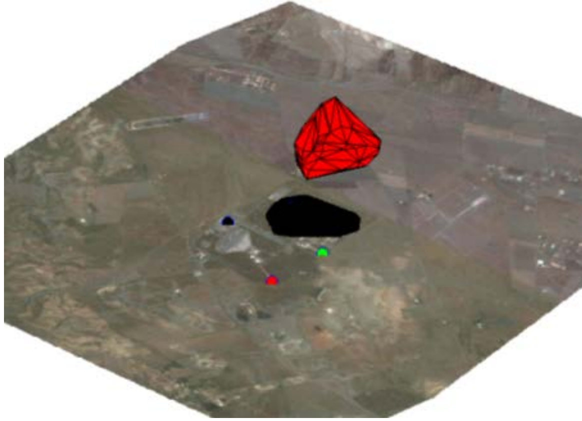

Cloud shadow maps from whole sky imagers and voxel carving

Daniel Oberländer, Christoph Prahl, Stefan Wilbert, Sebastian Müller, Badrudin Stanicki, Natalie Hanrieder

DLR - Institute for Solar Research

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Overview

- Motivation and Introduction
- What we do
  - Hardware: @ Plataforma Solar de Almeria (PSA)
  - Approach: voxel carving with whole sky imagers
- Results:
  - Proof of principle and validation with shadow cameras
  - Sensitivity analysis
- Outlook

Motivation for creating shadow maps

<u>Optimize energetic & financial yield & plant life time (our focus)</u>

- CSP (Concentrating Solar Power) plant operation involves e.g.
  - In tower plants: mirror focus control (avoid fast temperature changes of receiver, avoid overload dumping with dynamic aim-point selection)
  - In trough plants: Individual heat transfer fluid mass flow in different parts of the solar field
  - …
- Good plant operator decisions need **spatially resolved DNI data**
  - – Live data and nowcasting
  - – Shadow maps are the basis for this

Andasol parabolic trough plants

Solution

highly temp. and spatially resolved irradiance maps (nowcasts and live information) from cloud camera system

- Example for challenges:
  - High variability
  - Complex cloud formation/motion

  - Captured at PSA
    2014- 05-28, 10:00 - 17:00

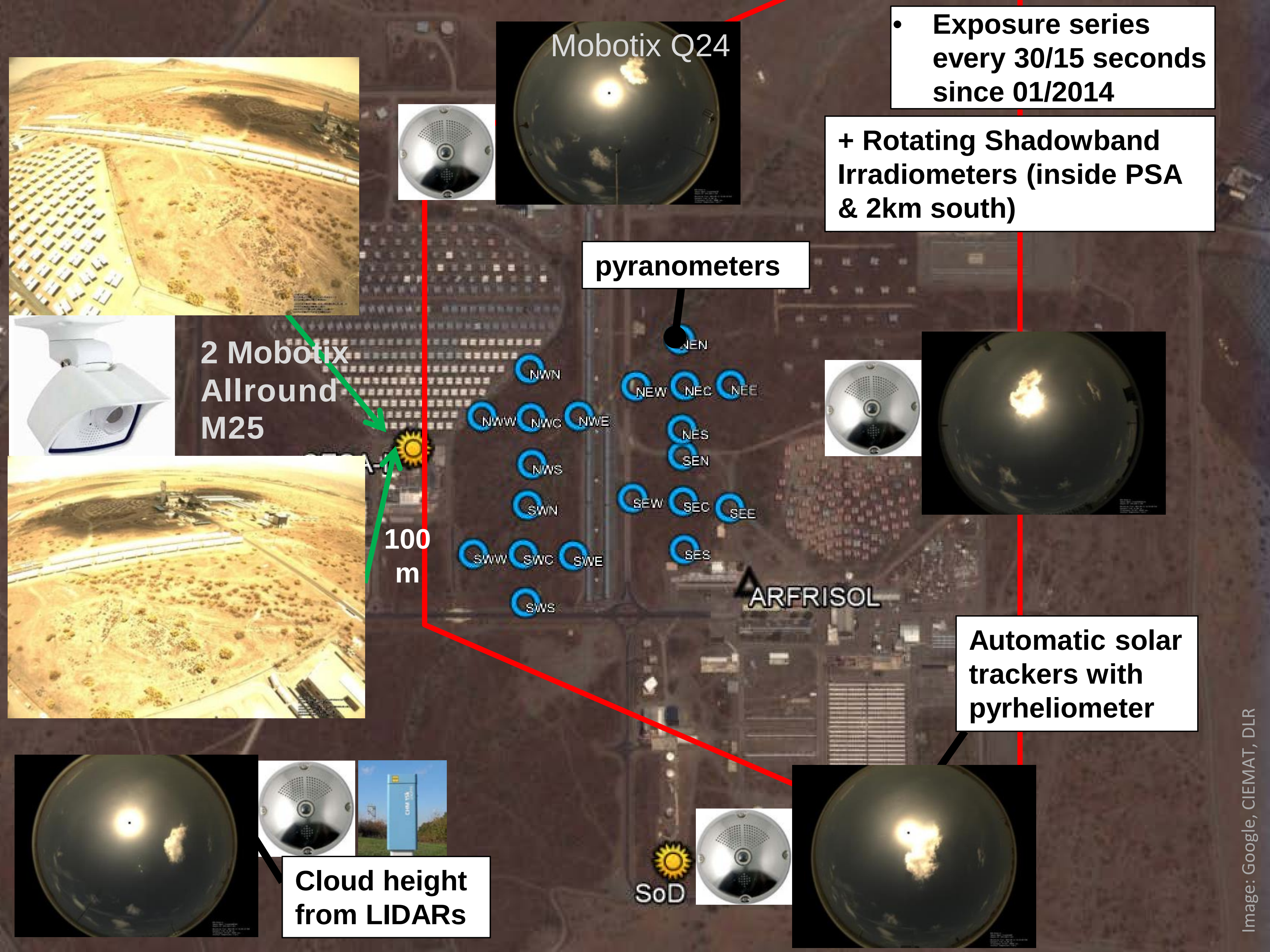
General Approach

investigate all components of a camera system that creates live and nowcasted shadow and irradiance maps:

- Camera system and validation network and create data
- Processing software:
    - Segmentation, classification
    - Cloud geo-location (3D)
    - Creation of shadow maps (later irradiance maps)
    - Nowcasting
    - Validation

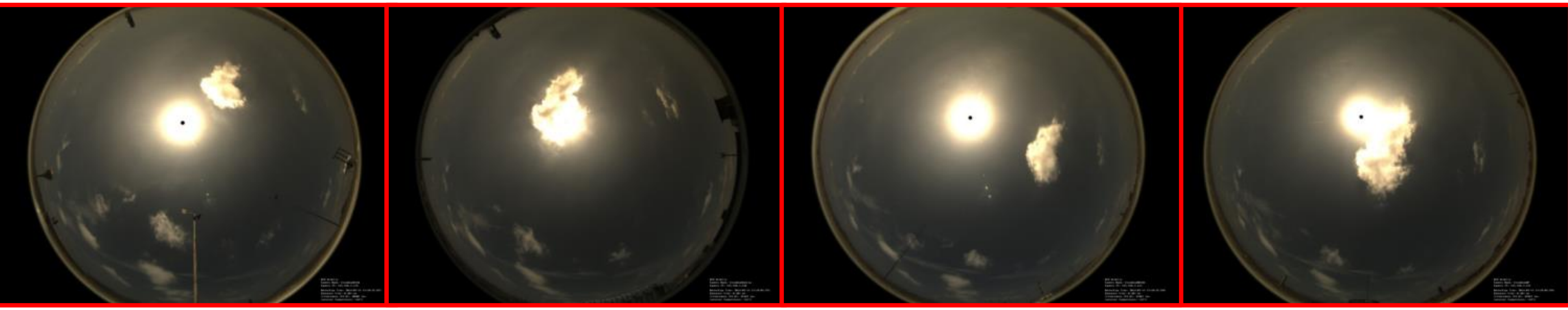
<u>Focus so far:</u>

- Geo-location (3D)
  4 cameras: voxel carving
- Verification of the system
    - Measured shadow maps from elevated shadow cams (to be combined with irradiance measurements)
    - Sensitivity analysis for camera setup geometry


Mobotix Q24
• Exposure series every 30/15 seconds since 01/2014
+ Rotating Shadowband Irradiometers (inside PSA & 2km south)
pyranometers
2 Mobotix Allround M25
100 m
NEN
NWN
NEW
NEC
NEE
NWW
NWC
NWE
NES
NWS
SEN
SWN
SEW
SEC
SEE
SWW
SWC
SWE
SES
SWS
ARFRISOL
Automatic solar trackers with pyrheliometer
Cloud height from LIDARs
SoD
Image: Google, CIEMAT, DLR

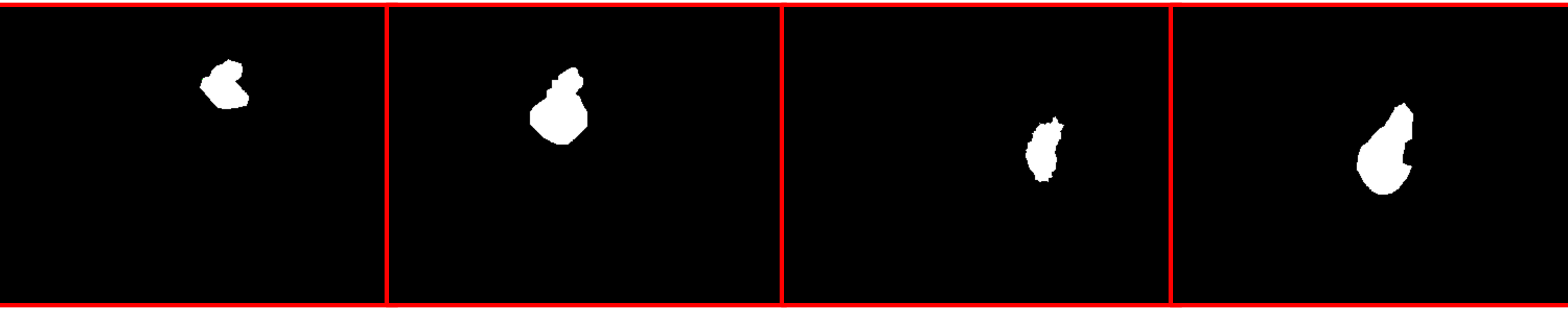
2014-05-13 12.29 PM

DISS Kontas Metas HP



1. Step of evaluation →

Segmentation



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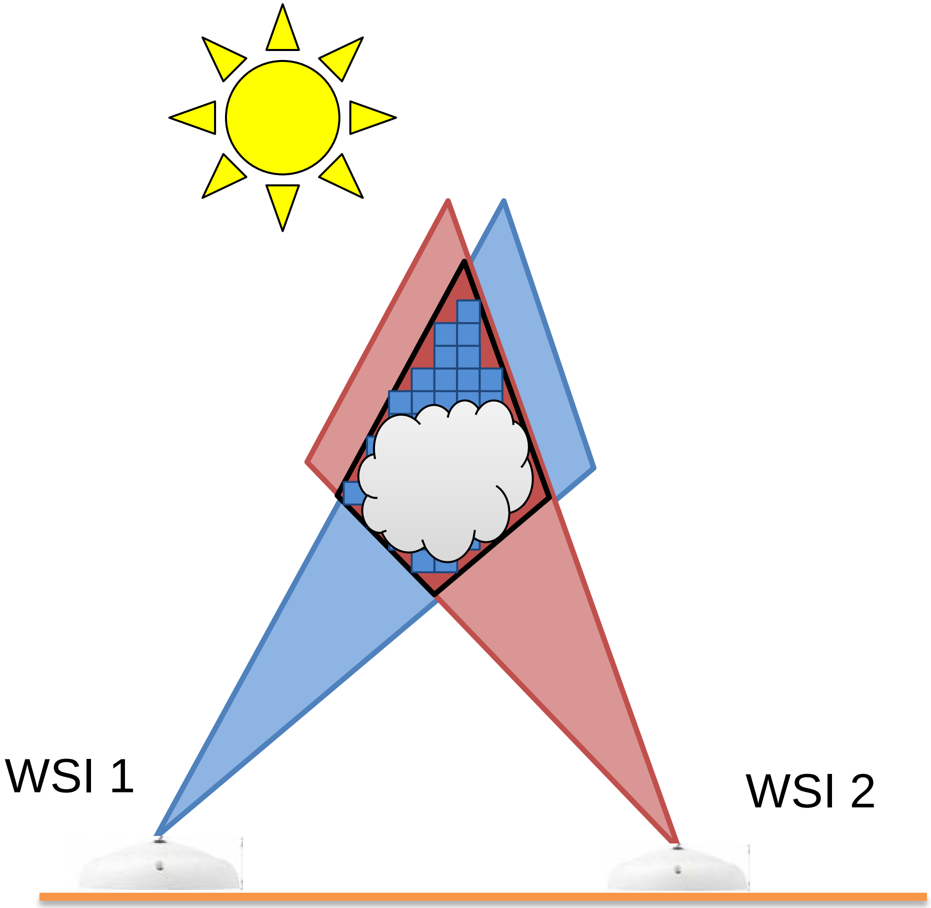
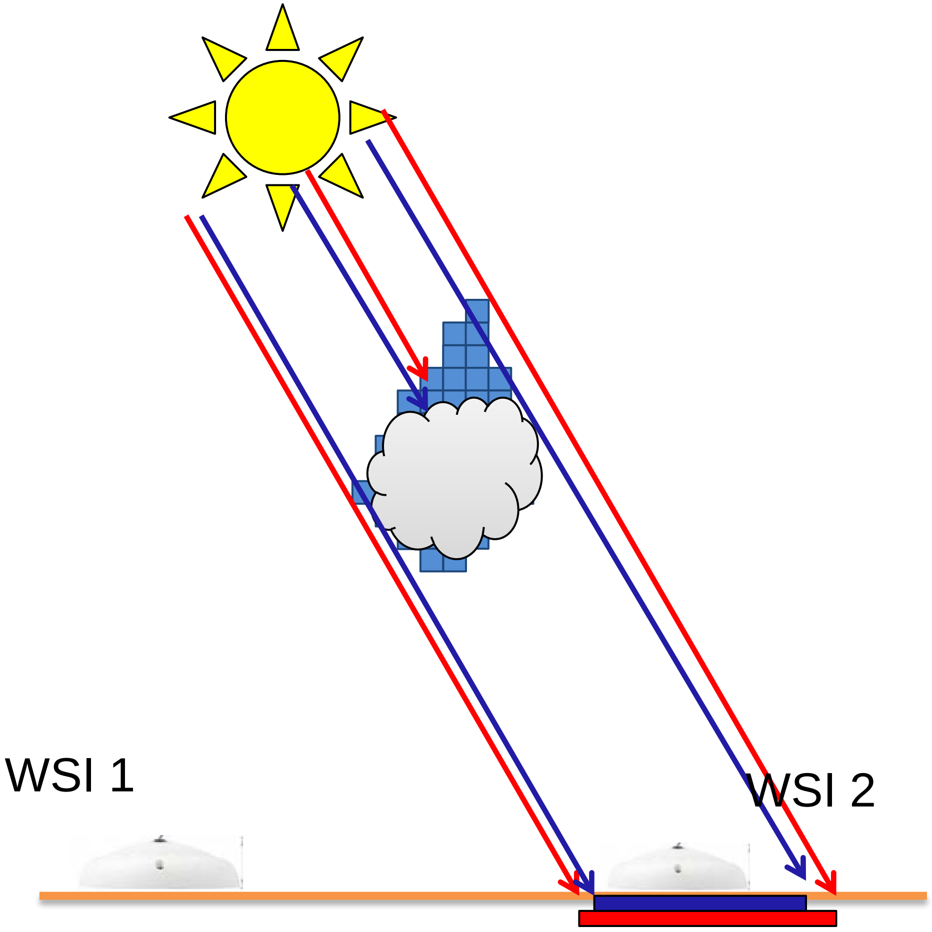
Voxel carving with WSI

- Back-projection of detected clouds view cone
- Intersection of view cones = cloud



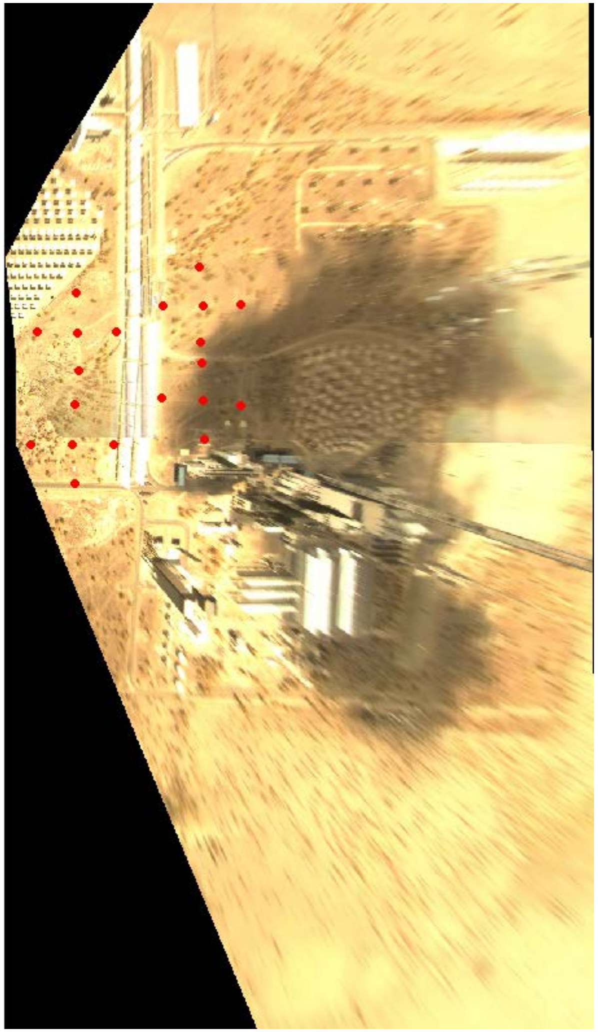
Shadow map calculation

- Back-projection of detected clouds view cone
- Intersection of view cones = cloud
- Calculation of modeled shadow



Validation: creation of ortho images

based on:
- position
- orientation
- camera model



1 Pixel ≙ 1 m

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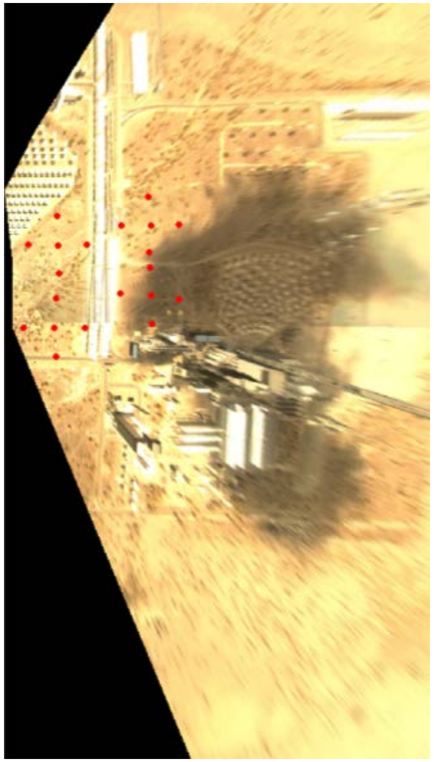
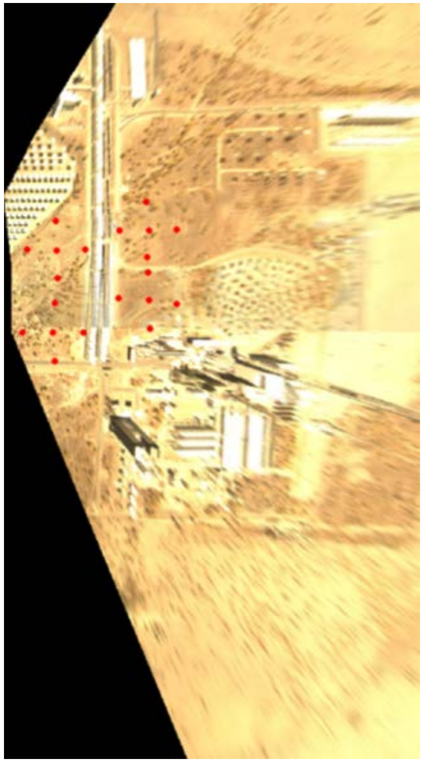
Validation: segmentation of ground shadow

Current Image

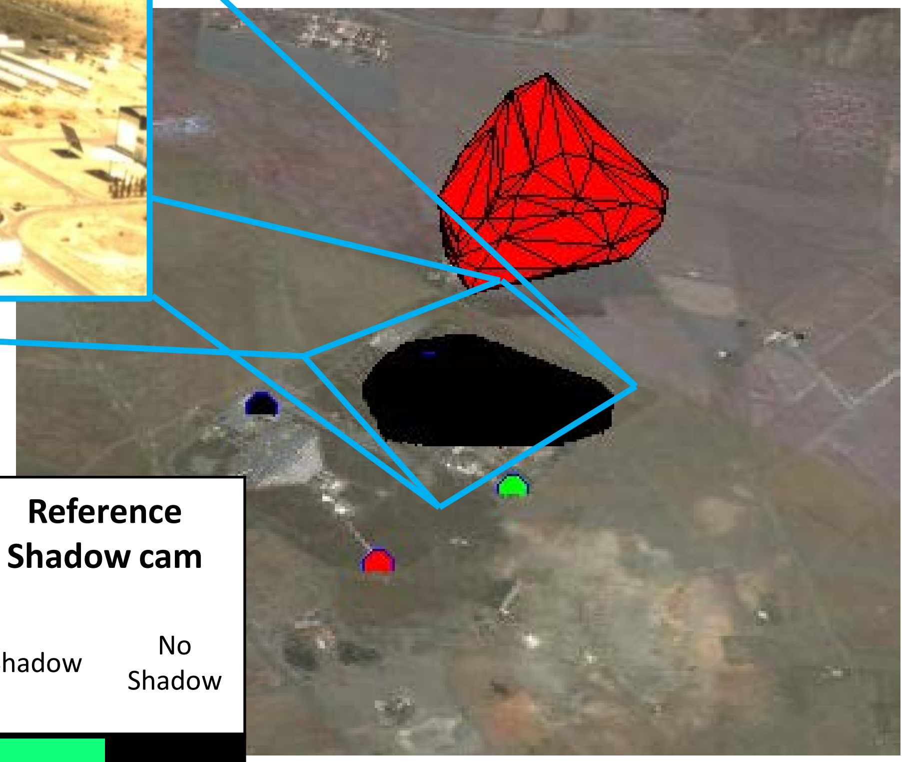


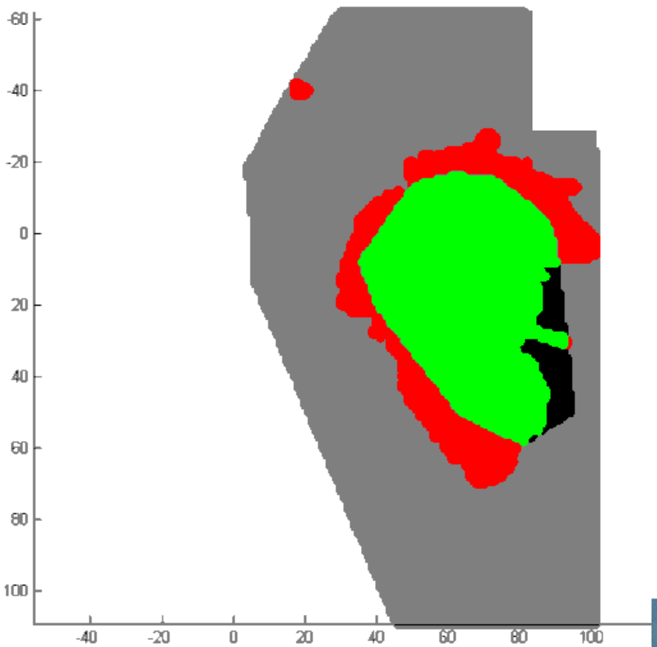
Reference image



Segmented shadow

Validation of modelled shadow



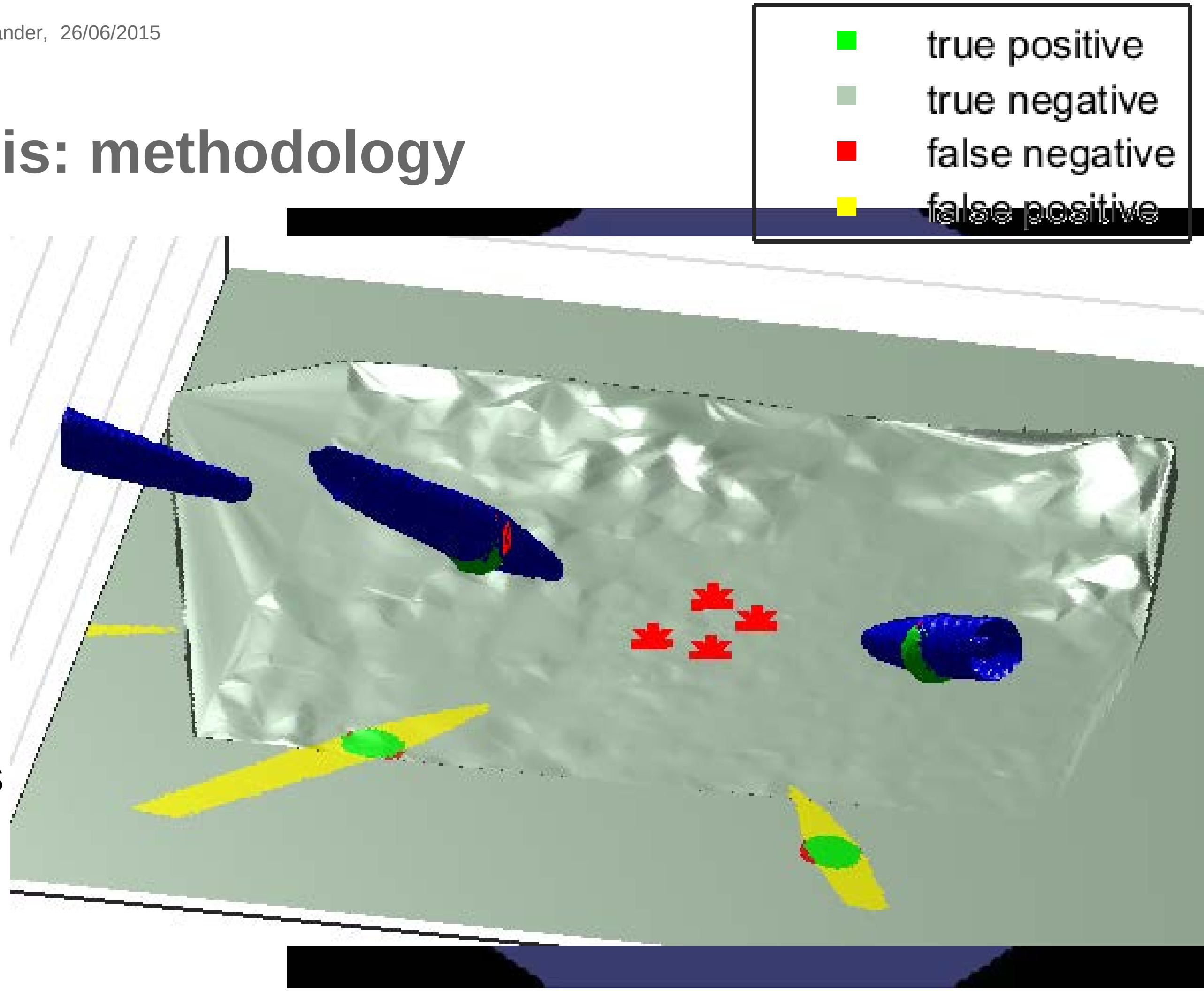


		Reference Shadow cam	
	(Pixel)	Shadow	No Shadow
Model Voxel Carv.	Shadow	TP	FP
	No shadow	FN	TN

ACC = (TP + TN)/surface
= 0.76

Sensitivity analysis: methodology

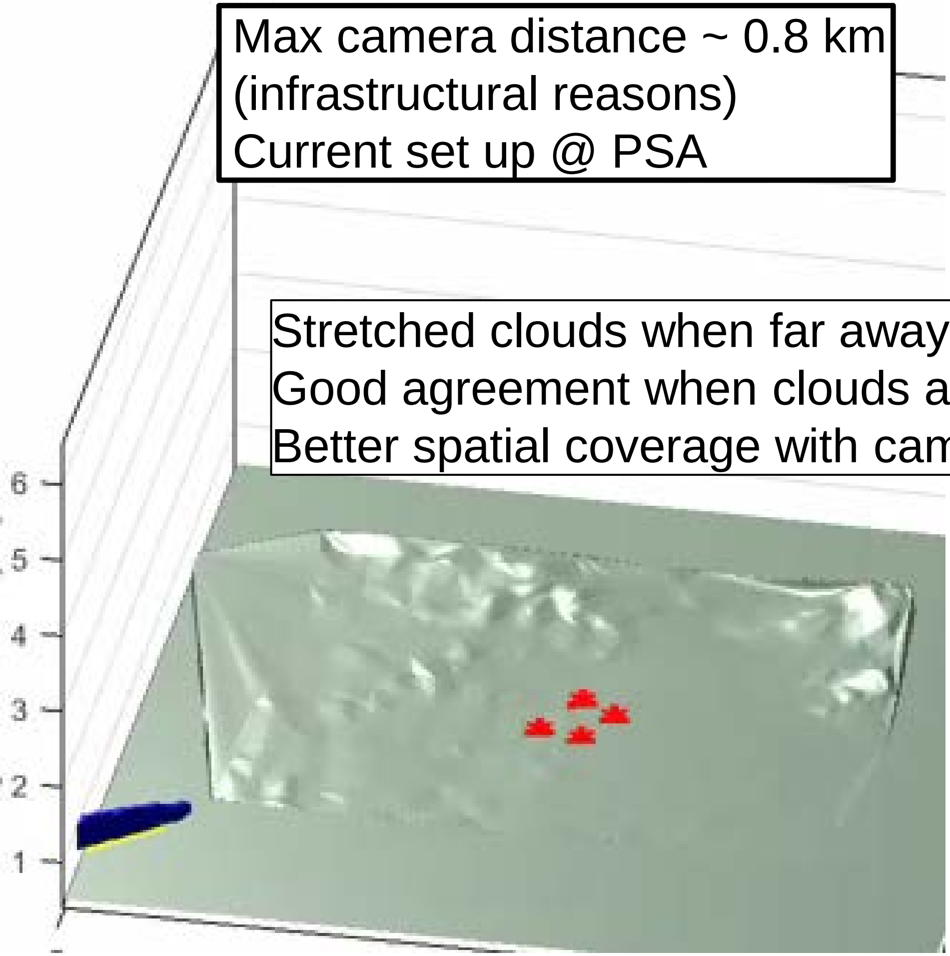
- Define artificial spherical clouds (initial position, radius, motion vector)
- Create artificial WSI Images from known camera setup
- Model shape and position of cloud and its shadow from artificial WSI images
- Compare shadow from artificial cloud and the voxel carving model



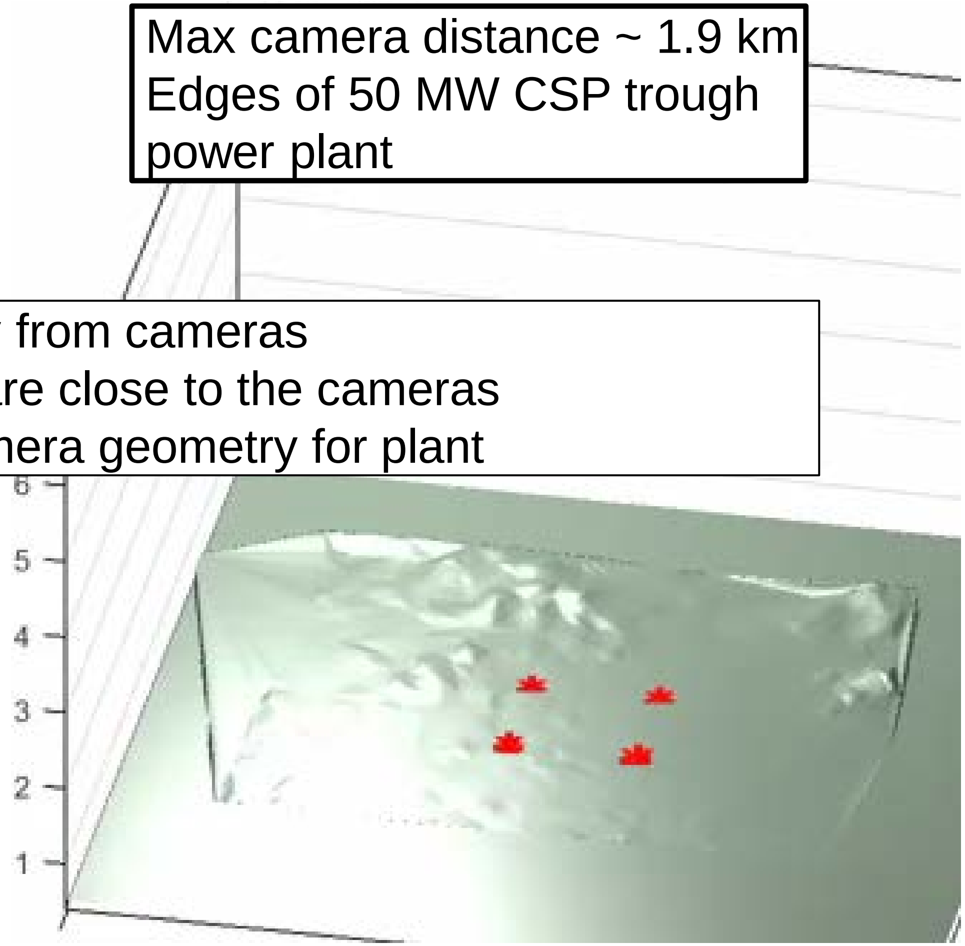
Sensitivity analysis: Comparison of Set ups

- true positive
- true negative
- false negative
- false positive

Max camera distance ~ 0.8 km
(infrastructural reasons)
Current set up @ PSA



Max camera distance ~ 1.9 km
Edges of 50 MW CSP trough power plant



Stretched clouds when far away from cameras
Good agreement when clouds are close to the cameras
Better spatial coverage with camera geometry for plant

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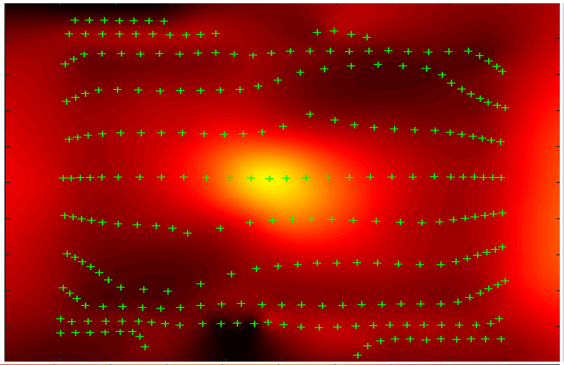
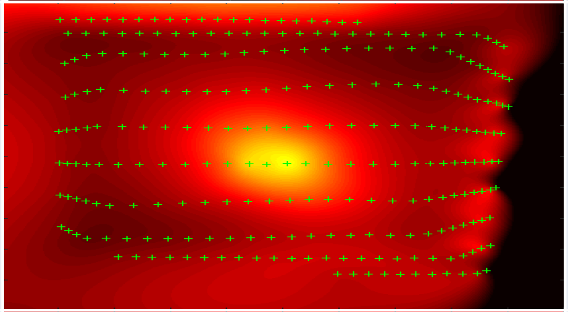
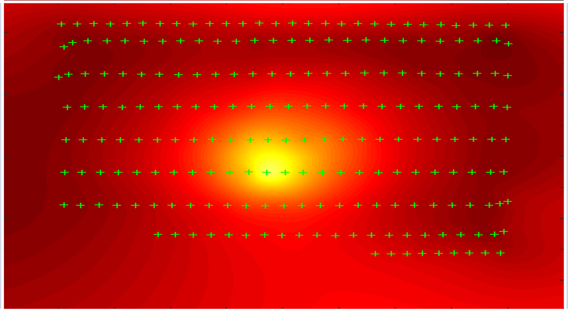
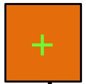
Sensitivity analysis: comparison of set ups

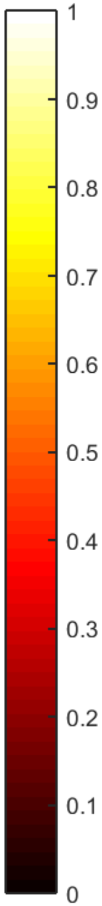
CH [m]	PSA set up	Quality	50 MW set up	Quality
1000		0.22		
3000		0.26		
5000		0.30		

Average of
TP/(TP + FN + FP)
for all simulated cases
(“small shadow skill”)

- pixel coordinates of figures are x and y coordinates at PSA

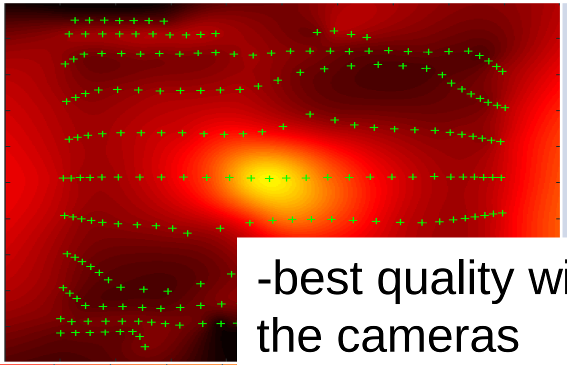
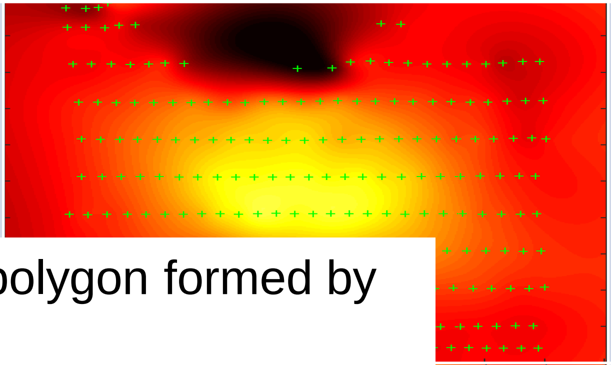
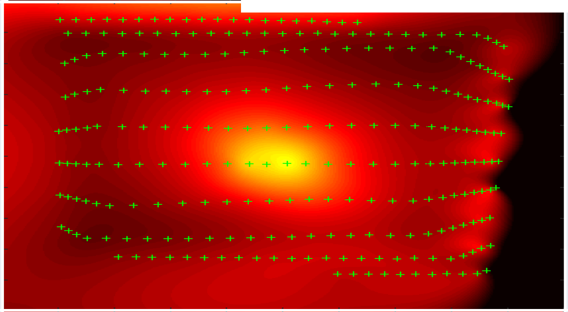
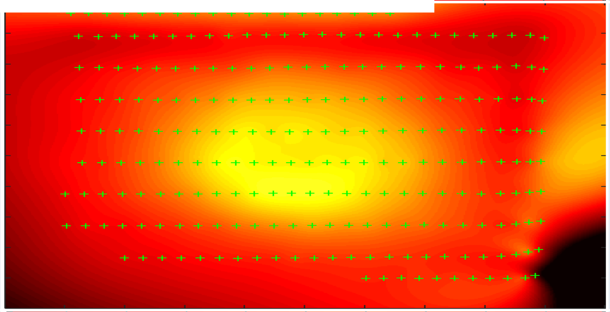
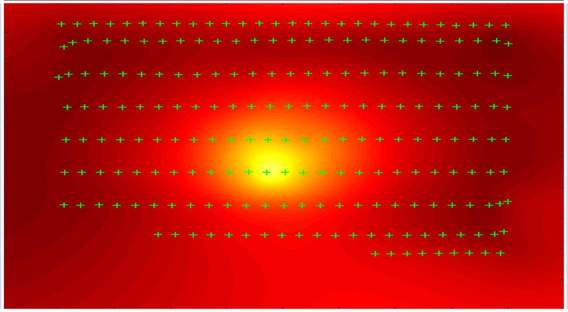
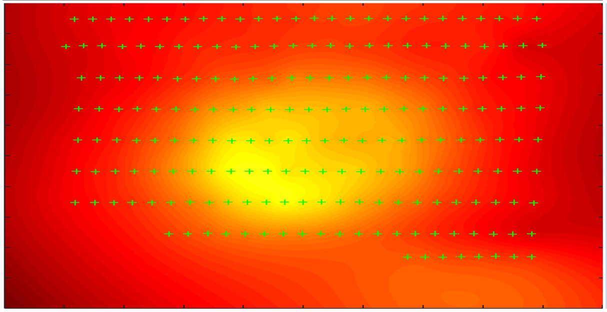
- green markers  position of shadow’s center for one simulation

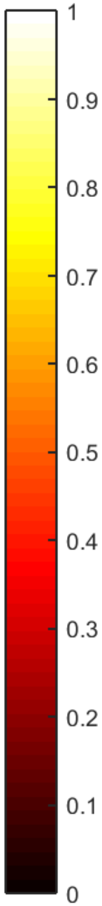
- color: quality for this point
- spatial interpolation of color only for visualization (average quality only from results for each simulation)



TP/(TP + FN + FP) changed by factor ~2

Sensitivity analysis: comparison of set ups

CH [m]	PSA set up	Quality	50 MW set up	Quality
1000		0.22		0.46
3000		0.26		0.49
5000		0.30		0.48



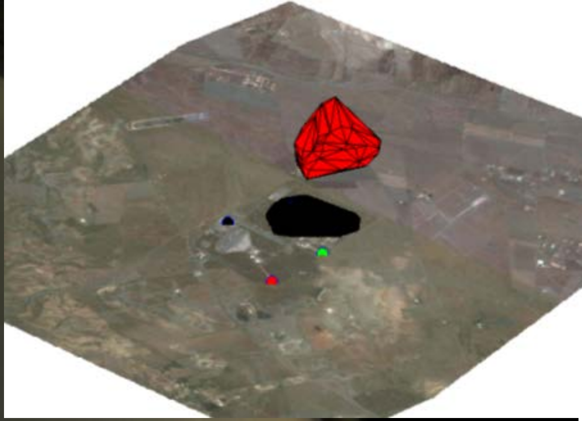
-best quality within the polygon formed by the cameras

Summary

- Modelling of cloud shape and position from WSI images by voxel carving is possible
- Validation with shadow cameras shows good agreement for selected events
- Sensitivity analysis reveals potential of long base line system (CSP plant size)
- Large data sets for solar radiation forecasting available

Outlook

- Implement additional measures/assumptions to trim implausible voxel carving results (typical cloud height and shapes from classification)
- Adjust experimental setup to plant geometry and create data for validation at several sites.
- Validation of method with time series > 1 year, for several sites
  - With irradiance maps instead of shadow maps (live and nowcasted)
- Implementation of adequate cloud evolution prediction
  - Investigate possible benefits for cloud tracking with voxel carving



Thank you for your attention.

For questions or further details please contact

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