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Small-scale solar irradiance nowcasting with sky imager pictures

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University of Oldenburg

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PERFORMANCE PLUS

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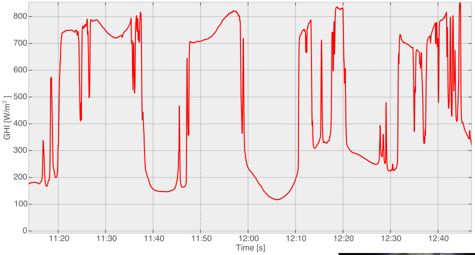
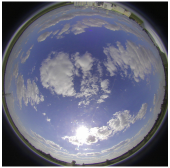
How can we use sky imagers to capture and predict high fluctuations in solar irradiance?



Picture: Martha Z



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Outline

- Methodology
- Experimental Setup
- Nowcast Results

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1. Methodology
2. Experimental Setup
2. Nowcast Results

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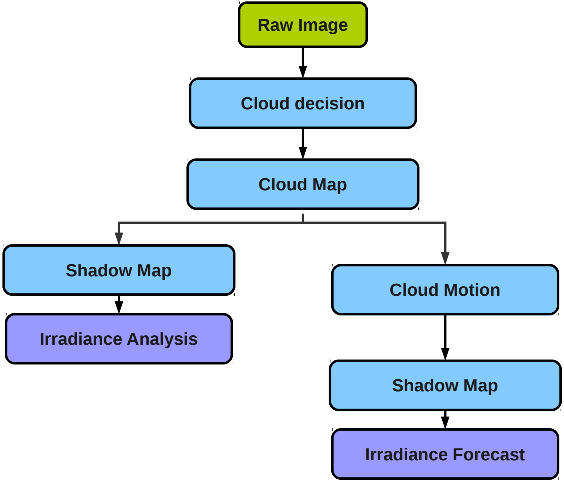
Processing Workflow



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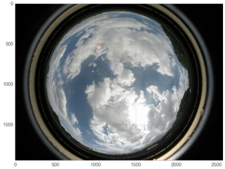
Cloud decision process

- The ratio of red and blue color (**R**ed-**B**lue-**R**atio) is used to separate cloud and sky
- Use clear sky library (CSL) for corrections
- Apply global threshold

Original Image



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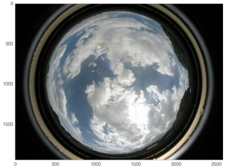
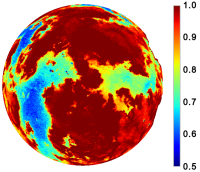


RBR



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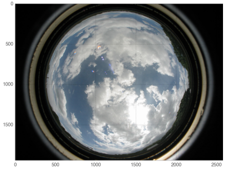

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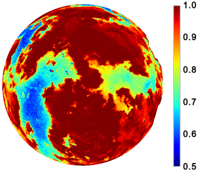
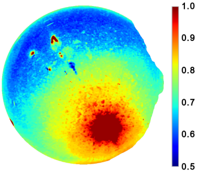


Clear Sky Reference



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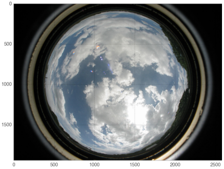

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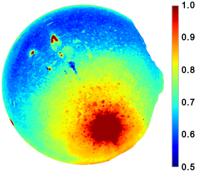

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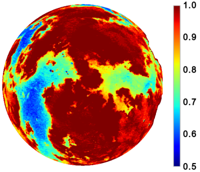
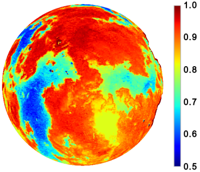


RBR corrected



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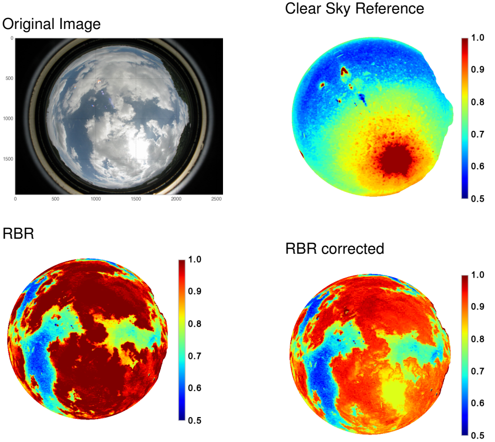

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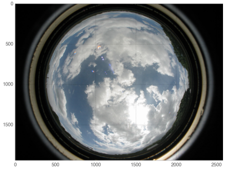
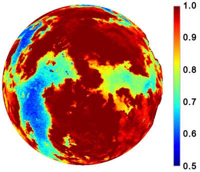
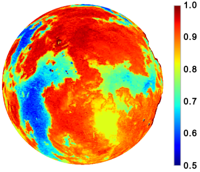


Cloud decision image

RBR



RBR corrected



Cloud and shadow map

For the transformation of the binary 2d cloud information to a cloud shadow field we need further information:

1. Cameras intrinsic and extrinsic parameters
2. Cloud base height
   (single layer assumption)
3. Sun position
   (zenith and azimuth angle)

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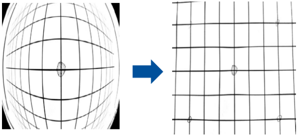

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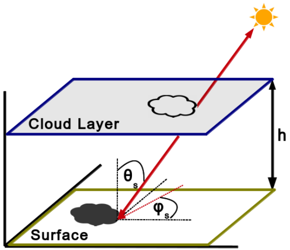

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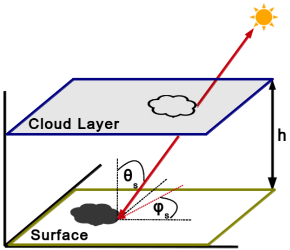

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Surface Irradiance Estimation

The surface irradiance field is derived by

1. Interpolating image pixels on regular grid
2. Smoothing values with a 3x3 cells gaussian filter
3. Transforming shadow/no shadow information to clear sky indizes
   $ClearSkyIndex = \frac{GHI_{Measurement}}{GHI_{ClearSky}}$

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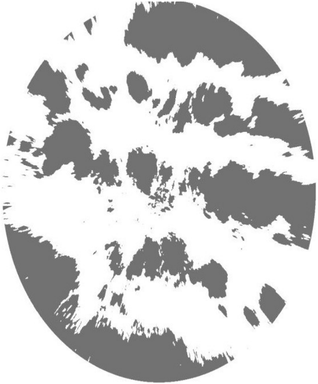

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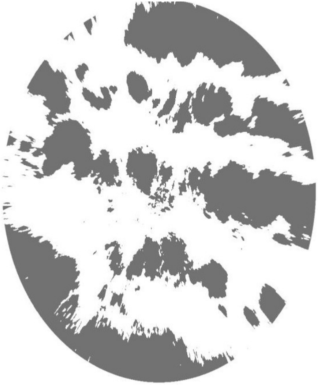

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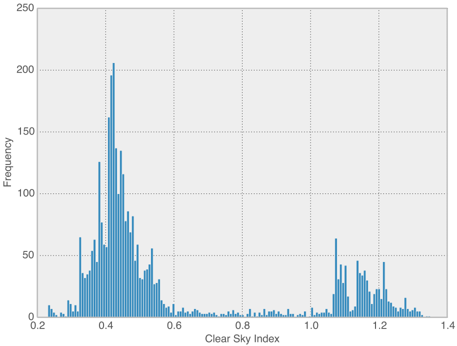

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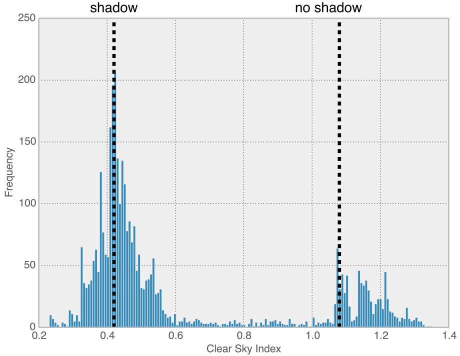

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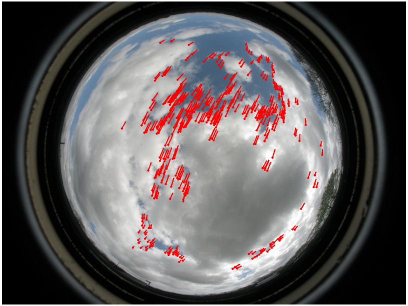
Cloud Motion

1. Optical flow algorithm for cloud tracking
   - Corner detection (Shi-Tomasi-Algorithm): Find good points to track
   - Optical flow (Lucas-Kanade-Algorithm): Find the points in the subsequent image
2. Apply quality check on all resulting vectors
3. Average all vectors to one global vector
4. The final vector is used for extrapolating the cloud field

2013-04-19 12:07:15 UTC



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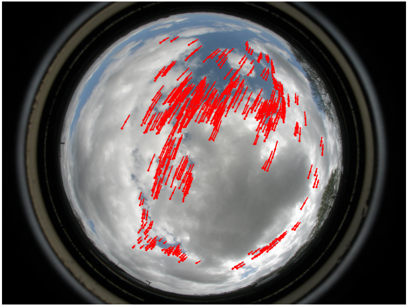

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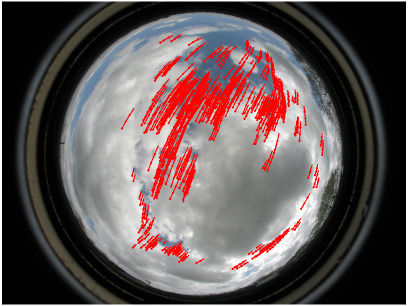

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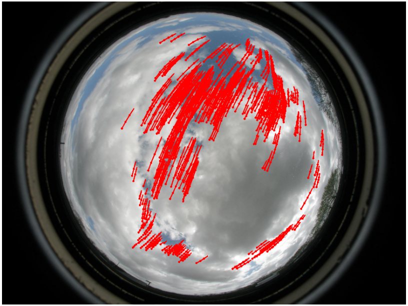
2013-04-19 12:08:00 UTC



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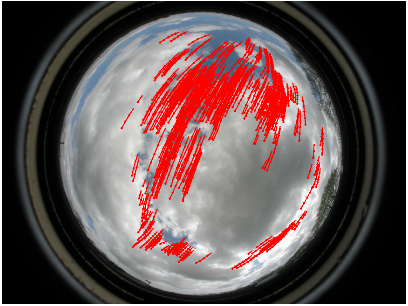

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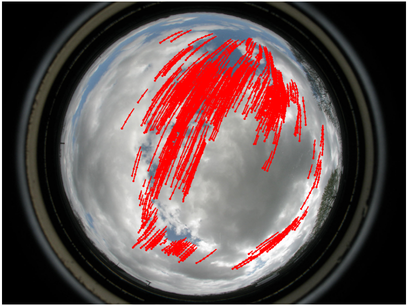
2013-04-19 12:08:30 UTC



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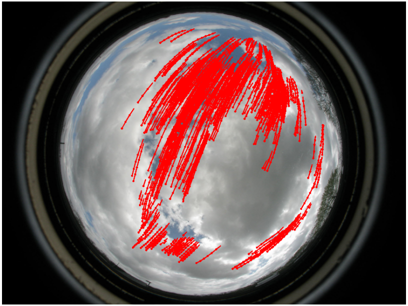

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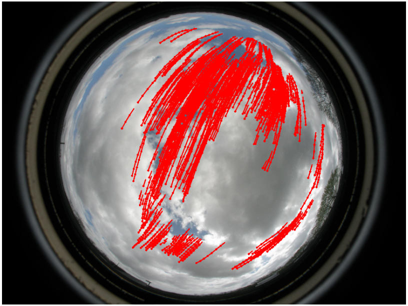

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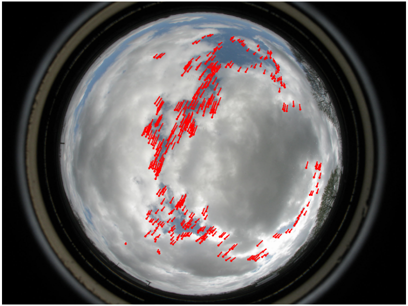

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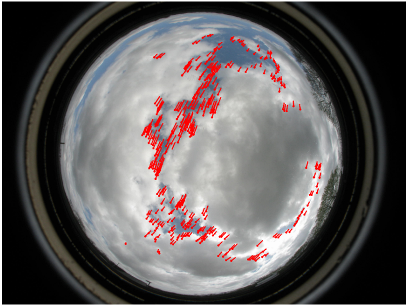

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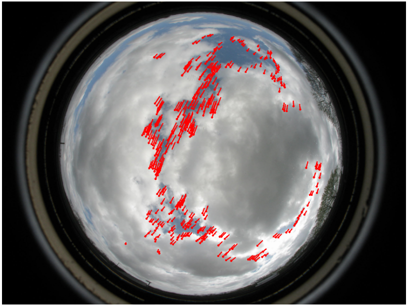

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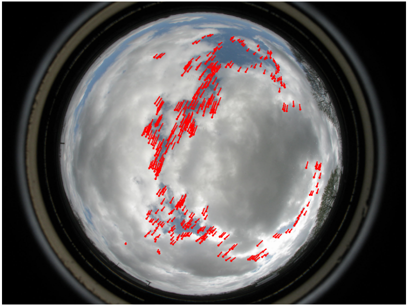

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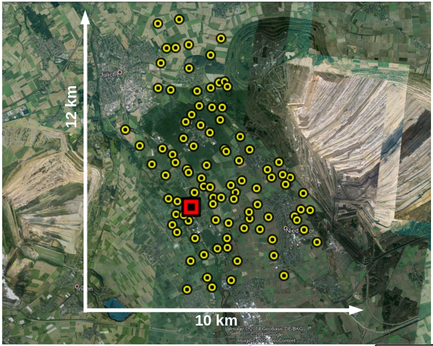
Database

Data originates from HOPE[1] campaign (April - July 2013, Juelich, Western Germany)

TROPOS Leibniz Institute for Tropospheric Research

Instruments:

- Canon G9 Camera with Fisheye lens (1844x1844 pixel, 15s resolution)
- 99 x EKO ML20-VM Si-Photodiode Pyranometers (distributed over 10x12 km, 1s resolution)
- Ceilometer for cloud base height detection (located next to camera, 15s resolution)



Background Image: GoogleEarth

[1] **H**DCP[2] **O**bservation **P**rototype **E**xperiment (*Madhavan et al., 2014, submitted to AMT*)

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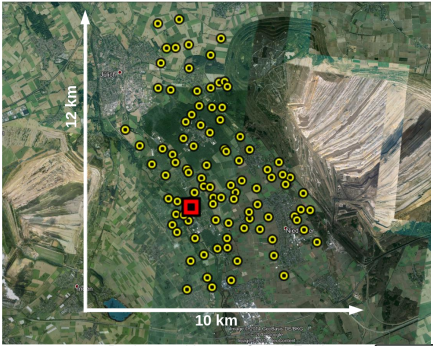
TROPOS
Leibniz Institute for Tropospheric Research

Forecast Setup:

- Forecast runs for 53 days, every 15 seconds and solar elevation > 10 degrees
- 25min (1500s) max. forecast horizon
- 1s temporal resolution
- timeseries for 99 stations
- grid size 20x20km
- grid resolution 20m



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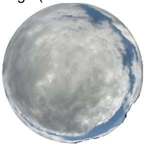
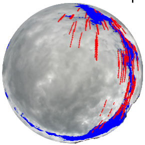
Example

2013-05-24 11:51:00 UTC

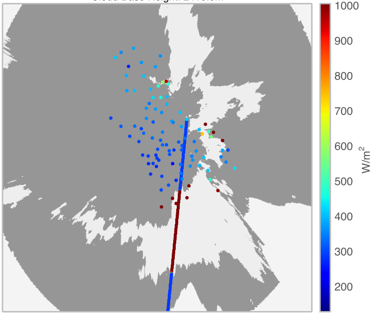
Raw Image (masked and rotated)



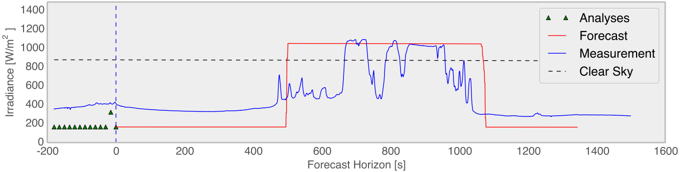
Cloud Decision Map



Cloud Base Height: 2410.0m



Station 45



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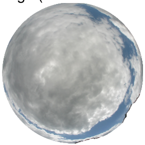
Example

2013-05-24 11:52:00 UTC

Raw Image (masked and rotated)



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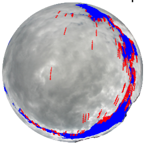

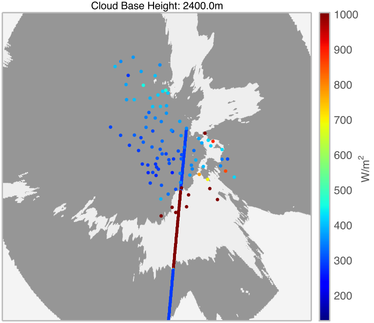

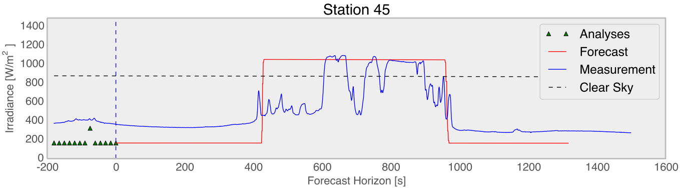

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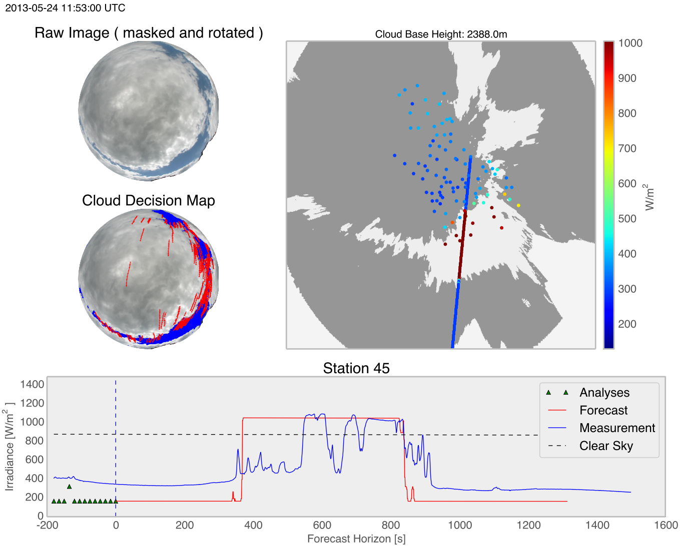
Example



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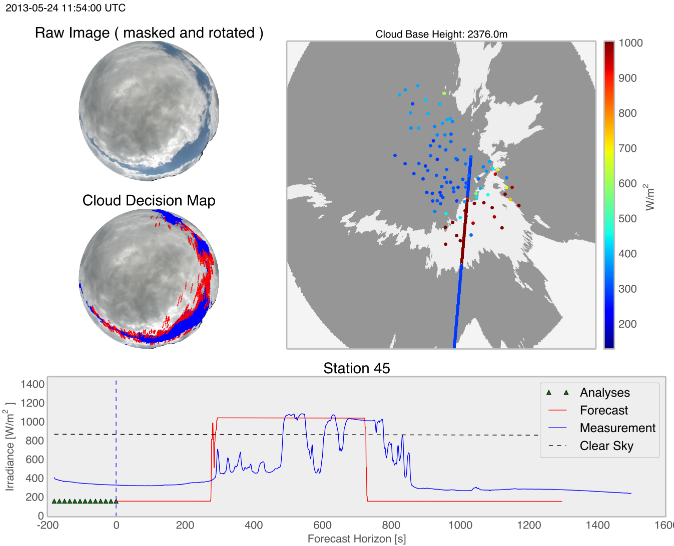
Example



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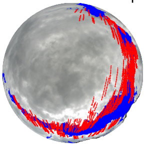
Example

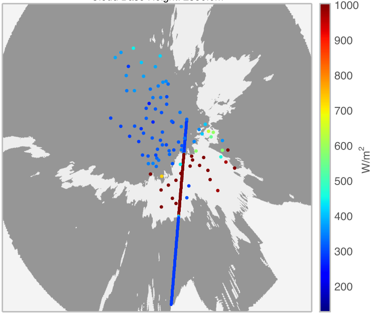
2013-05-24 11:55:00 UTC

Raw Image (masked and rotated)

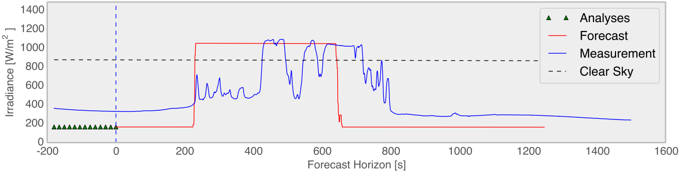
Cloud Decision Map



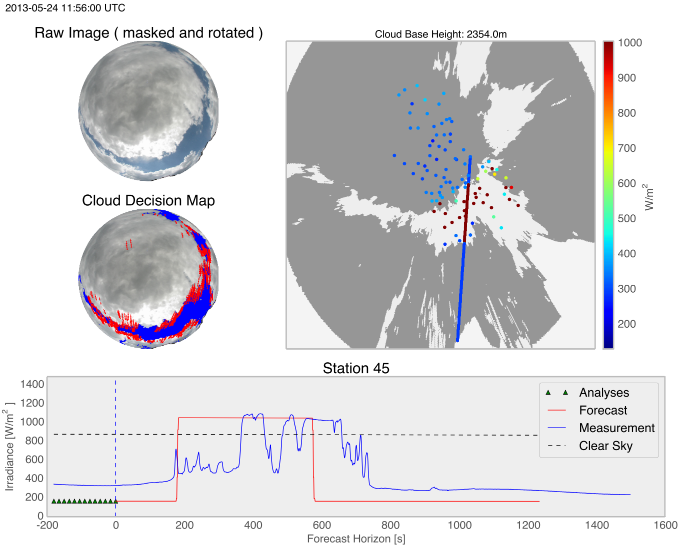
Cloud Base Height: 2356.0m



Station 45



Example


2013-05-24 11:56:00 UTC
Raw Image (masked and rotated)
Cloud Decision Map
Cloud Base Height: 2354.0m
1000
900
800
700
600
500
400
300
200
W/m2
Station 45
Irradiance [W/m2]
1400
1200
1000
800
600
400
200
0
-200
0
200
400
600
800
1000
1200
1400
1600
Forecast Horizon [s]
Analyses
Forecast
Measurement
Clear Sky

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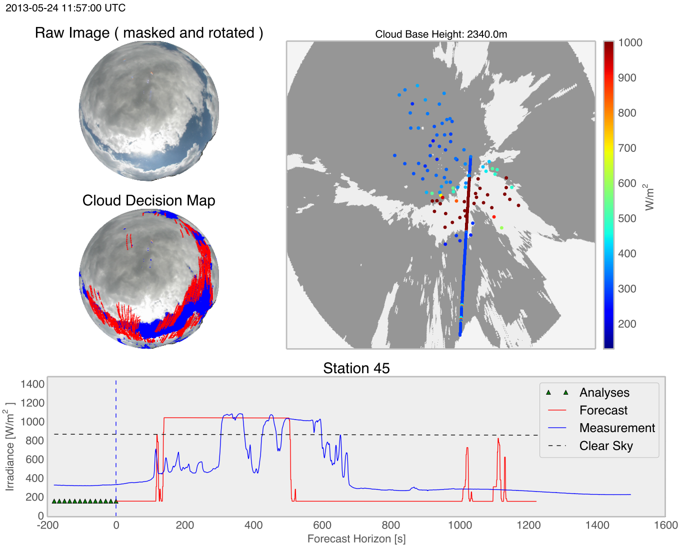
Example



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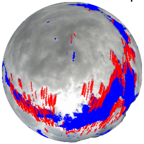
Example

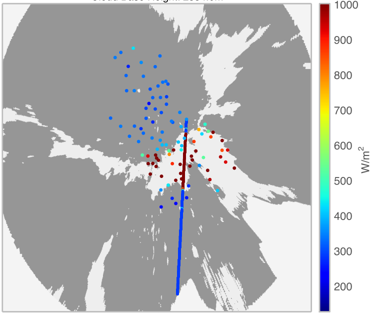
2013-05-24 11:58:00 UTC

Raw Image (masked and rotated)

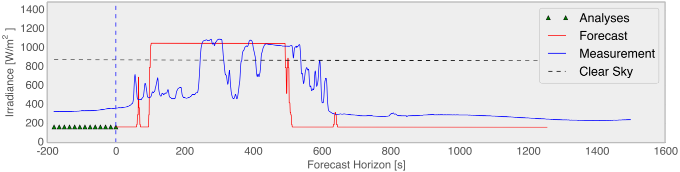
Cloud Decision Map



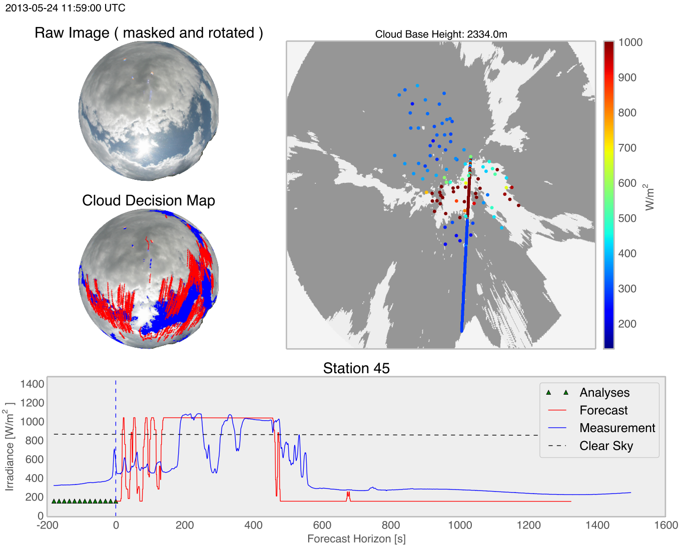
Cloud Base Height: 2334.0m



Station 45



Example


2013-05-24 11:59:00 UTC
Raw Image (masked and rotated)
Cloud Decision Map
Cloud Base Height: 2334.0m
1000
900
800
700
600
500
400
300
200
W/m^2
Station 45
Analyses
Forecast
Measurement
Clear Sky
Irradiance [W/m^2]
1400
1200
1000
800
600
400
200
0
-200
0
200
400
600
800
1000
1200
1400
1600
Forecast Horizon [s]

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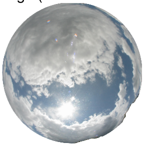
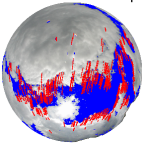
Example

2013-05-24 12:00:00 UTC

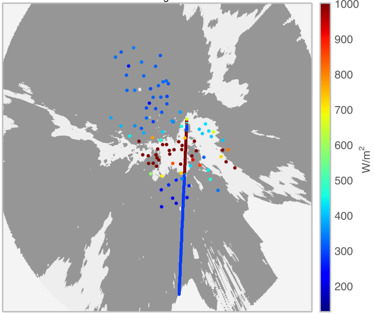
Raw Image (masked and rotated)



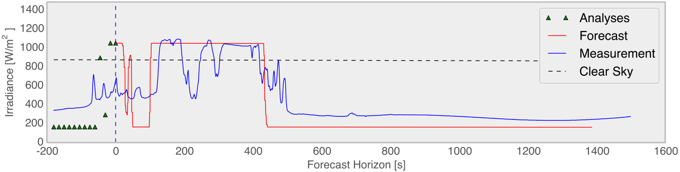
Cloud Decision Map



Cloud Base Height: 2334.0m



Station 45



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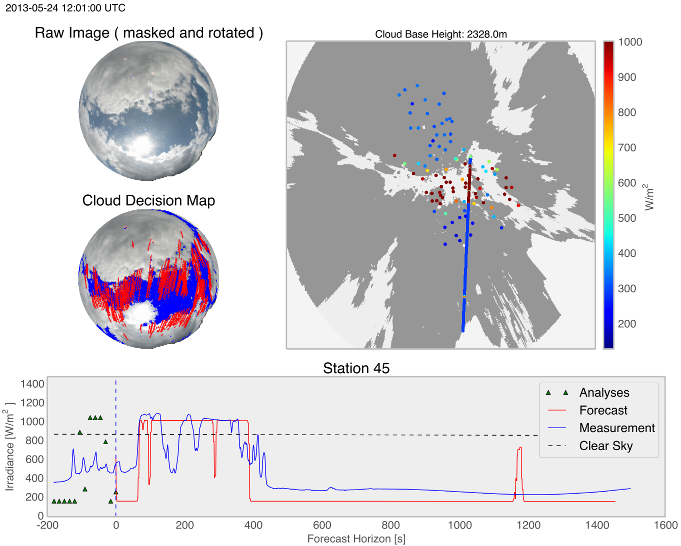
Example



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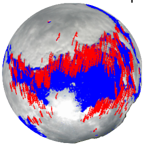
Example

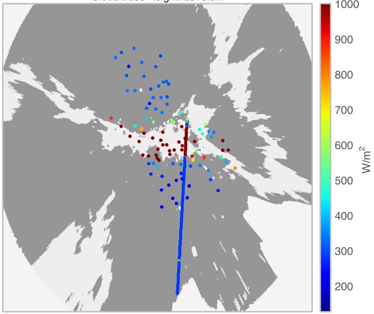
2013-05-24 12:02:00 UTC

Raw Image (masked and rotated)

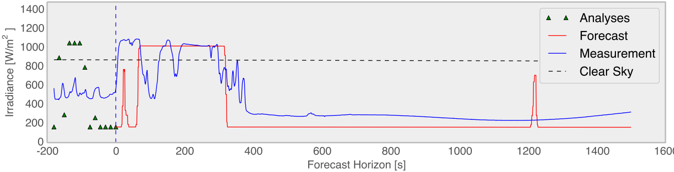
Cloud Decision Map



Cloud Base Height: 2316.0m



Station 45



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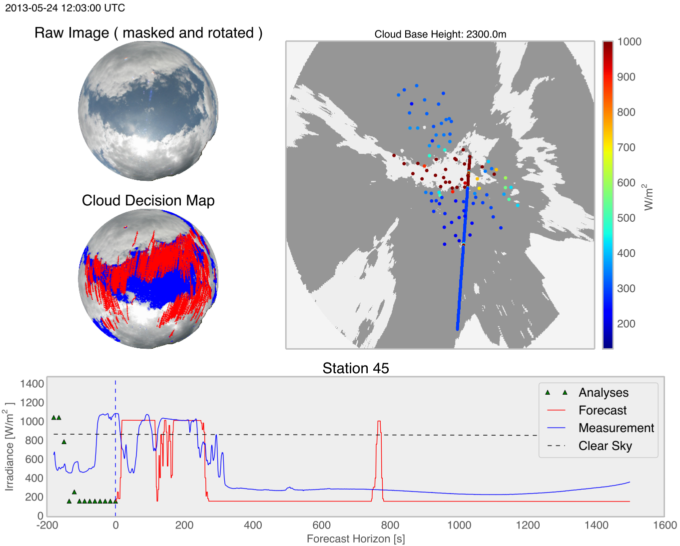
Example



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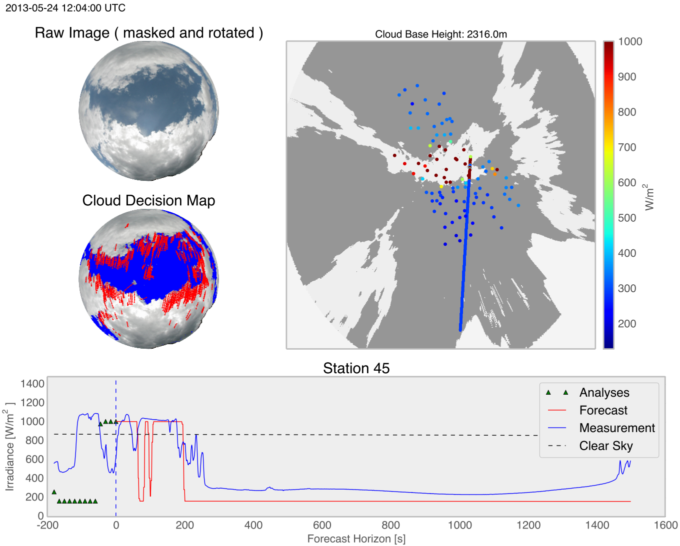
Example



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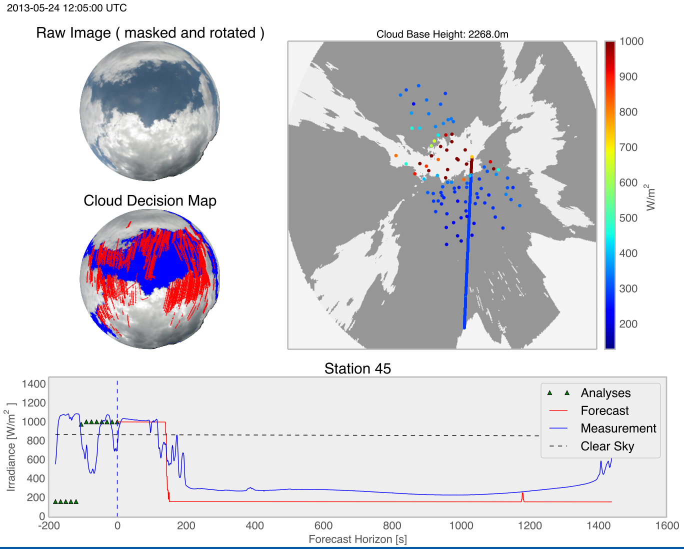
Example



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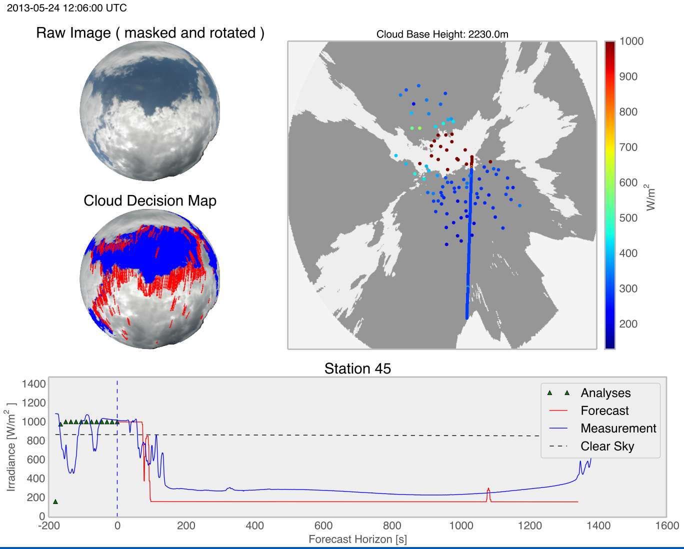
Example



Evaluation

Performance of sky imager forecasts is measured as forecast skill FS:

$$FS = 1 - \left(\frac{relRMSE_{Forecast}}{relRMSE_{Persistence}}\right)$$

FS > 0: Forecast outperforms Persistence

FS < 0: Forecast is worse than Persistence

- FS increases with forecast lead time
- on most of the days forecast performance is worse than persistence
- FS is > 0 on a couple of days

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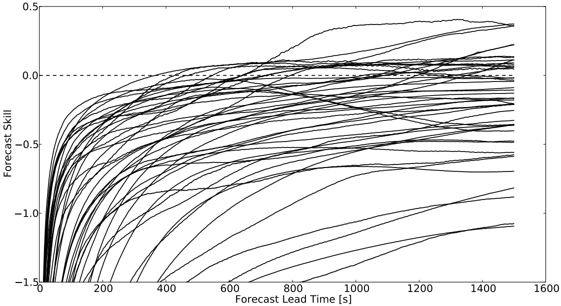

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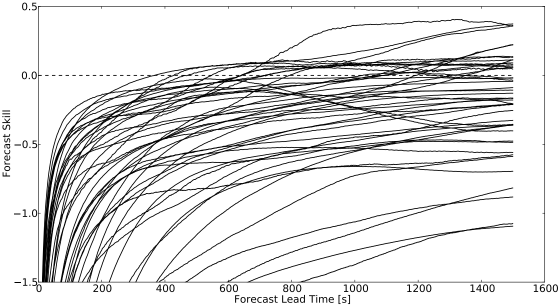

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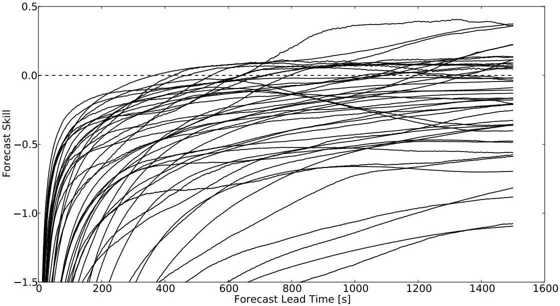

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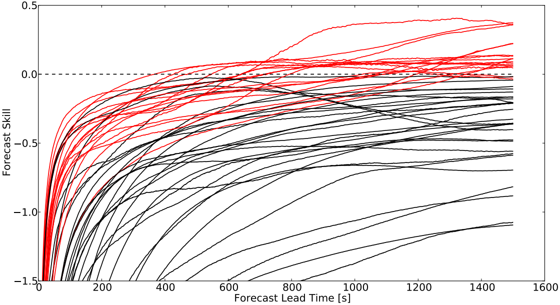

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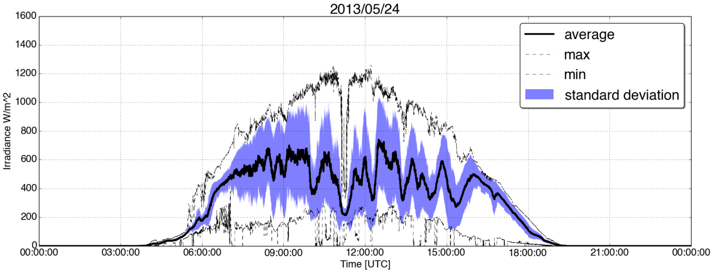
24th May 2013



- FS is much better on broken cloud days with high variability in solar irradiance
- FS is > 0 after approx. 6 minutes

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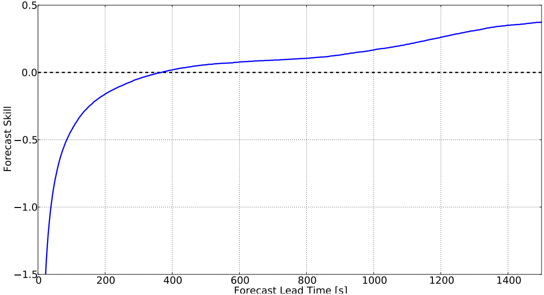
24th May 2013



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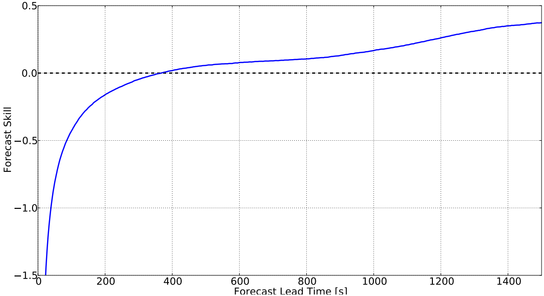
24th May 2013



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Summary and Outlook

Summary

- high-resolution shadow maps from sky imager pictures are able to reproduce surface irradiance measurement patterns
- positive forecast skill on broken cloud days with high irradiance fluctuations

Outlook

- Development: continuous scale (not only binary) irradiation estimation from images
- Analysis: focus on temporal-spatial performance of forecast experiment

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Thanks for your attention!