ISGAN – International Smart Grid Action Network

Smart4RES webinar on Advanced weather forecasting for RES applications – Part 2

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ISGAN in a Nutshell

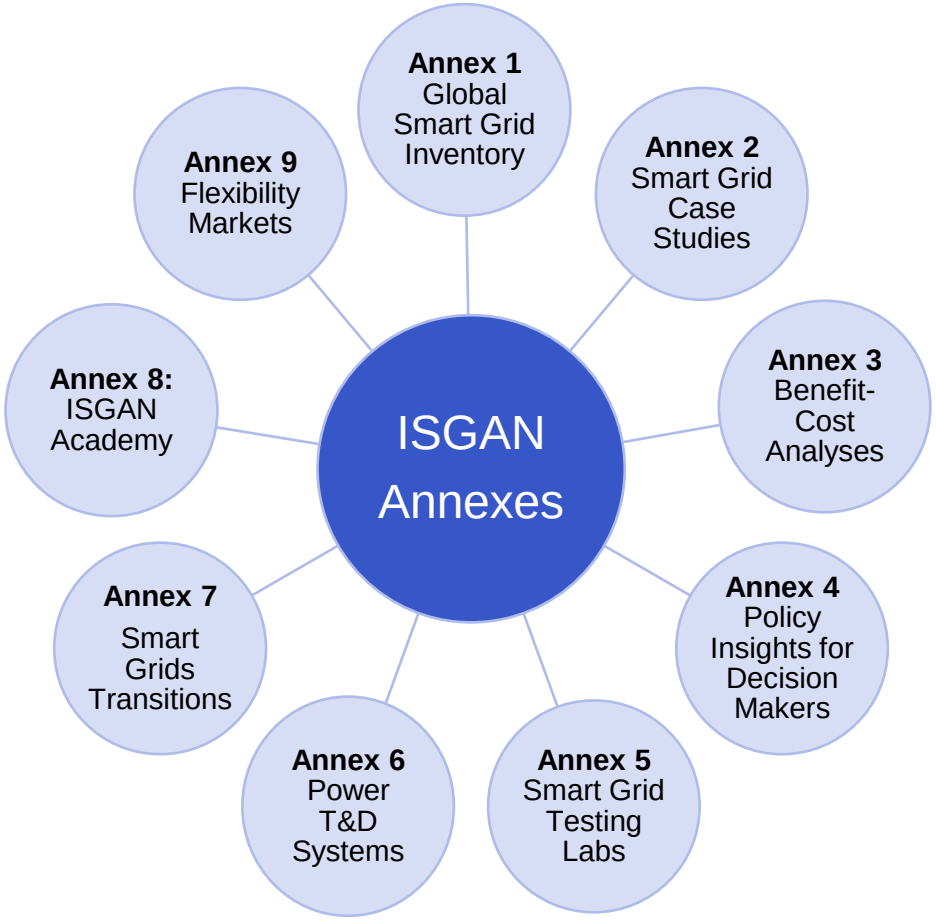
Created under the auspices of:

the Implementing Agreement for a Co-operative Programme on Smart Grids

an initiative of the Clean Energy Ministerial (CEM)

Strategic platform to support high-level government knowledge transfer and action for the accelerated development and deployment of smarter, cleaner electricity grids around the world

International Smart Grid Action Network is the only global government-to-government forum on smart grids.

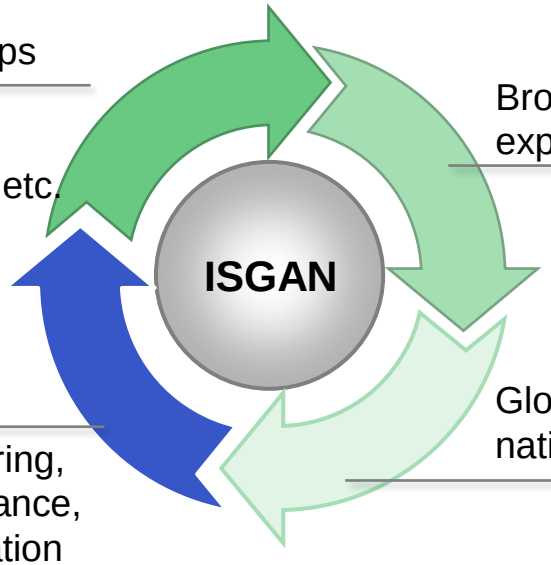


ISGAN's worldwide presence

Value proposition

Strategic partnerships

IEA, CEM, GSGF,
Mission Innovation, etc.



Broad international expert network

Global, regional & national policy support

Knowledge sharing, technical assistance, project coordination

Visit our website:
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Advanced weather forecasting for Renewable Energy System applications:

Multi-source observations to improve solar forecasting within the Smart4RES project

Agenda

- Smart4RES in a nutshell
- Motivation
- Data observations and assimilation
  - All sky imager (ASI) based nowcasts
  - Satellite based forecasts
  - Data assimilation

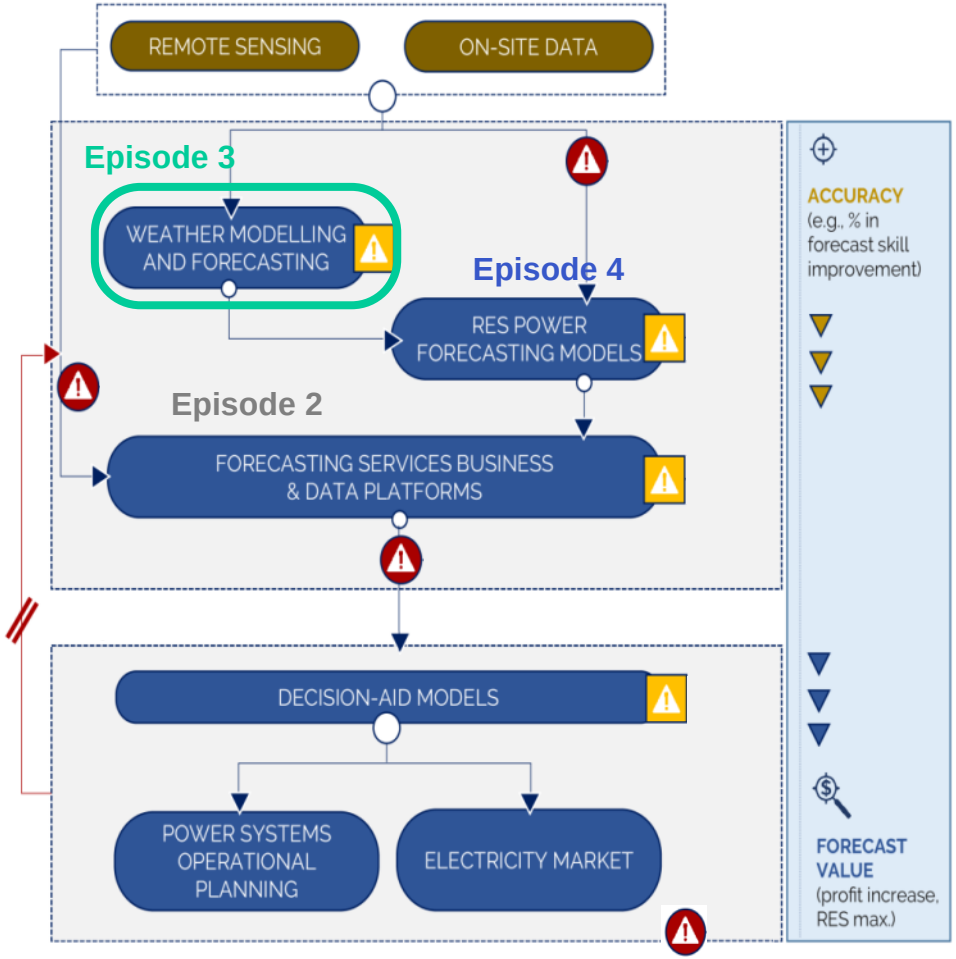
Smart4RES in a nutshell

Smart4RES in a nutshell

- RES forecasting is a mature technology with operational tools and commercial services used by different actors
- However, we want to make progress to improve the forecasting accuracy and to reduce costs of RES integration

Smart4RES vision

Science and industry closely co-operate to achieve outstanding improvements of RES forecasting by considering the whole model and value chain.



Smart4RES webinar series

Season1: Towards a new Standard for the entire RES forecasting value chain

#1
June 2020

Replay on Youtube

Introduction to Smart4RES - Data science for renewable energy prediction

ARMINES DTU

#2
Dec 2020

Replay on Youtube

Extracting value from data sharing for RES forecasting

INESCTEC DTU

#3
March & April 2021

Advanced weather forecasting for RES applications

3.1 NWP & High-resolution models

3.2 Data observations & assimilation

energy&meteo systems WHIFFLE DTU DLR METEO FRANCE

#4
June 2021

Optimising participation of RES generation in electricity markets: new opportunities and the role of forecasting

energy&meteo systems DTU ARMINES

#5
September 2021

Optimizing the value of storage in power systems and electricity markets

ARMINES NEWENERGYWORLD

#6
October 2021

Modelling tools for integrating RES forecasting in electrical grids

INESCTEC ARMINES

Smart4RES consortium

6 countries
12 partners

End-users
Industry
Research
Universities
Meteorologists

Funds: H2020 programme
Budget: 4 Mio€
Duration: 3.5 years

11/2019-4/2023

Denmark — DTU

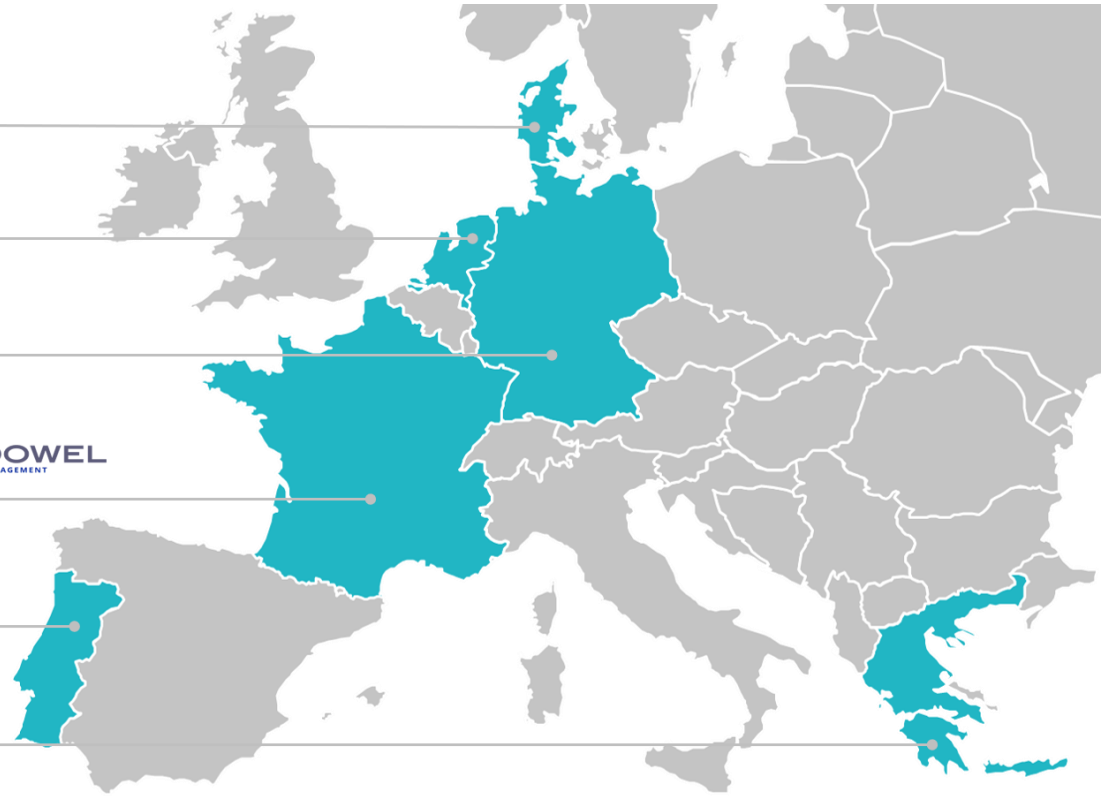
Netherlands — WHIFFLE, DNV·GL

Germany — DLR, energy & meteo systems

France — ARMINES, MINES ParisTech, METEO FRANCE, DOWEL MANAGEMENT

Portugal — INESCTEC, NEW ENERGY WORLD

Greece — HEDNO, ICCS



➲ **Follow us!**
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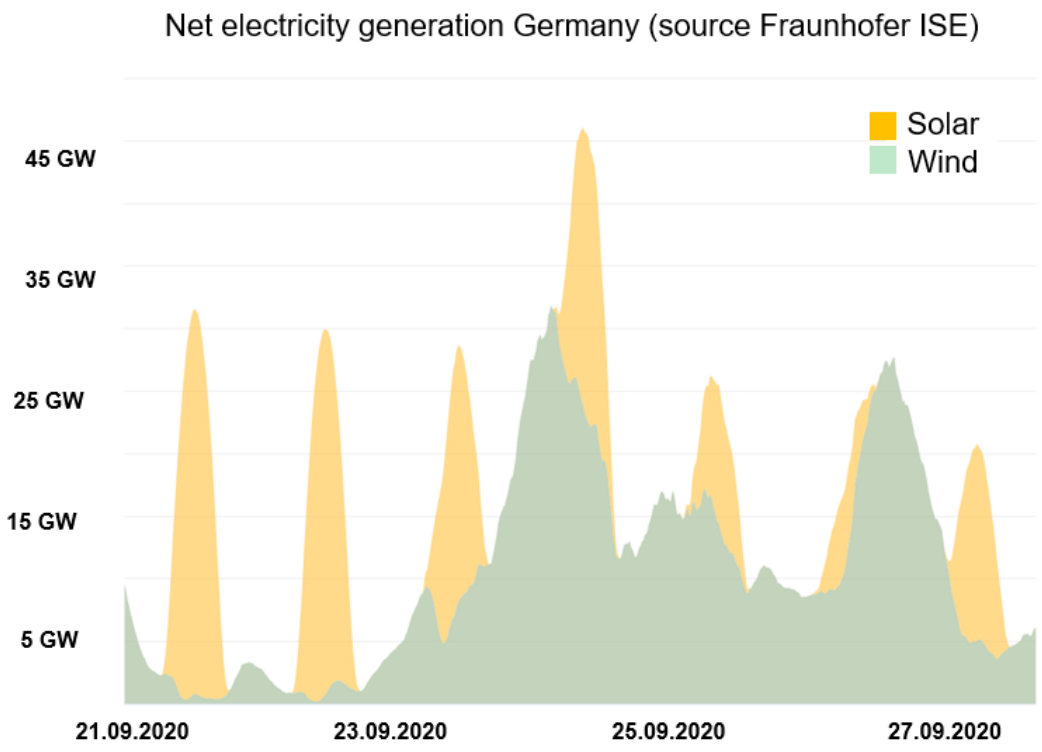
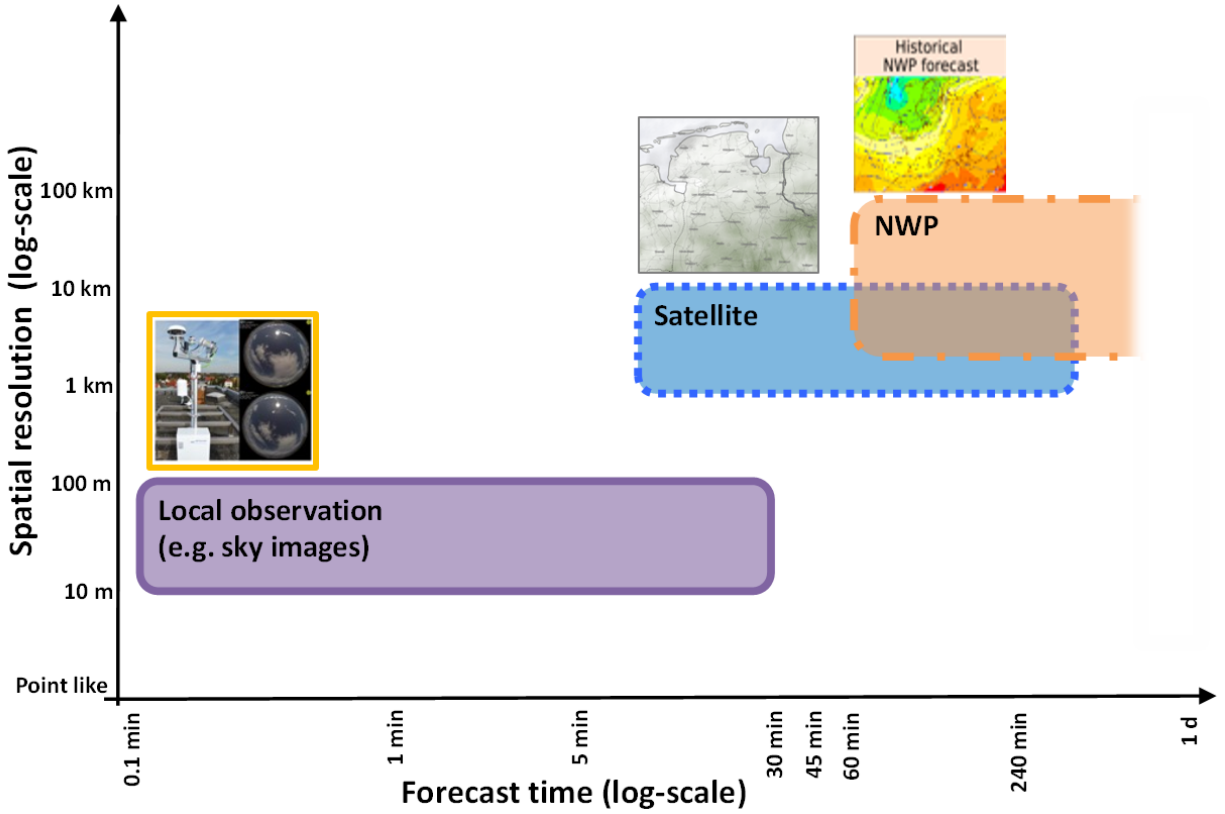
Motivation: challenges & opportunities in weather observations as well as forecasting

Challenges & opportunities in weather observations as well as forecasting





- Reduced forecasting errors: better decision-making under error prone variable conditions → higher profit, lower maintenance cost (e.g. extended battery life), better local grid management (e.g. less curtailment, cheaper balancing)
- How can we improve the weather forecast accuracy?

⇨ **Combine distinct sources and assimilate them to an improved seamless weather forecast**

Data observation and assimilation

- All sky imager (ASI) based nowcasts
- Satellite based forecasts
- Data assimilation

ASI test setup

Sky images from 2 to 4 all sky imager (ASI)

↓

Cloud detection

↓

Cloud tracking & geolocating

↓

Shadow projection

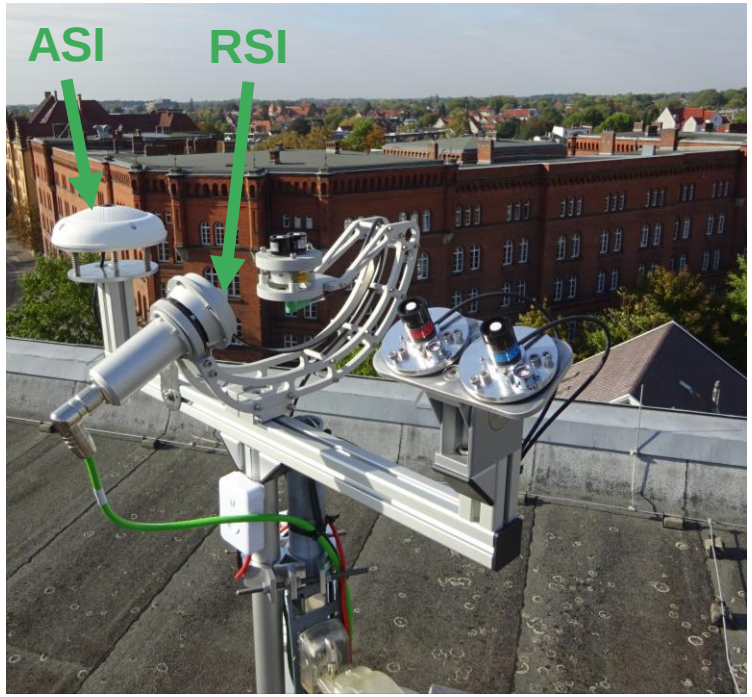
↓

Allocation of cloud transmittance

↓

Creation highly resolved irradiance maps

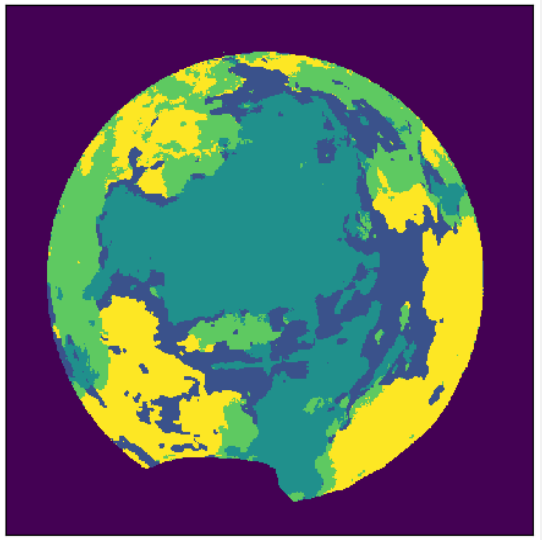
- Images from 2 to 4 Mobotix surveillance cameras
- Direct Normal Irradiance (DNI) measurements (e.g. Pyrheliometer or Rotating Shadowband Irradiometers RSI)



Cloud detection

- Sky images from 2 to 4 all sky imager (ASI)
- **Cloud detection**
- Cloud tracking & geolocating
- Shadow projection
- Allocation of cloud transmittance
- Creation highly resolved irradiance maps

Semantic cloud segmentation via Convolutional Neural Network in four classes [1]



Cloud segmentation accuracy

- Binary segmentation: **≈95%**
- Multi layer segmentation: **≈86%**

Cloud tracking and geolocating

Sky images from 2 to 4 all sky imager (ASI)

Cloud detection

Cloud tracking & geolocating

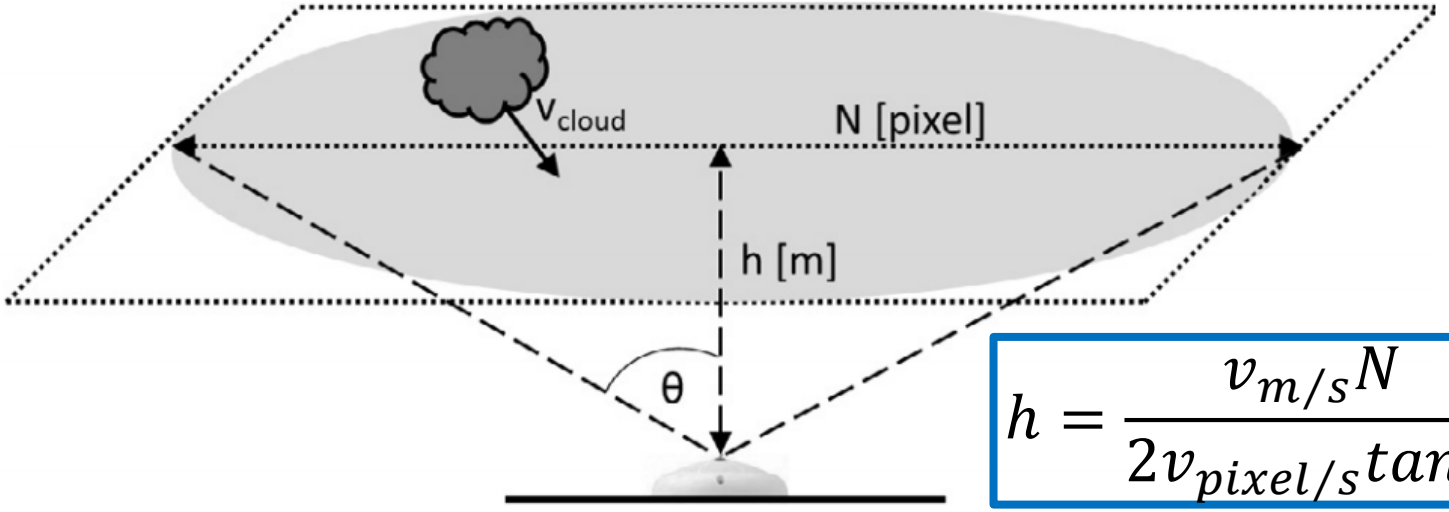
Shadow projection

Allocation of cloud transmittance

Creation highly resolved irradiance maps

Cloud tracking and geolocation via stereoscopic approach [2]

- Angular ($v_{pixel/s}$) and absolute ($v_{m/s}$) velocity derived via 2-D cross correlation from three sequential orthogonal images.
- Cloud height (h) determination based on:



$$h = \frac{v_{m/s} N}{2 v_{pixel/s} tan\theta}$$

Cloud shadow projection

Sky images from 2 to 4 all sky imager (ASI)

↓

Cloud detection

↓

Cloud tracking & geolocating

↓

Shadow projection

↓

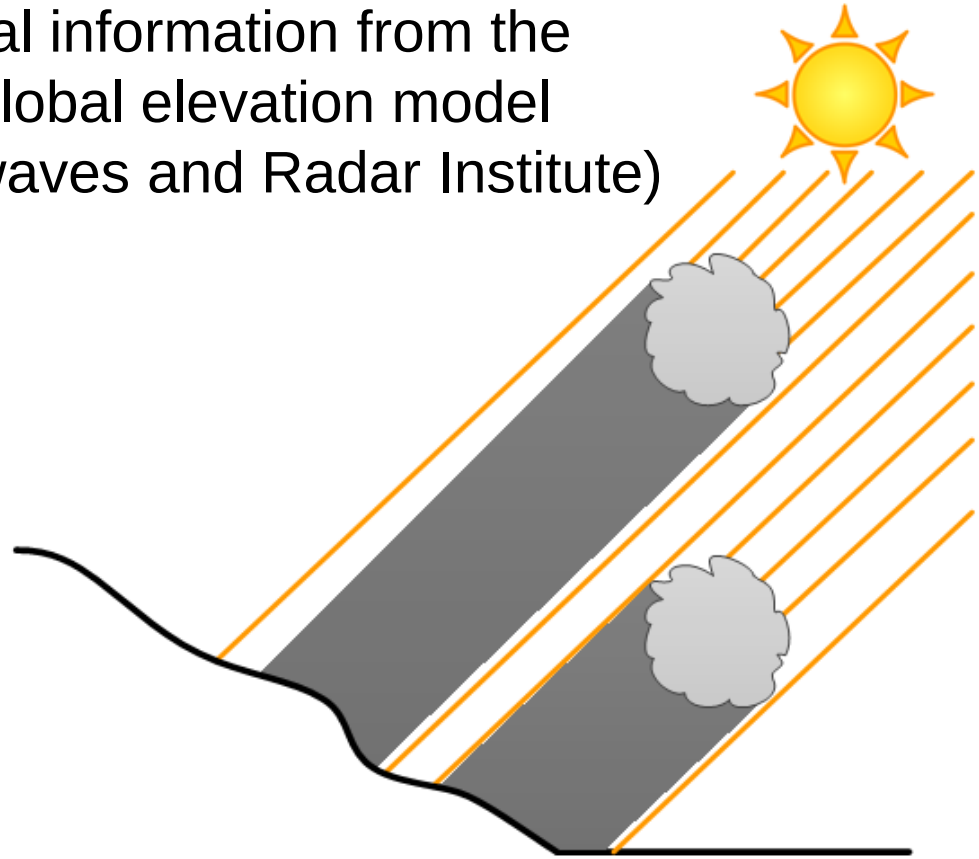
Allocation of cloud transmittance

↓

Creation highly resolved irradiance maps

Shadow projection via ray tracing

Topographical information from the TanDEM-X global elevation model (DLR Microwaves and Radar Institute)



Radiative effect of clouds

Sky images from 2 to 4 all sky imager (ASI)

↓

Cloud detection

↓

Cloud tracking & geolocating

↓

Shadow projection

↓

Allocation of cloud transmittance

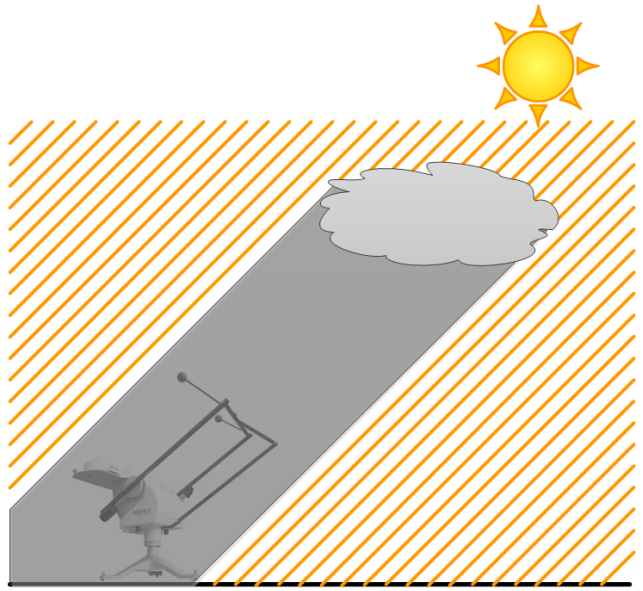
↓

Creation highly resolved irradiance maps

- Cloud transmittance by ground-based DNI measurements

$$\tau = \frac{DNI_{shaded}}{DNI_{clear}}$$

- Majority of clouds remain without transmittance measurements → **Probabilistic analysis for cloud transmittance estimation [3]**



Irradiance maps

Sky images from 2 to 4 all sky imager (ASI)

↓

Cloud detection

↓

Cloud tracking & geolocating

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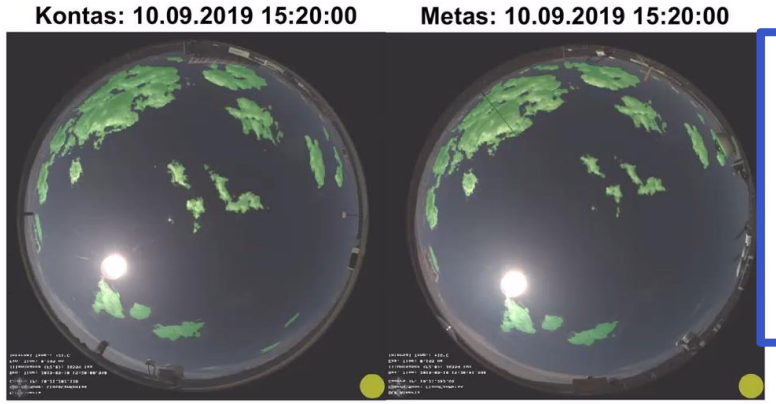
Shadow projection

↓

Allocation of cloud transmittance

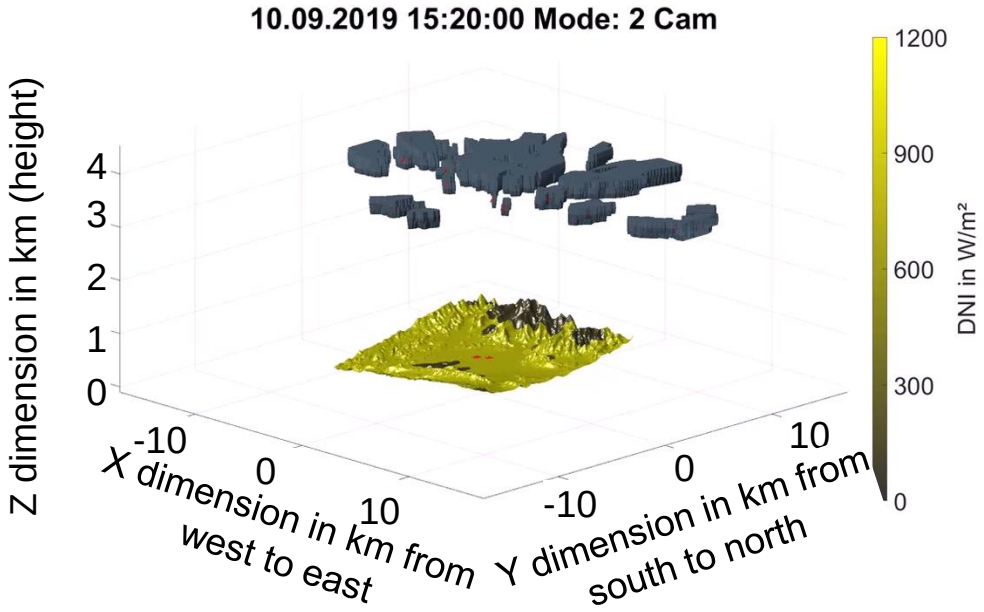
↓

Creation highly resolved irradiance maps



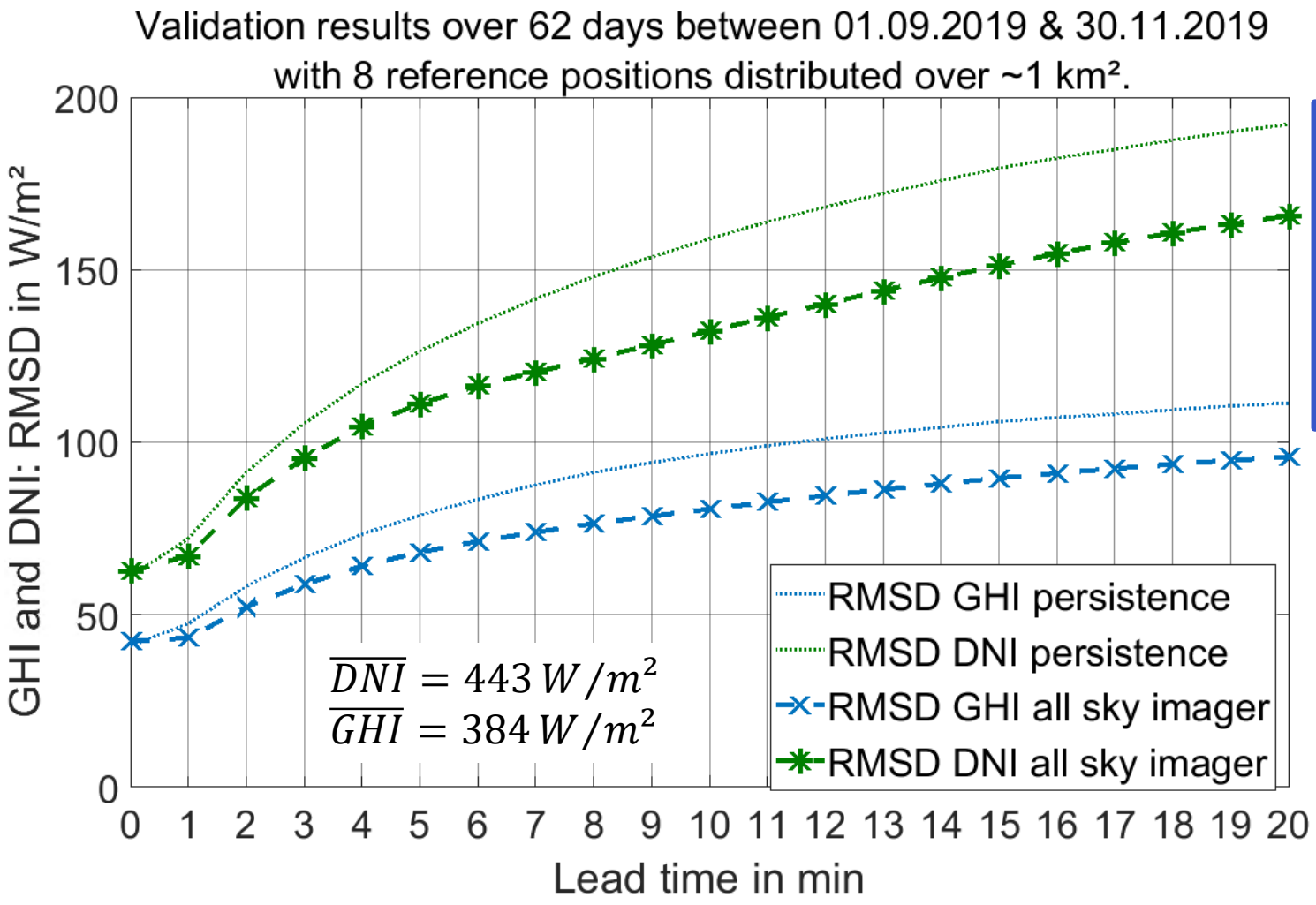
GHI and DNI maps

- **Coverage: >60 km²**
- **Spatial resolution: 20 m**
- **Temporal resolution: 30 s**
- **Nowcast horizon: ≤ 20 min**



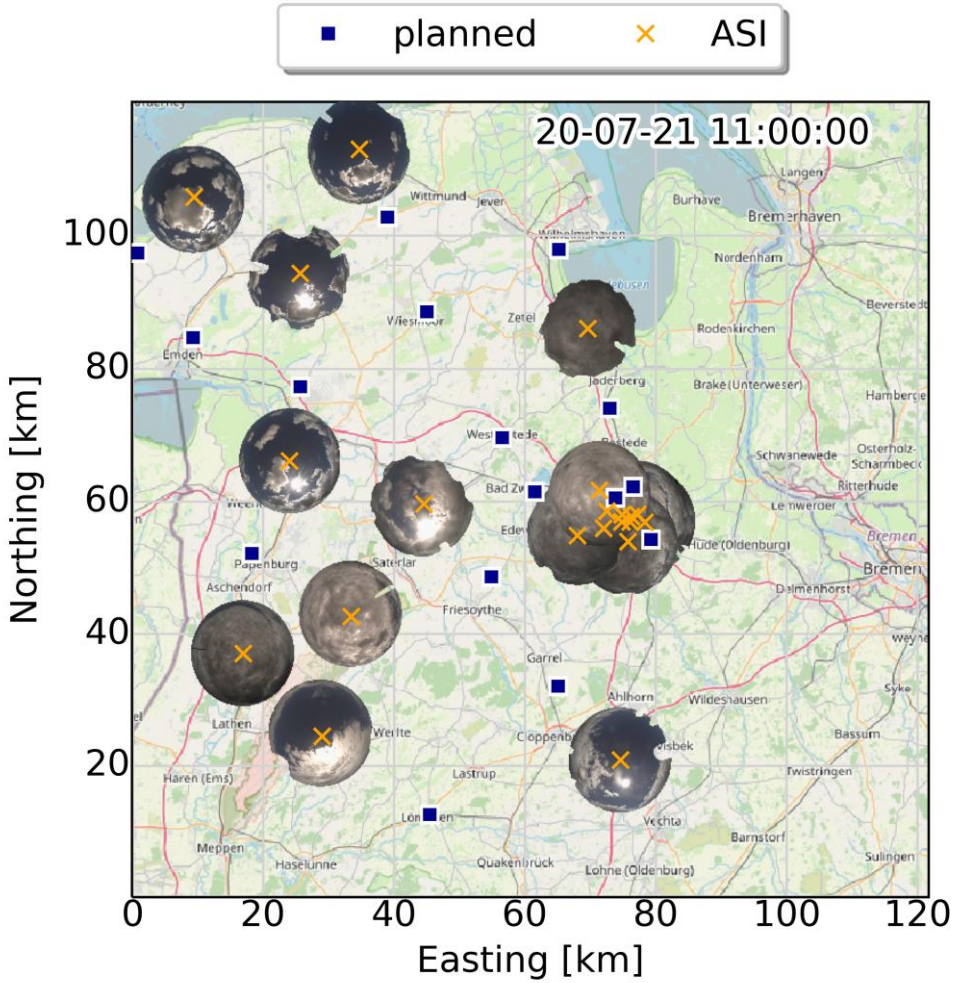
*Global Horizontal Irradiance

Validation results DNI and GHI nowcasts



- **Highly resolved nowcast from ASIs outperform smart persistence.**
- Nowcast horizons and spatial coverage from state of the art ASI approaches strongly limited by available line of sight.

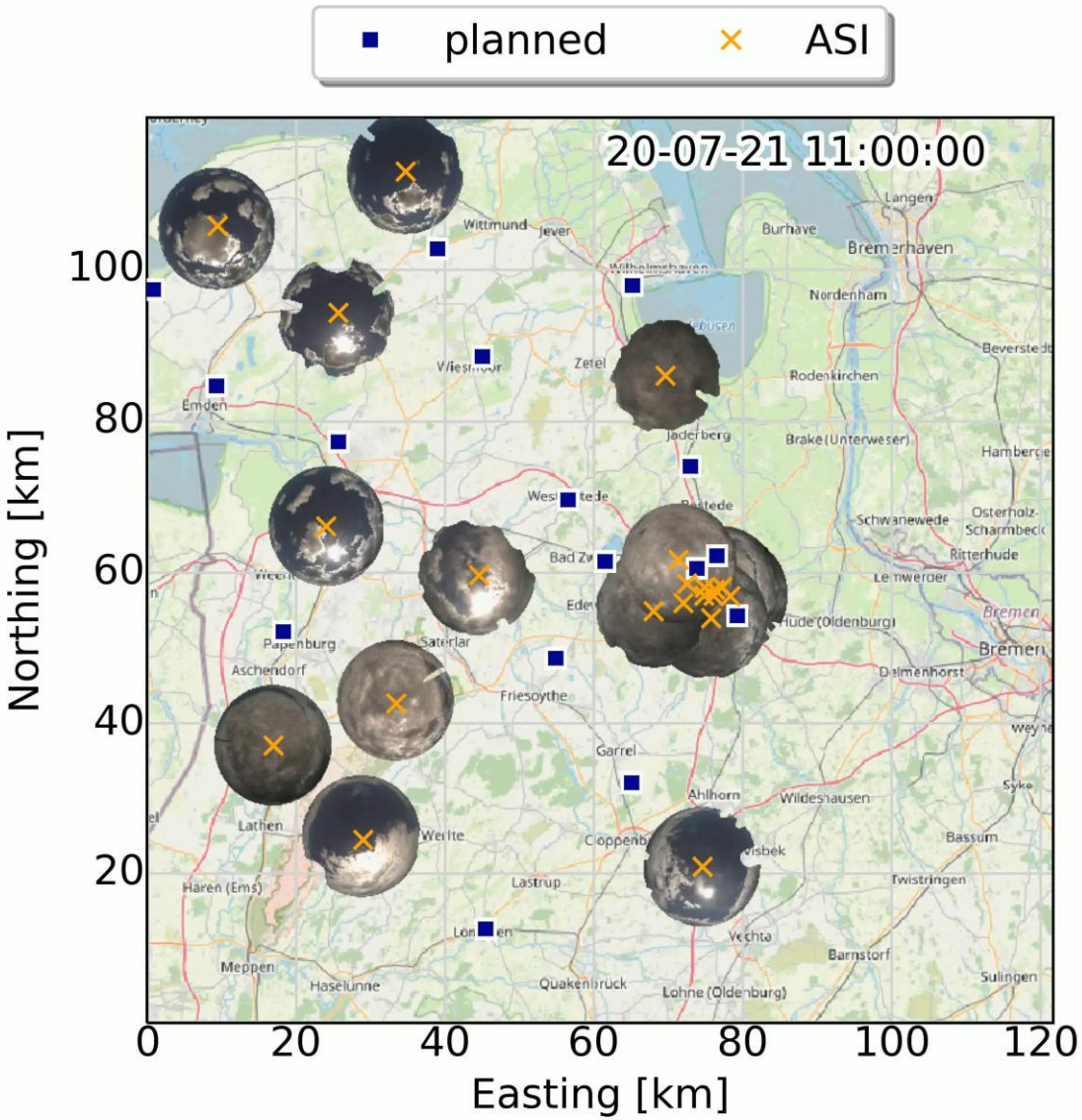
Eye2Sky ASI network

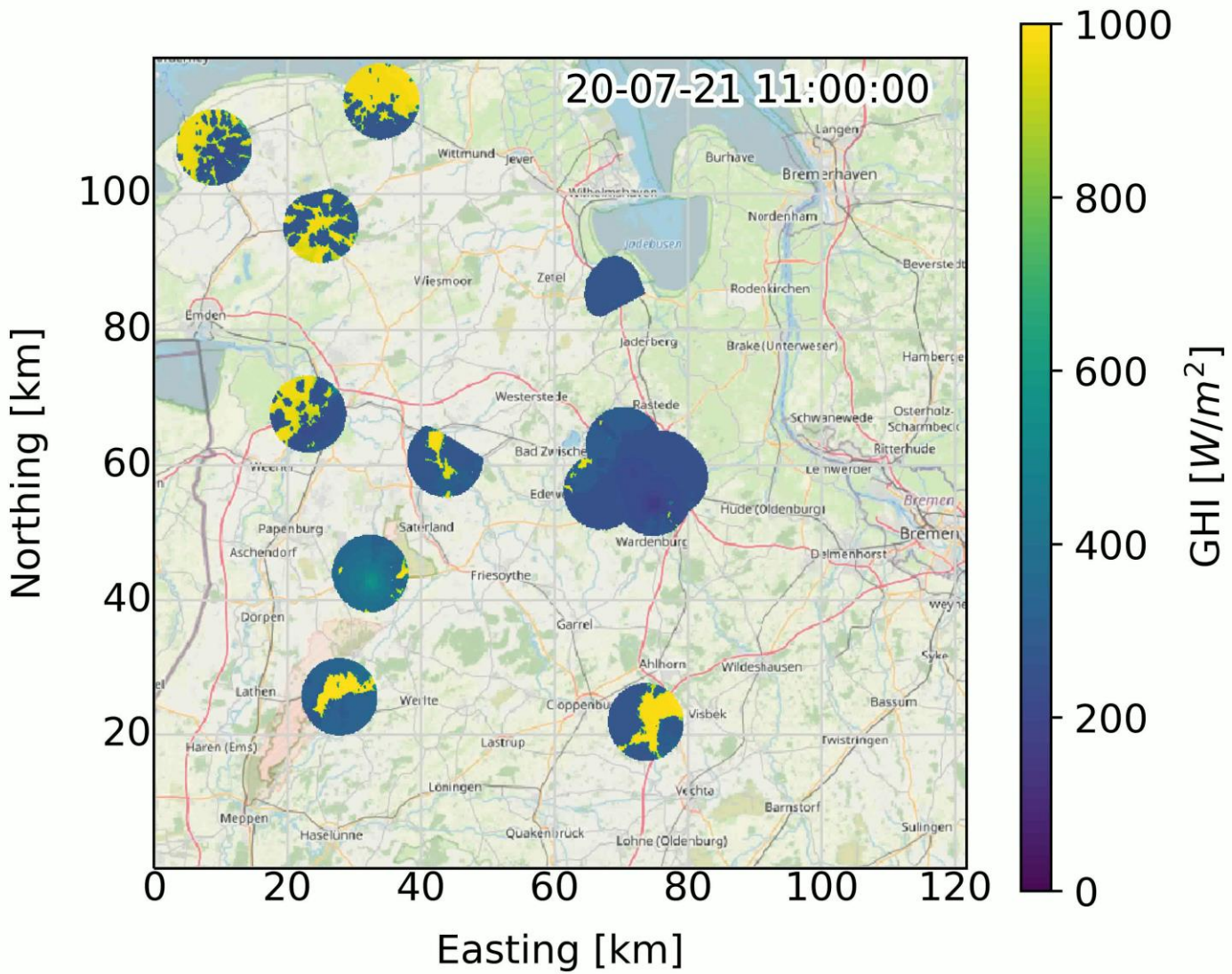


Prediction and analysis of solar irradiance and PV generation

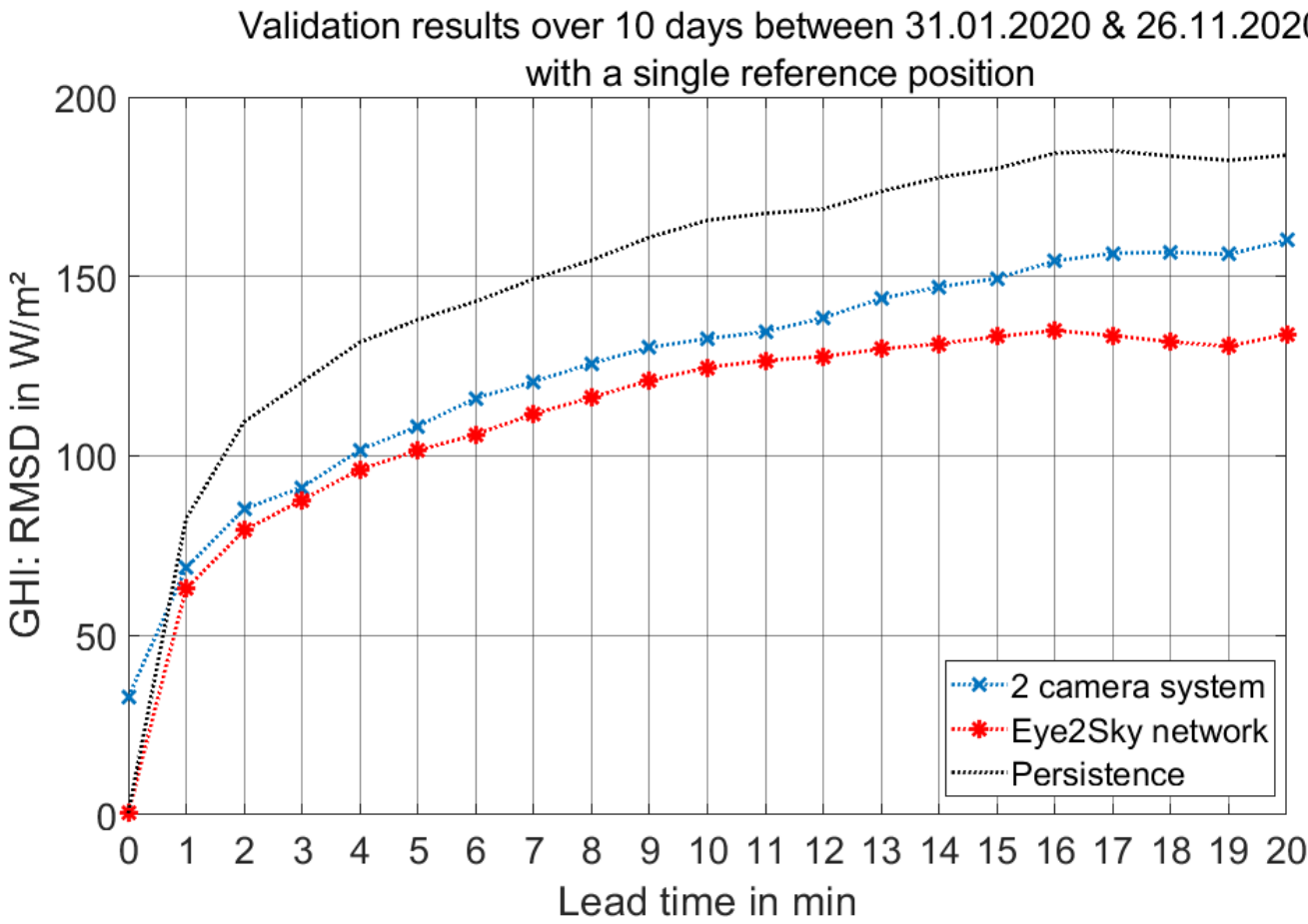
- High resolution over an area of 110 km x 100 km
- 27 / 39 Station in operation
  - 25 All sky imager
  - 10 Meteorological measuring stations with RSI
  - 2 highly precise reference stations with thermal radiometers
  - 2 Ceilometer
- Improved nowcasts accuracy and increased horizon via interconnection of all data sources and the exploitation of redundancies [4]

Eye2Sky network GHI maps LT0





Benchmark Eye2Sky network against 2Cam ASI system

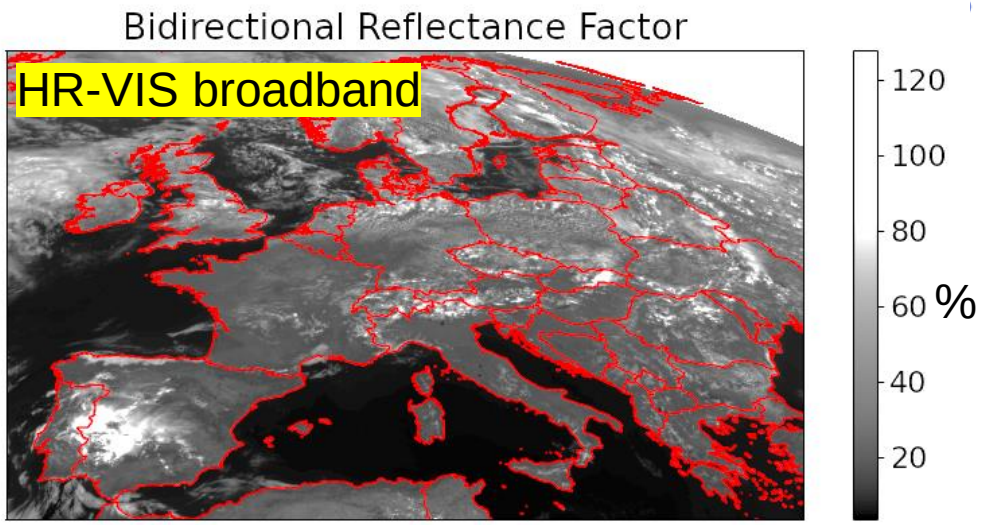


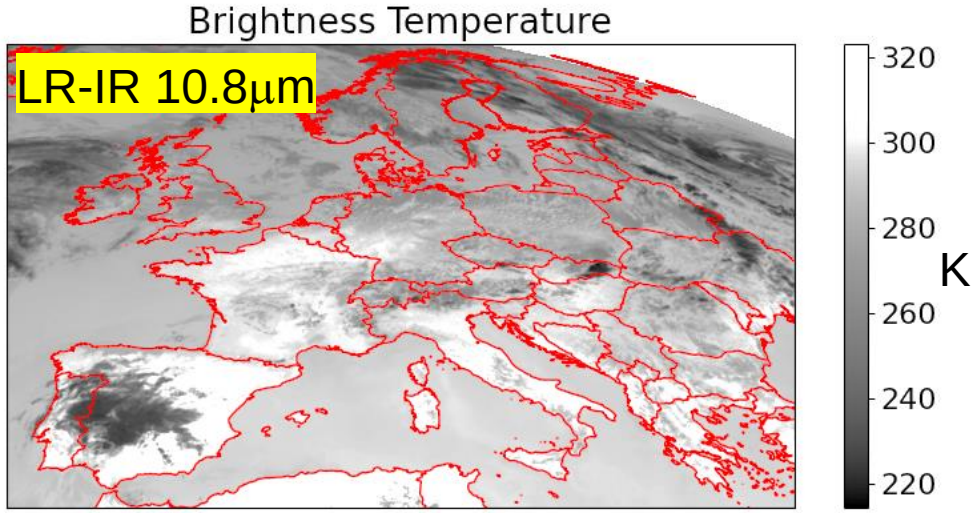
Reference position close to the center of the observed area 2 camera system. Advantage network increases with increasing distance from the center.

- All sky imager (ASI) based nowcasts
- Satellite based forecasts
- Data assimilation

Satellite images for Europe

- Meteosat Second Generation
- Scan every 15 min
- **HR**: High resolution broadband channel, 1km*1km, visible (VIS)
- **LR:** Low resolution narrow band channels, 3km*3km, visible and infrared (VIS and IR)





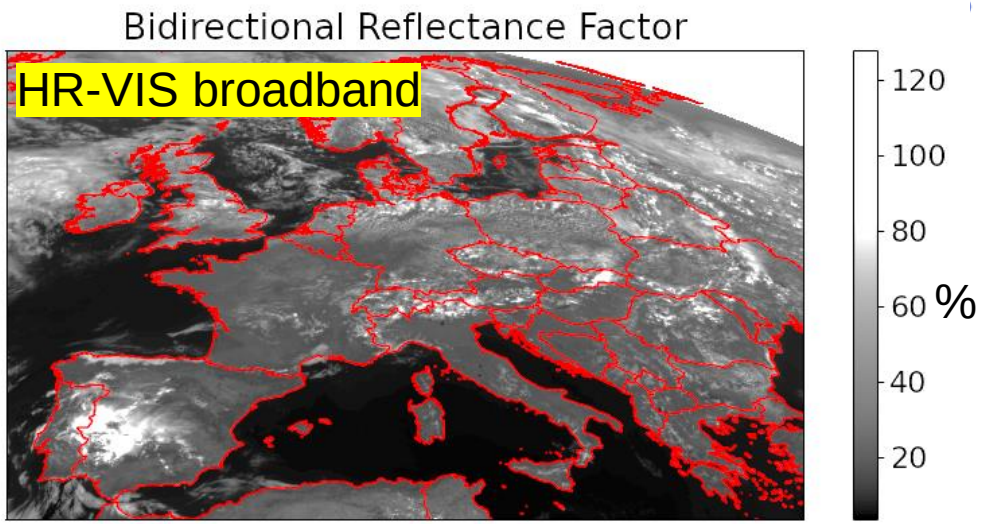
Satellite images for Europe

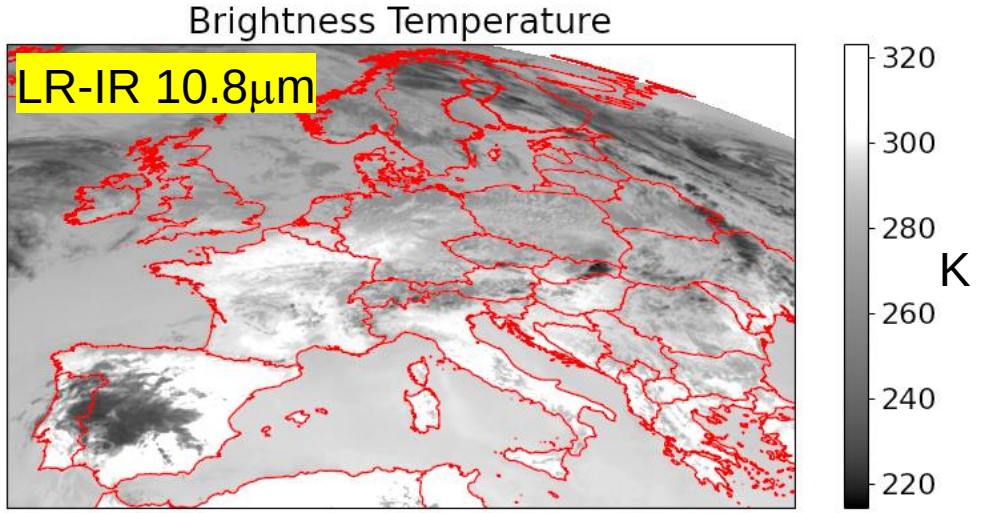
- Meteosat Second Generation
- Scan every 15 min
- **HR**: High resolution broadband channel, 1km*1km, visible (VIS)
- **LR:** Low resolution narrow band channels, 3km*3km, visible and infrared (VIS and IR)

VIS -> reflected sunlight: daytime; cloud detection, vegetation, snow

IR -> brightness temperatures: day and night; cloud top temperature / height

Combination of LR channels for cloud property retrieval





Heliosat method - Cloud detection and irradiance calculation

Bidirectional Reflectance Factor

↓

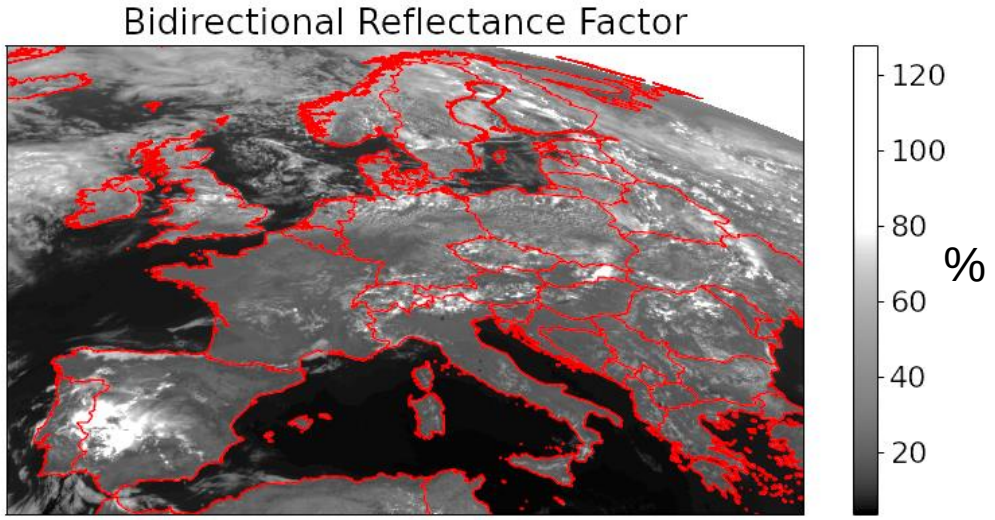
Cloud free reference

↓

Cloud Index / transmittance

↓

Irradiance map



ρ HR-VIS Bidirectional Reflectance factor

Heliosat method -
Cloud detection and irradiance calculation

Bidirectional Reflectance Factor

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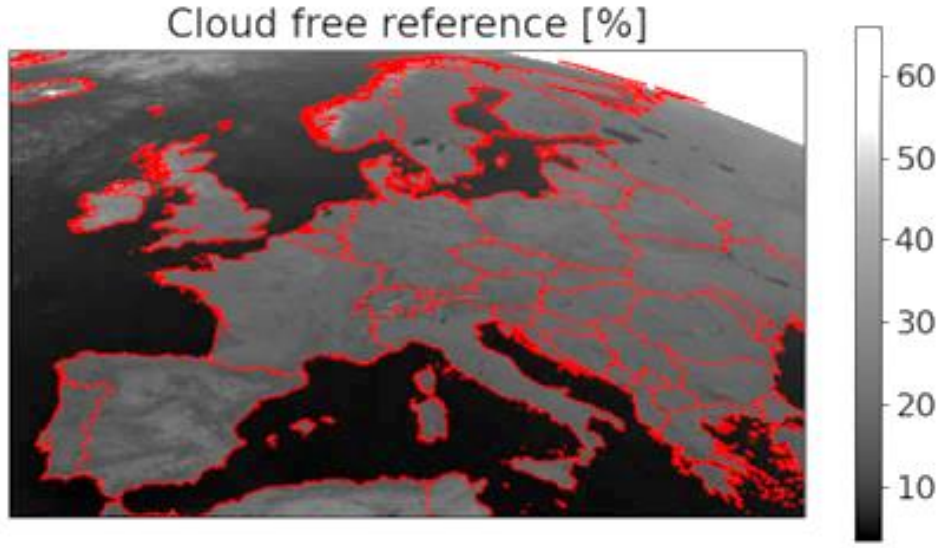
Irradiance map



ρ_{min} Cloud free Reference: „Minimum of the last days“

ρ_{max} Cloud Reference: „Maximum“

Heliosat method - Cloud detection and irradiance calculation

Bidirectional Reflectance Factor

↓

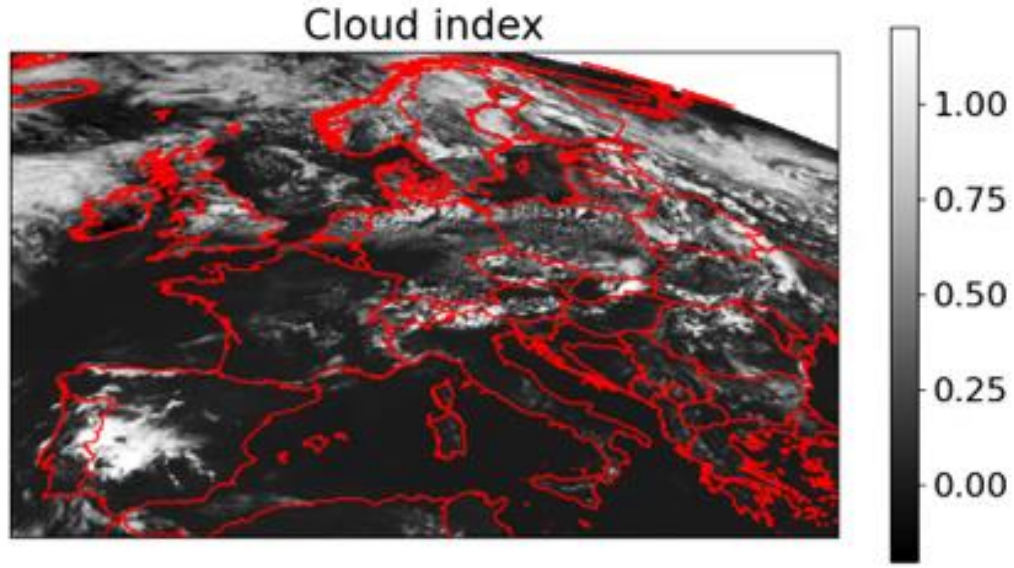
Cloud free reference

↓

Cloud Index / transmittance

↓

Irradiance map



Cloud Index $n = (\rho - \rho_{min}) / (\rho_{max} - \rho_{min})$

Heliosat method -
Cloud detection and irradiance calculation

Bidirectional Reflectance Factor

↓

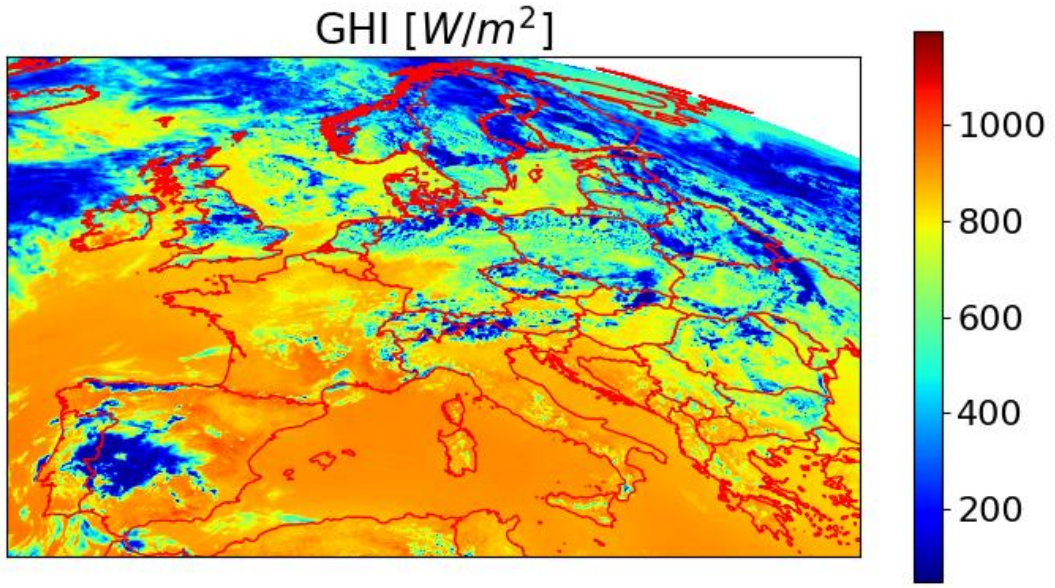
Cloud free reference

↓

Cloud Index / transmittance

↓

Irradiance map

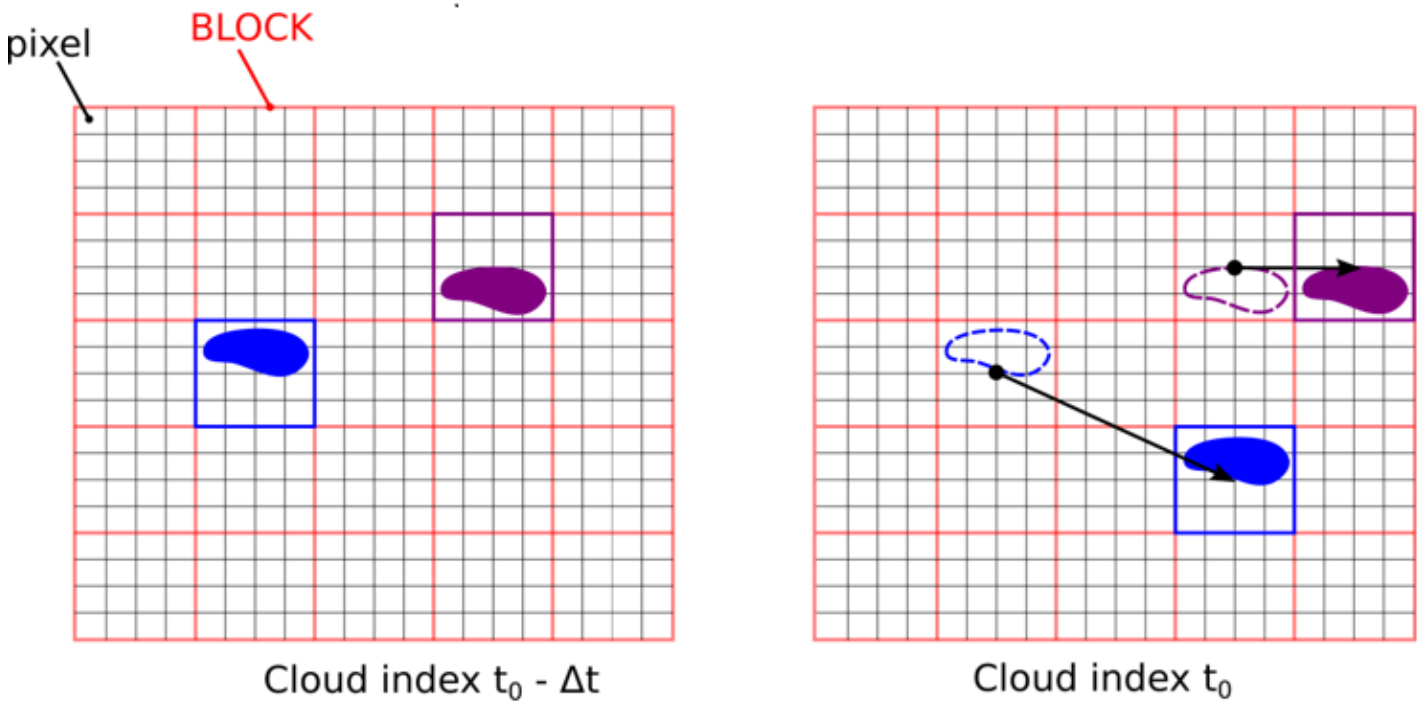


*GHI = (1 - n) * Gclearsky*

Gclearsky : Clearsky Model; f(Turbidity, solar elevation)

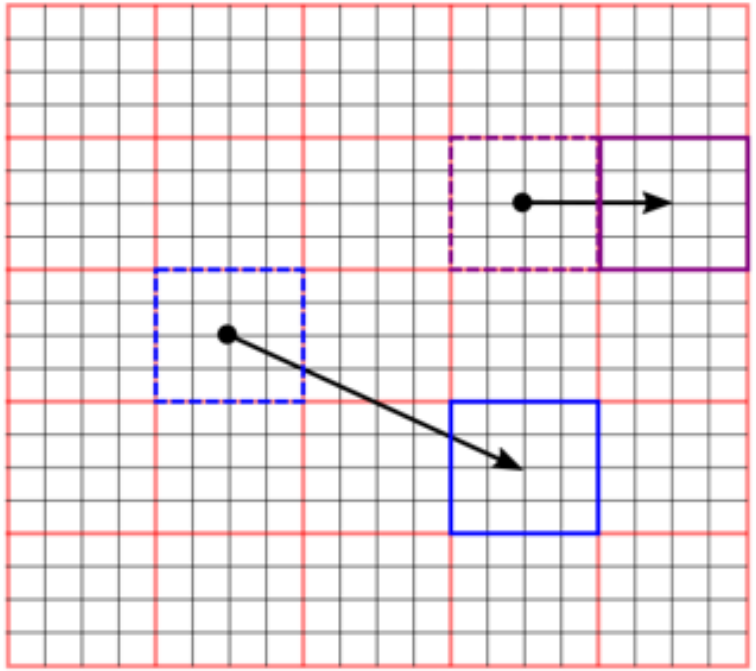
Intraday Forecasting

- **Find motion vectors:**
  block matching between the two most recent consecutive cloud index images
- t_0 : Forecast instance (now)



Intraday Forecasting

- **Extrapolate motion:**
  apply motion vectors for present cloud index blocks at *t0*
  to forecast the next image at $t_0 + \Delta t$

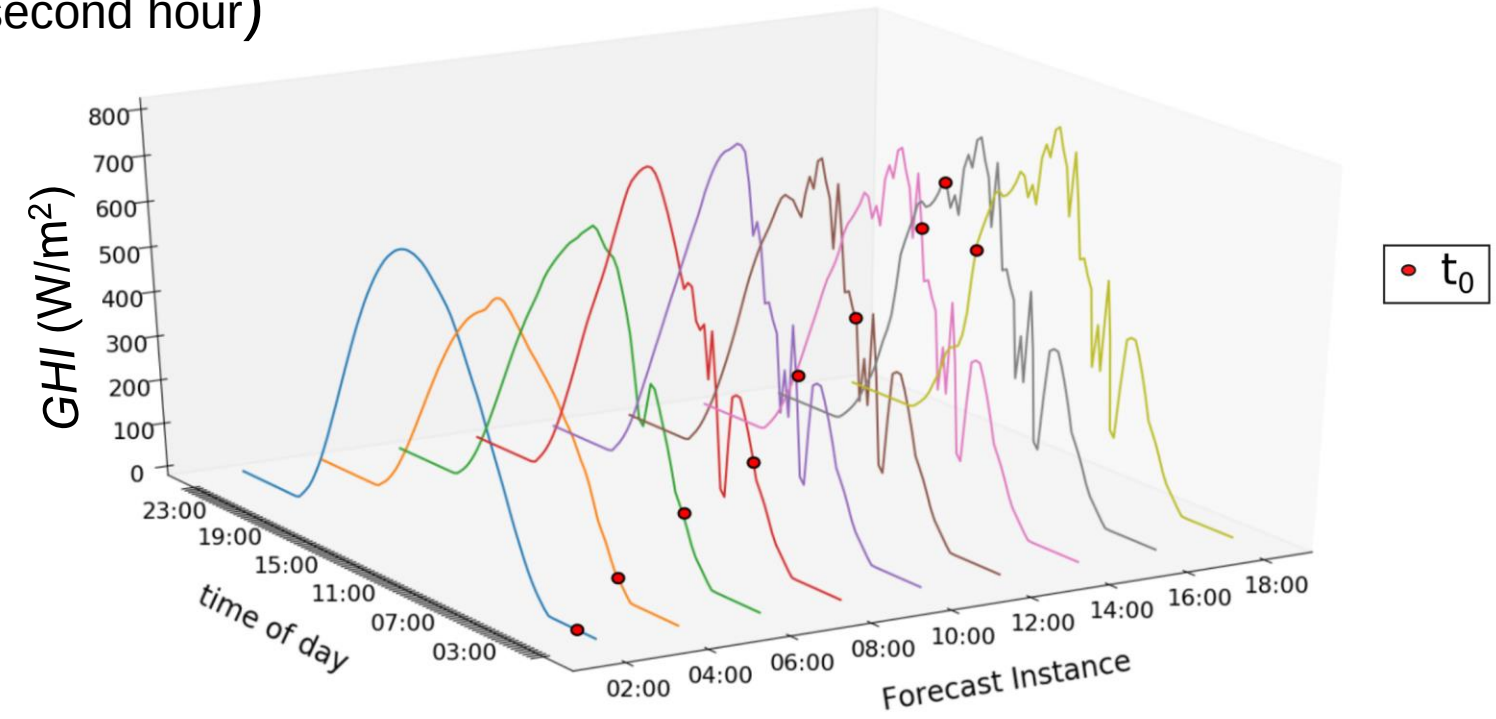


Cloud Motion Vectors (CMV)

- **Repeat** block shifts until end of the day
- **Calculate** *GHI* from Cloud Index

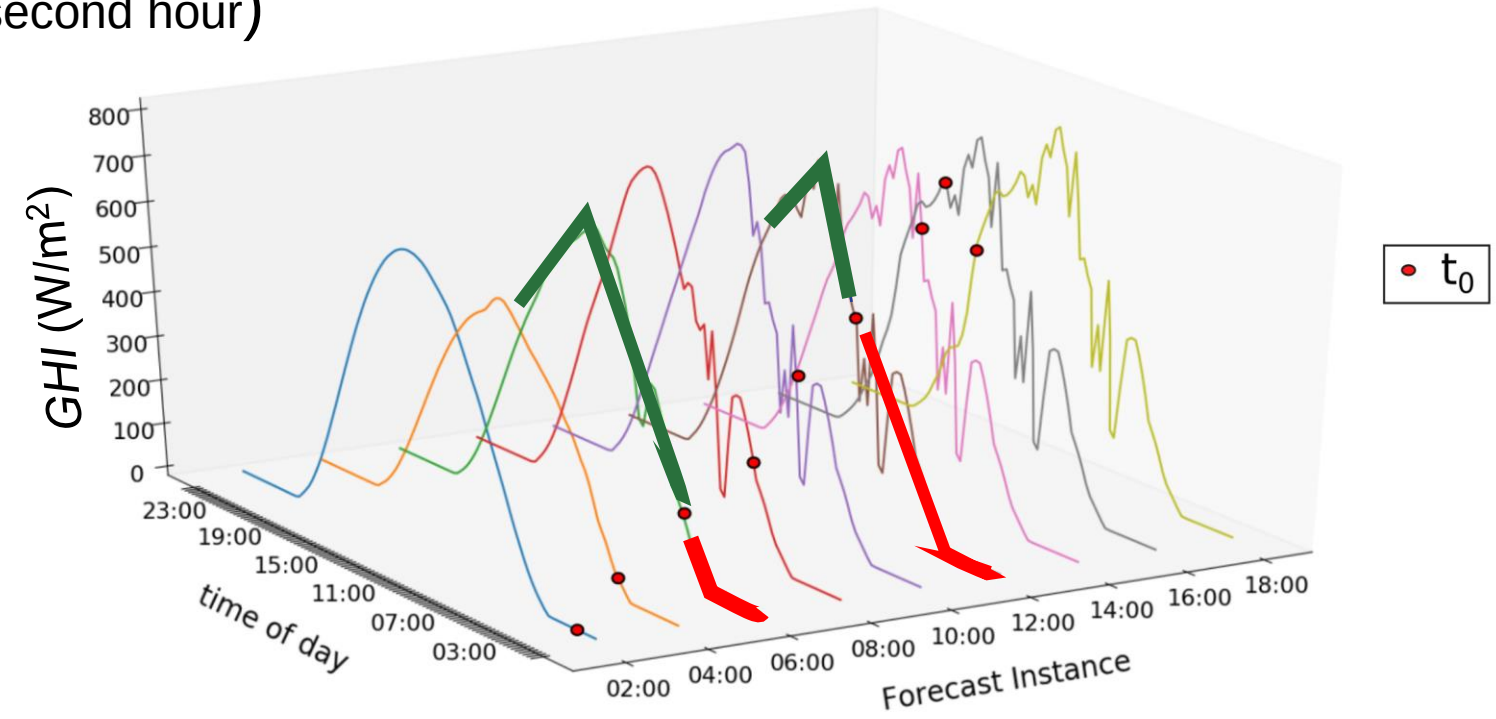
Intraday forecast product for a given site - example

- 96 timeseries of *GHI* (W/m^2) for one day
- Forecast instances *to* (here, every second hour)



Intraday forecast product for a given site - example

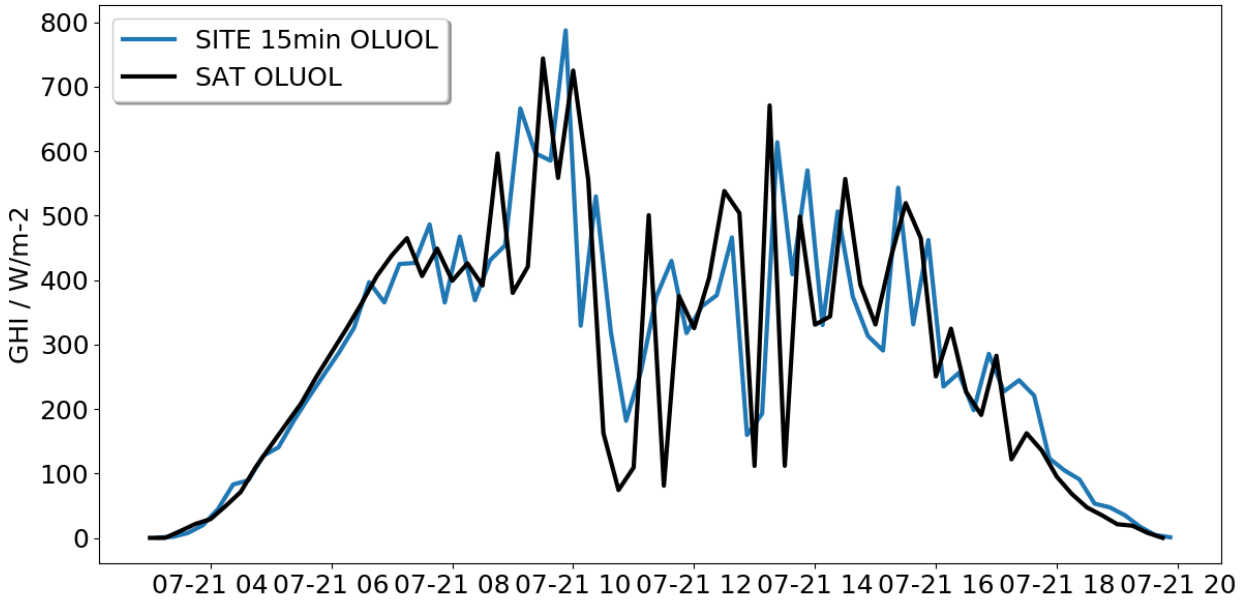
- 96 timeseries of *GHI* (W/m^2) for one day
- Forecast instances *to* (here, every second hour)
- Time series are changing over the day with new information
  - *t* < *to* analysis (past)
  - *t* > *to* forecasts (future)



Summary

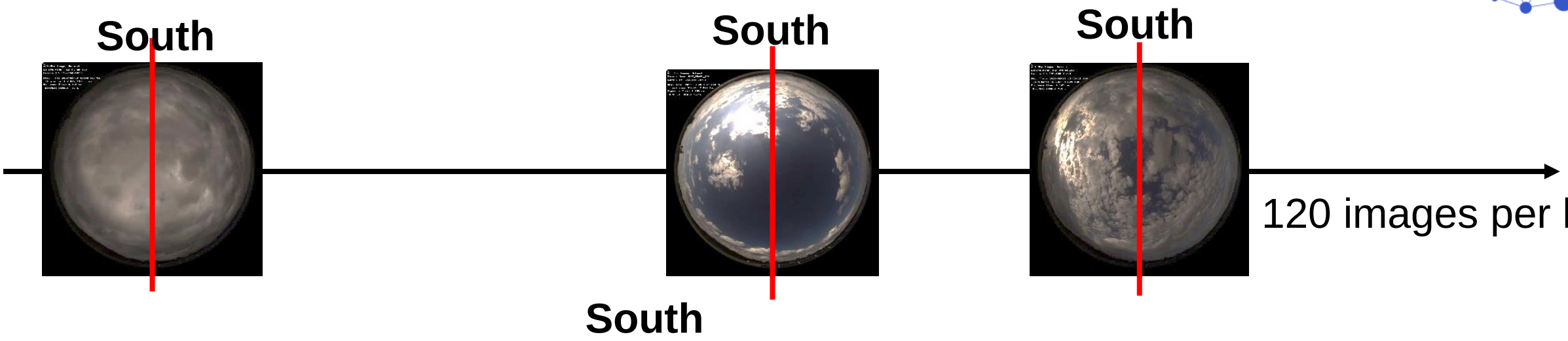
- Intraday forecasts of *GHI* are calculated with Heliosat method and block matching algorithm, see [5] for details
- Temporal resolution: 15 min
- Spatial resolution: 2km * 2.5km in Europe (1km * 1km at sub satellite point)

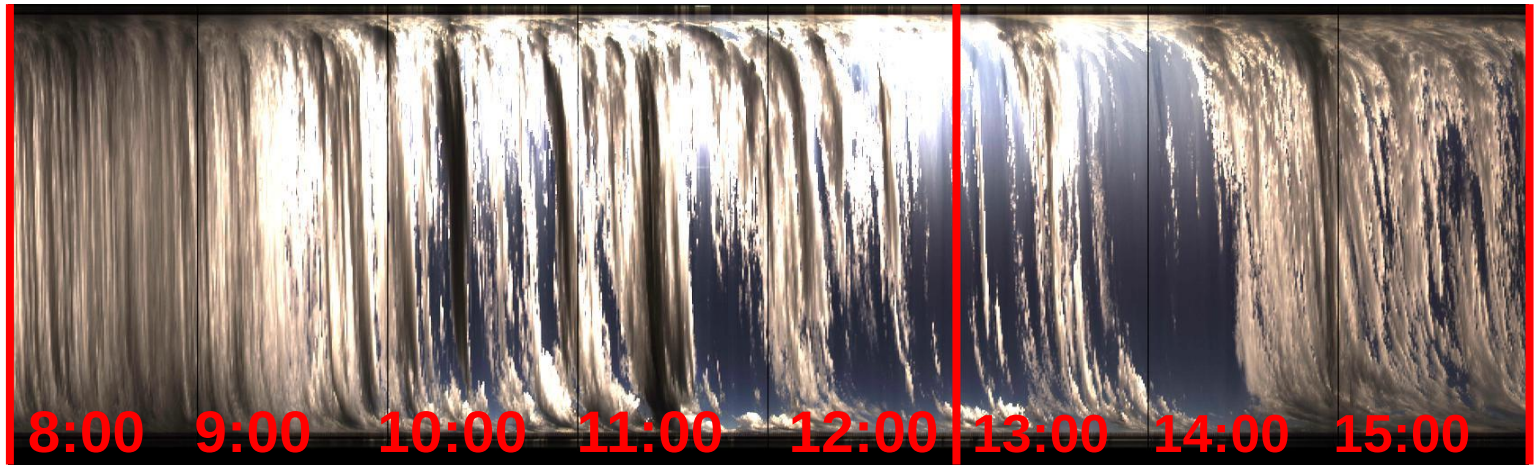
- Result *GHI* time series:
  satellite versus measured (15 min averages)
  at Oldenburg (2020-07-21)



- All sky imager (ASI) based nowcasts
- Satellite based forecasts
- Data assimilation

Keogram-
a fast impression of sky for a day

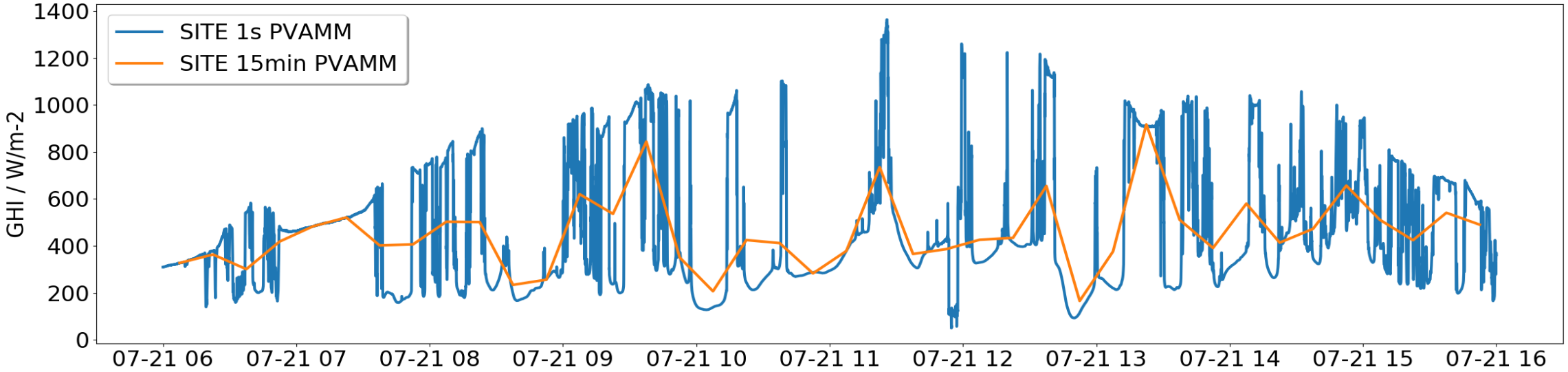




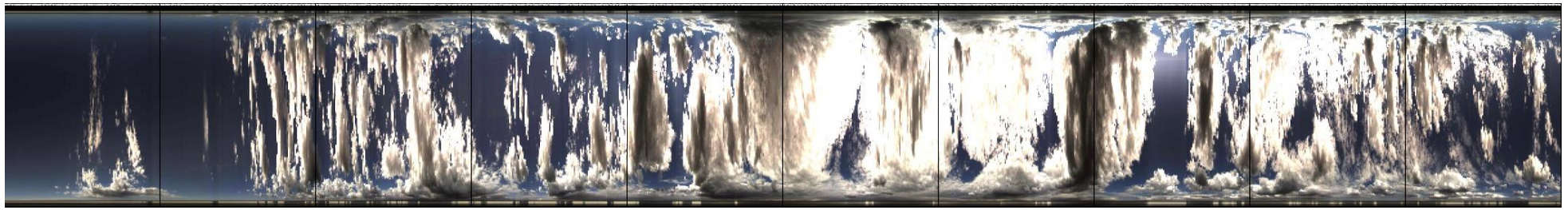
120 lines per hour

Oldenburg, 2020-08-28

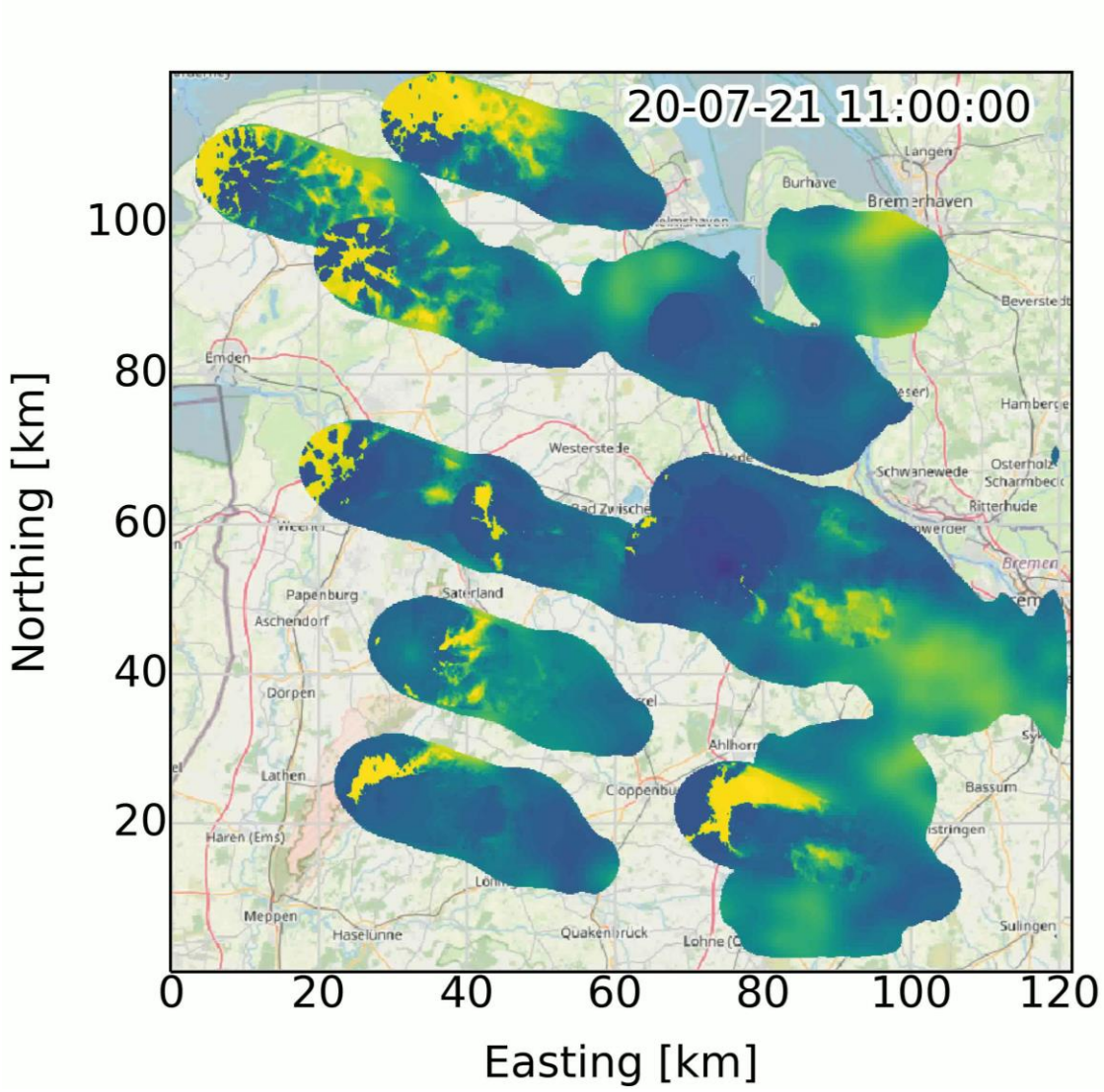
Time series 15 min and 1s, and Keogram

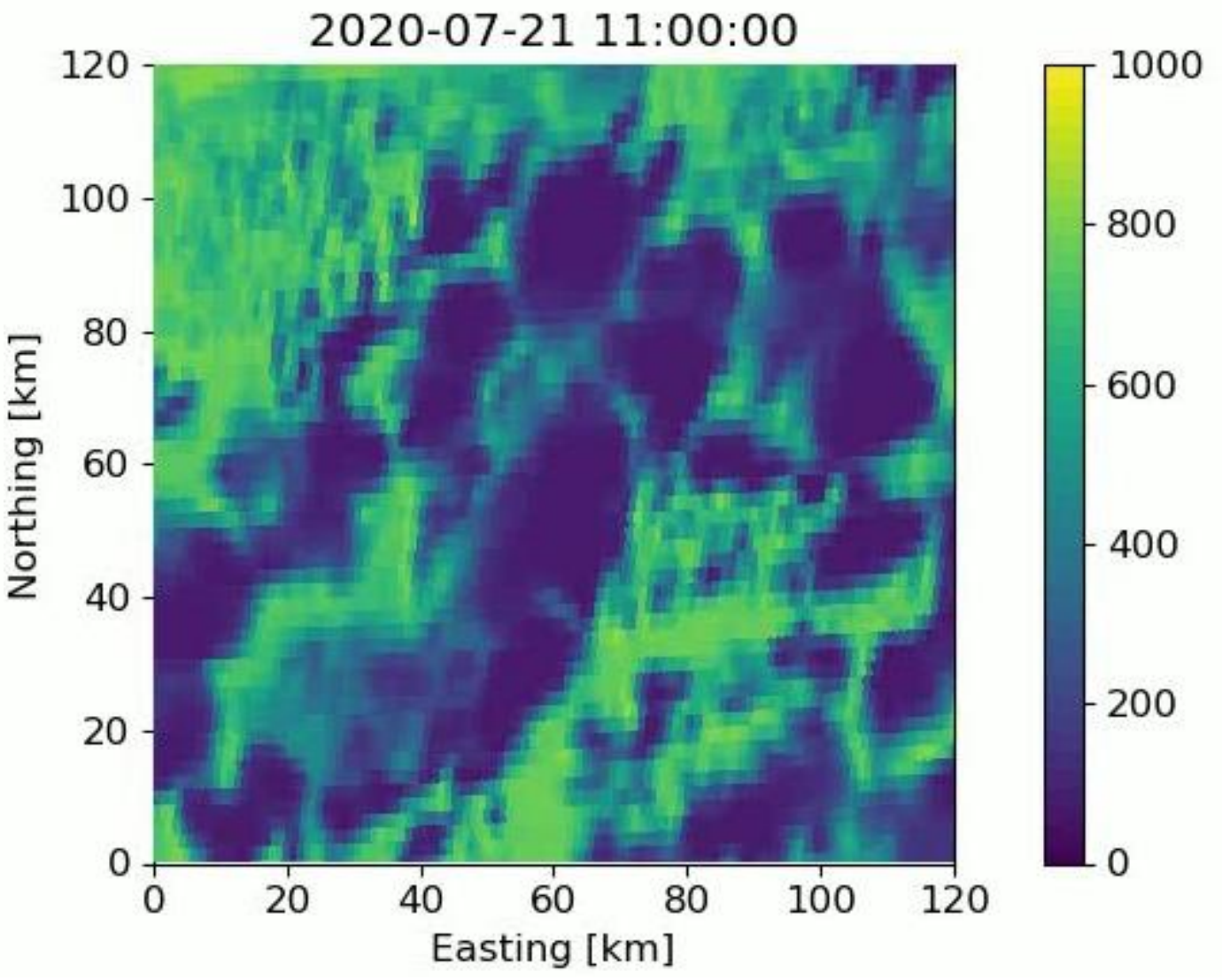


06:00
-
16:00



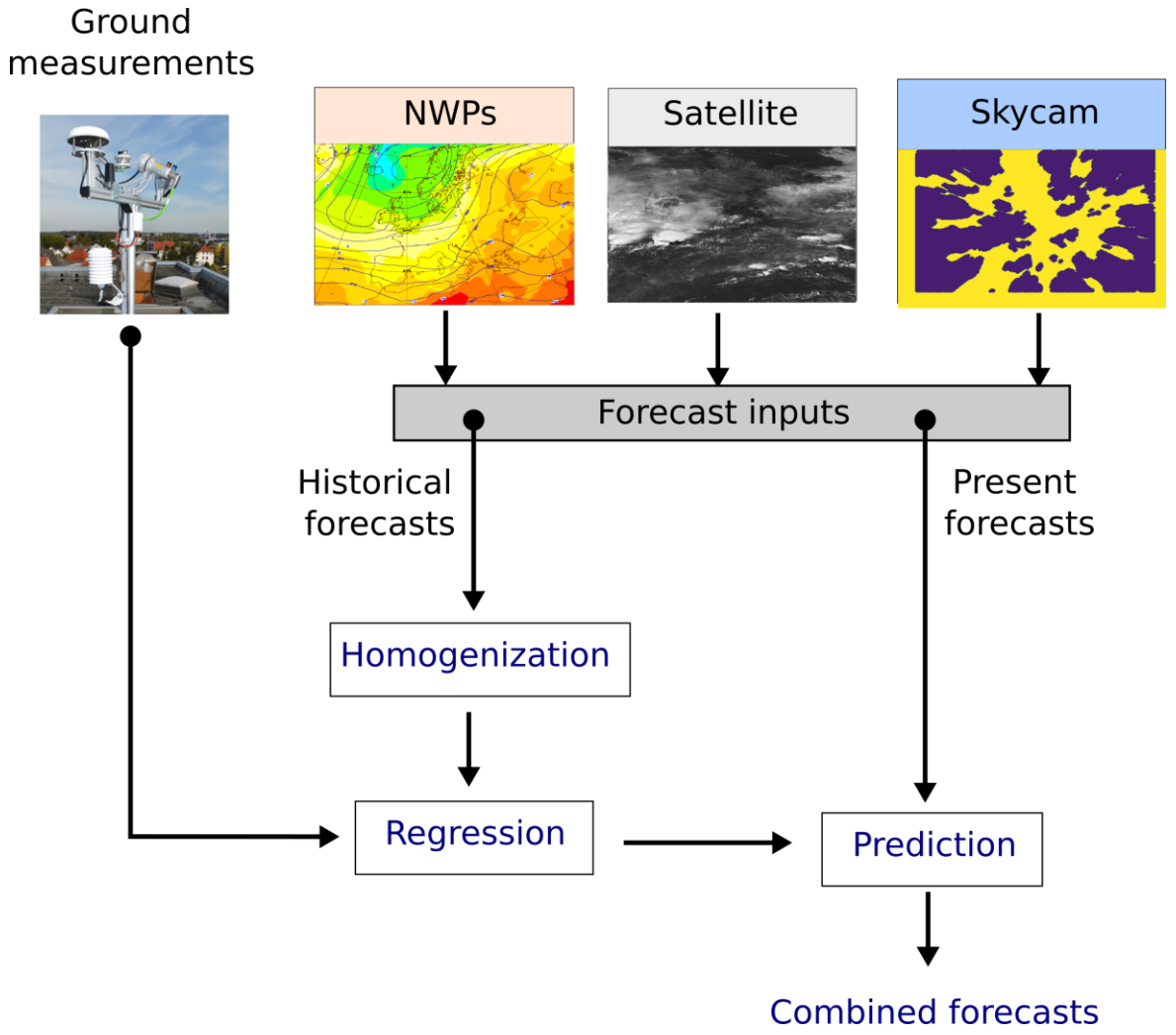
Comparison Eye2Sky network and satellite GHI maps





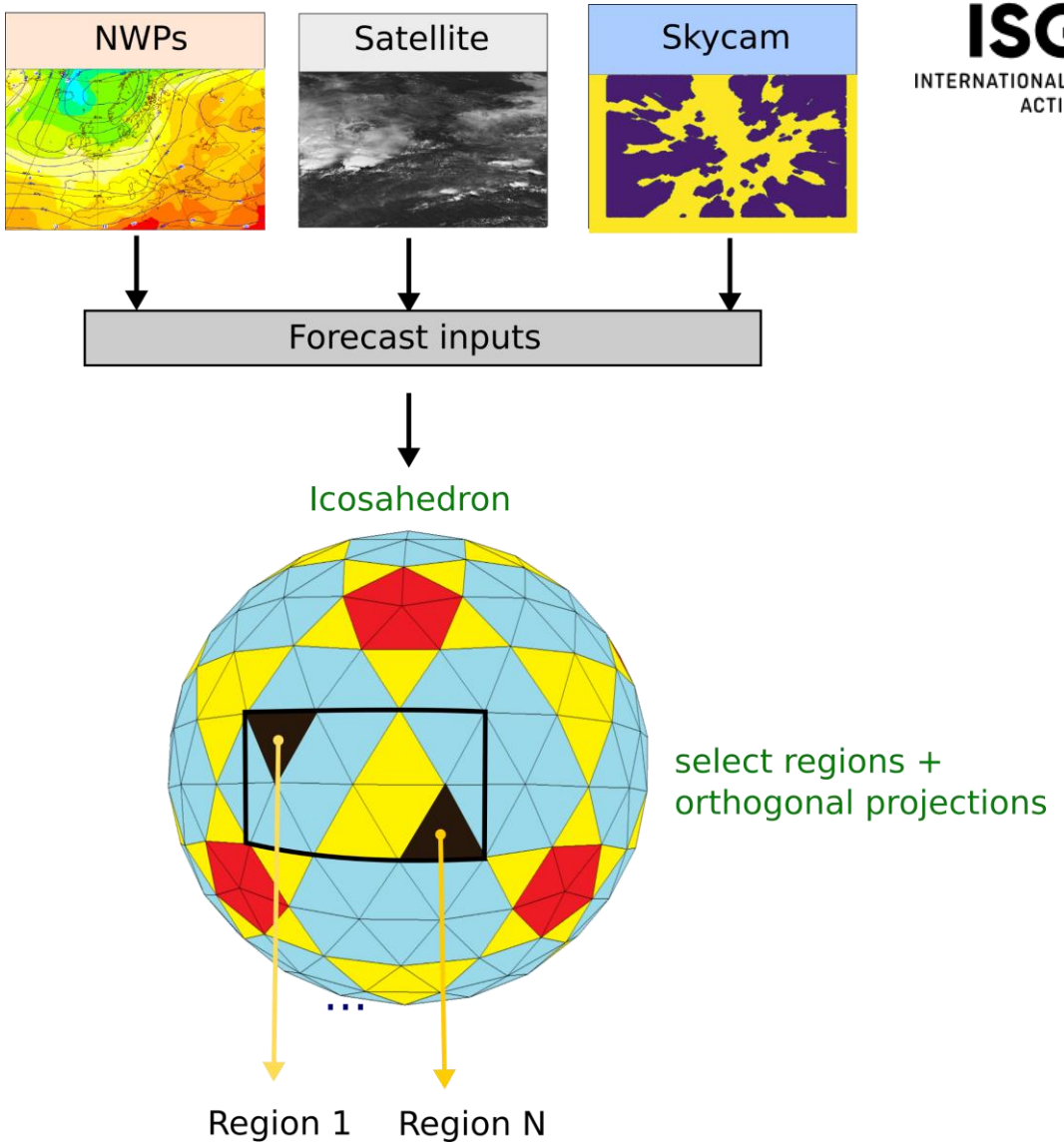
Data combination for GHI

- Combination of forecasts is trained with historical data for different horizons and situations
- The fitted regressors are applied to present input data to calculate a forecast



Homogenization

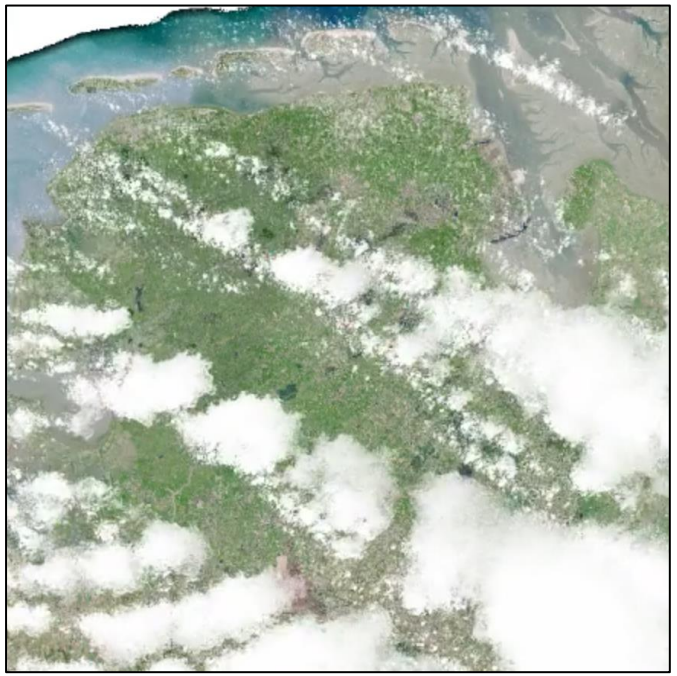
- How to combine different data?
- Icosahedron + orthogonal projections: minimum projection error
- Interpolate in space and time
- Parallel calculation of **independent** regions



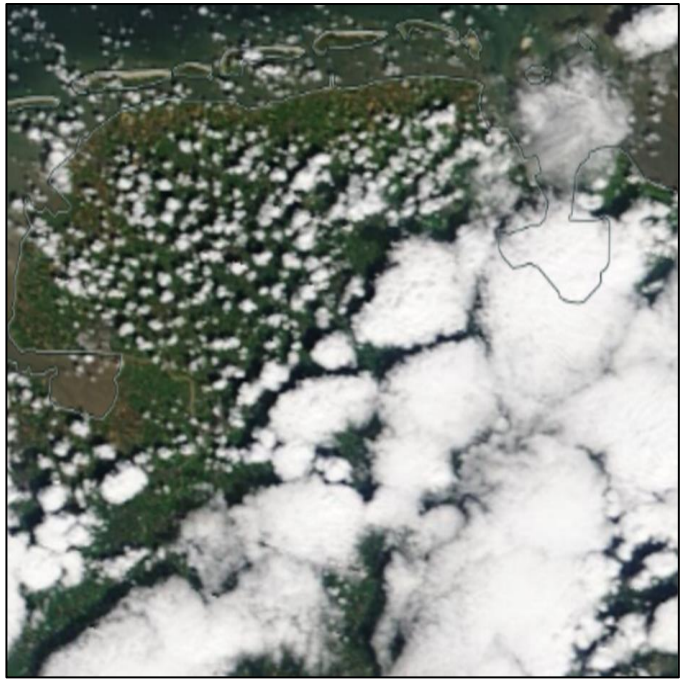
LES forecast for Oldenburg region 21-07-2020 13:00 CEST

- **LES: Large Eddy Simulation**
- Structure / statistical properties of the forecasted cloud field is good.
- Exact location and timing of individual cloud cell is difficult to predict.
- With **data assimilation**, the modeled clouds can be ‘forced’ in the correct position

Satellite view rendering of forecasted cloud field



Satellite image



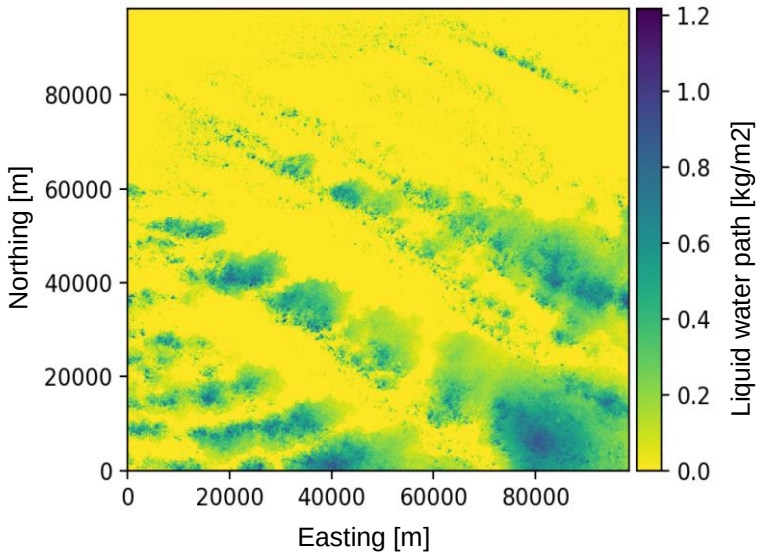
https://worldview.earthdata.nasa.gov/?v=5.95621960562242,51.744548693580 39,8.963660668204447,54.32139416778379&lg=true&t=2020-07-21-T00%3A00%3A00Z

Can we assimilate satellite and sky camera images into the LES model?

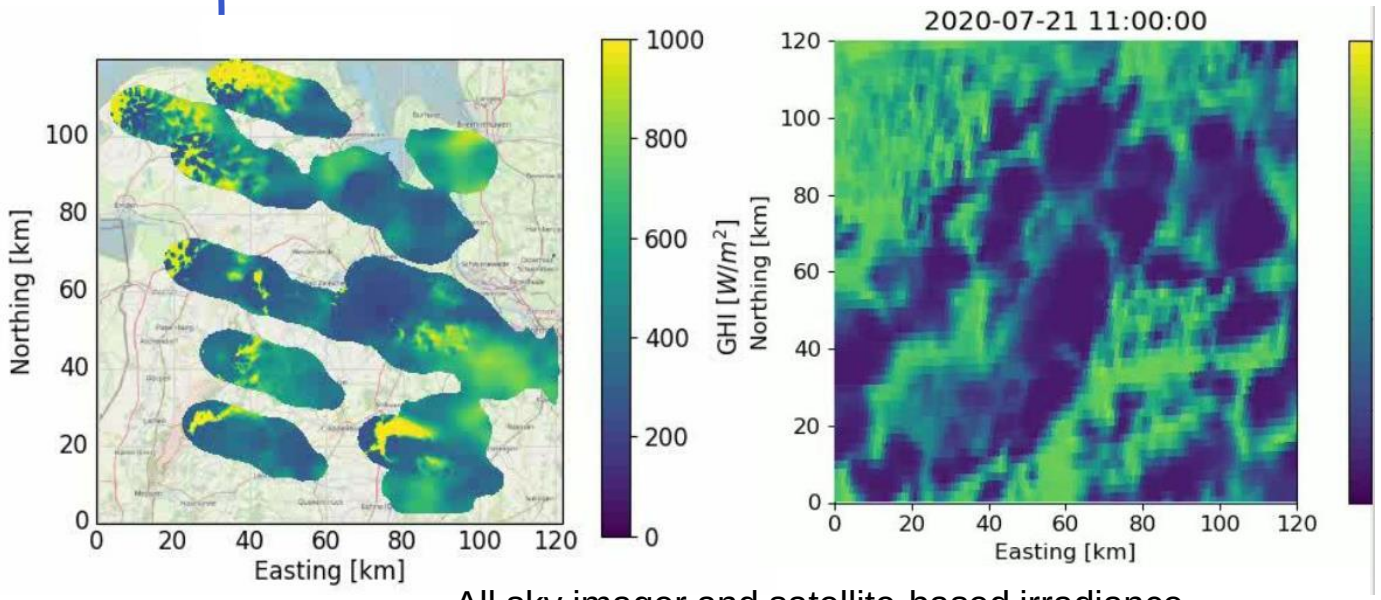
Data assimilation: estimating the state of a system (here: the atmospheric model) given a set of observations and the model dynamics

minimize obj = f (modeled state – observed state)
subject to model dynamics

Using the observed clouds, we can 'adjust' the LES variables so that they best match the observations



LES forecasted *liquid water path*
(total amount of cloud water in the atmospheric column)



All sky imager and satellite-based irradiance

Summary of tasks for advanced solar forecasting

- **Combination of data sources:** Eye2Sky sensor measurements, ASI based forecasts, satellite and NWP forecasts will be combined to a seamless forecast

- **Assimilation:** Eye2Sky data will be used in data assimilation to adjust NWP/LES forecasts

- **Aim:** An improved forecast of solar irradiance (global, direct, diffuse and tilted) will improve PV power forecasting

Further reading

(1) Fabel, Y., Nouri, B., Wilbert, S., Blum, N., Triebel, R., Hasenbalg, M., ... & Pitz-Paal, R. (2021). Applying self-supervised learning for semantic cloud segmentation of all-sky images. *Atmospheric Measurement Techniques Discussions*, 1-20.

(2) Nouri, B., Kuhn, P., Wilbert, S., Hanrieder, N., Prahl, C., Zarzalejo, L., ... & Pitz-Paal, R. (2019). Cloud height and tracking accuracy of three all sky imager systems for individual clouds. *Solar Energy*, *177*, 213-228.

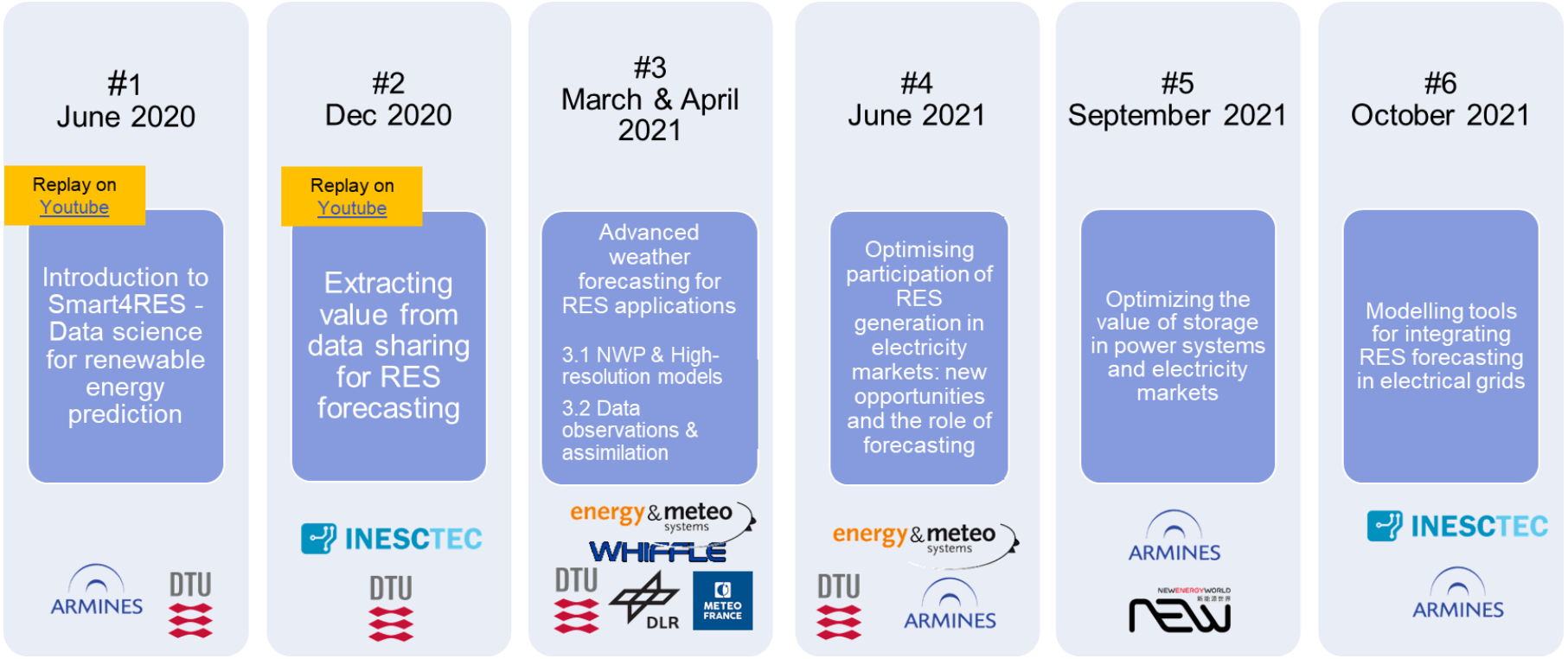
(3) Nouri, B., Wilbert, S., Segura, L., Kuhn, P., Hanrieder, N., Kazantzidis, A., ... & Pitz-Paal, R. (2019). Determination of cloud transmittance for all sky imager based solar nowcasting. *Solar Energy*, *181*, 251-263.

(4) Blum, N. B., Nouri, B., Wilbert, S., Schmidt, T., Lünsdorf, O., Stührenberg, J., ... & Pitz-Paal, R. (2020). Cloud height measurement by a network of all-sky-imagers. *Atmospheric Measurement Techniques Discussions*, 1-29.

(5) Hammer, A., Kühnert, J., Weinreich, K., Lorenz, E. (2015) „Short-Term Forecasting of Surface Solar Irradiance Based on Meteosat-SEVIRI Data Using a Nighttime Cloud Index.“ *Remote Sensing* 7, Nr. 7 (2015): 9070. doi:10.3390/rs70709070.

Smart4RES webinar series

Season1: Towards a new Standard for the entire RES forecasting value chain



Stay tuned!

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Thank you

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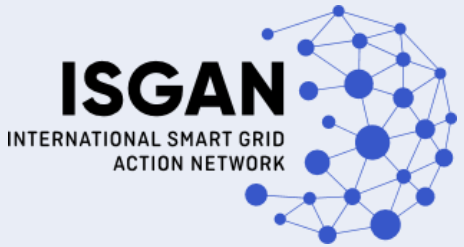

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