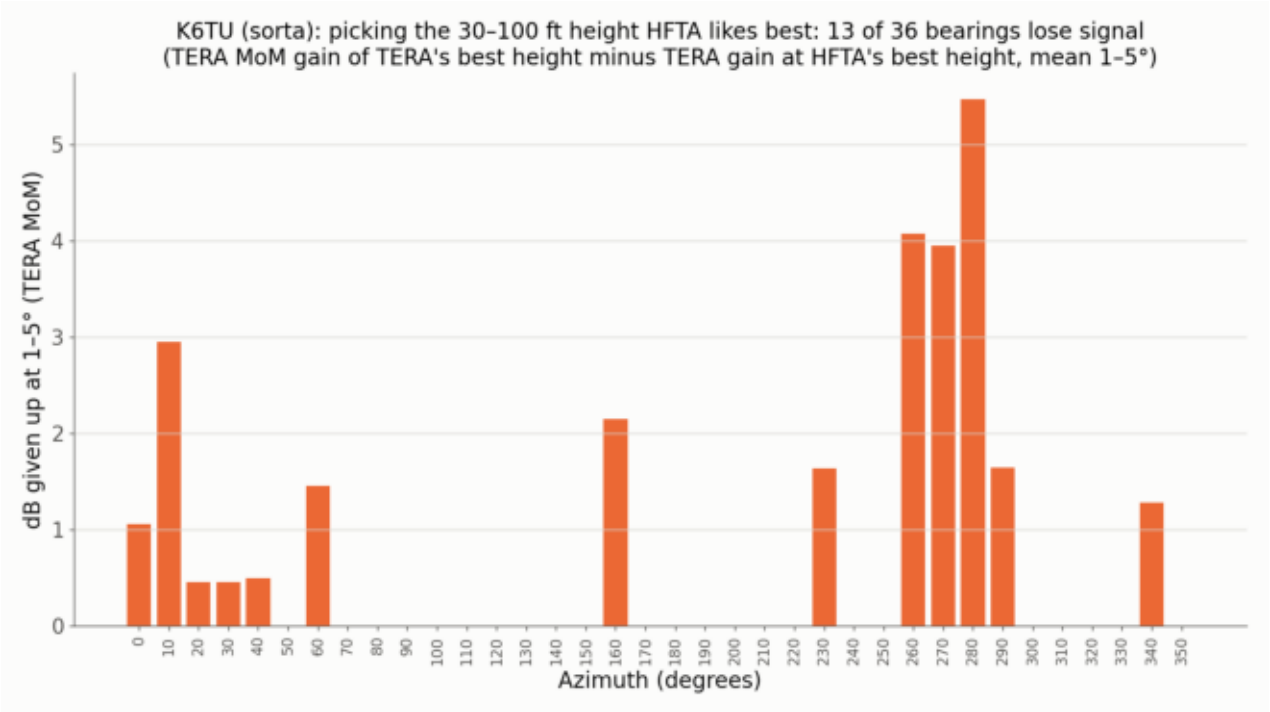
K6TU: dB given up by following HFTA's best height

At Mt Um the best heights differ on 9 of 24 bearings. Following HFTA costs under 1 dB on all but one, 45°, where HFTA picks 100 ft and TERA's best, 70 ft, is 2.6 dB better:

Mt Um azimuth	HFTA best	TERA best	dB given up
45°	100 ft	70 ft	2.6
60°	80 ft	70 ft	0.6
90°	80 ft	70 ft	0.2
105°	100 ft	80 ft	0.9
120°	100 ft	90 ft	0.3
240°	90 ft	100 ft	0.3
255°	90 ft	100 ft	0.2
285°	90 ft	100 ft	0.2
300°	90 ft	100 ft	0.4

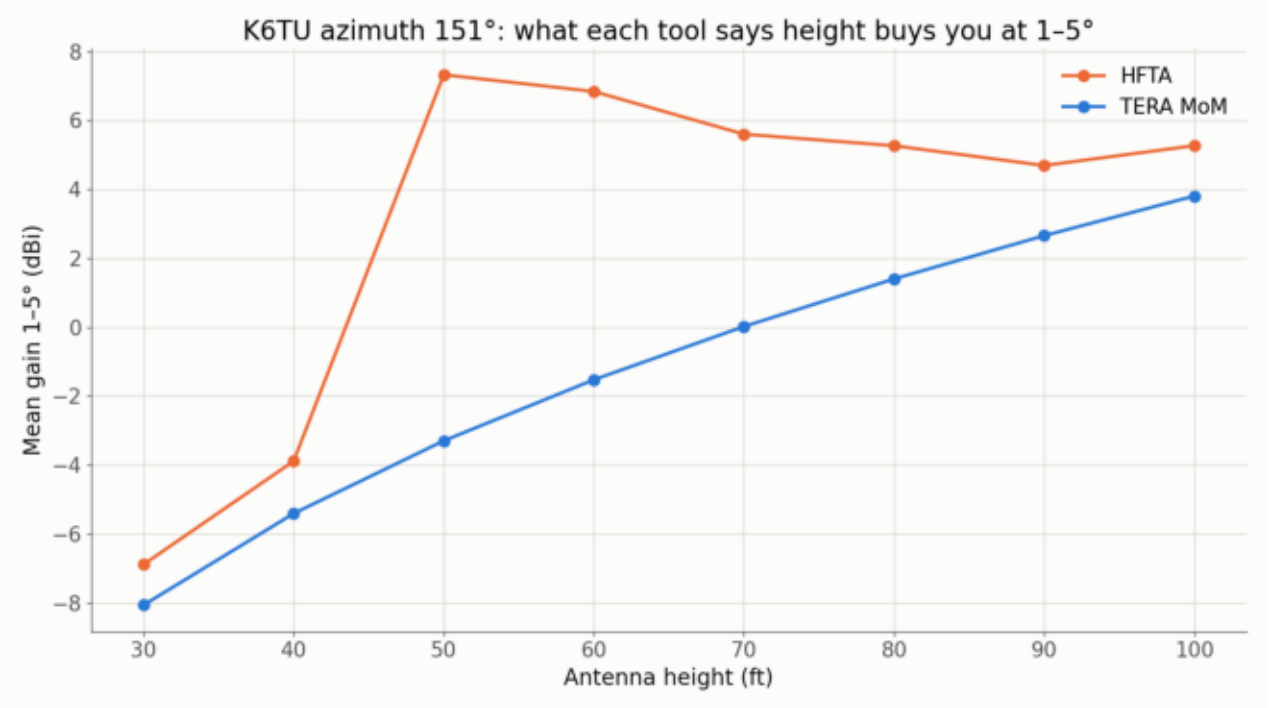
At sorta HFTA again reports about half the benefit of height. Its best height differs from TERA's on 13 of 36 bearings, and in every one of them TERA's best is 100 ft:

Sorta azimuth	HFTA best	TERA best	dB given up
0°	80 ft	100 ft	1.1
10°	60 ft	100 ft	2.9
20°	90 ft	100 ft	0.5
30°	90 ft	100 ft	0.5
40°	90 ft	100 ft	0.5
60°	80 ft	100 ft	1.5
160°	80 ft	100 ft	2.2
230°	80 ft	100 ft	1.6
260°	60 ft	100 ft	4.1
270°	60 ft	100 ft	4.0
280°	50 ft	100 ft	5.5
290°	80 ft	100 ft	1.6
340°	80 ft	100 ft	1.3

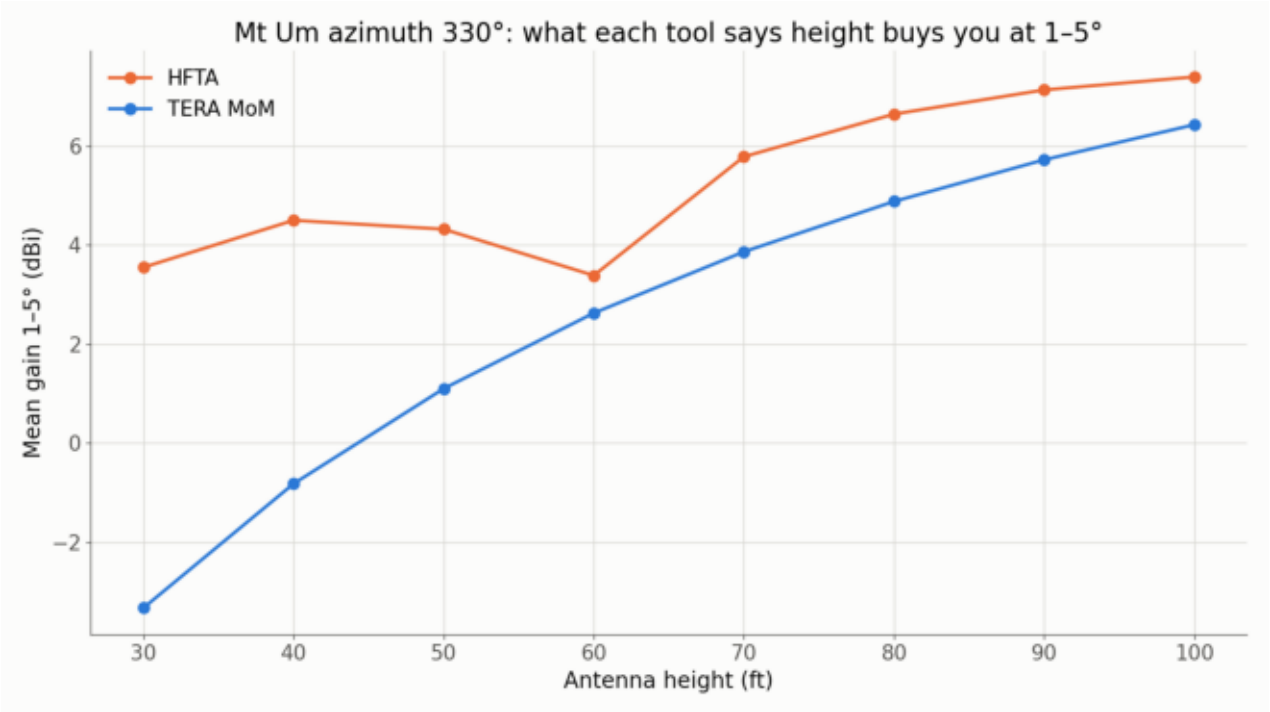


Sorta: dB given up by following HFTA's best height

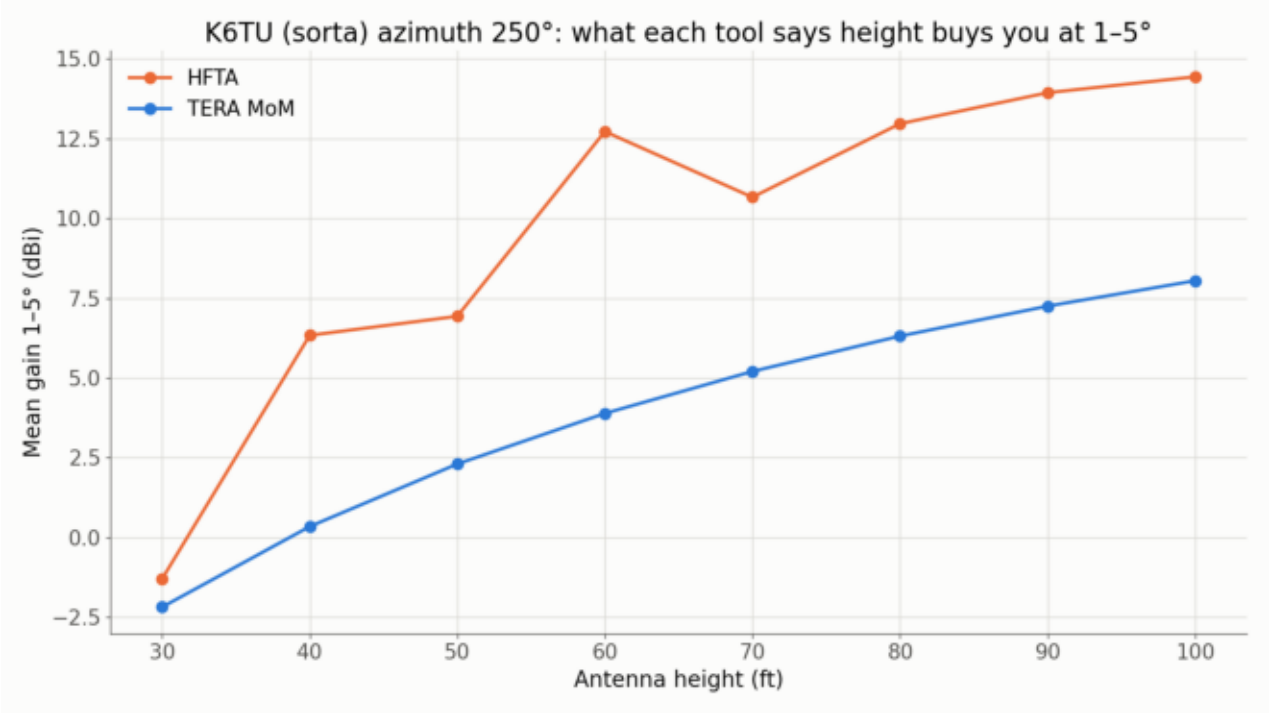
There is one more site difference. At K6TU, TERA's best height in 30–100 ft is always the tallest. At Mt Um, on bearings 30–135°, 70–90 ft beats 100 ft: from a summit, the drop-off below the antenna already provides the low-angle gain that height provides elsewhere.



K6TU 151°: height gradient



Mt Um 330°: height gradient



Sorta 250°: height gradient

7 Terrain beyond 4.41 km

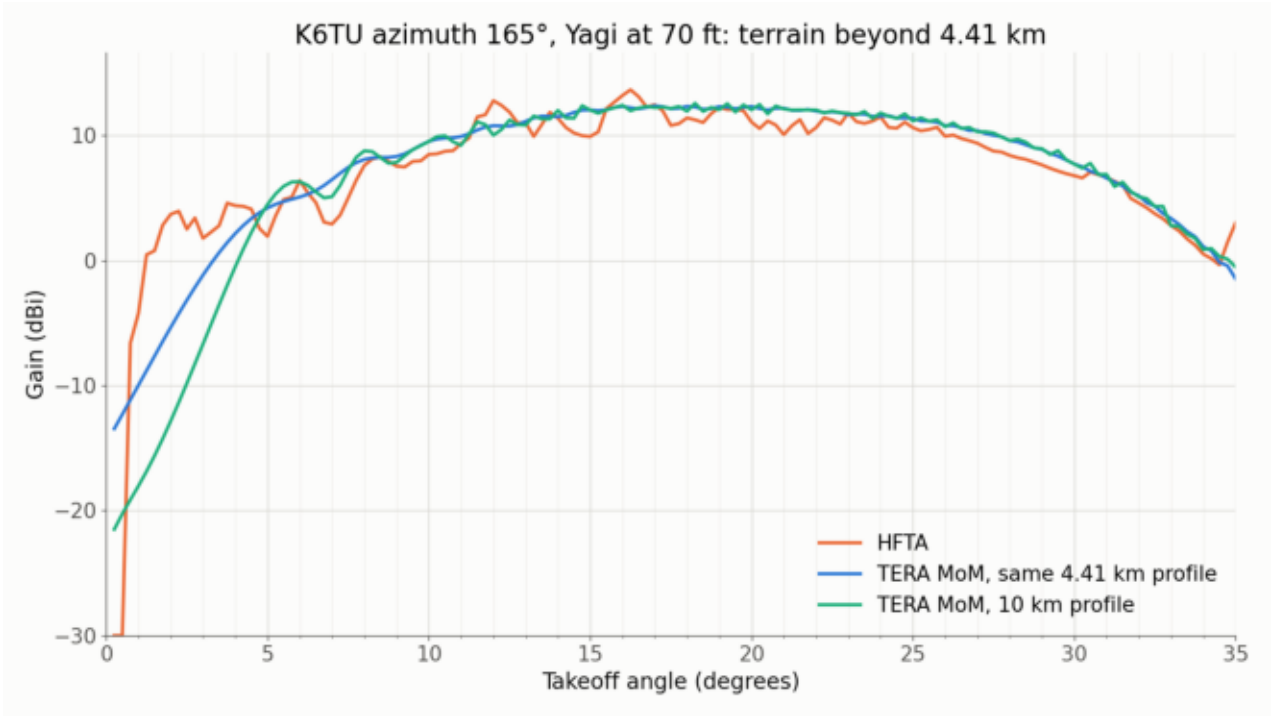
HFTA cannot see past its 148-point profile, however good its physics. TERA, run exactly on the 10 km profiles, shows how much that hides:

- K6TU: 1–3° moves more than 2 dB in 82 of 200 cases, by up to 7.2 dB at 165°, where the ground keeps climbing past 4.41 km.
- Mt Um: where the terrain falls away, the far ground sits below the low-angle rays. Only one bearing changes, 135° by +2.6 dB at all heights.
- Sorta: the largest range effect of the three sites. On every bearing from 150° to 290°, at every height, the 1–3° mean drops by more than 2 dB once the full 10 km is included. The median over heights is +2.6 to +10.0 dB, largest at 230–270°. The cause is a ridge 550–610 m above the site, 7.5–9.5 km out. At 250° it raises the 60 ft horizon from +0.35° on the 4.41 km profile to +4.3°. Elsewhere the terrain stays below the site, and including it changes 1–3° by less than half a dB.

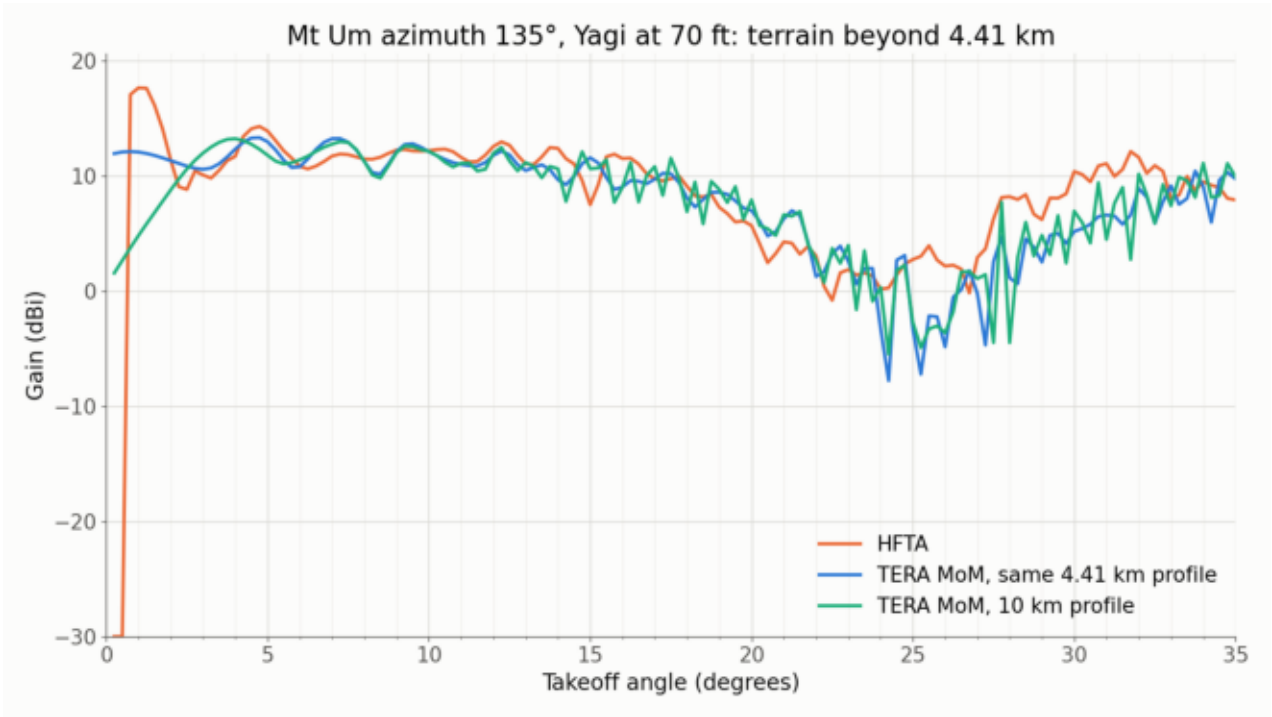
This matches the earlier K6TU azimuth survey: range costs most where the terrain climbs.

At sorta the two errors add. At 250° and 60 ft, HFTA shows +12.1 dBi averaged over 1–3°. TERA on the same 4.41 km profile gives +0.4, and on the full 10 km −9.0. HFTA's physics error is 12 dB, and the ridge it cannot see costs another 9 dB. The DEM item is 0.0 dB at this site, because both data sets are NED.

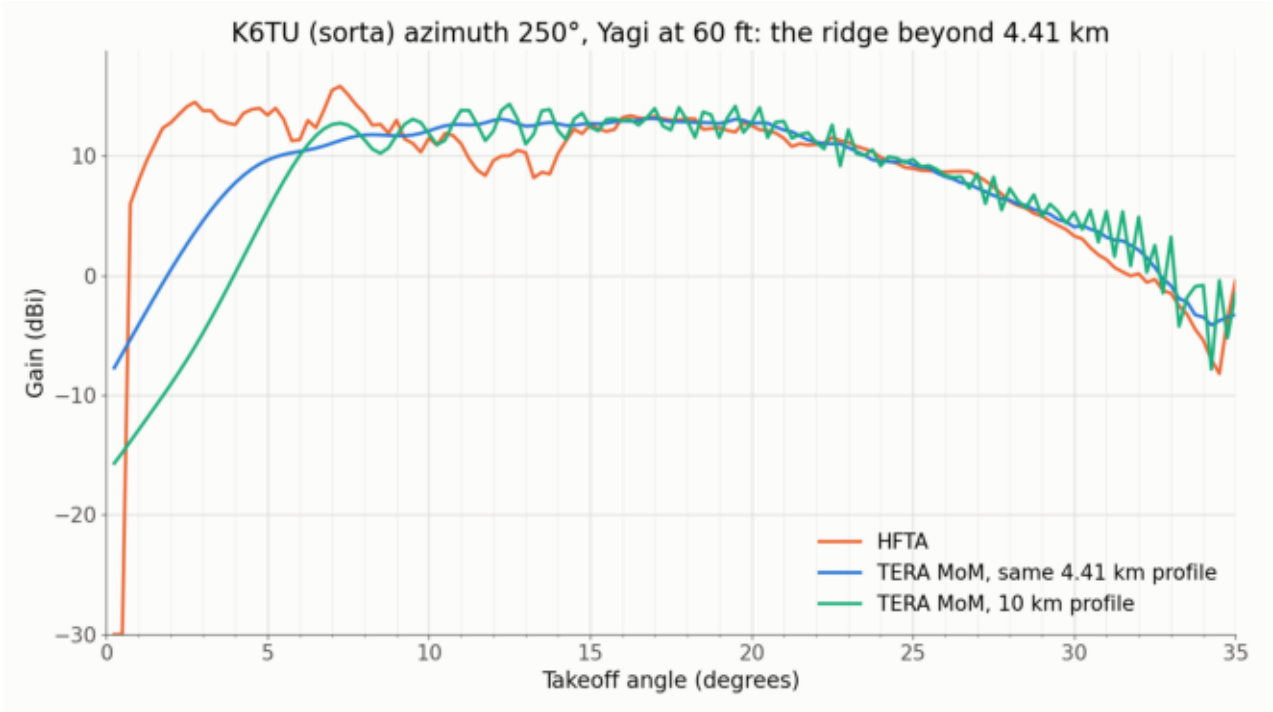
The ridge does not change the height choice: on the 10 km profile, TERA's best height at sorta is still 100 ft on every bearing.



K6TU 165°: 4.41 vs 10 km



Mt Um 135°: 4.41 vs 10 km



Sorta 250°: 4.41 vs 10 km

8 Other bands

All three sites were rerun at 7.1, 21.2 and 28.5 MHz with the same 30–100 ft heights, ground and bearings. Each band uses HFTA's built-in Yagi of the matching size and a generic NEC Yagi as the reference (scripts/nec_yagi_pattern.py --elements):

Band	HFTA antenna	NEC reference	Gain	F/B	Feed R
40 m, 7.1 MHz	2-Ele	2-el, 0.125λ boom	6.7 dBi	10.0 dB	27.5 Ω
20 m, 14.2 MHz	3-Ele	3-el, 0.30λ boom	8.1 dBi	24.5 dB	21.5 Ω
15 m, 21.2 MHz	4-Ele	4-el, 0.60λ boom	9.9 dBi	20.0 dB	24.7 Ω
10 m, 28.5 MHz	4-Ele	4-el, 0.60λ boom	10.0 dBi	25.2 dB	21.3 Ω

A 2-element Yagi cannot reach 20 dB F/B, so its design floor was set at 10 dB. The calibration on flat and sloped synthetic profiles was repeated on each band and showed the same behavior as 20 m. TERA's mesh is λ/10 on every band, twice as fine as TERA's default of λ/5. The 20 m results are unchanged.

Run time at 28.5 MHz. The study ran four bearings at a time with 2 threads each, which is fastest overall but slow per bearing: about 7.5 s for a 10 km profile. Measured on its own on the same 8-core machine, one 10 km bearing takes:

Mesh	2 threads	8 threads
λ/10 (this study)	4.5 s	3.2 s
λ/5 (TERA default)	1.5 s	1.1 s

These are for one antenna height; solving all eight heights together adds about 1.5 s. At this size TERA's iterative solver is limited by memory bandwidth rather than core count, which is why 8 threads gain little. The coarser mesh costs no accuracy that matters here: on the four worst bearings, λ/5 changed the window means by at most 0.24 dB at any height, against the study's 2 dB threshold.

K6TU Tower (200 cases per band):

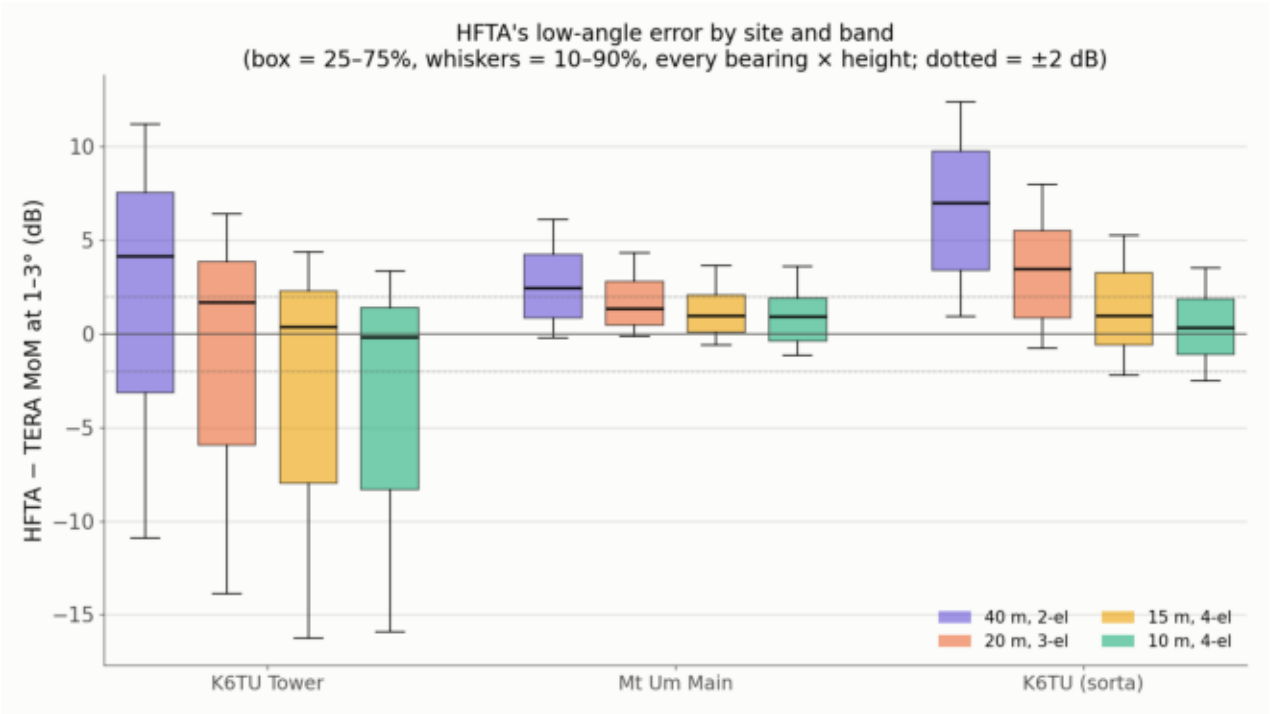
Result	40 m, 2-el	20 m, 3-el	15 m, 4-el	10 m, 4-el
Physics > 2 dB off, 1–3°	192	174	148	130
… of which HFTA high / low	142 / 50	120 / 54	90 / 58	69 / 61
Median total error, 1–3°	+4.2 dB	+1.7 dB	+0.4 dB	−0.2 dB
False lobes (> 10 dB high)	106	93	83	62
False shadows (no signal)	48	43	41	50
dB per 10 ft, TERA / HFTA	1.43 / 0.33	1.36 / 0.62	1.26 / 0.79	1.16 / 0.74
Wrong best height	11 of 25	11 of 25	9 of 25	9 of 25
Most dB lost to it	9.7	10.6	7.5	3.3
Range > 2 dB at 1–3°	83 (≤ 6.1 dB)	82 (≤ 7.2 dB)	72 (≤ 8.1 dB)	64 (≤ 8.9 dB)
HFTA vs TERA 10 km, 1–3°	+5.4 dB	+2.5 dB	+1.2 dB	+0.7 dB

Mt Um Main (192 cases per band):

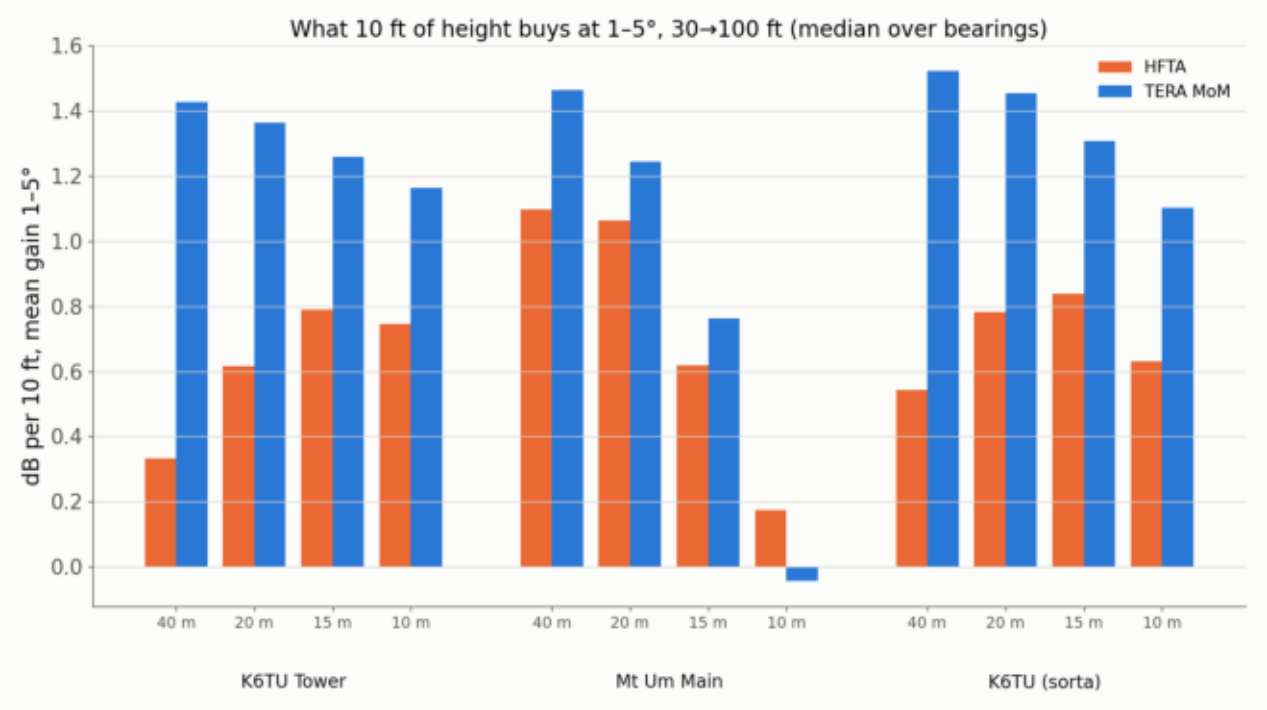
Result	40 m, 2-el	20 m, 3-el	15 m, 4-el	10 m, 4-el
Physics > 2 dB off, 1–3°	139	122	107	101
… of which HFTA high / low	136 / 3	122 / 0	107 / 0	100 / 1
Median total error, 1–3°	+2.5 dB	+1.3 dB	+1.0 dB	+0.9 dB
False lobes (> 10 dB high)	26	30	25	28
False shadows (no signal)	0	0	0	0
dB per 10 ft, TERA / HFTA	1.46 / 1.10	1.24 / 1.06	0.76 / 0.62	−0.04 / 0.17
Wrong best height	9 of 24	9 of 24	12 of 24	13 of 24
Most dB lost to it	4.2	2.6	0.8	4.3
Range > 2 dB at 1–3°	8 (≤ 4.0 dB)	8 (≤ 2.6 dB)	0 (≤ 1.2 dB)	0 (≤ 1.1 dB)
HFTA vs TERA 10 km, 1–3°	+2.5 dB	+1.6 dB	+1.2 dB	+1.0 dB

K6TU (sorta) (288 cases per band):

Result	40 m, 2-el	20 m, 3-el	15 m, 4-el	10 m, 4-el
Physics > 2 dB off, 1–3°	265	221	176	147
… of which HFTA high / low	258 / 7	210 / 11	159 / 17	127 / 20
Median total error, 1–3°	+7.0 dB	+3.5 dB	+1.0 dB	+0.3 dB
False lobes (> 10 dB high)	180	88	69	59
False shadows (no signal)	8	5	5	5
dB per 10 ft, TERA / HFTA	1.52 / 0.54	1.45 / 0.78	1.31 / 0.84	1.10 / 0.63
Wrong best height	22 of 36	13 of 36	15 of 36	18 of 36
Most dB lost to it	10.0	5.5	9.0	3.8
Range > 2 dB at 1–3°	120 (≤ 7.7 dB)	120 (≤ 10.3 dB)	120 (≤ 12.6 dB)	120 (≤ 15.9 dB)
HFTA vs TERA 10 km, 1–3°	+8.8 dB	+5.1 dB	+2.8 dB	+1.9 dB



HFTA minus TERA at 1–3° by site and band

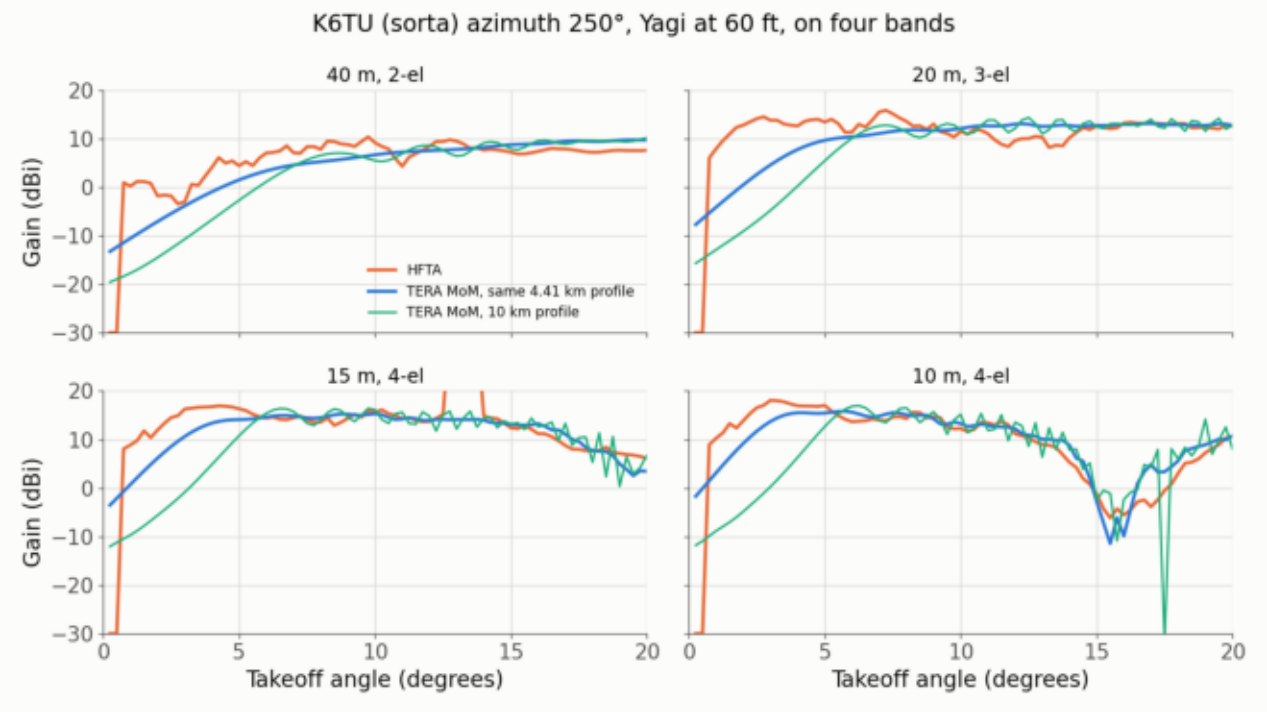


Height gradient by site and band

What changes with band:

- HFTA's low-angle optimism shrinks as frequency rises. At sorta the median like-for-like error at 1–3° falls from +7.0 dB on 40 m to +0.3 dB on 10 m, and false lobes from 180 cases to 59. The median falls with frequency at all three sites, though Mt Um's false-lobe count stays between 25 and 30 on every band. On 40 m, 30–100 ft is only 0.22–0.72 wavelengths, where a ray-tracing description of the antenna over terrain is at its weakest; this fits the trend, but the study does not test that explanation directly.
- A shrinking median does not mean HFTA becomes reliable. At K6TU Tower the median on 10 m is −0.2 dB, but 130 of 200 cases are still off by more than 2 dB. The errors there become two-sided: fewer false lobes, as many false shadows (41–50 on every band), and more cases where HFTA reads low. A median near zero is a balance of large errors in both directions.
- Mt Um stays the mild case on every band: always optimistic (at most 3 cases low on any band), no false shadows, and medians of +0.9 to +2.5 dB.
- Height: at K6TU Tower and sorta HFTA understates the benefit of height on every band, worst on 40 m (0.33 vs 1.43 and 0.54 vs 1.52 dB per 10 ft). Wrong best-height picks cost up to 9.7–10.6 dB on 40 and 20 m at K6TU Tower and up to 10.0 dB on 40 m at sorta. At Mt Um the benefit of height itself fades with frequency, to essentially zero on 10 m (−0.04 dB per 10 ft), so the best height there spreads across 40–100 ft and HFTA's pick can cost up to 4.3 dB.

- Range grows with frequency where a ridge lies beyond 4.41 km. At sorta the same 120 cases (15 bearings × 8 heights) exceed 2 dB on every band, but the largest effect rises from 7.7 dB on 40 m to 15.9 dB on 10 m. That is the expected direction for a ridge's diffraction shadow, which deepens as frequency rises. At Mt Um, where the far ground is below the site, range falls to nothing on 15 and 10 m.
- Antenna model: HFTA's built-in lobe is a uniform −1.2 dB on 40 m and −1.4 dB on 15 and 10 m against these NEC designs, a constant offset as on 20 m.



Sorta 250° at 60 ft on four bands

At sorta 250° and 60 ft, HFTA reads well above TERA below about 3–5° on every band. The ridge beyond 4.41 km pulls TERA's 10 km pattern below the 4.41 km one at low angles on all four.

9 Survey of 100 US stations

The three sites show how HFTA goes wrong; this survey measures how often. The plan, with every test and threshold, was written and committed before any site was generated (docs/hfta-multisite-plan.md, commit 6806cfc).

How the stations were chosen. The population is the locations in prod's legacy terrain profiles: 3,717 profiles from 971 users, the stations whose owners analyzed their terrain. The draw (scripts/hfta_survey_draw.py, seed 20261103) kept US locations only (CONUS, Alaska and Hawaii), so both tools' terrain comes from USGS data. It dropped the study's own sites, the K6TU and admin accounts and test entries, then took one site per user, so heavy users don't dominate. That left 574 eligible users, shuffled with the fixed seed and taken in order with a 2 km minimum separation. The 100 stations span 41 states. Station identities and coordinates are not published; sites are known only by survey ID

and state.

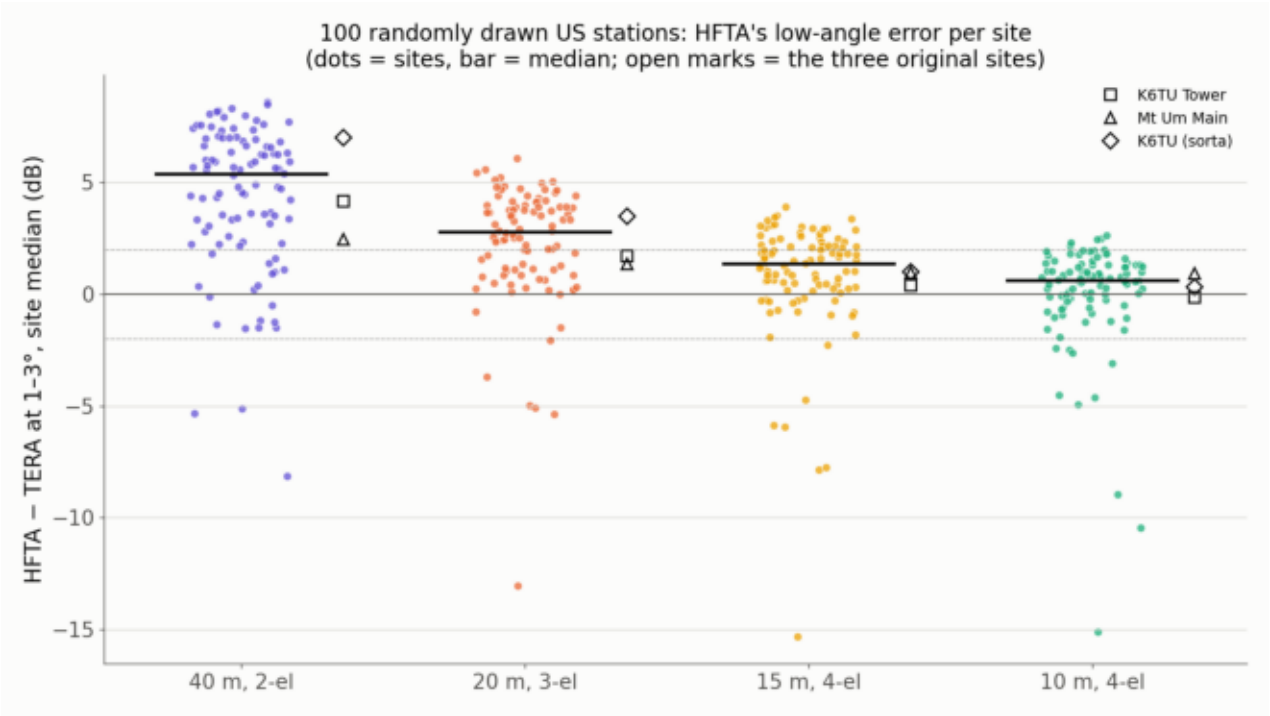
Two stages, by a rule fixed in advance. The plan called for 50 stations, extended to 100 only if the 95% interval for the wrong-height rate (P3) or the false-shadow rate still crossed 25% or 50%. After 50, the false-shadow intervals (39–74%) crossed 50% on every band, so the next 50 stations in the drawn order were run. P1 and P2 are tested once, at the final size of 100. The two halves agree: the median 1–3° error differs between them by 0.2–0.5 dB on every band.

How they were run. Each station's legacy profile (4.41 km) and TERA profile (10 km) were generated on dev under the K6TU account. All 200 completed, so no replacement stations were needed. Each station ran 36 bearings × 8 heights × 4 bands, exactly as the three sites did, at TERA's default λ/5 mesh. Rerunning K6TU Tower at λ/5 against its λ/10 results moved the 1–3° error by a median of 0.05 dB (maximum 0.49 dB over 200 cases), and changed which side of 2 dB a case falls on in 1 case of 200. 99 stations have NED data on both profiles. One (S047, Montana) received GEDTM30 on both; the cause was not determined. Its HFTA-vs-TERA comparison is still like-for-like, and every test gives the same answer without it.

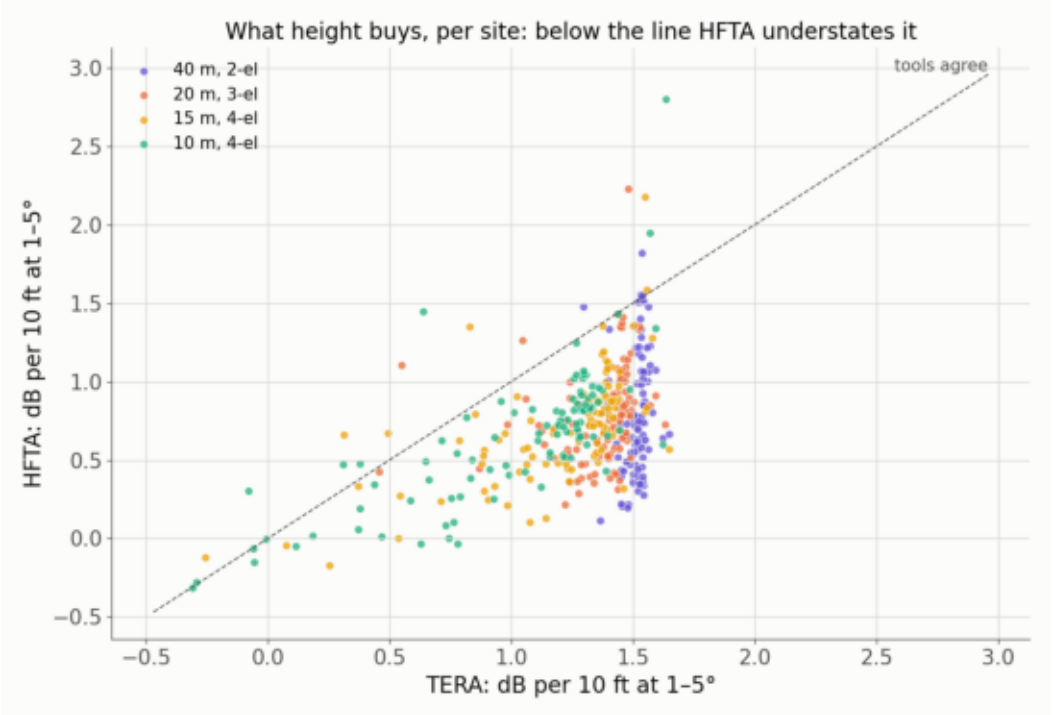
The tests. Each station counts once, using its median over 36 bearings × 8 heights. P1 and P2 are two-sided sign tests; rates carry 95% Wilson intervals.

Test (100 stations)	40 m	20 m	15 m	10 m
P1: HFTA high at 1–3°	89, p<0.0001	92, p<0.0001	78, p<0.0001	67, p 0.0009
Median error, dB (IQR)	+5.4 (2.5–6.8)	+2.8 (1.1–3.9)	+1.4 (0.2–2.2)	+0.6 (−0.3–1.3)
P2: height understated	94, p<0.0001	97, p<0.0001	94, p<0.0001	92, p<0.0001
dB/10 ft, TERA / HFTA	1.52 / 0.72	1.42 / 0.75	1.34 / 0.71	1.20 / 0.68
P3: height pick loses > 2 dB	90% (83–94)	88% (80–93)	82% (73–88)	76% (67–83)
Any false shadow	48% (38–58)	50% (40–60)	55% (45–64)	52% (42–62)
Any false lobe > 10 dB	99% (95–100)	100% (96–100)	100% (96–100)	100% (96–100)
Range moves 1–3° > 2 dB	42% (33–52)	43% (34–53)	40% (31–50)	42% (33–52)
HFTA vs TERA 10 km, median	+5.9 dB	+3.2 dB	+1.4 dB	+0.7 dB
Cases with physics > 2 dB	84%	79%	70%	61%

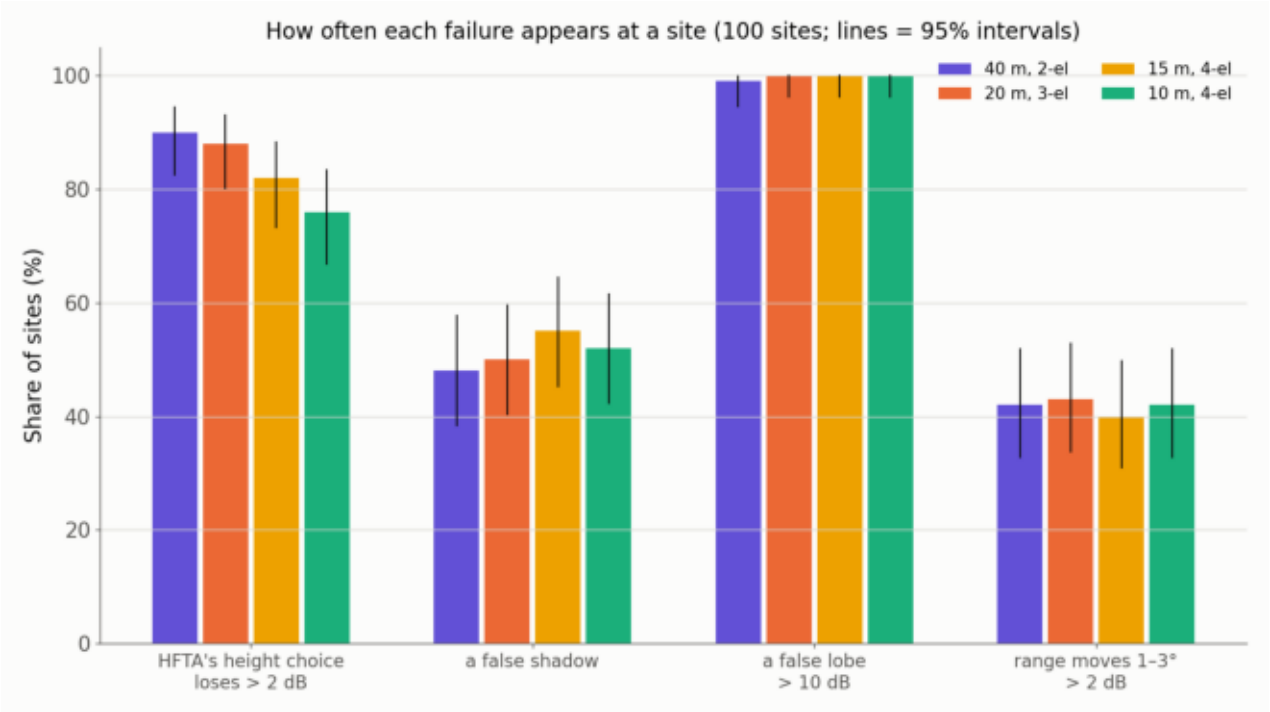
Counts are stations out of 100 (2-element Yagi on 40 m, 3-element on 20 m, 4-element on 15 and 10 m). Percentages carry their 95% interval in brackets.



Each station's median error by band



Height gradient per station



How often each failure appears

What the survey shows:

- HFTA is optimistic at low angles on every band. 89, 92, 78 and 67 of 100 stations read high on 40, 20, 15 and 10 m, all significant ($p < 0.001$). The typical station reads 5.4, 2.8, 1.4 and 0.6 dB high, so the band trend from section 8 holds across stations. On 10 m the bias is real but small. The first 50 stations alone (31 of 50) could not show it.
- HFTA understates what height buys, on every band. 92–97 of 100 stations, with HFTA reporting about half the benefit (0.68–0.75 against 1.20–1.52 dB per 10 ft). This is the most consistent finding in the study.
- Its height choice usually costs something. At 76–90% of stations, following HFTA's best height loses more than 2 dB at 1–5° on at least one of the 36 bearings.
- False lobes are everywhere, false shadows at about half the stations. Nearly every station has at least one case with a false lobe over 10 dB; on average they affect 22–51% of a station's cases, most on 40 m. False shadows appear at about half the stations (48–55%), in 6–8% of their cases.
- The 4.41 km limit matters at about 4 stations in 10. At 40–43% of stations, terrain past 4.41 km moves 1–3° by more than 2 dB on at least one bearing.
- The three original sites are typical. K6TU Tower and Mt Um fall between the 25th and 42nd percentile of the stations' medians on most bands (Mt Um reaches the 64th on 10 m); sorta falls between the 42nd and 78th. Choosing them did not exaggerate HFTA's error. If anything the typical station fares worse than two of them.

10 Caveats

- 2-D model. TERA's MoM treats the terrain as infinitely wide across the path. Against a 3-D FEKO model of WPR-Mtn-330 it matched at low angles and ran +2.7 dB high at 20–28°. Low angles, where nearly all of HFTA's error sits, are TERA's best-validated region.
- Three sites plus a 100-station survey, four bands, horizontal polarization only. The survey draws from stations whose owners used the terrain service, all in the US; it says nothing directly about stations elsewhere or about stations nobody analyzed. The sorta coordinates are rough (0.01°, about 1 km), so it stands for a kind of terrain, not a particular station.
- The Yagis are generic, not anyone's antennas. The antenna item (−1.1 to −1.4 dB) is HFTA's built-in lobe against these designs. A different Yagi shifts that number, not the terrain findings.
- Not modeled: near-field ground loss under the antenna (earlier TERA work found it matters mainly for verticals), and stacks.
- Framing. These are limits of the ray-tracing method in HFTA's 2003 engine, not bugs. Dean Straw himself warned about false gain spikes on steep upslopes at low frequency and low antenna height. HFTA was a large step forward, and its answers above 10° hold up well at every site.

11 Reproduce

```
conda run -n tera pip install PyNEC        # once
conda run -n tera python scripts/nec_yagi_pattern.py
# K6TU: legacy profiles in P/, 'K6TU Tower (TERA)' in J/
conda run -n tera python scripts/hfta_error_budget.py calibrate --pro-dir P
conda run -n tera python scripts/hfta_error_budget.py run --pro-dir P \
    --json-dir J
conda run -n tera python scripts/hfta_error_budget.py utd-reference \
    --pro-dir P --azimuth 151
# Mt Um: 'Mt Um - Main Tower' in P2/, '... (TERA)' in J2/
conda run -n tera python scripts/hfta_error_budget.py run --site mt-um \
    --pro-dir P2 --json-dir J2
# K6TU (sorta): 'K6TU (sorta)' in P3/, 'K6TU - sorta (TERA)' in J3/
conda run -n tera python scripts/hfta_error_budget.py run --site k6tu-sorta \
    --pro-dir P3 --json-dir J3
# figures, then this report as PDF
# other bands: NEC Yagis, then each site with --band 40 / 15 / 10
conda run -n tera python scripts/nec_yagi_pattern.py --freq 7.1 --elements 2 \
    --out data/antennas/yagi2-40m-elev.csv
conda run -n tera python scripts/nec_yagi_pattern.py --freq 21.2 --elements 4 \
    --out data/antennas/yagi4-15m-elev.csv
conda run -n tera python scripts/nec_yagi_pattern.py --freq 28.5 --elements 4 \
    --out data/antennas/yagi4-10m-elev.csv
conda run -n tera python scripts/hfta_error_budget.py run --band 40 --site k6tu \
    --pro-dir P --json-dir J               # likewise mt-um, k6tu-sorta; 15, 10
# survey (needs prod read access for the draw and dev for the profiles)
conda run -n tera python scripts/hfta_survey_draw.py --seed 20261103 --count 120
conda run -n tera python scripts/hfta_survey_generate.py --sites 100
conda run -n tera python scripts/hfta_survey_run.py
# HFTA itself: replay every run's HFTA inputs through YTWCore.dll under Wine
# (scripts/hfta_dll_replay/ on development: build_budget_inputs.py, replay.exe,
# budget_with_dll.py sidecars), then swap the DLL's curves into the cached runs
conda run -n tera python scripts/hfta_dll_inject.py SIDECARS
conda run -n tera python scripts/hfta_survey_report.py
conda run -n tera python scripts/hfta_error_plots.py --site k6tu
conda run -n tera python scripts/hfta_error_plots.py --site mt-um
conda run -n tera python scripts/hfta_error_plots.py --site k6tu-sorta
conda run -n tera python scripts/hfta_error_plots.py --site compare
conda run -n tera python scripts/hfta_error_plots.py --site terrain
conda run -n tera python scripts/hfta_error_plots.py --site bands
conda run -n tera python scripts/build_hfta_report.py
```

Cached results are kept one .npz per bearing, in investigations/hfta-error-budget/runs/ (K6TU) and runs-mt-um/ (Mt Um) and runs-k6tu-sorta/ (sorta). Other bands use the same directories with a -40m, -15m or -10m suffix. Each run holds HFTA's DLL curves as H0_<ft> and H0nd_<ft> (diffraction off), and OpenHFTA's original ones as H0_ohfta_<ft> and H0nd_ohfta_<ft>. The survey's runs (runs-survey/) are not committed because of their size; survey/results.json holds their summary. The profiles for the three terrain plots are kept in investigations/hfta-error-budget/terrain/.