Effect of Dust Aerosol on Surface Solar Irradiance Retrieval from Satellite Observations

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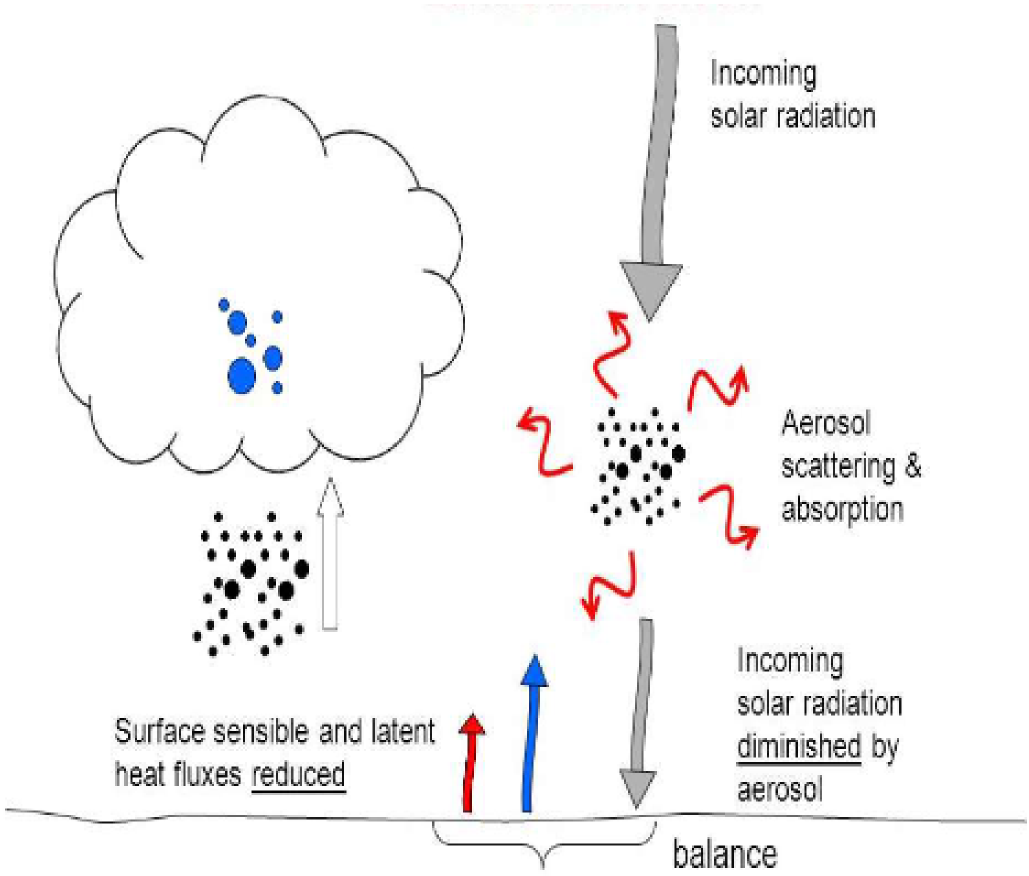
Introduction

- Doctoral researcher in the Energy Meteorology group, Institute of Networked Energy Systems, Oldenburg

- Intra-day solar irradiance forecast for tropical regions with atmospheric convection and high aerosol content
  - Impact of seasonal convection on the accuracy of Cloud Motion Vector forecast
  - Improved correction of cloud shadow location in satellite-based Surface Solar Irradiance (SSI) estimation for large Cloud Top Heights
  - Effect of extreme aerosol events on the accuracy of satellite-based SSI estimation

Introduction

- Tropical and sub-tropical regions receive high solar irradiance
- Rapid growth in grid-connected PV capacity
- 50 GW of solar PV systems connected to the Indian Electricity Grid (as of Feb 2022), target of 300 GW by 2030
- Increasing importance of SSI estimation and forecasts
  - Solar PV installation and long term electricity grid operation planning
  - Financially sound bids at the power market exchange
  - Secure operation of the electricity grid



Satellite Retrieval of Surface Solar Irradiance (SSI)

SSI estimation with Radiative Transfer Models (RTMs)

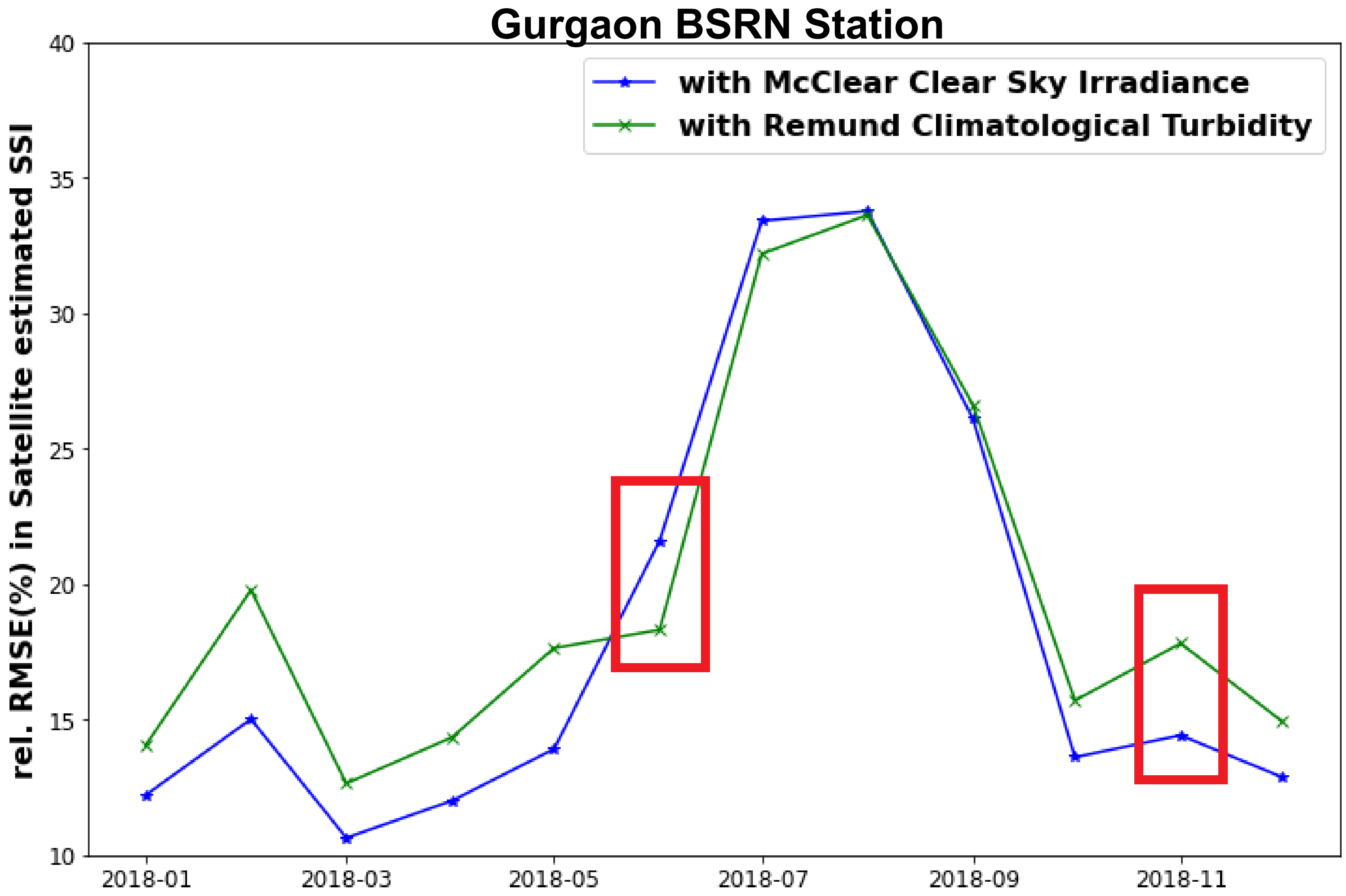
- Computationally expensive methods like MODTRAN and LibRadtran. Simpliflications are necessary
  - Look Up Table (LUTs)
    - CM-SAF
    - CAMS radiation service / Heliosat 4 (Qu et al. 2017)
  - Simplified RTMs
  - Parameterizations
- Aerosol information is directly used in RTM.

SSI with Statistical Methods

- Empirical relation between reflectance and cloudiness
  - Heliosat-2 model
  - SUNY / SolarGIS model
- Aerosol information is fed into a Clear Sky Model to produce clear sky irradiance estimates
- Clear sky irradiance is proportionally reduced based on cloudiness

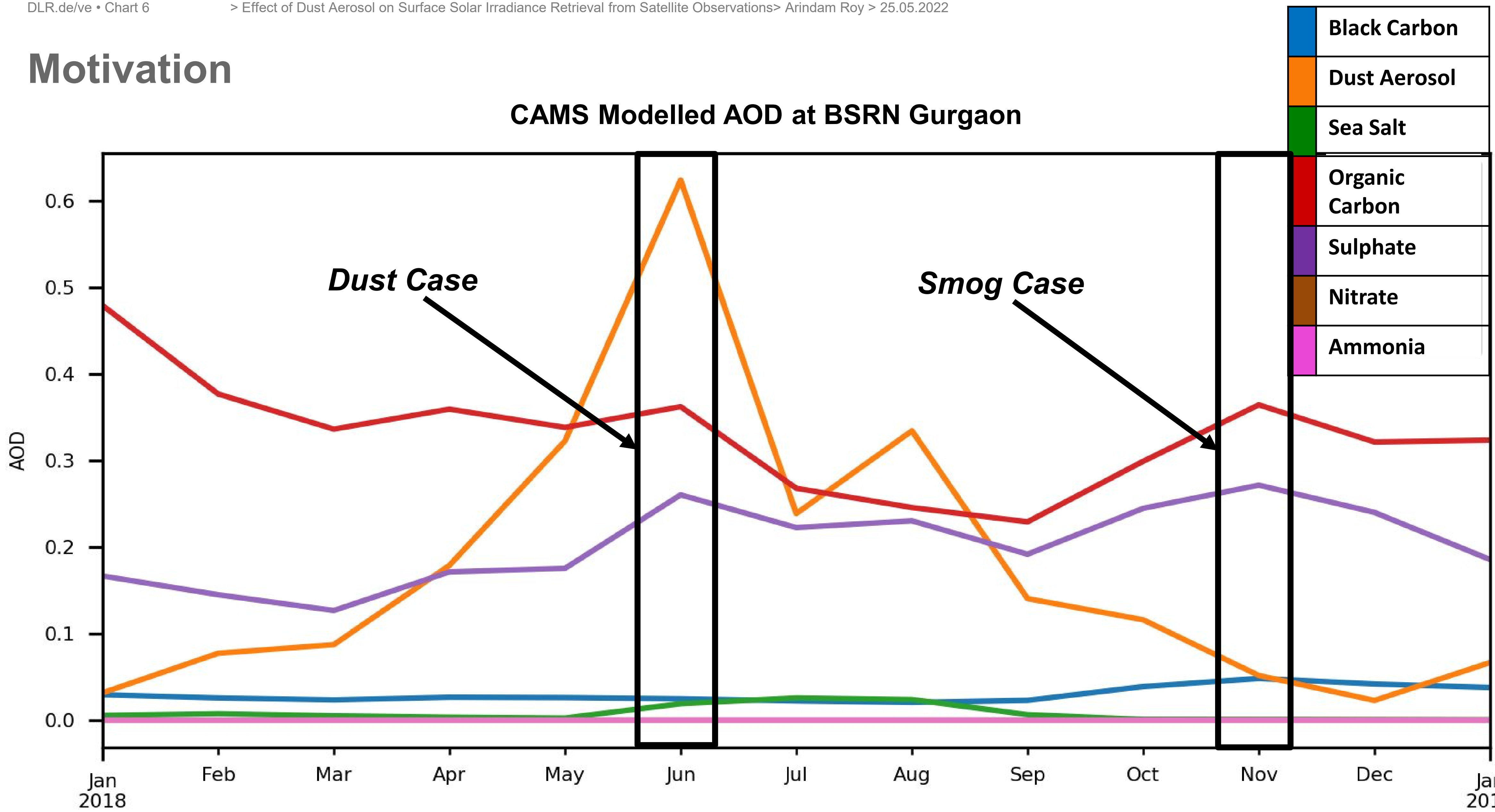
The Heliosat-2 method is used in this analysis.

Motivation

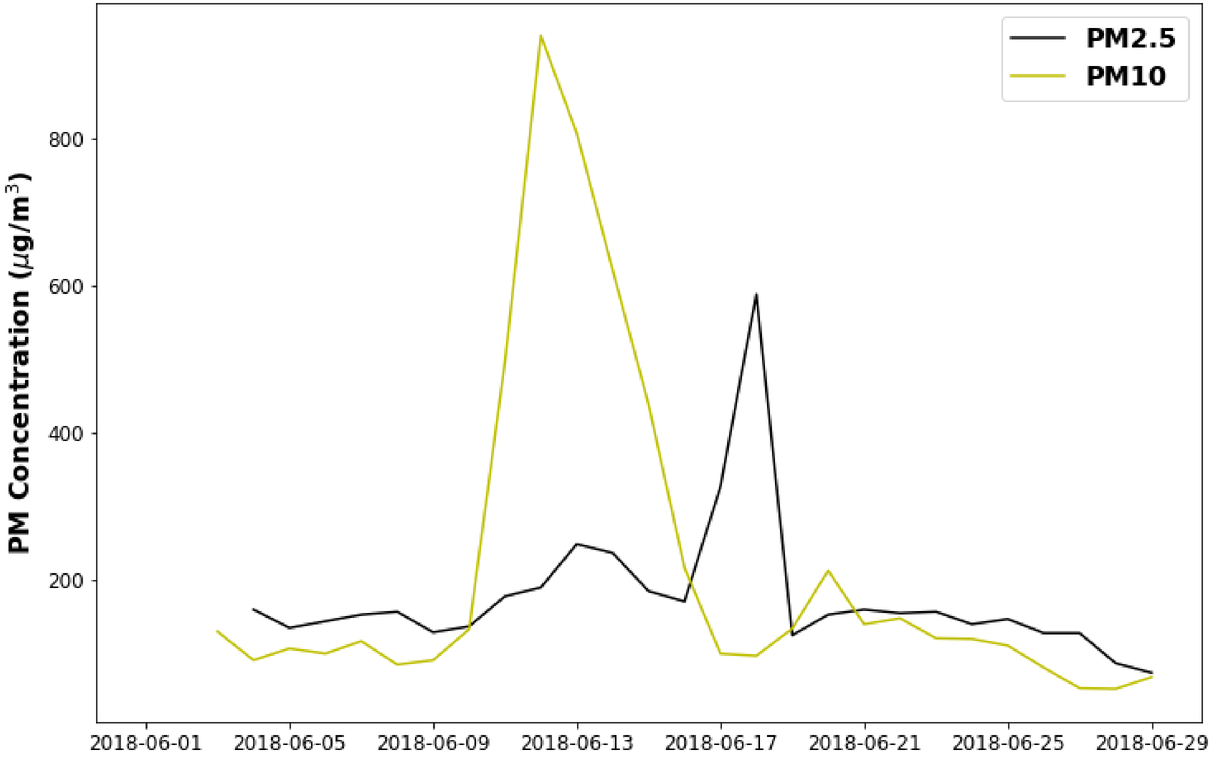


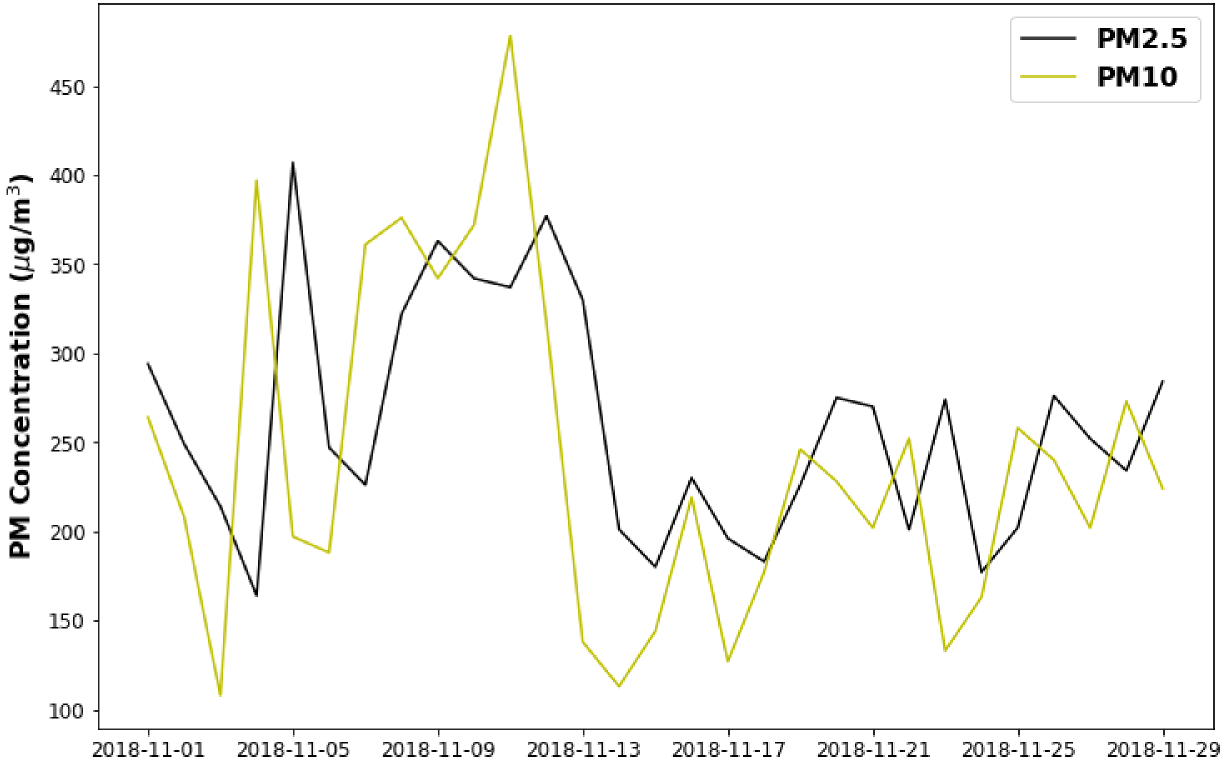
- Higher error in satellite estimated SSI with climatological turbidity
- Dust storm event in June 2018
- Smog event in Nov 2018

Motivation


CAMS Modelled AOD at BSRN Gurgaon
Black Carbon
Dust Aerosol
Sea Salt
Organic Carbon
Sulphate
Nitrate
Ammonia
Dust Case
Smog Case
AOD
0.6
0.5
0.4
0.3
0.2
0.1
0.0
Jan 2018
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Jan 2019

Motivation





Particulate Matter (PM) measured at the RK Puram station in Delhi. *World Air Quality Index (AQI) Project.* *https://waqi.info/de/*

Challenges

- Climatological turbidity data → Lack of information on extreme events like dust and smog
- Reanalysis and forecast products from NWP models → Gridded data with a spatial resolution of several tens of kilometers
- Ground measurements of AOD → Limited spatiotemporal coverage, expensive instruments

METeorological Aerodrome Report (METAR) provides indirect information on atmospheric turbidity with ground measured parameters like visibility, relative humidity, surface air temperature and pressure using a large network of measurements from existing airports.

Conversion of visibility for use in the model chain

Visibility to AOD

- Visibility in distance from METAR

- Conversion of Visibility to AOD (Vermote et al 2002[1]):

$$AOD_{550} = \frac{3.9449}{vis(km)} + 0.08498$$

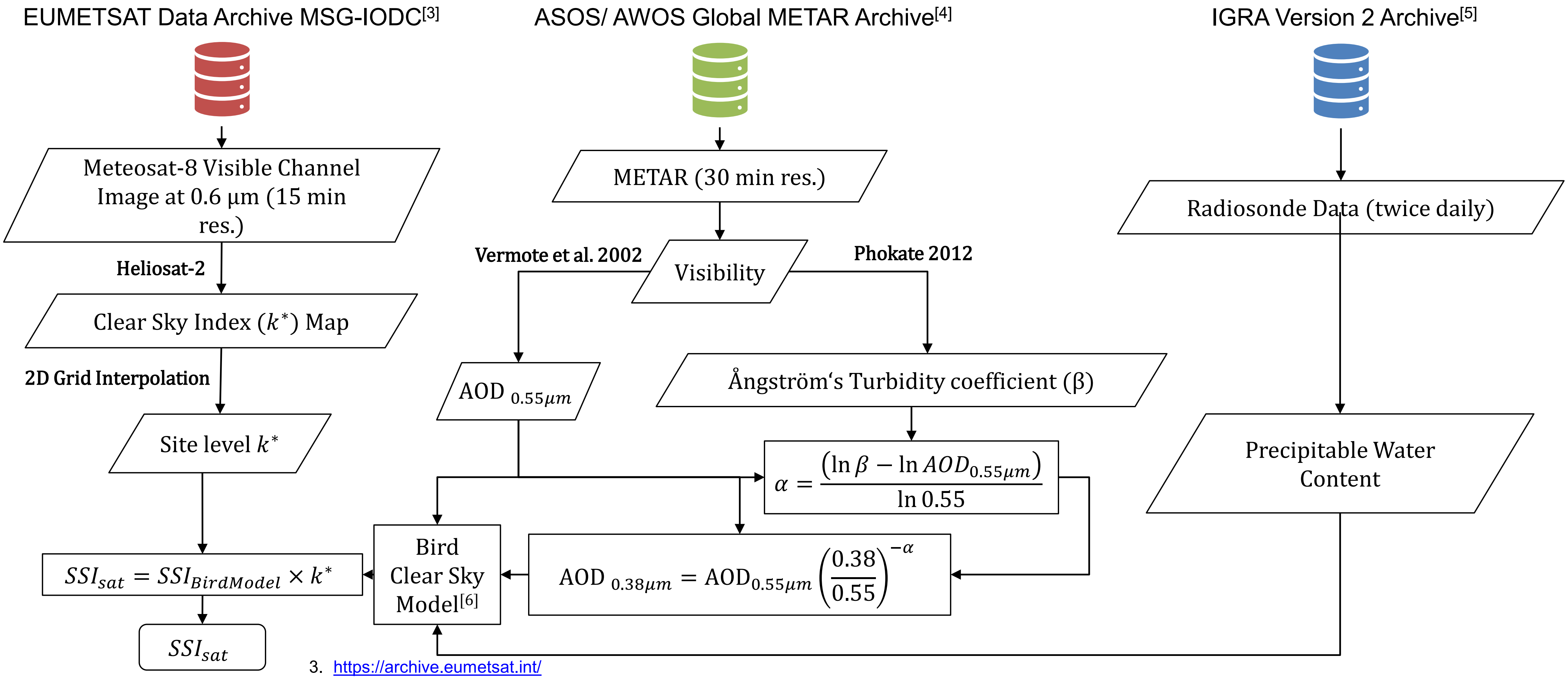
Visibility to Turbidity Coefficient

- Conversion of Visibility to Turbidity Coefficient (Phokate 2012[2]):

$$\beta = 0.0022(vis)^2 - 0.06(vis) + 0.5259$$

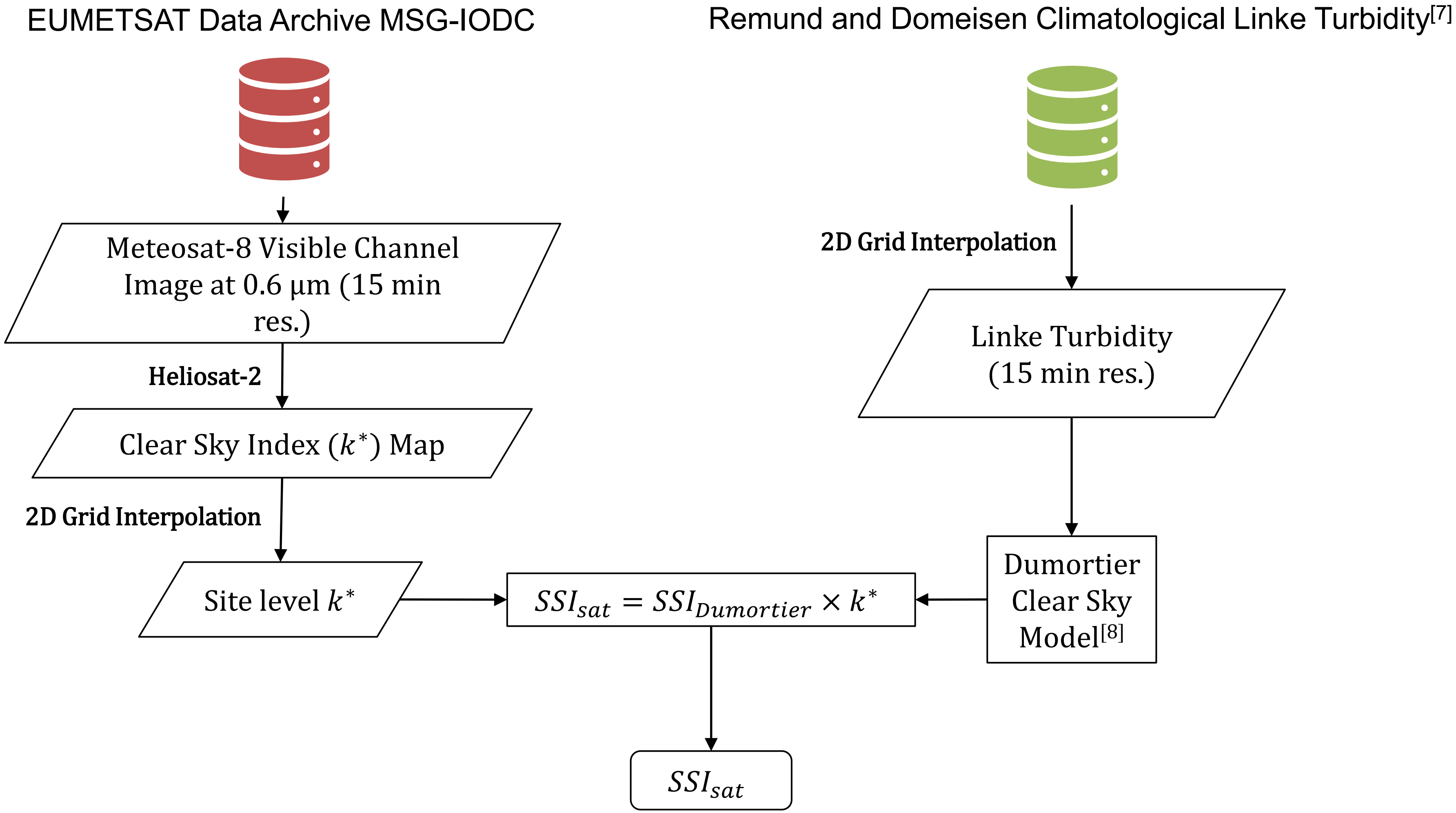
1. Vermote, E. F., et al., (2002), Suspended Matter. Visible/Infrared Imager/Radiometer Suite algorithm theroretical basis document. SBRS Document # Y2390, Raytheon Systems Company, Information Technology and Scientific Services, Maryland.
2. Phokate, S. (2012). A determination of atmospheric turbidity coefficient from visibility data. *Engineering and Applied Science Research*, 36(4), 333-338

Approach – with METAR derived AOD and Bird Clear Sky Model



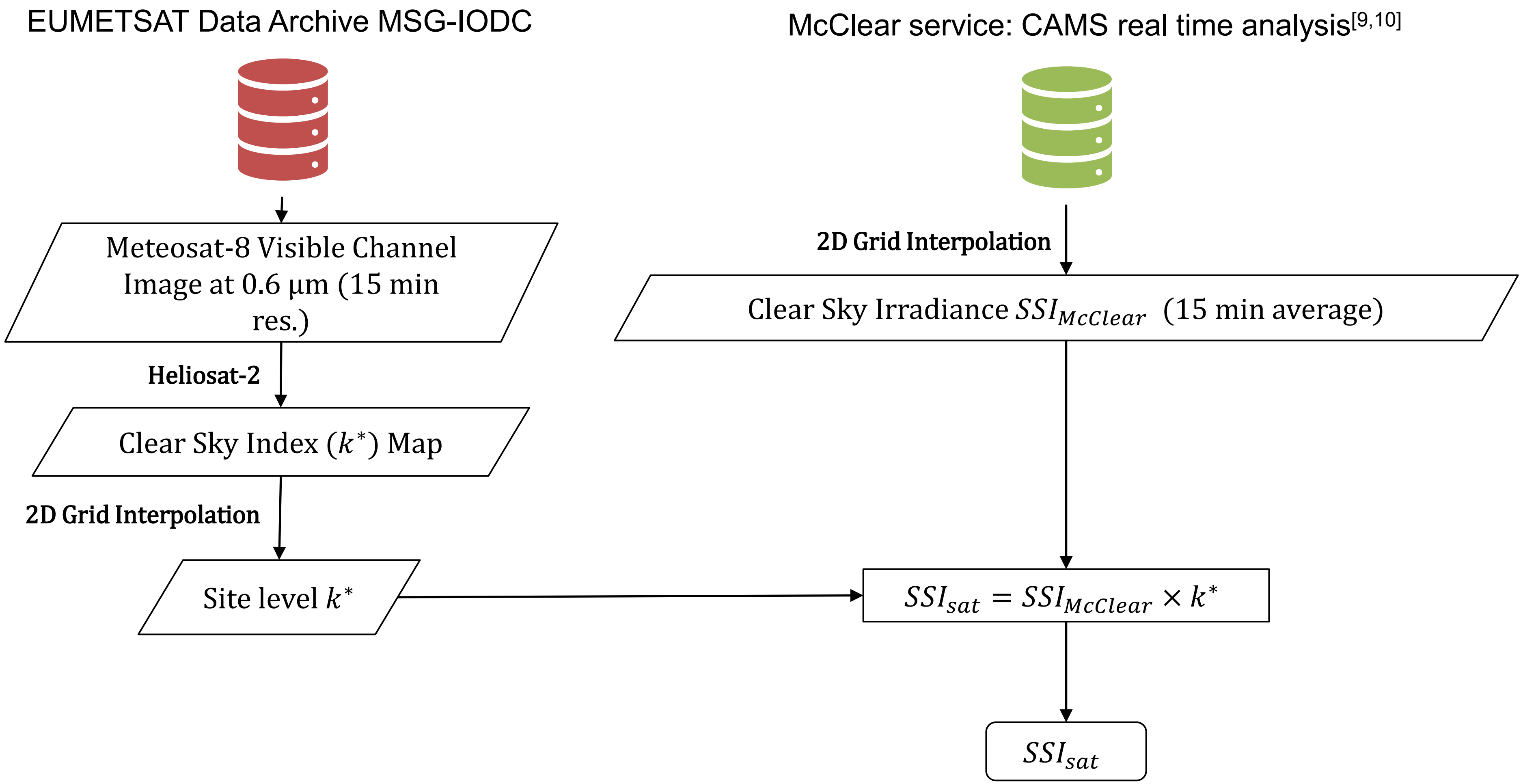
3. https://archive.eumetsat.int/
4. Iowa Environmental Mesonet https://mesonet.agron.iastate.edu/request/download.phtml
5. Durre, Imke; Xungang, Yin; Vose, Russell S.; Applequist, Scott; Arnfield, Jeff. (2016) Integrated Global Radiosonde Archive (IGRA), Version 2. NOAA National Centers for Environmental Information. DOI:10.7289/V5X63K0Q [21.05.2022].
6. Bird, R. E., and Hulstrom, R. L. Simplified clear sky model for direct and diffuse insolation on horizontal surfaces. United States: N. p., 1981. Web. doi:10.2172/6510849

Approach – with Remund Climatological Linke Turbidity and Dumortier Clear Sky Model



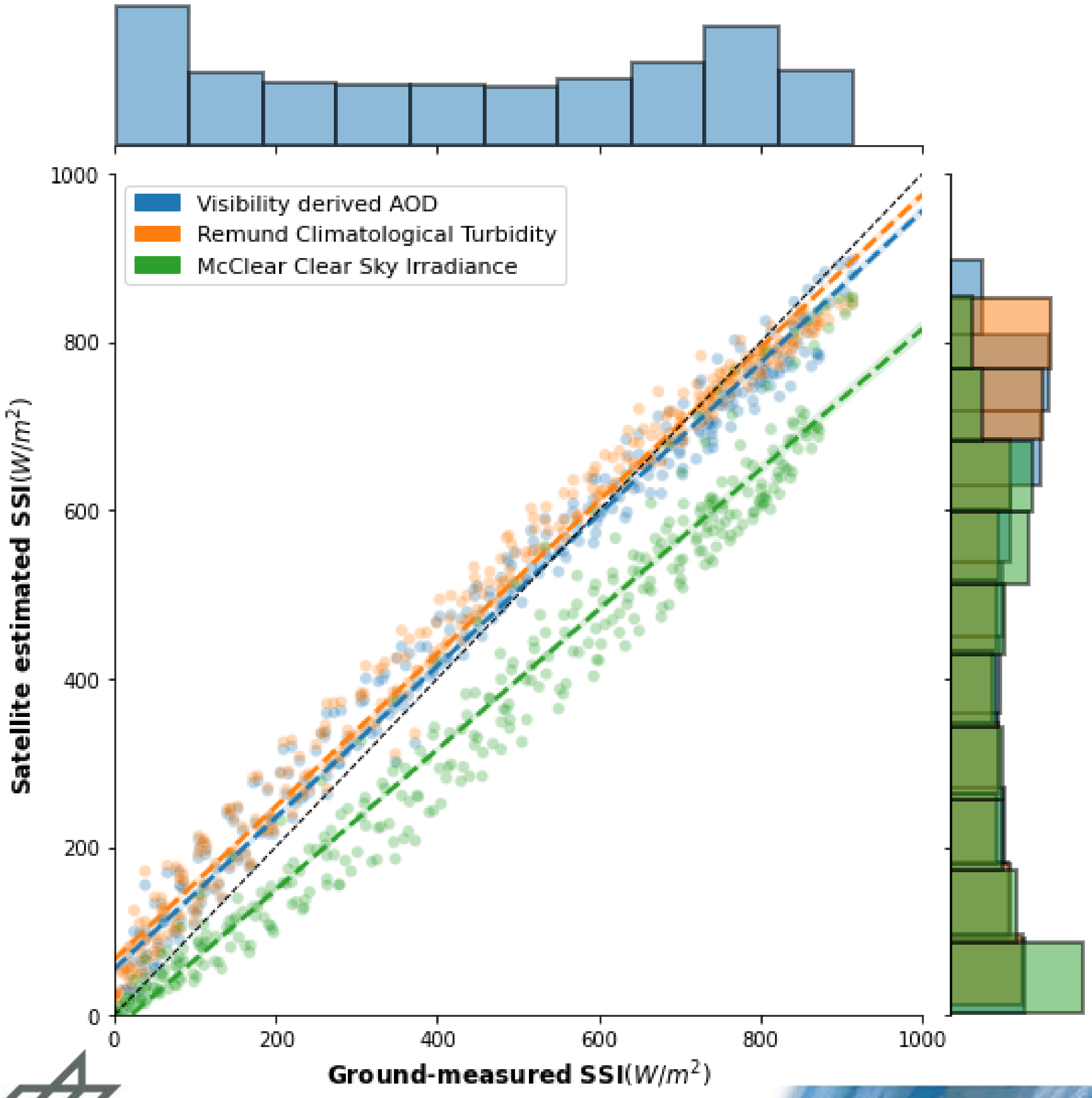
7. Remund J and Domeisen D 2009 Aerosol optical depth and Linke turbidity climatology *Description for final report of IEA SHC Task 36*
8. Dumortier D 1995 Modelling global and diffuse horizontal irradiances under cloudless skies with different turbidities Final Report JOU2-CT92-0144, Daylight II 2

Approach – with CAMS real time analysis Clear Sky Irradiance



9. McClear Data: https://www.soda-pro.com/web-services/radiation/cams-mcclear
10. Gschwind, B., Wald, L., Blanc, P., Lefèvre, M., Schroedter-Homscheidt, M., & Arola, A. (2019). Improving the McClear model estimating the downwelling solar radiation at ground level in cloud-free conditions–McClear-v3. Meteorologische Zeitschrift, 28(2)

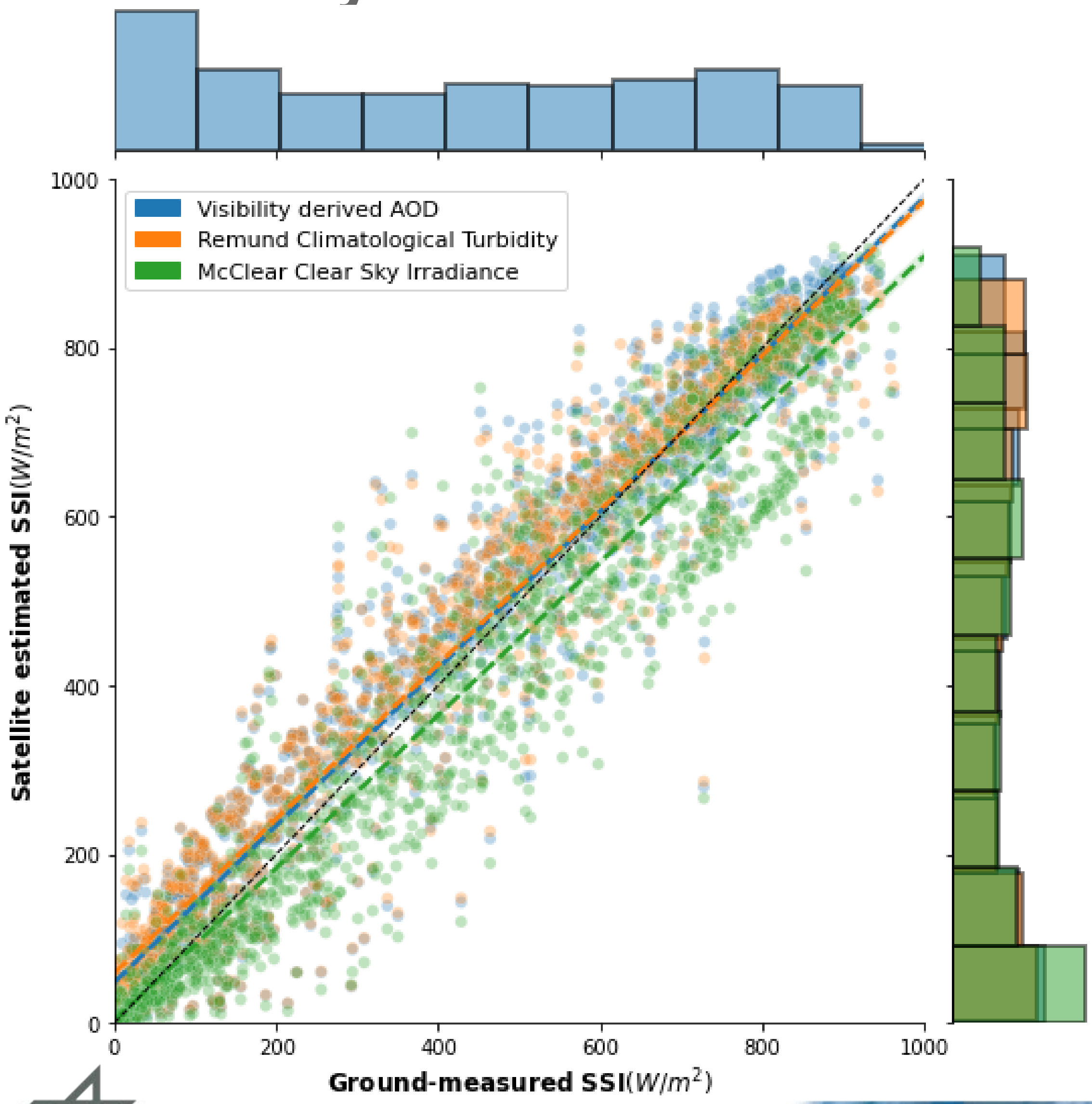
Case Study – I : Pre-monsoon Dust Storm



Validation of satellite derived SSI against ground-measured SSI from BSRN Gurgaon for the period 10.06.2018 to 16.06.2018

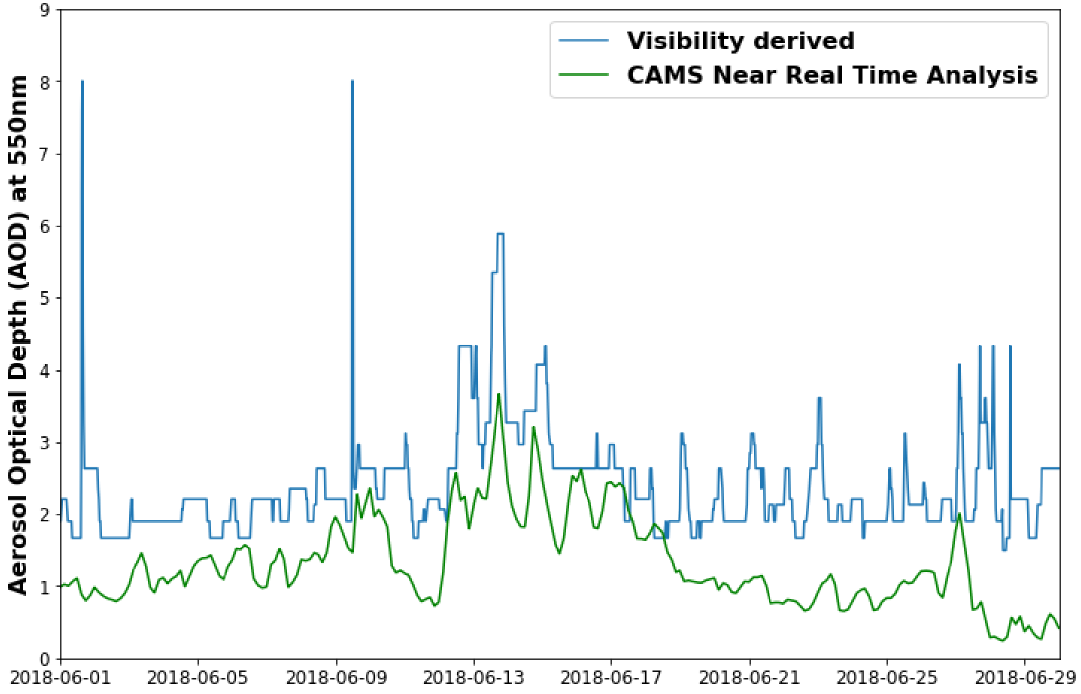
SSI retrieved with	Remund Climatological Turbidity	McClear	Visibility
rel. RMSE	10.6 %	25.4 %	9.9 %
rel. MBE	5.7 %	-20.6 %	2.4 %

Case Study – I : Pre-monsoon Dust Storm

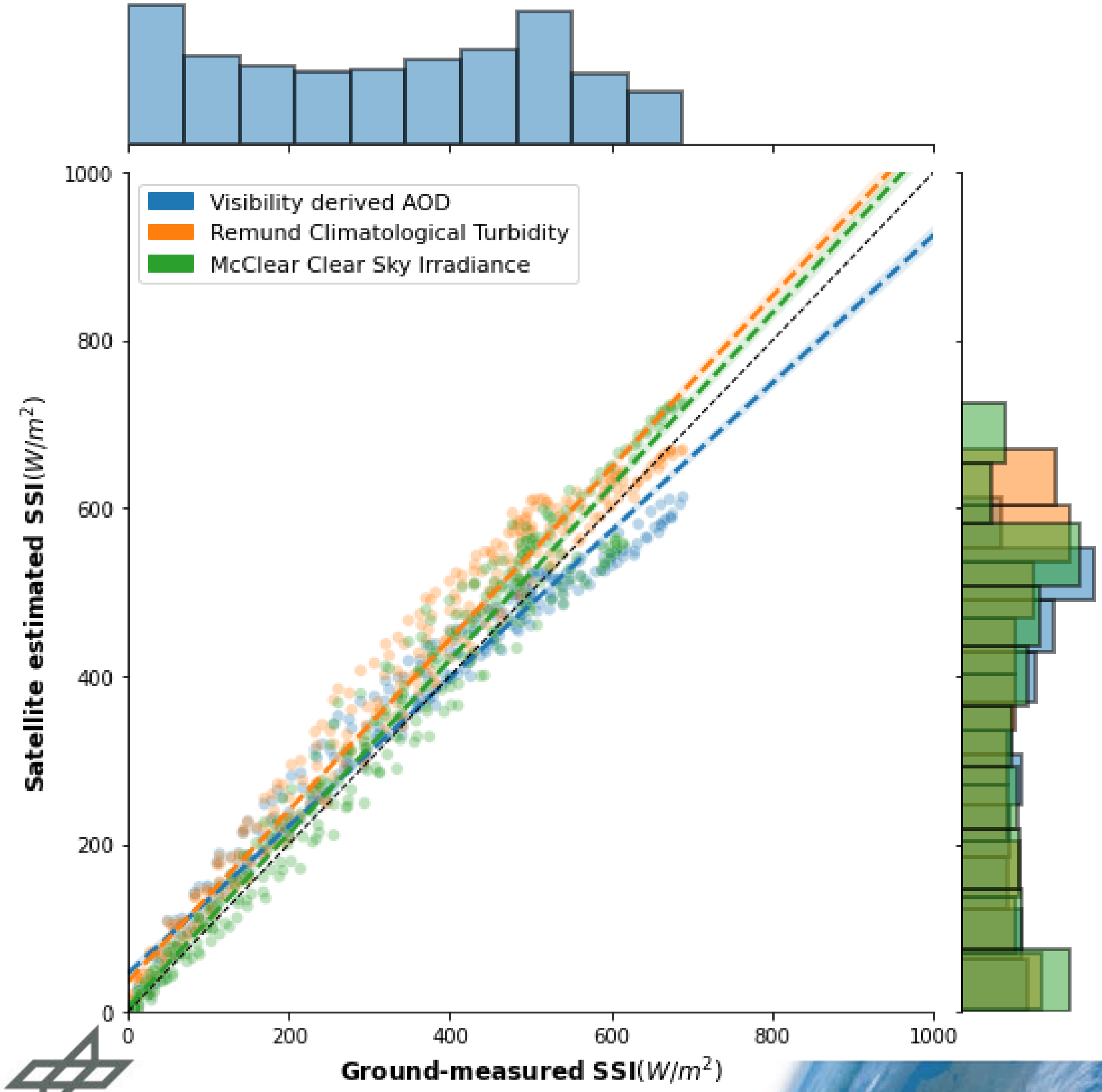


Validation of satellite derived SSI against ground-measured SSI from BSRN Gurgaon for June 2018

SSI retrieved with	Remund Climatological Turbidity	McClear	Visibility
rel. RMSE	18.3 %	21.5 %	18.1 %
rel. MBE	5.5 %	-8.8 %	4.4 %



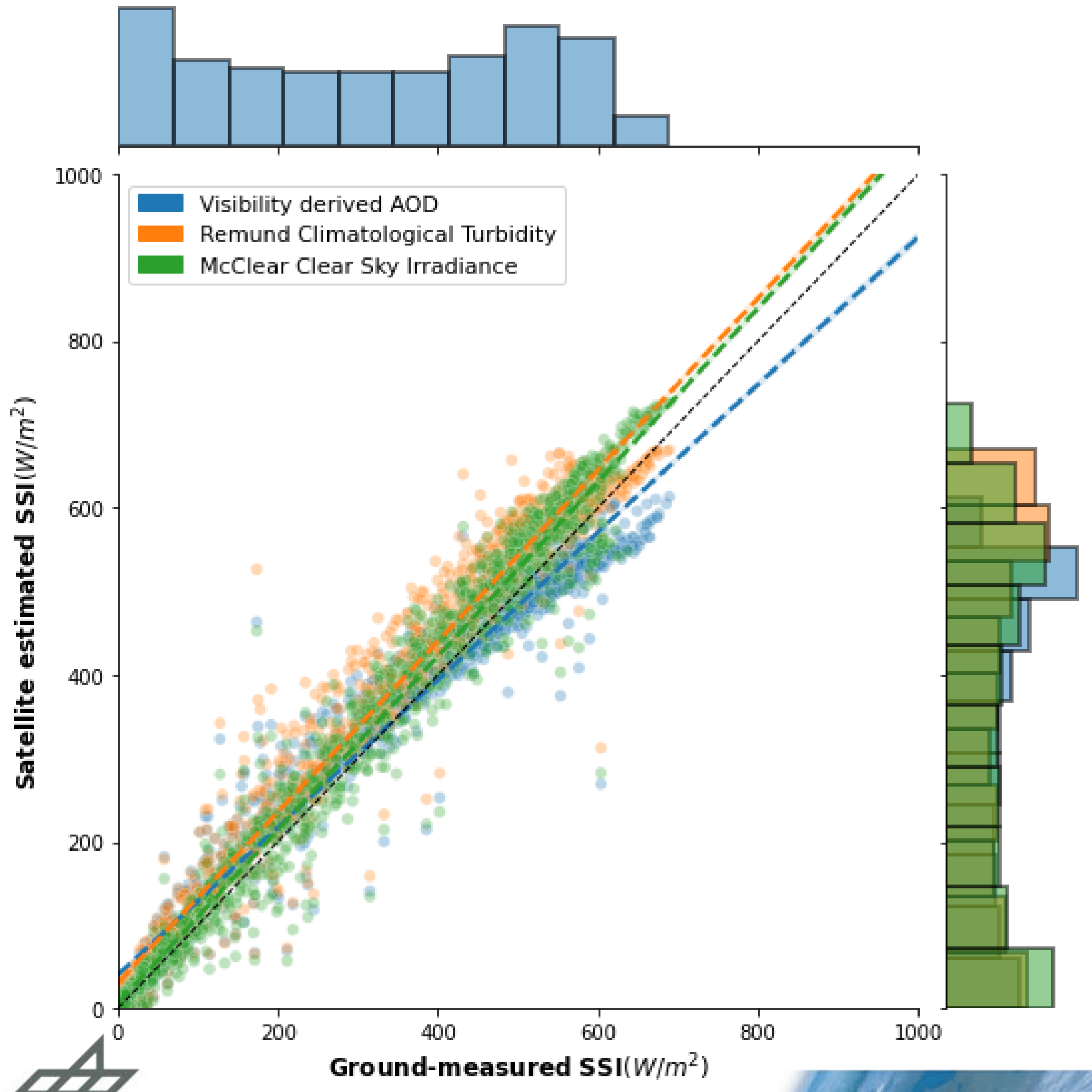
Case Study – II : Winter Smog



Validation of satellite derived SSI against ground-measured SSI from BSRN Gurgaon for the period 05.11.2018 to 12.11.2018

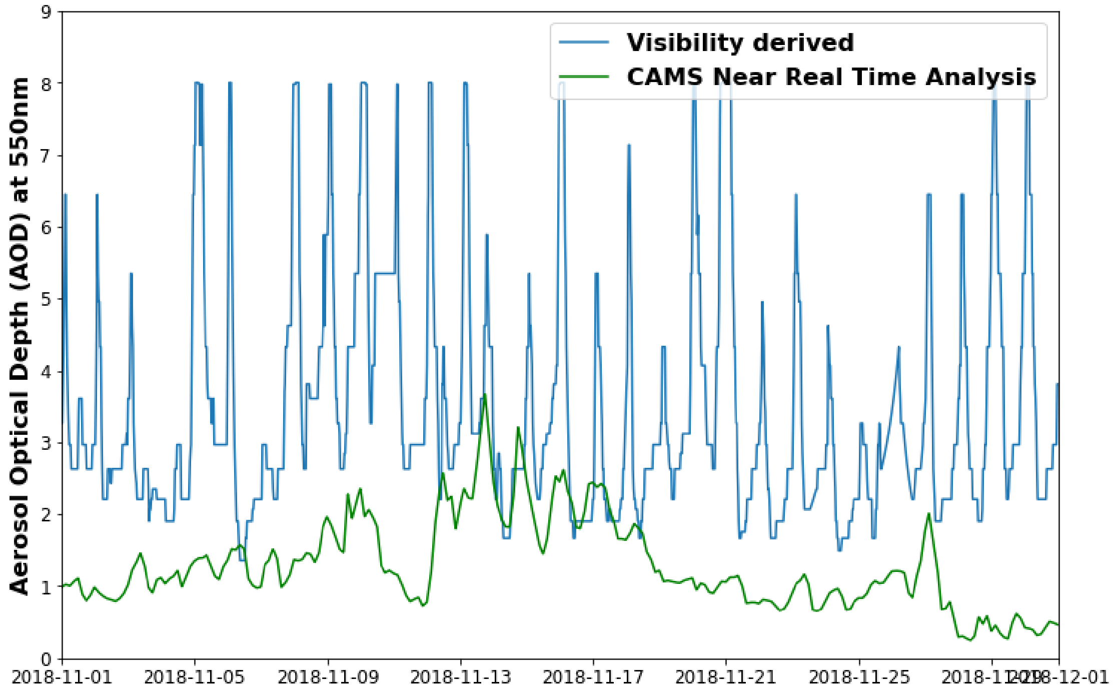
SSI retrieved with	Remund Climatological Turbidity	McClear	Visibility
rel. RMSE	16.9 %	12.4 %	12.1 %
rel. MBE	13.2 %	5.1 %	2 %

Case Study – II : Winter Smog



Validation of satellite derived SSI against ground-measured SSI from BSRN Gurgaon for November 2018

SSI retrieved with	Remund Climatological Turbidity	McClear	Visibility
rel. RMSE	17.5 %	14.2 %	13.9 %
rel. MBE	12 %	6 %	1 %



Summary

	Dust Event		Smog Event	
How good is the estimation of SSI ?	Periods of low irradiance	Periods of high irradiance	Periods of low irradiance	Periods of high irradiance
Remund Climatological Turbidty	Too high	Too low	Too high	Too high
McClear Clear Sky Irradiance	Very low	Very low	Fits nicely	Too high
Visibility derived AOD	Too high	Too Low	Too high	Too low

- METAR derived AOD with Bird model can be used for estimating SSI from satellite images
- CAMS perfoms generally better than climatology but there are outliers and we investigate such cases
- Validation of the method over a dataset covering the different seasons and weather situations
- How to use METAR in forecast ? Changes to precipitable water content acquisition method