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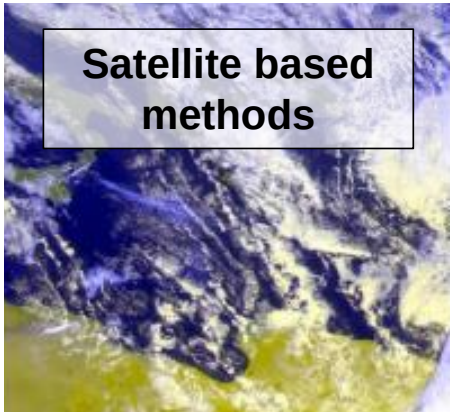
24 May 2016

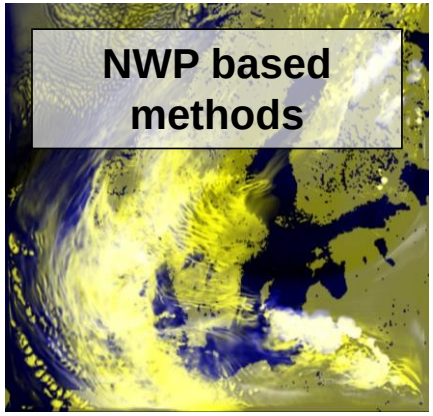
***DNICam**: Nowcasting of high resolution DNI maps with multiple fish-eye cameras in stereoscopic mode*

Methodology and Preliminary results

DNICast

- FP7 project: www.dnicast-project.net





+ validation

+ knowledge sharing & users

+ dissemination & communication

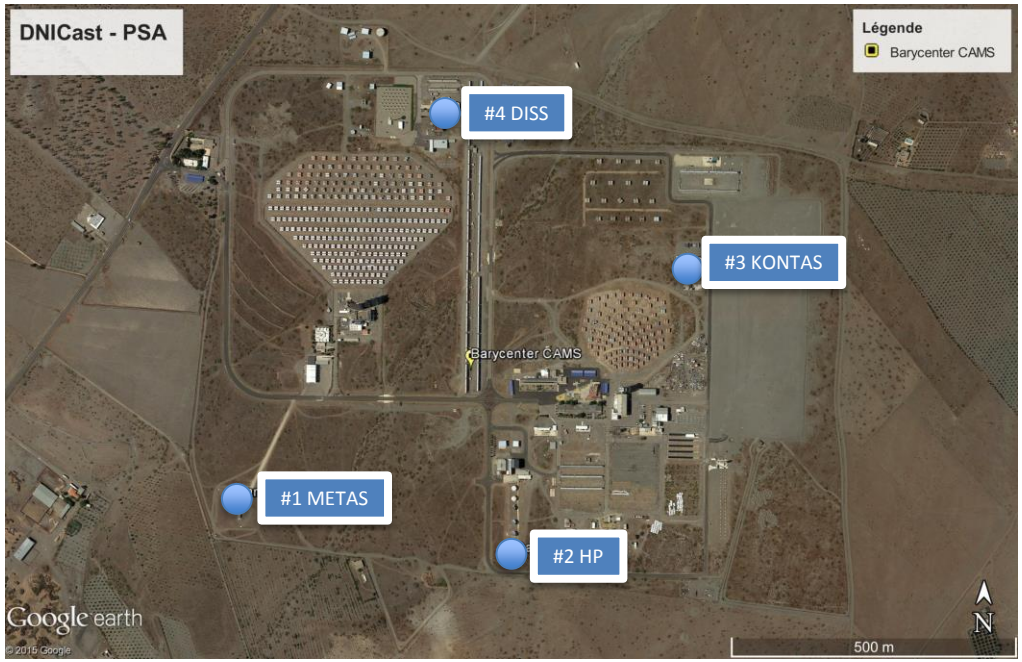
This project has received funding from the European Union's Seventh Programme for research, technological development and demonstration under grant agreement No [608623].

DNICast

Nowcasting of DNI maps with fish eye cameras

- Objective: provide nowcasting of DNI maps with multiple fish-eye cameras (or All-sky Imagers, ASI):
  - Time horizon of the forecast: 0 (real-time) to 30 min
  - Temporal resolution: 1 min
  - Update: every 1 min
  - Spatial resolution: 10 m
  - Spatial coverage: 2 km x 2 km

- 2-years experiments on the *Plataforma Solar de Alméria* (PSA), South of Spain
  - CIEMAT (Centre for Energy, Environment and Technology)
  - DLR (German Aerospace)

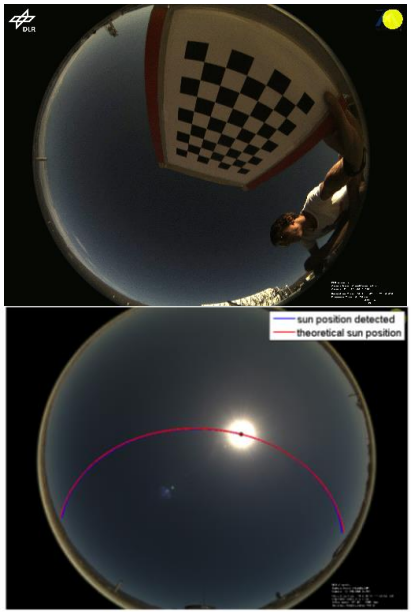


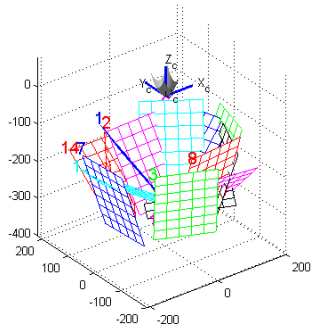
Installed fish-eye cameras

- Four fish-eye cameras Mobotix Q24 (DLR)
  - Standard security cameras
  - Cheap (< 900 euros), robust, easy to sue

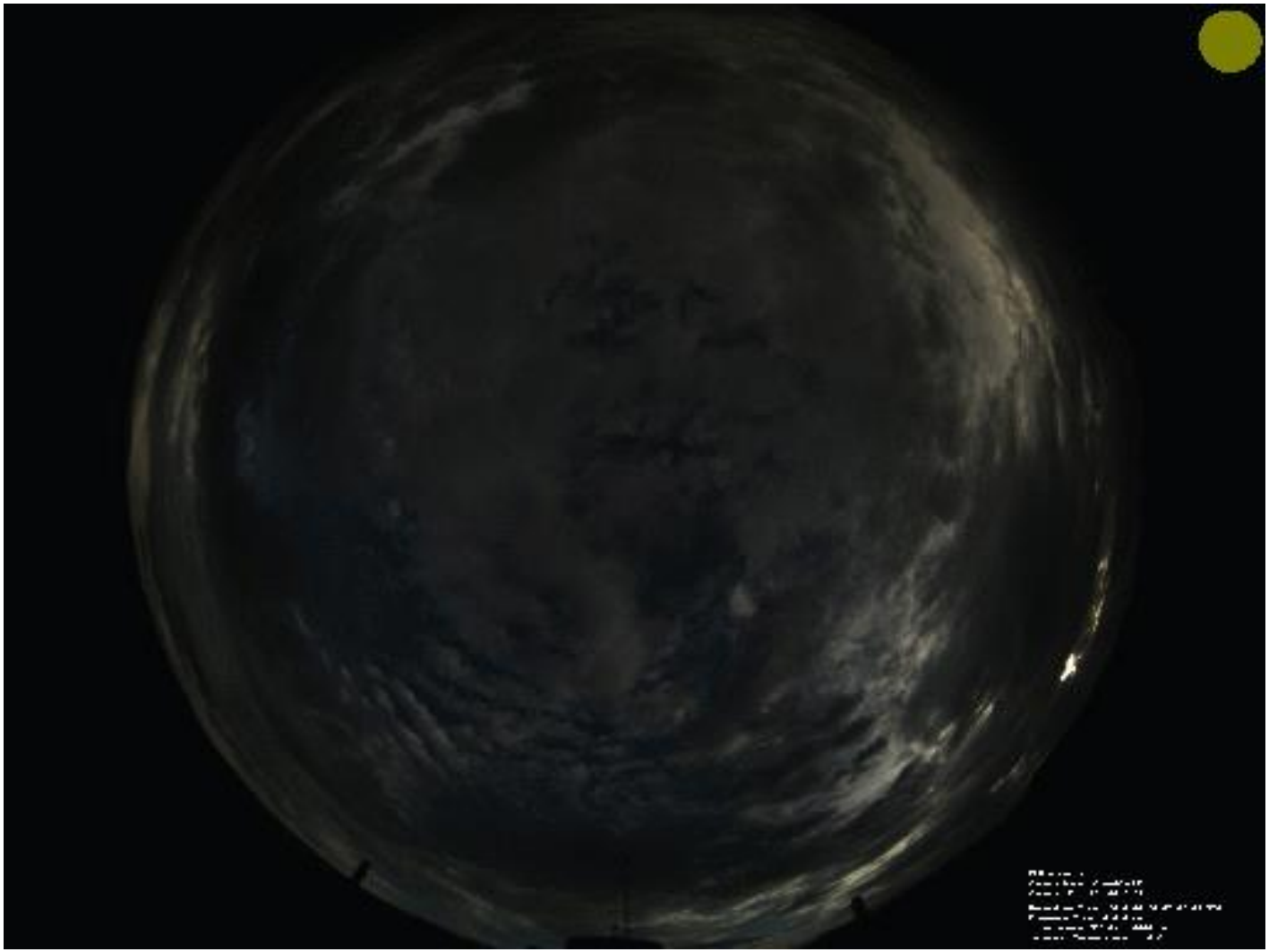
- Acquisition setup (DLR)
  - Sampling period: 30 s with acquisition with 3 exposure times
  - Image angular resolution: 0.1 - 0.15°
  - Continuous acquisition since 2014

- Geometric calibration (MINES ParisTech)
  - Intrinsic calibration with OcamCalib on Matlab® *(focal, optical deformation, pixel centers, etc.)*
  - Extrinsic calibration
    (3D orientation of the camera)
    with Automatic sun pixel detection
    - Orientation optimization with respect theoretical angular position of the Sun



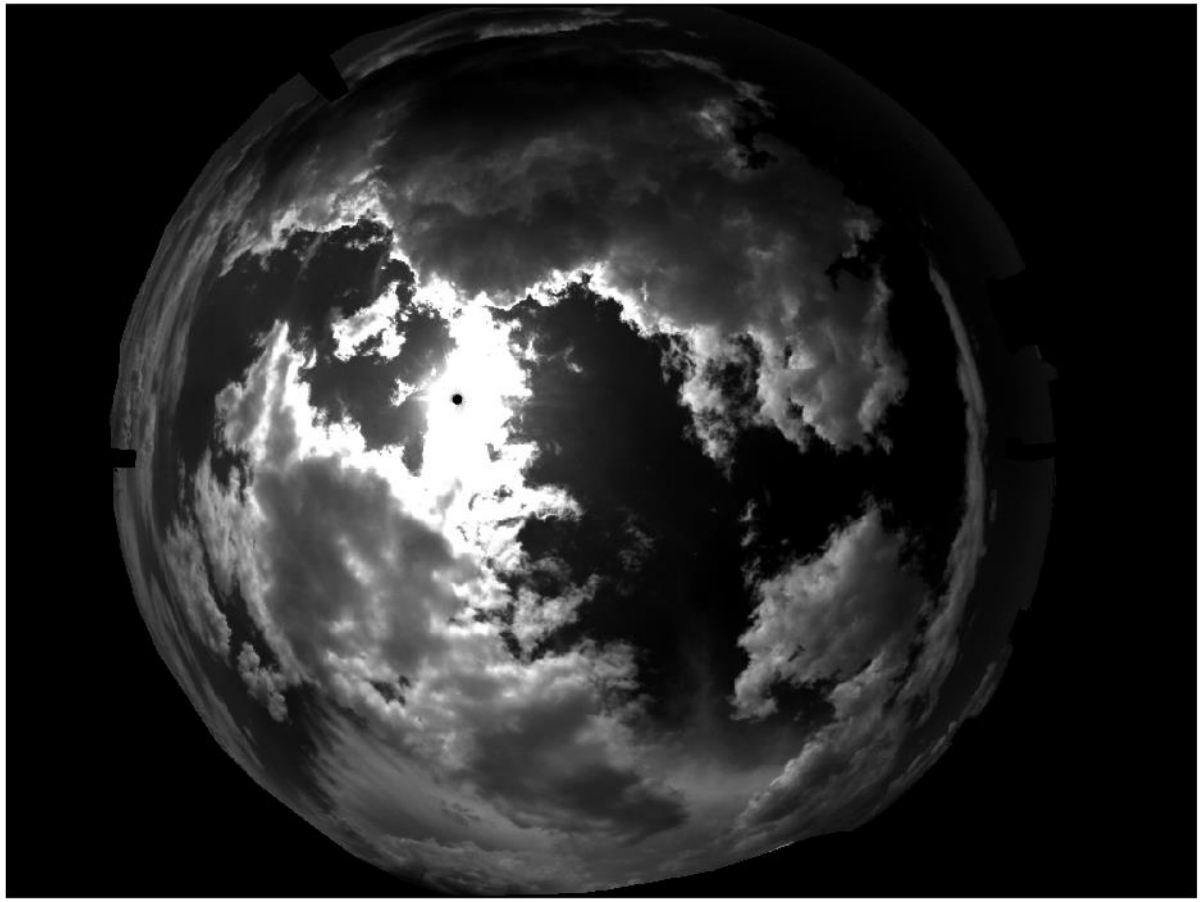


Example: 2014, June 24



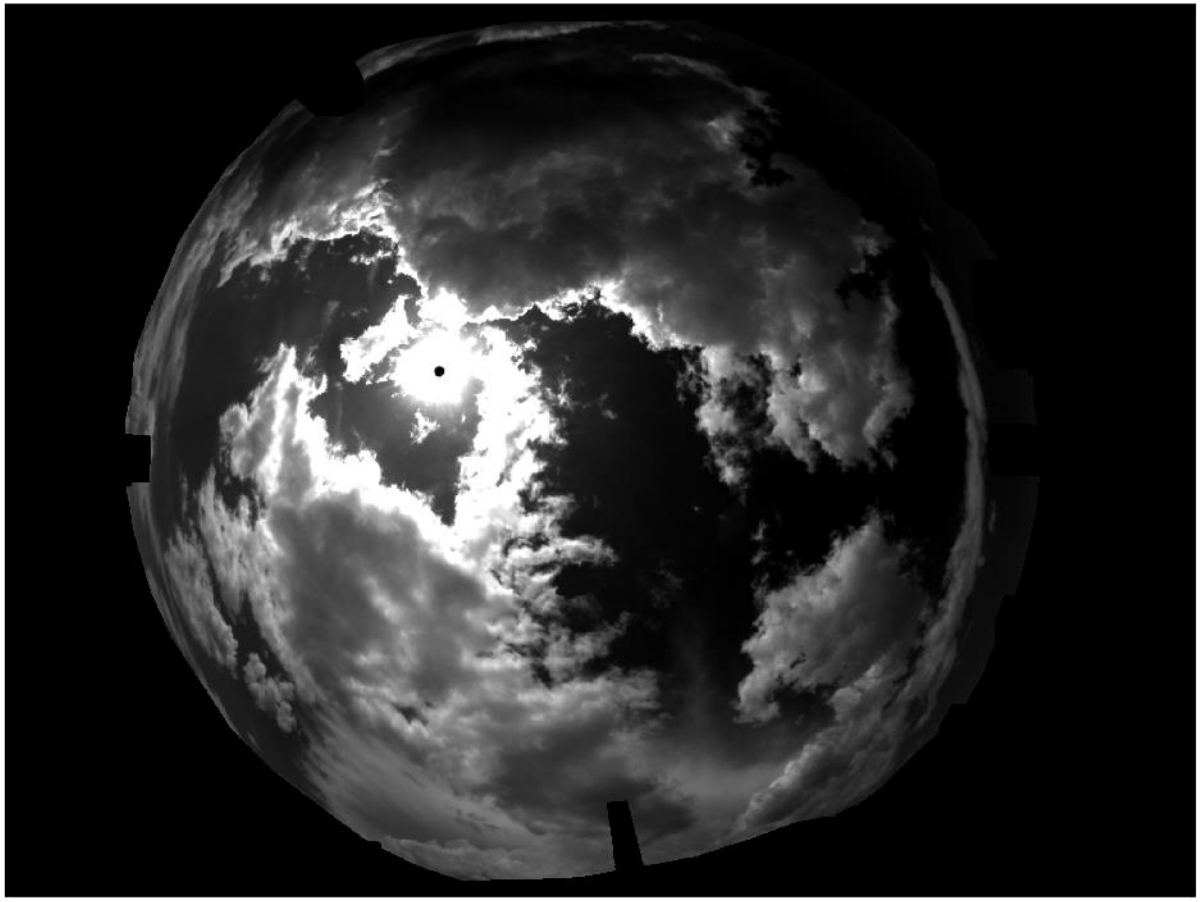
Parallax effects on the clouds

- Image from the KONTAS camera



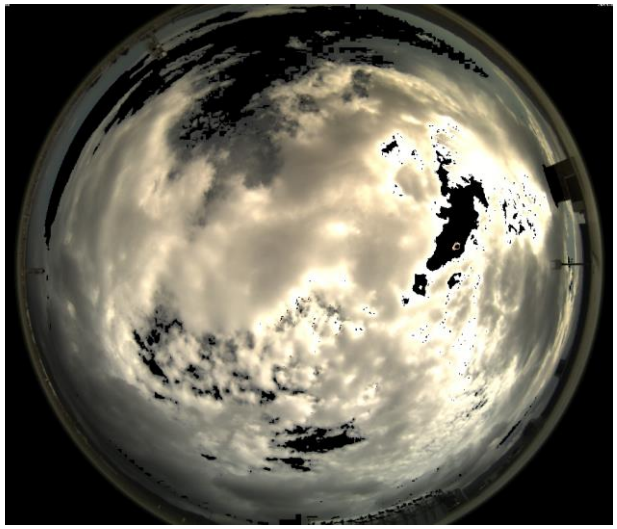
Parallax effects on the clouds

- Resampled image from the HP camera (assuming CBH = 4000 m)



Brief description of the real-time methodology

- **A: master camera**
  B: stereoscopic camera (maybe more than one)



- **Image A - instant t (University of Patras)**
  - Cloud detection
  - Cloud type (thin/thick cloud) classification
    Block-wise / Circumsolar area

- **Image A / Image(s) B - instant t**
  Stereoscopic analysis
  - Automatic tie points (TPs) detection in A
  - Fast automatic correlation-based matching of the TPs in image(s) B
  - Intersection of the line of sights (LoSs) with quality post-filtering
    - Level of correlation
    - Minimum distance between the LoSs

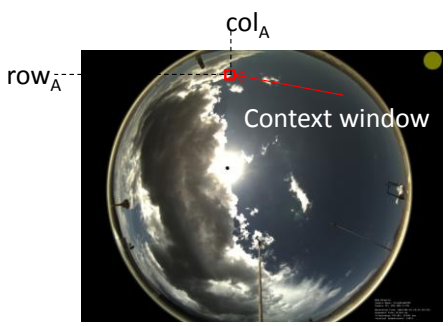


Image from camera A

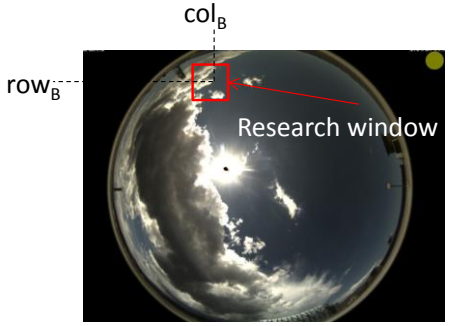


Image from camera B

Brief description of the real-time methodology

- **A: master camera**
  B: stereoscopic camera (maybe more than one)

- **Image A - instant t / Image A - instant t - 30 s**
  Cloud motion vector (CMV)
  - Same correlation-based techniques of TPs matching
  - No vertical wind speed
  - Same wind speed per detected cloud layers
    => Averaging wind speed par cloud layers

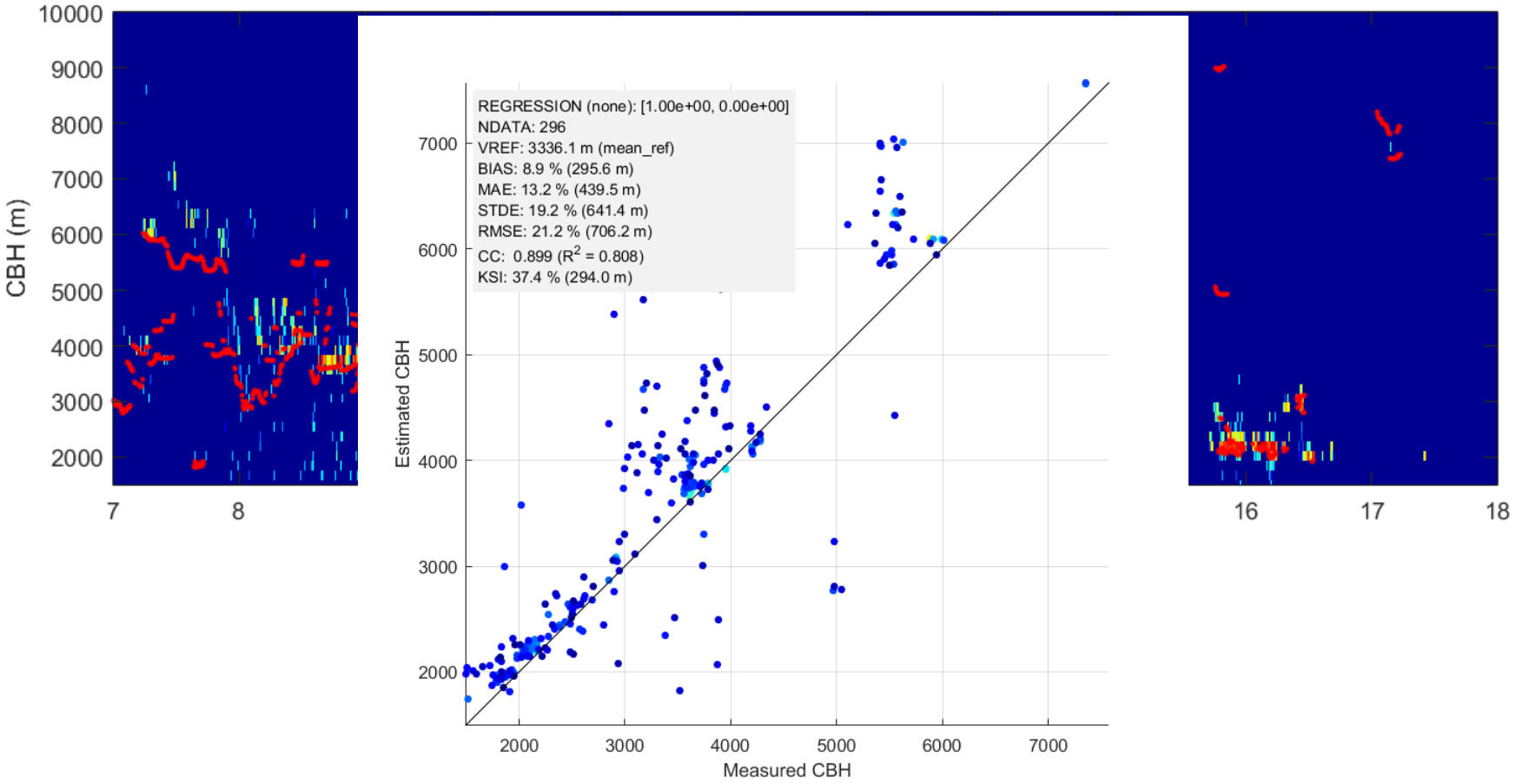
- **Projection of derived information in the geometry of image A**
  (CBH, cloud types, etc.)
  - Corresponding to the time of forecast $t+\Delta t$ (with CMV)
  - Following the direction of the sunlight at the time $t+\Delta t$ to cast shadows on the ground

- **Use of real-time measurement of DNI in one location in the site**
  Automatic relation between corresponding cloud types and forecasted clear-sky index

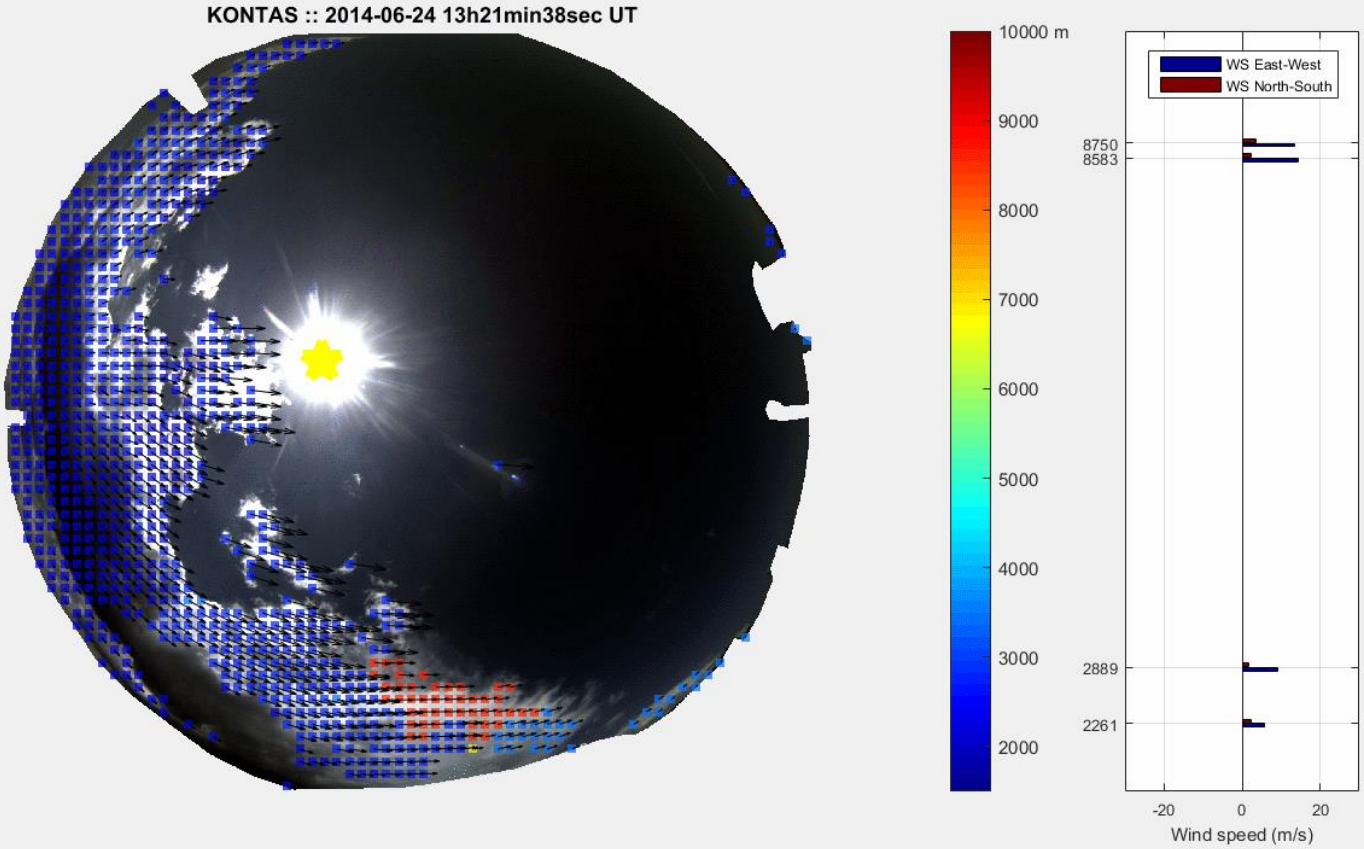
CBH estimation compared with a ceilometer

- Day 2014/06/24

- At the very vertical of the ceilometer

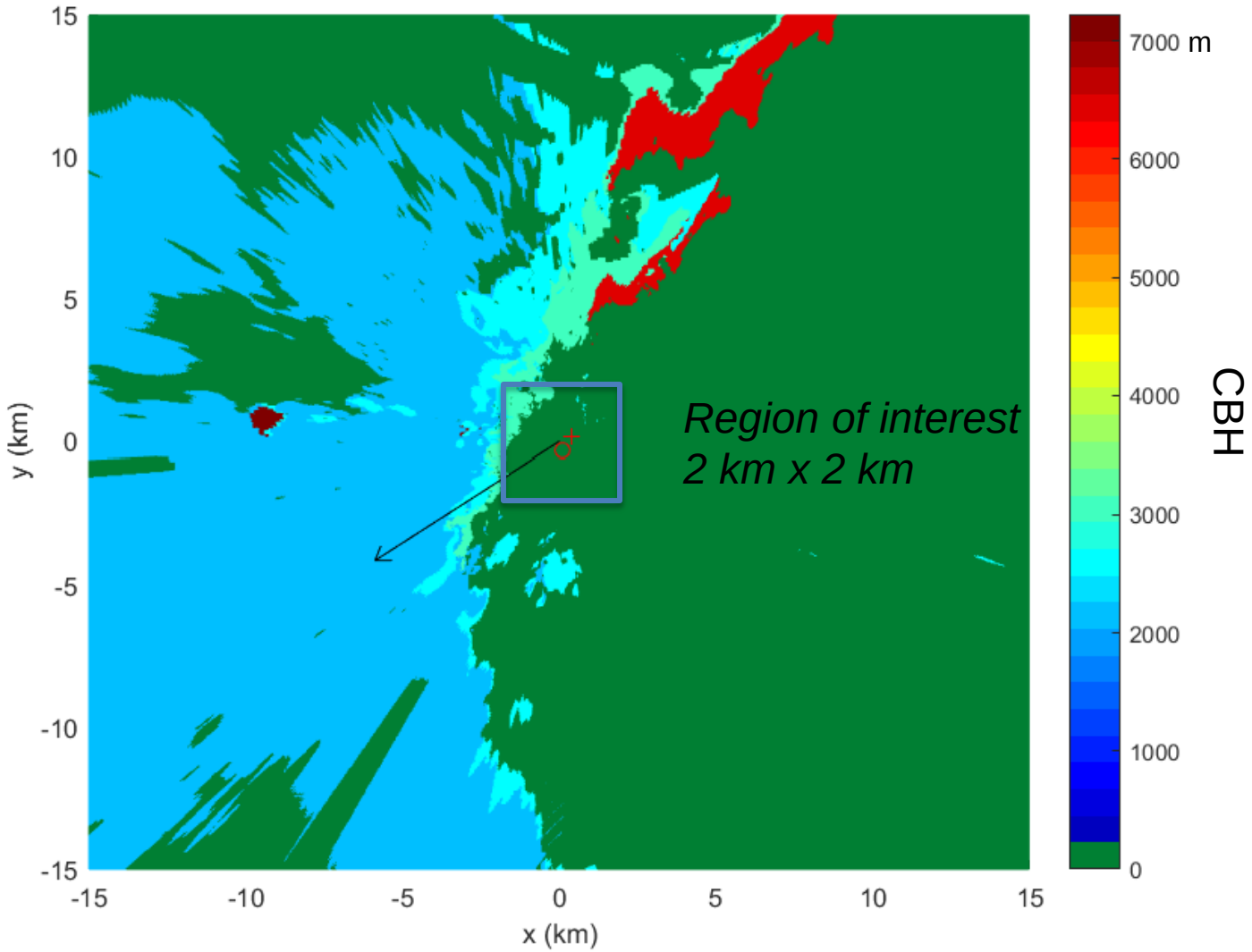


Display of CBH and CMV estimation

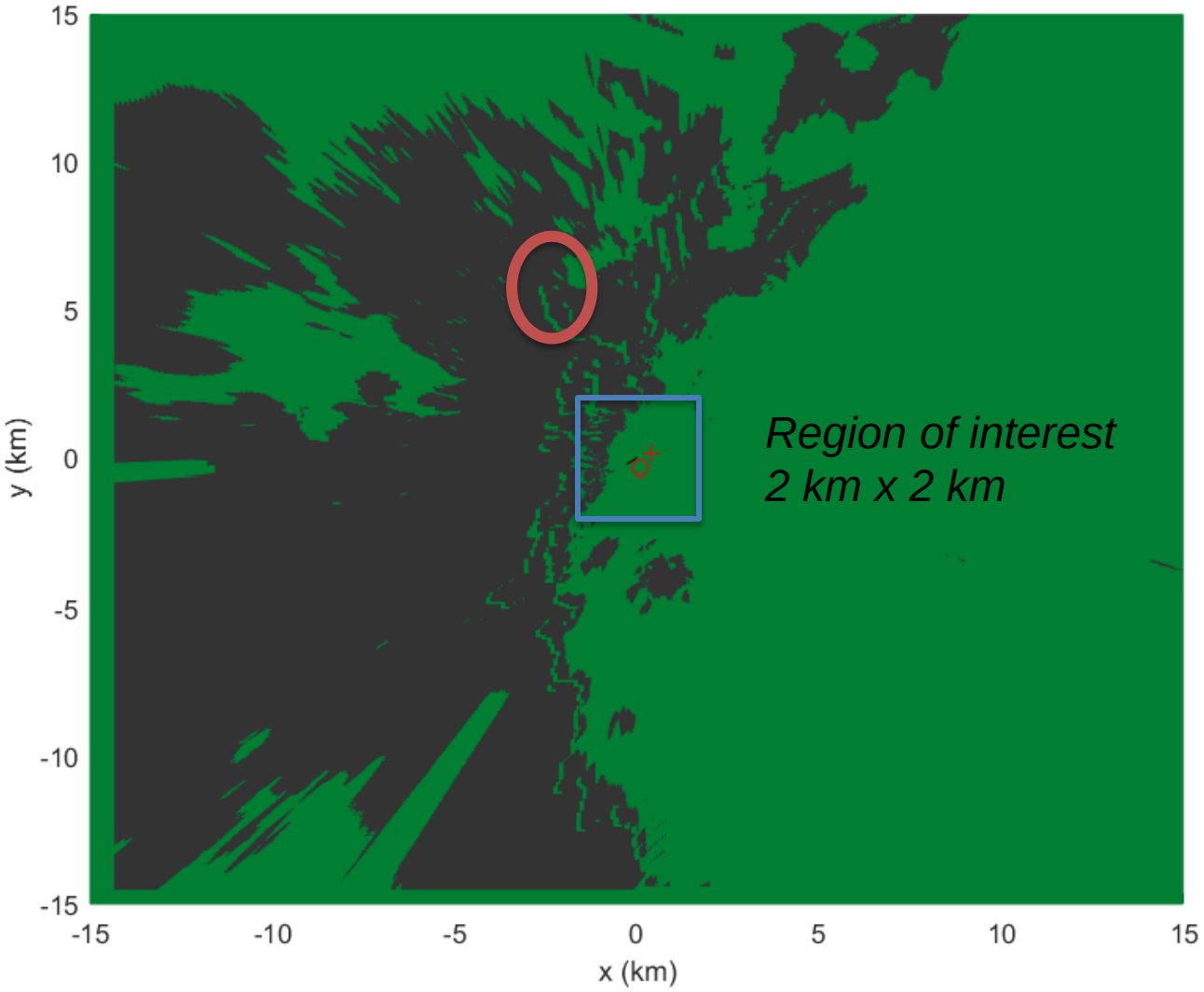


Orthoscopic projection of the clouds

- Spatial coverage : -15 km to 15 km



Shadow projection of the clouds

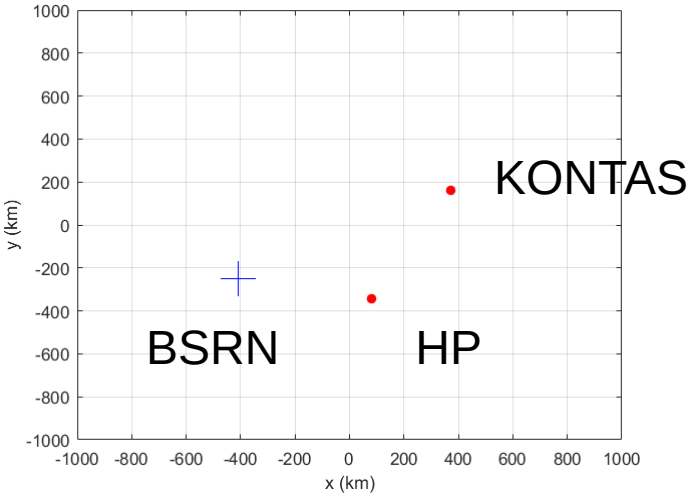


Results of the nowcasting

- 2014/06/24

- Clearness index nowcasted from:
  - The shadow projected of the type of clouds
  - Relationship with real-time DNI measurements at the HP location only

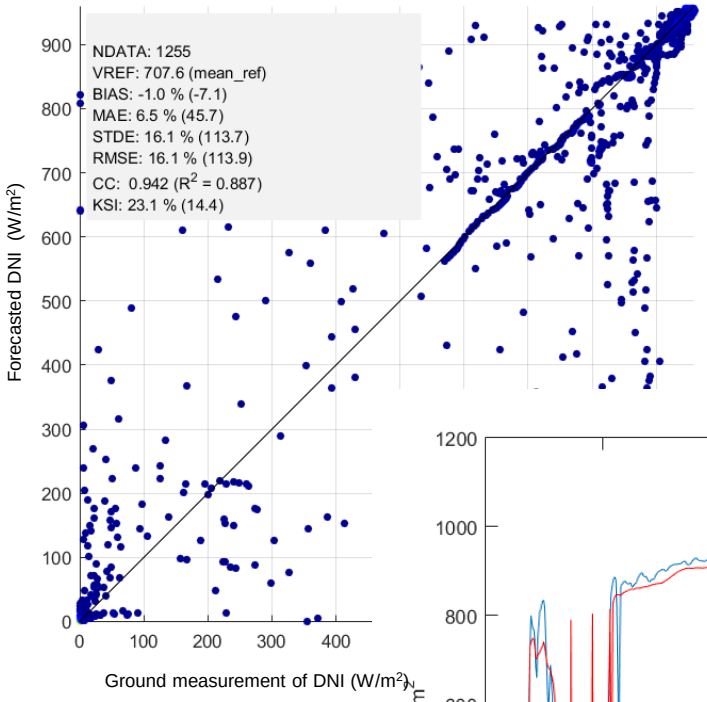
- Nowcasting comparison with
  - HP DNI measurements (only for horizon time > 0)
  - BSRN DNI measurements

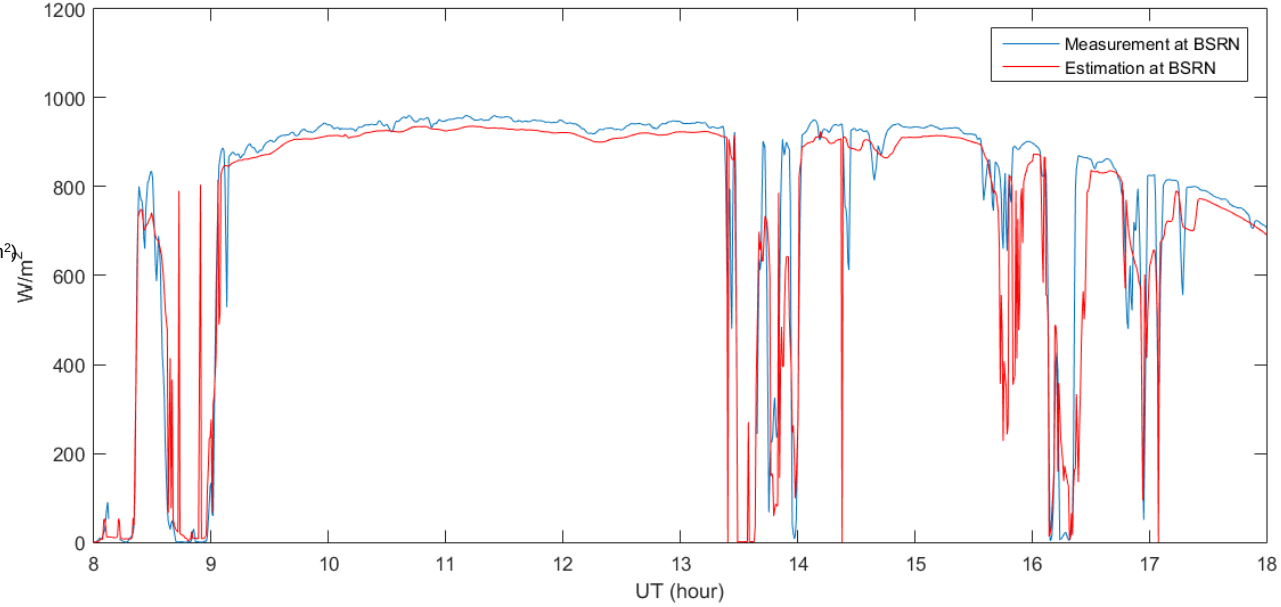


** MACC: Monitoring atmospheric composition & climate*

Real-time estimation at BSRN

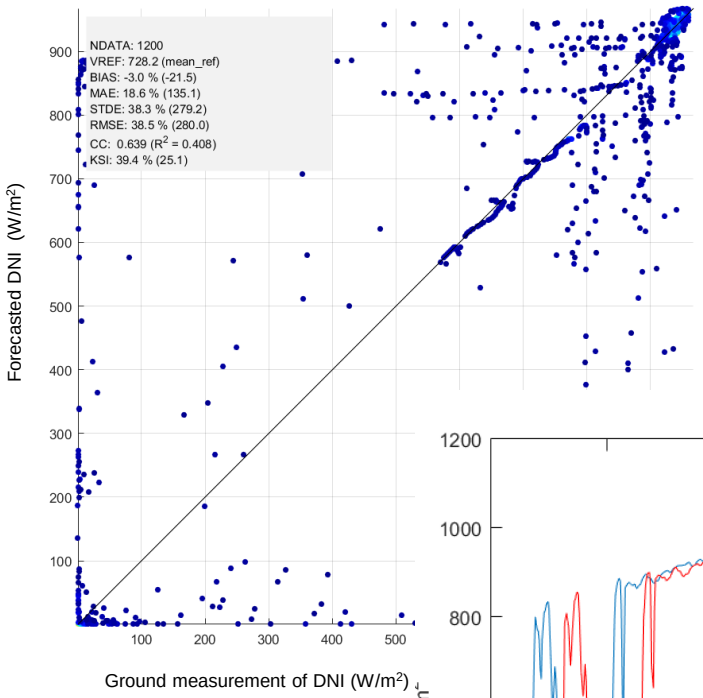
- Horizon time = 0

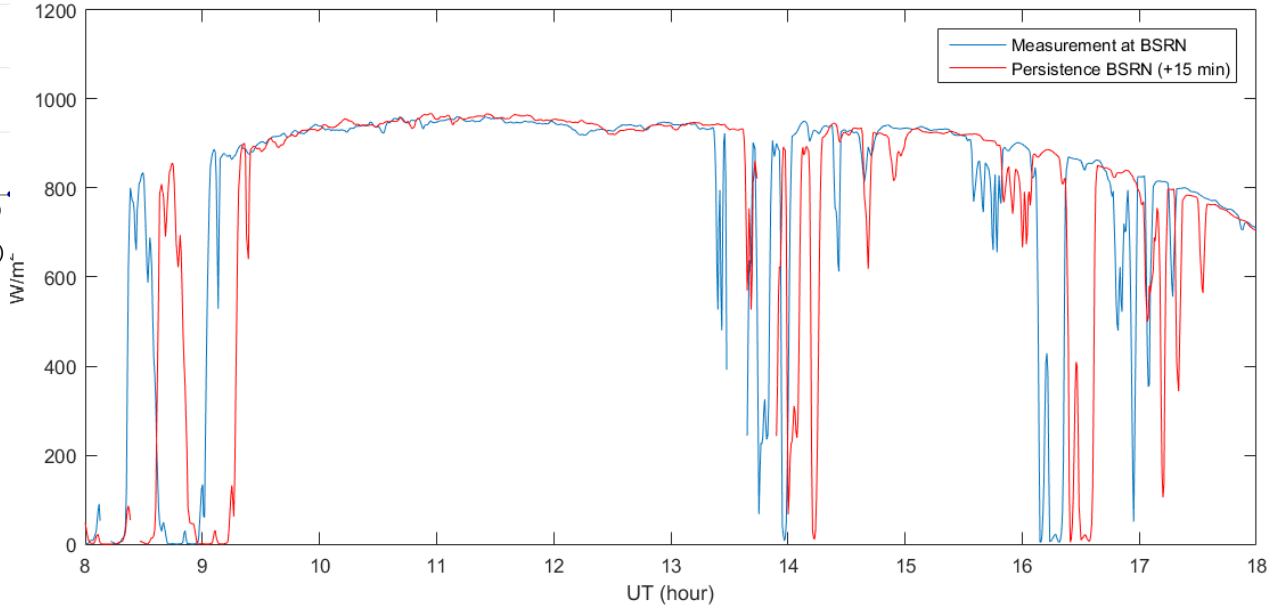




Nowcasting at BSRN (+15 min)

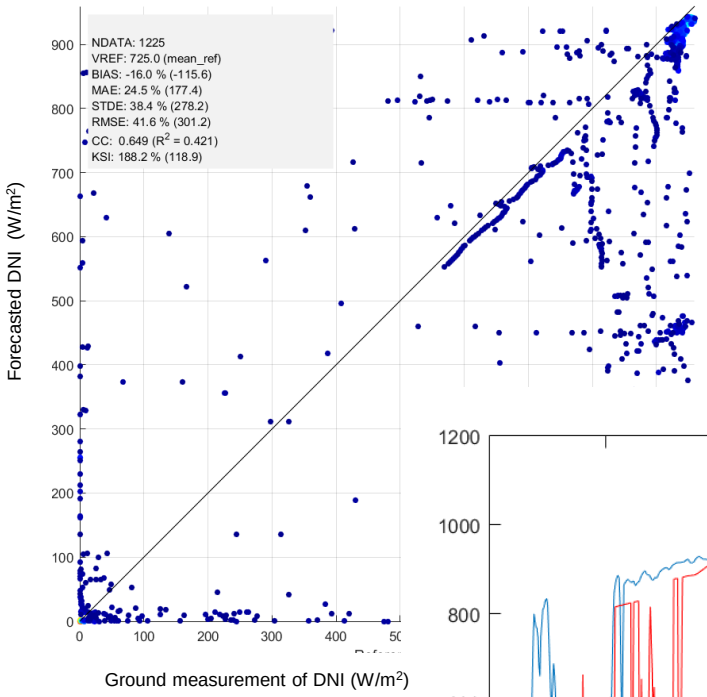
- Baseline forecast: clearness index persistence



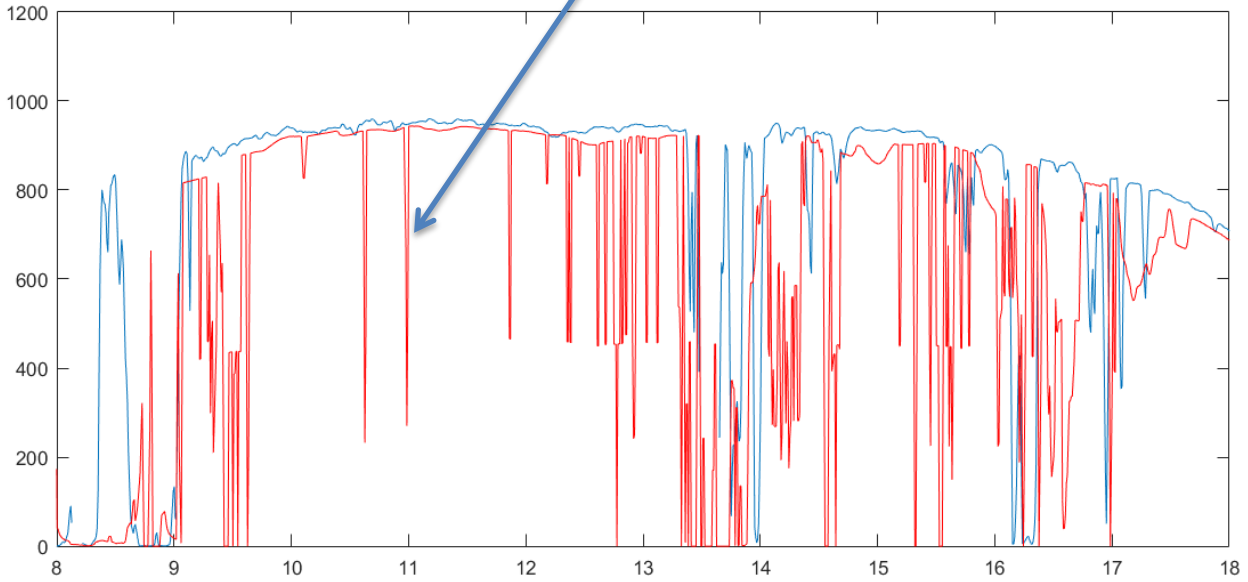


Nowcasting at BSRN (+15 min)

- "Raw" +15 min forecast from cameras

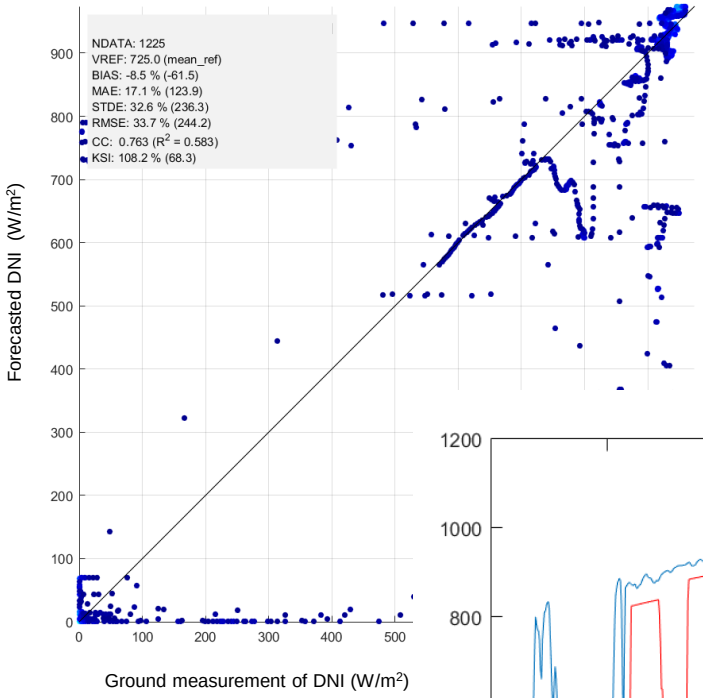


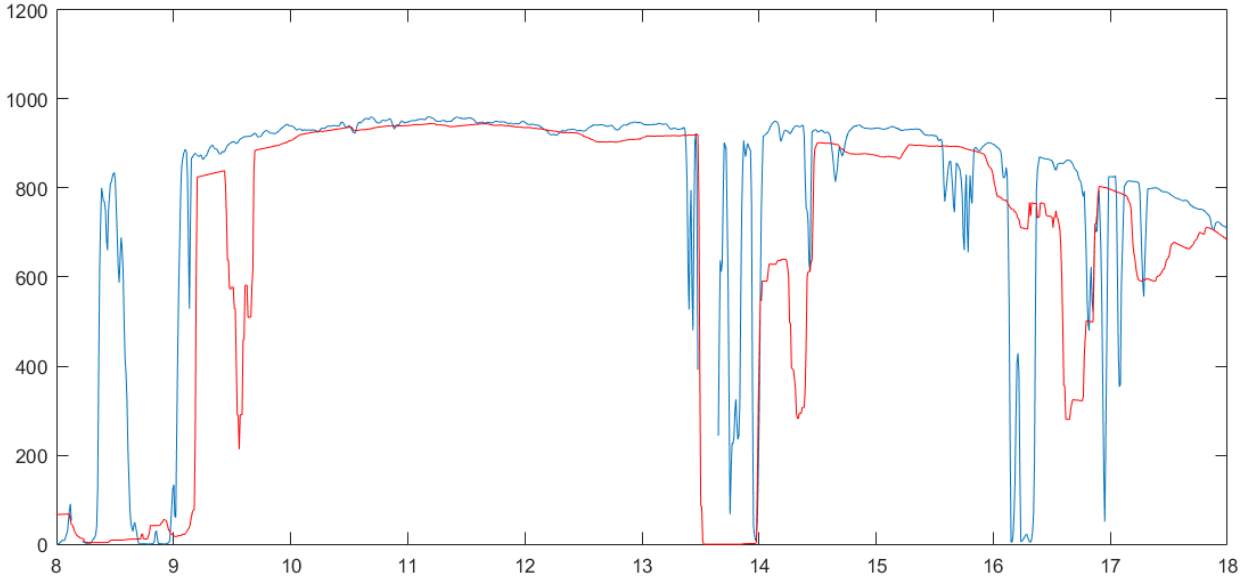
Cloud occlusion



Nowcasting at BSRN (+15 min)

- +15 min forecast from cameras with a causal median filter (15 min from the past)





Conclusion

- Real-time processing of fish-eye cameras in stereoscopic mode every 30 s (averaged to 1-min)
  Over a spatial coverage of 30 km x 30 km
  - Cloud detection and classification
  - CBH estimation with correlation-based photogrammetric method
  - CMV estimation with similar approach

  ⇒ Nowcasting of DNI maps on a sub-region of 2 km x 2 km using one pyrheliometer in real-time

- Encouraging forecasting results
  Need improvements of post-processing
  - Cloud occlusion => holes in the shadow on the ground
  - Wind speed per cloud layers to be filtered in a post-processing

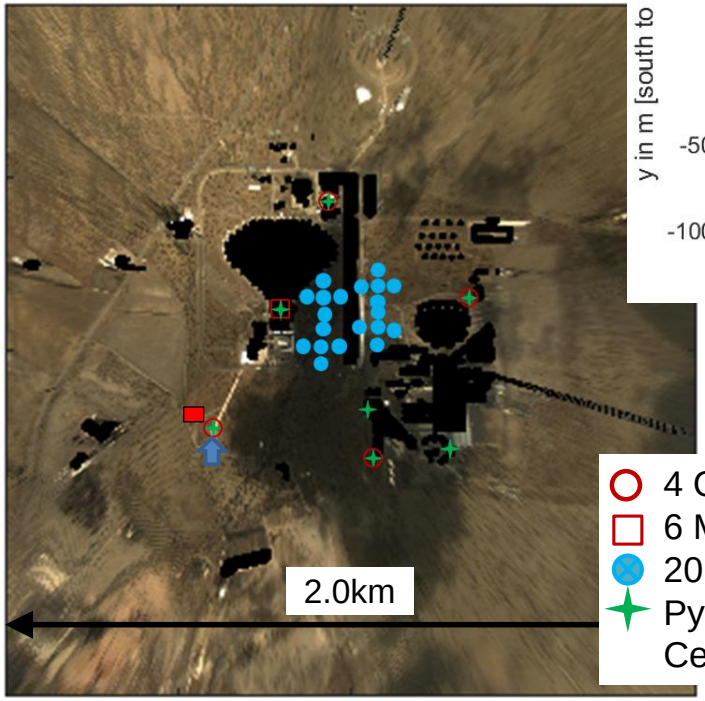
- Results of a collaborative work:
  - DLR (German Aerospace)
    - Setup of four fish-eye cameras in the *Plataforma Solar de Alméria*
    - Performance analysis of the DNI maps nowcasting (with Meteoswiss, Swiss)
  - University of Patras (Greece)
    - Algorithm for cloud mask and cloud classification (including in the circumsolar region)
  - MINES ParisTech (France)
    - Photogrammetric algorithm for cloud base height (CBH) and cloud motion vector
    - Geometric and radiometric calibration
    - Nowcasting algorithm

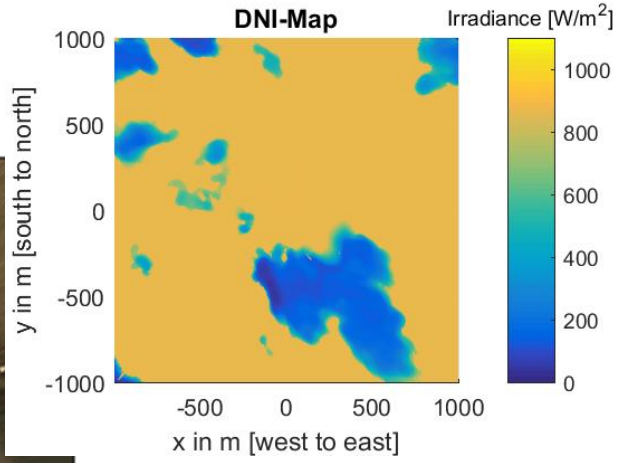
Conclusion

- **In-depth performance analysis of the DNI maps nowcasting**

Submitted to SolarPACES 2016, in Abu Dhabi

- 6 months of hemispherical images from the four cameras in PSA has been processed (June, July, August 2014 and September, October, November 2015)
- Specific sensors for the validation in PSA
  - 20+ Pyranometers / pyrheliometers
  - 6 Shadow Cameras
  - One ceilometer





4 Q24 ASI (All Sky Imager): *Sky*
6 M25 ShadowCams: *Shadows*
20 Si-pyranometers: *GHI*
Pyrheliometers + pyranometers
Ceilometer: *Cloud base height*

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