# High-resolution shortest-term forecasting with all sky imagers

**Nils Straub, Anna Dittmann und Elke Lorenz**
**Workshop Solar forecasts and their integration in the management of energy systems**
**20.08.2023**
**www.ise.fraunhofer.de**

# Agenda

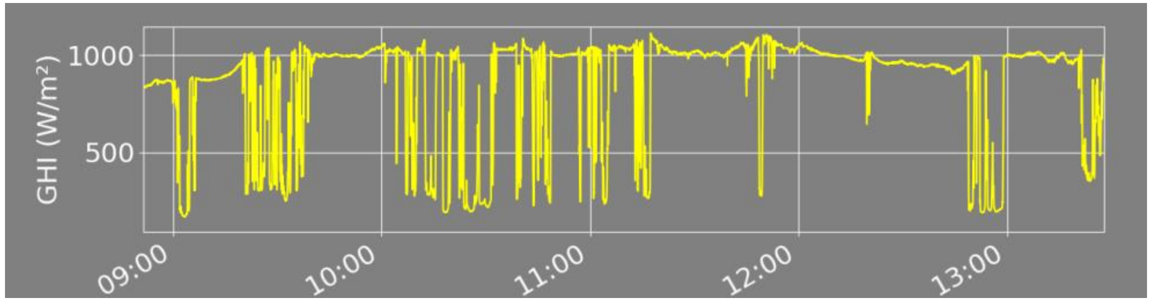
1. Introduction

2. Steps of a forecasting system

3. Examples and challenges

# Introduction

## What is All Sky Imager based forecasting?




### What is an All Sky Imager (ASI)?

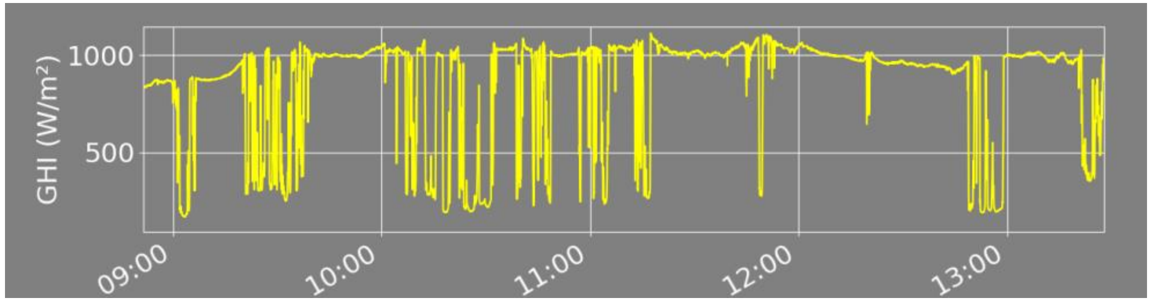
- Camera with a fisheye lens
- Takes 360° pictures of the whole sky

### Forecasting method:

- Detection of single clouds
- Projection of the cloud movement into the future
- Very high resolution
- Ramp forecasting

# Introduction

## What is All Sky Imager based forecasting?




**Applications that benefit from prior consideration of intra hour variability**

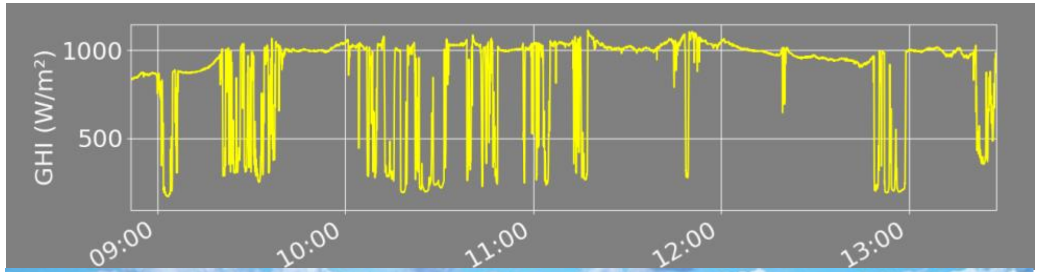
- Regulation of heating and cooling systems
- Energy market
- Management of distribution grid
- Battery management

# Introduction

## Differences to satellite based forecasting?

| | Satellite | ASI |
|---|---|---|
| Temporal resolution | 15 min | 10 s |
| Spatial resolution | <1 km | ~50 m |
| Forecast horizon | Several hours | 10-20 min |

Resolution and horizon of ASI based forecasting depends on the weather situation!




Source: Baywa r.e.

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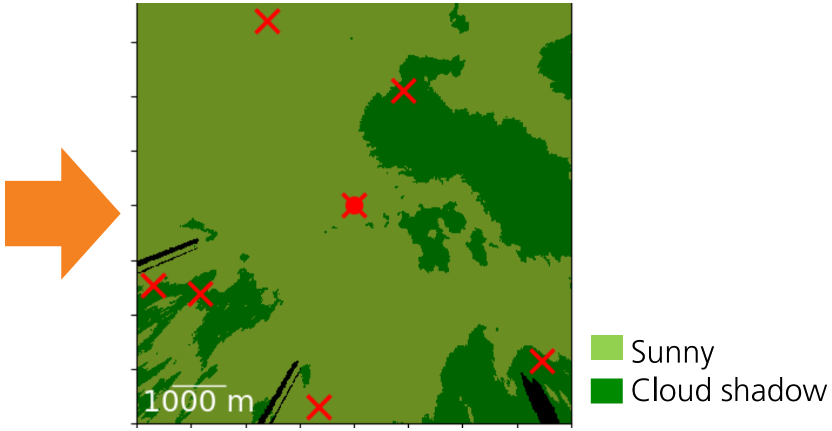


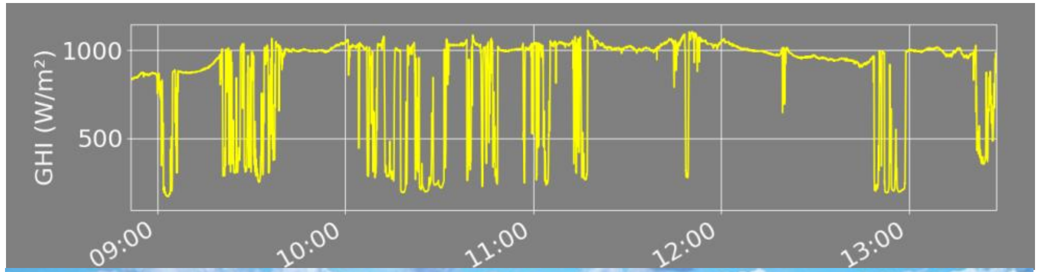


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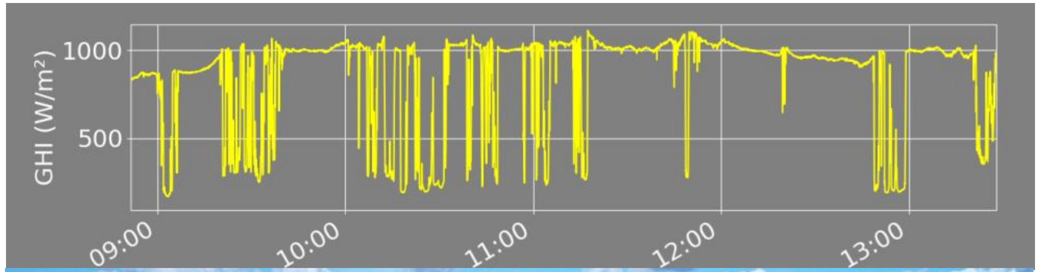
**Availability:**

- Satellite: Worldwide
- ASI:
  - Instruments have to be installed and maintained
  - Spatial coverage: ca. 10 km around camera
  - Forecast availability stongly dependent on weather situation!
  - Higher availability and horizon with several cameras

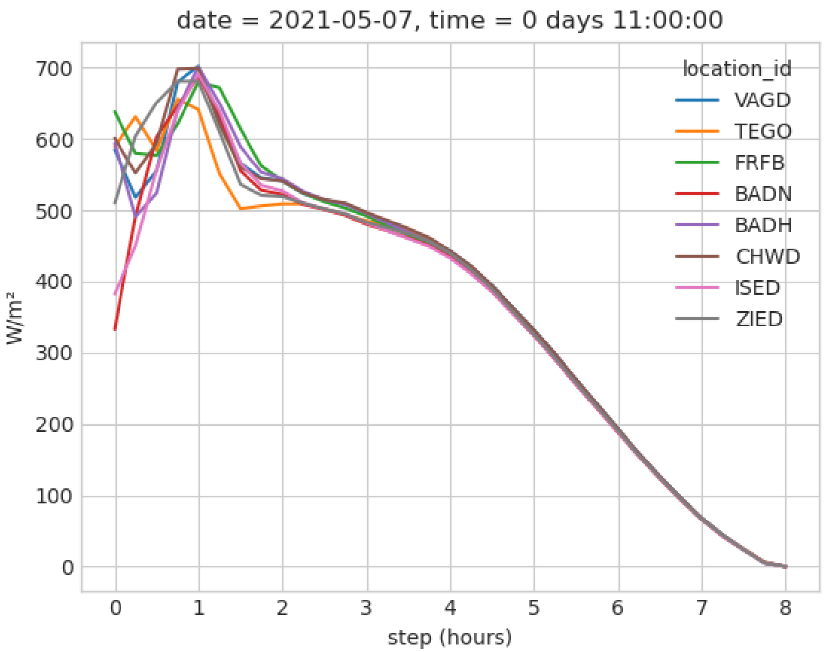



Source: Baywa r.e.

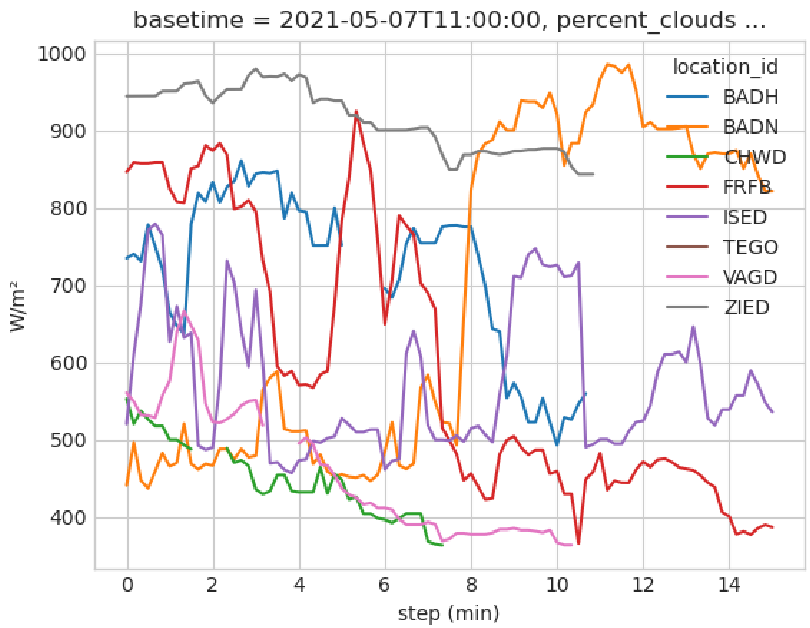
# Motivation

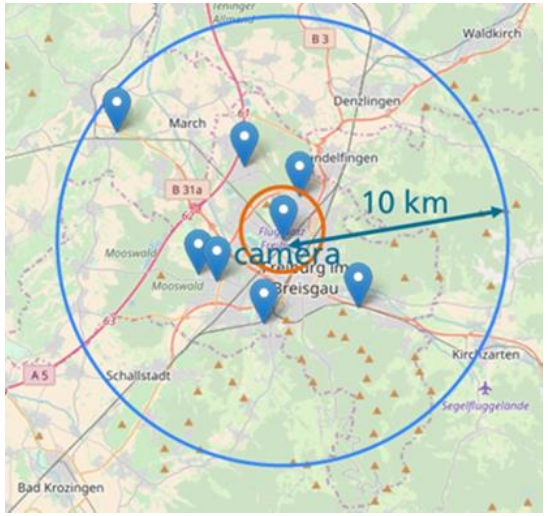
## Comparison timeseries from satellite-based irradiance

Satellite based forecast




ASI based forecast

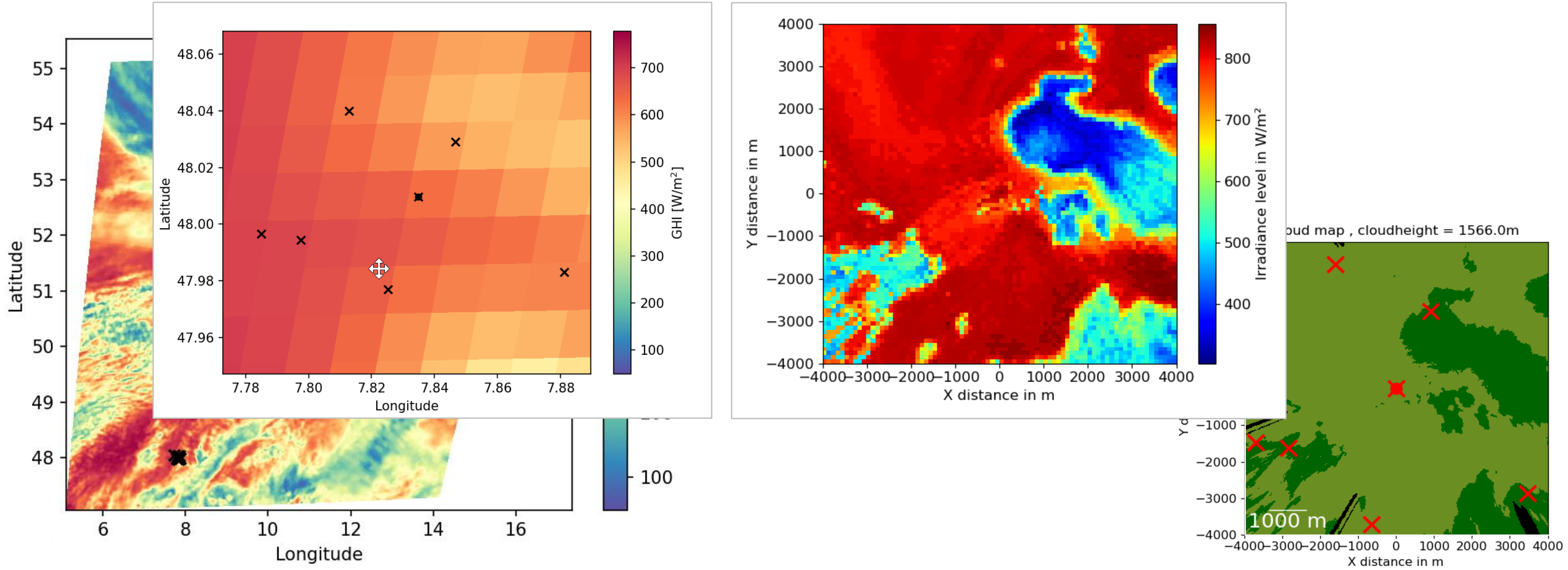



Advantage of ASI based forecasting: Forecasting of ramps resulting from single clouds

# Comparison of ASI and satellite-based forecasts

## Irradiance maps



# All Sky Cameras

## Camera types

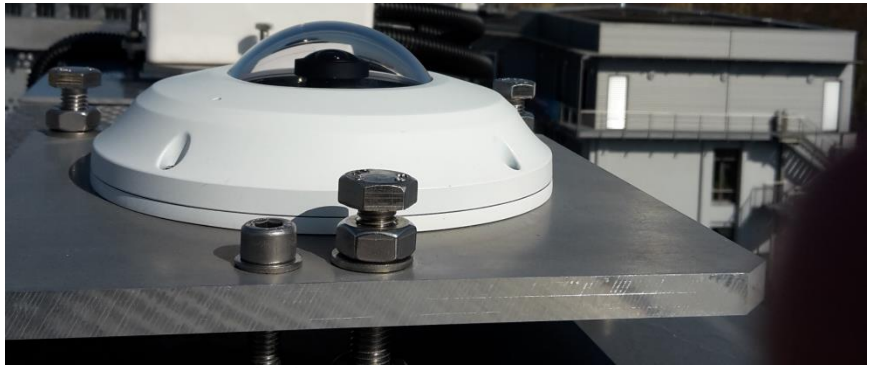
- Professional all sky cameras
  ~10.000T€
- Surveillance cameras
  ~1.000T€
- Prototype development at research institutes

## Image methods

- Visible Spectrum
- Infrared Spectrum
- High Dynamic Range

SONA Sieltec

Eko SRF-02 All-Sky Camera



Vivothek FE9831



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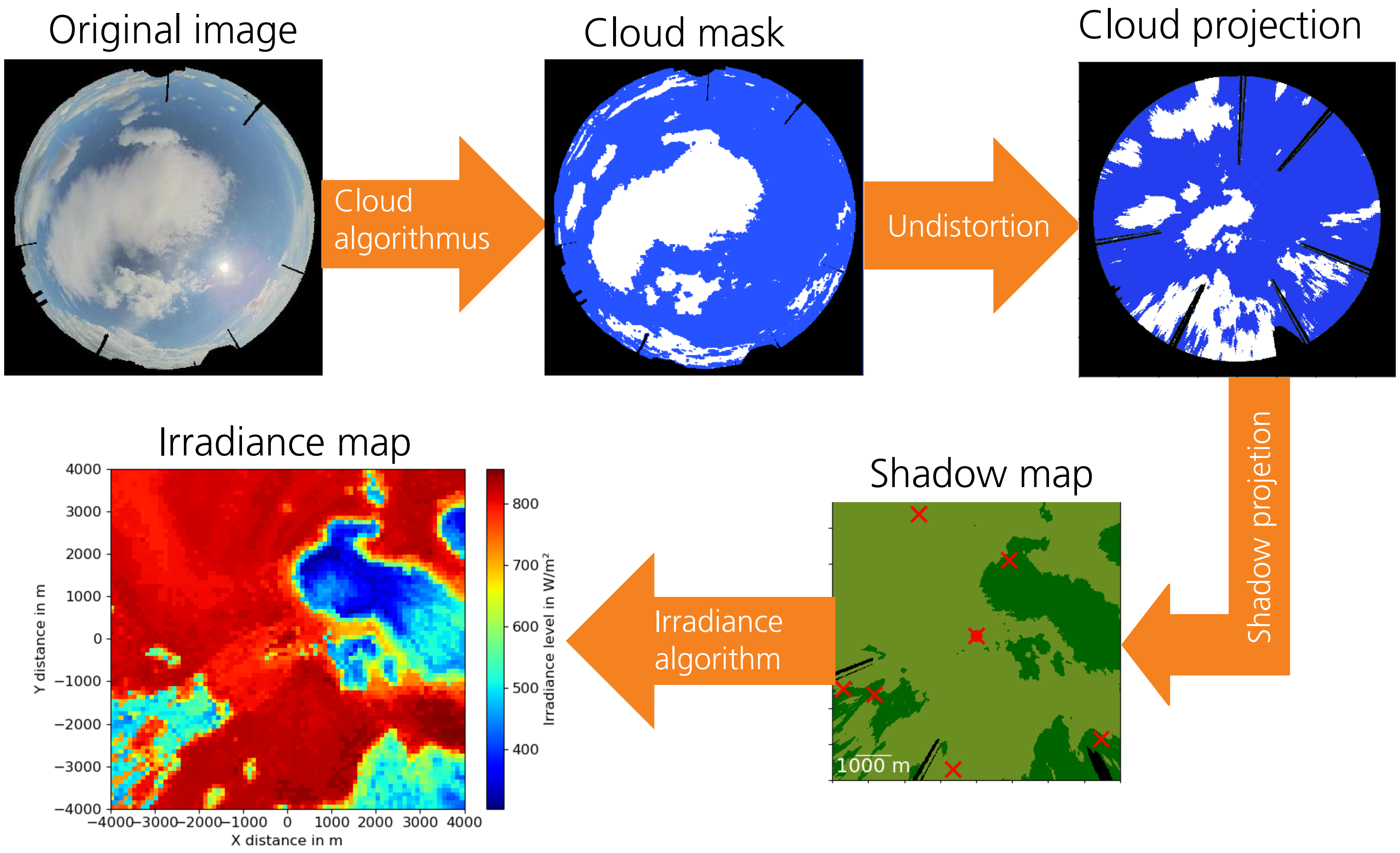
# ASI based irradiance retrieval

## At Fraunhofer ISE



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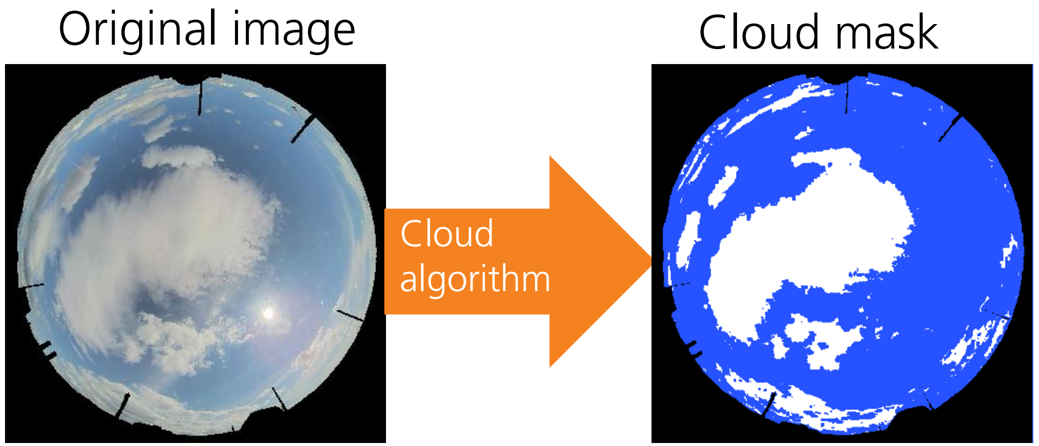
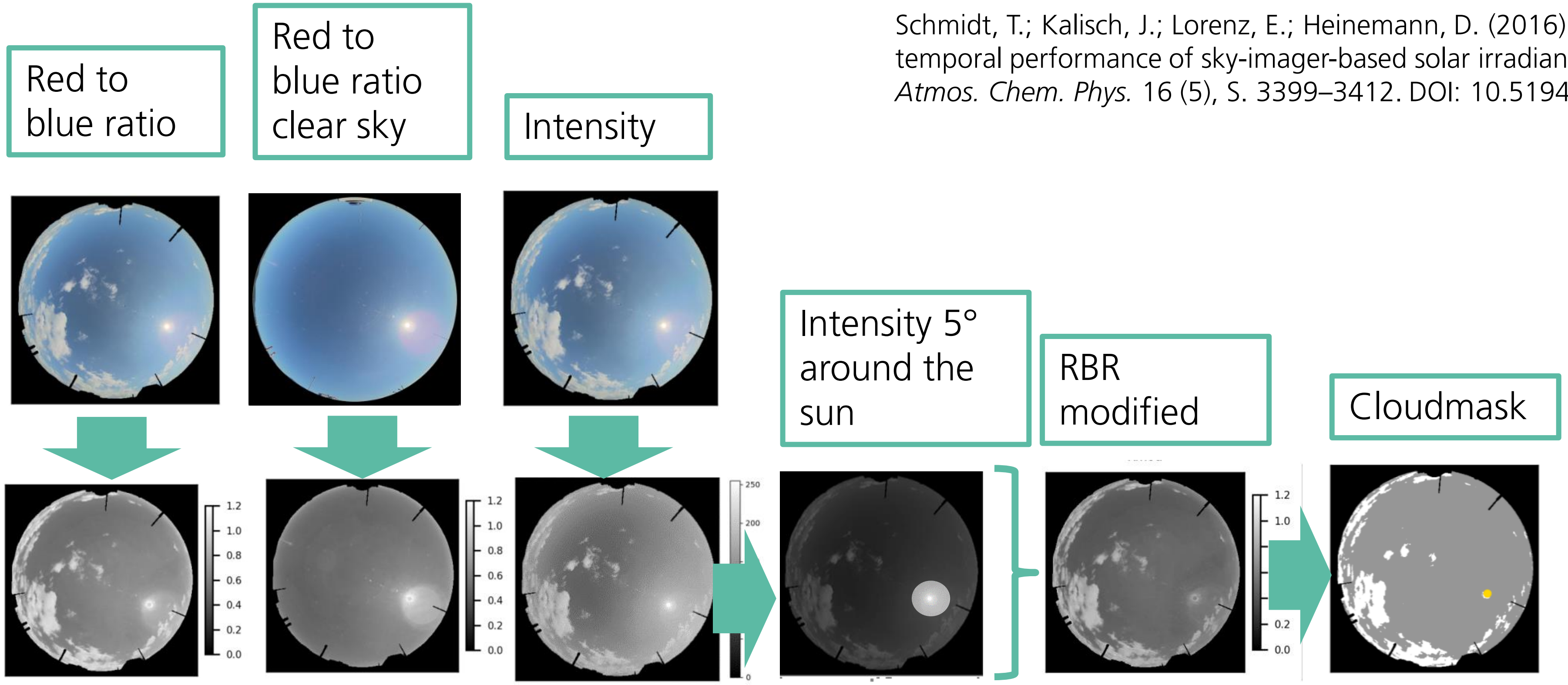


# Cloud detection

## Example of a cloud detection algorithm




Schmidt, T.; Kalisch, J.; Lorenz, E.; Heinemann, D. (2016): Evaluating the spatio-temporal performance of sky-imager-based solar irradiance analysis and forecasts. In: *Atmos. Chem. Phys.* 16 (5), S. 3399–3412. DOI: 10.5194/acp-16-3399-2016.

# ASI based irradiance retrieval

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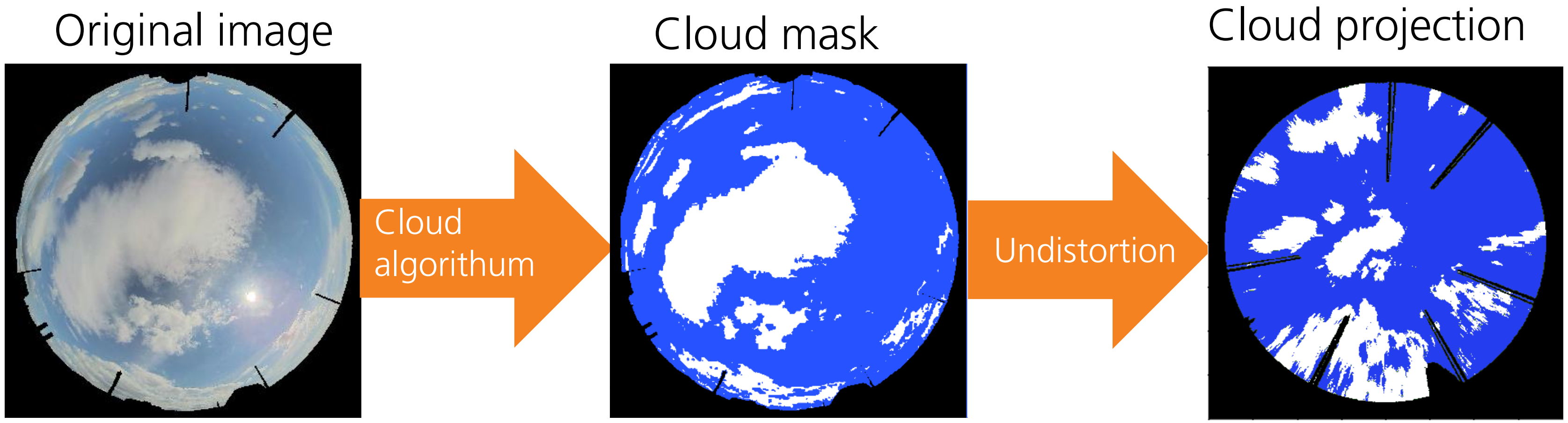
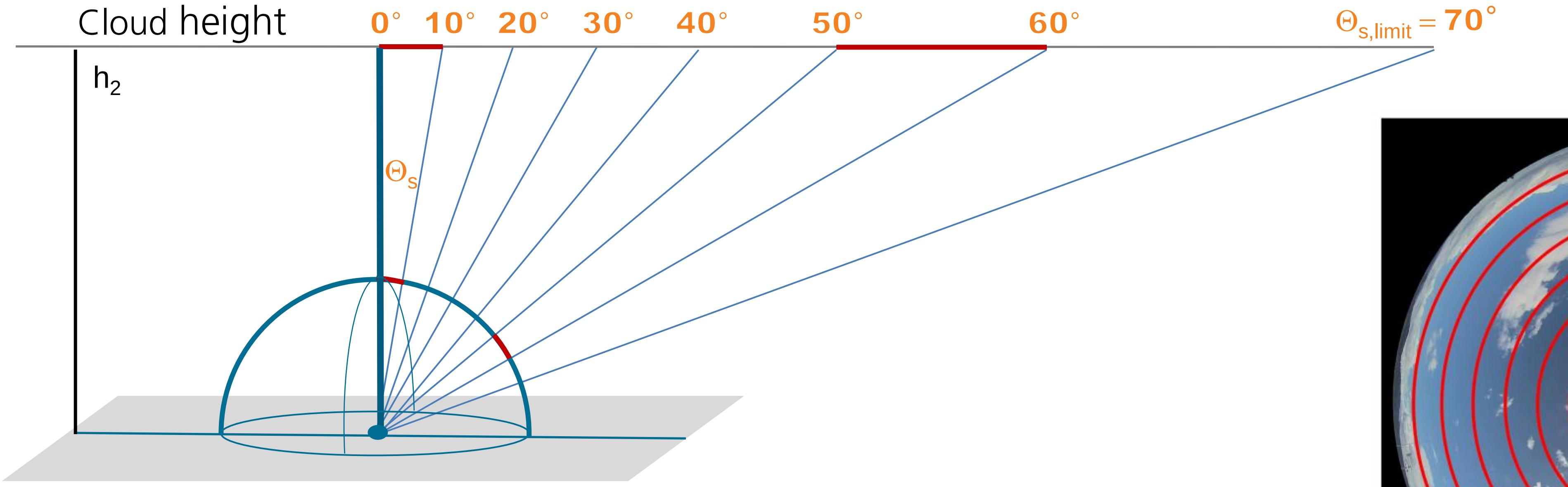
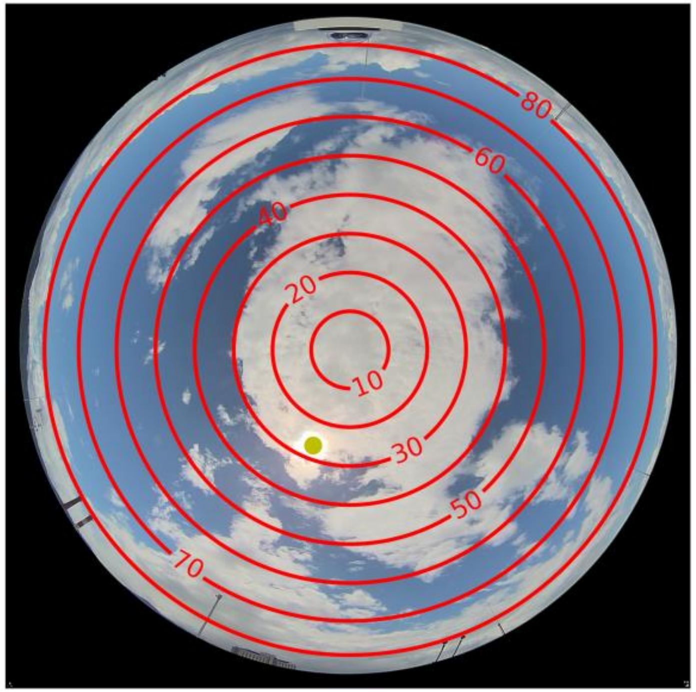


# Image undistortion



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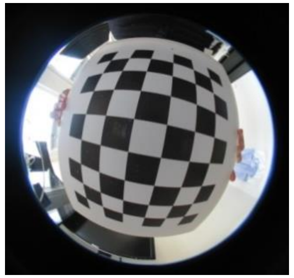
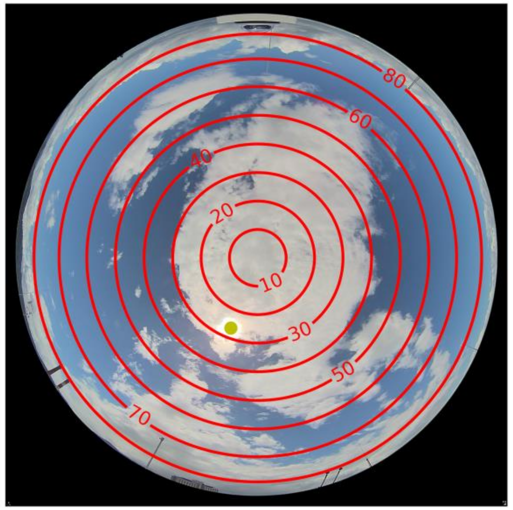
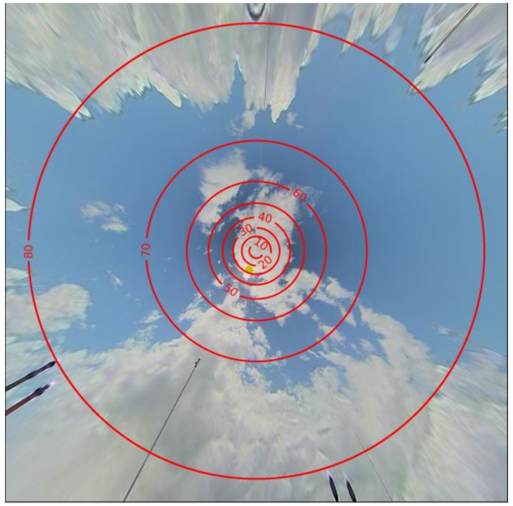


Lens Parameter

Distorted image




Undistorted image



# ASI based irradiance retrieval

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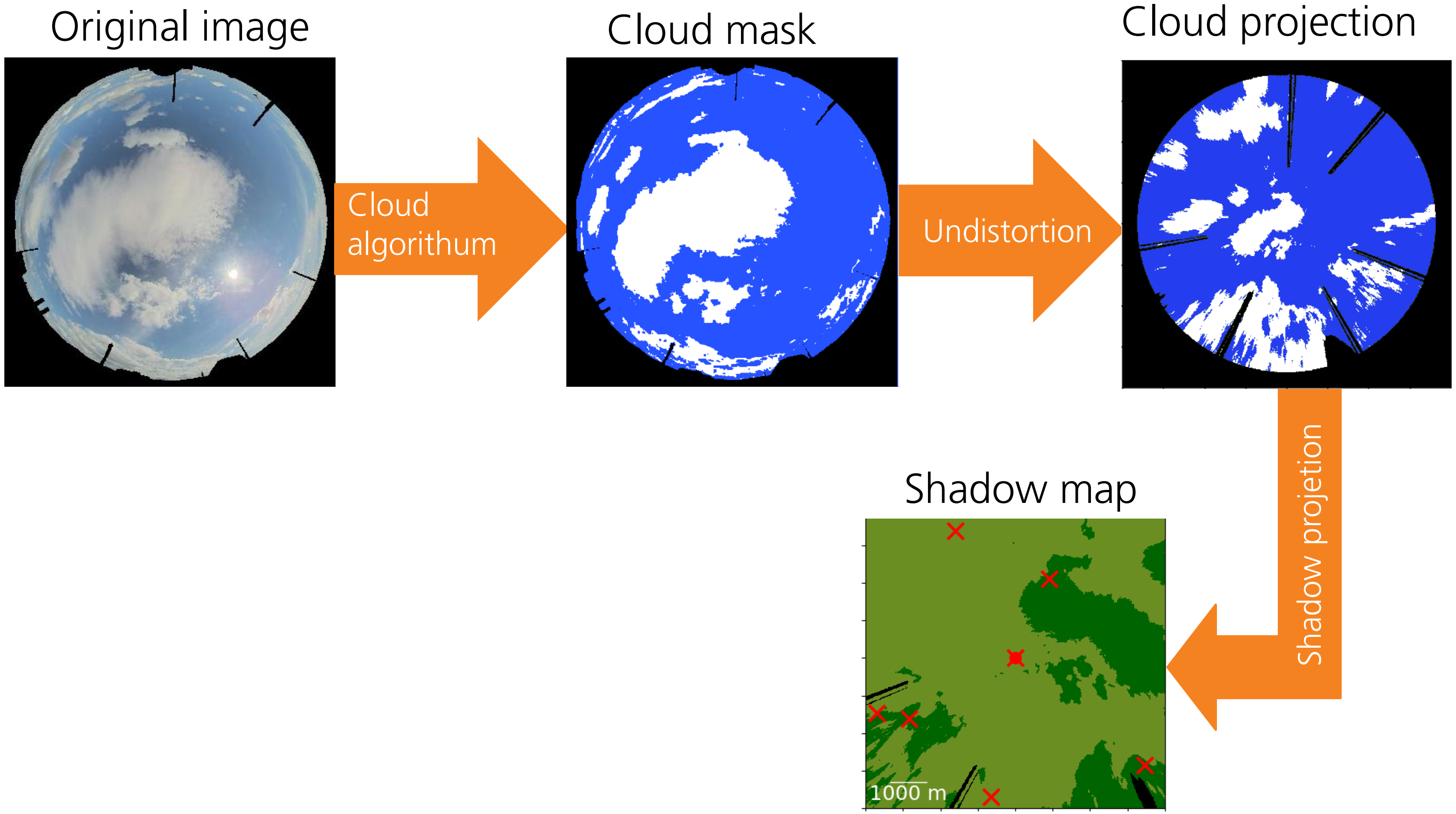
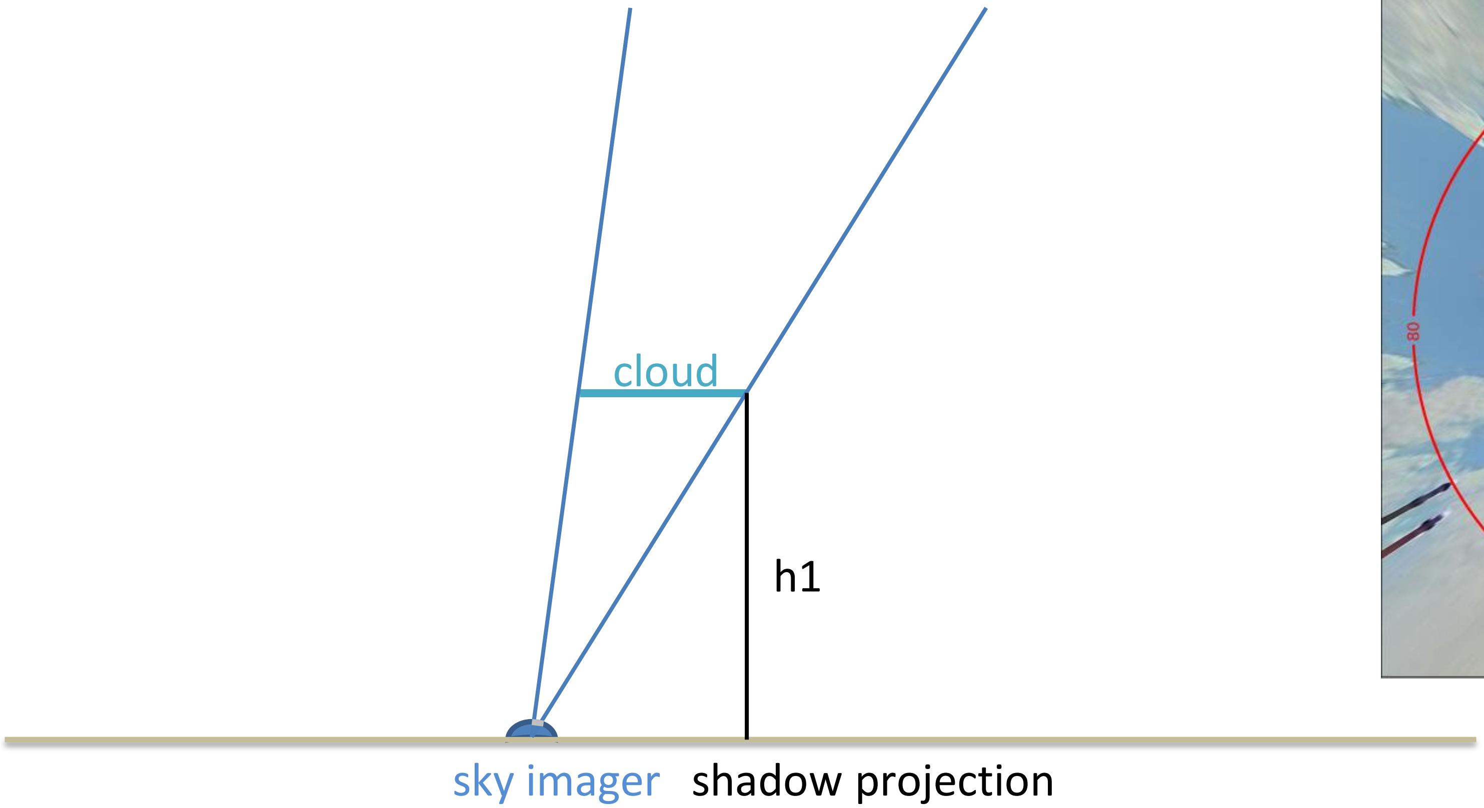
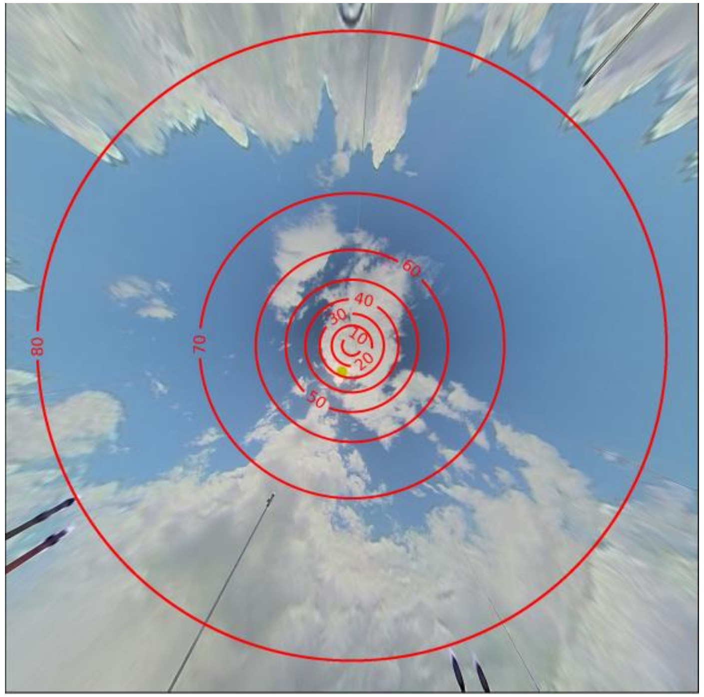


# Shadow projection



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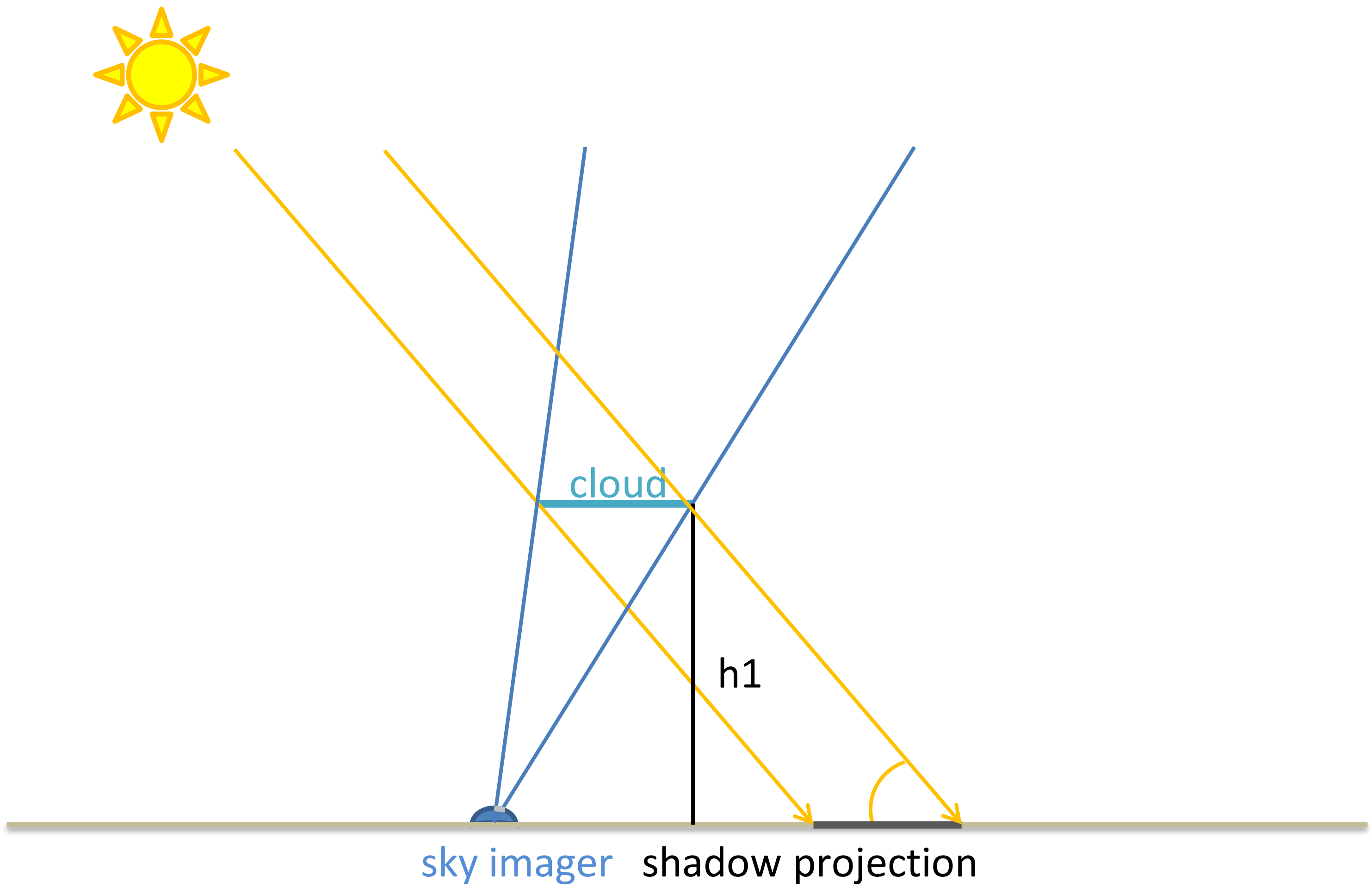

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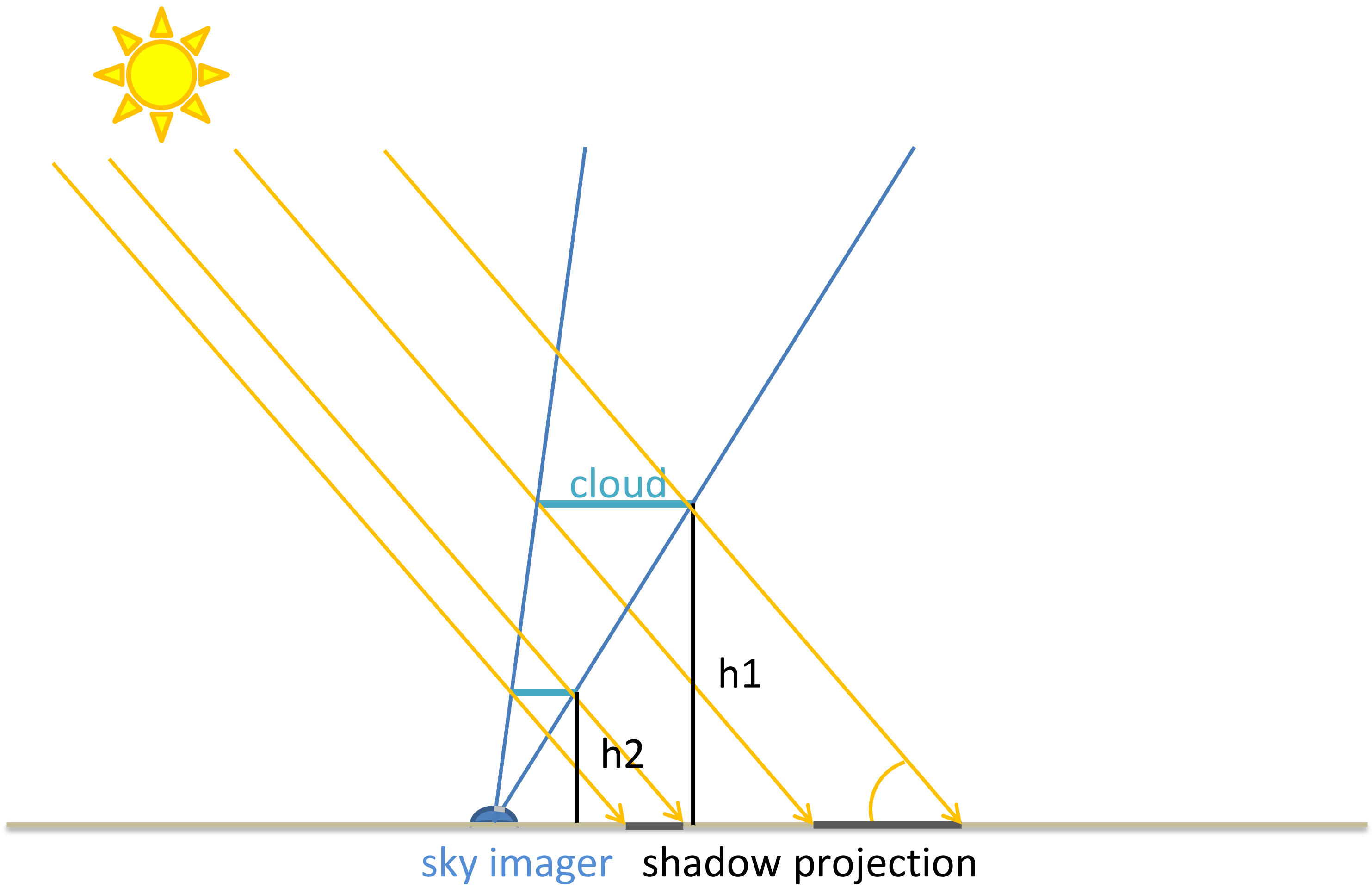

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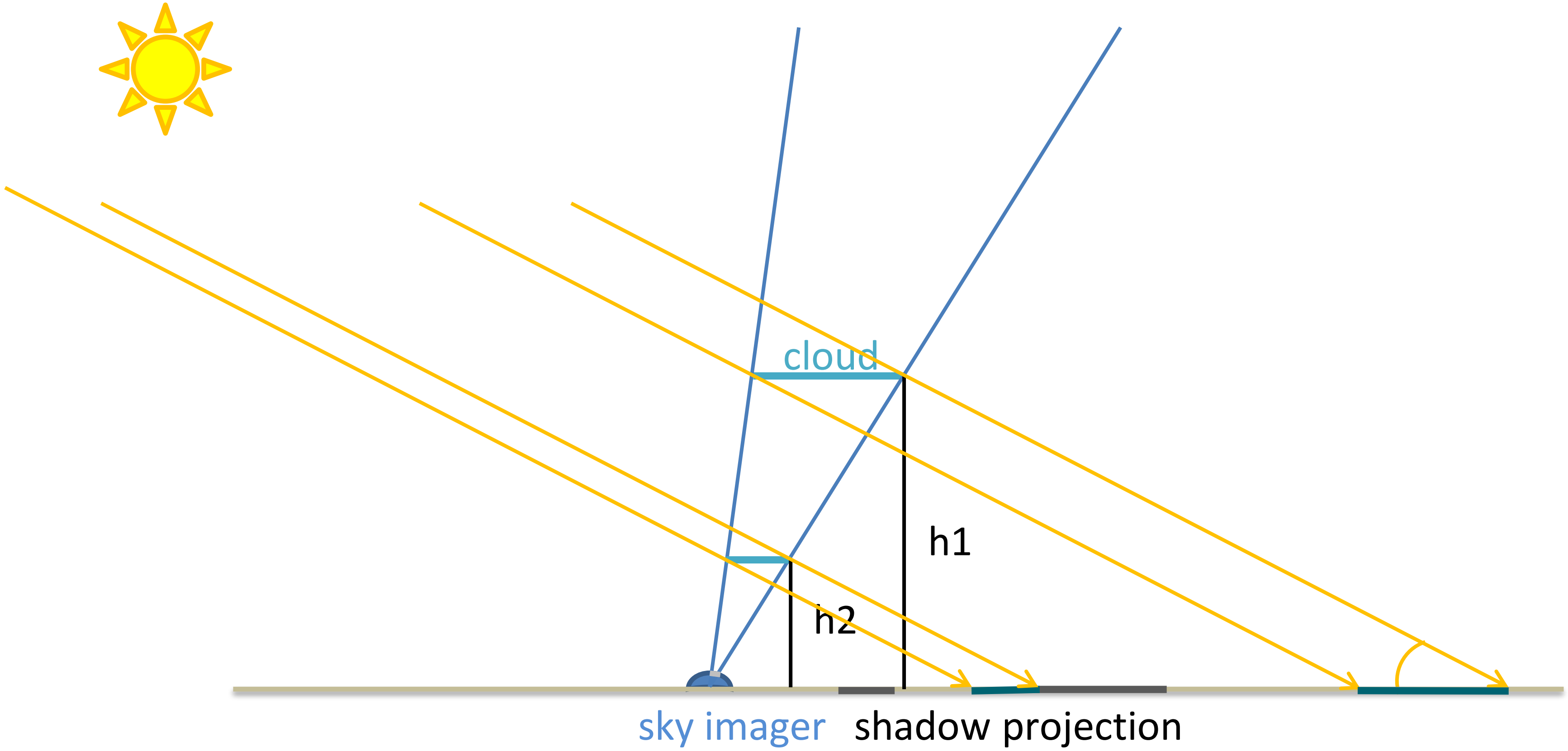
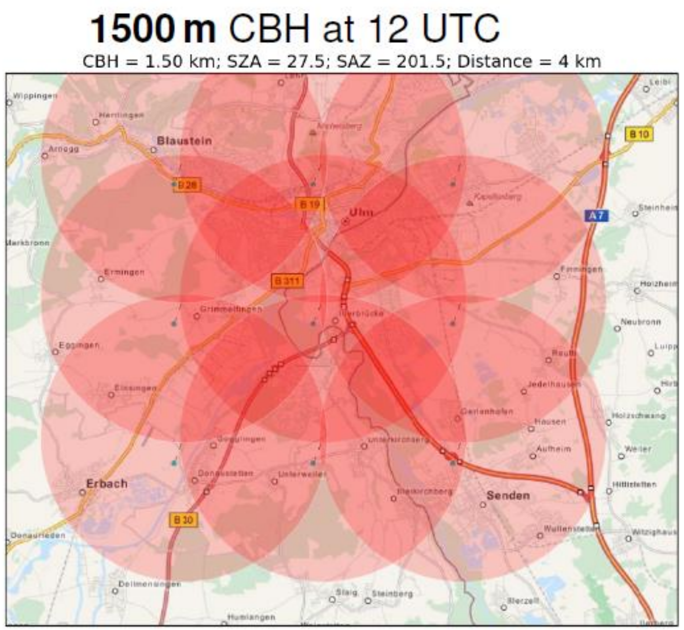
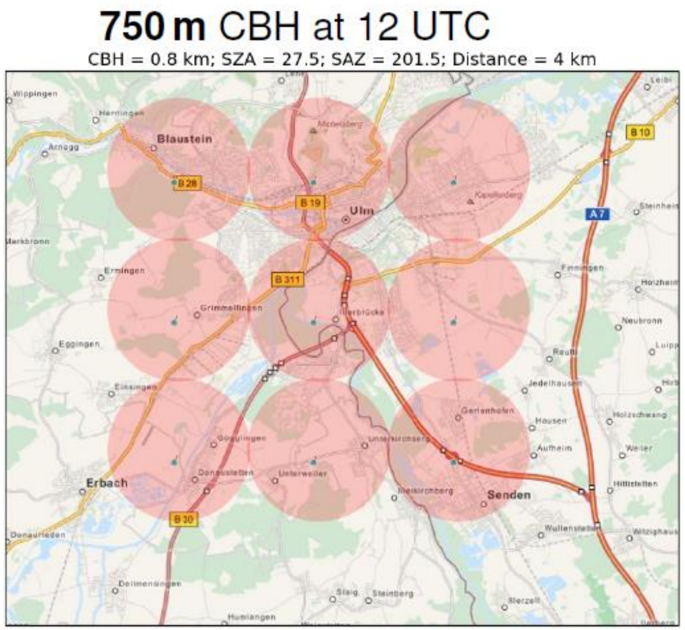


# Shadow projection

## Simulation

Dependence of cloud height



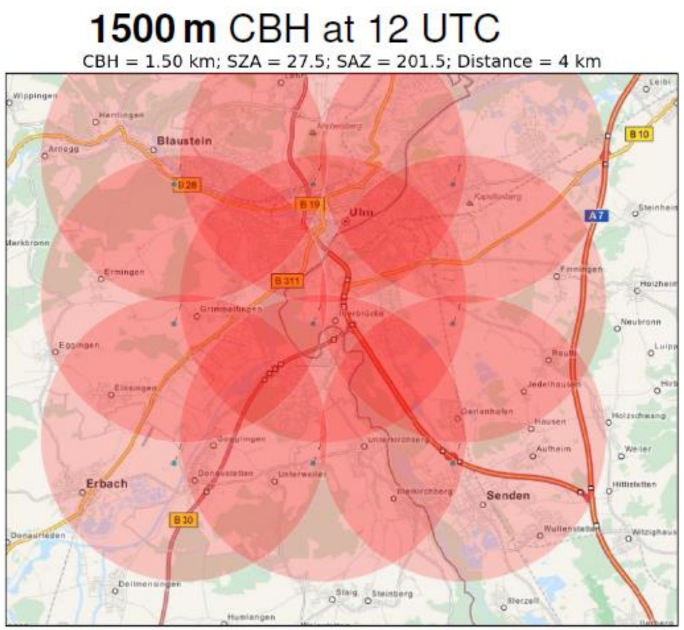



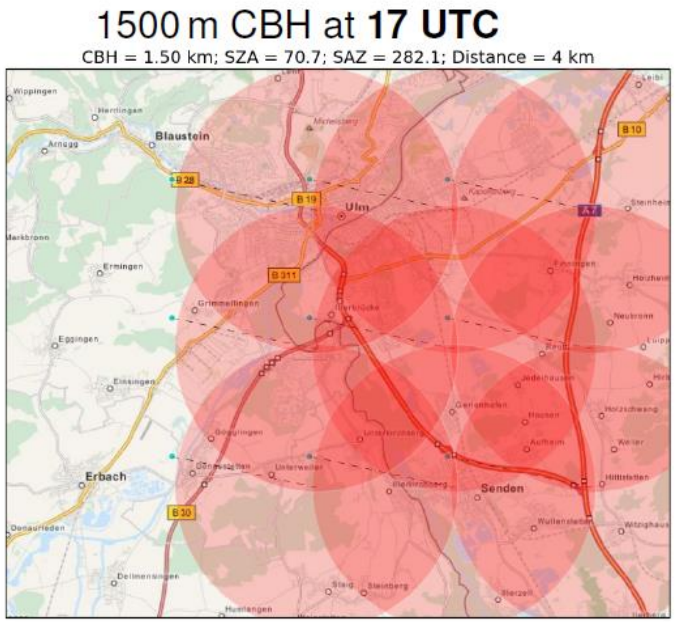

T.Schmidt: Potential and challenges of sky imager-based forecasting, 6th PV Performance Modelling and Monitoring Workshop, 24th October 2016

# Shadow projection

## Simulation

### Dependence of sun position



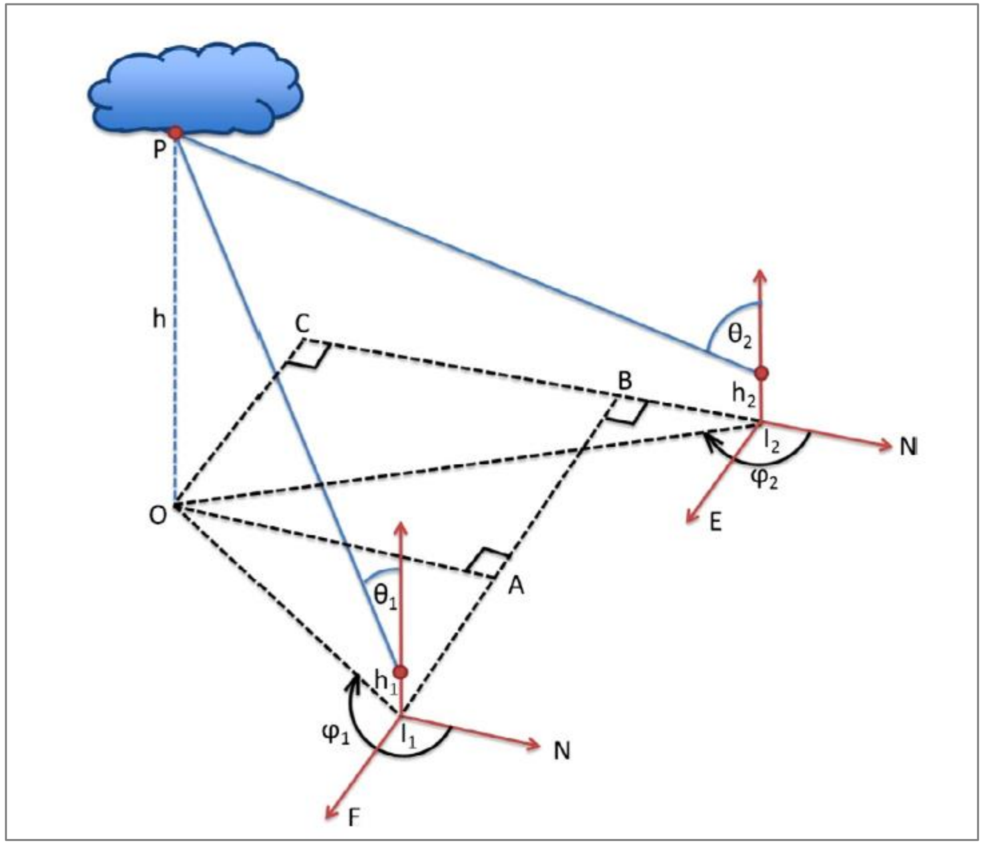




T.Schmidt: Potential and challenges of sky imager-based forecasting, 6th PV Performance Modelling and Monitoring Workshop, 24th October 2016

→ **Shadow projection**: Coverage depends strongly on CBH and sun position
→ **Forecasts:** Coverage depends additionally on the direction and velocity of cloud motion!

# How to obtain information on cloud height?

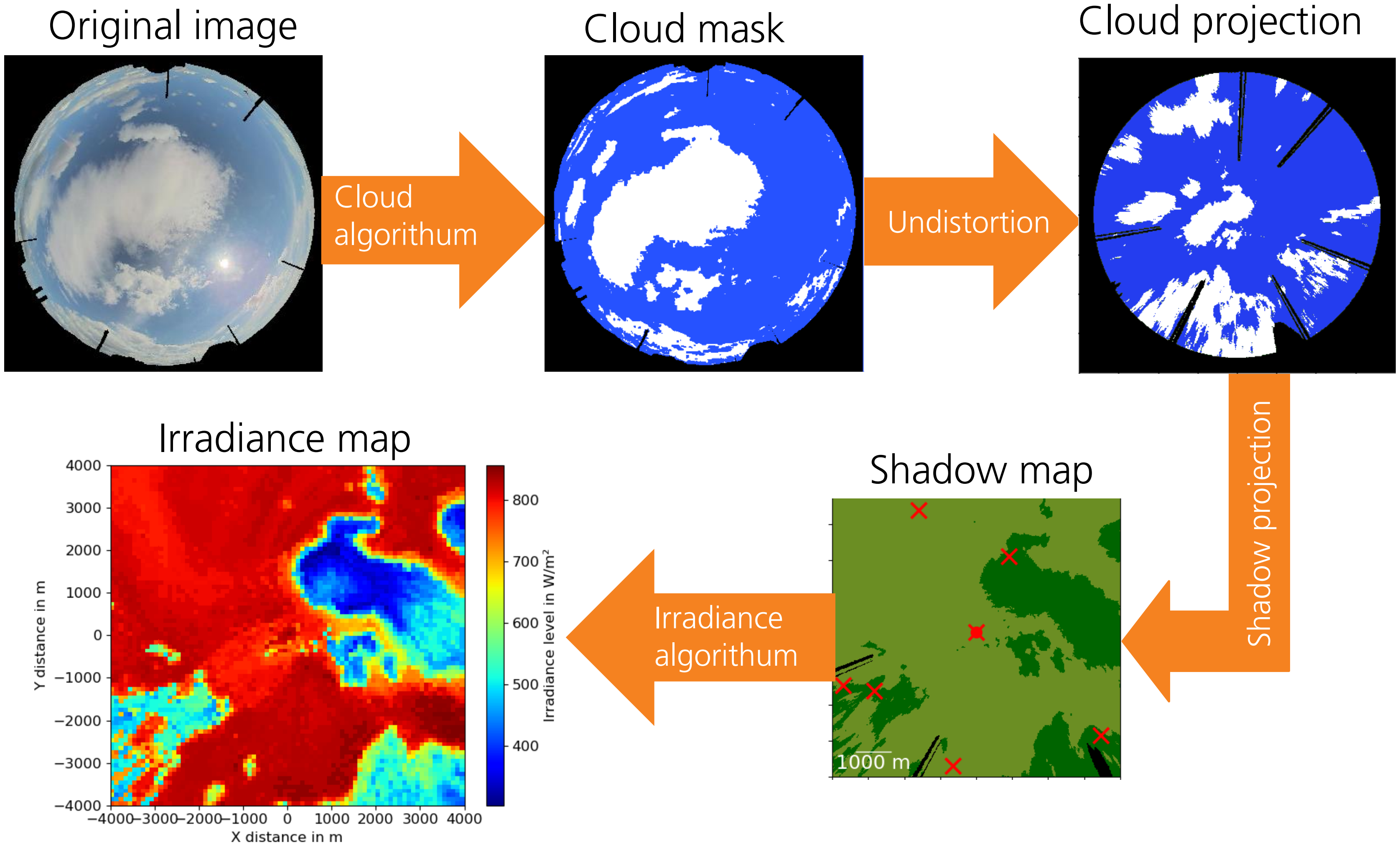
- Ceilometers
- Multiple Cameras - Stereo photography
- Satellite derived cloud height
- Cloud height from NWP models
- Cloud height by combining/matching information from different images/data sources:
  - Stereography from different sky imagers
  - Irradiance time series: ground measured/sky imager
  - cloud speed ground measured/sky imager/Satellite/NWP




Nguyen, D.; Kleissl, J. (2014): Stereographic methods for cloud base height determination using two sky imagers. In *Solar Energy* 107, pp. 495–509. DOI: 10.1016/j.solener.2014.05.005.

# ASI based irradiance retrieval

## At Fraunhofer ISE





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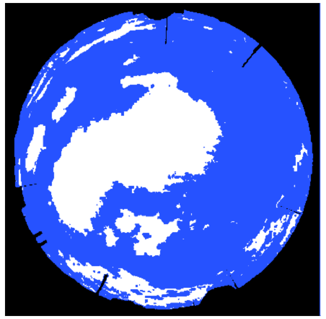
# Irradiance modelling

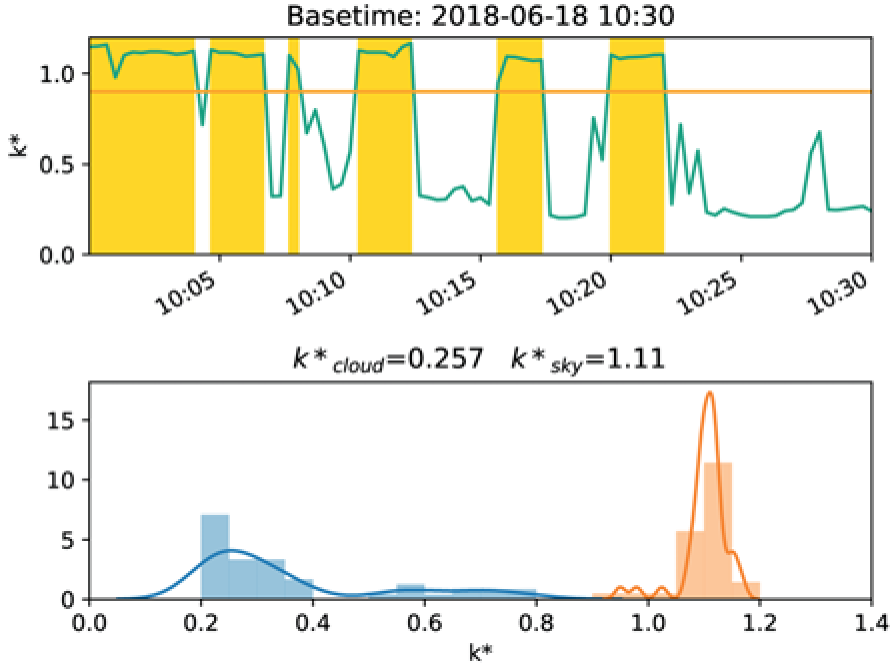
## Statistic approach

### Important metric Clear-sky Index

- Ratio between Global horizontal irradiance (GHI) and GHI at clear-sky conditions $GHI_{clear}$
  - $k^* = \frac{GHI}{GHI\_clear}$
    - $GHI_{clear}$ can be computed with high accuracy
    - Can be > 1 due to reflections on downsides of clouds

- Removes diurnal dependencies
  - Direct metric for impact of clouds





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# Irradiance modelling

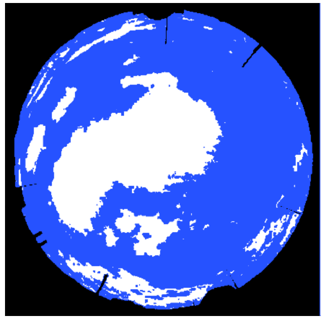
## Statistic approach

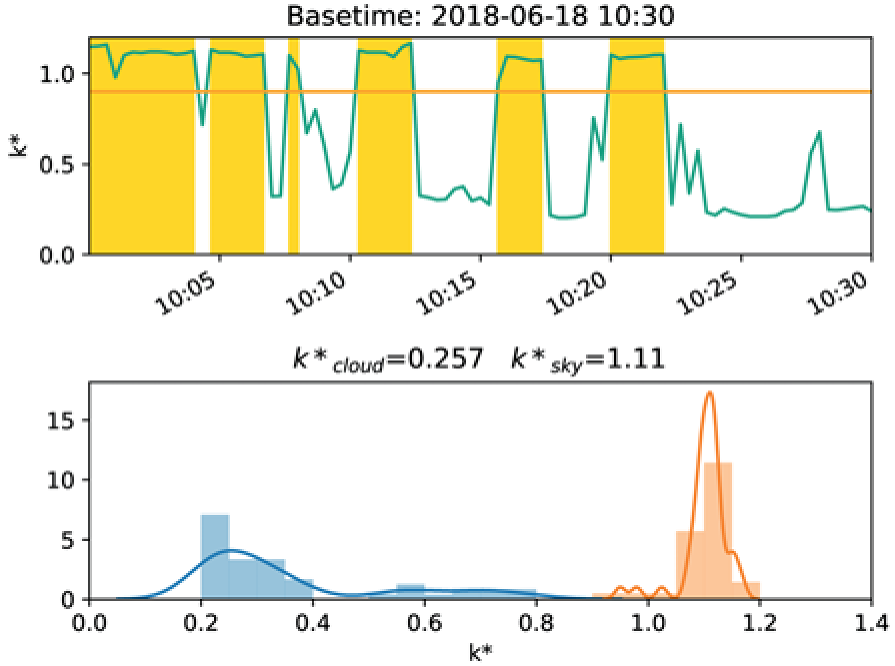
**Binary cloud mask:**
**shadow/no shadow**

↓

**Solar irradiance:**
**k* shadow, k* no shadow**

- Irradiance measurements  from last period
- Analysis of clear sky index



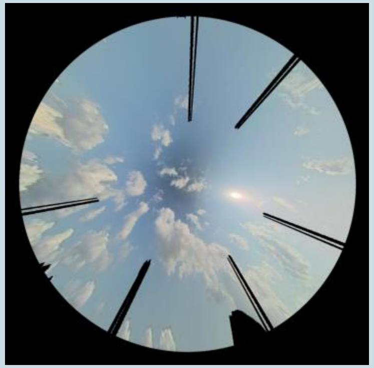


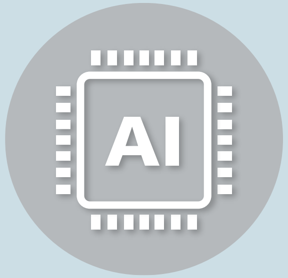
# Irradiance modelling

## Machine learning approach

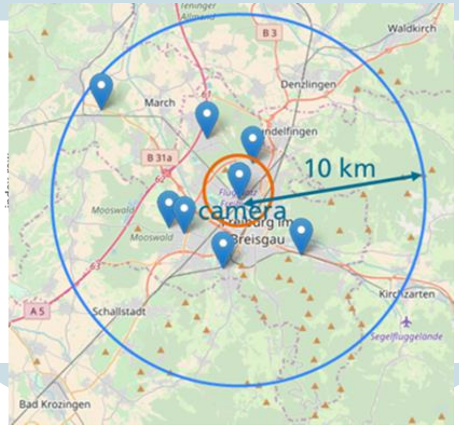
### Training

| Input | ML-Method | Target Value |
|---|---|---|






Gradient Boosting Regressor





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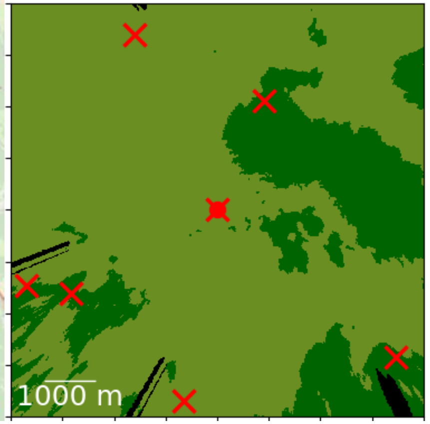
# Irradiance modelling

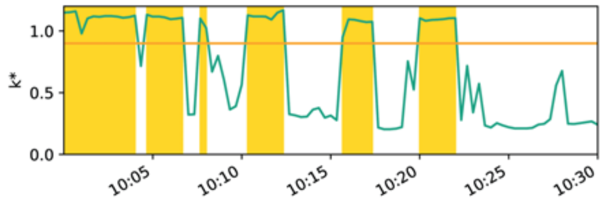
## Machine learning approach

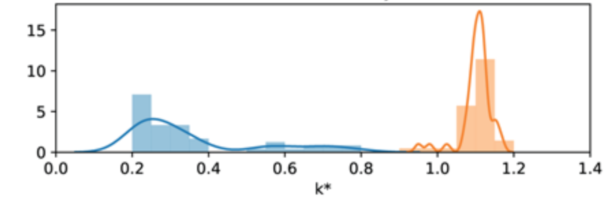
- **Local features**:

  Mapping of the image pixel position to the position of the measurement stations
  e.g. pixel values, cloud mask, also average around pixel position

- **Global features:**
  e.g. cloud cover, sun position, irradiance at the camera position

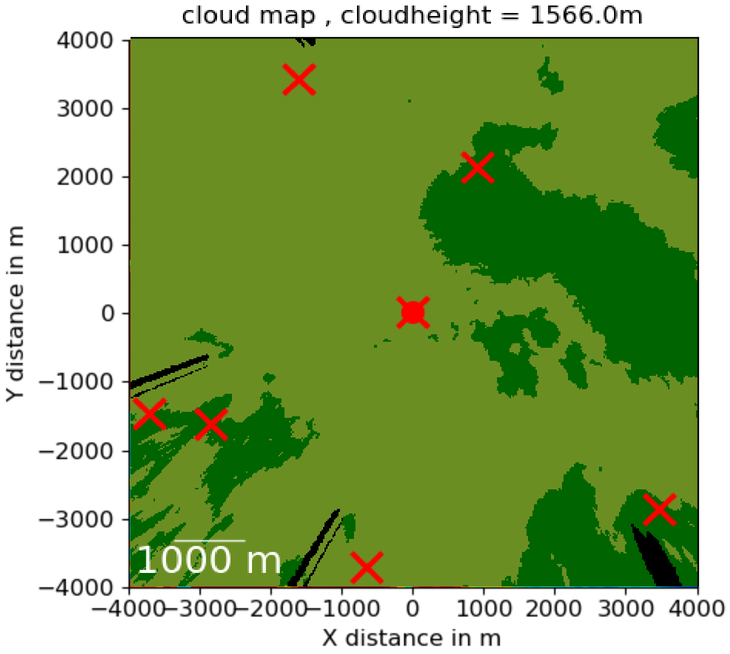



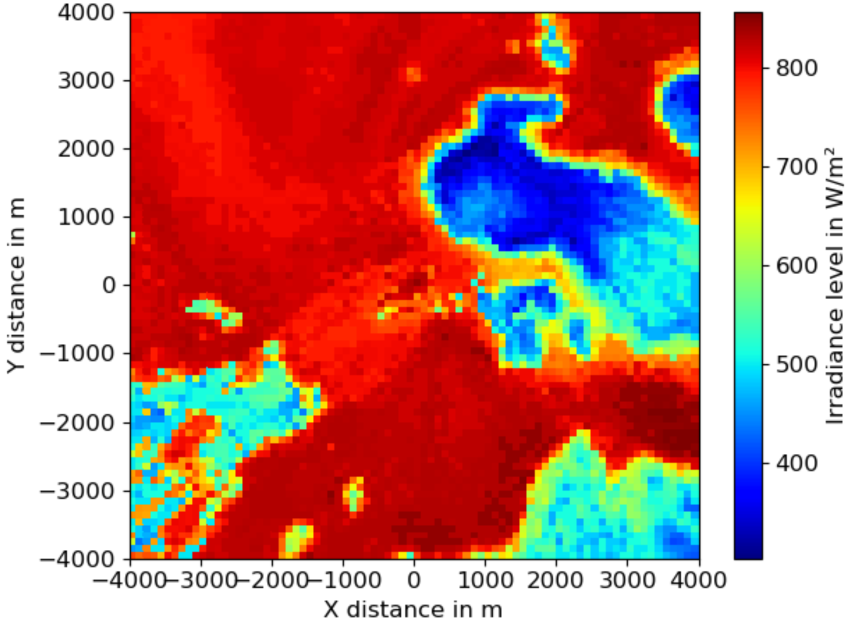



# Irradiance modelling

## Shadow map




## Irradiance map



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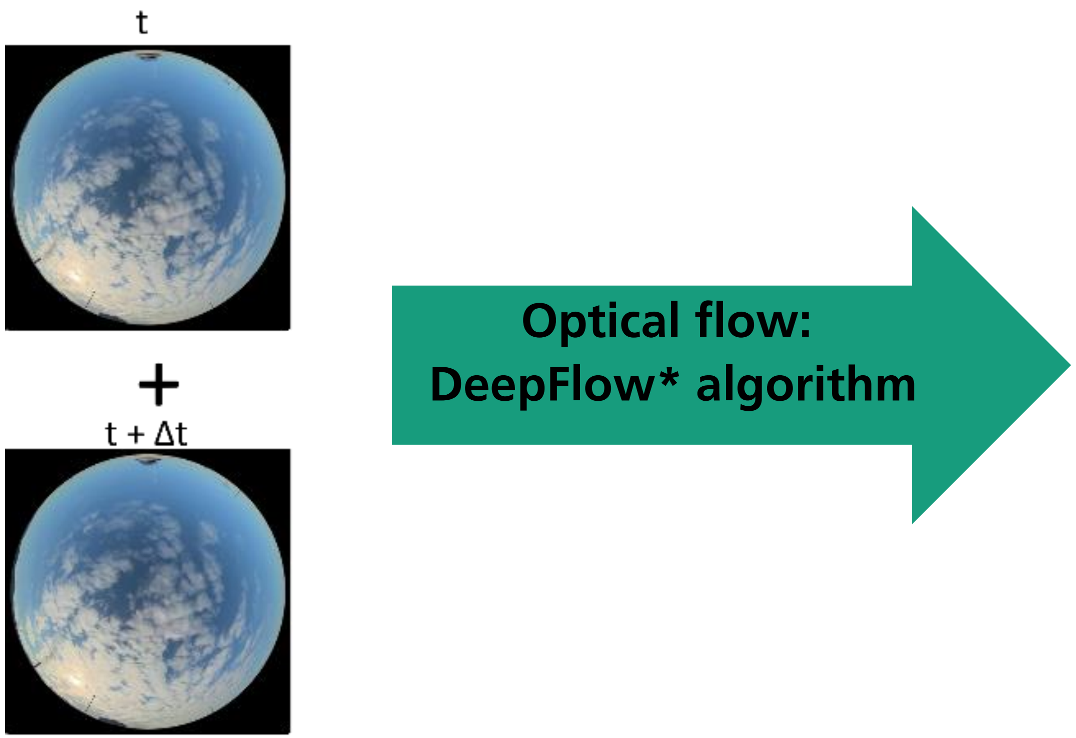
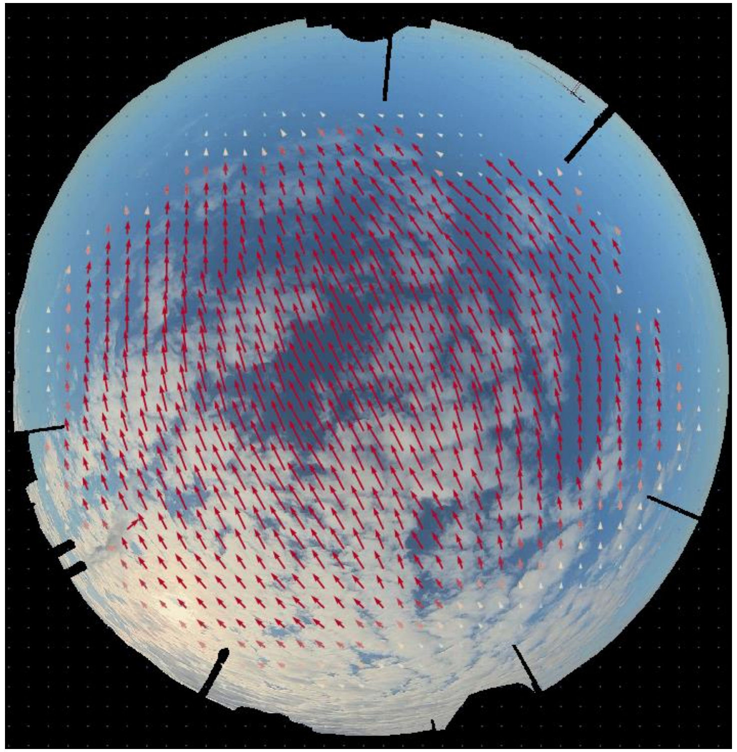
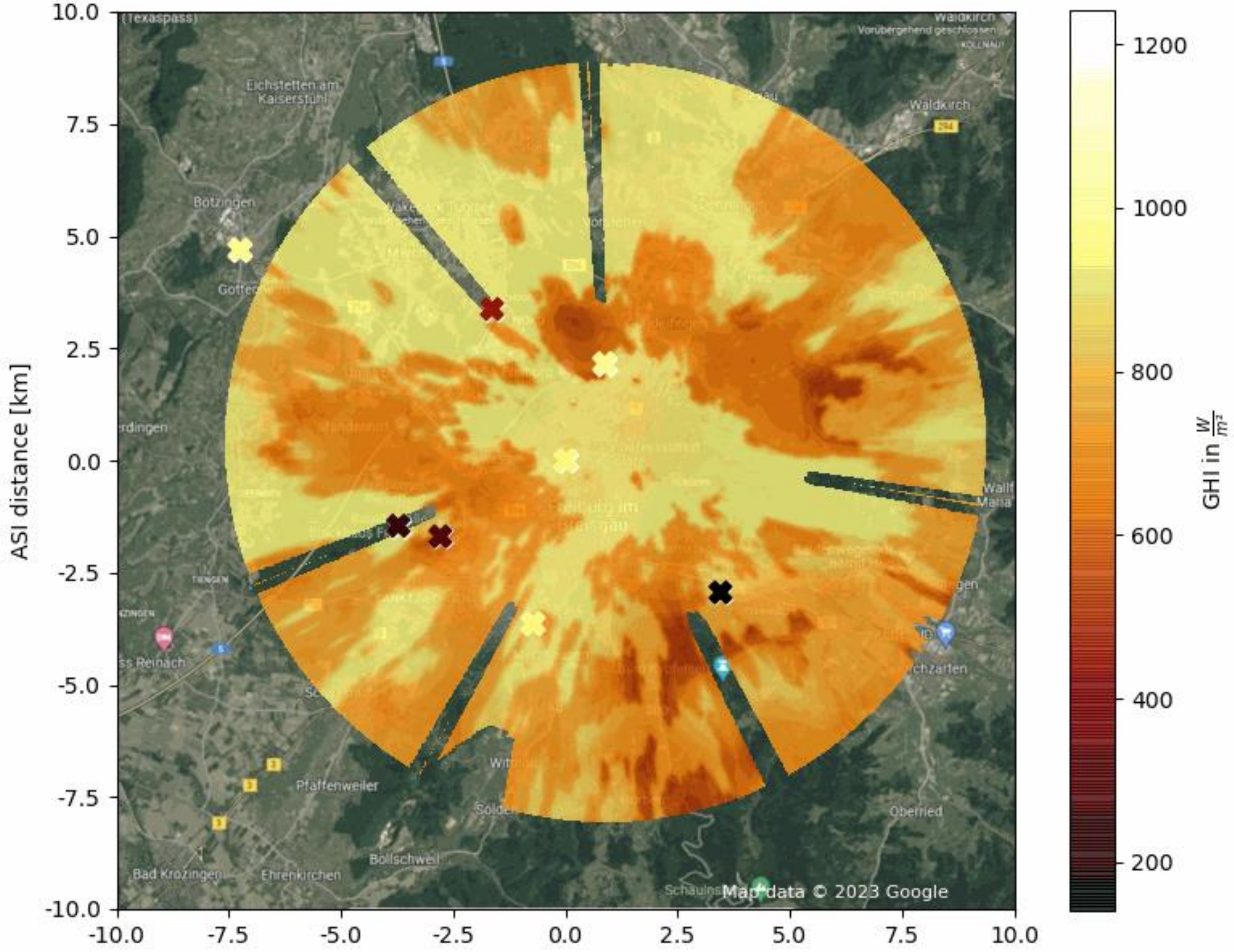
# Cloud motion



*Philippe Weinzaepfel, Jérôme Revaud, Zaid Harchaoui, Cordelia Schmid. DeepFlow: Large displacement optical flow with deep matching. ICCV - IEEE International Conference on Computer Vision, Dec 2013, Sydney, Australia. IEEE, pp.1385-1392, 2013

# Irradiance Forecast
## Visualization



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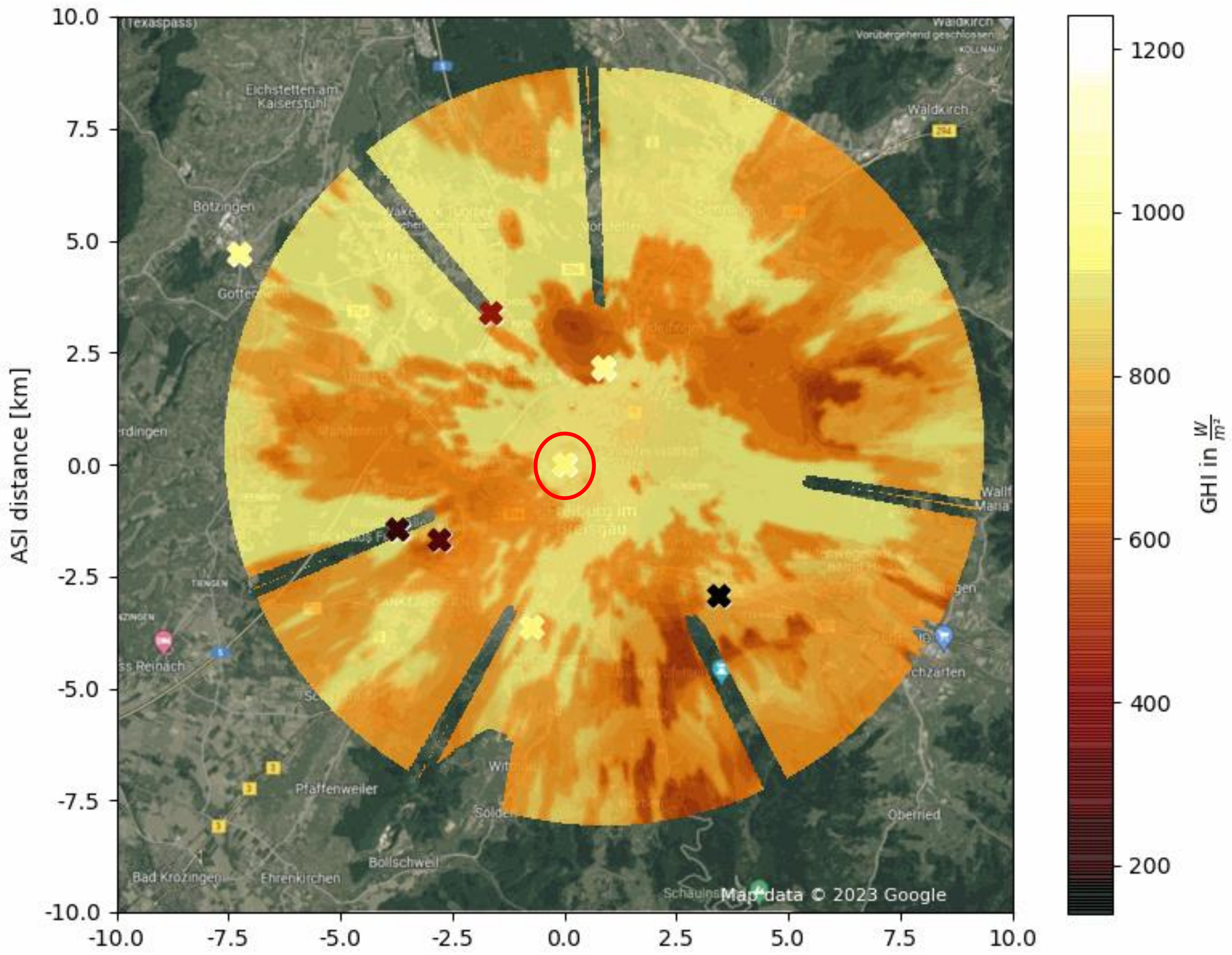
# Irradiance Forecast
## Visualization

### Forecasted irradiance field in Freiburg

- 15 minutes ahead
- ASI in the center (red circle)
- 8 measuring stations (crosses)
  - Color code: measured irradiance



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# Challenges and limits of ASI based forecasts

## Convection

- Clouds are no static objects; they form and dissolve and change their shape!
- Assumption that cloud motion persists is not true in many situations
- Forecast accuracy depends on the weather situation!

Solutions:

- Calculate uncertainty for specific situation
- Calculate divergence/convergence of cloud motion vectors



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# Challenges and limits of ASI based forecasts

## Cloud layers

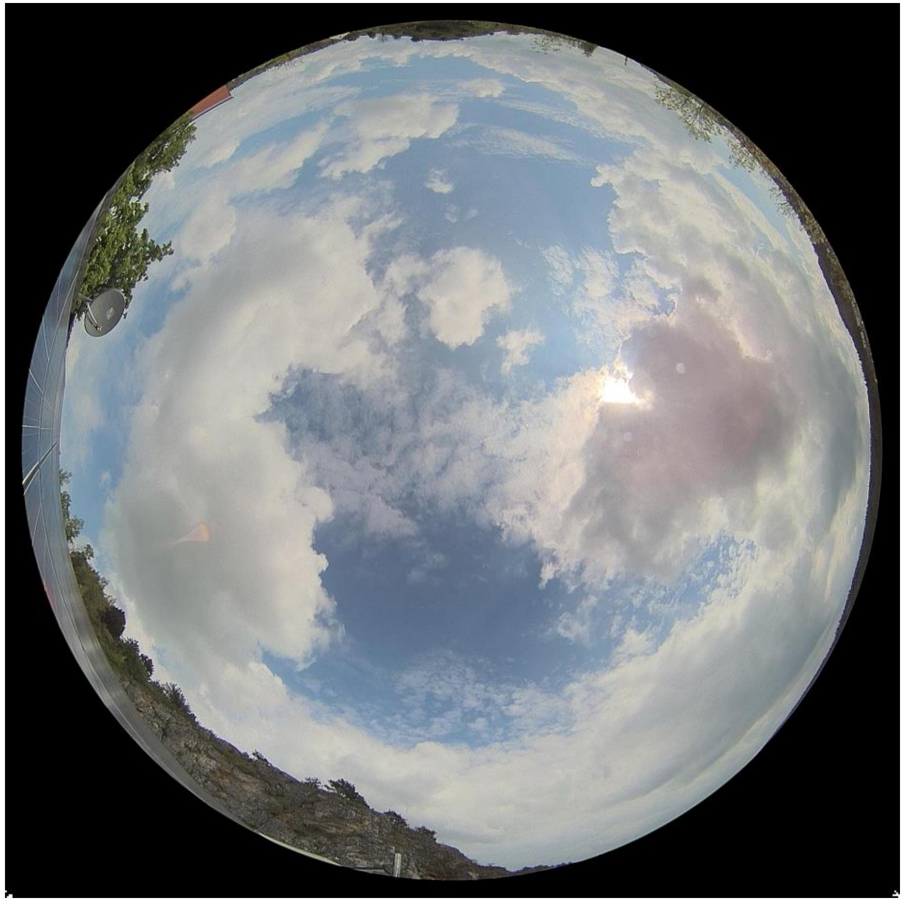
- More than one cloud layer can be present

- Cloud layers have different height and different motion vectors!

Solutions:

- Calculate cloud height pixelwise
- Calculate 3D cloud objects

But: Higher hidden cloud layer can hardly be detected and forecasted





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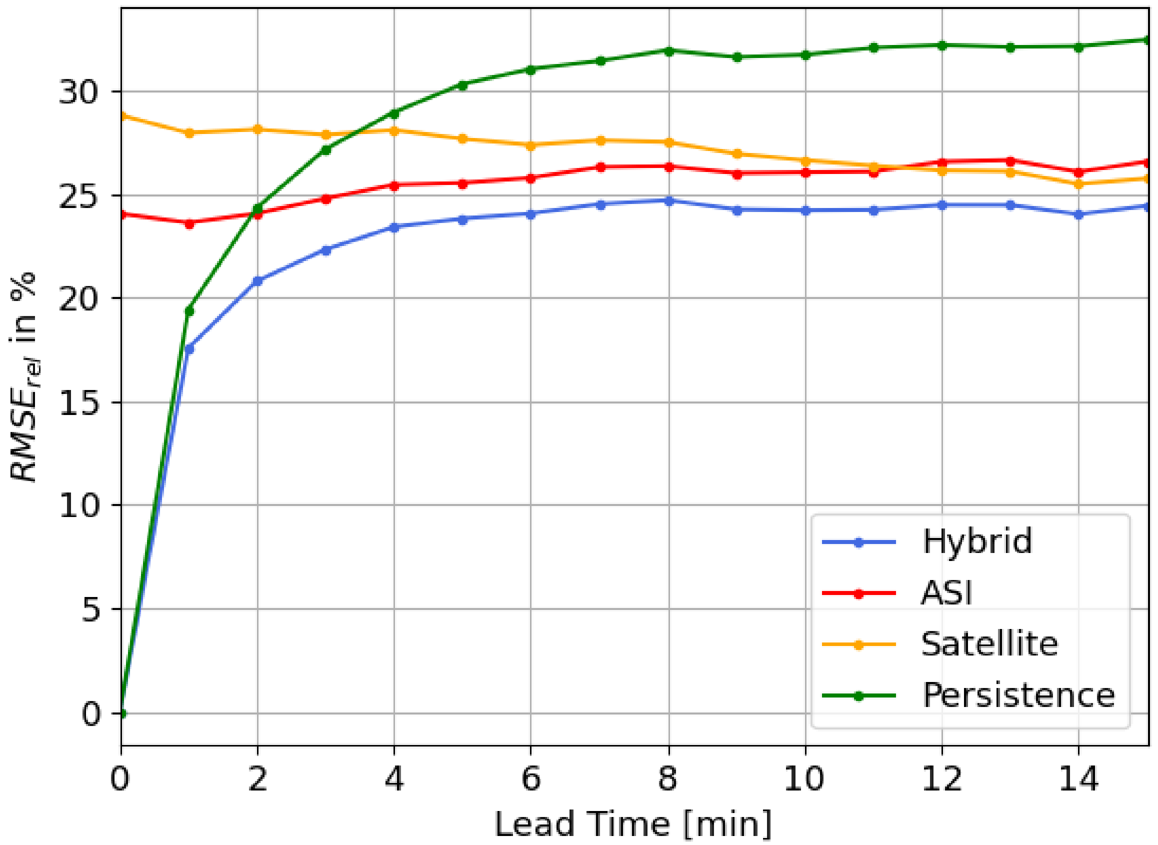
# Comparison of ASI and satellite-based forecasts

## Evaluations with the measurement network in Freiburg




**Dataset:**

- ~17000 forecast runs over the course of one year
- Evaluated at Freiburg network – 8 stations

$$RMSE = \sqrt{\frac{\sum_{i=0}^{N}(p_i - m_i)^2}{N}}$$

# Comparison of ASI and satellite-based forecasts

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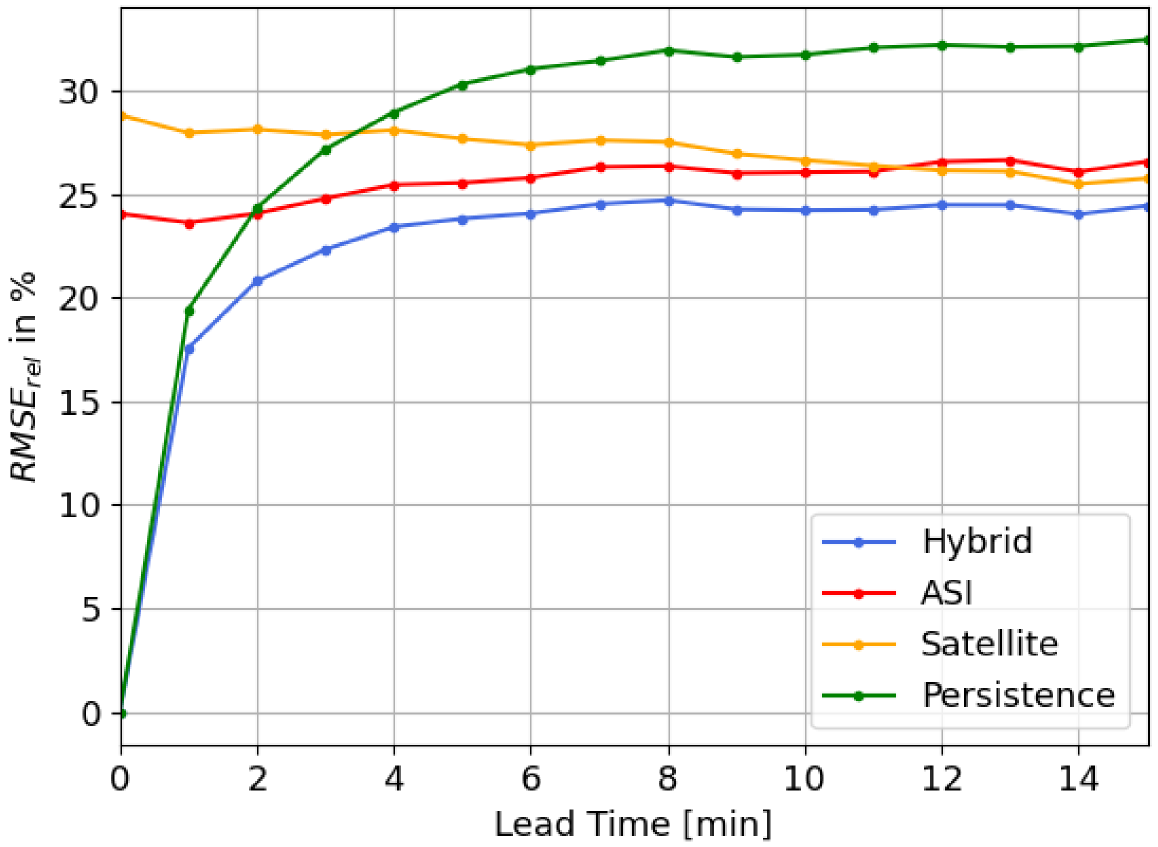


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$$RMSE = \sqrt{\frac{\sum_{i=0}^{N}(p_i - m_i)^2}{N}}$$

**Forecasting models:**

- ASI – Skyimager
- Satellite
- Persistence
  - Persistence of prevailing irradiance conditions
- Hybrid
  - Linear combination of three individual methods


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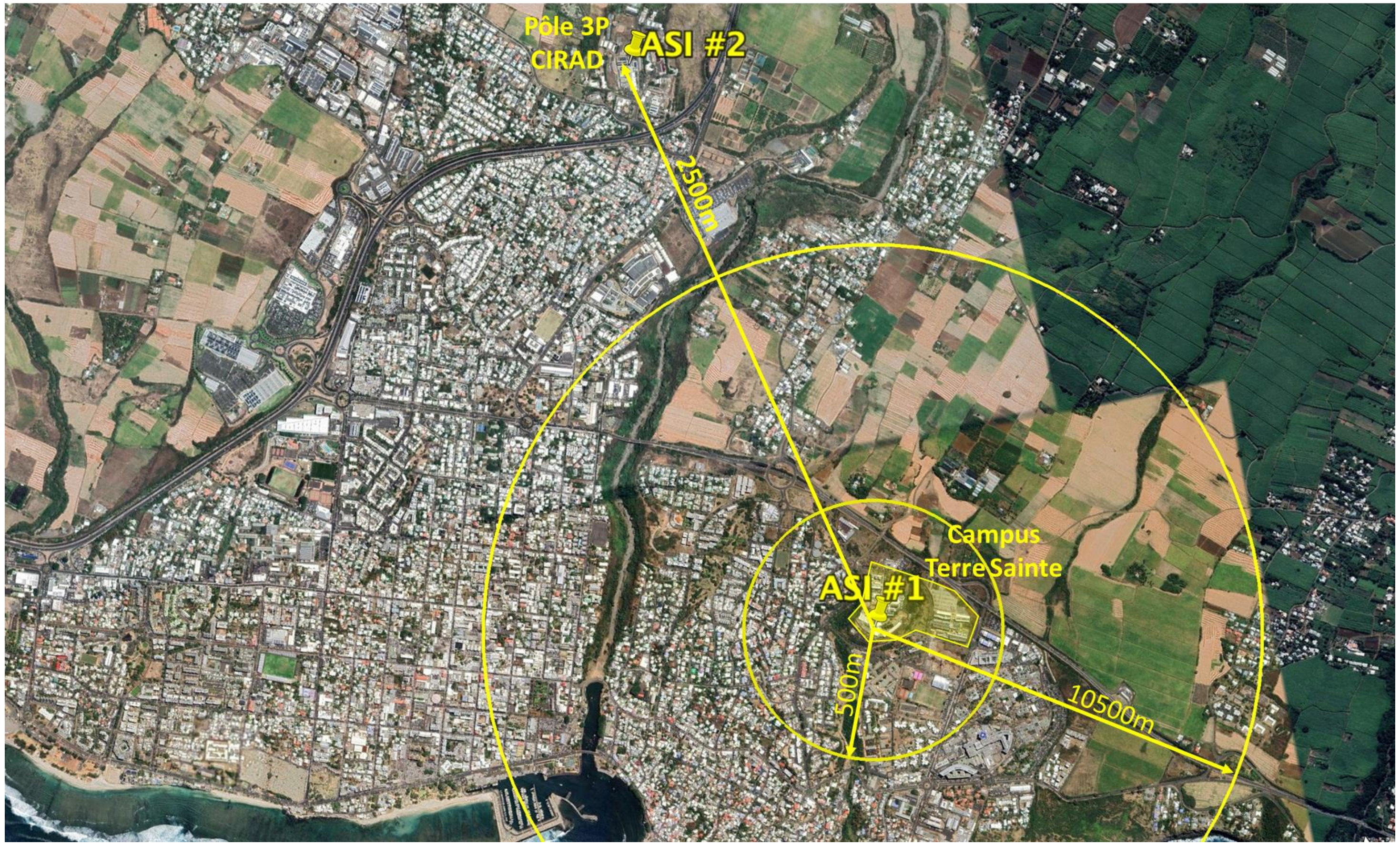
# Planned ASI measurement stations at La Reunion




# Contact

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