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Spatio-Temporal Visualisation of Reflections from Building Integrated Photovoltaics

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Background: Reflections in Urban Environments

- Just how bad are reflections from specular façades / BIPV?
  → External glare?
- Few objective criteria, regulations vague & subjective
- Only recommended criteria in guidelines
- Need urban legislation
- Idea: Apply criteria to predict glare from simulated PV reflections in planning phase

Recommended Assessment Criteria & Thresholds

Parameter	Description	Threshold
τ_d	Distance to PV	50 m (commercial) 100 m (residential)
τ_A	Area of PV	100 m^2 (commercial) 10 m^2 (residential)
τ_L	Reflected luminance	30 kcd/m^2 (MIT) 50 kcd/m^2 (Swissolar)
τ_E	Irradiance at receiver	10 W/m^2 (Sandia Labs) ≈16.8 W/m^2 (MIT) 30 W/m^2 (Swissolar)
τ_t	Max. daily sustained glare duration	0.5 hours (Swissolar)
τ_T	Cumulative annual glare duration	50 hours (Swissolar)

PV Glare Assessment Workflow Overview

- Annual Simulation of irradiance on built environment
  → identify potential glare as “hotspots” on neighbouring buildings
- RADIANCE photon mapping with 1 bounce from PV (=photon port)
  → precomputed flux transport to surroundings
- Render time series of 2D irradiance maps with *rcontrib*
  → 3D *spatio-temporal* irradiance volume
- 3D image-based postprocessing using Python + NumPy/SciPy
- Apply recommended thresholds to identify glare in irradiance maps
  → cumulative annual glare, glare duration
- Visualise results in context of built environment
  → intuitive for practitioners and non-experts (clients, building authorities)

PV Reflection Case Study: St. Michael's Church, Lucerne

- Built 1967, planned PV roof retrofit
- Measured candidate PV samples, simulated as data driven BSDFs
- Digital terrain model of built environment for context

Published in:

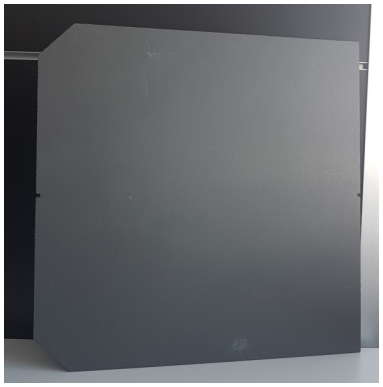
R. Schregle, C. Renken, S. Wittkopf; **Spatio-Temporal Visualisation of Reflections from Building Integrated Photovoltaics;** *Buildings* 2018, 8(8), 101; https://doi.org/10.3390/buildings8080101

PV Reflection Case Study: Materials

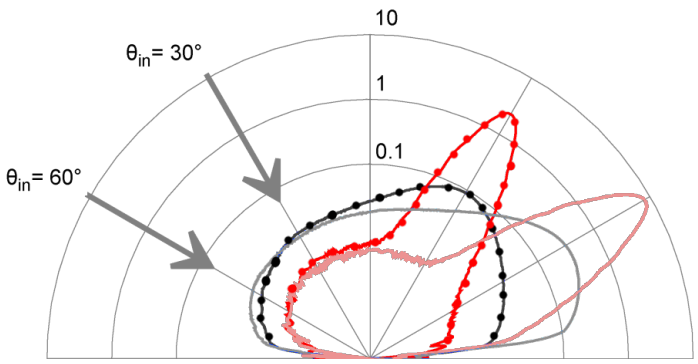
Standard PV

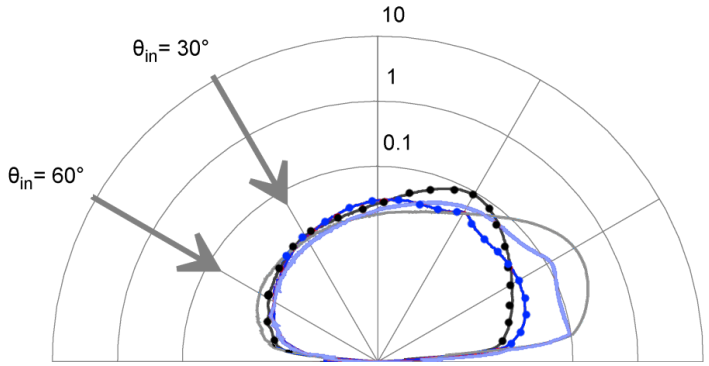
Satinated PV

Current roof tile



Roof tile 30°
Standard PV 30°
Roof tile 60°
Standard PV 60°
Roof tile 30°
Satinated PV 30°
Roof tile 60°
Satinated PV 60°

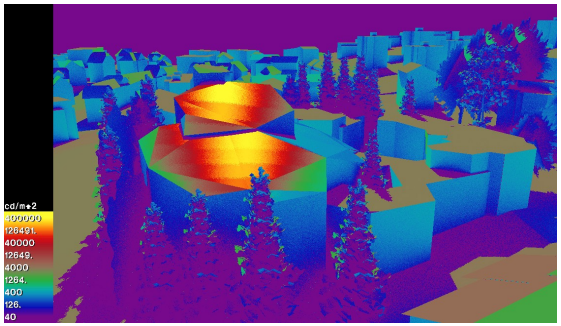


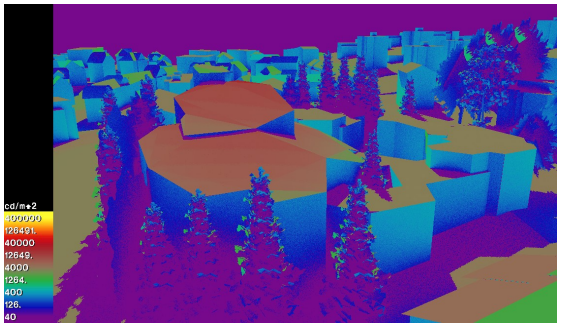


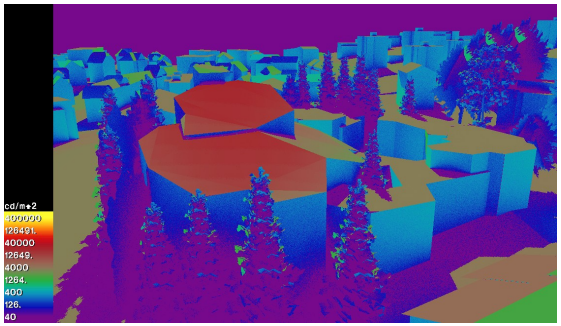
Goniophotometer → Measured scattering distribution (BSDF)

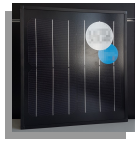
PV Reflection Case Study: Data Driven BSDFs

June 11th at 8:30 am

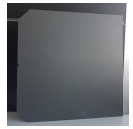


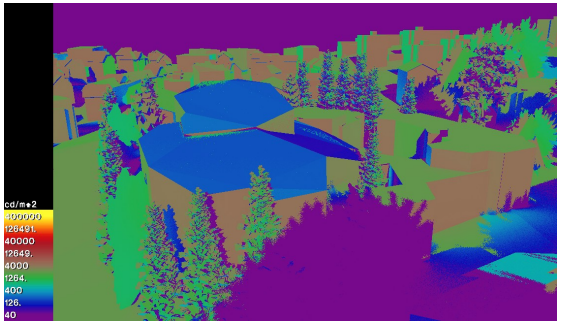


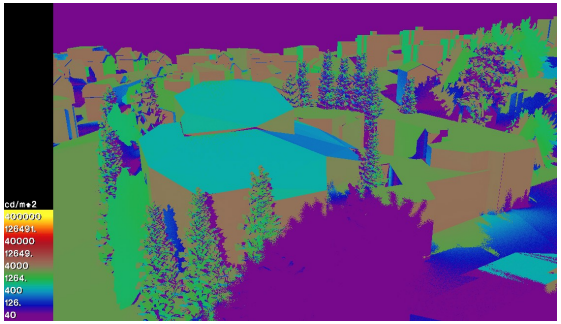


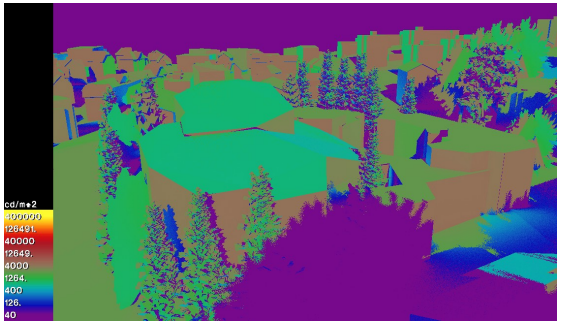
Standard PV 

Satinated PV 

Current roof 

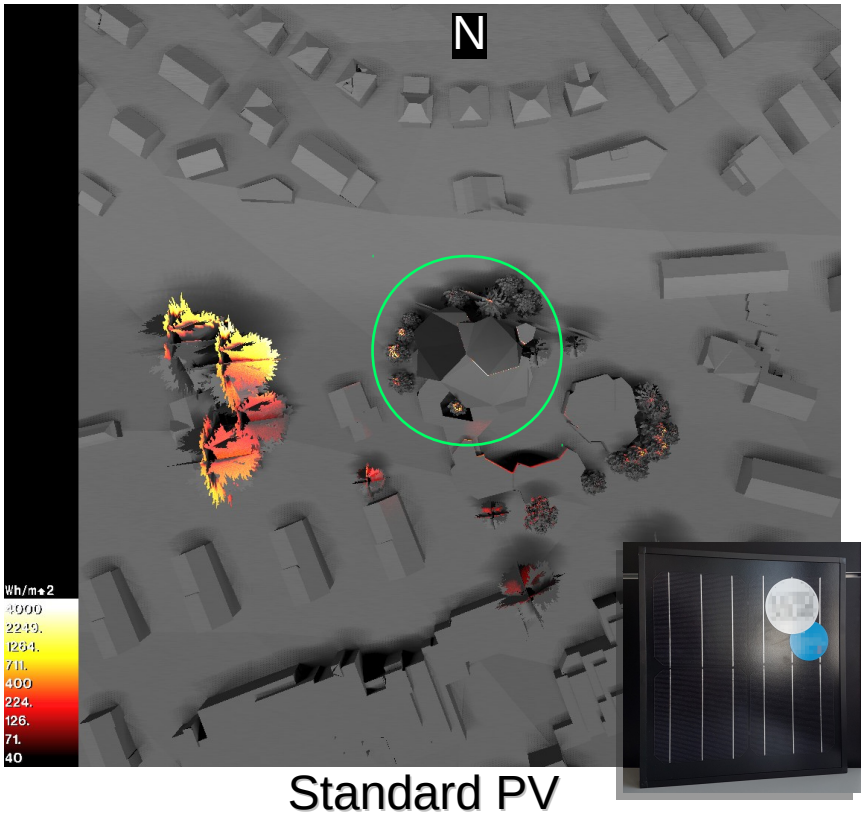




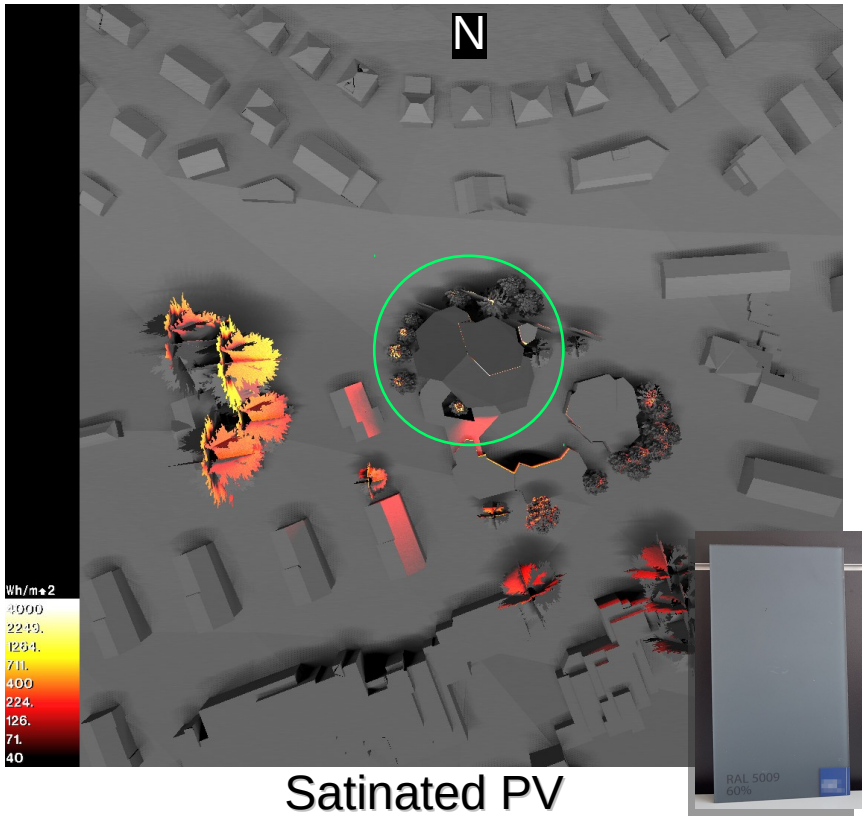


June 11th at 5:30 pm

PV Reflection Case Study: Simulation (Plan View)



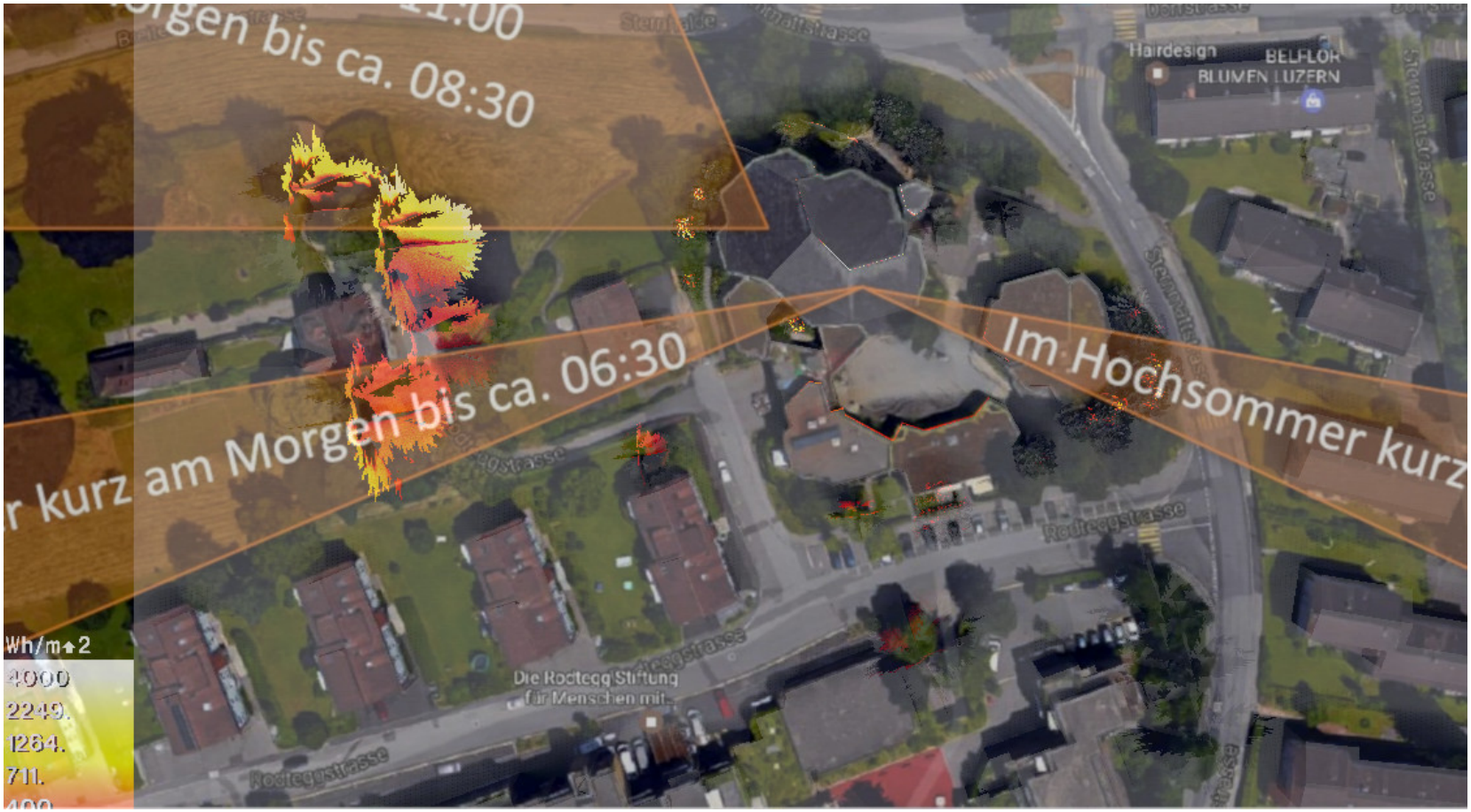
Standard PV



Satinated PV

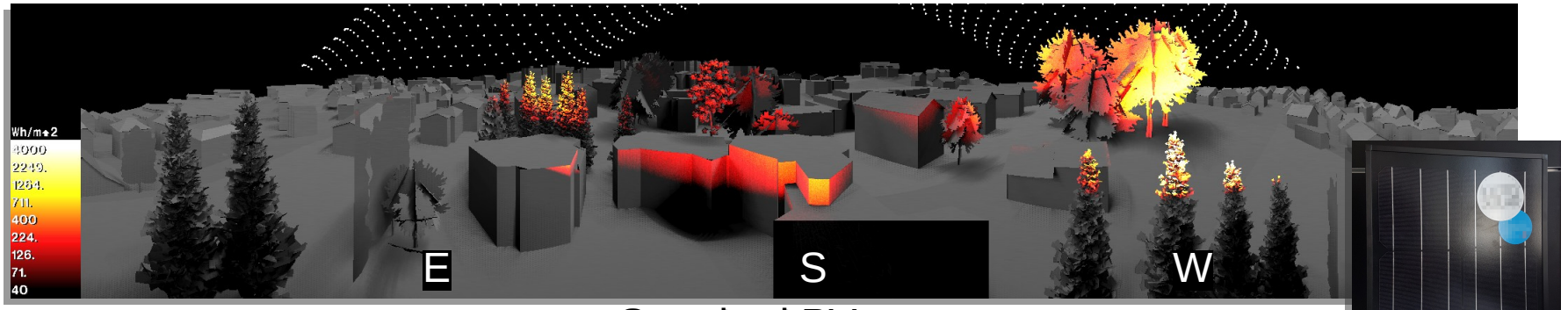
- Annual irradiance [Wh/m²] reflected from roof-mounted PV
- Plan view for orientation

Simulation vs. PV Planner’s Prediction

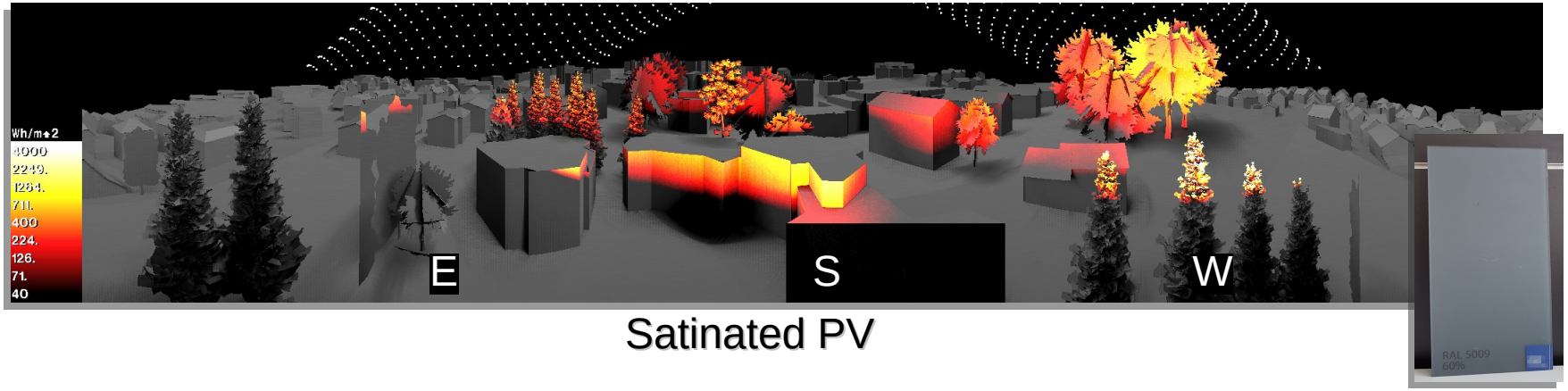


Composite of PV planner’s prediction and simulated plan view

PV Reflection Case Study: Simulation (Panoramic View)



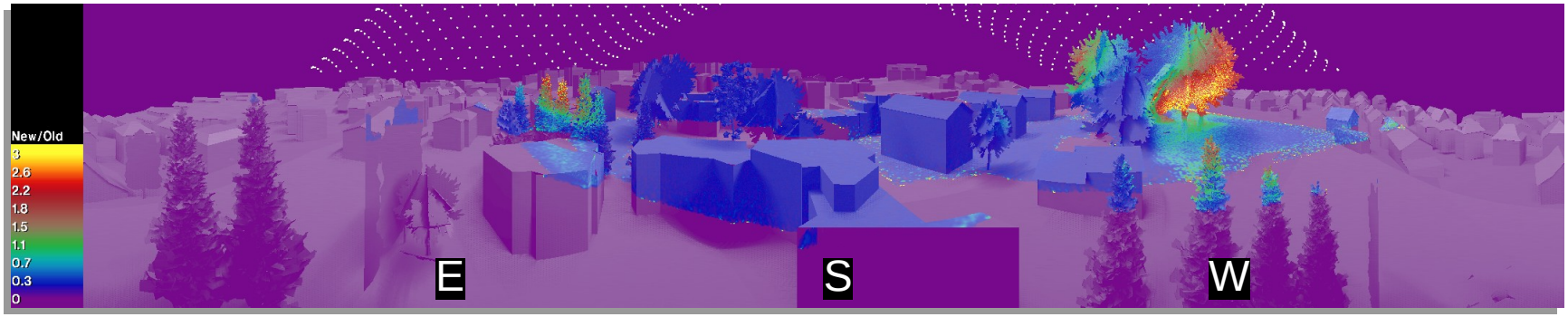
Standard PV



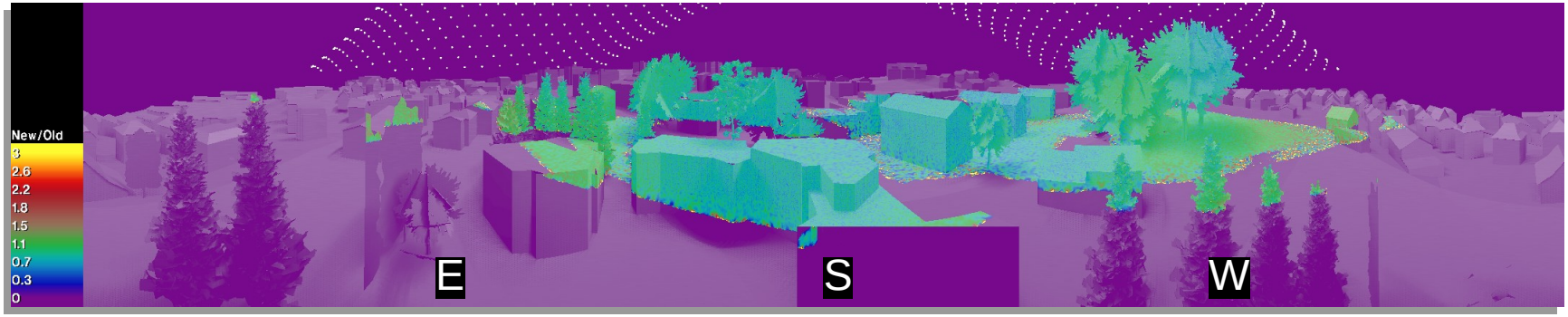
Satinated PV

- Annual irradiance [Wh/m²] reflected from roof mounted PV
- 360° panoramic view from roof to identify critical regions

PV Reflection Case Study: Simulation (Panoramic View)



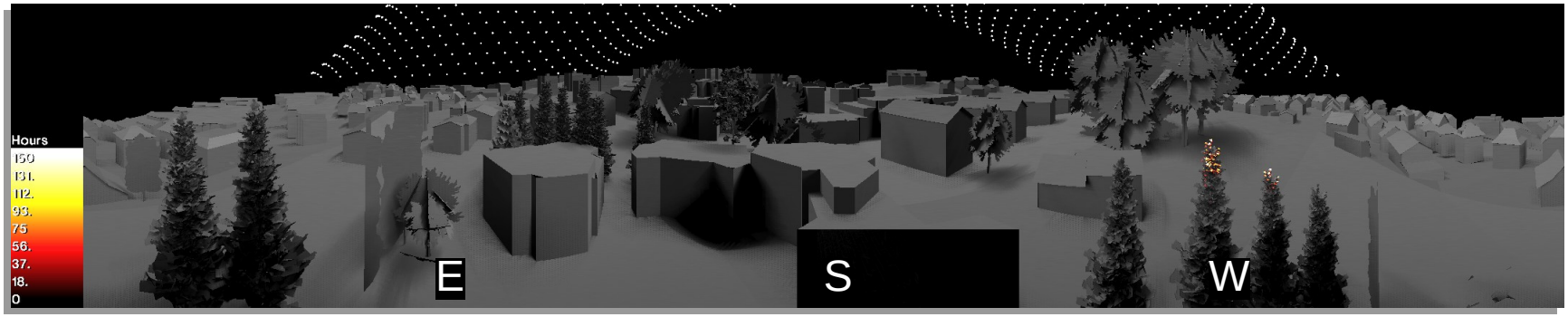
Standard PV



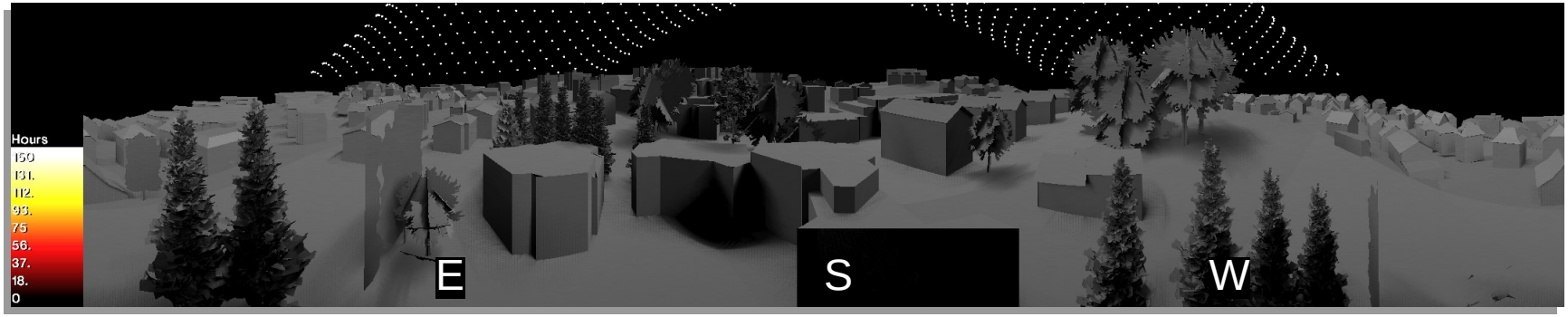
Satinated PV

- Irradiance distrib of PV (“New”) relative to roof tile (“Old”)
- Colour coded ratio: New<Old, New≈Old, New>Old

Cumulative Annual Glare Duration (τ_E = 30 W/m²)



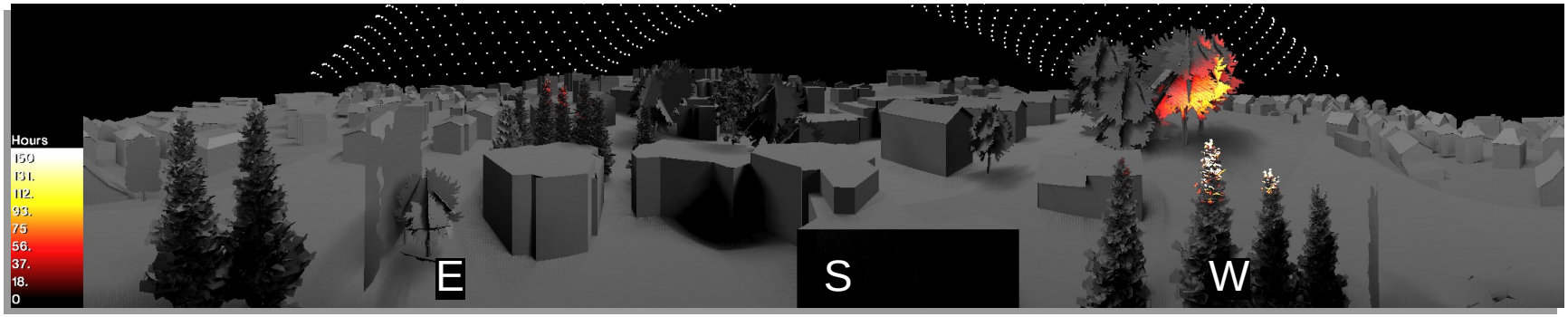
Standard PV



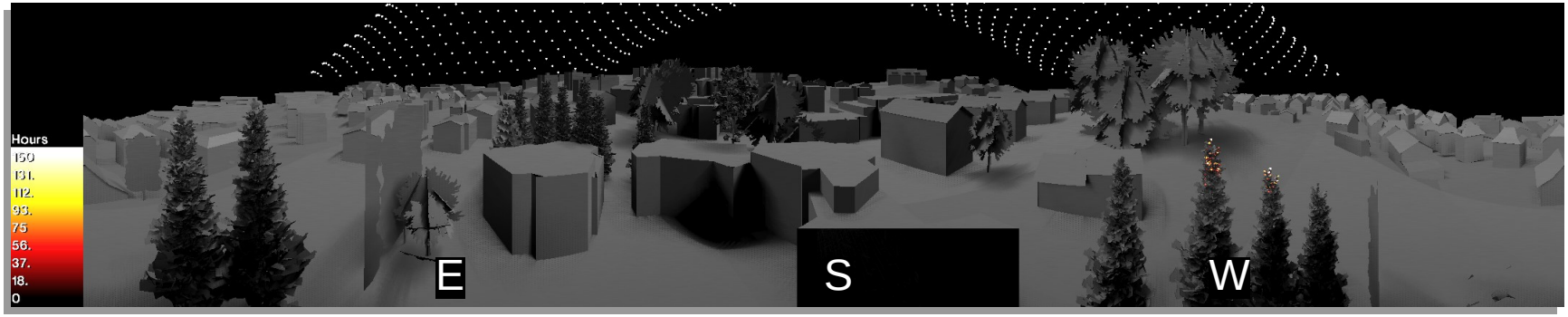
Satinated PV

- Glare criterion: Irradiance E>τ_E for >50 hours / year
- Recommended by Swissolar

Cumulative Annual Glare Duration (τ_E = 10 W/m²)



Standard PV: **≈100 h / year**



Satinated PV

- Glare criterion: Irradiance E>τ_E for >50 hours / year
- Recommended by Sandia Labs (10 W/m² → potential after-images)

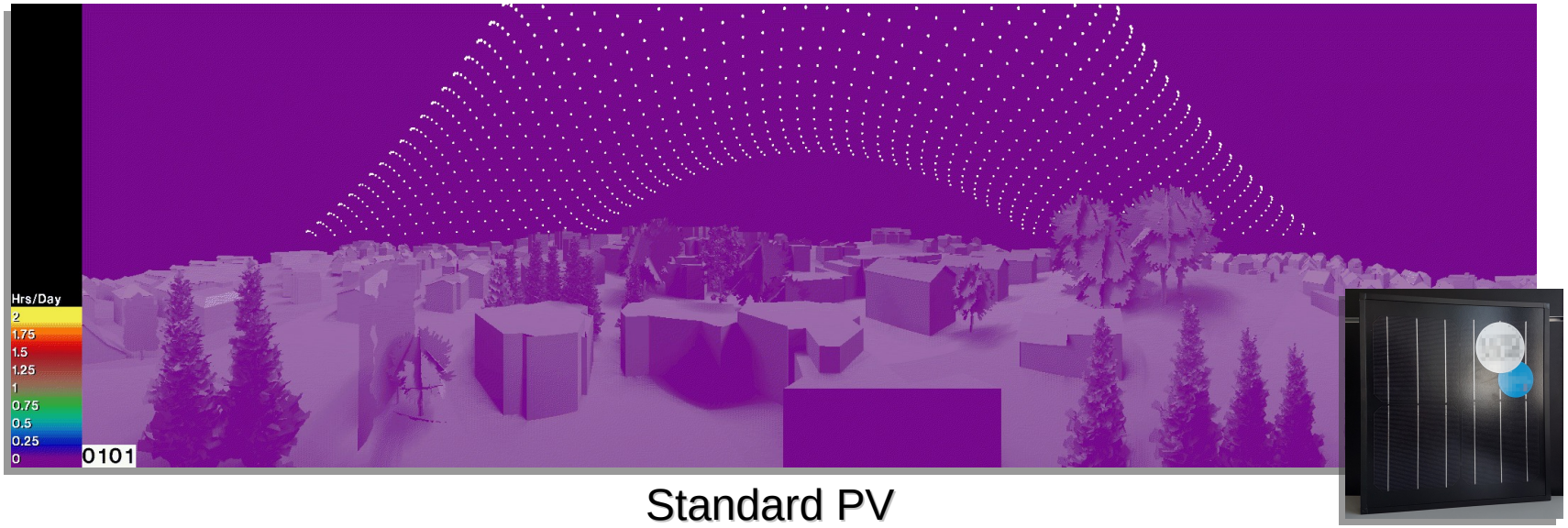
Max. Daily Sustained Glare Duration (τ_E = 10 W/m²)

Standard PV: **max. ≈1h / day**

Satinated PV

- Glare criterion: Irradiance E>τ_E for >0.5 hours / any day of year
- Extraction of features contiguous in spatial & temporal domain (3D)

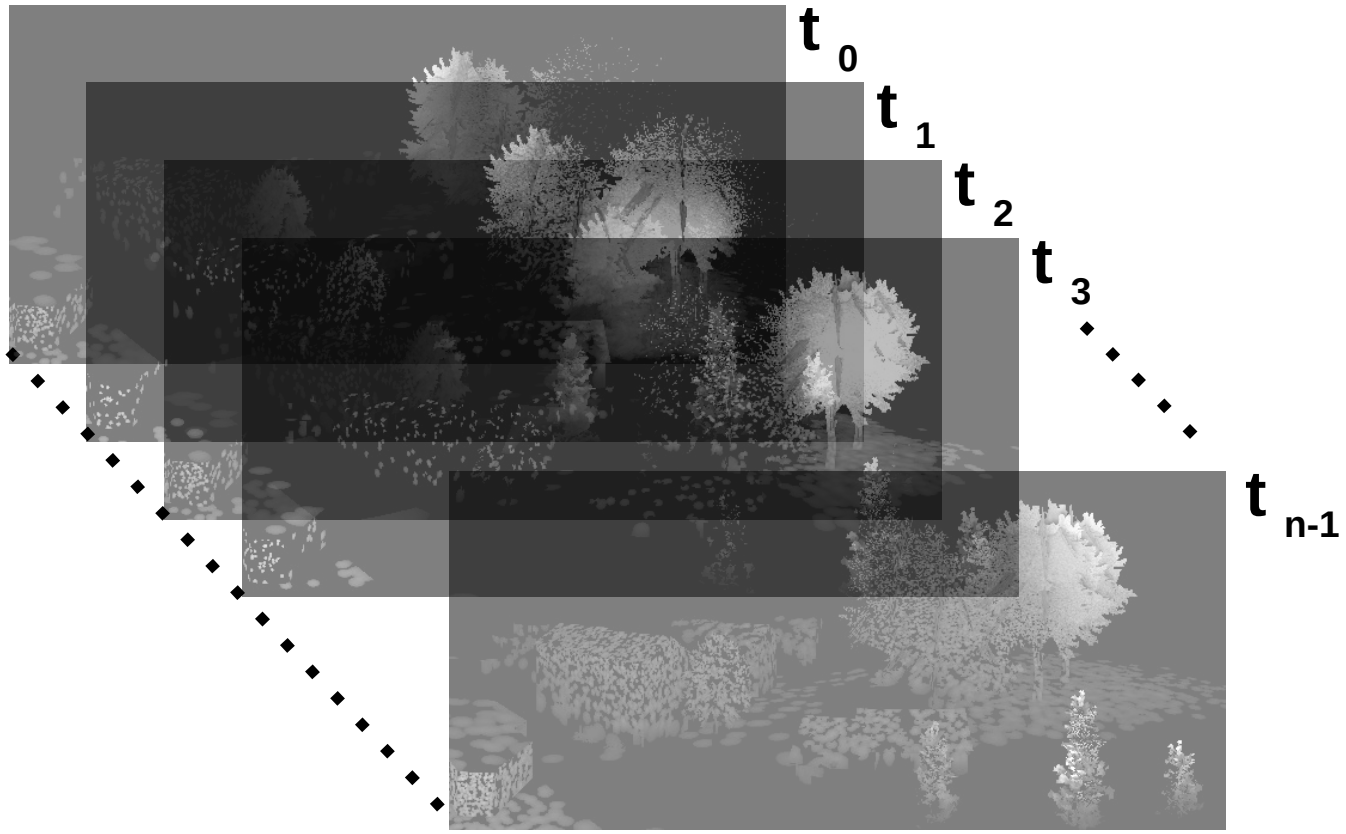
Max. Daily Sustained Glare Duration (τ_E = 10 W/m²)



Standard PV

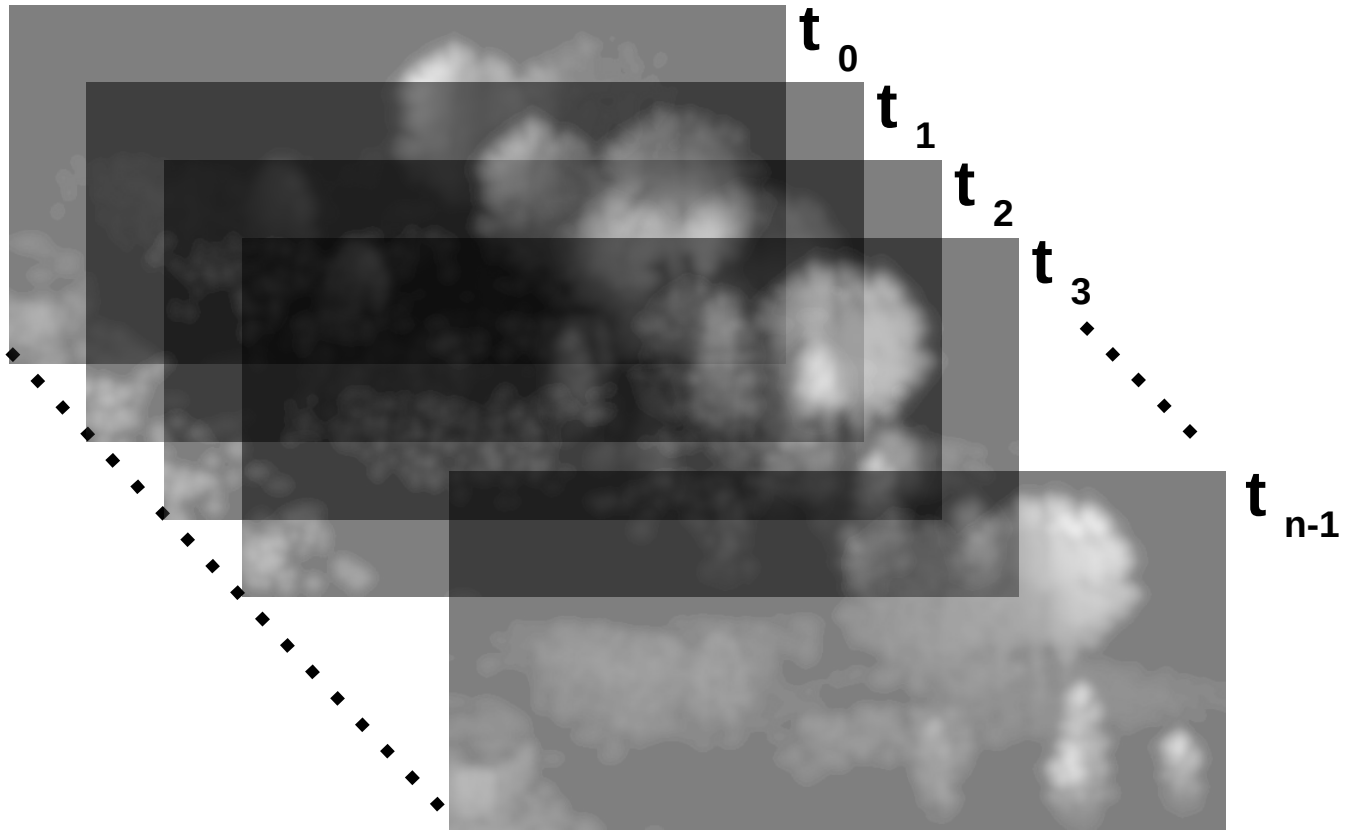
- 0.25h increments / day
- 7-day increments / month
- 6 months / year

Spatio-Temporal Analysis 1: Irradiance Maps



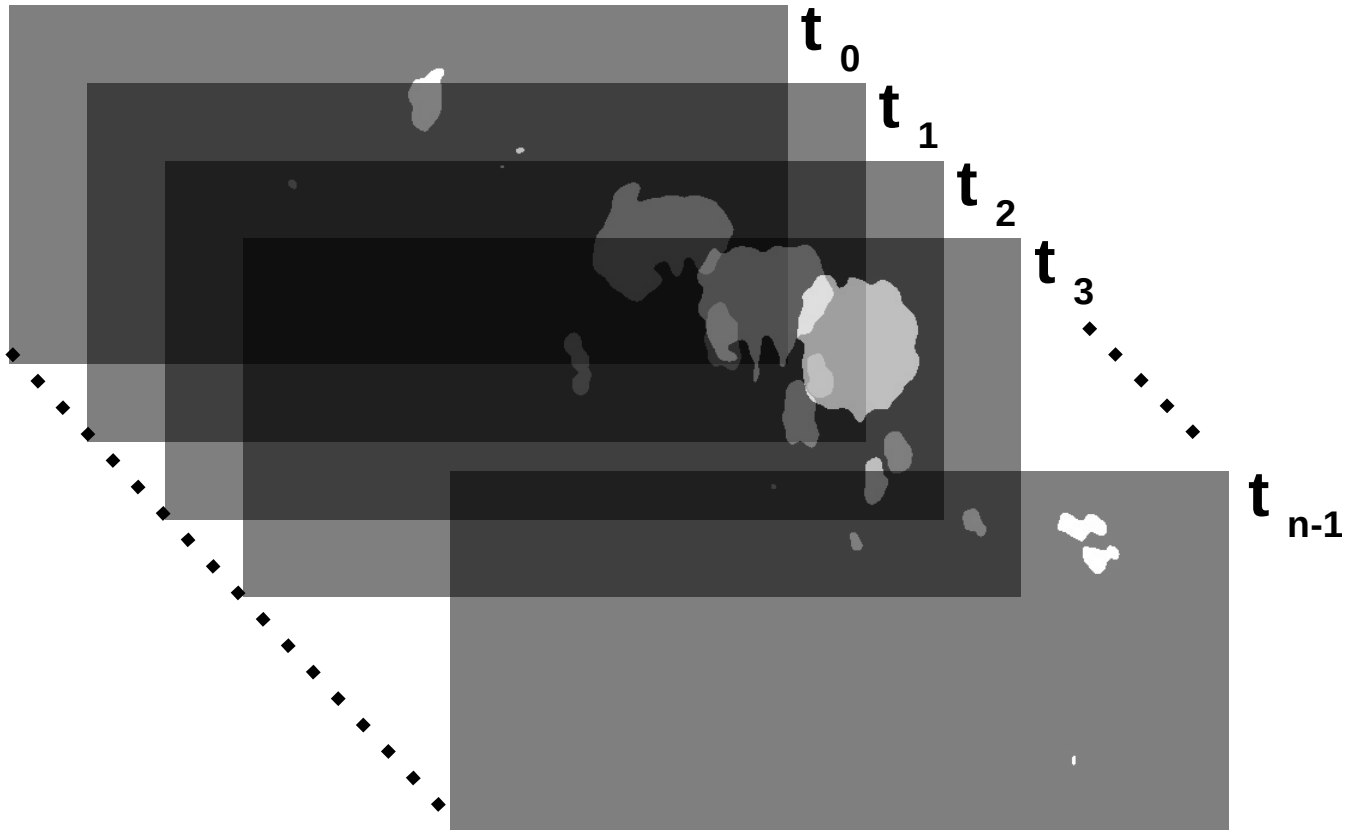
2D irradiance maps at times t_0 .. t_{n-1} → 3D spatio-temporal volume

Spatio-Temporal Analysis 2: 3D Gaussian Filter



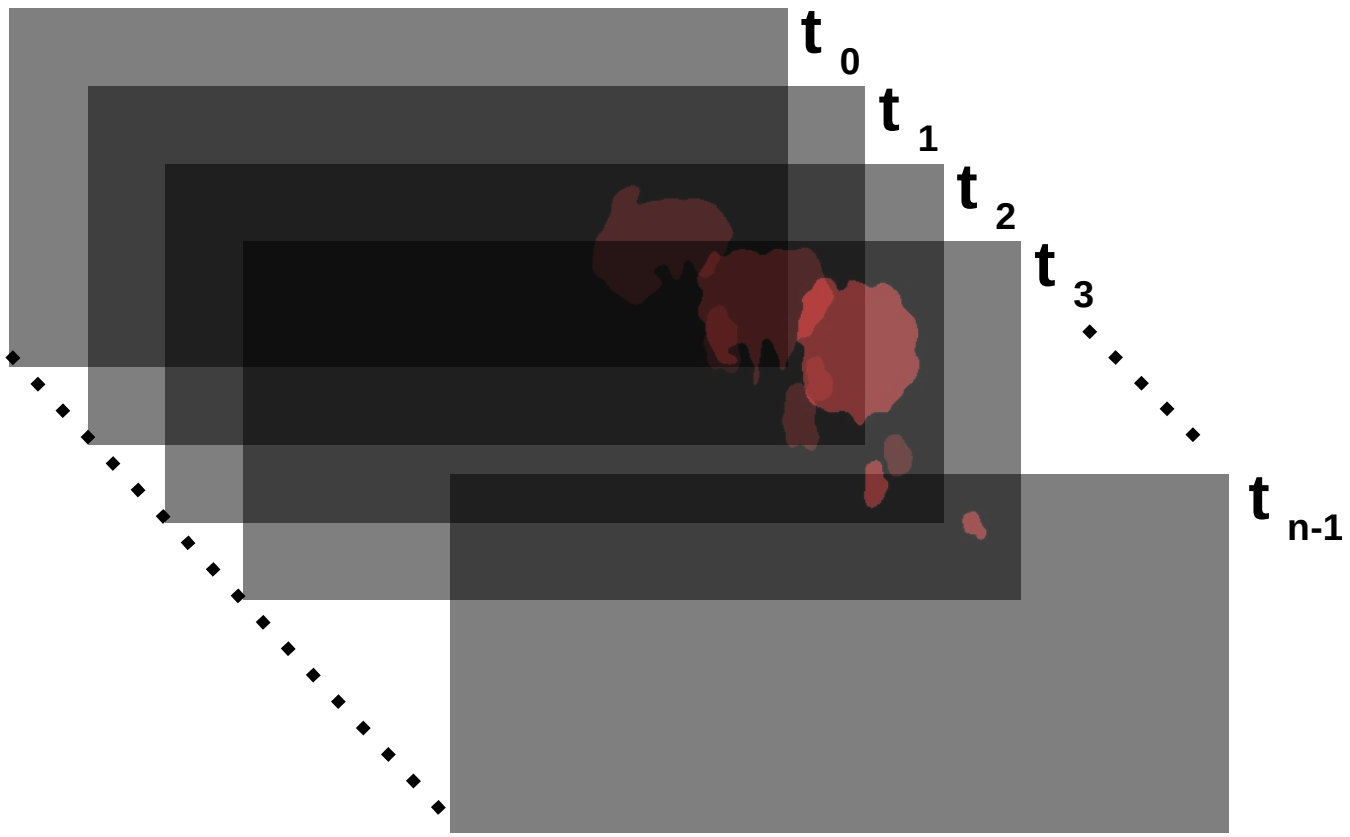
Removes noise, reduces temporal fluctuation during thresholding

Spatio-Temporal Analysis 3: Threshold Against τ_E



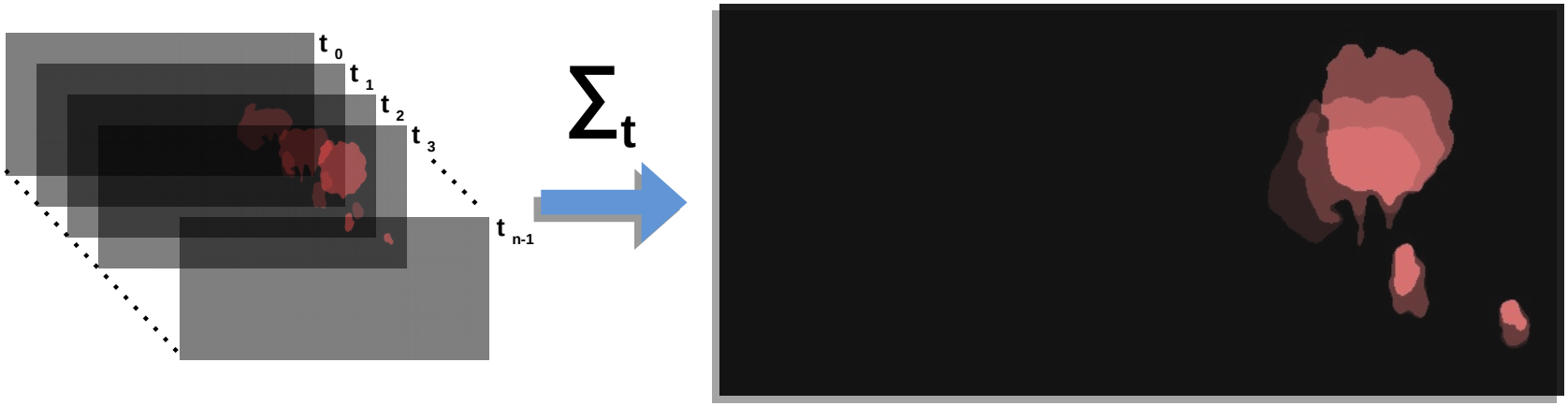
Binary pixel values: $<\tau_E \rightarrow$ black, $>\tau_E \rightarrow$ white

Spatio-Temporal Analysis 4: 3D Feature Labelling



Nonzero values (labels) in contiguous pixels along spatial and temporal axes

Spatio-Temporal Analysis 5: Sum Nonzero, Reduce to 2D



- Sum number of neighbouring nonzero pixels (labels) along temporal axis → reduce to 2D image
- Accumulate maxima if features overlap → multiple glare events in same region, e.g. from several PVs.
- Multiply by temporal increment (0.25h) to get sustained glare duration

Conclusions

- Reflections from BIPV can lead to potential glare, need to predict.
- Visualisation indicating reflected irradiance on environment intuitive for planners and non-experts.
- Application of recommended thresholds and spatio-temporal analysis evaluates sustained glare.
- Case study demonstrates proposed workflow. Results agree with PV planner’s prediction, glare non-critical as shielded by trees.
- Need more refined assessment criteria (subjective evaluation, exterior context, contrast)
- Proposed workflow as testbed for RealLife™ cases and new criteria.

Thank you for your attention!

Our website: http://www.hslu.ch/cc-ease

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