Forecasting Solar Irradiance by looking at clouds from above and below

Helmholtz Imaging Conference, Hamburg, 14.-17. June 2023

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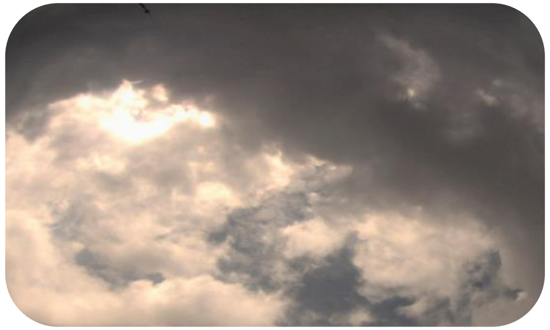
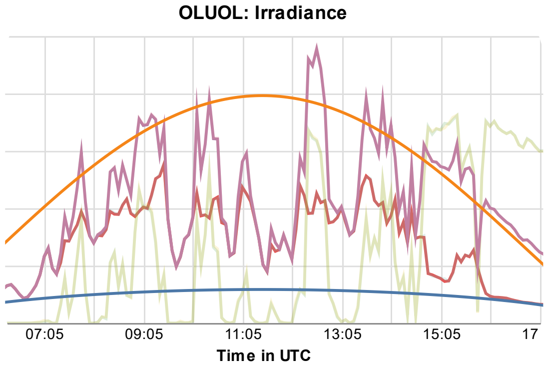
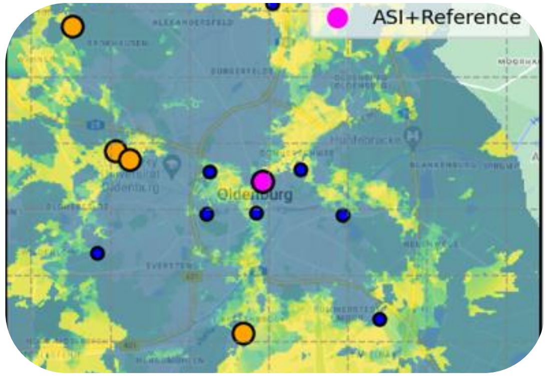
Overview



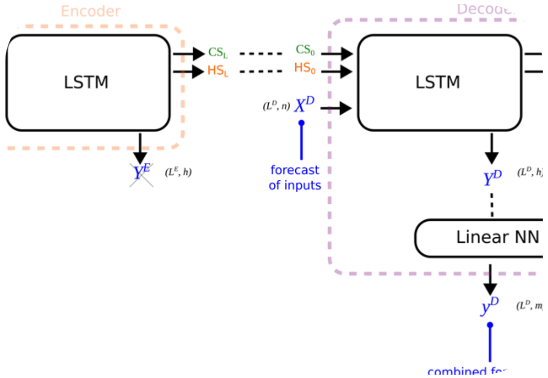
Tracking clouds from above and below – data sources



Solar irradiance modelling in the presence of clouds



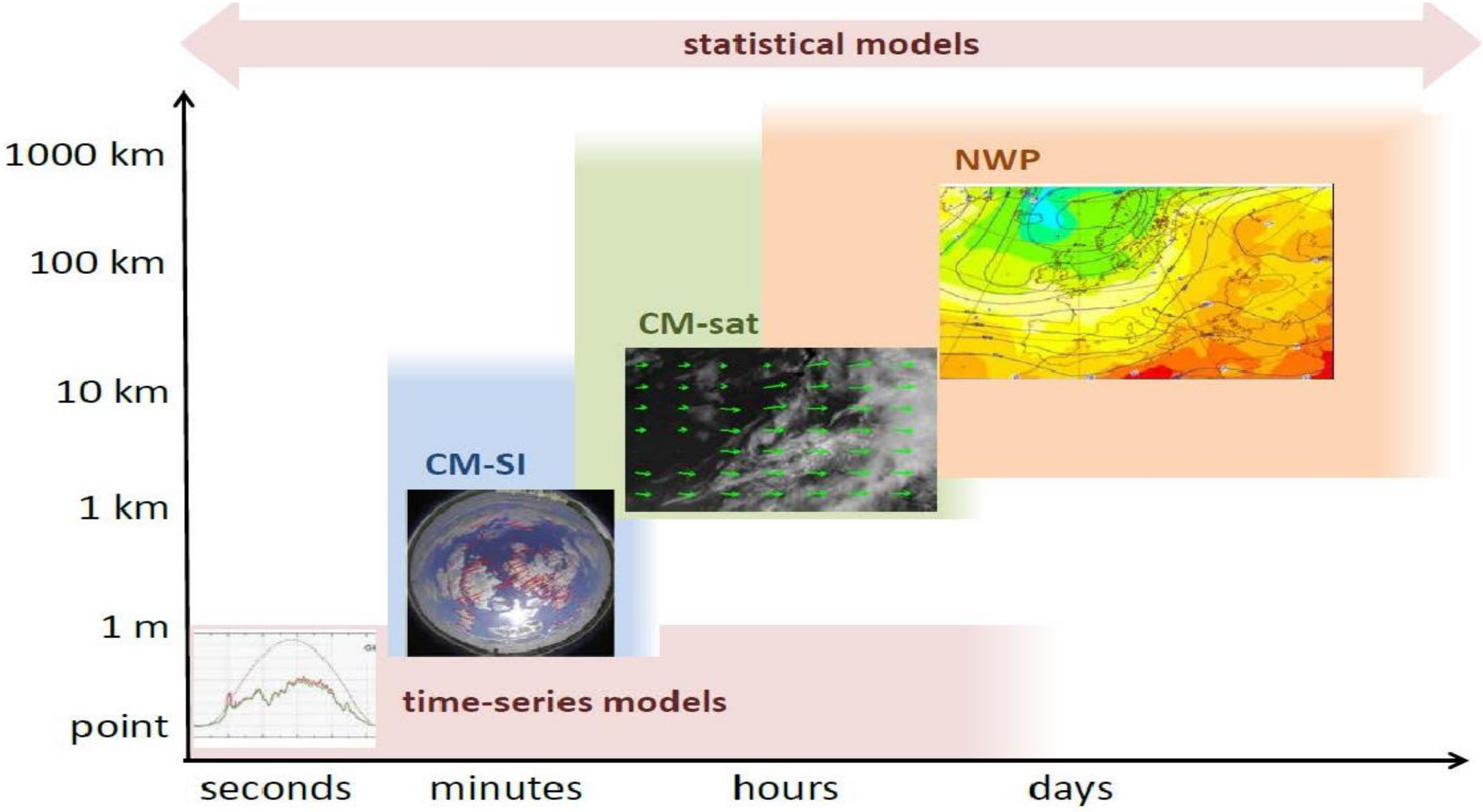
Towards a seamless forecast – from deterministic modelling to AI approaches



Collaborations within Helmholtz Community

DATA SOURCES

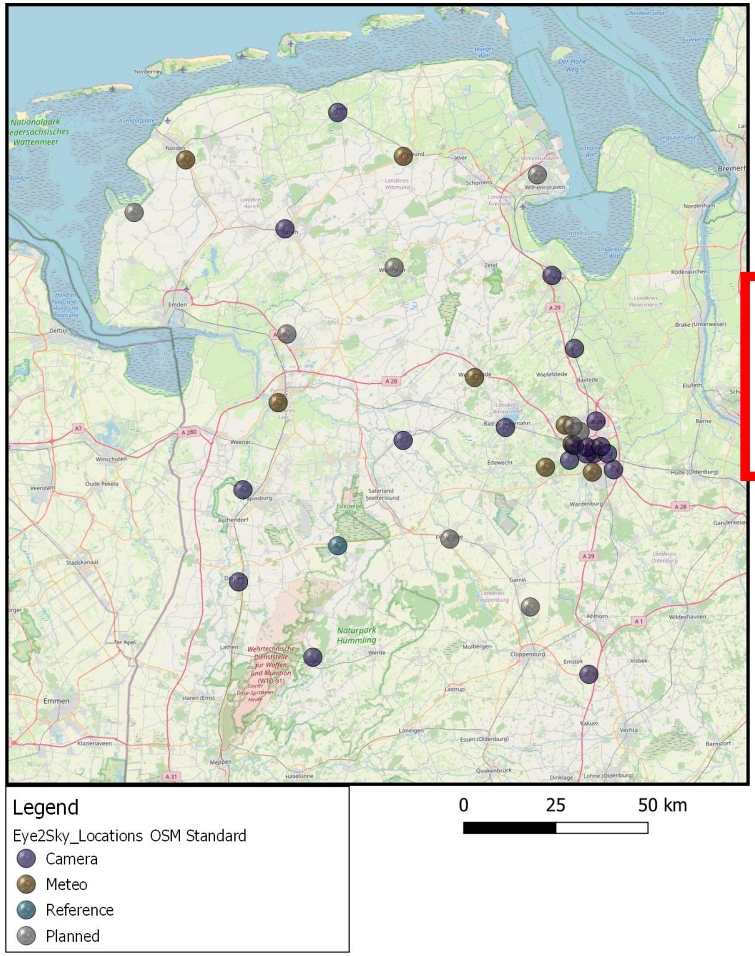
Solar Power Forecasts



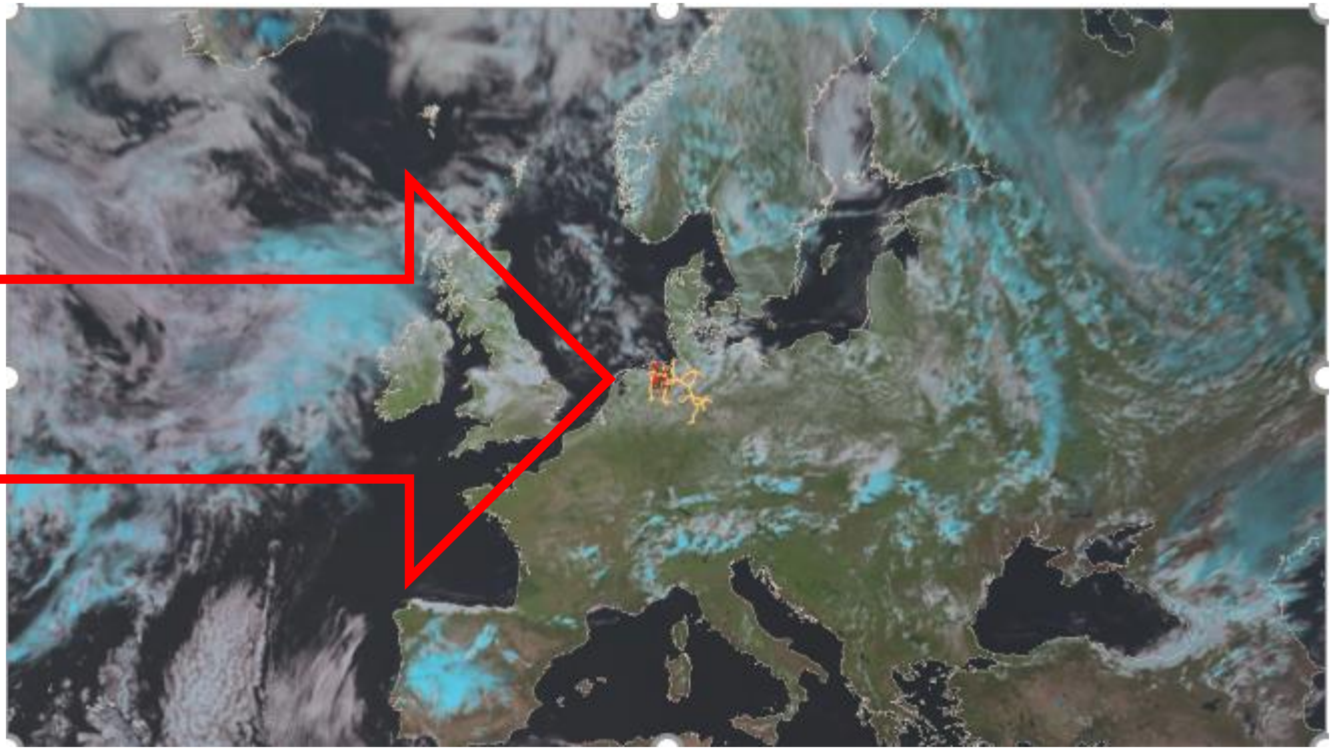
Sengupta et al.: Best Practices Handbook for the Collection and Use of Solar Resource Data for Solar Energy Applications, Technical Report NREL/TP-5D00-63112, Denver, 236pp, 2015

Data Sources for Cloud Detection and Solar Irradiance Measurements

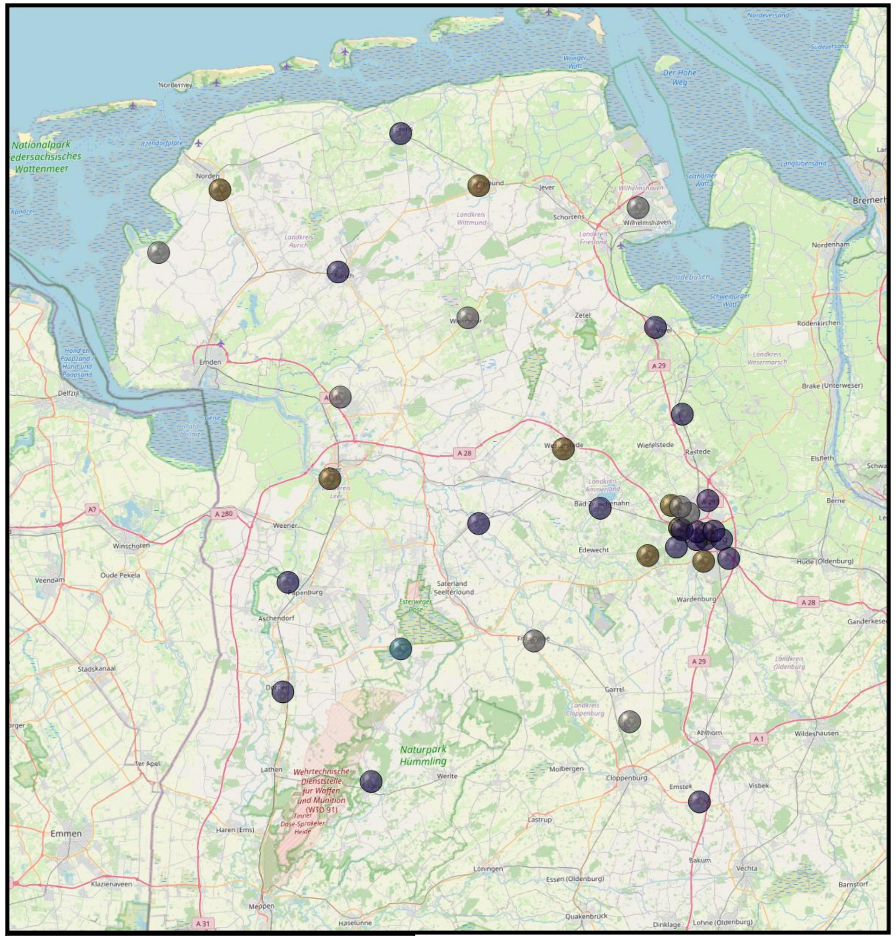
Eye2Sky - Cloud camera and meteorological measurement network in Oldenburg



Meteosat Second Generation – geostationary satellite



Eye2Sky - Cloud camera and meteorogical measurement network in Oldenburg

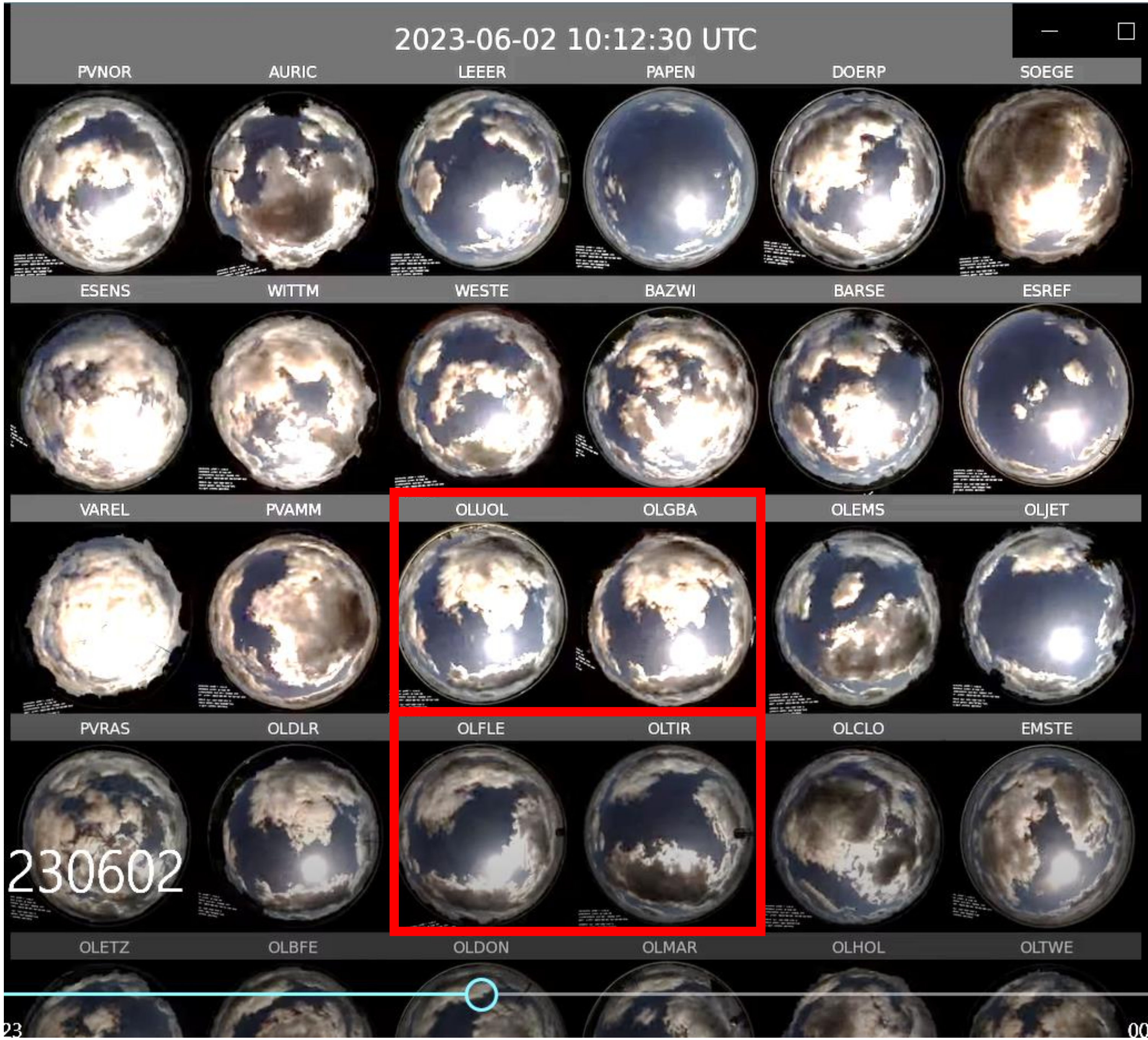


Legend

Eye2Sky_Locations OSM Standard

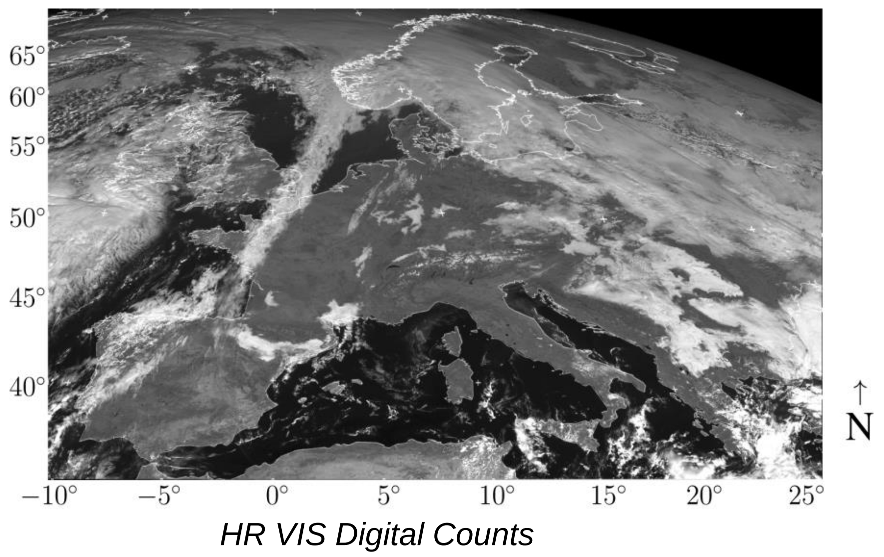
- Camera
- Meteo
- Reference
- Planned

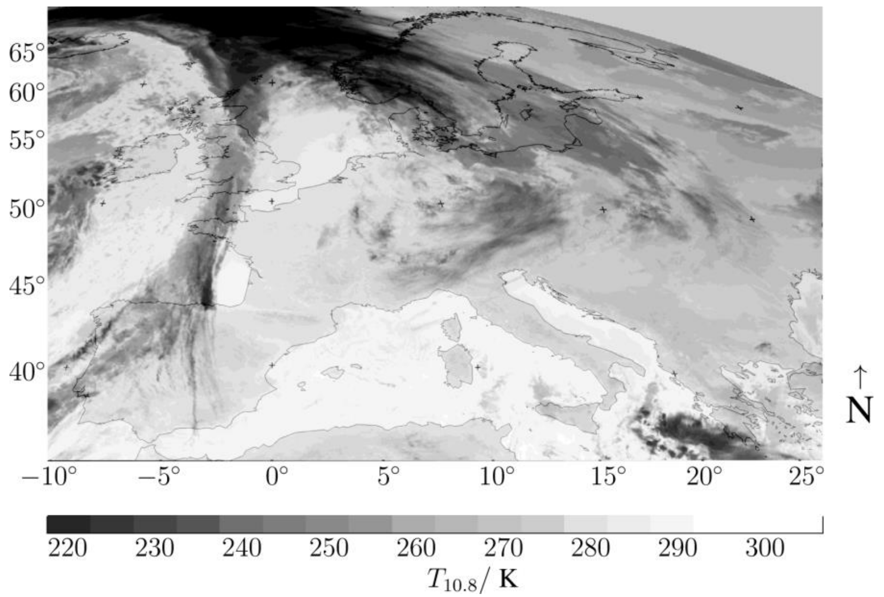
0 25 50 km

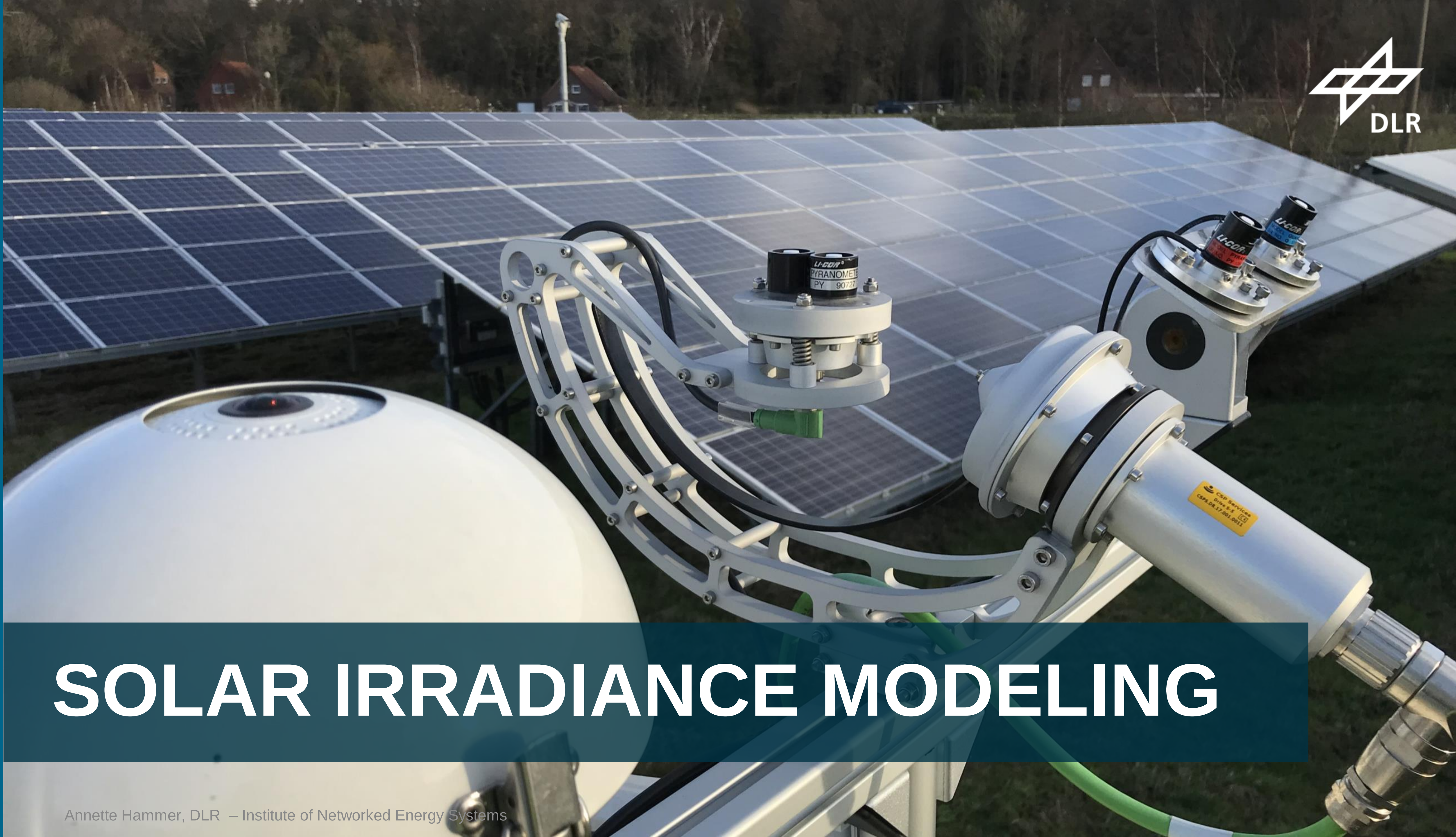


Meteosat Second Generation vs Eye2Sky

	Eye2Sky	Meteosat Second Generation
Instrument and Provider	All Sky Imager: Webcam with fish eye lense; Mobotix	Spinning Enhanced Visible and InfraRed Imager (SEVIRI); EUMETSAT;
Data	RGB images	12 channels (600nm -12µm)
Type and Size	JPG 2112 x 2048 pixel	HRIT 10bit per pixel -> HDF5 3600 x 1800 pixel for Europe
Spatial resolution	50 m x 50 m	1km x 1km (High Resolution Visible) / 3km x 3km other solar and thermal channels (at sub satellite point)
Update frequency	30 s	15 min; 5 min rapid scan



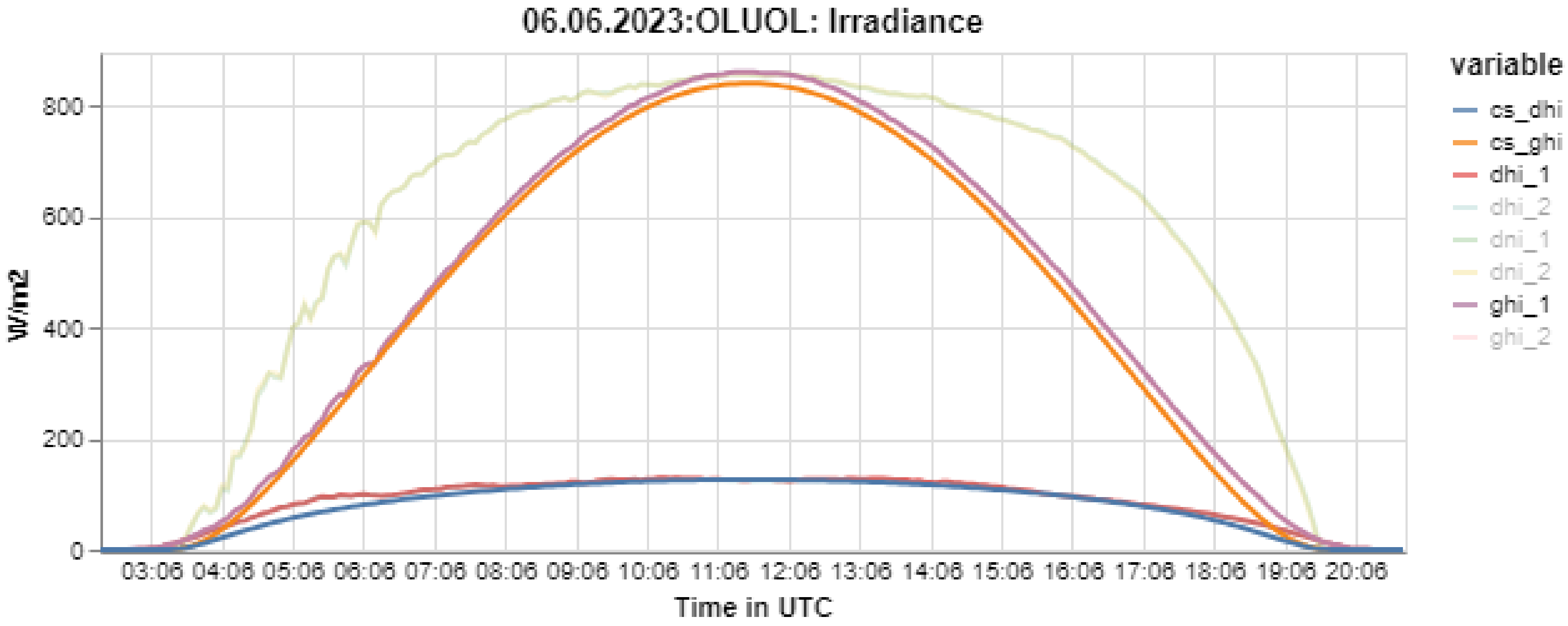




SOLAR IRRADIANCE MODELING

Annette Hammer, DLR – Institute of Networked Energy Systems

Solar irradiance in a clear sky



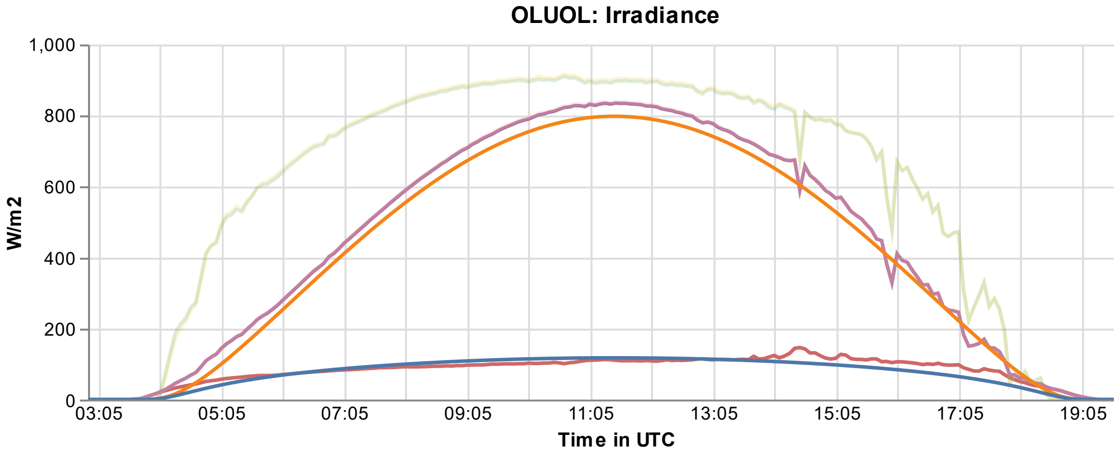
Global Horizontal Irradiance (GHI); Clear Sky Model GHI; Measurement GHI
Diffuse Horizontal Irradiance (DHI); Clear Sky Model DHI; Measurement DHI

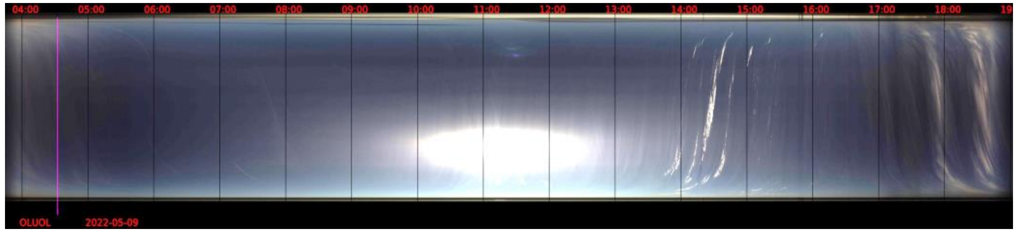
Clear Sky Model

Inputs: atmospheric turbidity and solar elevation

Variability of solar irradiance mainly caused by clouds

2022-05-09





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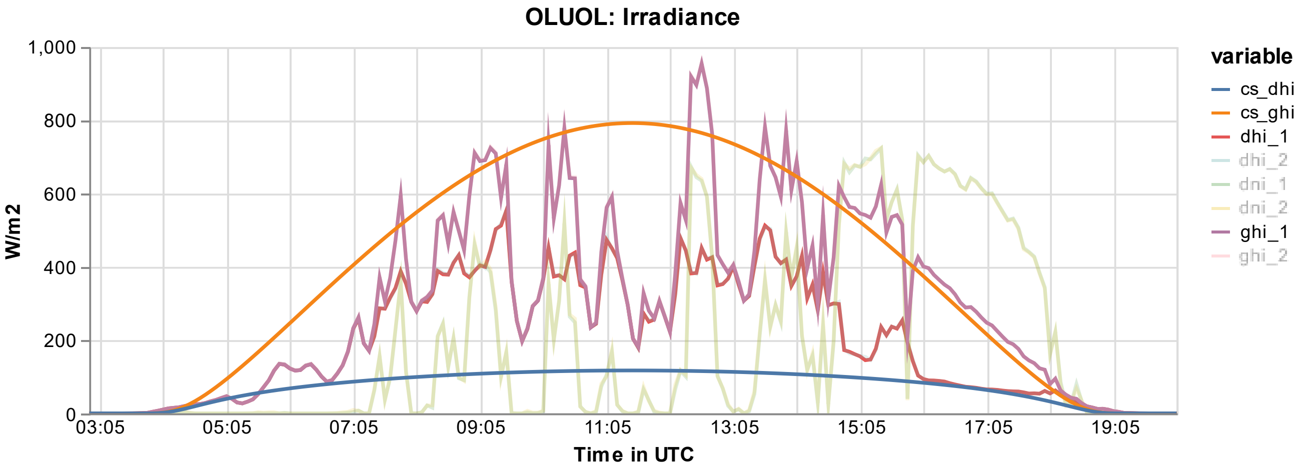
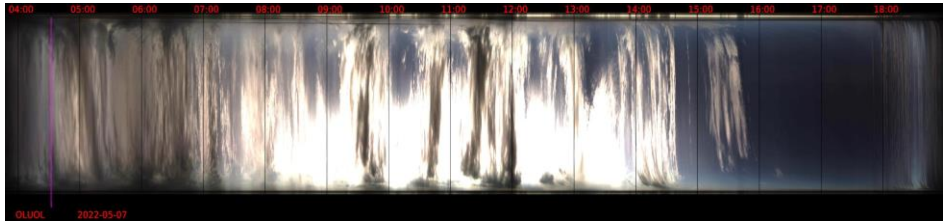




SOLAR IRRADIANCE FORECASTING

Annette Hammer, DLR – Institute of Networked Energy Systems

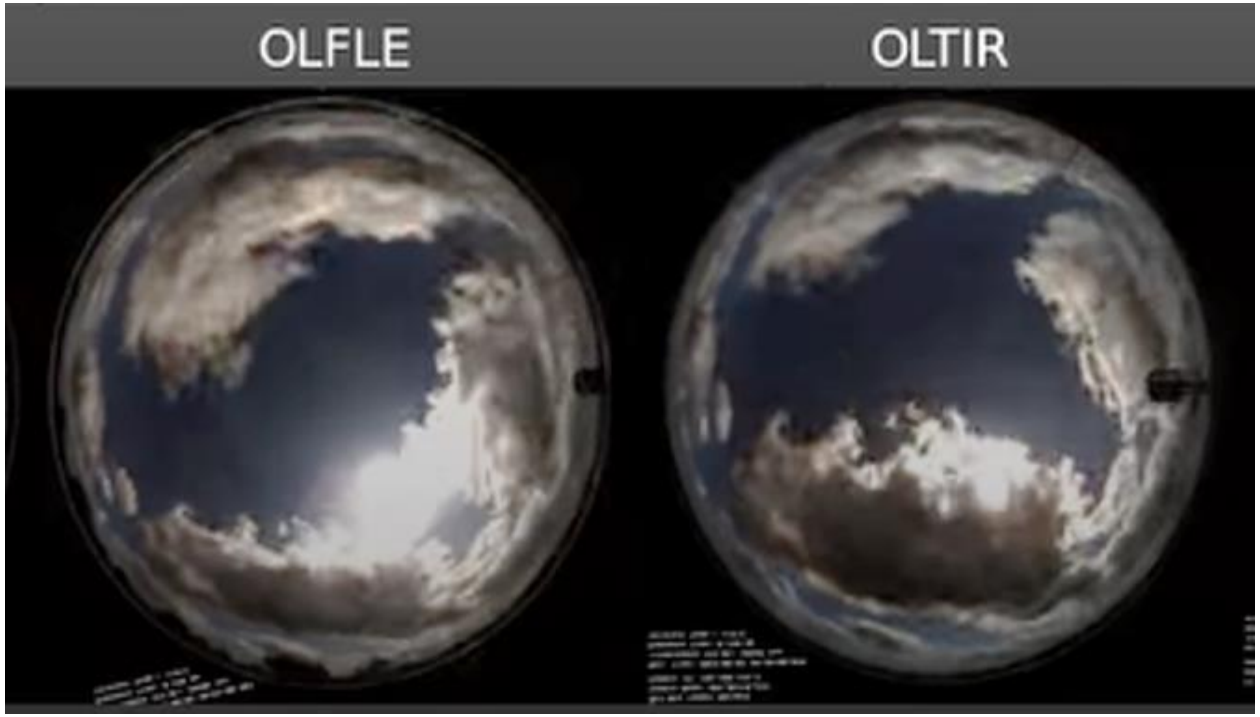
What do we need to know for deterministic forecasting?

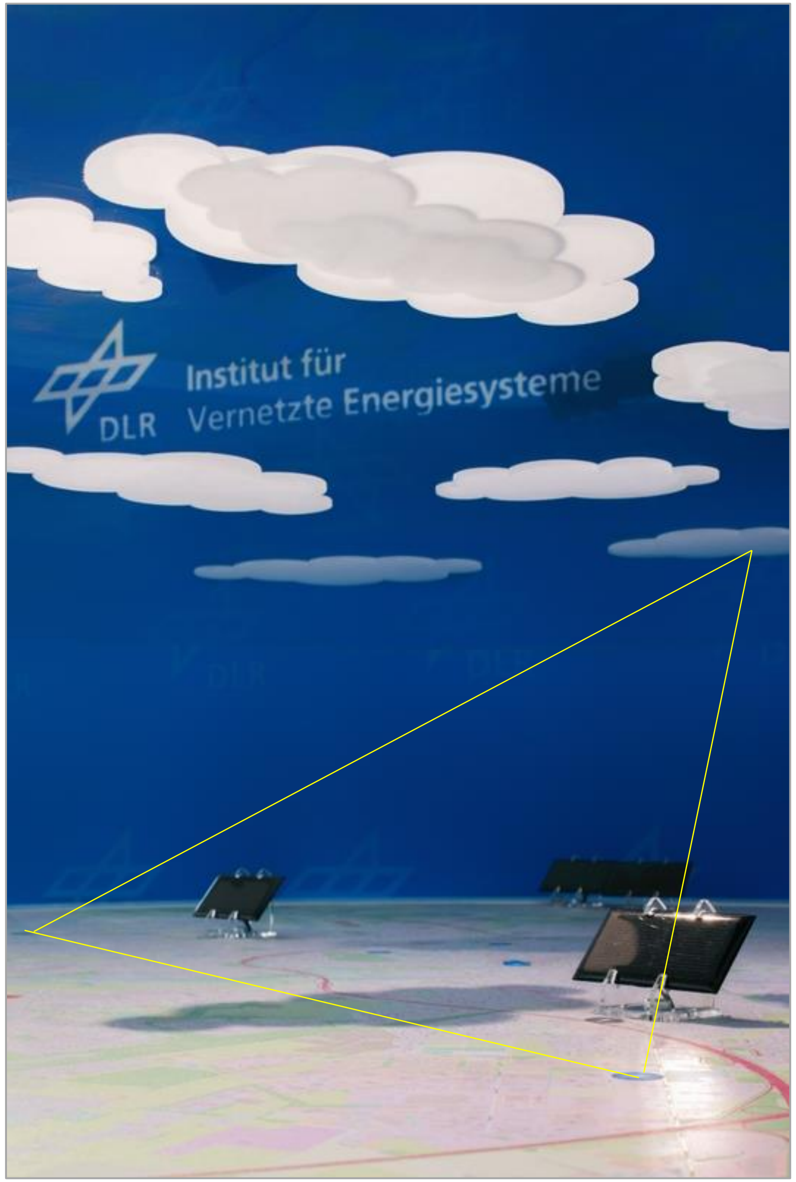
- Clear sky model
- Optical thickness of clouds / transmission

- Future positions of clouds (and sun)
- Cloud Motion Vectors

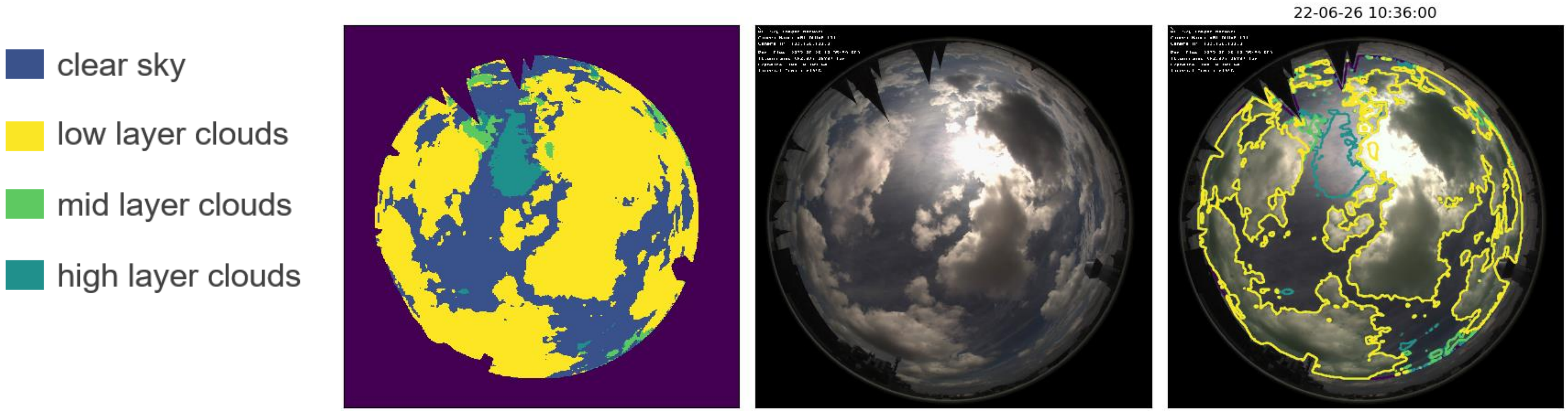
What do we need to know for deterministic forecasting?

- Use two cameras for cloud height detection

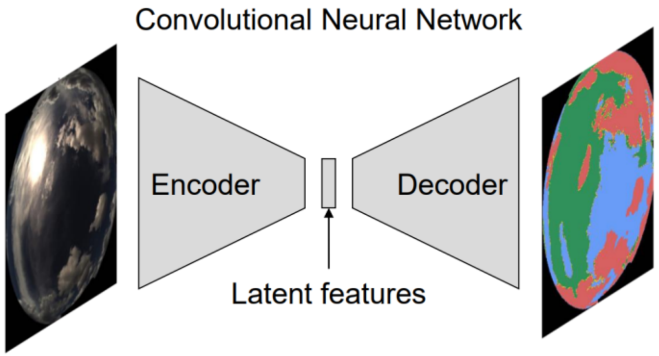




Cloud Detection – Semantic Segmentation



Cloud classes | original RGB image | cloud edges



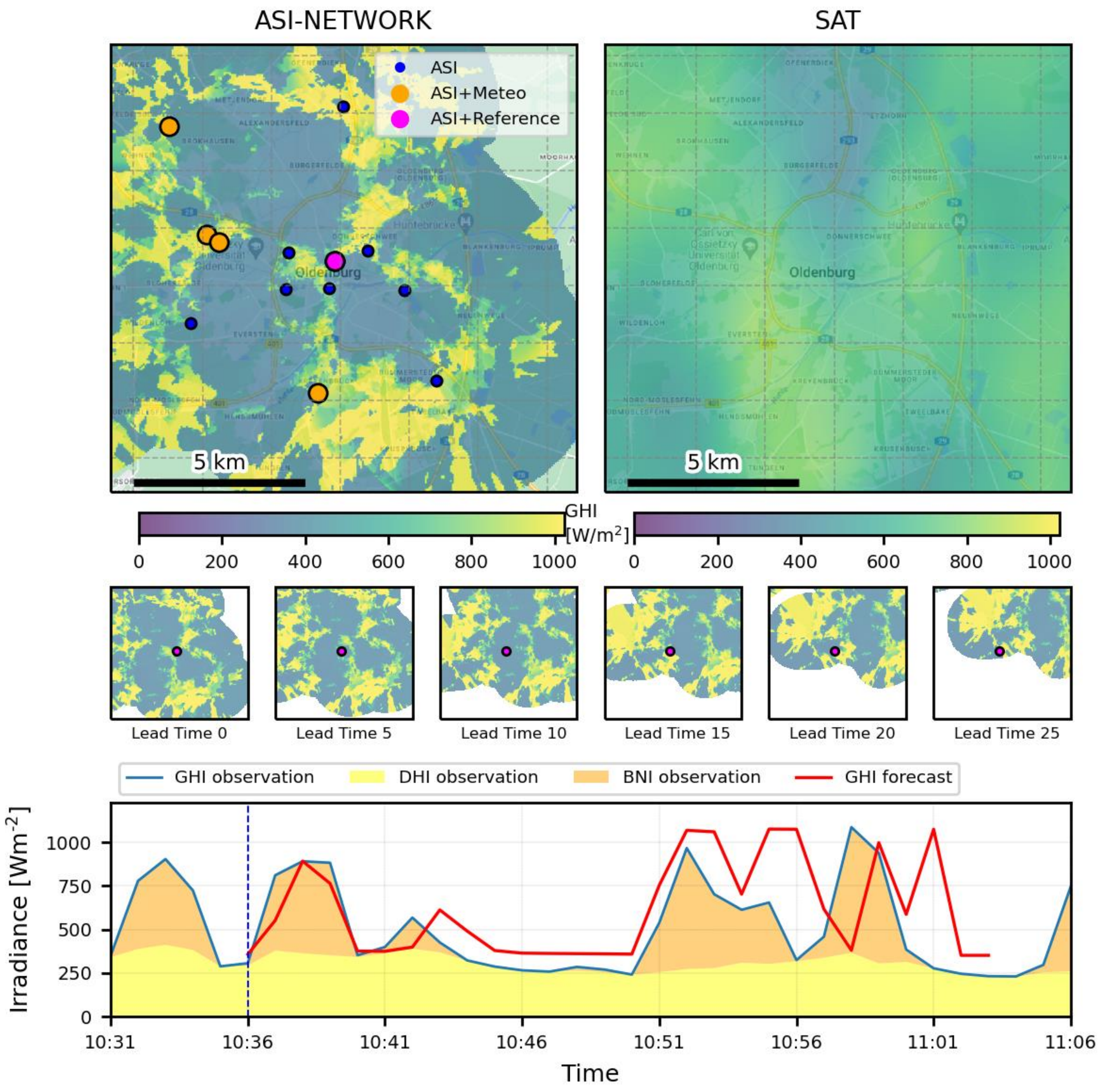
Fabel, Y.; Nouri, B.; Wilbert, S.; Blum, N.; Triebel, R.; Hasenbalg, M.; Kuhn, P.; Zarzalejo, L.F.; Pitz-Paal, R.
Applying self-supervised learning for semantic cloud segmentation of all-sky images.
Atmos. Meas. Tech. **2022**, *15*, 797–809.

30min ahead forecasting for domain Oldenburg

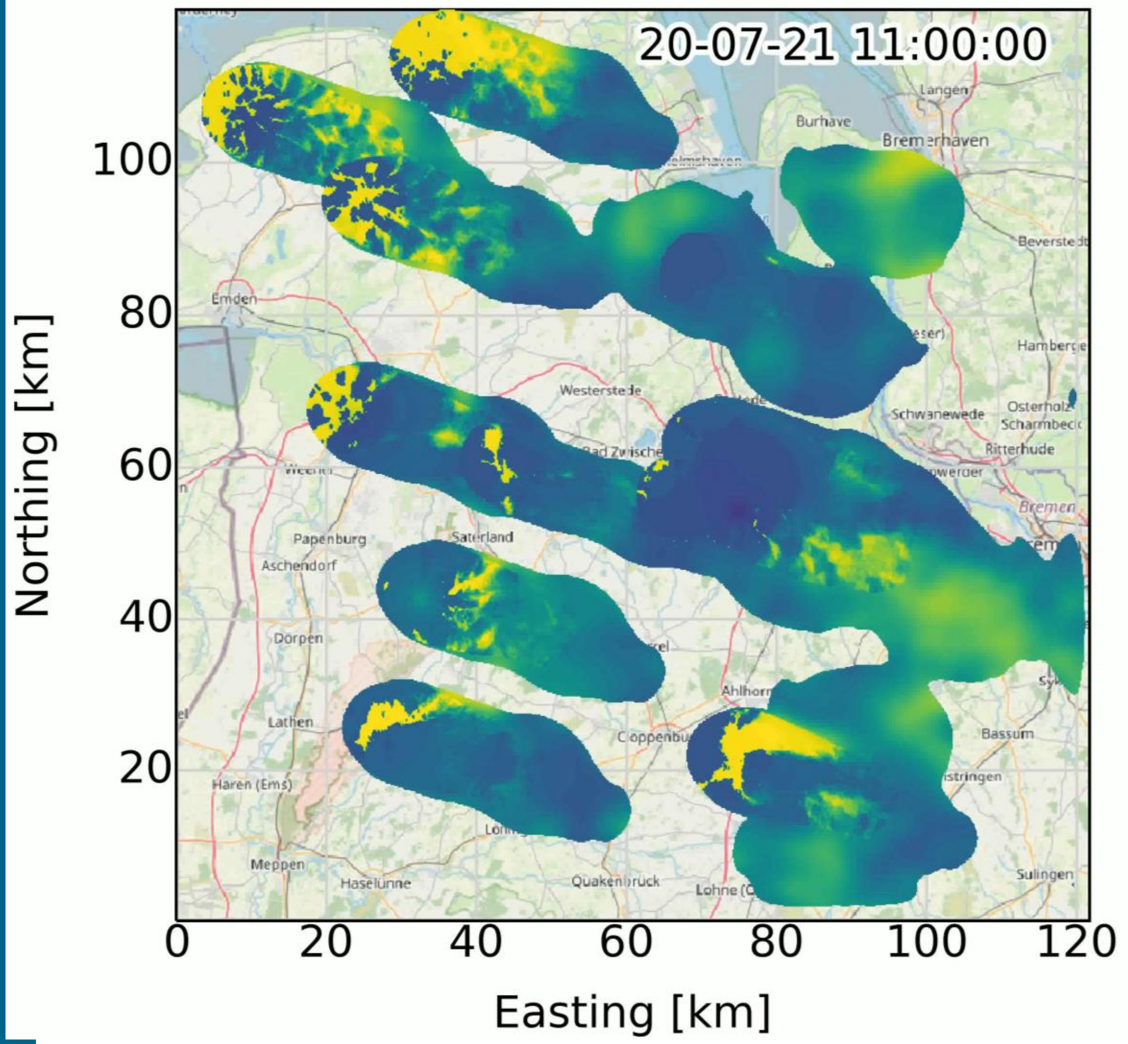
Method

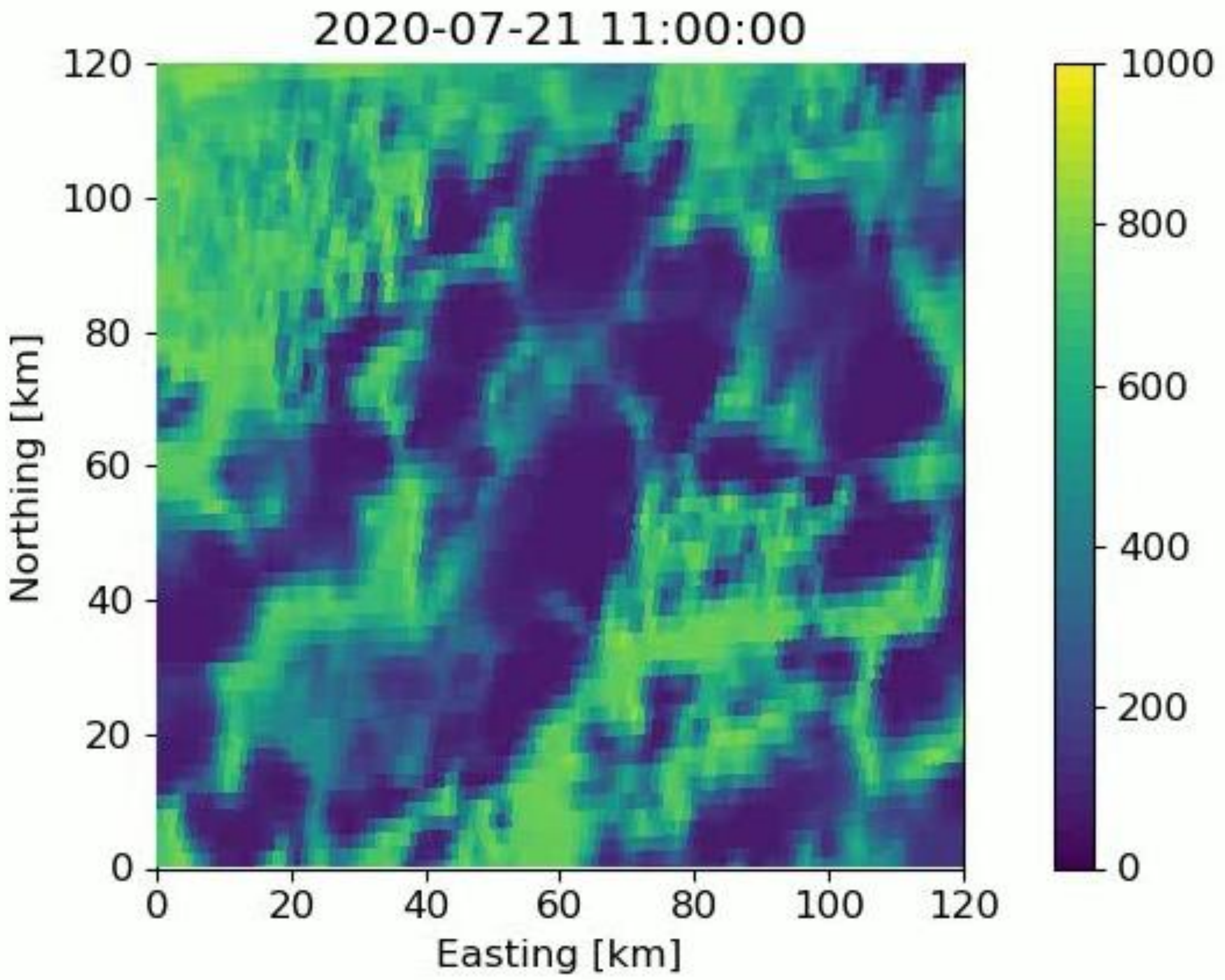
Blum, Niklas, 2022: Nowcasting of Solar Irradiance and Photovoltaic Production Using a Network of All-Sky Imagers. Dissertation, RWTH Aachen

Visualization for 2022-06-26: Thomas Schmidt



120min ahead forecasting for domain Weser Ems





Hybrid Forecasts

Combine both data sources
to get a best estimate
and a seamless forecast!

End-to-End Nowcasting:

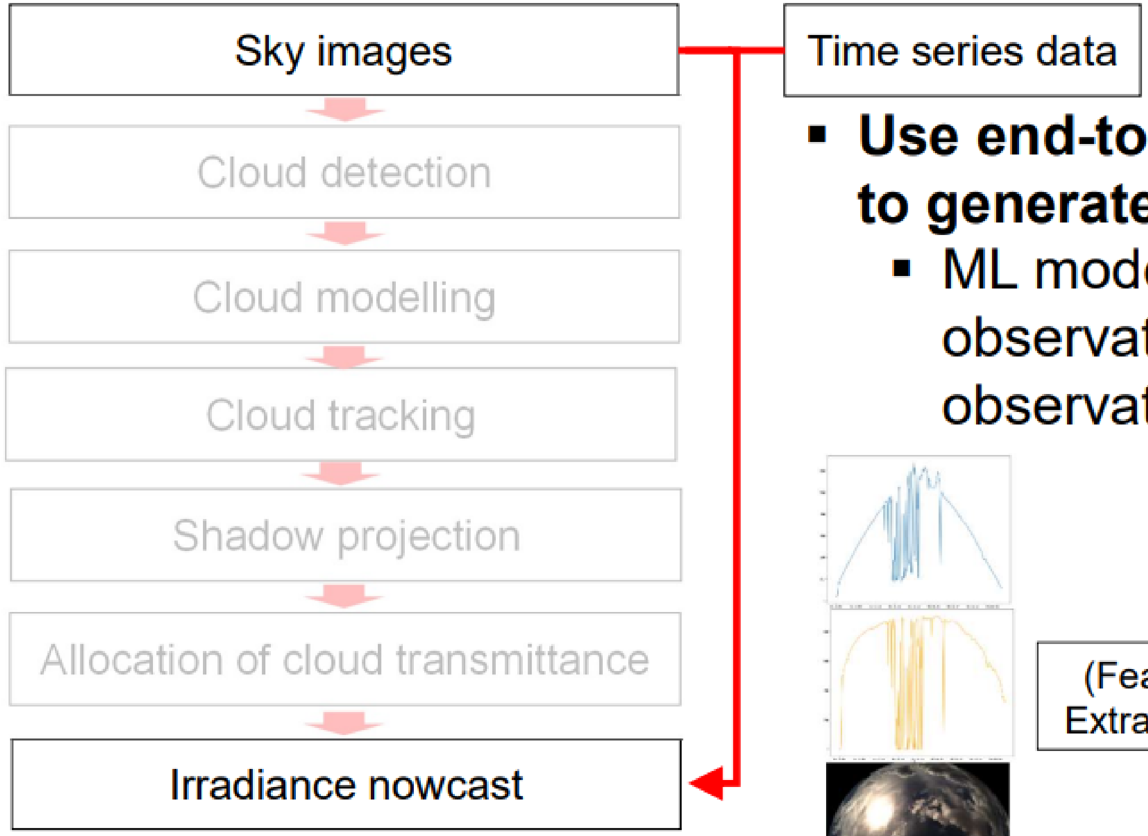
INPUT: Original images
OUTPUT: GHI Timeseries

Blending / Postprocessing:

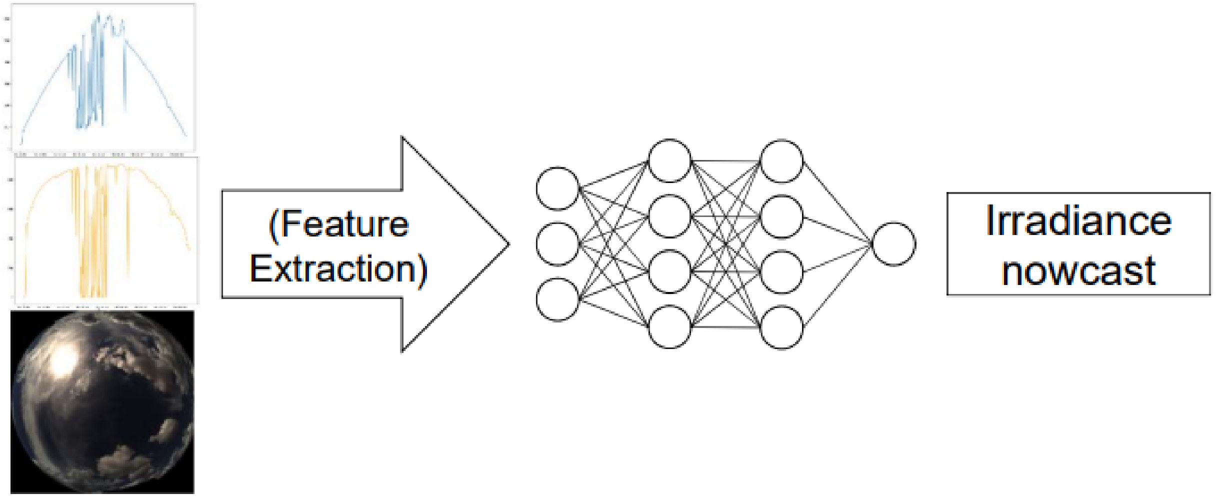
INPUT: SAT and ASI maps
OUTPUT: GHI maps or timeseries
- Linear Regression
- Random Forest
- LSTM

AI APPROACHES AND COLLABORATIONS

End-to-end Nowcasting – A data-driven approach



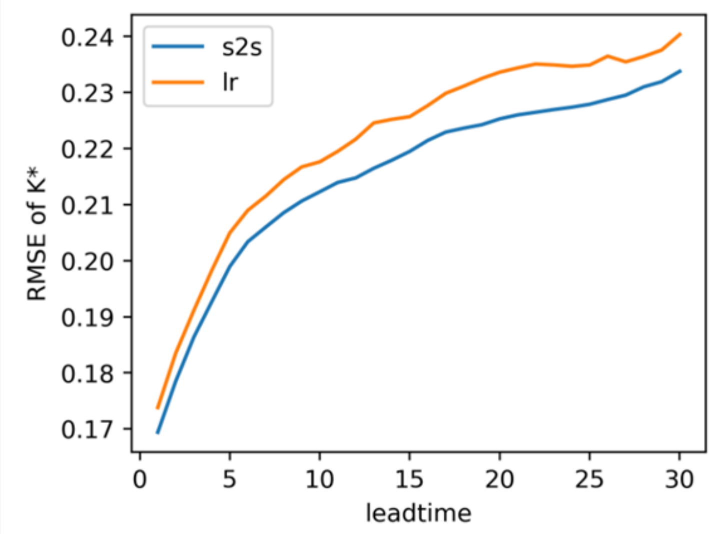
- **Use end-to-end machine learning (ML) models to generate nowcast directly from raw data**
  - ML models are trained on large amounts of observations or features extracted from observations to learn patterns in the data

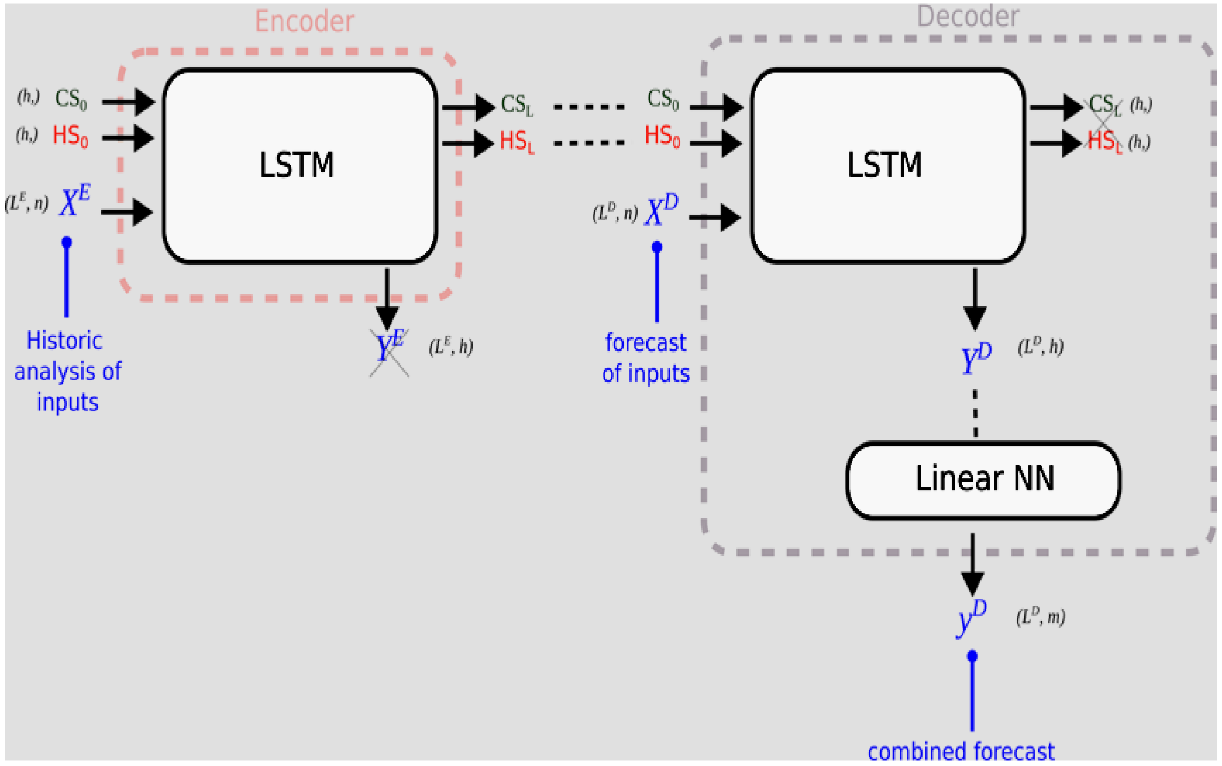


Fabel, Y.; et al: *Solar Nowcasting Systems Using AI Techniques.* 25th Cologne Solar Colloquium, 22nd of June 2022, Jülich, Germany.

Sequence to Sequence (LSTM)

- **INPUT:** SAT and ASI maps of GHI
- **OUTPUT:** Sequences **for all map pixels**
- Better performance than Linear Regression





Helmholtz AI Voucher: Jorge Lezaca (DLR),
Markus Götz, Charlotte Debus, and Arvid Weyrauch,
Karlsruher Institut für Technologie (KIT),
Steinbuch Centre for Computing (SCC)

End-to-End-Combination

PALETTA, Q., ARBOD, G., LASENBY, J., 2023: Omnivision forecasting: combining satellite observations with sky images for improved intra-hour solar energy predictions, Applied Energy, Volume 336, DOI:10.1016/j.apenergy.2023.120818.

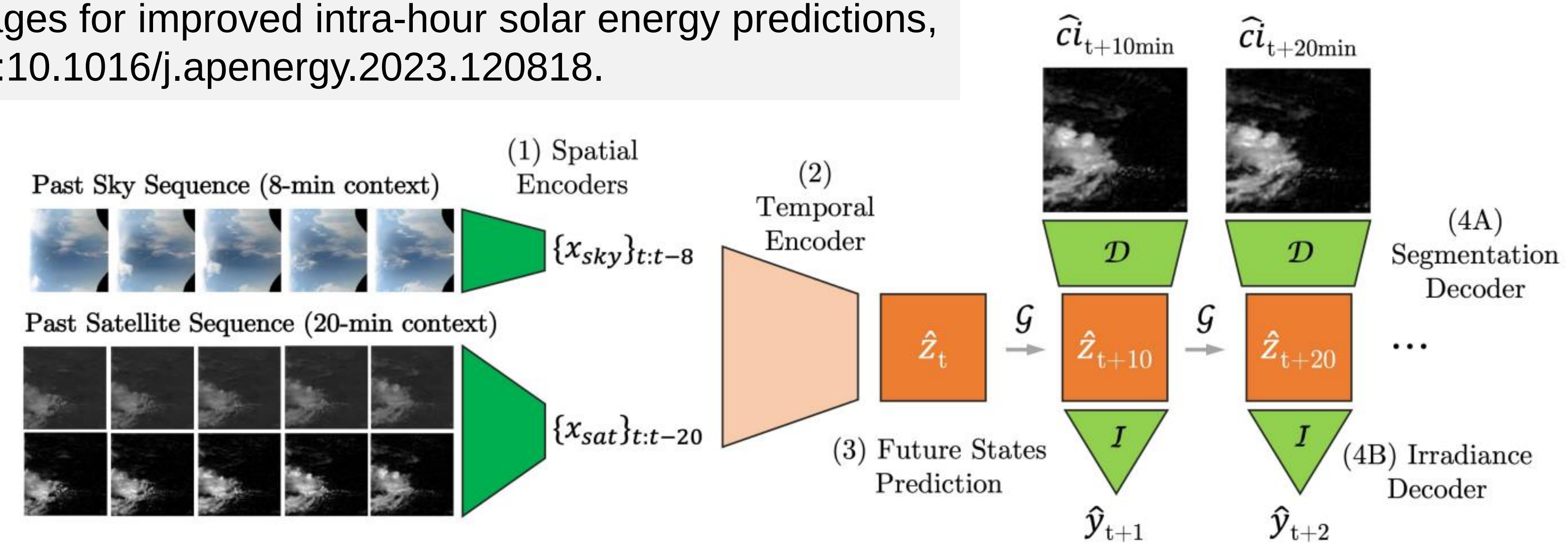


Figure 4: DL architecture predicting future cloud index maps and corresponding irradiance levels from past sky and satellite images. Parallel encoders are used to extract spatial features from the sequences of past sky and satellite observations (raw images and cloud index maps). Future states are iteratively predicted from the output of the temporal encoder. Each state can then be decoded into different representations (cloud index maps and irradiance levels in the figure).

Will be tested in Project DESYS by

- Keisuke Tanaka and Frank Dressel, DLR Institute of Software Methods for Product Virtualization
- Thomas Schmidt and Annette Hammer, DLR VE

Thank you!

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- DLR-Project DESYS (Design and operation of networked energy systems)