

Using UAVs to Simulate Atmospherically-induced Scintillation of Free-Space Optical Ground-Satellite Links

Poster presented at the workshop:
Communications and Observations through
Atmospheric Turbulence (COAT 2025)

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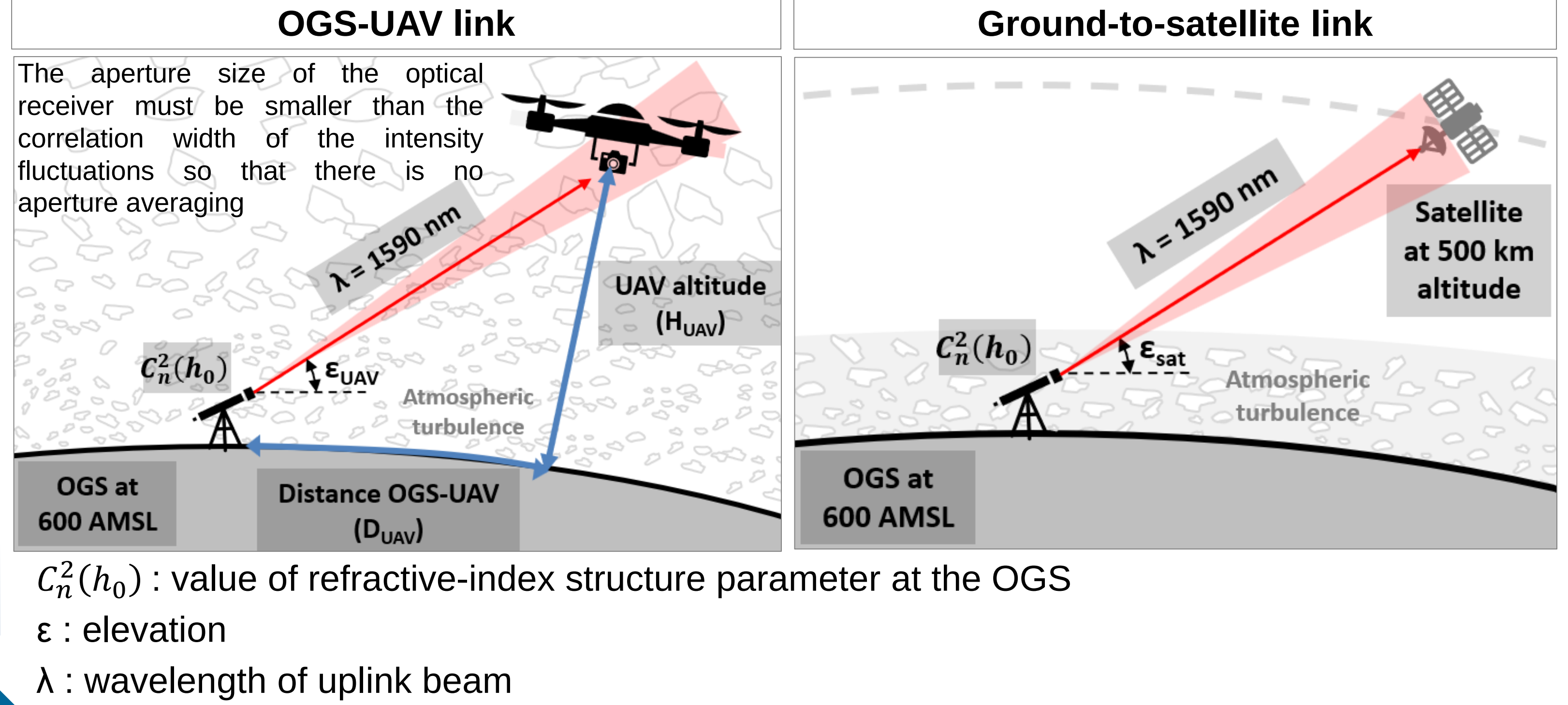
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1. Background

We propose to use unmanned aerial vehicles (UAVs) equipped with an on-board optical receiver to detect a signal transmitted from an optical ground station (OGS), to allow monitoring expected atmospherically-induced signal fluctuations similar to those experienced in ground-to-satellite links. We propose to fix the horizontal distance of the UAV from the OGS and to change the altitude of the UAV for two main purposes. First, to simulate different LEO-satellite elevations during a vertical flight of the UAV. Second, to facilitate compliance with unmanned aircraft system regulations in Europe for UAV flights outside the open category of operations.

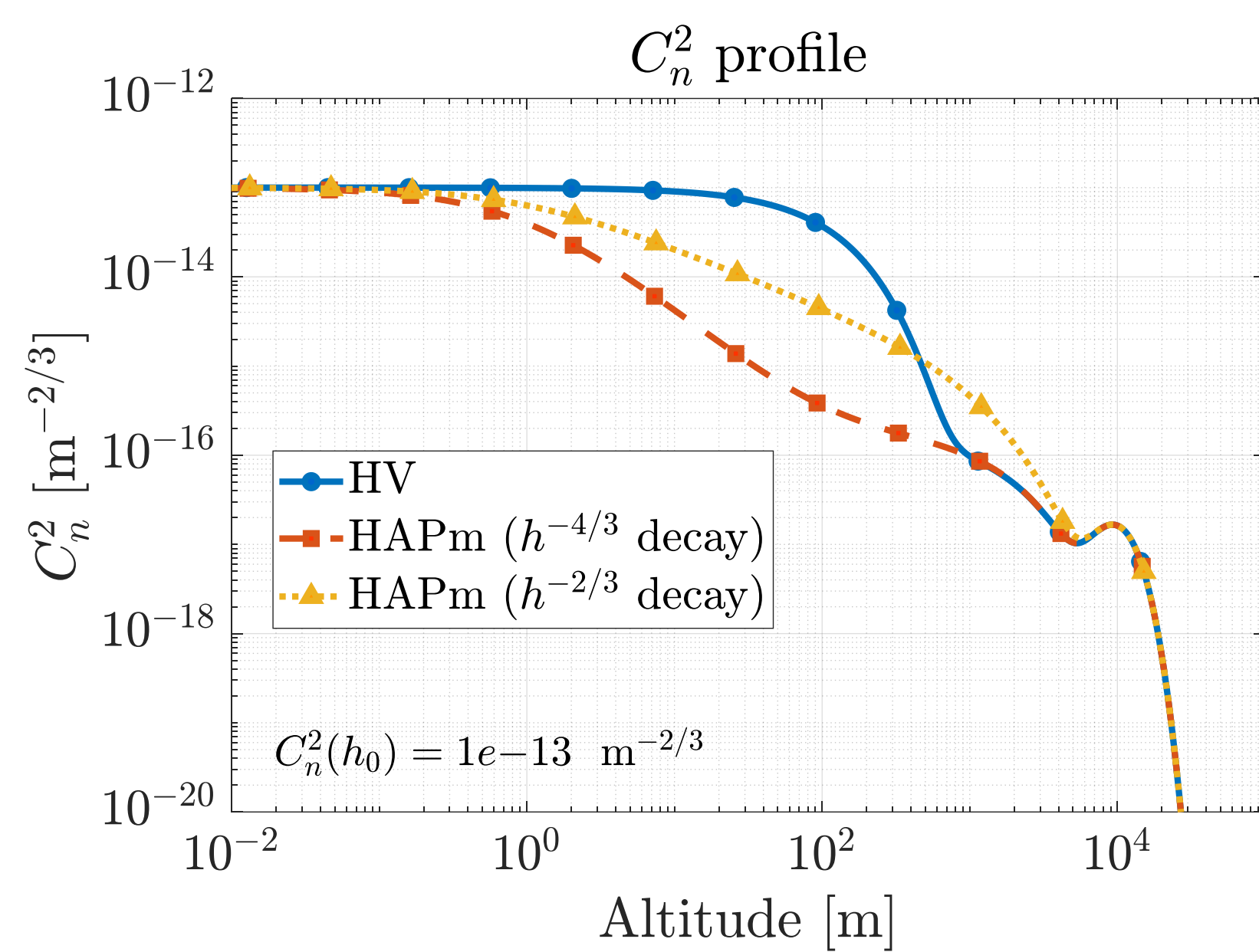
The expected intensity fluctuations for the ground-to-satellite and -UAV links are compared in terms of the expected on-axis scintillation index at the receiver aperture as a function of the satellite elevation and the UAV altitude, respectively. We consider spherical-Earth models to calculate the scintillation index and relevant parameters.

2. Scenario



3. Approach

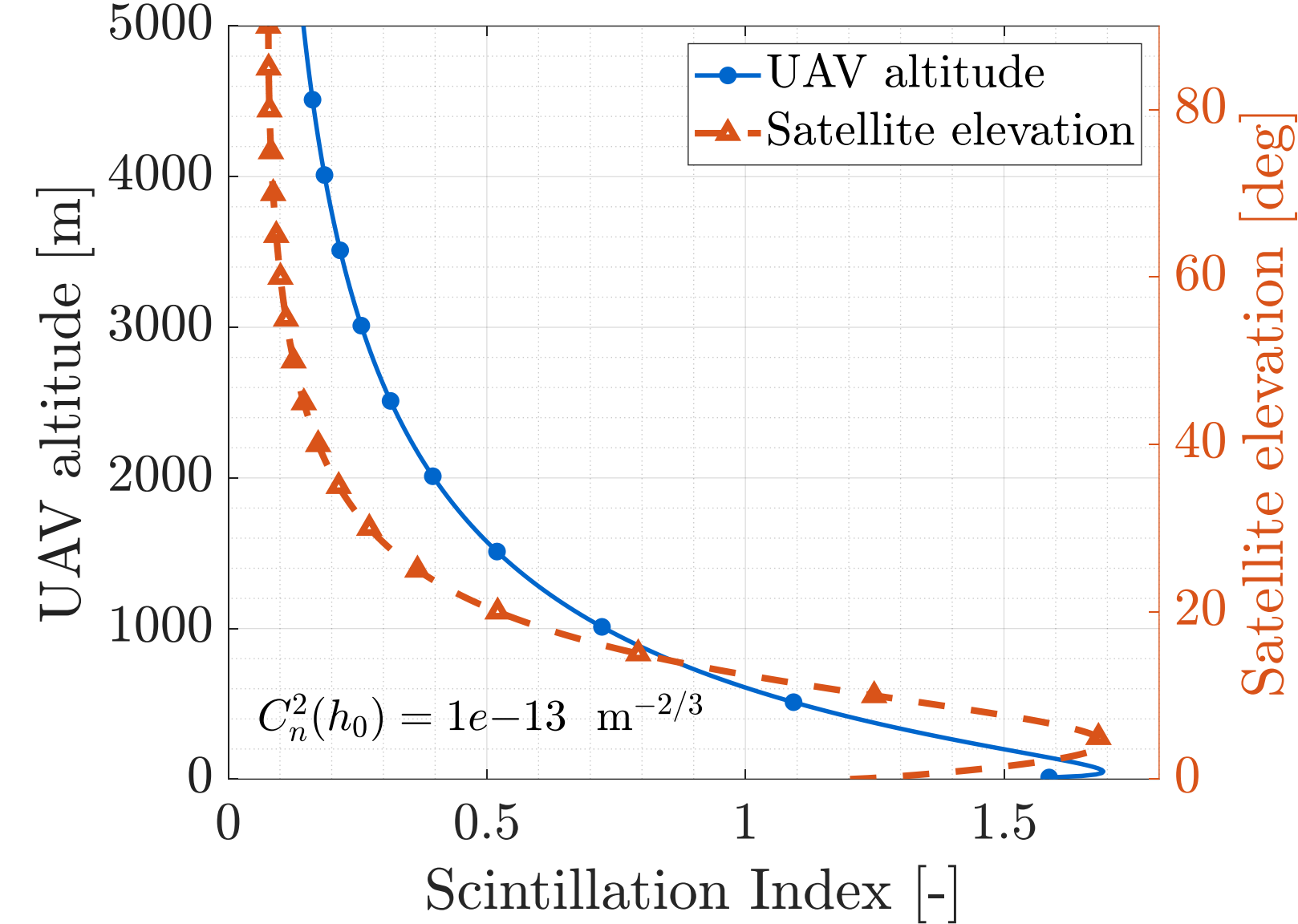
We employ the Hufnagel/Andrews/Phillips Modified (HAPM) model for calculating the C_n^2 with a near-ground decay of $-2/3$ with altitude (h)^{1,2}.



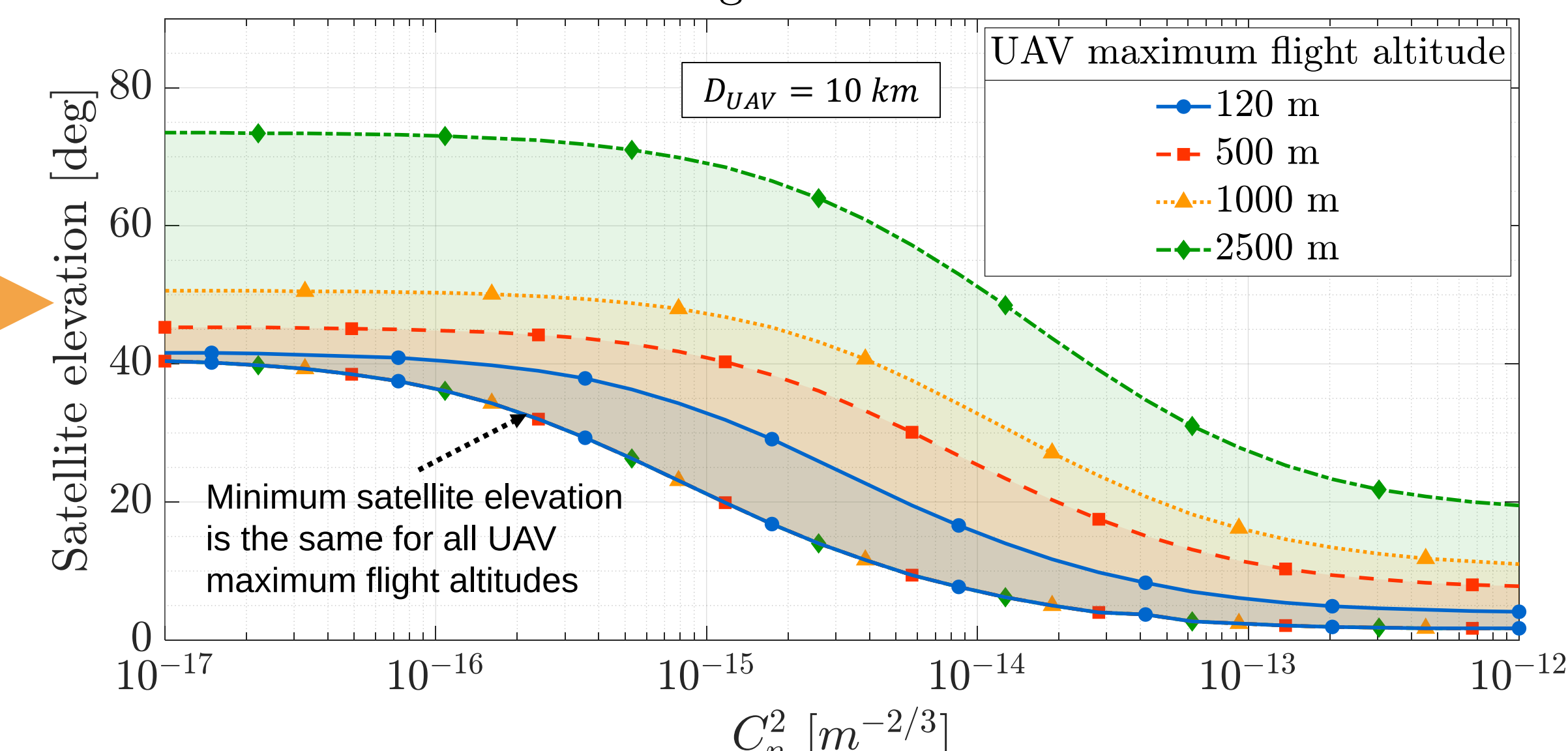
The range of satellite elevations that can be simulated with an OGS-UAV link depends mainly on:

1. The UAV maximum flight altitude (defined by legal and technical constraints).
2. The C_n^2 value on ground - $C_n^2(h_0)$ -.

Scintillation Index of OGS-UAV and OGS-to-LEO satellite links



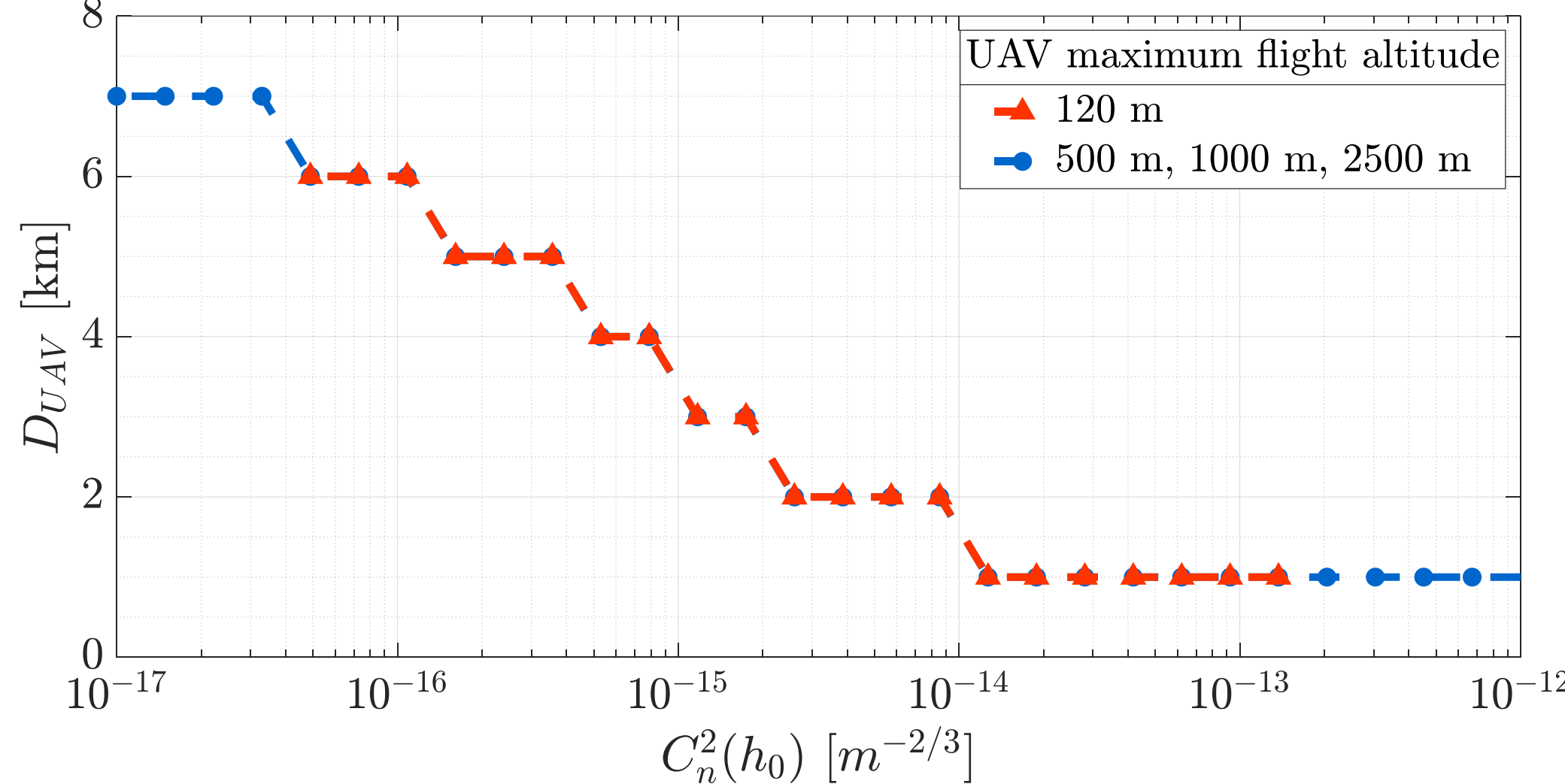
Satellite elevation range simulated with OGS-UAV link



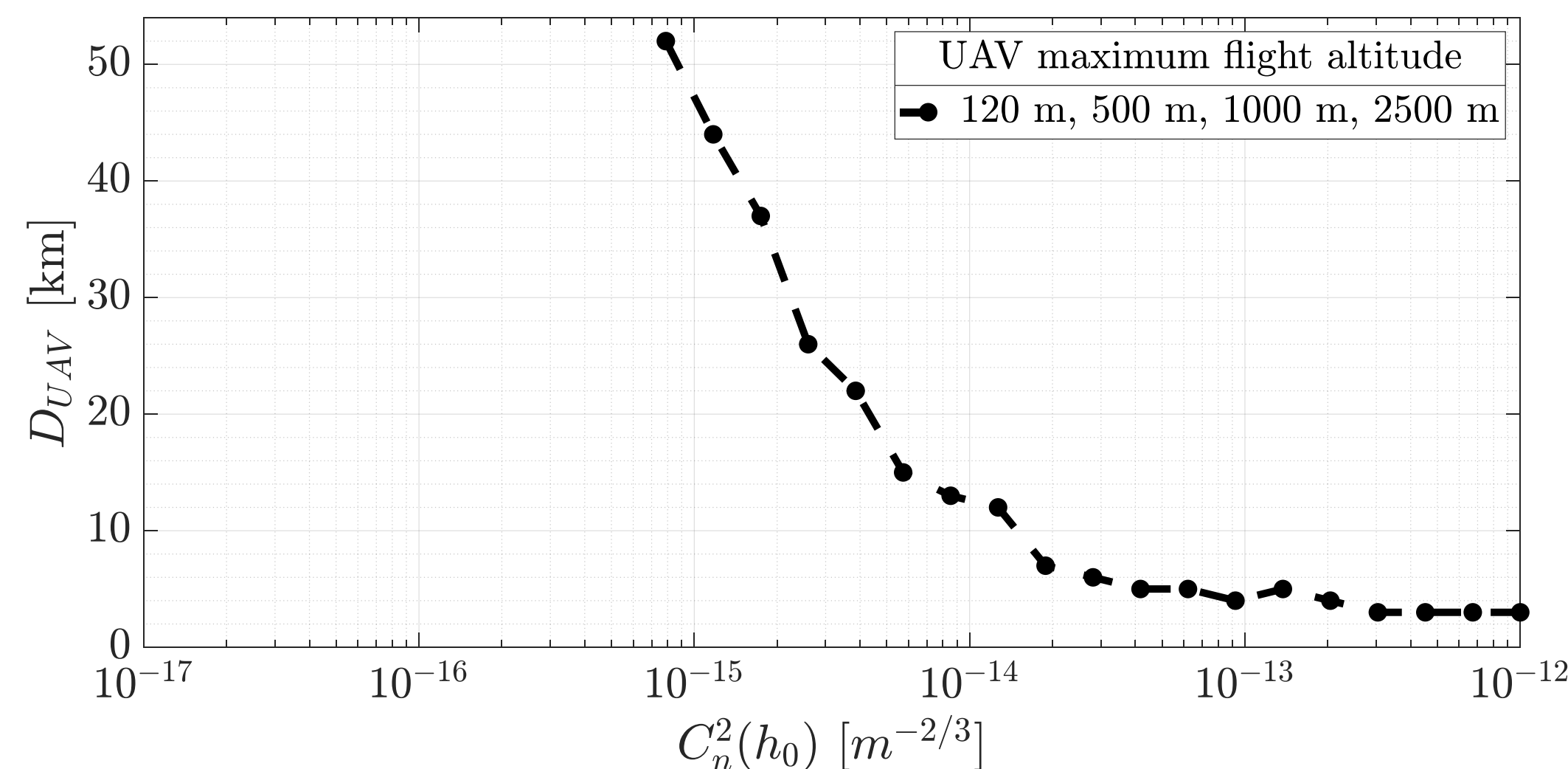
4. Results

The horizontal distance at which the UAV should be from the OGS (D_{UAV}) to detect a similar scintillation index as a ground-to-satellite link at a given satellite elevation can be determined considering a known $C_n^2(h_0)$ and the maximum flight altitude of the UAV (H_{UAV}). For example:

Minimum horizontal distance to UAV to simulate 90° satellite elevation



Minimum horizontal distance to UAV to simulate 5° satellite elevation



D_{UAV}	Max H_{UAV}	Simulated satellite elevation range			
		$C_n^2(h_0)$ = $1E-12 m^{-2/3}$	$C_n^2(h_0)$ = $1.4E-13 m^{-2/3}$	$C_n^2(h_0)$ = $1.3E-14 m^{-2/3}$	$C_n^2(h_0)$ = $1.2E-15 m^{-2/3}$
1 km	120 m	14.1° to 49.4°	19.2° to 90°	59.2° to 90°	-
	1000 m	14.1° to 90°	19.2° to 90°	59.2° to 90°	-
	2500 m	14.1° to 90°	19.2° to 90°	59.2° to 90°	-
3 km	120 m	4.4° to 14.6°	5.9° to 19.9°	16° to 56.2°	62.2° to 90°
	1000 m	4.4° to 38.1°	5.9° to 54.3°	16° to 90°	62.2° to 90°
	2500 m	4.4° to 62.4°	5.9° to 90°	16° to 90°	62.2° to 90°
5 km	120 m	2.4° to 8.6°	3.1° to 11.6°	8.8° to 29.7°	30.5° to 90°
	1000 m	2.4° to 22.4°	3.1° to 30.1°	8.8° to 90°	30.5° to 90°
	2500 m	2.4° to 38.1°	3.1° to 52.4°	8.8° to 90°	30.5° to 90°
10 km	120 m	1.7° to 4.1°	2.1° to 5.4°	6.2° to 14°	19.9° to 31.9°
	1000 m	1.7° to 11°	2.1° to 14.6°	6.2° to 30.7°	19.9° to 46.8°
	2500 m	1.7° to 19.5°	2.1° to 25.3°	6.2° to 48.5°	19.9° to 68.5°

5. Conclusion

- We have theoretically demonstrated that OGS-UAV links can be performed to measure atmospherically-induced signal fluctuations similar to those experienced in ground-to-LEO satellite links at different satellite elevations. By fixing the horizontal distance of the UAV from the OGS and flying the UAV vertically, several satellite elevations can be simulated during an OGS-UAV link. The range of satellite elevations that can be simulated depends on the distance between the OGS and the UAV, and the UAV's maximum flight altitude. Knowledge of the C_n^2 profile at the test site is desirable in determining the link scenario to simulate the desired satellite elevation range.
- Since the strongest atmospheric turbulence is closer to the ground, the **minimum satellite elevation** that can be simulated with an OGS-UAV link is when the UAV is closest to the ground and visible from the OGS. The larger the horizontal distance between the OGS and the UAV, the lower the satellite elevation that can be simulated.
- The **maximum satellite elevation** that can be simulated with an OGS-UAV link is mainly constrained by the UAV's maximum flight altitude. Higher maximum UAV flight altitudes allow higher satellite elevations to be simulated. For very short horizontal OGS-UAV distances, the integrated turbulence along the propagation path is so weak that even at low UAV flight altitudes the measured scintillation index can be as low as the expected scintillation index for ground-to-satellite links at 90° satellite elevation.

The presented results can be used for channel modelling of ground-to-UAV links, for simulating FSO satellite links using UAVs, and for testing atmospheric mitigation techniques in the presence of atmospherically-induced signal distortion. The impact of transmitter diversity will be investigated for low elevations.

References

- [1] L. C. Andrews, R. L. Phillips, D. Wayne, T. Leclerc, P. Sauer, R. Crabbs, J. Kiriases, "Near-ground vertical profile of refractive-index fluctuations," Proc. SPIE 7324, Atmospheric Propagation VI, 732402 (30 April 2009); <https://doi.org/10.1117/12.820369>
- [2] F. Moll, "Aspects of scintillation modelling in LEO-ground free-space optical communications," Proc. SPIE 10437, Advanced Free-Space Optical Communication Techniques and Applications III, 104370D (6 October 2017); <https://doi.org/10.1117/12.2282152>