CLOUD SHADOWS IN SATELLITE-BASED SOLAR IRRADIANCE ESTIMATION: IMPROVED CORRECTION USING EUMETSAT‘S CLOUD TOP HEIGHT DATA

Arindam Roy, Annette Hammer, Detlev Heinemann and Ontje Lünsdorf

German Aerospace Center (DLR) Institute of Networked Energy Systems, Oldenburg

DLR

INTRODUCTION

Arindam Roy, German Aerospace Center (DLR) Institute of Networked Energy Systems, Oldenburg, 06.09.2022

Clouds and solar PV

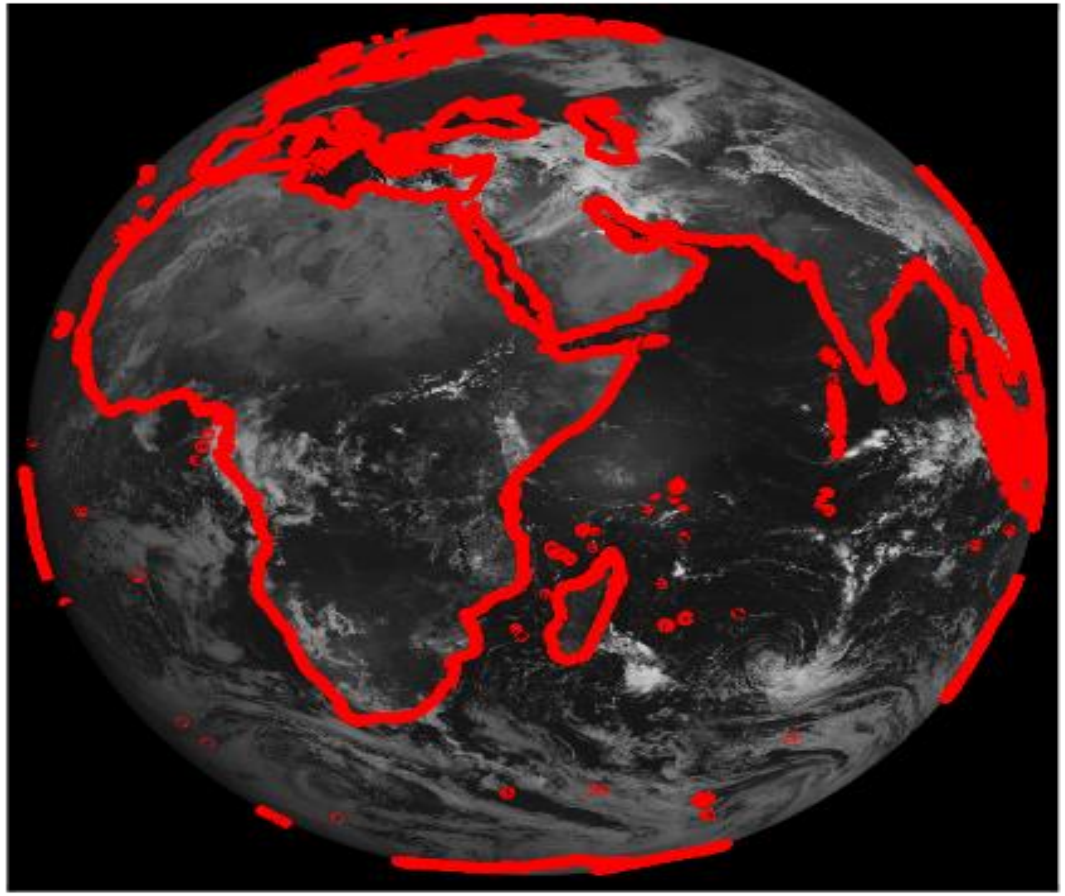
- Reduced output of solar PV under cloud shadow

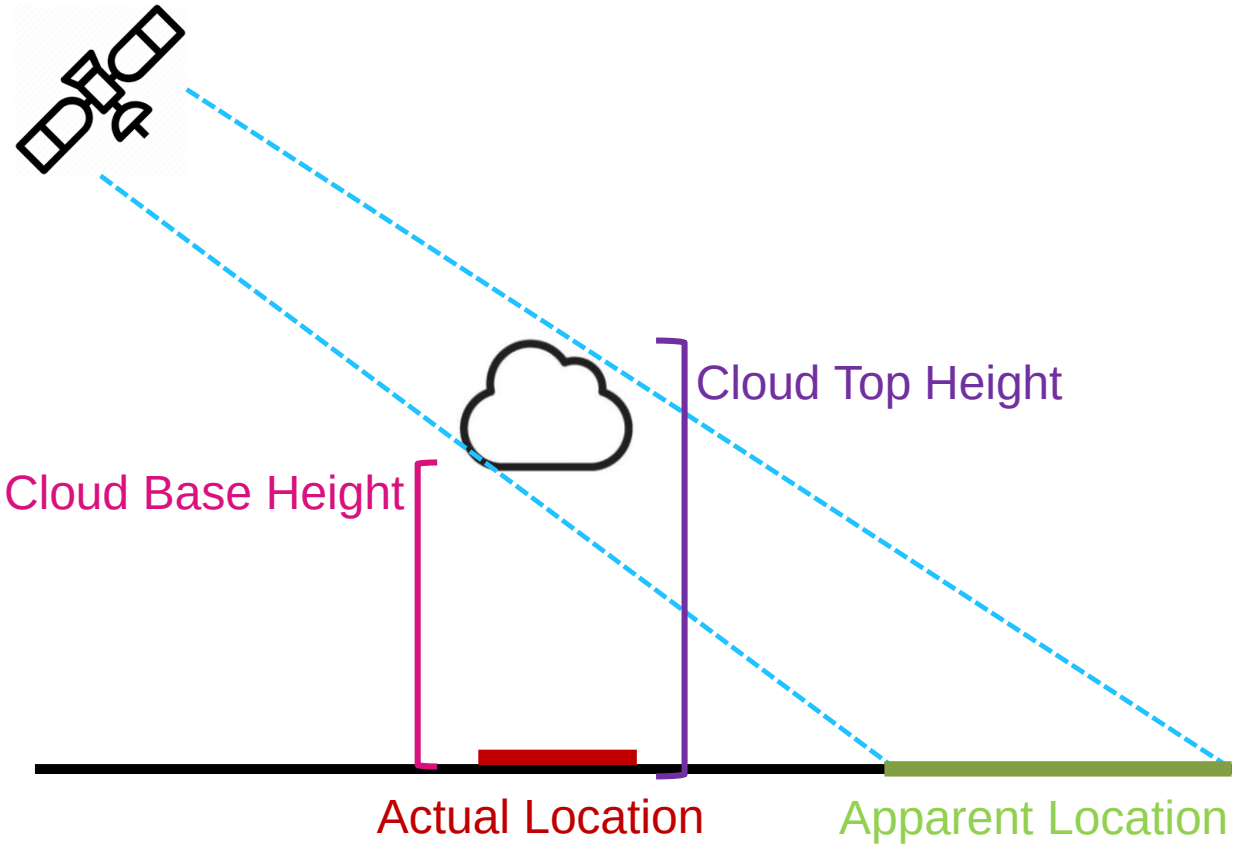
Source: https://www.shutterstock.com

epexspot

Clouds in Satellite Images

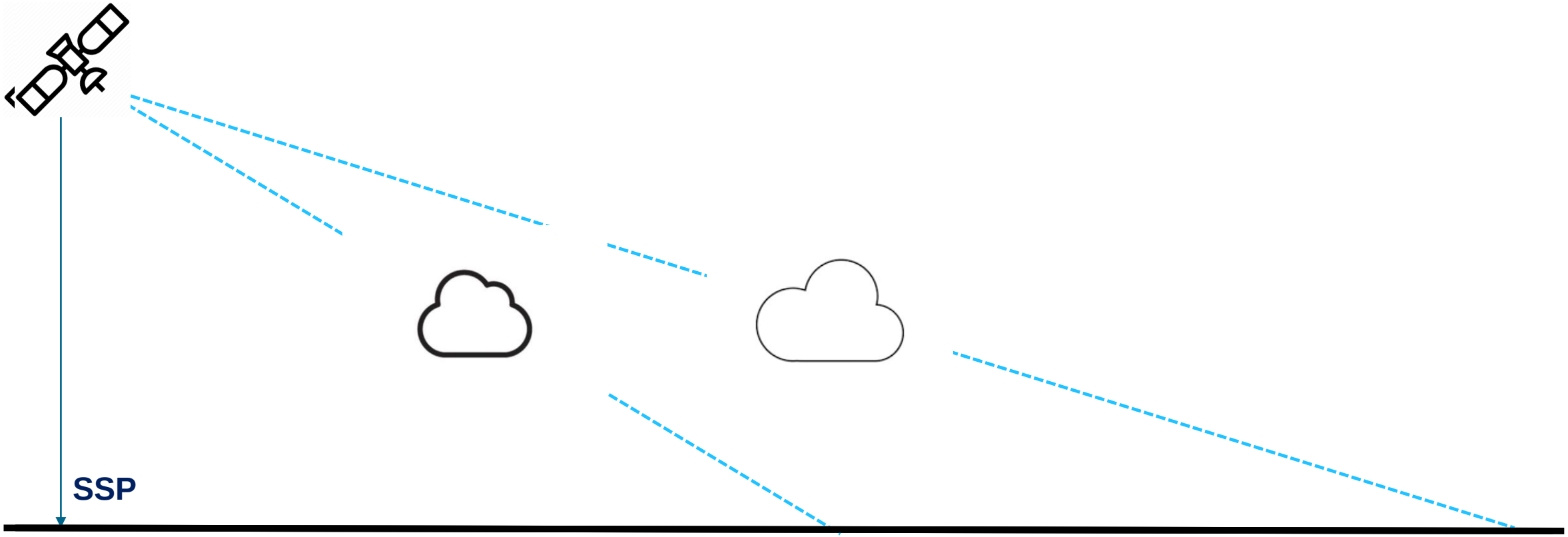
- Meteosat-8 at 41.5° East





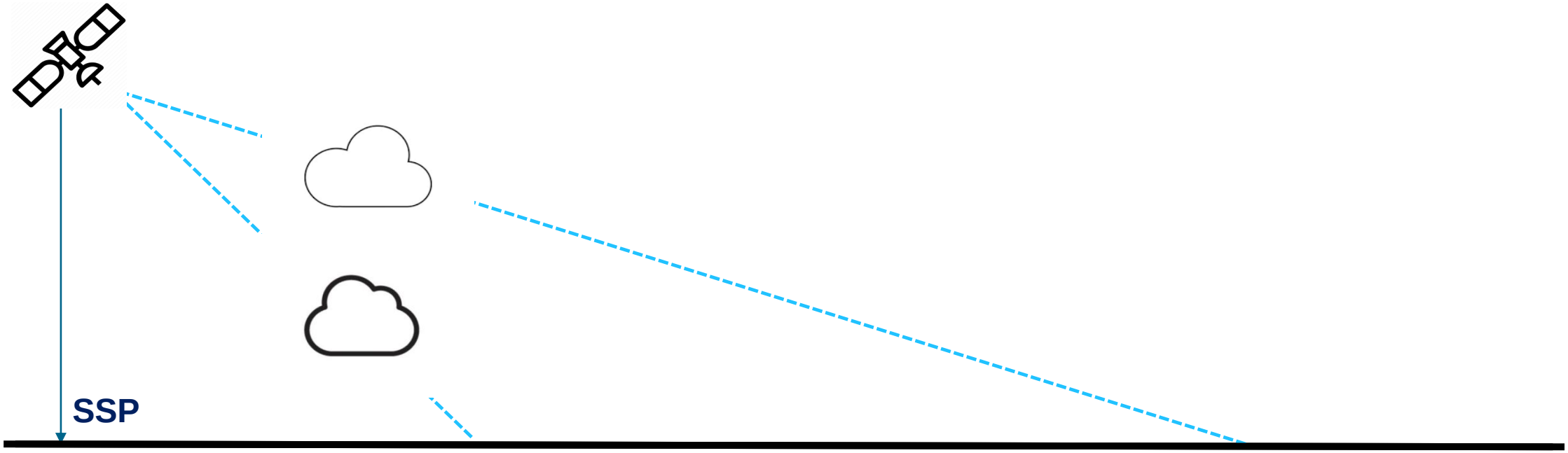
Cloud Location from the Satellite Point of View

- Difference between the apparent and actual location of clouds:
  - Distance from the Sub-Satellite Point (SSP)



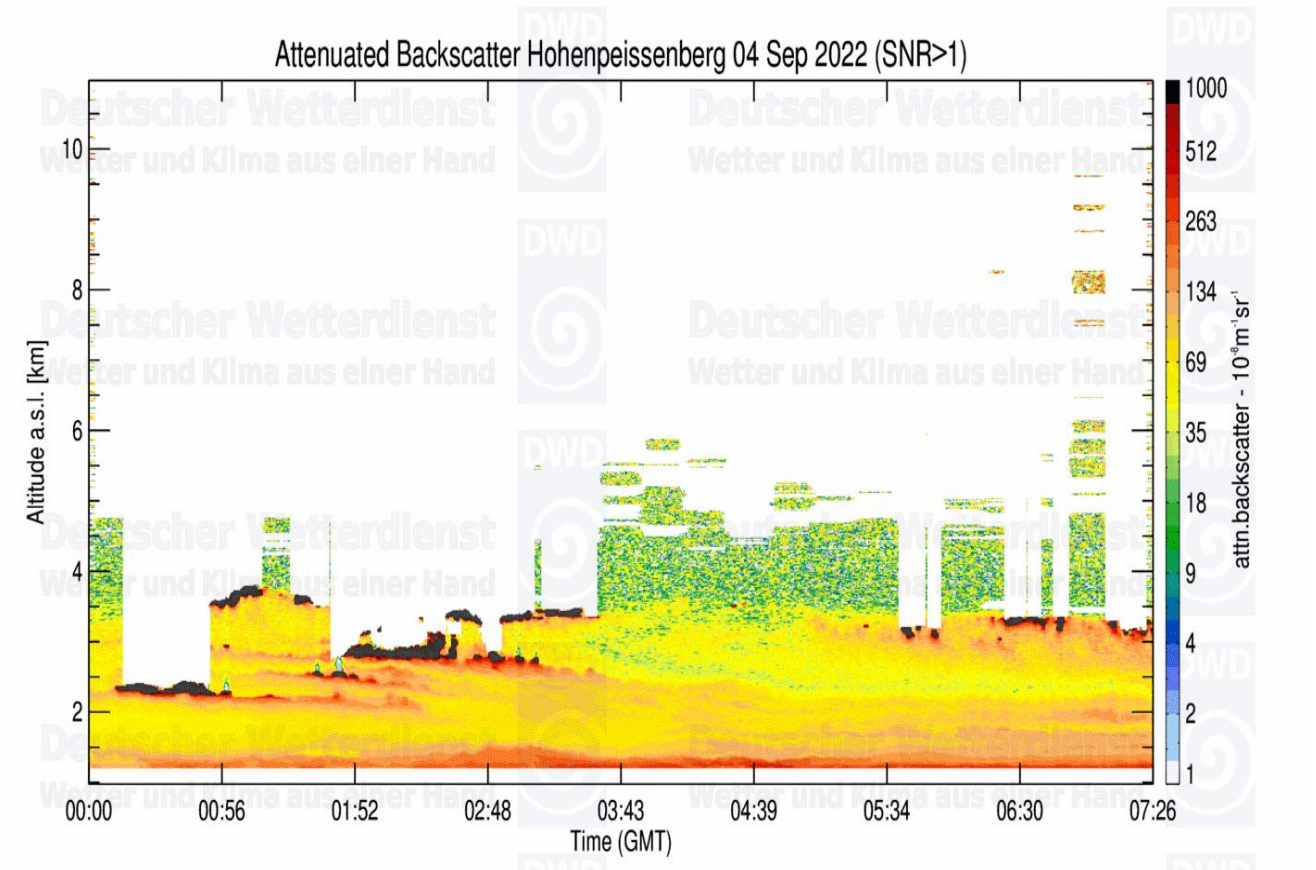
Cloud Location from the Satellite Point of View

- Difference between the apparent and actual location of clouds:
  - Distance from the Sub-Satellite Point (SSP)
  - Cloud height and geometry



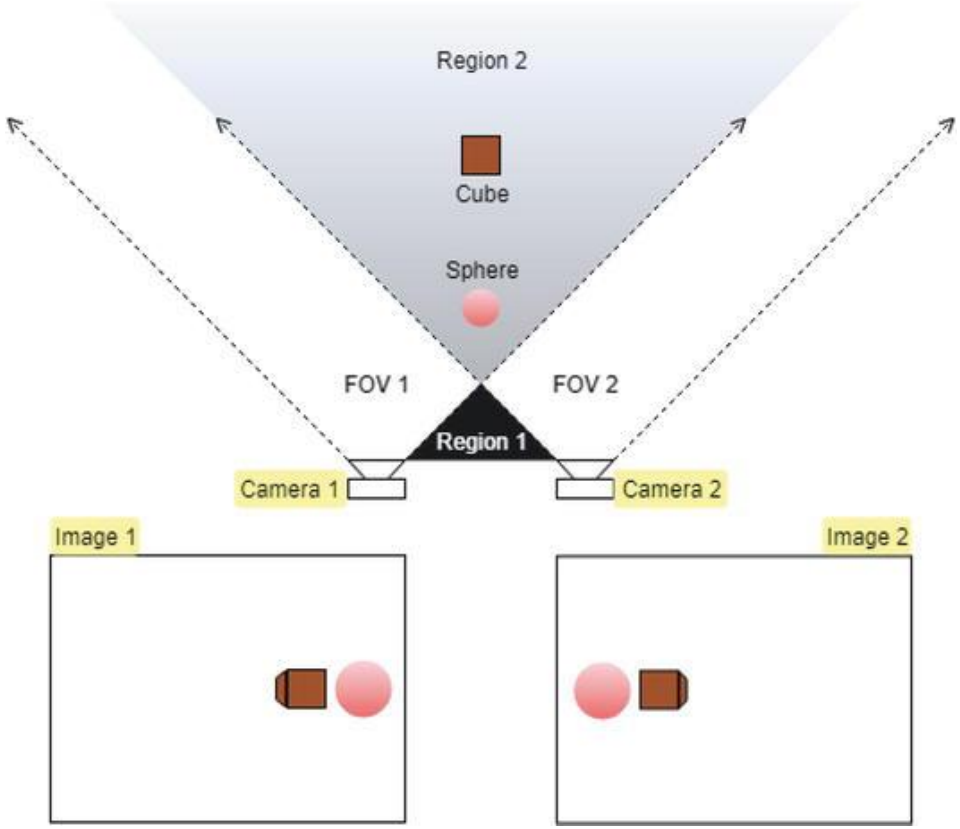
Sources of Cloud Height Information

- Ceilometer
  - Cloud Base Height (CBH)



Sources of Cloud Height Information

- Ceilometer
  - Cloud Base Height (CBH)
- Stereo-Imaging with multiple sky cameras
  - CTH or CBH or Cloud Center Height (CCH)



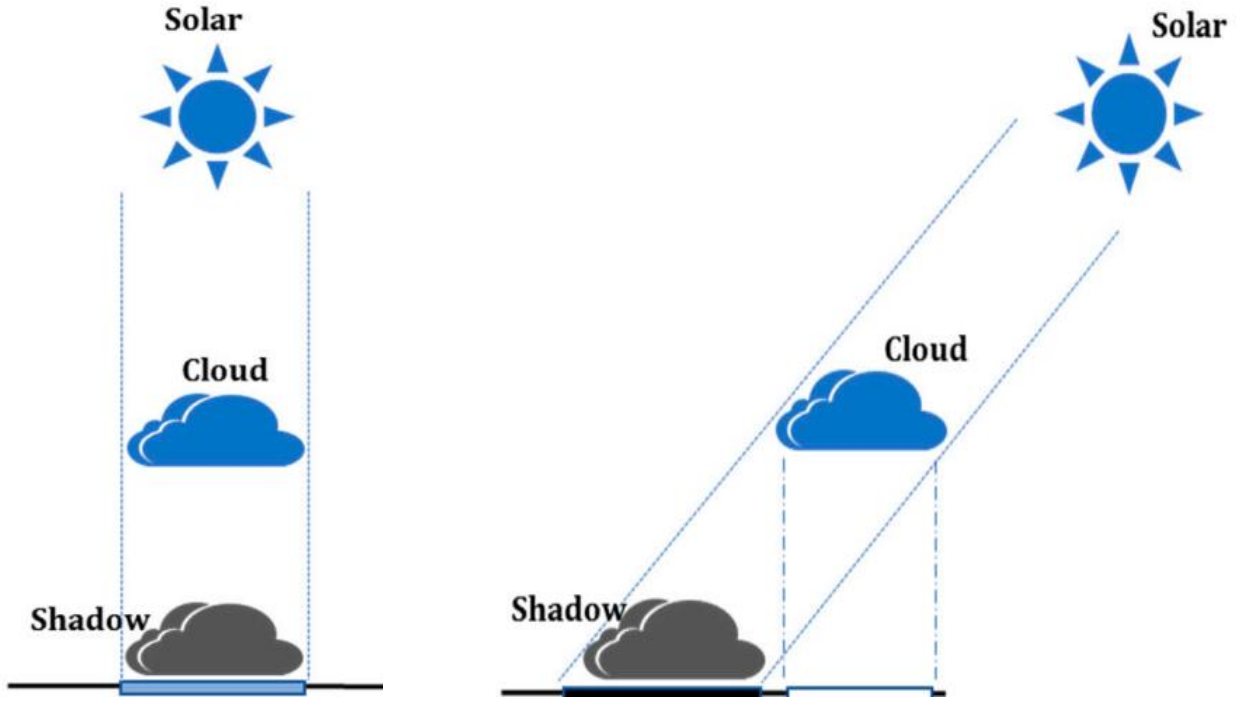
Source: Praveen S 2019 Efficient Depth Estimation Using Sparse Stereo-Vision with Other Perception Techniques

Sources of Cloud Height Information

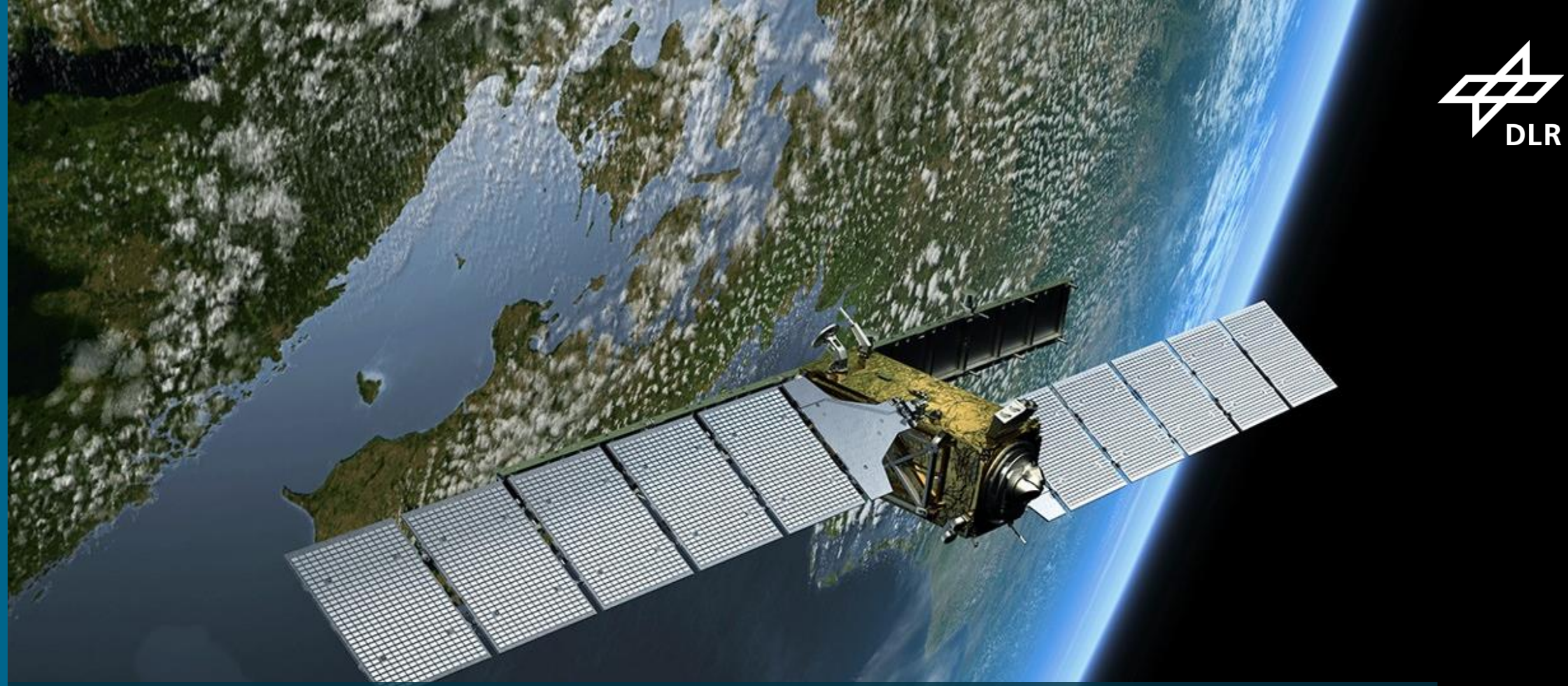
- Ceilometer
  - Cloud Base Height (CBH)
- Stereo-Imaging with multiple sky cameras
  - CTH or CBH or Cloud Center Height (CCH)
- Satellite images in infrared and O2 channels
  - Cloud Top Height (CTH)
  - Gridded data covering a large area

Cloud Shadow Location

- Difference between the cloud and cloud shadow location
  - Solar elevation angle (time of the day)
  - Cloud height and geometry



Source: Wang et al 2017 Effect of Solar-Cloud-Satellite Geometry on Land Surface Shortwave Radiation Derived from Remotely Sensed Data



PARALLAX AND CLOUD SHADOW CORRECTION - APPROACH

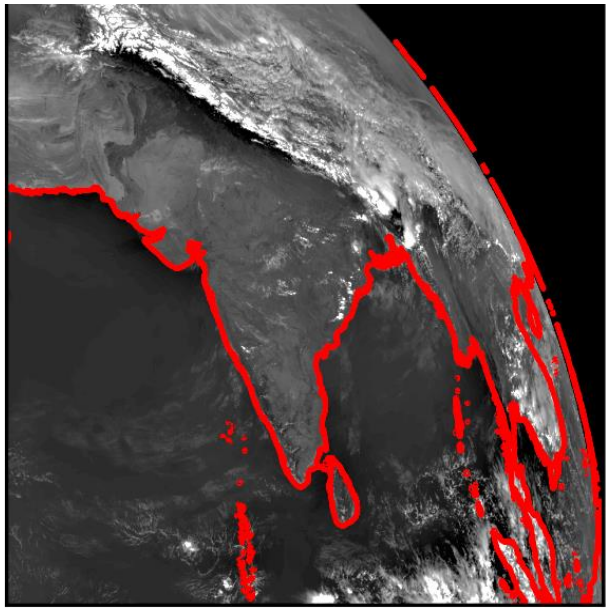
Arindam Roy, German Aerospace Center (DLR) Institute of Networked Energy Systems, Oldenburg, 06.09.2022

Cloud Index Map

- 0.6 µm Low Resolution (LR) visible channel images at 15 minutes resolution

- Conversion to cloud index using the Heliosat method – Intermediate product

Meteosat-8 Full Disk Image



Cloud Index image n ∈ [0,1]

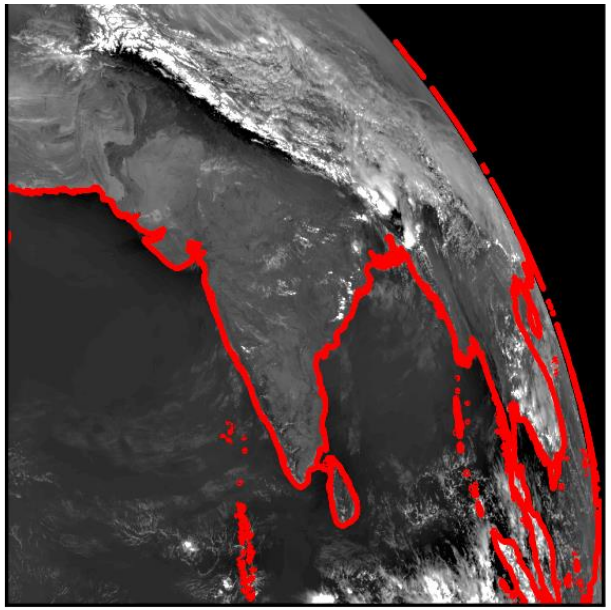
$$n = \frac{(\rho_{sat} - \rho_{clear})}{(\rho_{cloud} - \rho_{clear})}$$

Cloud Index Map

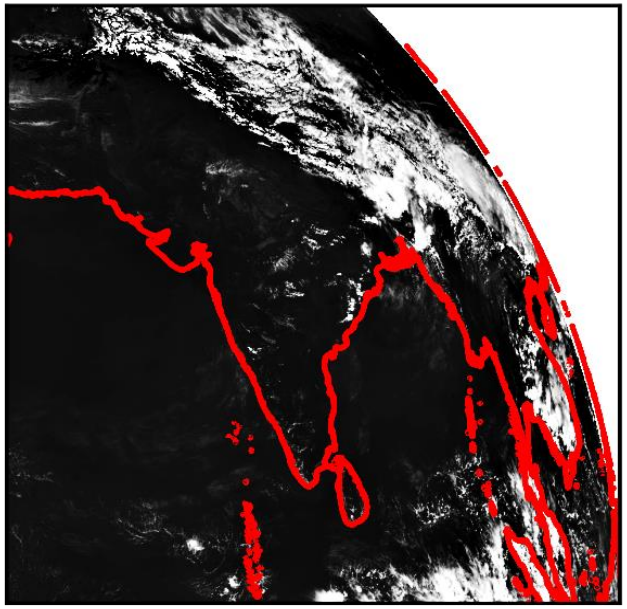
- 0.6 µm visible channel images at 15 minutes resolution

- Conversion to cloud index using the Heliosat method – Intermediate product

Meteosat-8 Full Disk Image



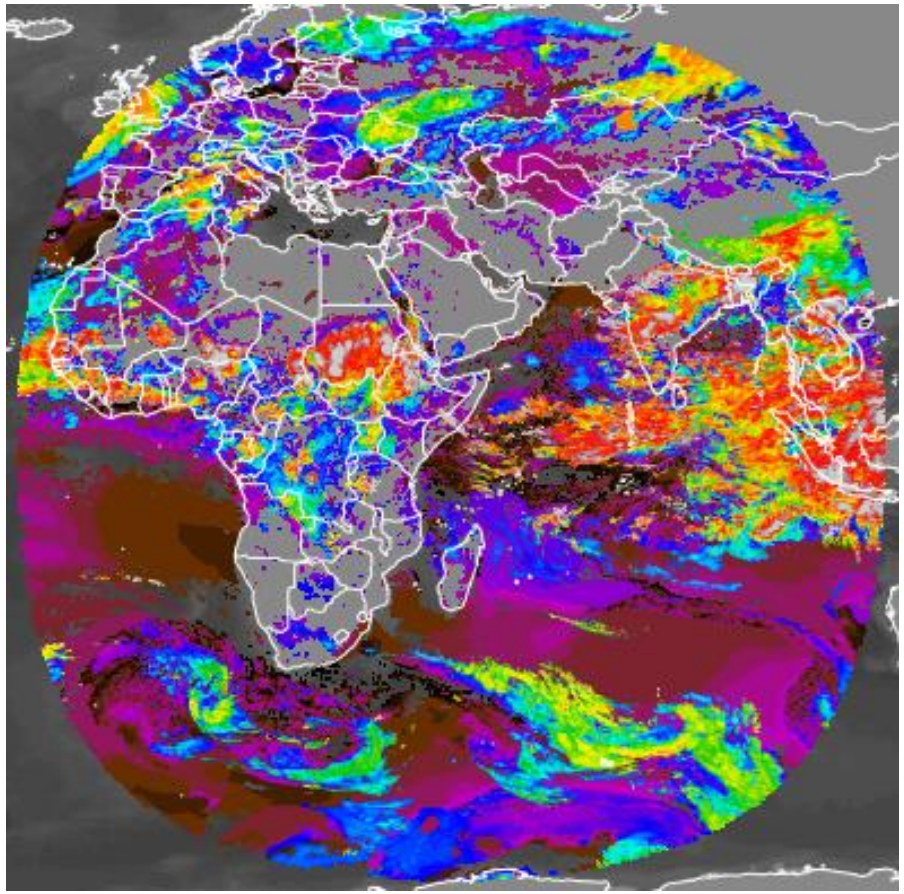
Cloud Index image n ∈ [0,1]



Cloud Top Height (CTH)

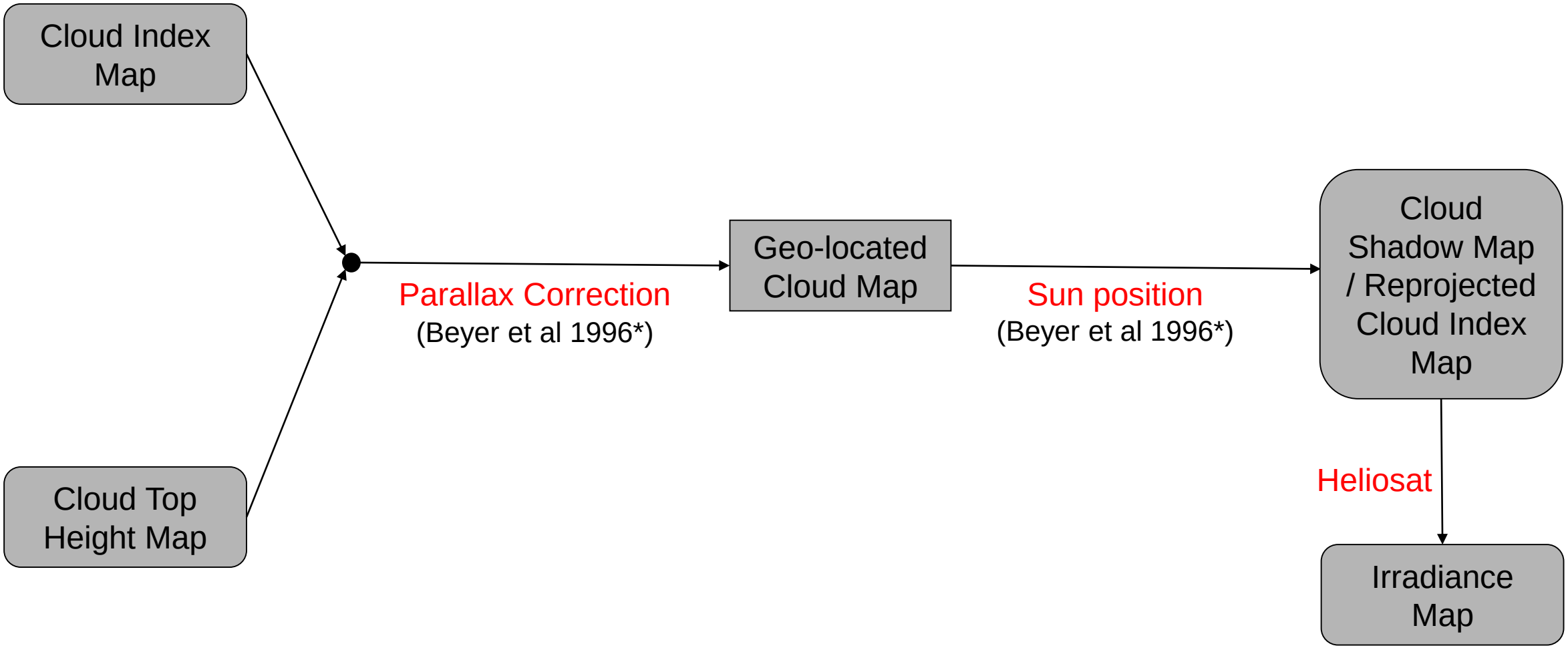
- Gridded dataset from EUMETSAT CM-SAF

- Each CTH pixel contains 3 x 3 LR pixels (approx. 9 km x 9 km at Nadir)



Source: https://view.eumetsat.int/productviewer?v=msg_iodc:cth#

Main Steps

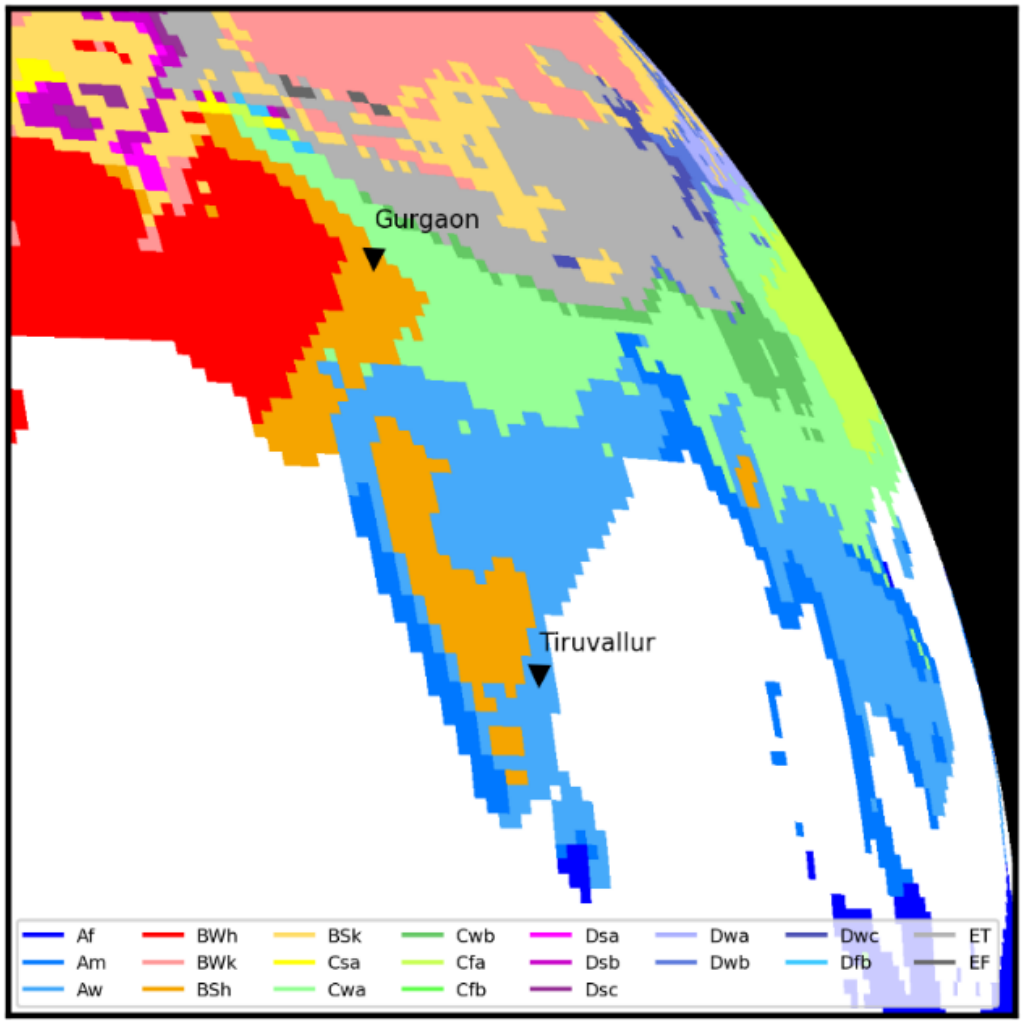

Cloud Index Map
Cloud Top Height Map
Parallax Correction
(Beyer et al 1996*)
Geo-located Cloud Map
Sun position
(Beyer et al 1996*)
Cloud Shadow Map / Reprojected Cloud Index Map
Heliosat
Irradiance Map

Validation against Ground Measurements

- Baseline Surface Radiation Network (BSRN)
- High quality Surface Solar Irradiance (SSI) data
- Station 1: Gurgaon (Hot semi-arid climatic zone *Bsh*)
- Station 2: Tiruvallur (Tropical Savannah climatic zone *Aw*)

Validation against Ground Measurements

- Station 1: Gurgaon (Hot semi-arid climatic zone *Bsh*)
- Station 2: Tiruvallur (Tropical Savannah climatic zone *Aw*)

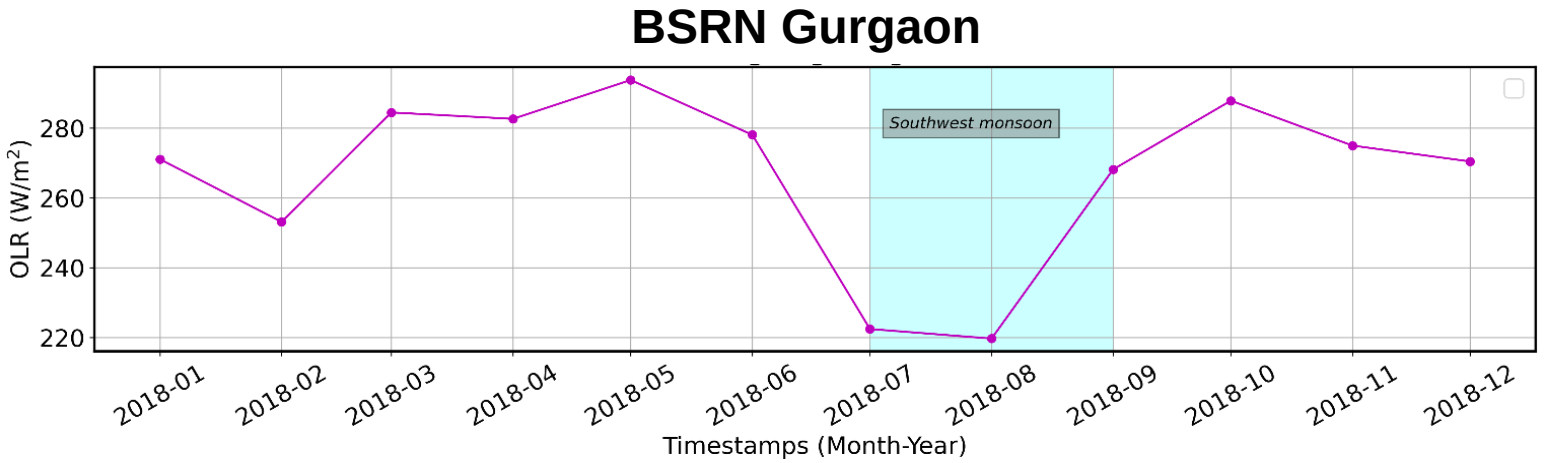


VALIDATION RESULTS

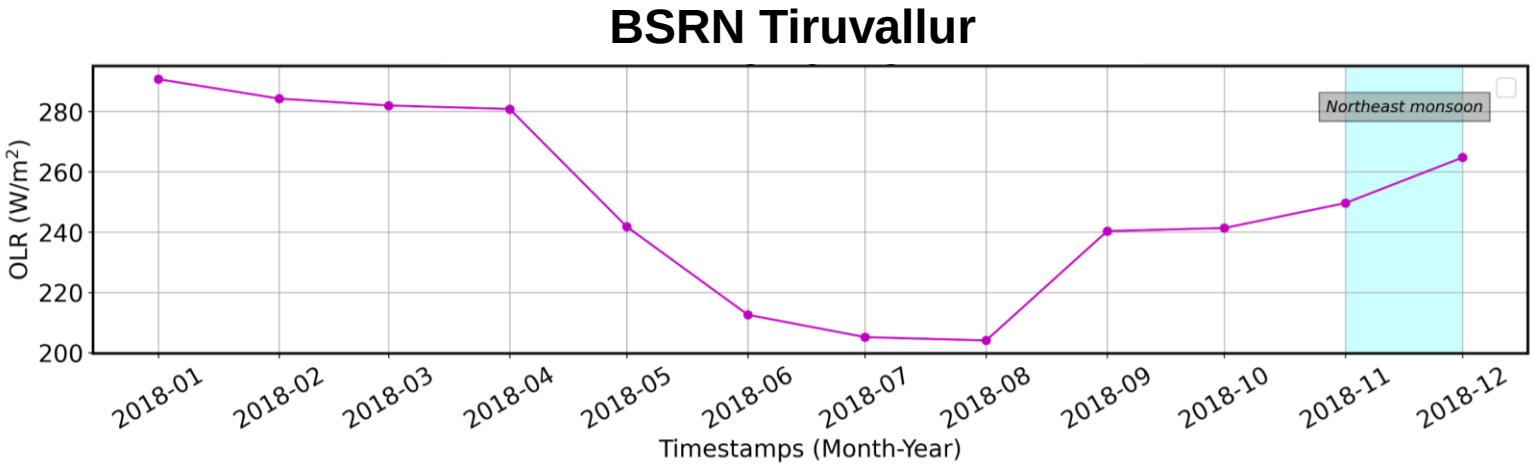
Arindam Roy, German Aerospace Center (DLR) Institute of Networked Energy Systems, Oldenburg, 06.09.2022

Evaluation Period

- Highest cloudiness in July, September and August

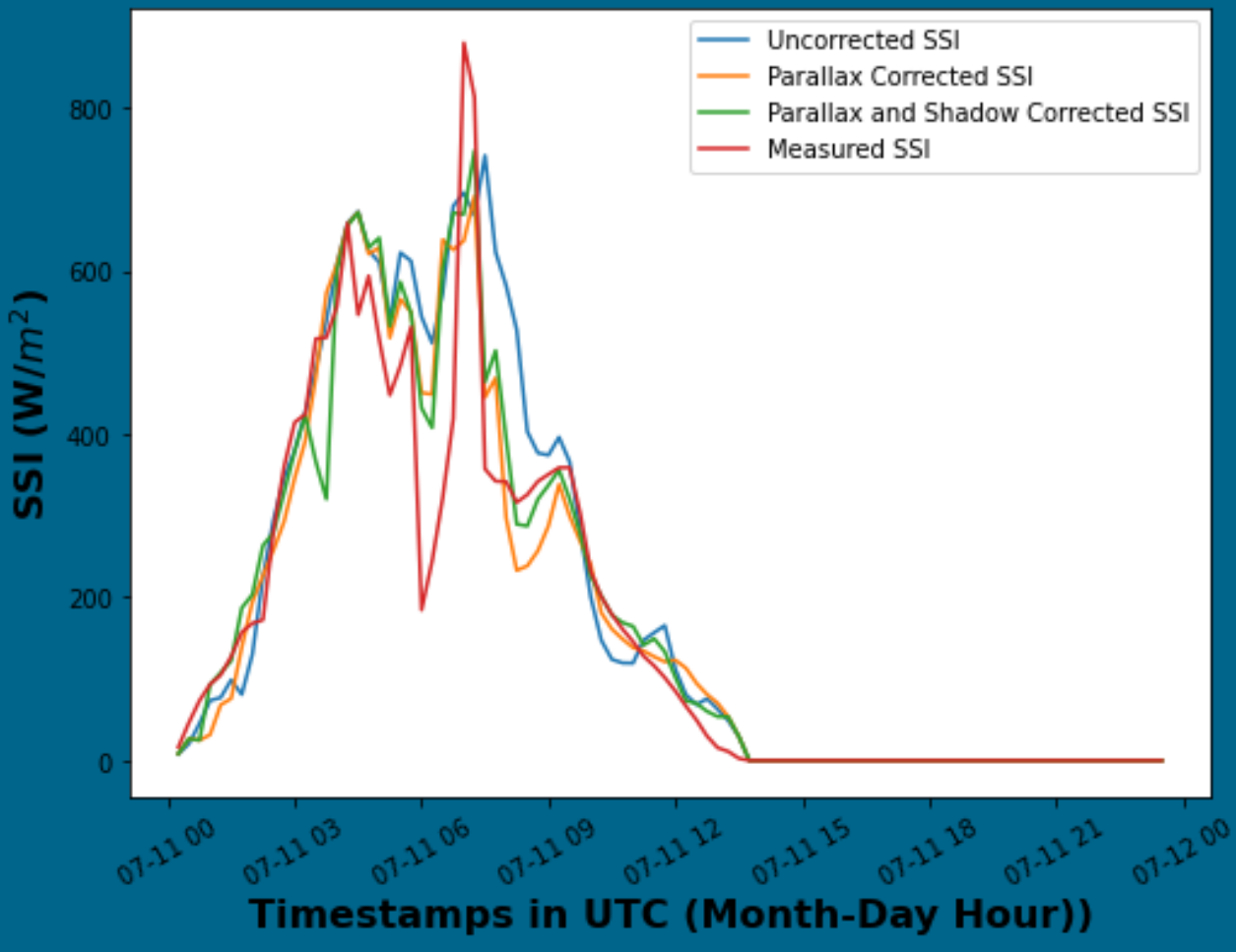


- Deep convection with large Cloud Top Height (CTHs)



SSI Estimation Error – Individual Days

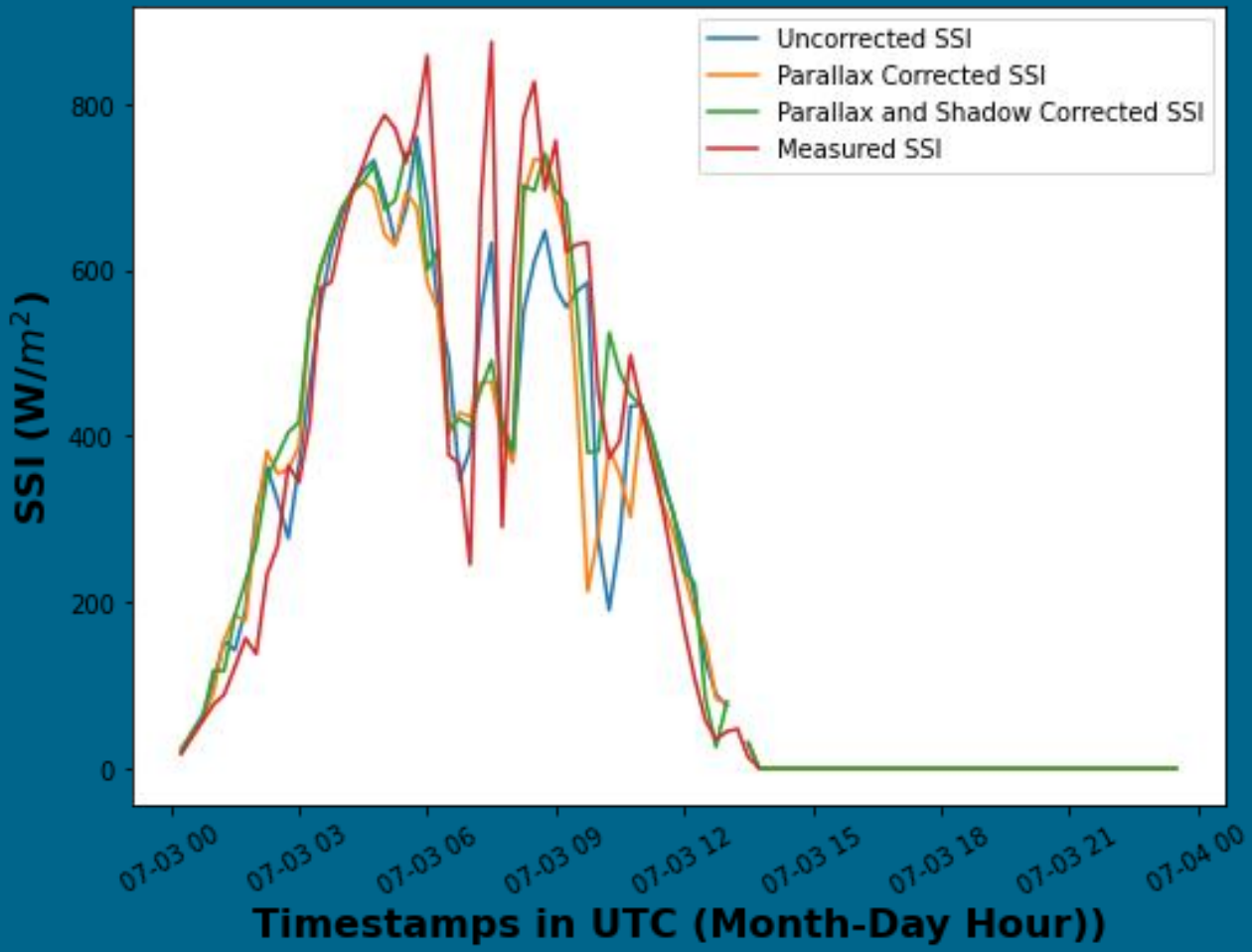
Error Metrics		BSRN Gurgaon
rel. RMSE	Uncorrected	**32.50 %**
	Only Parallax	**24.63 %**
	Parallax and cloud shadow	**24.26 %**
rel. MAE	Uncorrected	**16.12 %**
	Only Parallax correction	**13.13 %**
	Parallax and cloud shadow	**11.77 %**



Arindam Roy, German Aerospace Center (DLR) Institute of Networked Energy Systems, Oldenburg, 06.09.2022

SSI Estimation Error – Individual Days

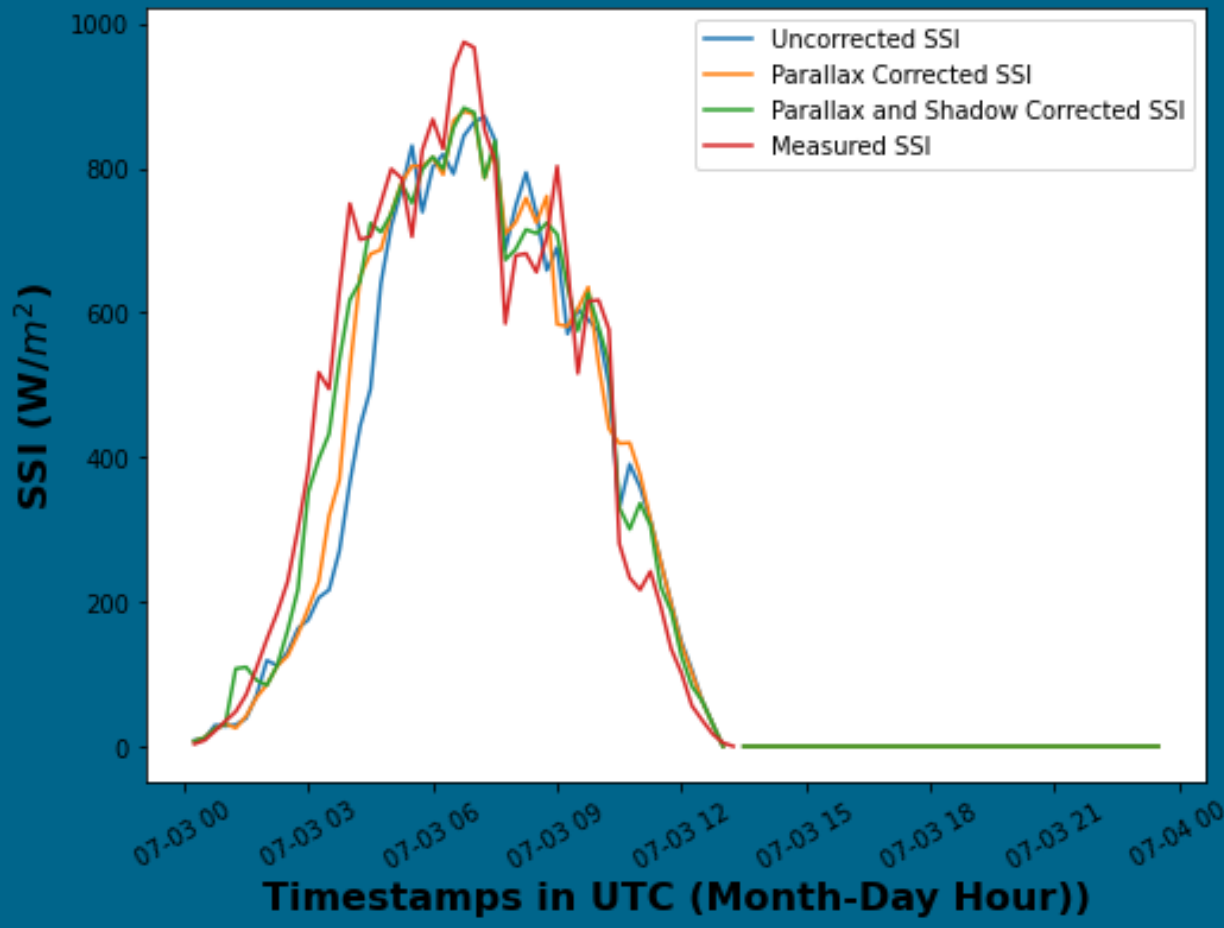
Error Metrics		BSRN Gurgaon
rel. RMSE	Uncorrected	**18.93 %**
	Only Parallax	**23.26 %**
	Parallax and cloud shadow	**19.79 %**
rel. MAE	Uncorrected	**10.98 %**
	Only Parallax correction	**12.13 %**
	Parallax and cloud shadow	**10.73 %**



Arindam Roy, German Aerospace Center (DLR) Institute of Networked Energy Systems, Oldenburg, 06.09.2022

SSI Estimation Error – Individual Days

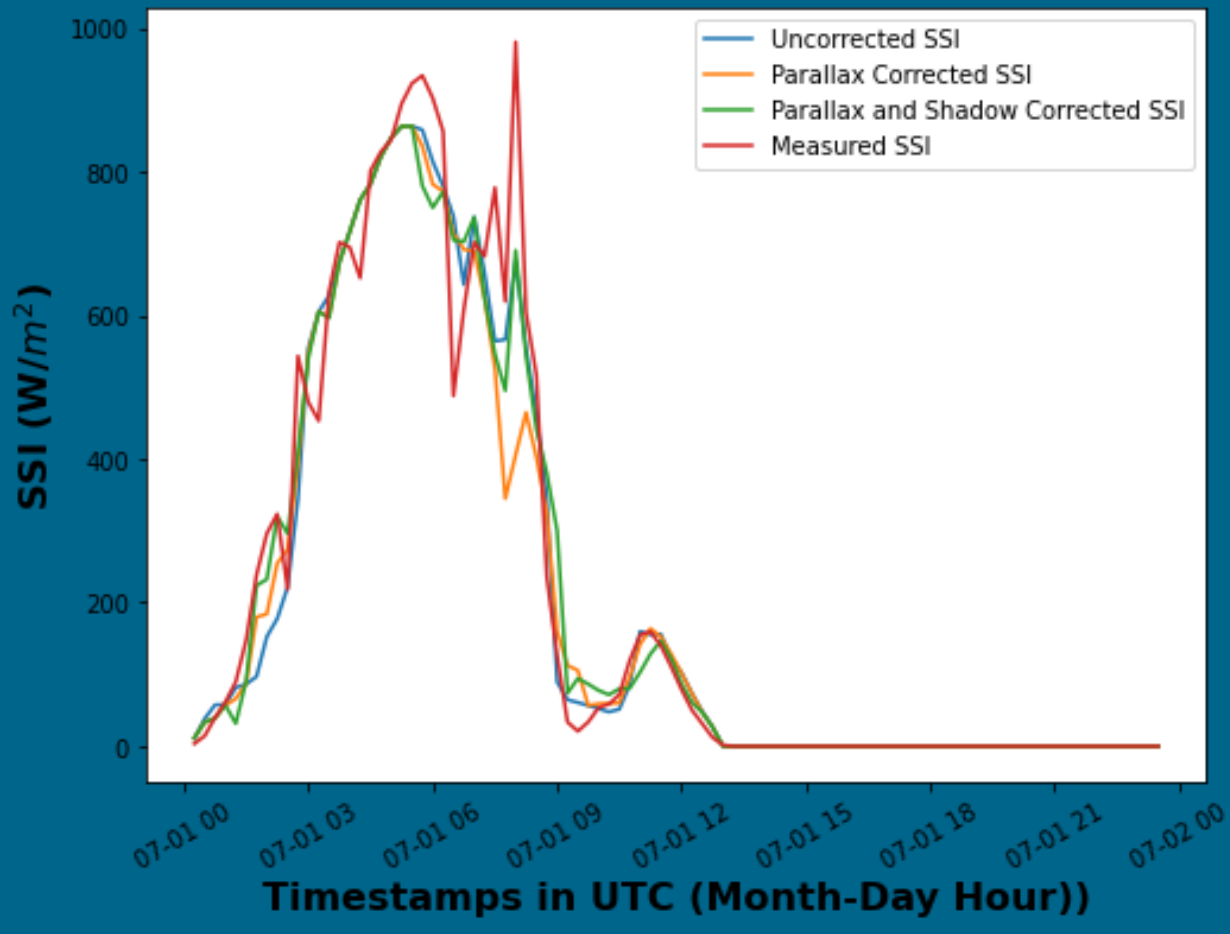
Error Metrics		BSRN Tiruvallur
rel. RMSE	Uncorrected	**21.43 %**
	Only Parallax	**17.51 %**
	Parallax and cloud shadow	**9.59 %**
rel. MAE	Uncorrected	**11.63 %**
	Only Parallax correction	**10.00 %**
	Parallax and cloud shadow	**5.95 %**



Arindam Roy, German Aerospace Center (DLR) Institute of Networked Energy Systems, Oldenburg, 06.09.2022

SSI Estimation Error – Individual Days

Error Metrics		BSRN Tiruvallur
rel. RMSE	Uncorrected	**17.02 %**
	Only Parallax	**22.68 %**
	Parallax and cloud shadow	**17.46 %**
rel. MAE	Uncorrected	**8.13 %**
	Only Parallax correction	**9.96 %**
	Parallax and cloud shadow	**9.00 %**

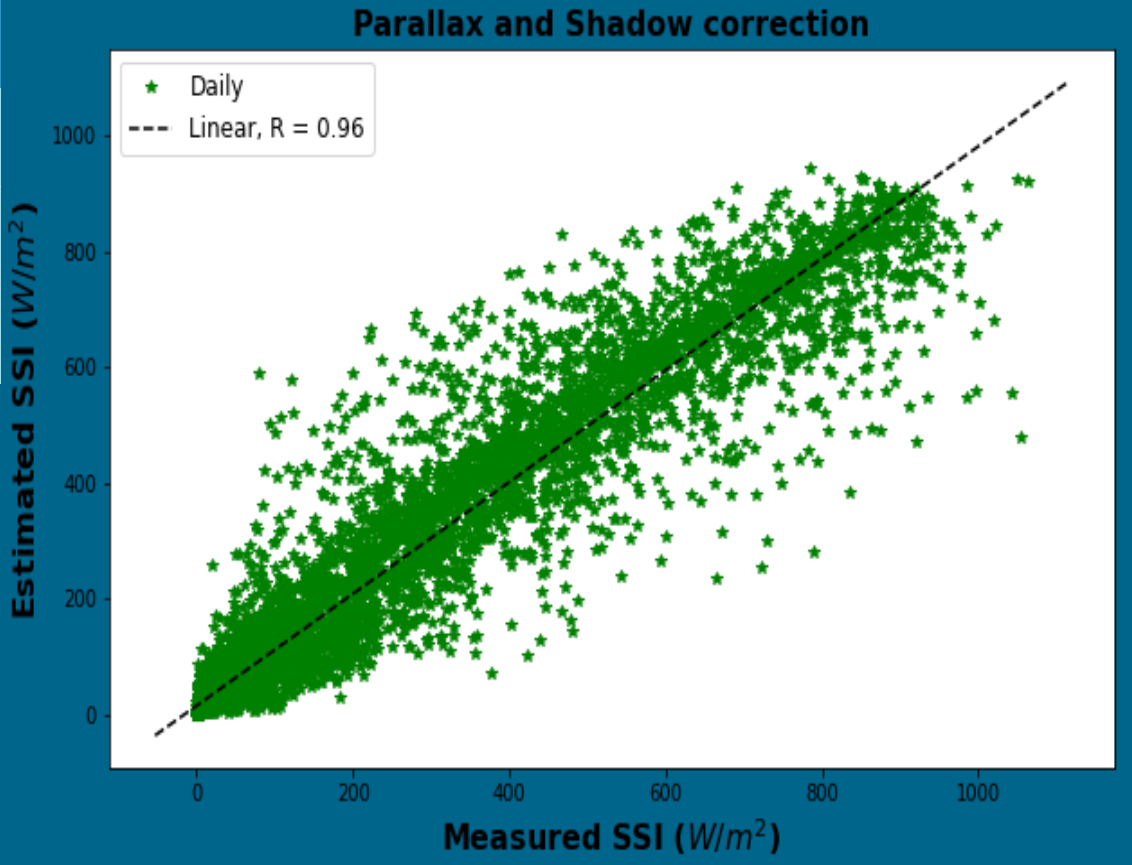


Arindam Roy, German Aerospace Center (DLR) Institute of Networked Energy Systems, Oldenburg, 06.09.2022

SSI Estimation Error - Overall

BSRN Gurgaon

Error Metrics		Jul	Aug	Sep
rel. RMSE	Uncorrected	**24.33 %**	**25.10 %**	**18.92 %**
	Only Parallax	**24.51 %**	**25.02 %**	**18.58 %**
	Parallax and cloud shadow	**22.97 %**	**21.66 %**	**16.87 %**
rel. MAE	Uncorrected	**13.09 %**	**12.84 %**	**8.82 %**
	Only Parallax correction	**13.04 %**	**12.84 %**	**8.65 %**
	Parallax and cloud shadow	**12.10 %**	**11.13 %**	**8.04 %**

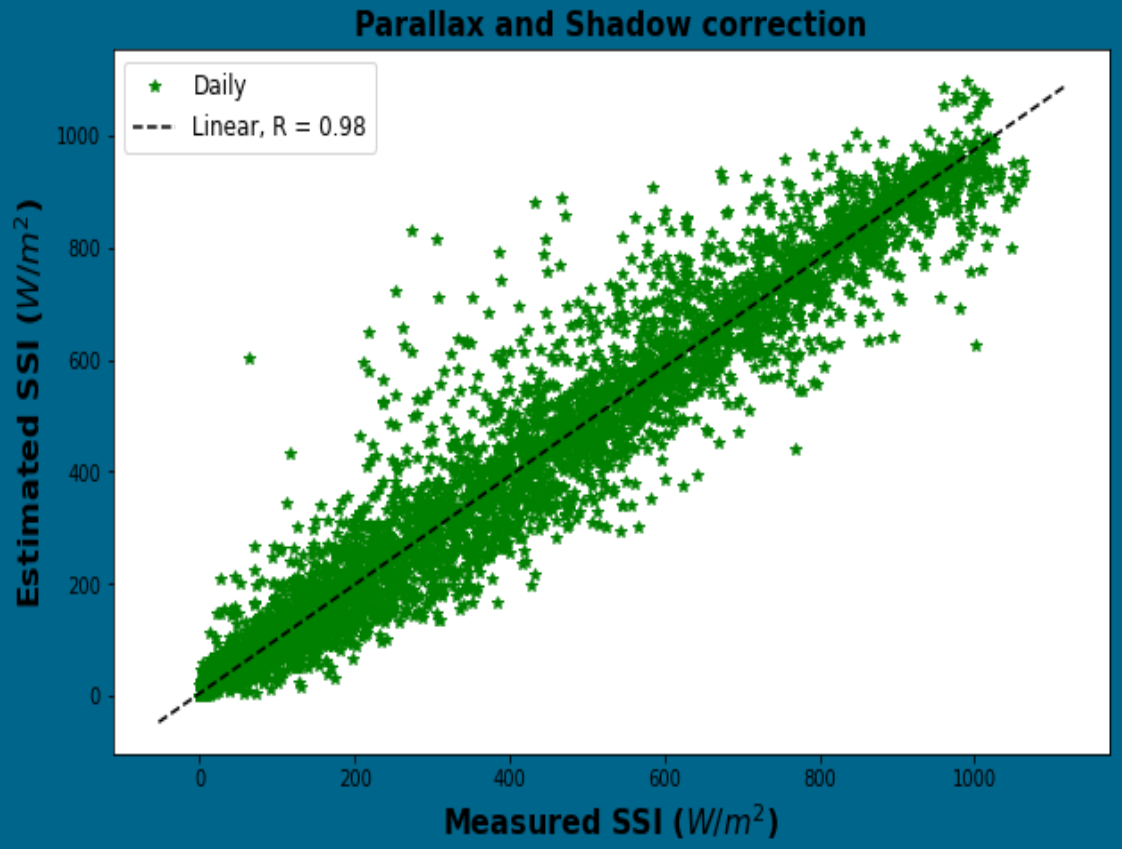


Arindam Roy, German Aerospace Center (DLR) Institute of Networked Energy Systems, Oldenburg, 06.09.2022

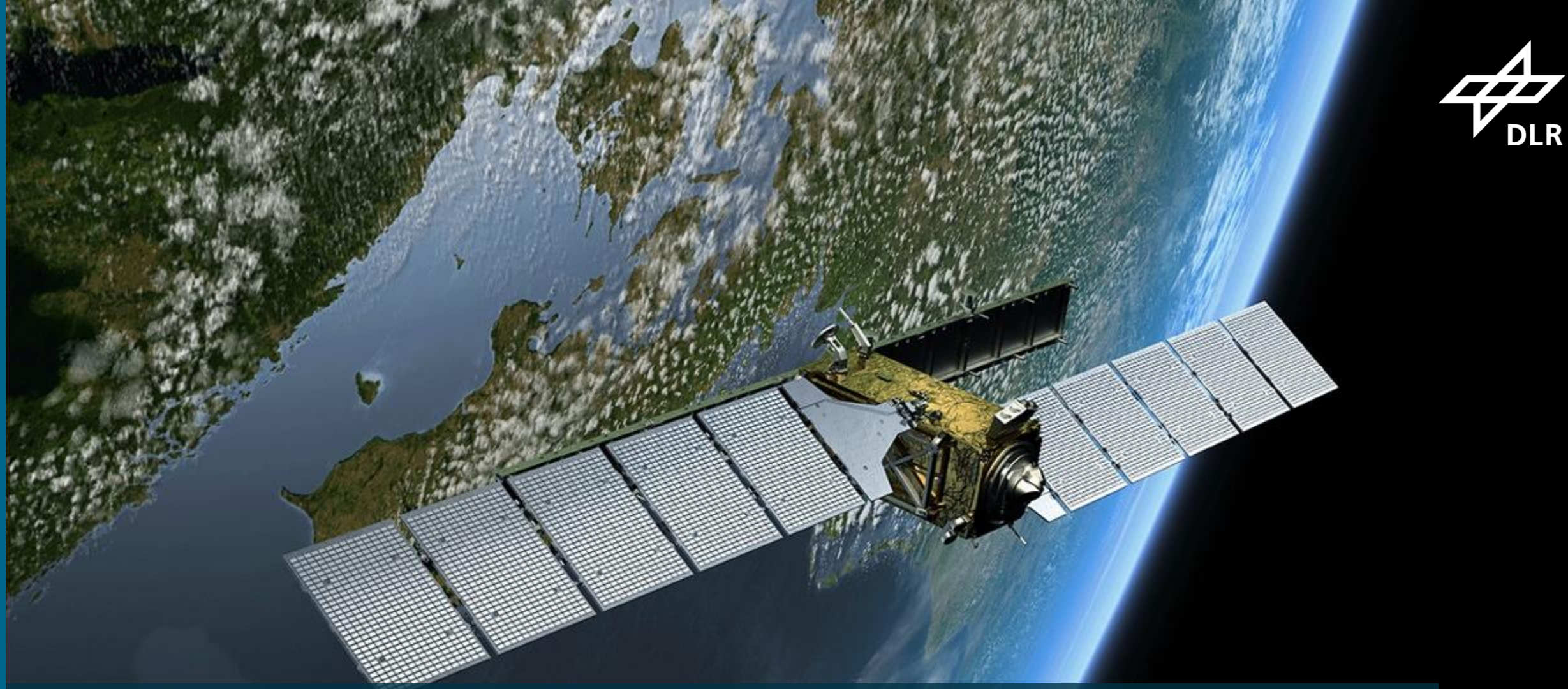
SSI Estimation Error - Overall

BSRN Tiruvallur

Error Metrics		Jul	Aug	Sep
rel. RMSE	Uncorrected	**14.52 %**	**14.94 %**	**16.47 %**
	Only Parallax	**13.98 %**	**15.48 %**	**16.73 %**
	Parallax and cloud shadow	**11.84 %**	**14.04 %**	**15.59 %**
rel. MAE	Uncorrected	**7.30 %**	**7.69 %**	**7.39 %**
	Only Parallax correction	**7.24 %**	**7.88 %**	**7.70 %**
	Parallax and cloud shadow	**6.23 %**	**7.30 %**	**6.94 %**



Arindam Roy, German Aerospace Center (DLR) Institute of Networked Energy Systems, Oldenburg, 06.09.2022



SUMMARY

Arindam Roy, German Aerospace Center (DLR) Institute of Networked Energy Systems, Oldenburg, 06.09.2022

Key Observations

- Overall Improvement in Satellite-based SSI estimation
- Low resolution of CTH data deteriorates the accuracy in specific cases.

Future Steps

- Better 3D modelling of clouds (Now they are modelled as flat plates floating in the sky !)

- Multiple cloud layers in the path of solar irradiance