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1 Context and goal

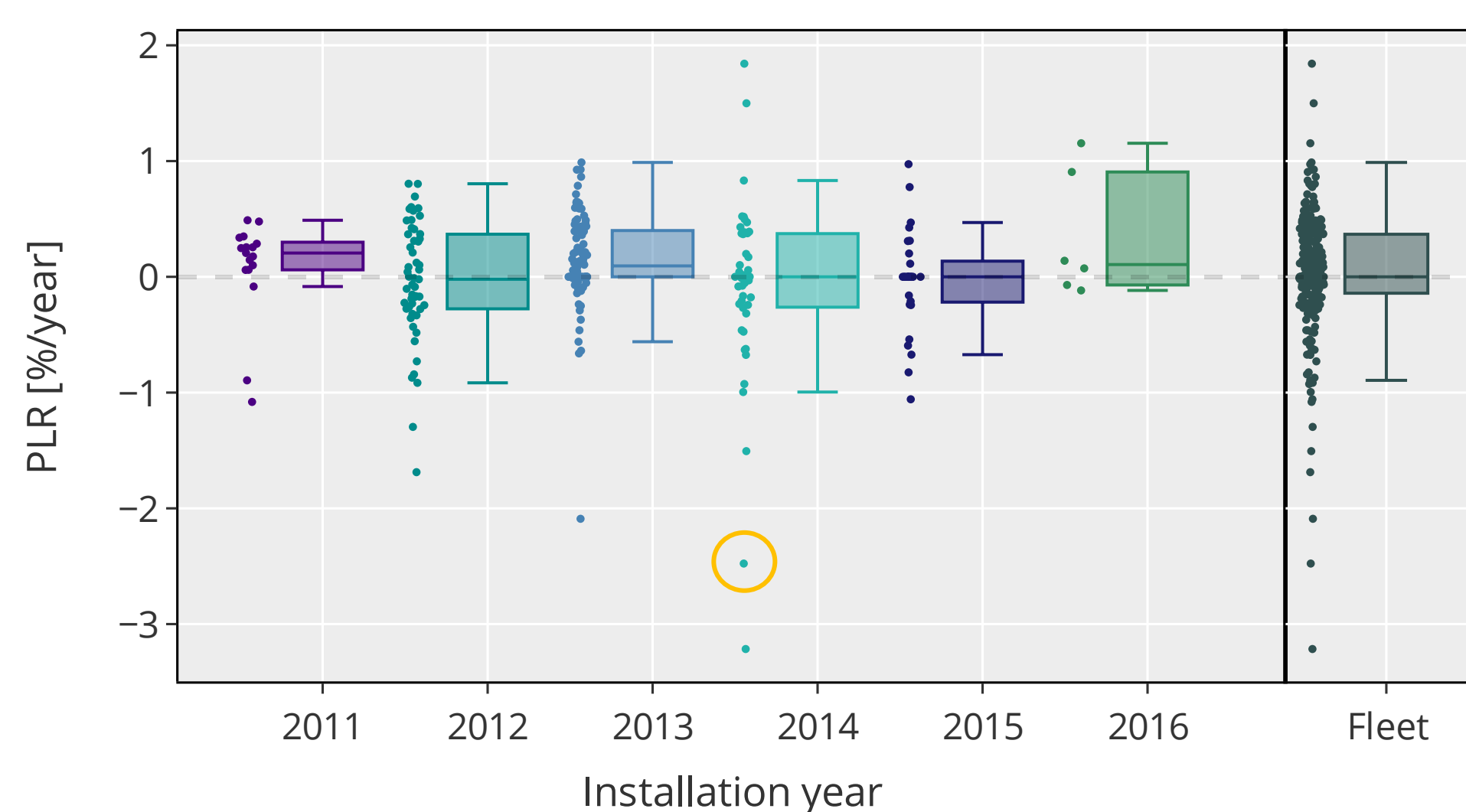
- Building integrated photovoltaics (BIPV) are key to achieving Switzerland's 2050 Energy Strategy targets for renewable energy.
- BIPV systems often operate at high temperatures and can face recurrent shading, and these stresses could lead to accelerated performance loss.
- Up to now there are few reports on the long-term performance of these systems, even though they constitute the vast majority of Swiss PV plants.

This work presents a **long-term performance analysis** of 50+ systems (200+ strings) in central Switzerland, along with a parallel **fault detection and diagnosis (FDDA)** to link performance losses to system faults.

3 Results – fleet analysis

- On average, low performance loss rates (PLR) were observed with a fleet median and mean of **0.1 %/year** and **0.04%/year** respectively, i.e. essentially no degradation though there is a large spread of rates. *N.B.: negative value denotes performance loss, positive value signifies performance gain*
- No trend by installation year was identified (see Fig. 1), and no systems exhibited obviously non-linear performance loss behavior.
- Fig. 2 shows the fleet characteristics – most systems were South-facing with 30° tilts, the average string capacity was 5.9 kWp, and the PLR ranged from -3.2 %/year to 1.8%/year.

Next step: analyse the **confounding factors** that lead to outliers in PLR (shading, climate, installation...)



Confounding factors behind performance loss

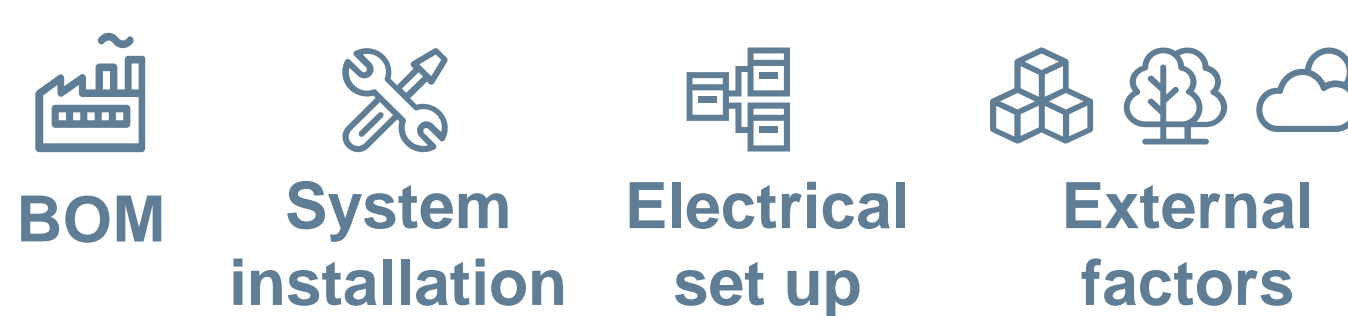


Fig. 1: PLRs [% year⁻¹] for 52 BIPV systems (242 module strings) by installation year showing median, confidence intervals (CI, 25–75% and 5–95%), and outliers. Outlier used for the case study is circled.

4 Case study – shaded system

- A fault detection and diagnosis algorithm (FDDA) was developed to automatically identify shading faults.
- An outlier system with high PLR was identified for a case study analysis:

Fig. 3 shows the fault-type heat map of the outlier string, where recurring shading is observed, linked to the chimney and surrounding trees.

Fig. 4 shows the PLR year-on-year analysis and performance ratio (PR) trends, comparing the shaded string with the neighbouring string. Severe performance loss is observed for string 1, whilst string 2 is stable.

Given that the two strings are from the same rooftop BIPV system, the remaining distinguishing confounding factor behind PLR is shading, and a clear link between shading and higher PLR is observed.

In a previous large-scale analysis [1], the shading factor was found to delineate an upper limit on the PLR. Moreover, average shading factors were found to increase in newer systems and decrease in larger capacity systems.

5 Conclusion

Overall, the BIPV fleet average PLR is found to be essentially zero (median of 0.1 %/year), but a large spread of rates is observed.

Low performing systems show recurrent shading through a fault detection and diagnosis algorithm, but other confounding factors should be further analysed.

Highlights the importance of alleviating shading stresses through innovative BIPV system design, which has particular relevance to the Swiss PV market.

2 Modelling approach

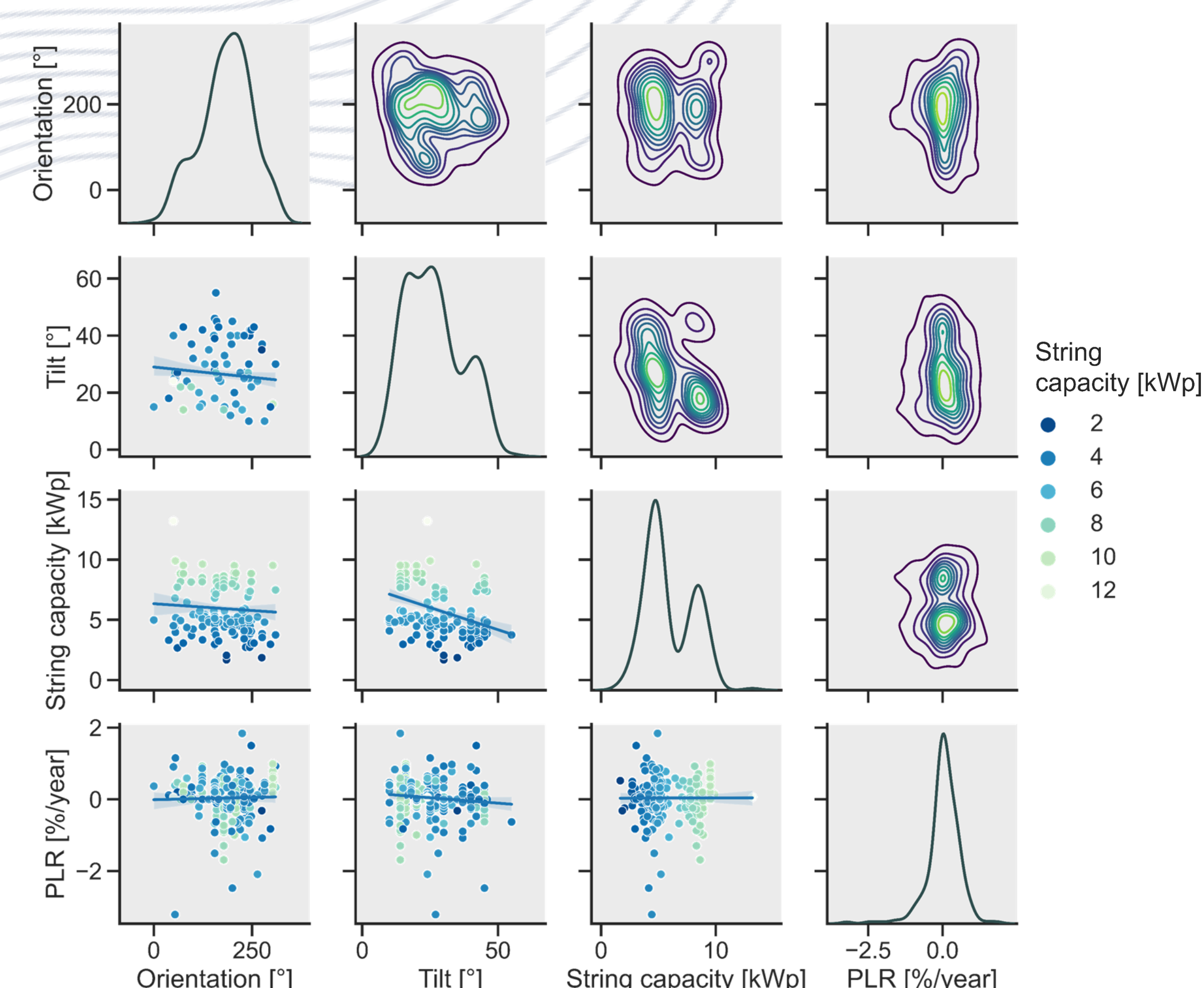
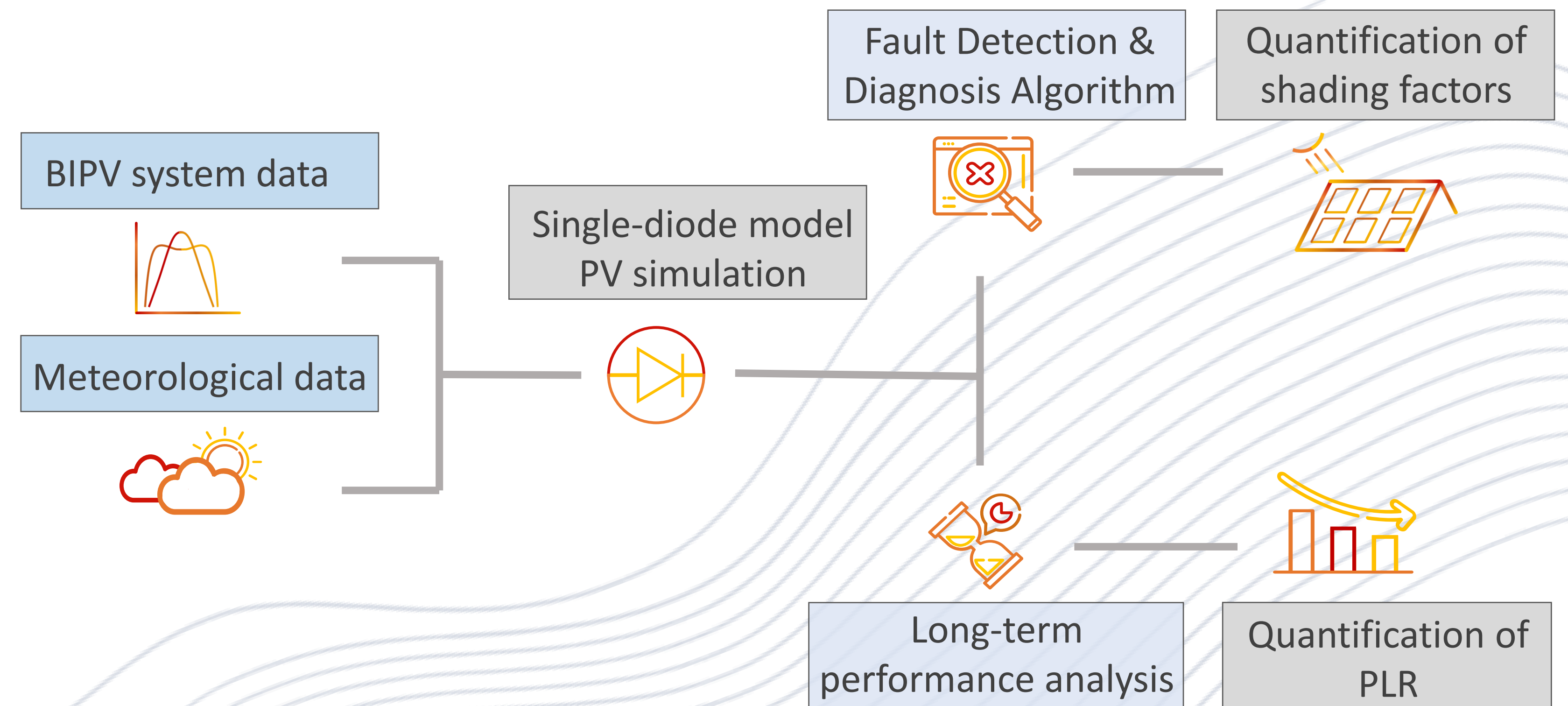


Fig. 2: Pair grid matrix overview of the BIPV fleet characteristics. Diagonal: probability distributions, Upper: kernel density estimate (KDE) distributions, Lower: scatter plots with linear trends and string capacity colour map.

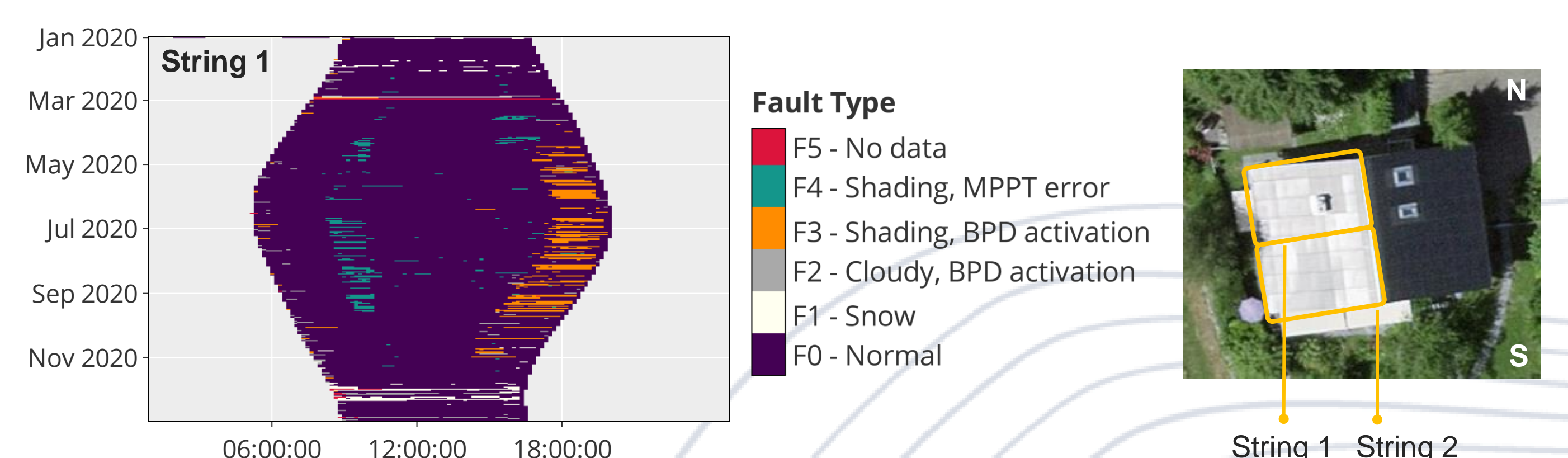


Fig. 3: Fault-type heat map of the top string of the analysed West-facing BIPV system, in 2020. Recurring shading events are observed in the morning and evening hours.

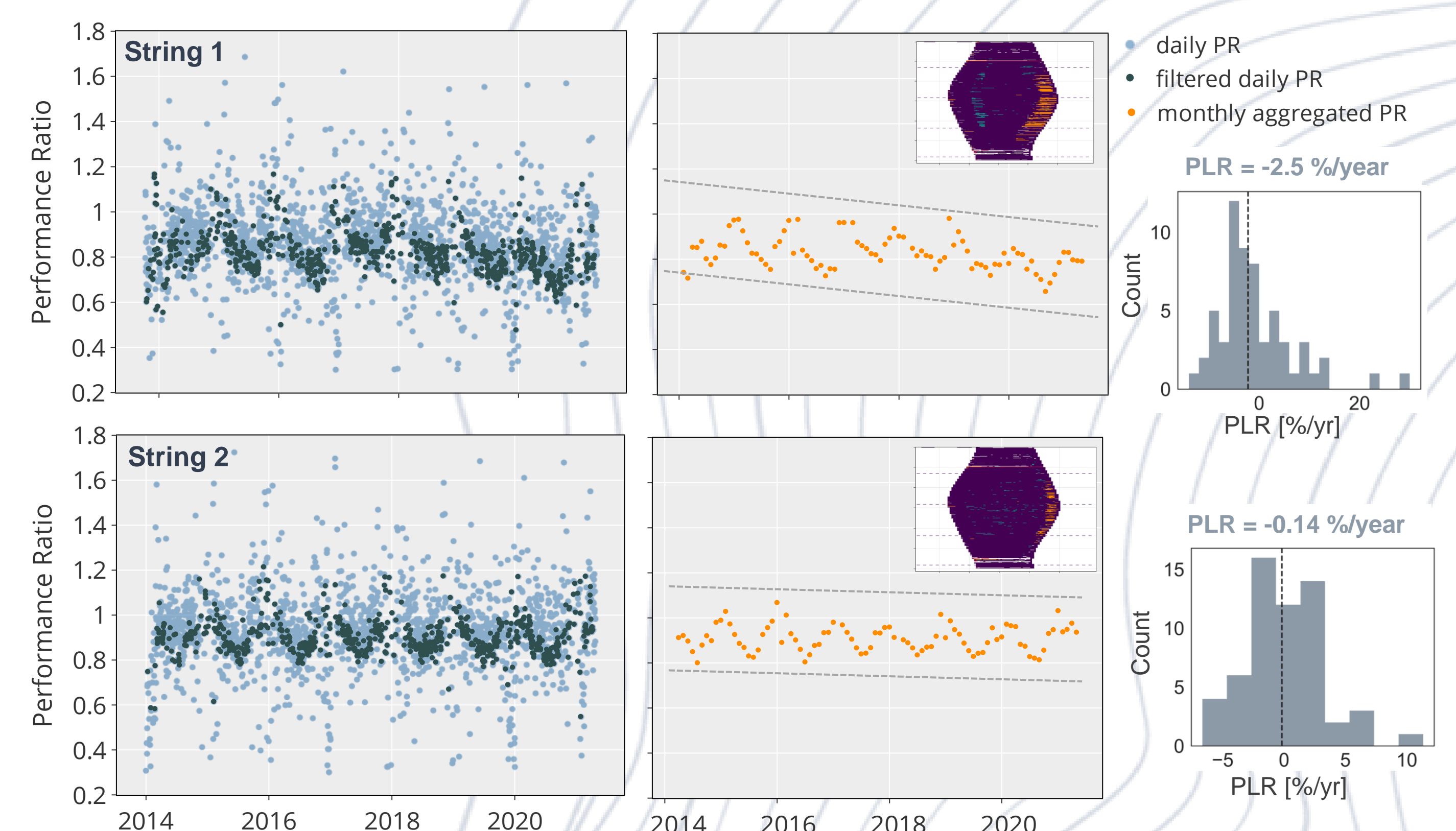


Fig. 4: Daily performance ratio (PR) trends for the two system strings (before and after filtering and monthly aggregation) and PLR distribution plots with indicated median value. A clear performance loss trend is observed for the heavily shaded string 1.

Acknowledgements

3S Solar Plus supervision: Pascal Müller, Philipp Wälchli
EPFL thesis supervisor: Prof. Christophe Ballif,
EPFL co-supervision: Dr. Alessandro Virtuani, Dr. Andrew Fairbrother
The authors thank Baur AG for providing access to the system data,
and Solcast for providing satellite-derived meteorological data.

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