

E2E PERFORMANCE OF A GEOSTATIONARY SATELLITE BASED OPTICAL TELECOMMUNICATION SERVICE

V. Leloup⁽¹⁾, N. Larive⁽¹⁾, E. Vretman⁽¹⁾, M. Faugeron⁽¹⁾, A. Le Kernec⁽¹⁾, T. Benaddi⁽¹⁾, J. Sommer⁽²⁾, V. Darchy⁽²⁾, C. Laborde⁽¹⁾

⁽¹⁾*Thales Alenia Space, 26 avenue J-F Champollion, BP 1187, 31037 Toulouse, France*

⁽²⁾*Centre National d'Etudes Spatiales, 18 avenue E Belin, 31401 Toulouse Cedex 09*

ABSTRACT: While optical inter-satellite links are well-established, atmospheric impairments remain a major challenge for space-to-ground and ground-to-ground optical communications. Leveraging DP-QPSK coherent modulation formats and upper-layer techniques, offers a solution to achieve high-capacity links (up to 100 Gb/s per wavelength) resilient to these impairments. Because atmospheric effects (e.g., turbulence, aerosols) are highly stochastic, system performance must be evaluated statistically. In this paper, we present a Monte Carlo simulation framework that samples atmospheric variable distributions to generate achievable data rate statistics over one-hour timeslots. Applied to an architecture derived from the SOLiS project, we evaluate two distinct operational use cases: trunking and feeder links. For ground-to-ground trunking via a transparent GEO relay, results demonstrate that an adaptive data rate approach can sustain 70 Gbps/wavelength with >70% exceedance probability, and 40 Gbps/wavelength with >90% exceedance probability. Conversely, the strict 99.9% availability requirement for feeder links makes adaptive operations significantly more challenging. Finally, we combine these simulated data rate distributions with site-specific cloud coverage data to evaluate scheduling strategies and derive Key Performance Indicators (KPIs) tailored to each scenario.

Keywords: Satellite-based Optical Communications, Transparent Trunking service, Feeder link service, Monte Carlo approach, Telecom

1. INTRODUCTION

The integration of optical communication technologies into satellite to ground links offers a paradigm shift in data transfer capabilities. However, addressing the stochastic nature of the atmospheric channel requires tailored operational strategies depending on the end-user application. In this context, cross-atmosphere optical links can be broadly categorized into two distinct use cases—trunking and feeder links—each governed by fundamentally different requirements in terms of availability, and payload architecture.

Trunking service refers to the high-capacity, point-to-point transfer of massive aggregated data volumes between a primary gateway and a specific end-user node. Unlike traditional telecommunication services that mandate stringent and continuous availability, the primary requirement of a trunking mission is the successful delivery of bulk data tolerating intermittent atmospheric outages. Consequently, trunking operations are highly resilient and flexible, designed to leverage short, opportunistic communication windows during favorable weather conditions.

Conversely, feeder link services mandate a highly reliable, permanent and stable connection between the space and ground segments, typically targeting an availability of 99.9%. To support this continuous operation, the system inherently requires an on-board coherent modem—a component that is not strictly mandatory for transparent trunking architectures.

Given these diverging operational paradigms, the stochastic analysis of atmospheric impairments must be conducted using distinct metrics tailored to each service. In this paper, the trunking service is evaluated using two primary metrics. The first is the **Expected value of the mean data rate per wavelength**, which provides a reliable estimate of the total data volume transferable over a prolonged cumulative communication period (e.g., fulfilling customer requirements expressed in terabytes per week or month). The second metric is the **Data rate per wavelength as a function of its Frequency of Exceedance (FoE)**. The FoE evaluates the system's reliability in transferring a specific data volume within a discrete 1-hour communication slot (temporal granularity of the present paper), thereby offering granular insights into link stability. For the feeder link service, the analysis focuses strictly on the **achievable data rate that satisfies a 99.9% FoE threshold** for both the uplink and downlink paths.

To provide a concrete evaluation of these services, specific operational scenarios are defined based on the SOLiS project architecture. For the trunking study, we assume the GEO satellite is positioned at 39°E orbital slot, with the optical

gateway located in Kofinou, Cyprus. The data transfer is directed towards two end-users situated in Dubai and Warsaw, establishing the Kofinou-to-Dubai and Kofinou-to-Warsaw optical paths. The gateway and user facilities are referred to as Optical Ground Stations (OGS).

For the feeder link study, we model a diverse terrestrial OGS network designed to mitigate weather and sun-exclusion constraints through site diversity. This network is assumed to guarantee the visibility of at least one OGS for 99.95% of the time, and at least two OGSs for 99% of the time. The optical performance of each individual satellite-to-OGS link within this network is assumed to be equivalent to the baseline satellite-to-Kofinou link.

It should be noted that throughout this paper, the Frequency of Exceedance (FoE) is systematically calculated under the assumption that the link is already established. This implies favorable weather conditions, valid sun exclusion angles, the absence of hardware failures at both the payload and satellite levels, and the successful completion of Pointing, Acquisition, and Tracking (PAT) procedures. During the communication, the targeted Quality of Service (QoS) is a BER lower than 10^{-9} in more than 99.9% of the transferred data and the extra latency is less than 200 ms in the trunking case while it is 70 ms for the feeder.

2. STOCHASTIC APPROACH USING MONTE CARLO METHOD

a) Channel Model and Attenuation Dynamics

From a theoretical standpoint, all factors contributing to the space-to-ground optical channel attenuation exhibit dynamic behavior; however, they operate across fundamentally different temporal scales. Parameters such as terminal antenna gains, free-space path loss, and optical amplifier output power (P_{out}) vary at an exceedingly slow rate, allowing them to be modeled as static contributors within the link budget.

Conversely, atmospheric turbulence induces rapid fluctuations at the millisecond scale, characterized by severe signal attenuation spikes commonly referred to as "fadings". Due to these rapid transients, maintaining a strictly continuous "Quasi-Error-Free" (QEF) status throughout the entire attenuation time series is physically unfeasible. Consequently, a statistical QEF criterion must be adopted: in this study, the QEF condition is considered fulfilled when the Bit Error Rate (BER) remains below 10^{-9} for more than 99.9% of the attenuation time series. While the individual fadings occur at the millisecond level, their frequency and intensity are governed by the macroscopic turbulence profile. In this paper, we postulate that this overall turbulence profile acts as a "quasi-static" contributor, evolving over a nominal one-hour timescale. Similarly, atmospheric attenuations caused by aerosols (AOD) and thin clouds¹ (channel assumed to be blocked in case of thick clouds) are treated as following this same 1-hour quasi-static evolution. Based on these distinct temporal dynamics, the various channel attenuation contributors can be classified into three fundamental categories, as summarized in **Table 2-1**.

From an operational perspective, it is assumed in this paper that typical customer requirements will involve communication sessions lasting in the order of one hour. Over such temporal windows, the macroscopic variability of the achievable data rate is predominantly governed by the aforementioned quasi-static atmospheric effects. Consequently, the proposed Monte Carlo methodology is specifically tailored to sample the statistical distributions of these quasi-static contributors, ensuring a representative assessment of the system's performance during these targeted operational time slots.

Table 2-1: Channel link budget contributor

Channel link budget contributor		
Type	Time scale	Contributors
Static	NA	OA P_{out} Terminal gains Free space losses
Quasi-static	~1h	AOD Thin clouds Turbulence profile
Dynamic	~1ms	Turbulence

¹ Clouds undetectable by meteorological satellites.

b) Quasi static contributors' hypothesis

α. AOD distribution

In the present study, the statistical distribution of the Aerosol Optical Depth (AOD) was derived using the dataset from the Copernicus MACv2 climatology [1]. As AOD is inherently site-specific, the baseline zenithal data must be adjusted to account for the slant path corresponding to the satellite's elevation angle. The resulting elevation-corrected AOD distribution for the Kofinou OGS, based on the SOLiS orbital slot, is illustrated in **Figure 1** (blue curve). Corresponding data for the Plateau de Calern is also included for comparative purposes.

β. Thin clouds distribution

The statistical distribution of thin cloud attenuation was derived from the study conducted by Reuniwatt, as detailed in [2]. This specific attenuation arises from optically thin clouds that fall below the detection threshold of meteorological satellites in “clear sky conditions” but remain present along the optical line of sight. Similar to the AOD methodology, the baseline measurements require a geometrical adjustment to account for the specific elevation angle of the satellite. The resulting elevation-corrected distribution for thin cloud attenuation is depicted in **Figure 1** (red curve). One can notice that there is a step in the cloud attenuation CDF around 15 dB at Kofinou and around 22 dB at Calern. It can be explained by the fact that the Sky InSight instrument saturates and the elevation correction to get Kofinou and Calern curves changes the value of the saturation threshold.

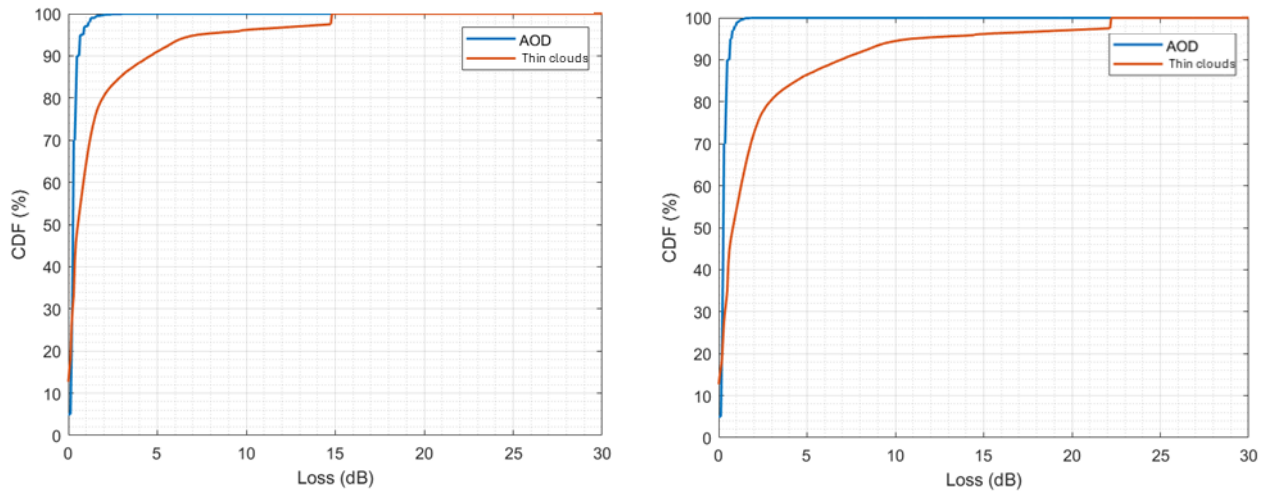


Figure 1. Cumulative density function (CDF) of the attenuations related to AOD (blue) and thin clouds (red) for Kofinou (left) and Plateau de Calern (right) sites.

γ. Turbulence profile

For the selection of turbulence profiles, we rely on the Observatoire de la Côte d’Azur (OCA) statistics derived at the Plateau de Calern (south east of France), which report the occurrence rates of the turbulence profile sets P_1 , $R_T P_{10-10}$, and $R_T P_{30-30}$ in the UL case and P_2 , $R_S P_{10-10}$, and $R_S P_{30-30}$ in the DL case as well. For the sake of simplicity, we assume that:

- 1) All considered locations experience the same profile occurrence probabilities as those given by the OCA data for the Calern site.
- 2) Fried’s parameter r_0 , isoplanatic angle θ_0 and scintillation index σ_χ^2 are perfectly correlated (relaxing this assumption would require minor adjustments to the distribution).

Therefore, at each site, the corresponding selection probabilities are:

- 9% for P_1 and for P_2
- 20% for $R_T P_{10-10}$ and for $R_S P_{10-10}$
- 70% for $R_T P_{30-30}$ and for $R_S P_{30-30}$.
- The remaining 1% corresponds to a blocking profile (denoted “cut”), for which no achievable rate is observed in this configuration.

At each site, the resulting probability mass function over turbulence profiles is provided in **Figure 2**. Thus, when considering a pair of independent sites (useful in the trunking case), the joint selection probabilities for every possible

combination of turbulence profiles are obtained by computing the corresponding pairwise probability distribution provided **Figure 3**.

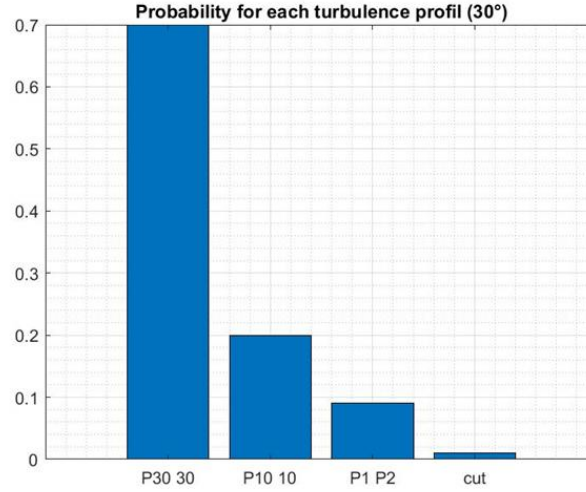


Figure 2. Selection probability for each profile, for a given site

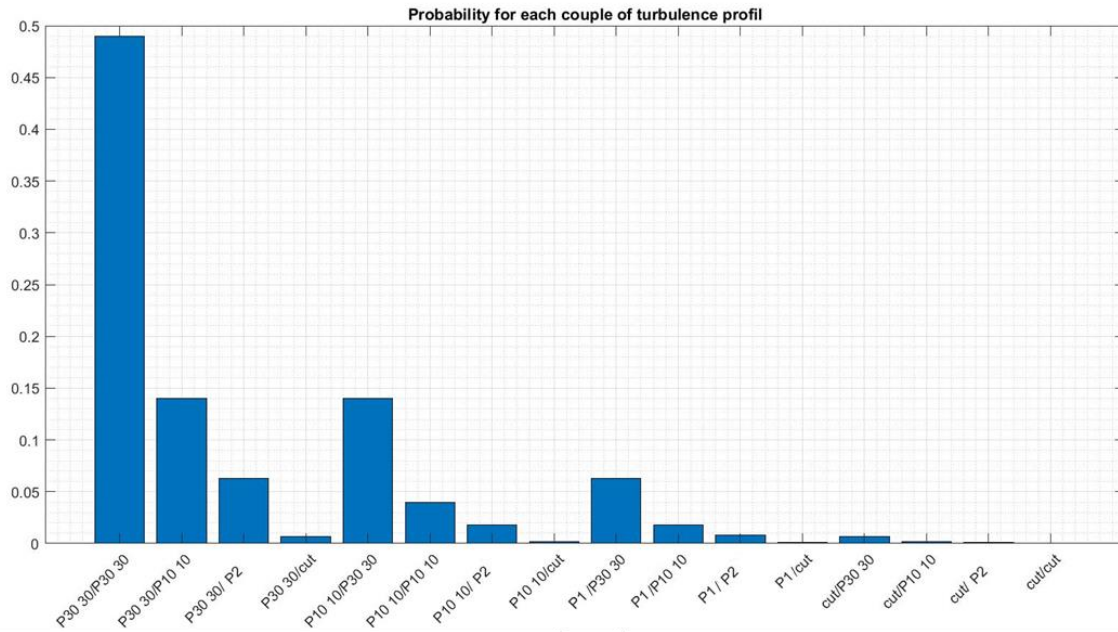


Figure 3. Selection probability for each profile combination, for a given couple of sites

c) Monte Carlo simulations

Building upon the previously defined statistical distributions, the next step is to evaluate the end-to-end performance of the considered optical links. Throughout this analysis, a Dual Polarization Phase Shift Keying (DP-QPSK) modulation format is assumed. Regarding the system's architecture, two distinct configurations are evaluated:

- For the trunking scenario, a transparent payload architecture is considered: the GEO satellite acts as a simple amplify-and-forward relay, optically amplifying the signal transmitted from OGS1 before routing it to OGS2 (as depicted in **Figure 4**²).
- For the feeder scenario, an on-board regenerative modem is assumed, since the optical feeder link requires the signal to be fully demodulated and decoded at the satellite level.

² Only one user can be addressed at the same time.

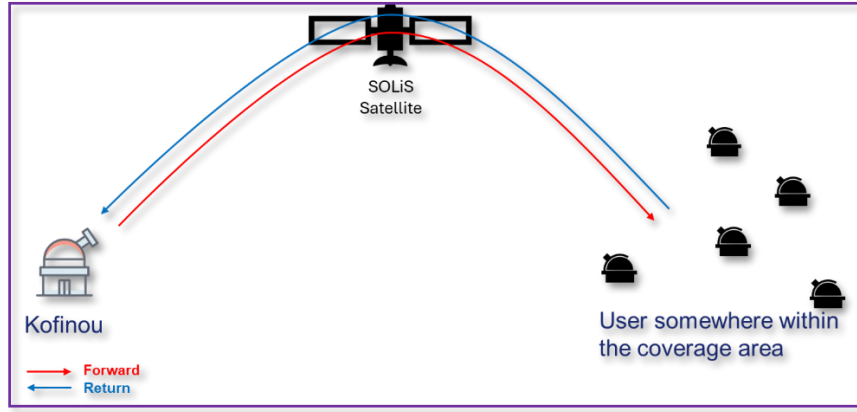


Figure 4. Trunking service

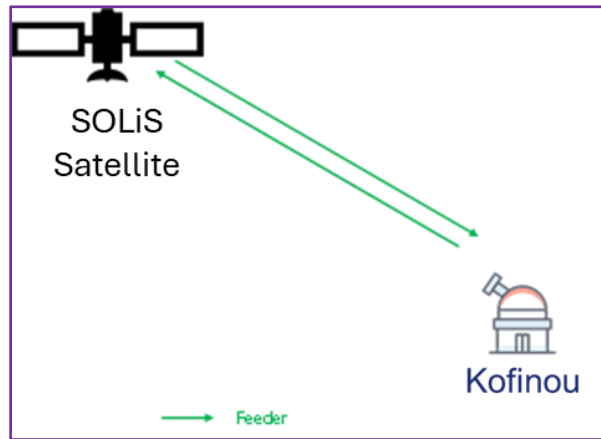


Figure 5. Feeder service

The overall performance of these optical links is governed by a combination of static, quasi-static, and dynamic parameters. With the system's static parameters strictly defined, a Monte Carlo approach is used to randomly sample³ the quasi-static parameters based on the aforementioned distributions. It is important to note that the dynamic fading losses are implicitly accounted for within the specific choice of turbulence profiles. Ultimately, this statistical sampling allows us to derive the distribution of the end-to-end achievable data rate over typical 1-hour operational time slots.

The output of this method is the FOE⁴ of the data rate per wavelength for a given link.

³ The number of Monte Carlo random draws is chosen to be sufficiently large to ensure that the sample mean closely approximates the theoretical expected data rate (see **Appendix A.b**).

⁴ The FOE is defined as the complement of the CDF, i.e. $1 - CDF$.

3. RESULTS

a) Trunking service

To evaluate the performance of a trunking service, two primary aspects must be considered: the system's capacity to transmit large volumes of data over a specific duration, and the stability of this capacity. The former is estimated by multiplying the expected data rate per wavelength by the cumulated link time, while the latter is assessed using the FOE. **Figure 6**⁵ presents the results for both Key Performance Indicators (KPIs). Based on the methodology described in Section 1, we generated maps illustrating the data rate per wavelength for a forward-path trunking mission (from Gateway to User), assuming the gateway is located in Kofinou⁶. The order of magnitude for the return path (from User to Gateway) remains consistent with the forward path. Notably, results vary according to the user's location due to local parameter variations, specifically the distance to the satellite and the Aerosol Optical Depth (AOD) contribution. A long-term mean data rate per wavelength of ~ 70 Gb/s is achieved towards Dubai, compared to ~ 60 Gb/s towards Warsaw. Regarding link stability, the data rate exceeded 75% of the time stands at 70 Gb/s for the former, and 50 Gb/s for the latter.

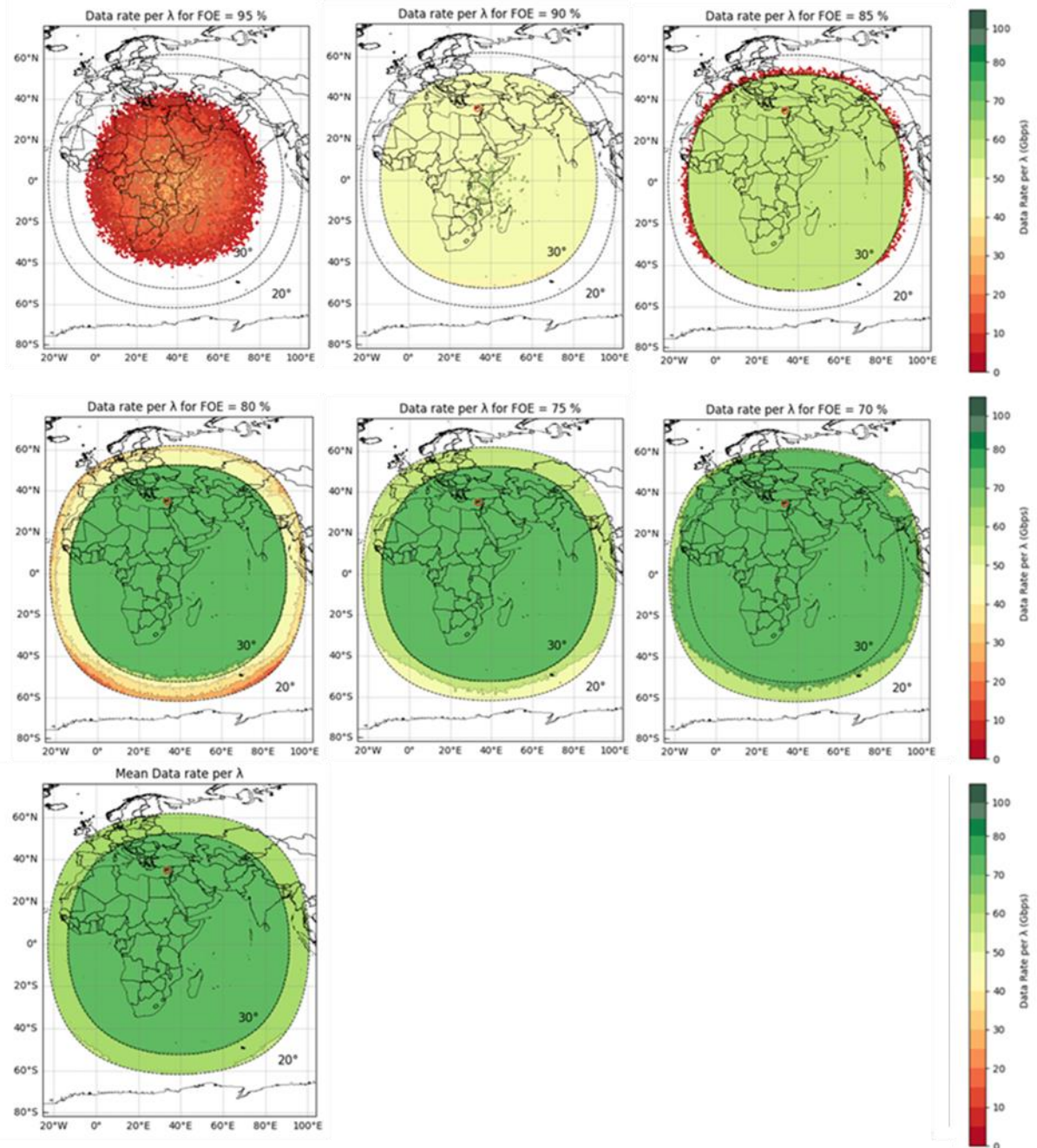


Figure 6. Data rate maps for FOE between 70% and 95% from Kofinou (gateway) to a user within the coverage area

⁵ Due to a lack of granularity in turbulence data, we only have turbulence simulations at 20° and 30° of elevation. Thus, 30° turbulence data is uniformly applied to the area between 30° and 90° and data corresponding to 20° is uniformly applied to the area between 20° and 30°, creating a conservative performance step. Elevations <20° are modeled as zero data rate zones.

⁶ Highlighted with a red circle on the maps.

However, as previously discussed, these initial KPIs assume an established link and therefore do not account for meteorological conditions (cloud blockage) or system availability constraints. To provide a comprehensive analysis, we incorporated weather data and availability constraints into two specific scenarios: a link from Kofinou to Dubai (KD) (favorable weather, elevation $> 30^\circ$) and one from Kofinou to Warsaw (KW) (bad weather, elevation $< 30^\circ$). Operationally, data transfer is modeled using one-hour time slots, allocating 5 minutes for the Pointing, Acquisition, and Tracking (PAT) procedure, while assuming the Optical Ground Station (OGS) preparation is completed prior to the link sequence. **Figure 7** presents a statistical synthesis over a five-year period (2021–2025) of the monthly data volume per wavelength that could have been transferred if such a system was deployed for both scenarios. The 2021–2025 meteorological datasets utilized for this study are detailed in **Appendix B**. One can compare the result with a 10 Gb/s permanent link for instance, that allows to transfer 3250 Tbytes over 30 days can be outperformed by a factor higher than 4 with 4 wavelengths in the KD case. A schedule can be established in order to share the service between Dubai and Warsaw, by prioritizing Warsaw because of its low weather availability and making transfer with Dubai in the remaining time for instance; the high availability of Dubai allows to keep transferring a large amount of data to that user.

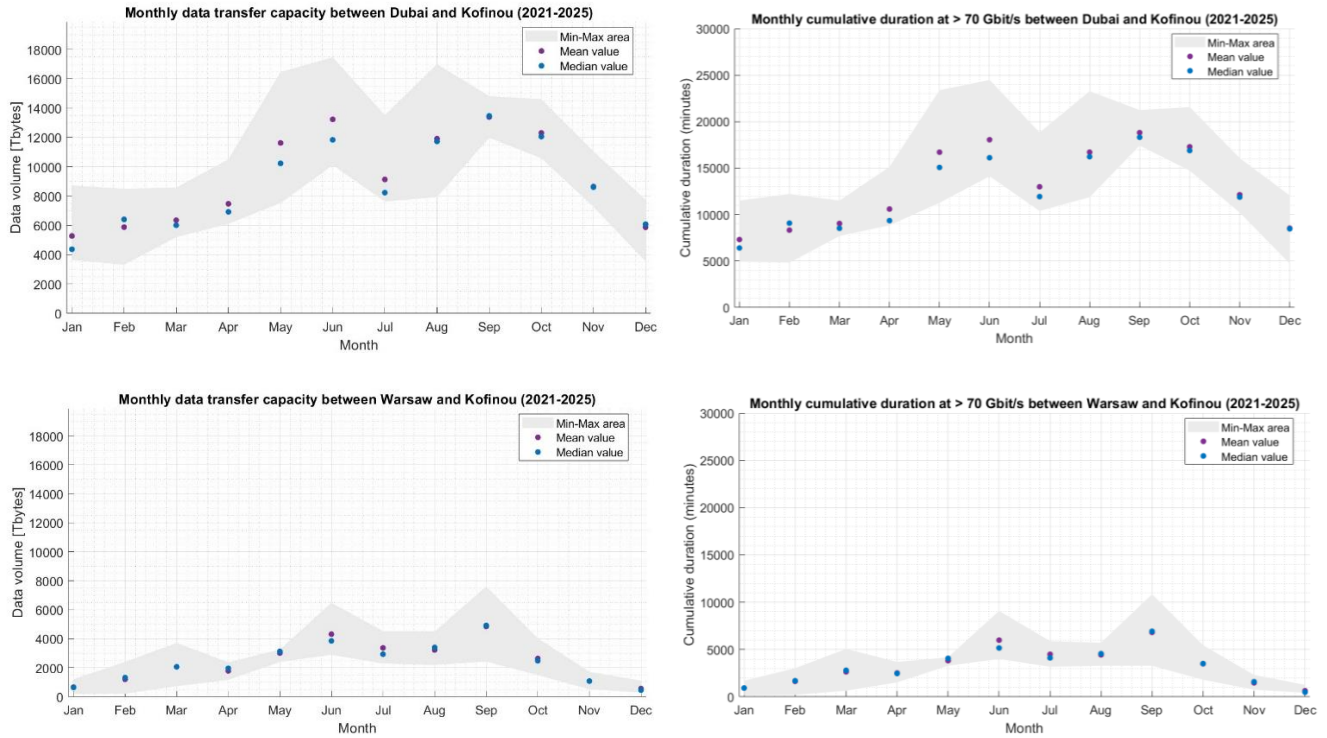


Figure 7. Monthly data transfer capacity (left) and number of minutes the data rate per wavelength exceeds 70 Gb/s (right), for Kofinou-Dubai (top) and Kofinou-Warsaw (bottom)

b) Feeder service

To evaluate the optical feeder link, we assumed a spatially diverse network of terrestrial OGS designed to overcome atmospheric blockages and solar interference. This network architecture guarantees the availability of at least one OGS for 99.95% of the time, and at least two OGSs simultaneously for 99% of the time. Such availabilities can be achieved with a network of about ten OGSs.

For modeling purposes, the optical link budget of each station within this network is assumed to match the baseline performance established for the satellite-to-Kofinou link. If we are able to choose the best link when 2 OGSs are visible, it strongly increases the FOE of the data rate provided by the system. We provided the FOE vs data rate per wavelength for only one OGS and the max between two OGSs respectively, assuming the atmospheric conditions are totally decorrelated between the two sites. We can derive from these metrics the availability of the system (all parameters included) as a function of the data rate per wavelength. One can see **Figure 8** that in with one OGS, 50 Gb/s per wavelength are exceeded 97.99% of the time, while it is 99.94% with two OGSs. From the ability of the network, one can obtain an overall availability at 50 Gb/s of 99.98% in uplink. In downlink, we reach an overall availability at 20 Gb/s of 99.89%. A capacity of 400 Gb/s in uplink and 100 Gb/s in downlink are then achievable with such a system accommodating 8 wavelengths in uplink and 5 in downlink. The method is detailed in **Appendix A.c**). One can compare with the KVHTS system that has the same capacity and availability with a network of 15 gateways.

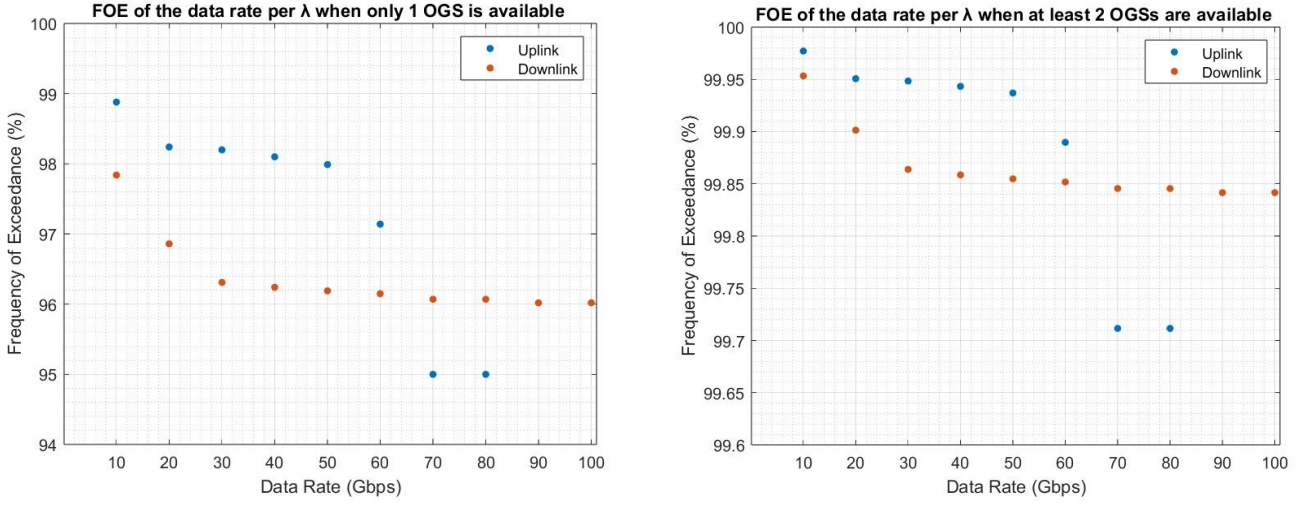


Figure 8. FOE of the data rate of a feeder link when 1 (left) or 2 (right) OGSs are available

4. CONCLUSION

This paper has investigated the performance of satellite-to-ground optical communications by assessing two fundamentally different operational paradigms: trunking and feeder links. By applying a rigorous statistical approach based on the SOLiS project architecture, we demonstrated that the stochastic nature of the atmospheric channel can be successfully mitigated when the system strategy is tailored to the specific end-user application.

For the trunking service, our analysis reveals that massive data volumes can be reliably transferred during opportunistic 1h communication slots. By evaluating the Kofinou-to-Dubai and Kofinou-to-Warsaw scenarios over a five-year meteorological period, we highlighted a strong geographical and seasonal dependency. Importantly, the data reveals a substantial and consistent number of high-capacity minutes every month. This frequent occurrence of peak data rates significantly bolsters confidence in the link's reliability for short-term, punctual operations. As a result, despite atmospheric impairments, the optical trunking system proves highly efficient: leveraging only four multiplexed wavelengths this baseline can be exceeded by a factor of 4 to 20, definitively confirming that optical links can guarantee large bulk data transfers over short periods. Crucially, this exceptional capacity is achieved through a fully transparent space payload. By eliminating the need for on-board coherent modems, this architecture significantly reduces the payload's complexity and power constraints while maintaining outstanding end-to-end data throughput.

Conversely, the feeder link service demands stringent, continuous availability. Our results demonstrate that this requirement can be robustly met through a spatially diverse network of approximately ten Optical Ground Stations (OGS). Crucially, the ability to dynamically select the best optical path when at least two OGSs are visible drastically enhances the system's Frequency of Exceedance (FoE). With this diversity strategy, an overall availability of 99.98% at 50 Gb/s per wavelength (uplink) and 99.89% at 20 Gb/s (downlink) is achieved. By multiplexing 8 wavelengths in uplink and 5 in downlink, the proposed optical architecture delivers a continuous capacity of 400 Gb/s and 100 Gb/s, respectively.

Ultimately, this study confirms that a smart optical site diversity strategy allows next-generation optical feeder networks to successfully match the immense capacity and ultra-high availability of state-of-the-art RF satellites, such as the Ka-band KVHTS system, while potentially reducing the required number of ground gateways.

Beyond these fixed ground network scenarios, the proposed transparent optical payload architecture opens promising perspectives for extended mission profiles. The GEO satellite could seamlessly act as a high-capacity optical data-relay node to continuously download massive observation datasets generated by Low Earth Orbit (LEO) satellites. Furthermore, owing to the inherently narrow beamwidth of laser communications—which guarantees exceptional anti-jamming resilience and a strict Low Probability of Intercept (LPI)—the opportunistic trunking paradigm could be effectively extended to highly secure, point-to-point data transfers for mobile platforms, such as naval vessels or aircraft. These perspectives underscore the versatility of optical satellite communications in addressing both massive commercial capacity demands and strategic security requirements.

ACKNOWLEDGEMENTS

This work is carried out in the frame of the SOLiS project, under the French space agency (CNES) supervision within the France 2030 program launched by the French government.

The authors thank Olivier Liandrat from Reuniwatt, for cloud analysis.

The authors thank Frédéric Lacoste, Project Officer at CNES, for his support to these activities.

REFERENCES

- [1] Stefan Kinne. Aerosol radiative effects with MACv2. *Atmos. Chem. Phys.*, vol. 19, pp. 10919–10959, 2019 <https://doi.org/10.5194/acp-19-10919-2019>.
- [2] Nicolas Sebastien *et al.* Relevance of the NWC SAF Cloud Type product to assess the impact of clouds on Free Space Optical Communication. Proceedings of *IEEE International Conference on Space Optical Systems and Applications (ICSOS)*, 2025.
- [3] Géraldine Artaud *et al.* Flight results of bidirectional communications with a GEO using a bi-static optical ground station. Proceedings of *IEEE International Conference on Space Optics (ICSO)*, 2026.

APPENDIX

A. BAYESIAN STATISTICS USED IN THIS PAPER

a) Expected value of the data rate per wavelength

To estimate the expected value of the data rate per wavelength, let's establish first the conditional expected value according to the experienced turbulence conditions $\begin{cases} P_{i,j} \text{ for pairs of profiles (trunking)} \\ P_i \text{ for a given profile (feeder)} \end{cases}$

In the following, the probability to get the couple $P_{i,j}$ is referred to as $p_{i,j}$ and the probability to get the given profile P_i as p_i . The values of these probabilities are given **Figure 2** and **Figure 3**. The expected value of the data rate, knowing the $P_{i,j}$ (resp. P_i) is written $\overline{D}_{i,j}$ (resp. $\overline{D}_i$). We focus on the trunking case; the feeder can be done easily.

Thus, Law of Total Expectation we have: $\overline{D} = \sum_{i,j} p_{i,j} \cdot \overline{D}_{i,j}$, where $\overline{D}$ is the overall expected value of the data rate.

In the present paper, the parameters that are considered as stochastic (in addition to the turbulence profiles dealt with just above) are the AOD and thin clouds attenuations. We assume the total contribution of these two effects is the sum of both terms. Our main variable is thus the total attenuation (in dB) random variable $H_{tot} = H_{AOD} + H_{clouds}$.

Let's introduce the data rate random variable $g_{i,j}(H_{tot})$ knowing that the turbulence couple is $P_{i,j}$. Thanks to the Law of the Unconscious Statistician, we have:

$\overline{D}_{i,j} = \int_{\Omega_{H_{tot}}} f_{H_{tot}}(\eta) g_{i,j}(\eta) d\eta$, where $f_{H_{tot}}$ is the probability density function of H_{tot} . $g_{i,j}(H_{tot})$ is given by the communication chain architecture and will not be detailed in this paper.

Assuming H_{AOD} and H_{clouds} are independent, we have:

$$f_{H_{tot}}(\eta) = \int_0^\eta f_{H_{AOD}}(\eta_{AOD}) f_{H_{clouds}}(\eta - \eta_{AOD}) d\eta_{AOD}.$$

To finish, $f_{H_{AOD}}$ and $f_{H_{clouds}}$ can be derived from **Figure 1** using $f_{H_{AOD}}(\eta_{AOD}) = \frac{dCDF_{AOD}(\eta_{AOD})}{d\eta_{AOD}}$.

Using all the above, one can now obtain the final value of $\overline{D}$ according to the considered link.

b) Number of draws in the Monte-Carlo simulations

For all Monte-Carlo simulations presented in this paper, the number of iterations was determined using a statistical confidence interval. Specifically, a sufficiently large sample size was chosen to ensure a $\beta = 99\%$ probability that the empirical mean deviates by less than $\alpha = 5\%$ from the theoretical expected data rate. Let D^k be the data rate of the k -th independent realization, and $\widehat{D} = \frac{1}{n} \sum_{k=1}^n D^k$ be the empirical mean estimator. According to the Bienaymé-Chebyshev inequality, we have:

$$P(|\widehat{D} - \overline{D}| \geq \alpha \overline{D}) \leq \frac{\text{Var}(\widehat{D})}{(\alpha \overline{D})^2}$$

Considering the D^k as independents and identically distributed, the variance of the estimator becomes :

$$\text{Var}(\widehat{D}) = \frac{1}{n^2} \sum_{k=1}^n \text{Var}(D^k) = \frac{1}{n} \text{Var}(D)$$

Similarly to **Section A.a)**, the Law of Total Variance allows us to calculate the overall variance $\text{Var}(D)$:

$$\text{Var}(D) = \sum_{i,j} p_{i,j} \text{Var}(D_{i,j}) + \sum_{i,j} p_{i,j} (\overline{D}_{i,j} - \overline{D})^2.$$

Therefore, to satisfy the confidence requirement $\beta = 1 - P(|\hat{D} - \bar{D}| \geq \alpha \bar{D}) \geq 0.99$, we must have $n \geq \frac{1}{1-\beta} \frac{\text{Var}(D)}{\bar{D}^2 \alpha^2}$. In our model, running $n=5000$ iterations easily satisfies this conservative lower bound, ensuring robust convergence for the simulation results.

c) FOE of the max data rate between 2 independent OGSs following the same law

To get the results from **Figure 8**, we had to calculate the probability law of the discrete random variable:

$$D_{2OGS} = \max(D_{OGS1}, D_{OGS2})$$

D_{OGS1} and D_{OGS2} refer to the data rate of the link established with OGS1 and OGS2 respectively. Thus, we have:

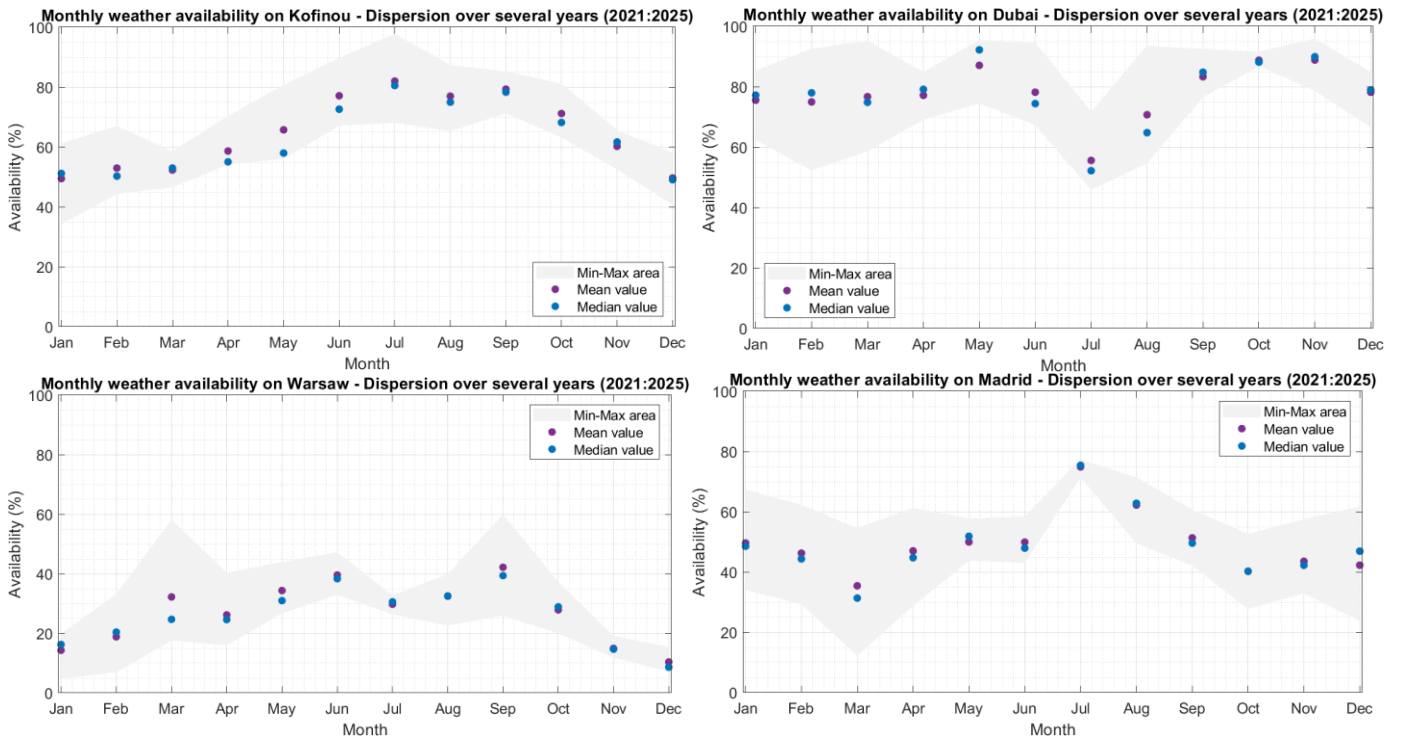
$$(D_{2OGS} \geq x_l) = (D_{OGS1} \geq x_l) \cup (D_{OGS2} \geq x_l)$$

D_{OGS1} and D_{OGS2} follow the same discrete probability law and are independent so that:

$$FOE_{2OGS} = 2FOE_{OGS1} - FOE_{OGS1}^2$$

B. WEATHER DATA

In this paper, all the weather data is extracted from the ICARE database including data from MSG and MTG missions. It was then post processed by Reuniwatt to correct some parallax effects with respect to the 39°E satellite position before sending it to Thales Alenia Space. We gathered data from 2021 to 2025 for 7 different locations: Kofinou, Dubai, Warsaw, Madrid, Plateau de Calern, Ramstein, and Kyiv. The results for each site are shown **Figure 9**. For each site, we can see a trend that seems to repeat itself over the 5 years. The particular value of July in the case of Dubai is due to sand storms in that region.



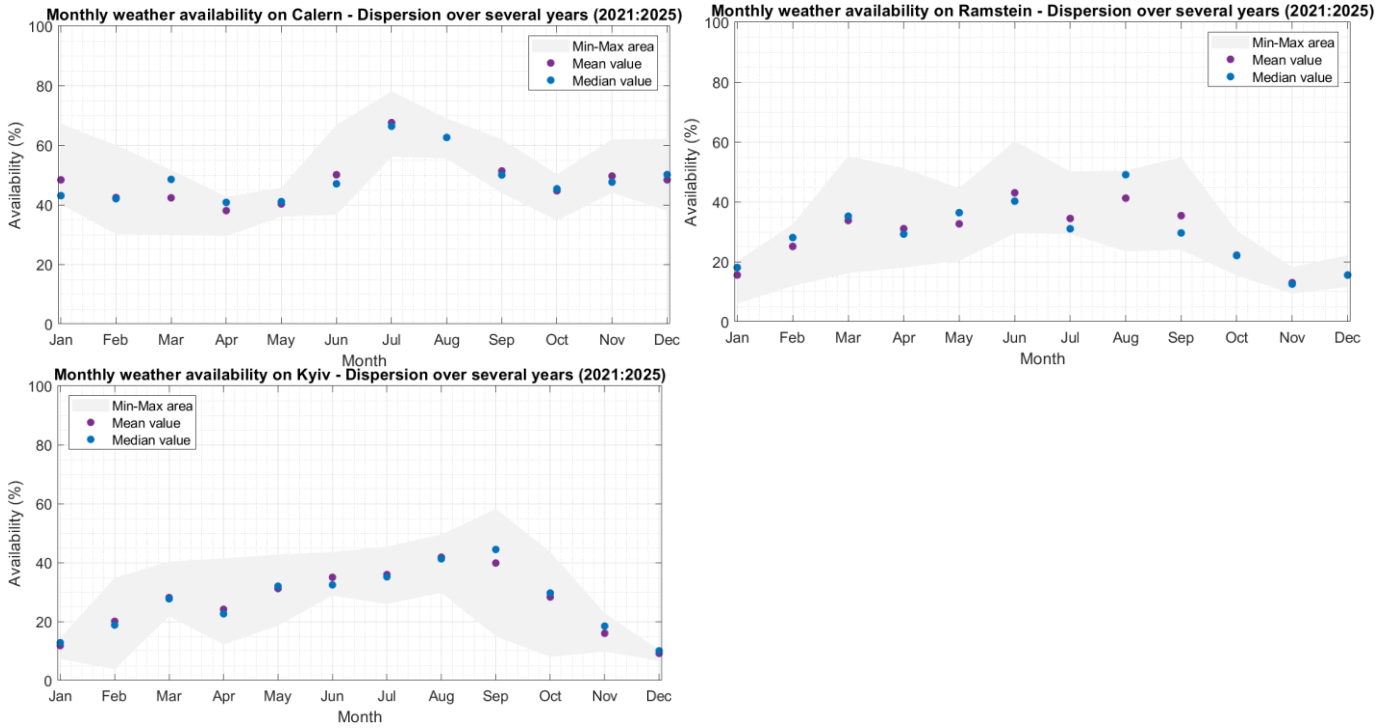


Figure 9. Monthly weather availability from 2021 to 2025 for each site

Joint availability for Kofinou-Dubai and Kofinou-Warsaw couples (interesting for trunking cases) are given **Figure 10**. As expected, the weather availability of the Kofinou-Dubai couple is much better than for the Kofinou-Warsaw couple.

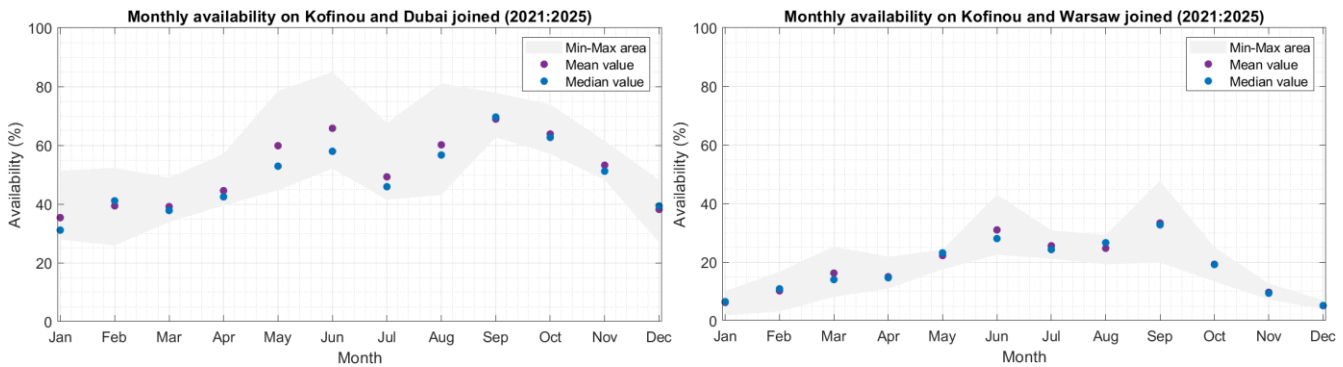


Figure 10. Monthly joint weather availability from 2021 to 2025 for Kofinou-Dubai and Kofinou-Warsaw

To close the present chapter, we provide the availability of an european feeder link network deploying 1 to 6 OGSs following the order: Kofinou, Plateau de Calern, Warsaw, Madrid, Ramstein, and Kyiv. In this, 93% availability can be achieved with that very bad weather network. One can assume that with a well-chosen network with more or less ten OGSs, the 99.95% availability can be achieved.

One can notice that once the first OGSs are deployed, it gets more and more complicated to achieve a huge increasing of the network's availability.

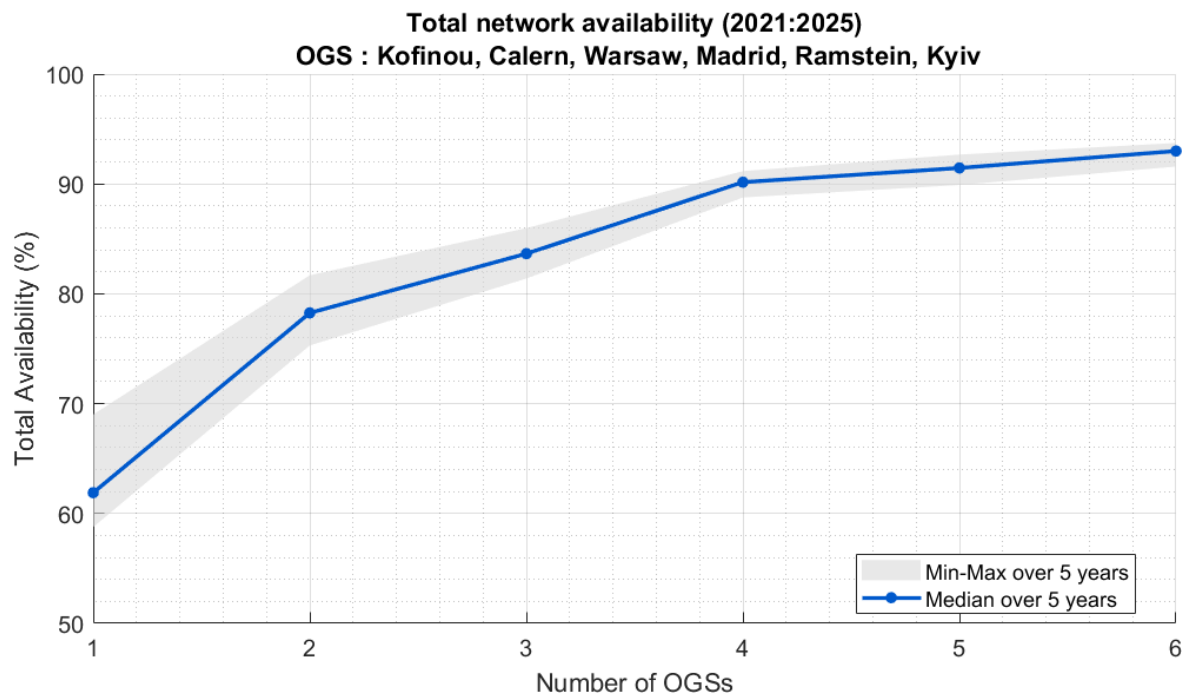


Figure 11. Network availability as a function of the number of OGSs