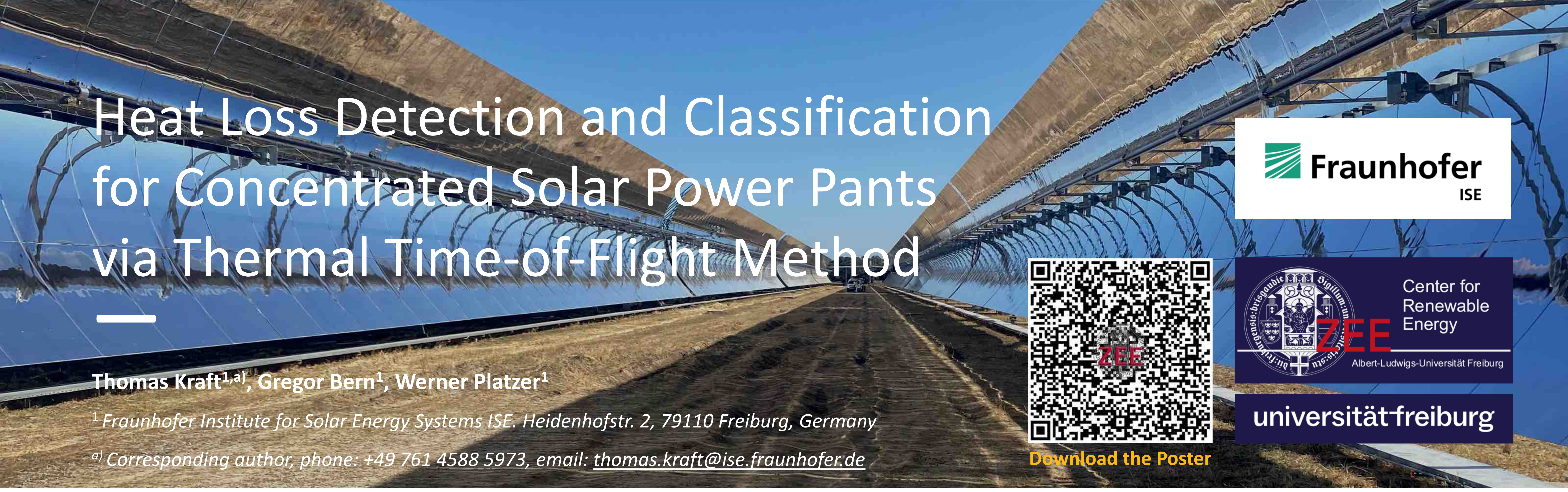

Heat Loss Detection and Classification for Concentrated Solar Power Pants via Thermal Time-of-Flight Method

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To maximize the thermal efficiency of Concentrating Solar Power (CSP) plants, early detection and reduction of existing heat losses and efficiency decreases is a key factor. This poster describes a Thermal Time-of-Flight (ToF) method especially developed for the CSP sector, used for the determination of the mass flow distribution within a solar field and its application for the detection of vacuum losses.

Heat Loss Calculation

Heat losses of a heat transfer fluid (HTF) can be calculated using the following equation:

$$\dot{Q}_L = \dot{m} \cdot \overline{c_P} \cdot \Delta T$$

where, in addition to the mean specific heat capacity $\overline{c_P}$, the mass flow $\dot{m}$ and the average cooling of this HTF ΔT are considered.

Background Vacuum Losses

A good vacuum between the absorber tube and the glass envelope contributes significantly to the reduction of heat losses from parabolic trough collectors (PTC). This vacuum decreases over time due to the diffusion of hydrogen from the HTF and the entry of air through microcracks in such a way, that replacing the affected tubes can be economically reasonable [2] (Fig. 1).

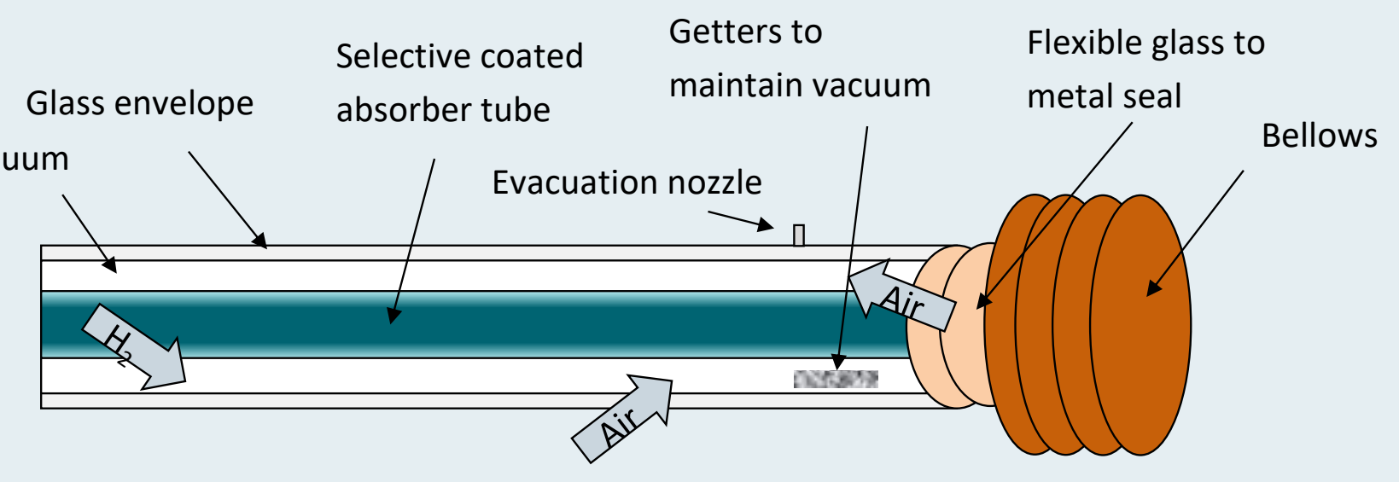

Fig. 1: Scheme of an absorber tube in a CSP plant [3]

So far, detecting vacuum losses involves high effort, for example by installing additional temperature sensors on the glass surface or measuring using infrared cameras. As there are much fewer factors affecting the solar field efficiency, nighttime operation is preferred for heat loss detection as a strong indicator for vacuum losses (Fig. 2).

Efficiency affecting factors during operation (daytime/ day- & nighttime)

- Soiling
- Misalignment of absorber tubes
- Offset in collector focus
- Canting errors of single mirrors
- DNI fluctuation (clouds, shading, …)
- Vacuum losses
- Conduction losses via connections (e.g. poor isolation of glass to metal seals)

Fig. 2: Parabolic Trough Collector (PTC) and factors including its efficiency during day- and nighttime operation

Mass Flow Measurement

An individual mass flow control has only been introduced in recent power plants, while a mass flow measurement with high temporal and spatial resolution has not yet been implemented. The ToF method to determine the mass flow distribution through the individual loops of the solar field in a CSP plant bases on measuring thermal step responses existing in typical power plant configurations. The analysed thermal step responses occur during preheating of the solar field at night or in the morning (Fig. 3) and can be measured with already installed temperature sensors.

The following conditions have been chosen as a basis for the demonstration of the ToF mass flow measurement method [1]:

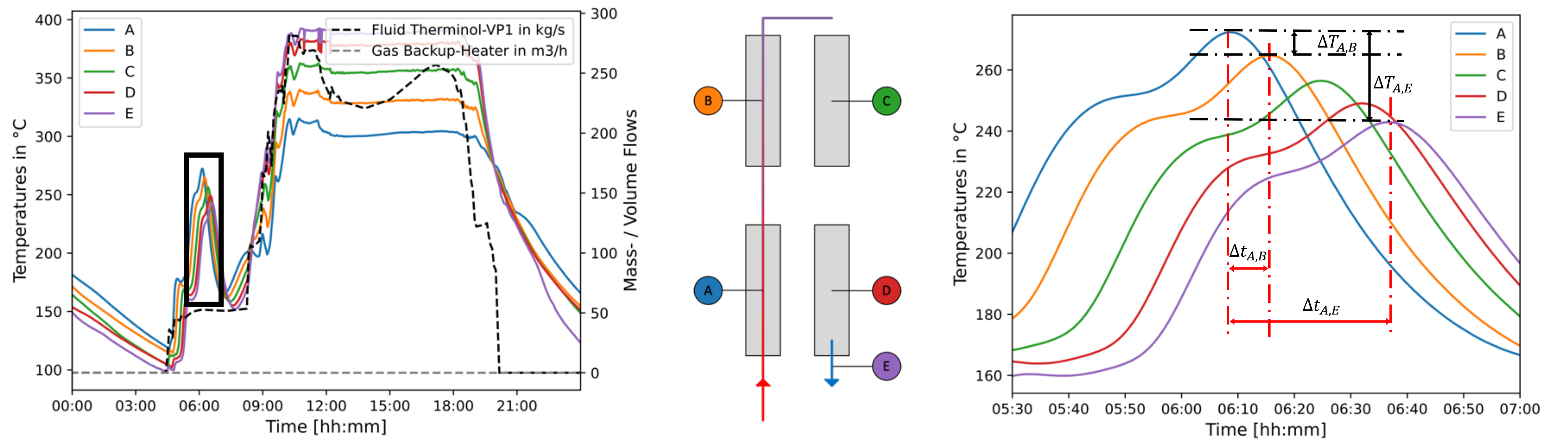

Fig. 3: Scheme of a PTC Loop with four SCAs and five temperature sensors (center). Corresponding temperatures for one example day (25th of September 2019) of the operating power plant Andasol III (left). Framed area is shown again in high resolution including two example measurements of temperature reduction and time delay between different temperature peaks (right) [3].

1. Uniform thermal step response through the solar field
   - No additional external heat source or sink superimposing the thermal step response (e.g. electrical/thermal heater or fluctuant DNI on collectors)
   - Constant mass flow between first and last temperature measurement in the corresponding loop
2. The associated loop must be in operation and must not be hydraulically locked
3. Known or equal geometries and sensor positions of the corresponding loops

Temperature Reduction Measurement

As can be seen in Figure 3, the reduction in temperature can be measured directly by the temperature sensors, in contrast to the mass flow.

Reference Plant and Dataset

Reference Plant (Fig. 4)

- Andasol III, 50 MW$_{el}$ CSP plant, located in southern Spain
- PTC solar field, divided into 4 subfields (NW / NE / SE / SW)
- Solar field consists of 152 loops, 38 per subfield
- 4 SCAs & 5 temperature sensors per loop
- Mass flow controlled (pumps) and measured (mass flow meters) on subfield level

Dataset

- Measurement period: 15 consecutive days
- Temporal resolution: Approx. 1 measurement every 10 sec
- Spatial resolution: Sensor data of 760 (5*152) temperature sensors (s. Fig. 3) and 4 mass flow meters

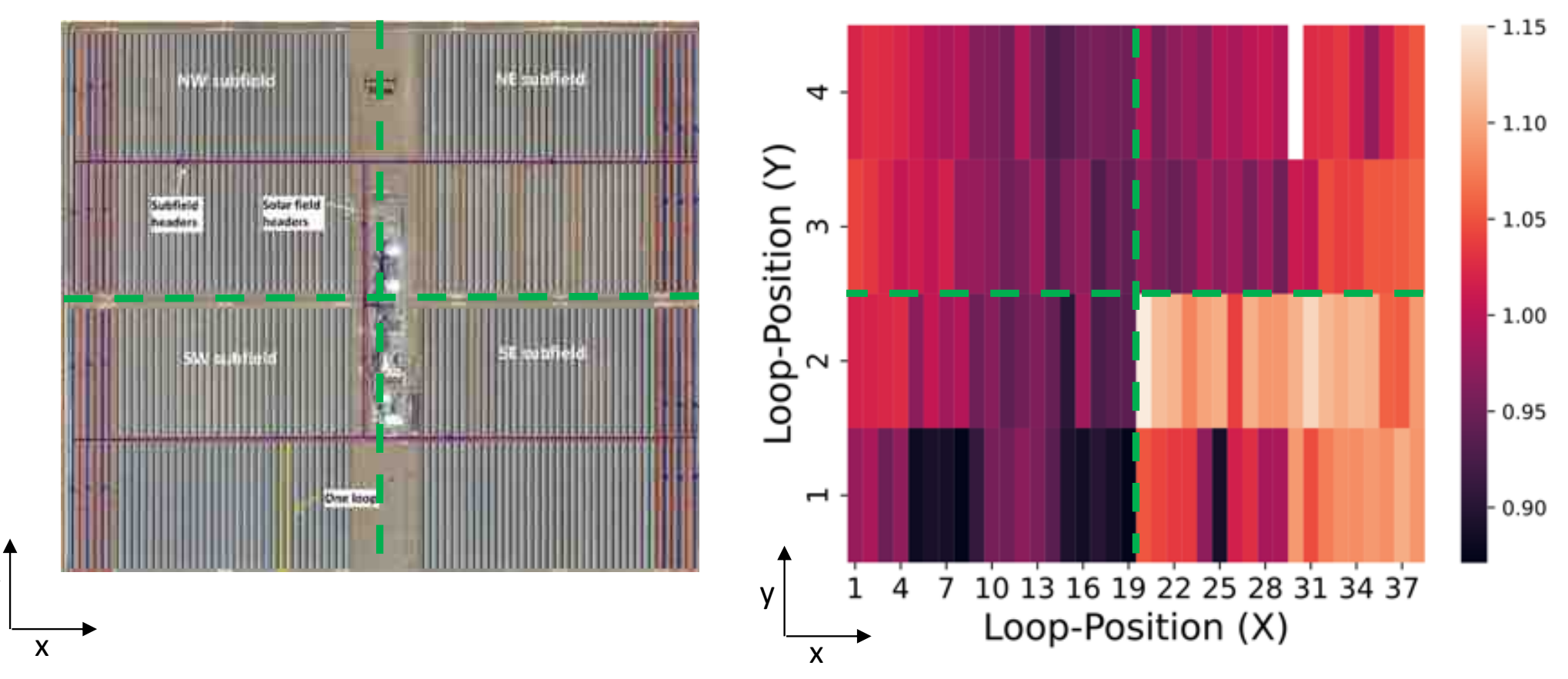

Fig. 4. Aerial view of CSP plant Andasol III, including the four subfields (left [4]) and normalized measured mass flows for all loops of one example day, 26th of September 2019 (right [1]).

Results

Validation Mass Flow Measurement ToF Method

The validation of the presented method took place on two different levels: subfield level and loop level. At subfield level, the calculated mass flow (sum of the individual loops) was compared directly with the measured mass flows (Fig. 5), measuring 94% of the data within ± 5% of full scale.

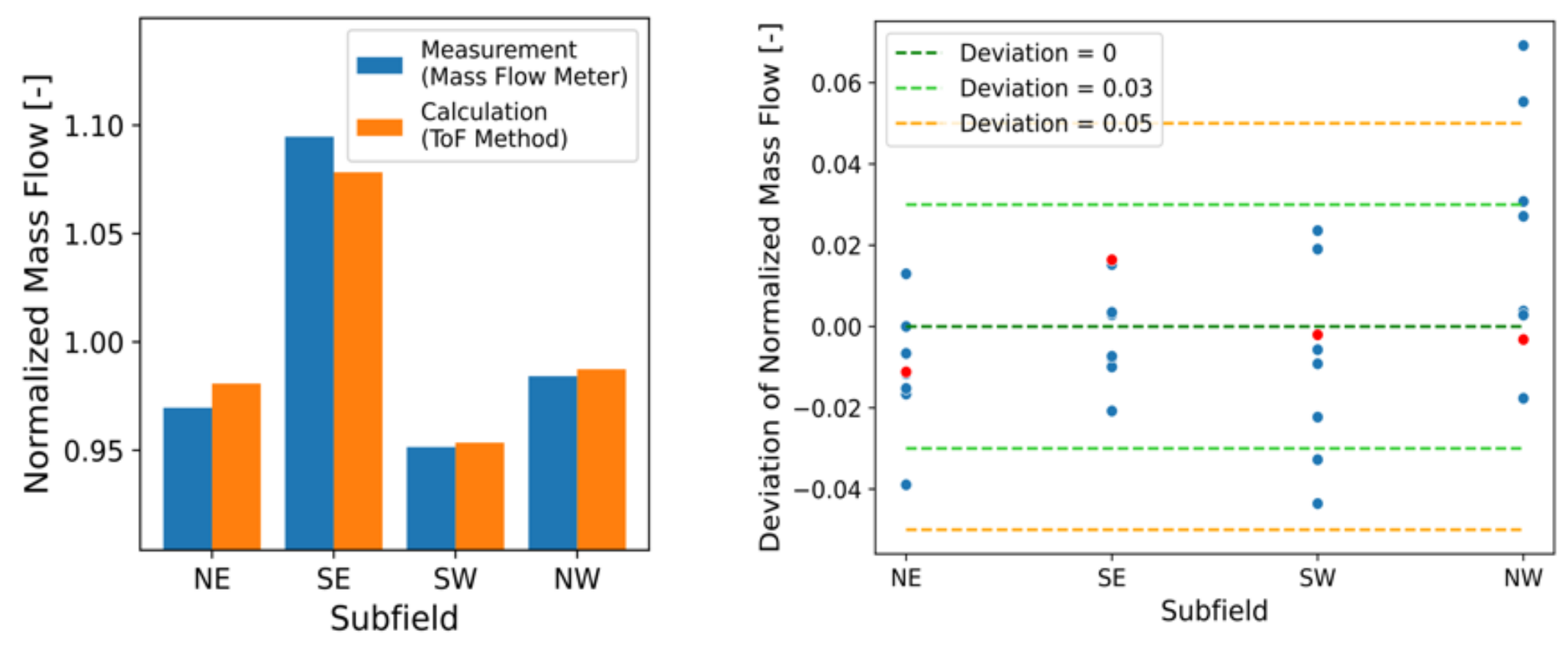

Fig. 5: Measured and calculated mass flows through the different subfields during example thermal step response on 26th of September 2019 (left) and for all measurements (right). Red points correspond to the example measurement [1].

At loop level, mass flow of all loops was measured between sensors A and B as well as between sensors C and D, which in theory should be identical for constant mass flows (Fig. 6).

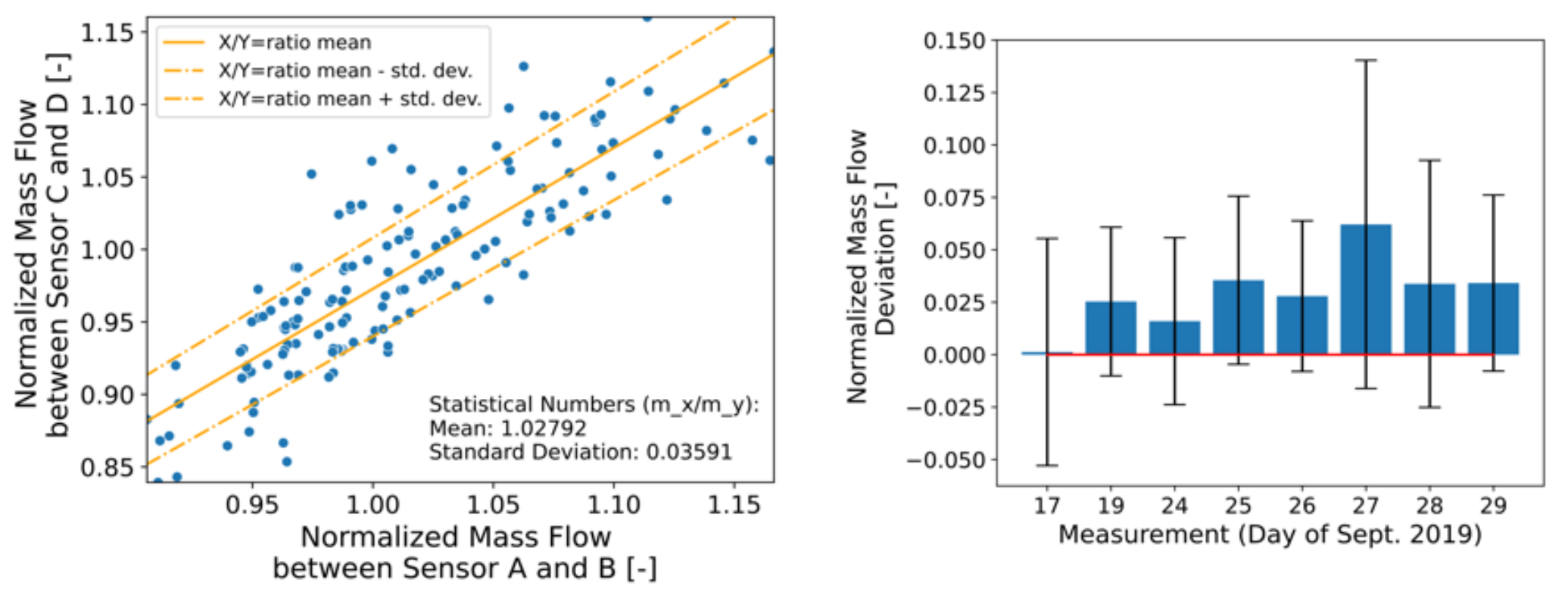

Fig. 6. Mass flow calculated with sensor-pairs A/B and C/D for all 152 loops on one example day (26th of September 2019) (left) and its mean and standard deviation for all measurements (right). Red line represents theoretical, identical values [1].

Vacuum Loss Detection

Combining the results, Fig. 7 shows loops that have higher heat losses during preheating although they have a lower mass flow and thus a higher probability of having vacuum losses.

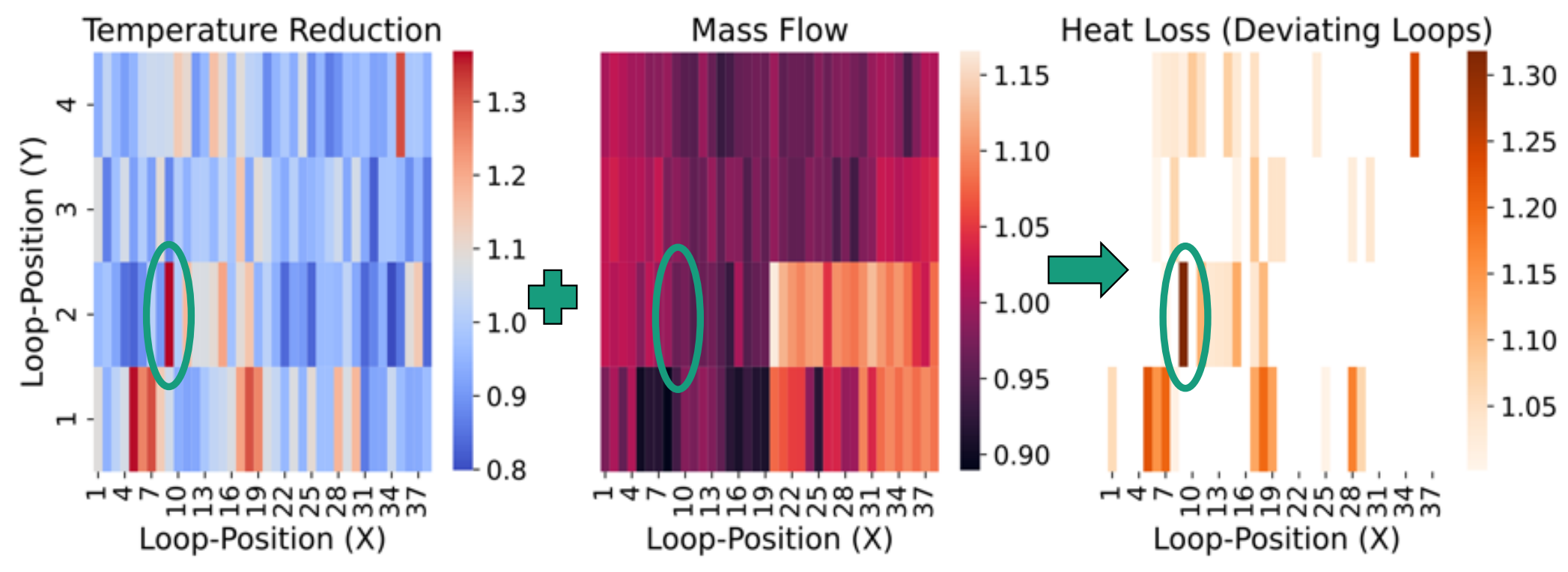

Fig. 7: Mean normalized temperature reduction (left) and mass flow (center) for each loop and corresponding heat loss (right) for loops with higher heat loss and lower mass flow [3].

Conclusion and Outlook

The presented ToF method determines the mass flow distribution through a solar field measuring 94% of the data within ± 5% of full scale only using existing temperature sensors. As the presented method is simple, safe, cost effective and non-invasive, it has a high potential to increase solar field efficiency due to early heat loss detection and the possibility of improved maintenance.

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[1] Kraft et al. (2023): Mass Flow Distribution Measurement in Concentrated Solar Power Plants via Thermal Time-of-Flight Method. Submitted on 30th of September in Solar Energy
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[4] Rohani, Shahab (2015): Modelling, Simulation and Data Validation of a Solar Thermal Parabolic Trough Plant with Storage. Master Thesis. Faculty of Mechanical, Electrical and Industrial Engineering, Brandenburg University of Technology Cottbus-Senftenberg. Fraunhofer Institute for Solar Energy Systems (ISE).

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