Uncertainty quantification of network availability for networks of optical ground stations

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INTRODUCTION

Free space optical communications is envisioned as the next milestone in space communications, due to the higher data-rates achievable (an increase of 10 to 100 times compared to current RF technology), and its lower size, weight, and power. The main drawback of this technology is the decrease in network availability due to link outages caused by cloud coverage.

In the last few years, several studies have been conducted to determine the optimal location of the optical ground stations, both for networks that serve GEO satellites and LEO satellites. However, no analyses have been conducted **to quantify the uncertainty** of the results when a) the inputs of the models come from **different datasets**, and b) the network availability is computed using **different methods**. See the motivational example below:

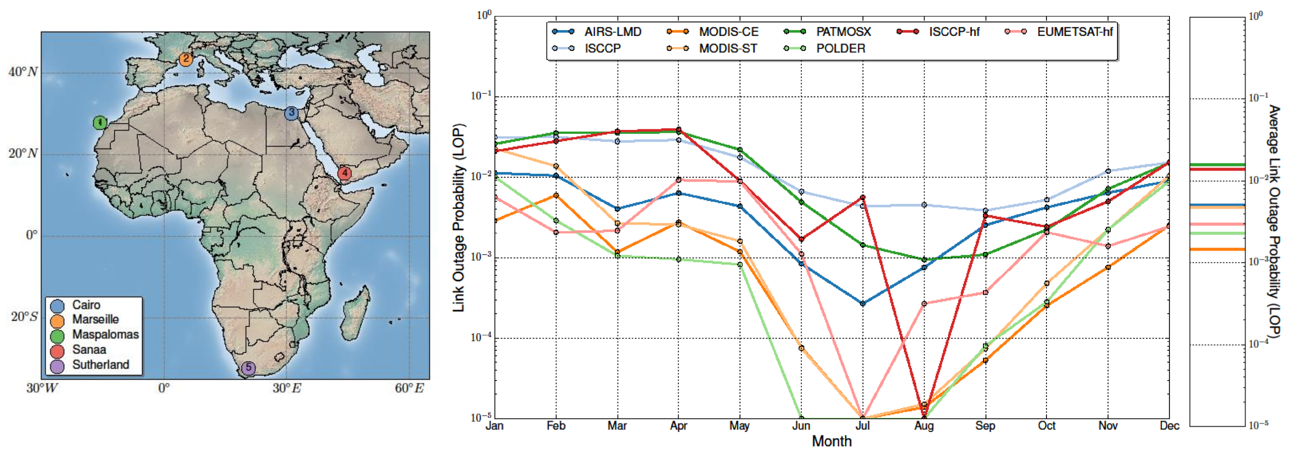


Fig. 1 Average monthly link outage probability (years 2004-2008)

UNCERTAINTY ANLYSIS

1. Approximations and assumptions incorporated in the link outage probability (LOP) **estimation methods**.
2. **Variations in repeated estimations** of the LOP under identical conditions.
3. Inexact values of cloud probabilities obtained from **external sources** and used in the estimation algorithms

UNCERTAINTY IN METHODS

Uncorrelated ground stations in which LOP is defined as having less than M ground stations with clear skies:

$$LOP = \sum_{m=0}^{M-1} \binom{N}{m} (1-p)^m p^{N-m}$$

$$u_{LOP} = \sqrt{\left[\sum_{m=0}^{M-1} \binom{N}{m} (1-p)^{m-1} p^{N-m-1} \big(m - N(1-p)\big)\right]^2 u^2}$$

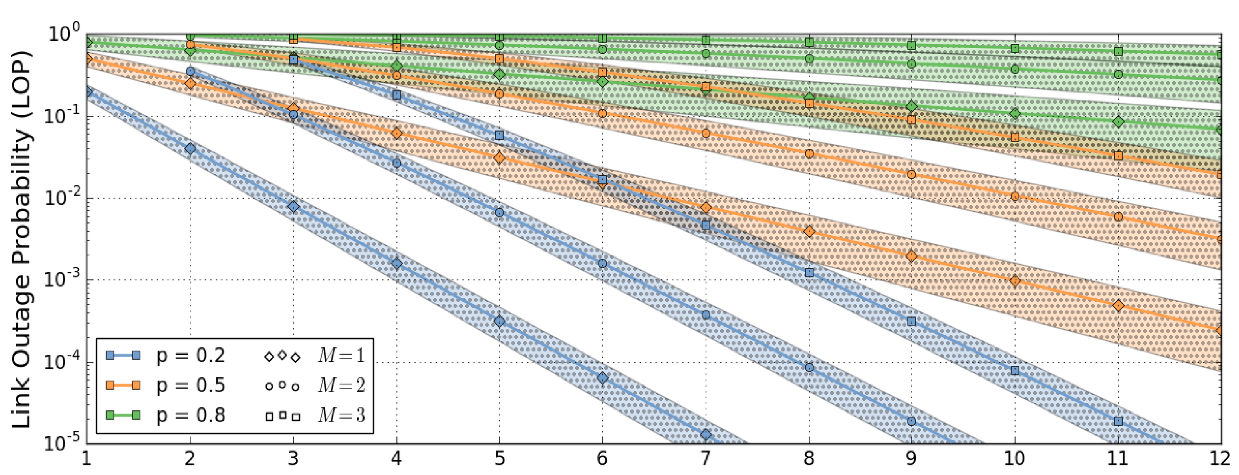


Fig. 2 Link outage probability for multiple station availability (M = 1, 2, 3) for different single-site cloud probabilities (p) and relative uncertainty (u = 10%) vs. different number of stations in the network.

For **correlated ground stations**, an approximation Monte Carlo method has been proposed[1]. We quantify the uncertainty associated to the randomness inherent to this method as a function of cloud probability, correlation index between ground stations, and number of samples.

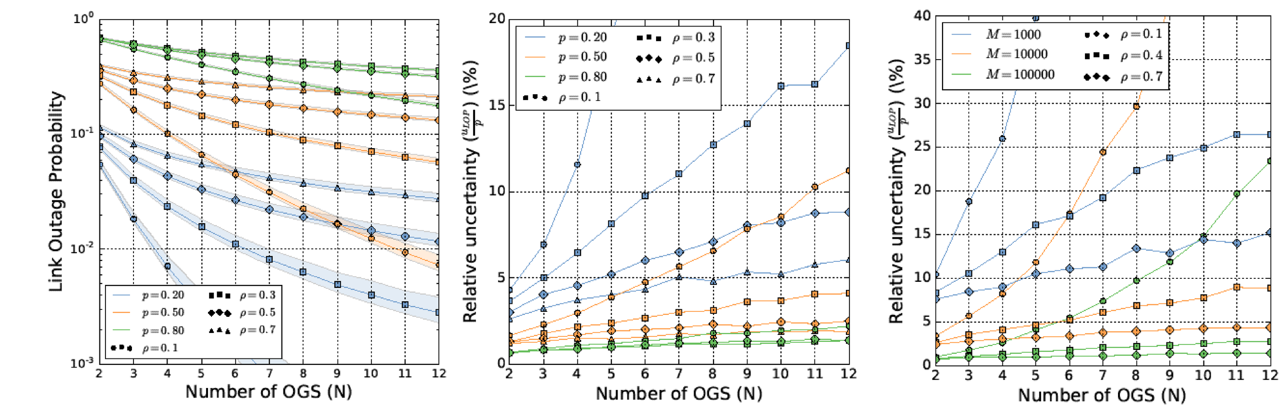


Fig. 3 Uncertainty vs. cloud probability, correlation index, and number of samples for the approximation MCS method.

UNCERTAINTY IN DATASETS

A pairwise comparison of cloud probabilities monthly averages from different datasets reveals mean standard deviations of 0.15 and biases of 0.02.

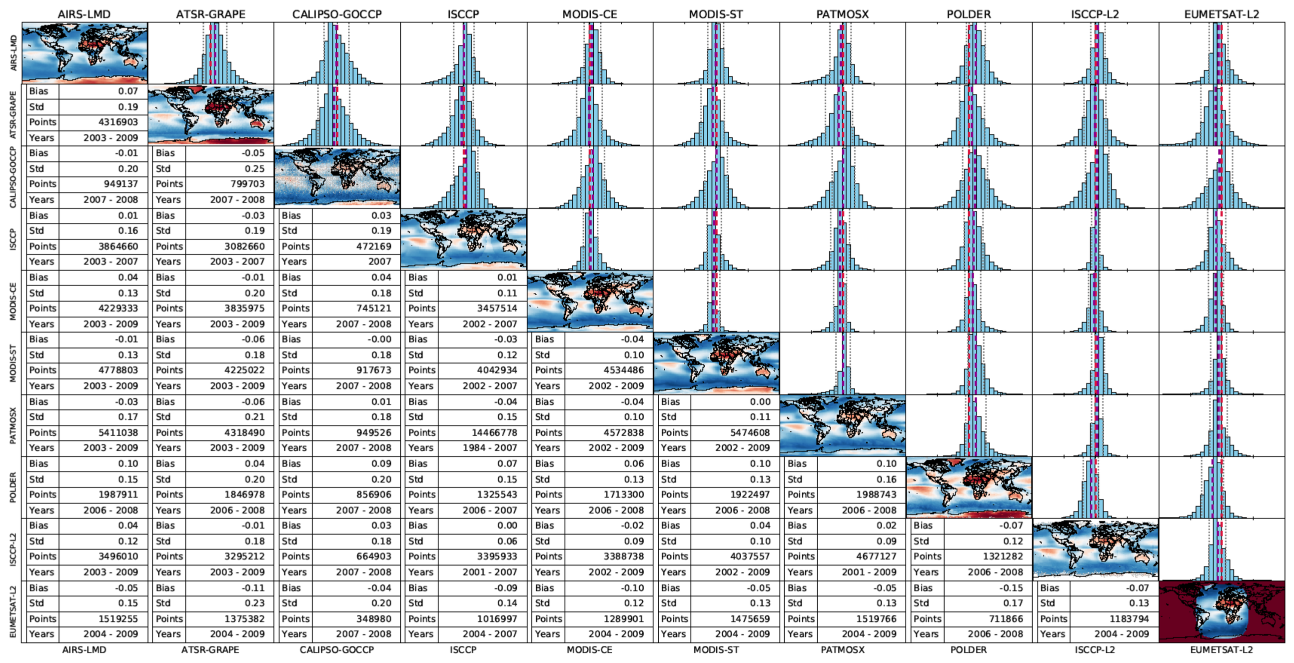


Fig. 4 Pairwise comparison of cloud probabilities among datasets.

PROPOSED METHOD

We provide a dataset that includes average cloud probability and the associated monthly standard uncertainty. This uncertainty takes into account both a) **inter-annual variations**, and b) different cloud probability estimations obtained using **different datasets.**

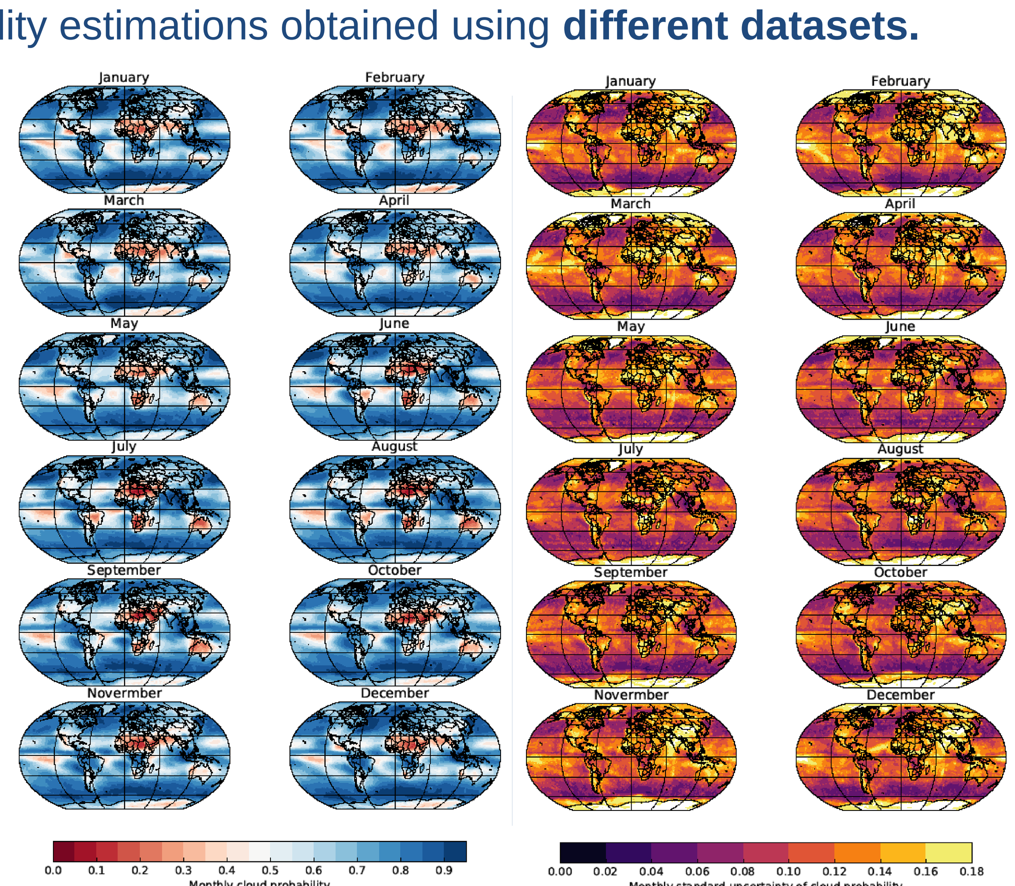


Fig. 4 Global model for cloud probability and associated uncertainty

We provide a 5 step method to compute the LOP and the associated uncertainty, accounting for inter-annual variations and differences in clouds datasets.

RESULTS

Revisiting our motivational example, all the monthly average link outage probability points fall in the 99% CI predicted by our model. Also the yearly average LOP.

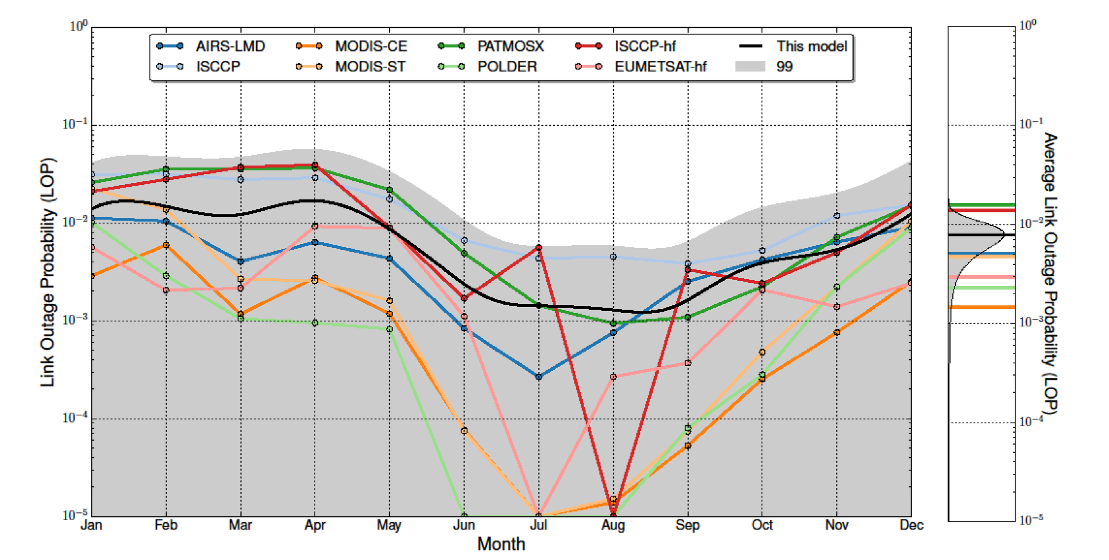
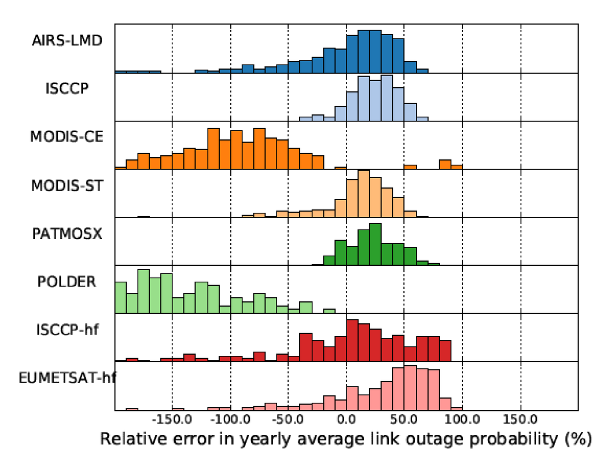


Fig. 5 Results of motivational example

Comparing our model to the results obtained when using other datasets:

- Low bias (except with MODEIS-CE and POLDER)
- Relatively low variance.



Dataset	Yearly	
	$E[e_y]$ [%]	σ_y [%]
AIRS-LMD	-2.5	50.3
ISCCP	23.7	20.7
MODIS-CE	-126.5	110.3
MODIS-ST	9.5	30.9
PATMOSX	22.6	21.0
POLDER	-285.6	186.8
ISCCP-hf	-65.8	189.3
EUMETSAT-hf	24.9	61.6

Fig 6 Relative errors of yearly average link outage probability between the values of our model and those obtained using other datasets

CONCLUSIONS

1. **We present a method to quantify uncertainty in network availability estimations.**
2. **We quantified uncertainty due to different methods (uncorrelated OGSs and correlated OGSs) and different datasets.**
3. **We produced a global dataset of monthly cloud probabilities and associated uncertainty.**
4. **Aute iruin renderit.**

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REFERENCES

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