Validation of an all-sky imager based nowcasting system for industrial PV plants

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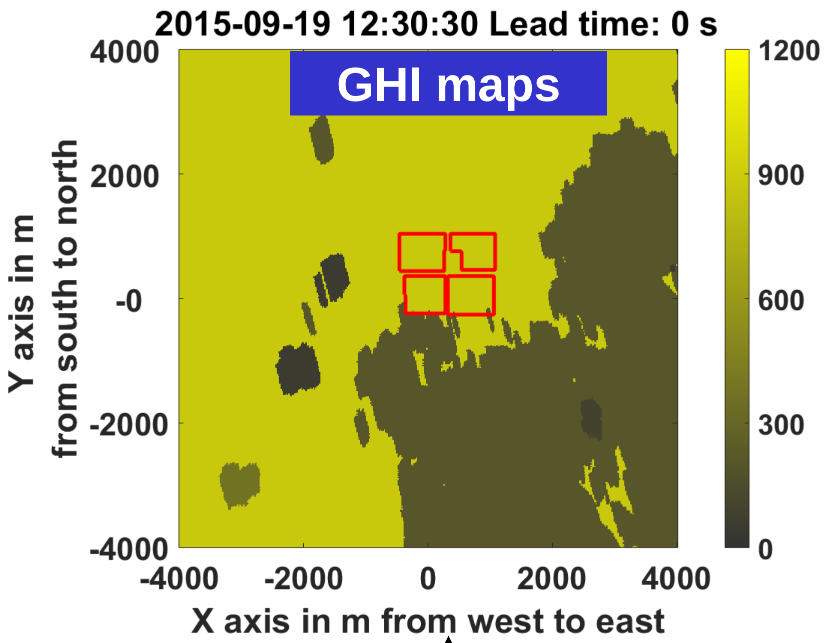
Overview

1. Relevance of nowcasting systems
2. The WobaS nowcasting system
3. **Validation of nowcasting systems**
4. Conclusion and further work



Relevance of nowcasting systems

Both on plant and grid level, nowcasting systems are of interest

- Ramp rate penalties potentially **reduce gross revenue of solar plants by 20%**, only 10% with forecasts. [1]
- Solutions:
  1. Curtailment: dumping money
  2. Batteries: still too expensive [2]
  3. Forecasts: e.g. camera-based nowcasts

➡ Combination might be optimum solution

- Both **solar plants** and **grid operators** benefit from forecasts [3]

[1] D. Cormode, A. Lorenzo, W. Holmgren, S. Chen and A. Cronin, "The economic value of forecasts for optimal curtailment strategies to comply with ramp rate rules," *2014 IEEE 40th Photovoltaic Specialist Conference (PVSC)*, Denver, CO, 2014, pp. 2070-2075. doi: 10.1109/PVSC.2014.6925334

[2] Richard Perez, Thomas Hoff, John Dise, David Chalmers, Sergey Kivalov, The Cost of Mitigating Short-term PV Output Variability, Energy Procedia, Volume 57, 2014, Pages 755-762, ISSN 1876-6102, http://dx.doi.org/10.1016/j.egypro.2014.10.283.

[3] Bird, L., Cochran, J., Wang, X., 2014. Wind and Solar Energy Curtailment: Experience and Practices in the United States. NREL. https://www.nrel.gov/docs/fy14osti/60983.pdf

Working principle of the WobaS-4cam nowcasting system

Standard surveillance cameras are used to derived short-term forecasts

4 all-sky imagers take images

Clouds are segmented

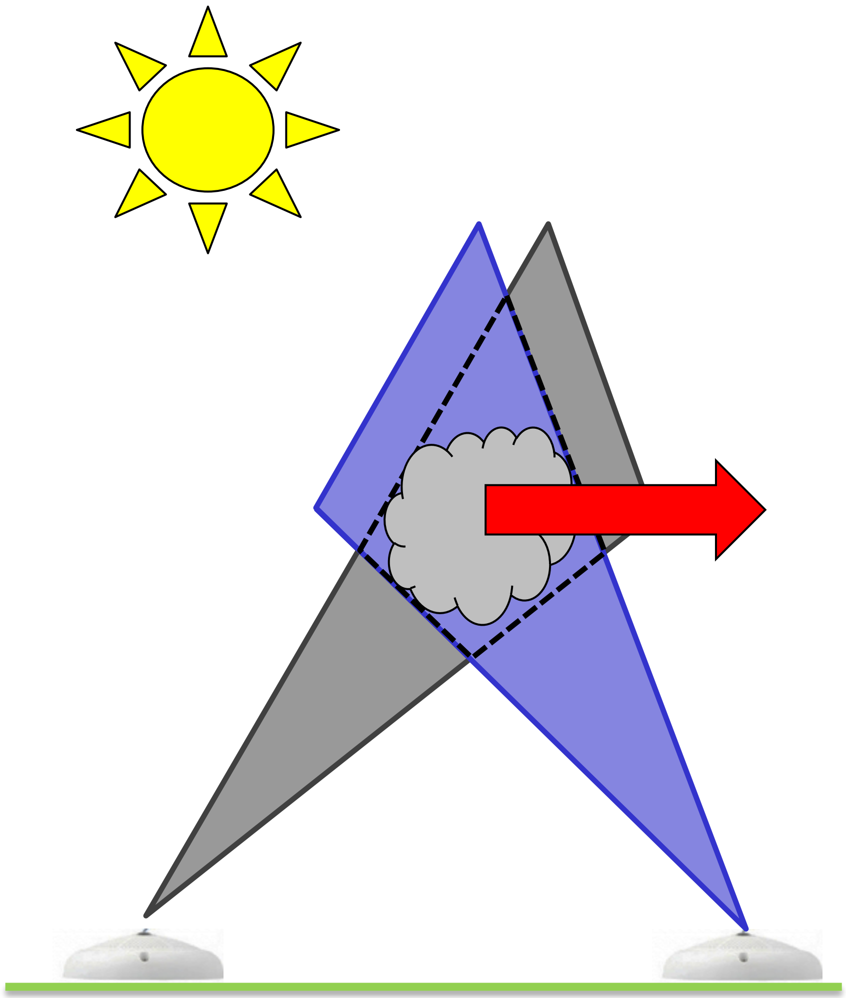
Clouds are modelled

Shadow maps are created

Sensors provide irradiance data

Cloud tracking

Irradiance map is created

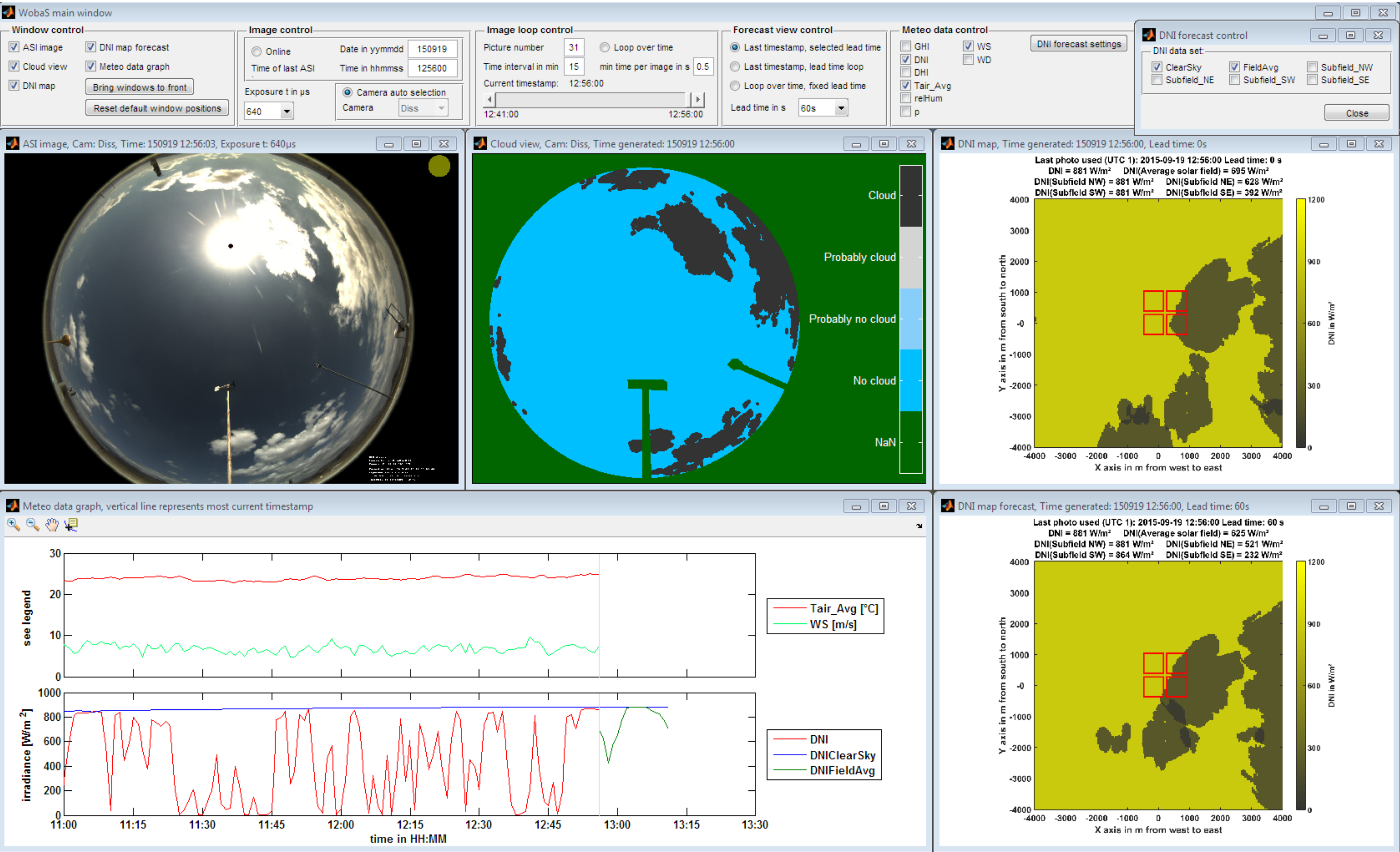


Also validated:

WobaS-1cam, WobaS-2cam, WobaS-3cam and shadow camera based systems

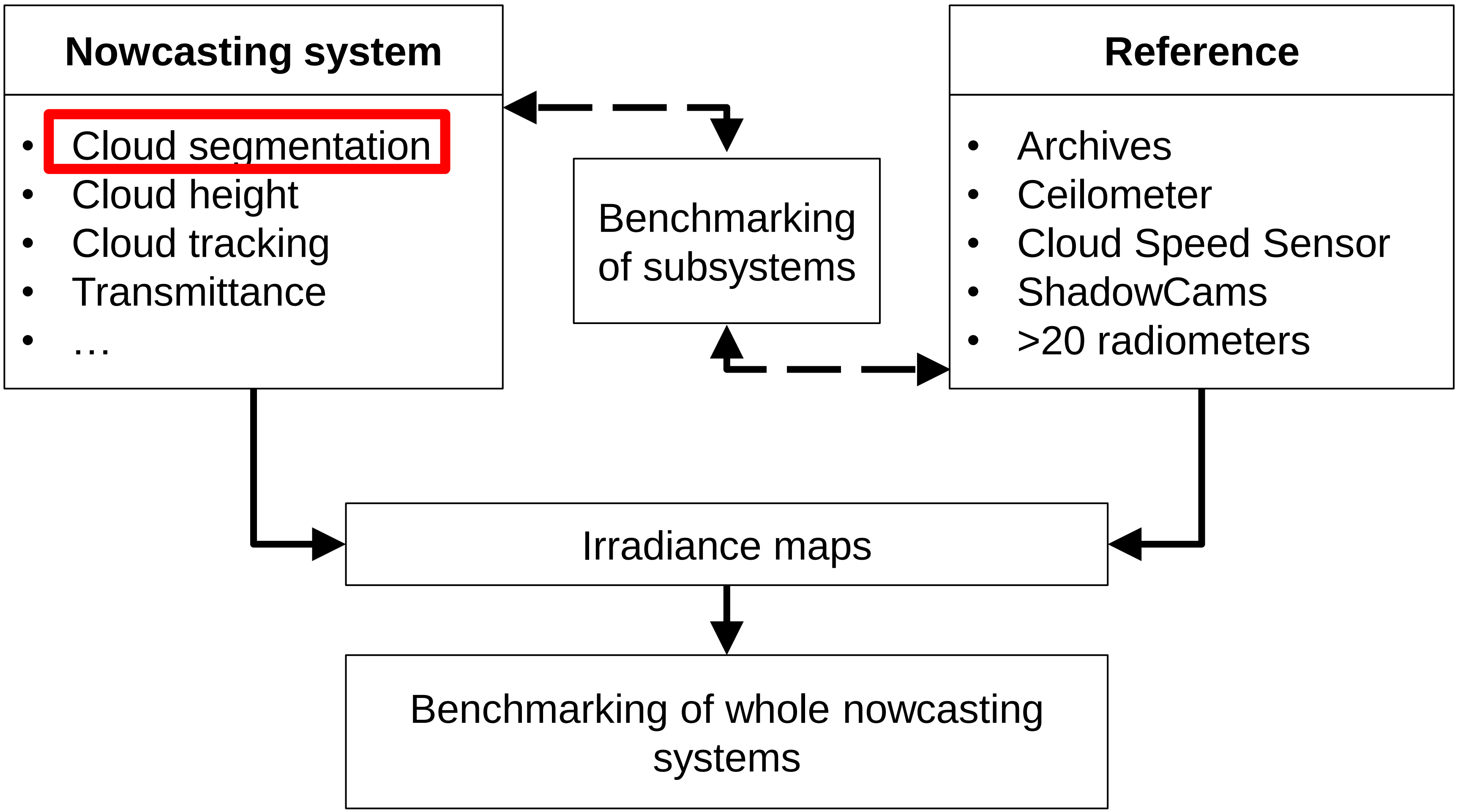
WobaS nowcasting system: User interface

WobaS can be linked to FoSyS, providing satellite and NWP forecasts



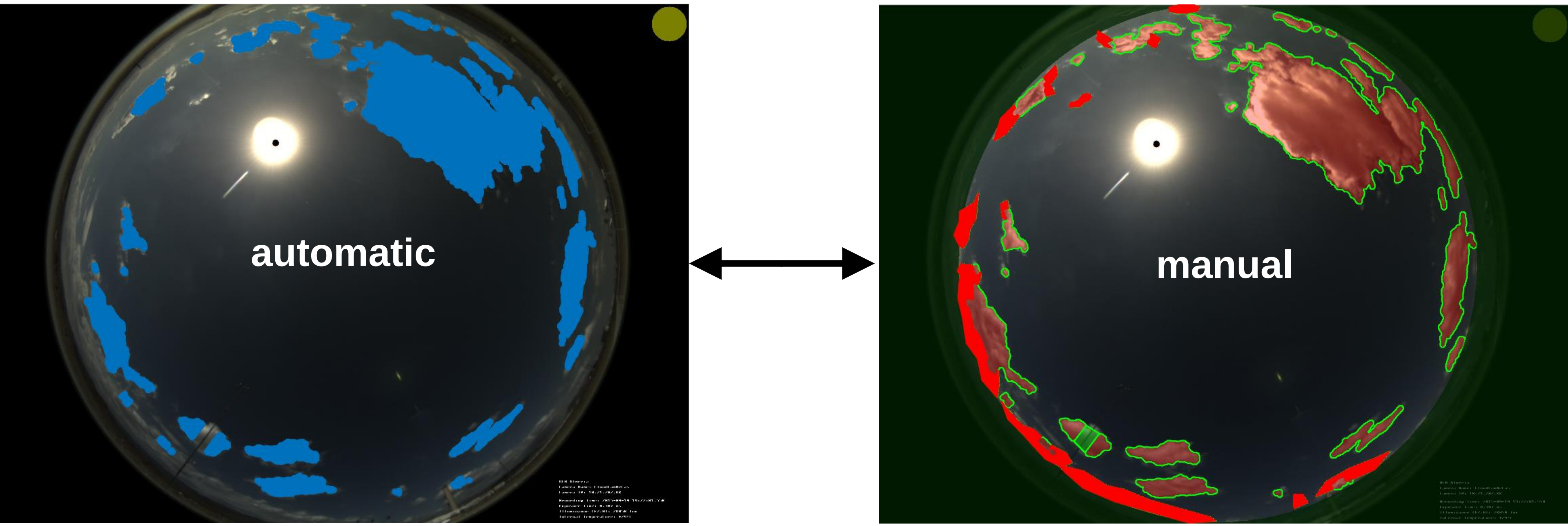
Validation of nowcasting systems

Both final predictions and intermediate results are validated



Validation of a submodule: Cloud segmentation

Cloud segmentation is validated on a manually segmented reference data set

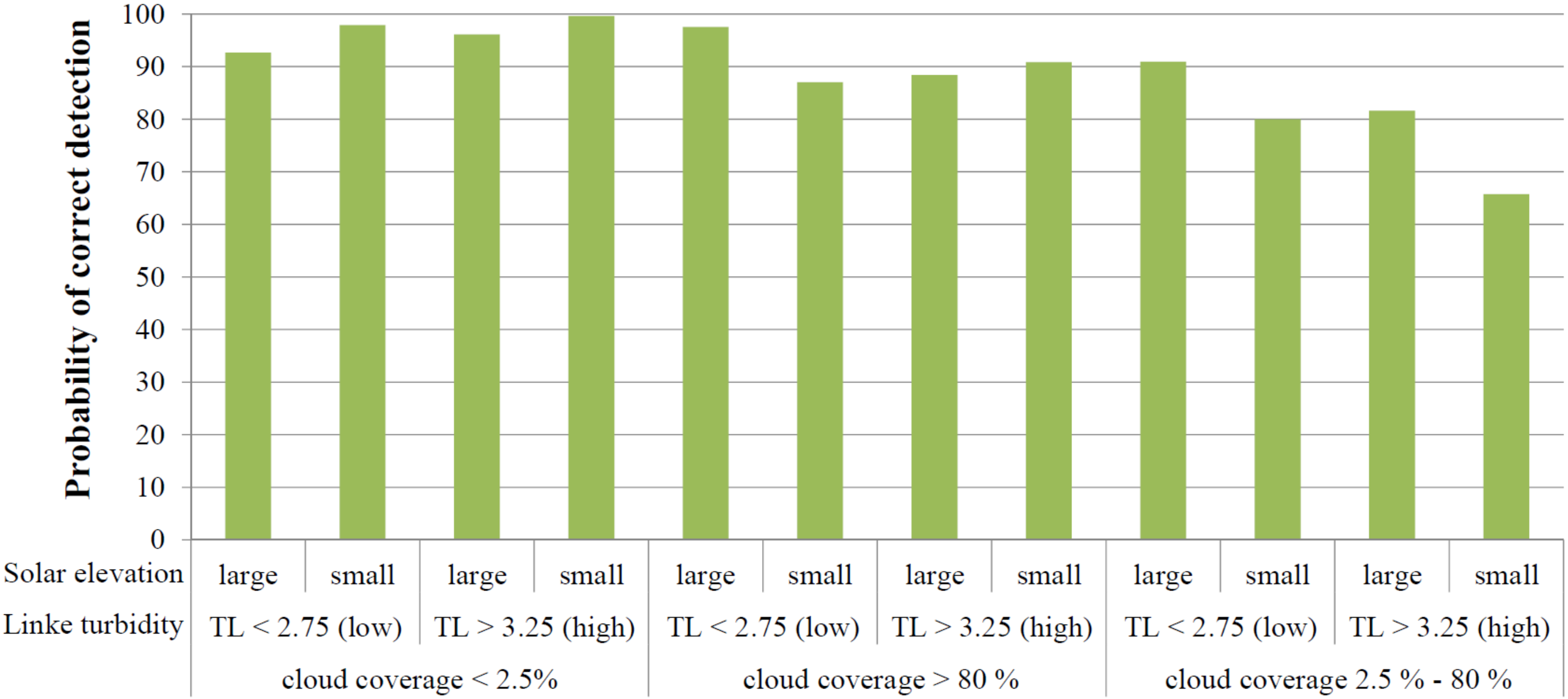


- Validation by comparison of automatic to manual cloud segmentation
- Reference-dataset of >600 images per camera model
- Performance is studied for various sun elevations and Linke turbidities

Validation of a submodule: Cloud segmentation results

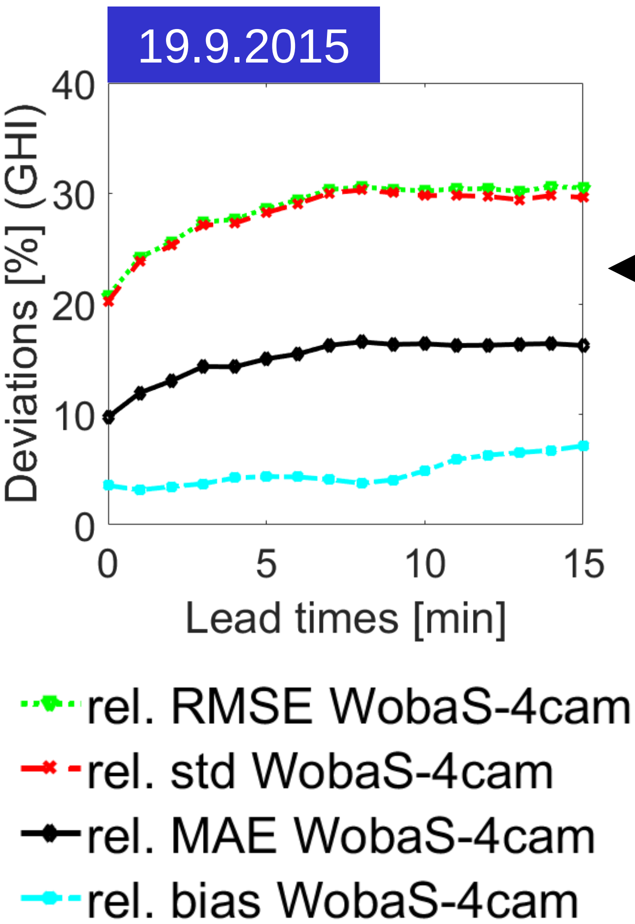
Clear Sky Libraries are found to be best suited for cloud detection

- Cloud detection via 4-dimensional clear sky library based on air mass, Linke turbidity and pixel positions
- Simple approaches, e.g. Red-Blue-Ratio, are not feasible
- Low sun elevations and high Linke turbidities complicate cloud detection



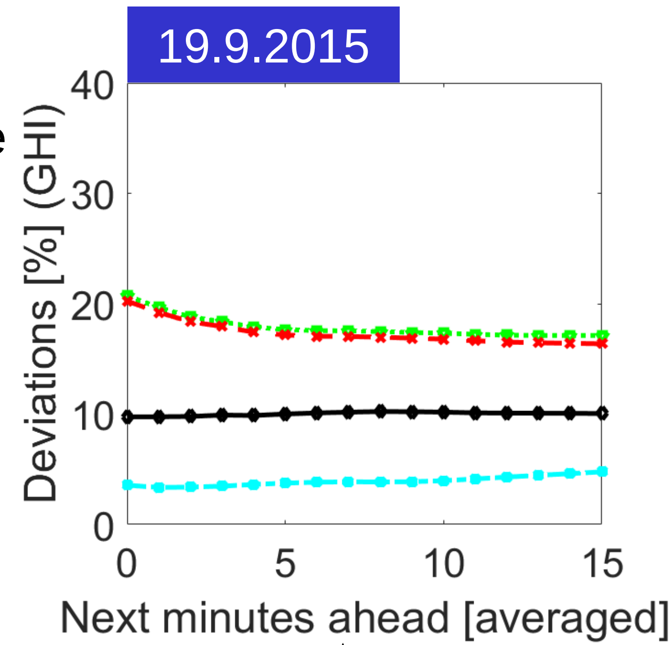
Validation of all-sky imager based nowcasting systems

Spatial and temporal aggregation effects must be considered



Standard in literature: Validations against (few) radiometers for one-minute averages

Temporal aggregation effects not considered, but relevant for PV-battery plants



Temporal aggregation effects change the behavior.

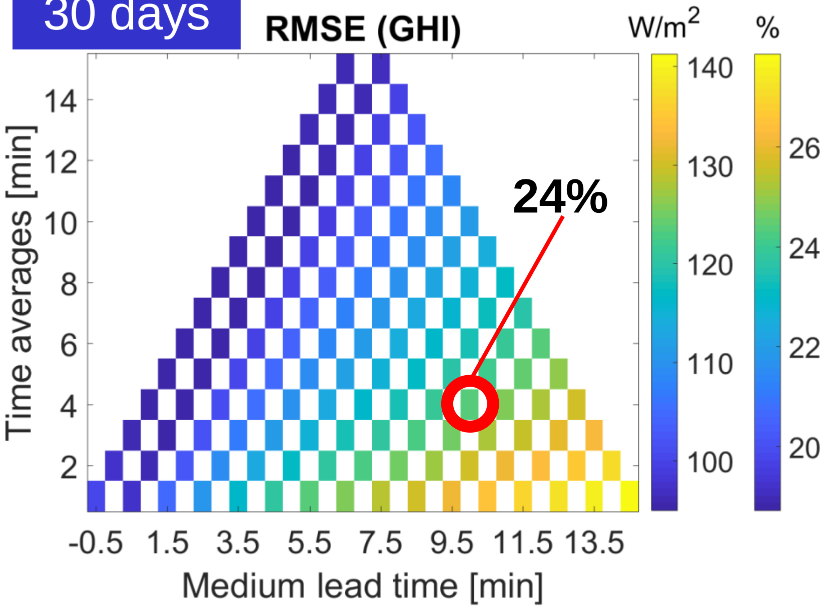
Validation of WobaS nowcasting maps

Temporal aggregation effects determine the size of buffers, e.g. batteries

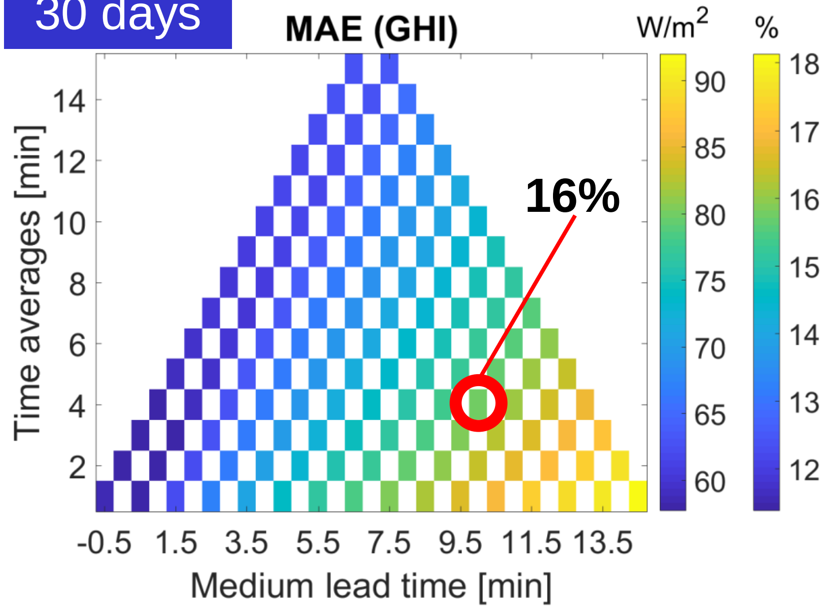
- Temporal aggregation effects studied on 30 days
- Key finding: Deviations significantly reduced by aggregation

<u>Investigation of temporal aggregation effects:</u>

30 days



30 days



What about spatial aggregation effects?

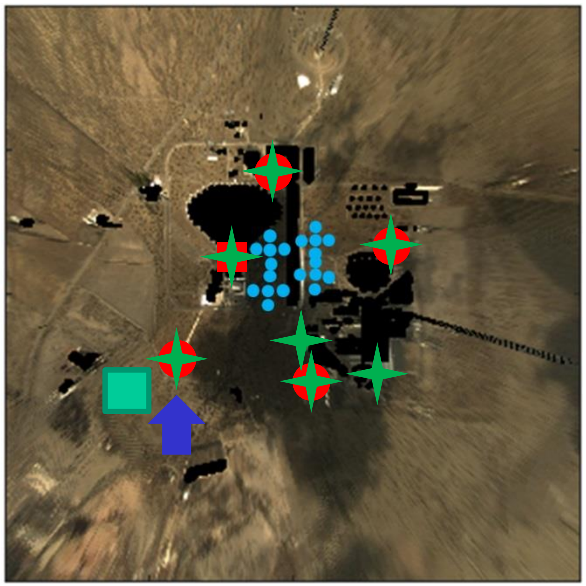
DLR

Spatial aggregation effects: reference irradiance maps

Two options are available for highly spatially resolved irradiance maps

Grid of irradiance sensors [4]

- Straight forward approach
- Costly and labor intensive
- Limited spatial coverage



- 4 all-sky imager
- 6 shadow cameras
- 20 Si-pyranometers
- Pyrheliometers + pyranometers
- Ceilometer
- Cloud Speed Sensor

Shadow camera system [5]

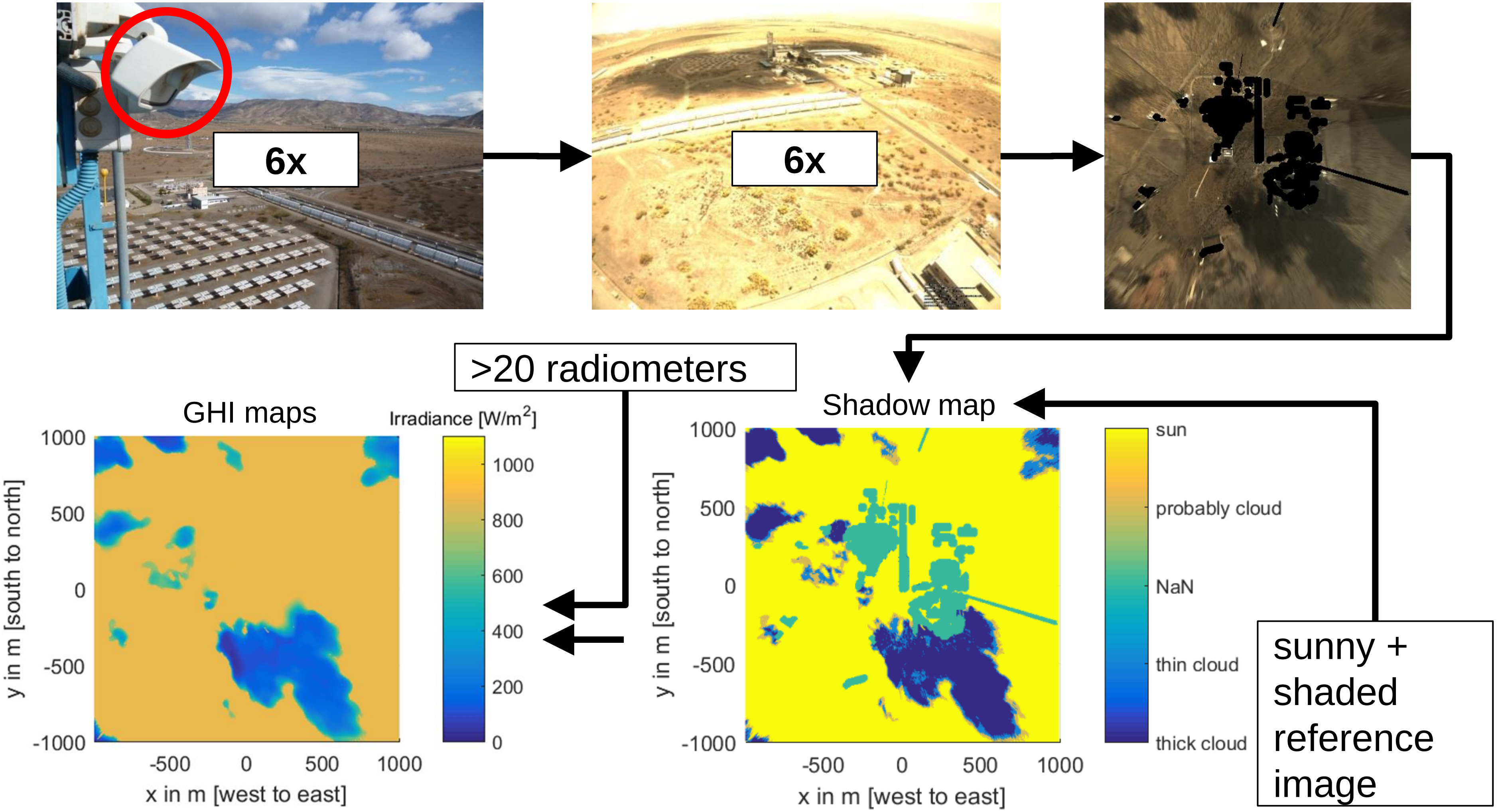
- Fairly inexpensive
- Low maintenance
- Large imaged area

[4] H. Schenk, et al., Design and Operation of an Irradiance Measurement Network, Energy Procedia, Volume 69, 2015, Pages 2019-2030, ISSN 1876-6102, http://dx.doi.org/10.1016/j.egypro.2015.03.212.(http://www.sciencedirect.com/science/article/pii/S1876610215005184)

[5] Kuhn, P., et al., “Shadow camera system for the generation of solar irradiance maps“, Solar Energy (2017), https://doi.org/10.1016/j.solener.2017.05.074.

Shadow cameras provide reference irradiance maps

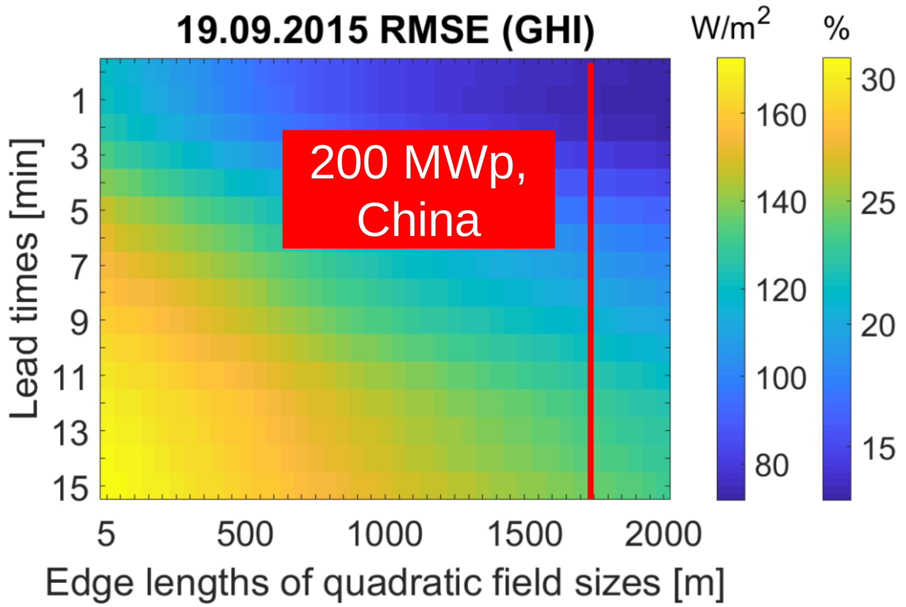
A shadow camera system derives spatially resolved maps for validations

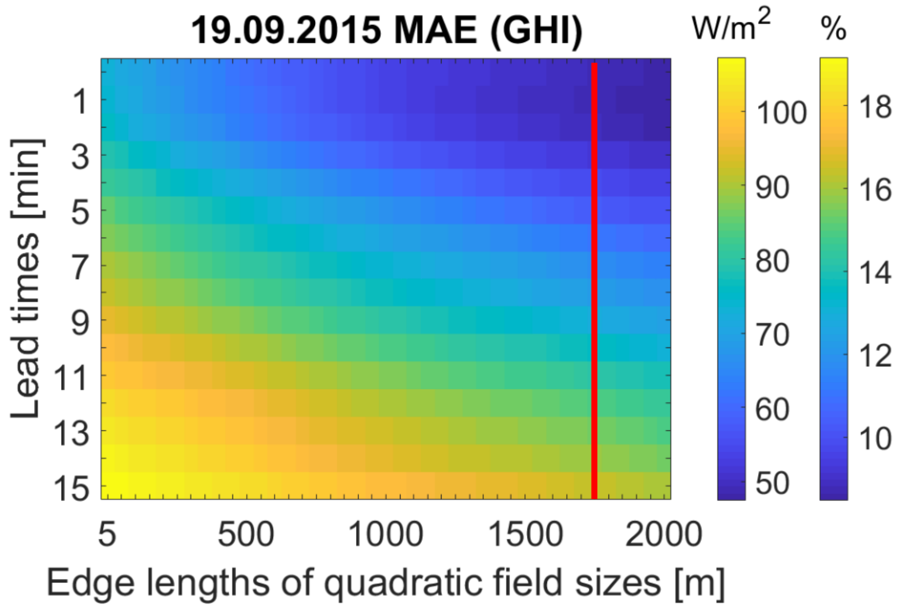


Considering spatial aggregation effects

A unique shadow camera system is available, providing reference maps

- Comparison between reference irradiance maps and nowcasted irradiance maps considering various field sizes
- Previously: Validations of nowcasting systems only against (few) radiometers
- Spatial aggregation effects significantly reduce deviations





Conclusion and further work

Supported by:
Federal Ministry for Economic Affairs and Energy
on the basis of a decision by the German Bundestag

- Validations on extended validation periods and various weather conditions
- Validations of sub-modules
- Consideration of spatial aggregation effects
- Consideration of temporal aggregation effects
- Auto-validations of dubious value
- WobaS-4cam: state-of-the-art and commercially used
- Nowcasting systems both for plant and grid operations

DNICast

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PREDICTABLE&FLEXIBLE SOLAR POWER WITH MOLTEN SALT ENERGY STORAGE

Future work:
- WobaS system for grid operations, project has started

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Thank you! **Questions?**

Thank you!

Questions?

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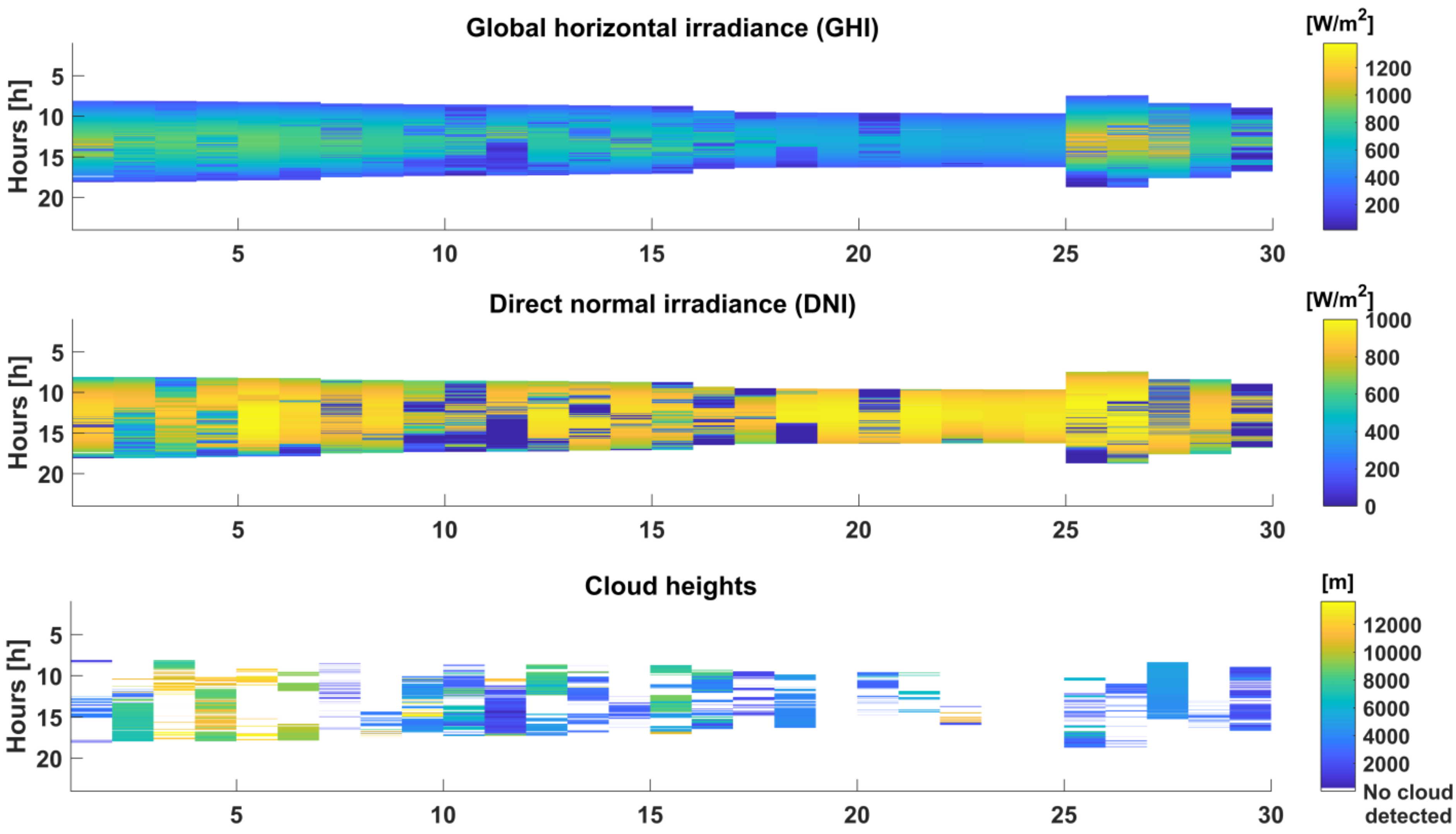
This presentation is a summary of the paper highlighted with a red box

Publications

- Kuhn, P., et al. „Validation of Spatially Resolved All Sky Imager Derived DNI Nowcasts”, AIP Conference Proceedings, 2017, http://aip.scitation.org/doi/abs/10.1063/1.4984522.
- Kuhn, P., et al., “Shadow camera system for the generation of solar irradiance maps“, Solar Energy (2017), https://doi.org/10.1016/j.solener.2017.05.074.
- Kuhn, P., et al., “Validation of an All Sky Imager based nowcasting system for industrial PV plants”, EUPVSEC 2017, submitted to Progress in Photovoltaics.
- Kuhn, P., et al., “Benchmarking three low-cost, low-maintenance cloud height measurement systems and ECMWF cloud heights”, submitted to Solar Energy (2017).
- Kuhn, P., et al., “Field validation and benchmarking of a cloud shadow speed sensor”, submitted to Solar Energy (2017).
- Kuhn, P., et al., “All-sky imager based ramp rate prediction for PV”, article of the month June 2017, Sun&Wind Energy, available online: http://www.sunwindenergy.com/content/sky-imager-based-ramp-rate-prediction-pv
- Kuhn, P.; Wilbert, S.; Prahl, C.; Kazantzidis, A.; Ramirez, L.; Zarzalejo, L.; Vuilleumier, L.; Blanc, P.; Pitz-Paal, R.; *Validation of nowcasted spatial DNI maps*, DNIcast Deliverable 4.1, available online: http://www.dnicast-project.net/.


Global horizontal irradiance (GHI)
[W/m2]
1200
1000
800
600
400
200
Hours [h]
5
10
15
20
5
10
15
20
25
30
Direct normal irradiance (DNI)
[W/m2]
1000
800
600
400
200
0
Cloud heights
[m]
12000
10000
8000
6000
4000
2000
No cloud detected