Generating local spectral skies for spectral daylight simulations using radiative transfer libraries

Priji Balakrishnan | Department of Lighting Technology, Technical University of Berlin | Radiance Workshop, Innsbruck, 29 August 2023

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Lichttechnik
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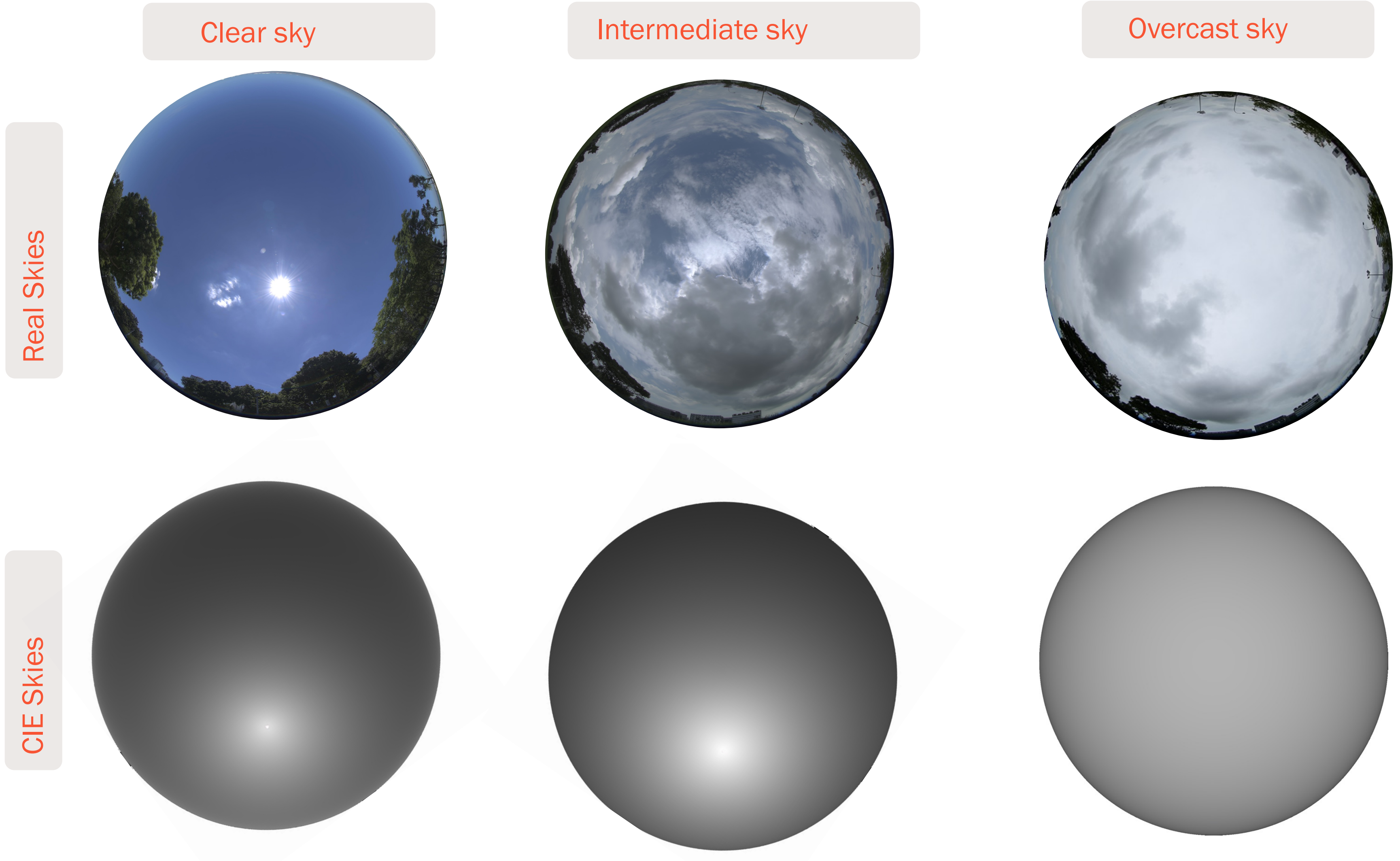
Most commonly used skies in daylight simulations: CIE or Perez skies

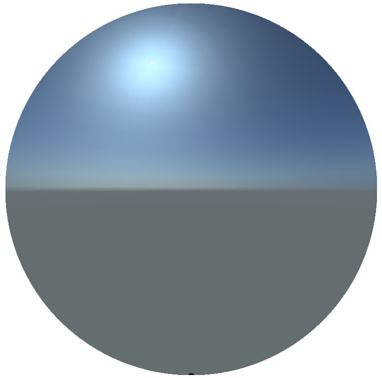


- CIE and Perez skies have only luminance distribution.
- They lack colour and spectral information of light
- Both sun and sky are colourless and modelled as equal energy white light sources.

Currently used spectral skies in spectral daylight simulation tools

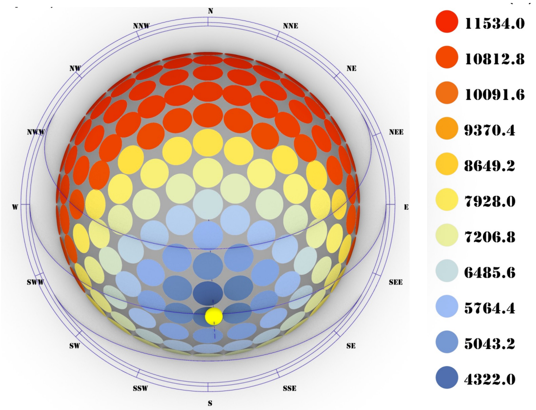
Based on CIE and Perez sky model with inputs of measured global spectral irradiances or CCT.

Sun is not coloured, it is equal energy white source



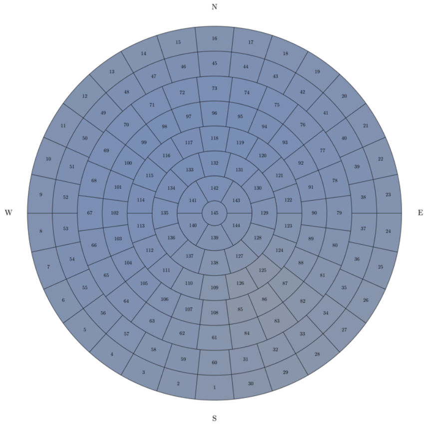
libRadtran skies (precomputed using radiative transfer calculations through atmospheric layers). Standard atmospheric profile is used.

Sun is coloured based on the atmospheric path of light travel



Based on CIE and Perez sky models. Using conversion models from luminance to CCT.

No sun model present



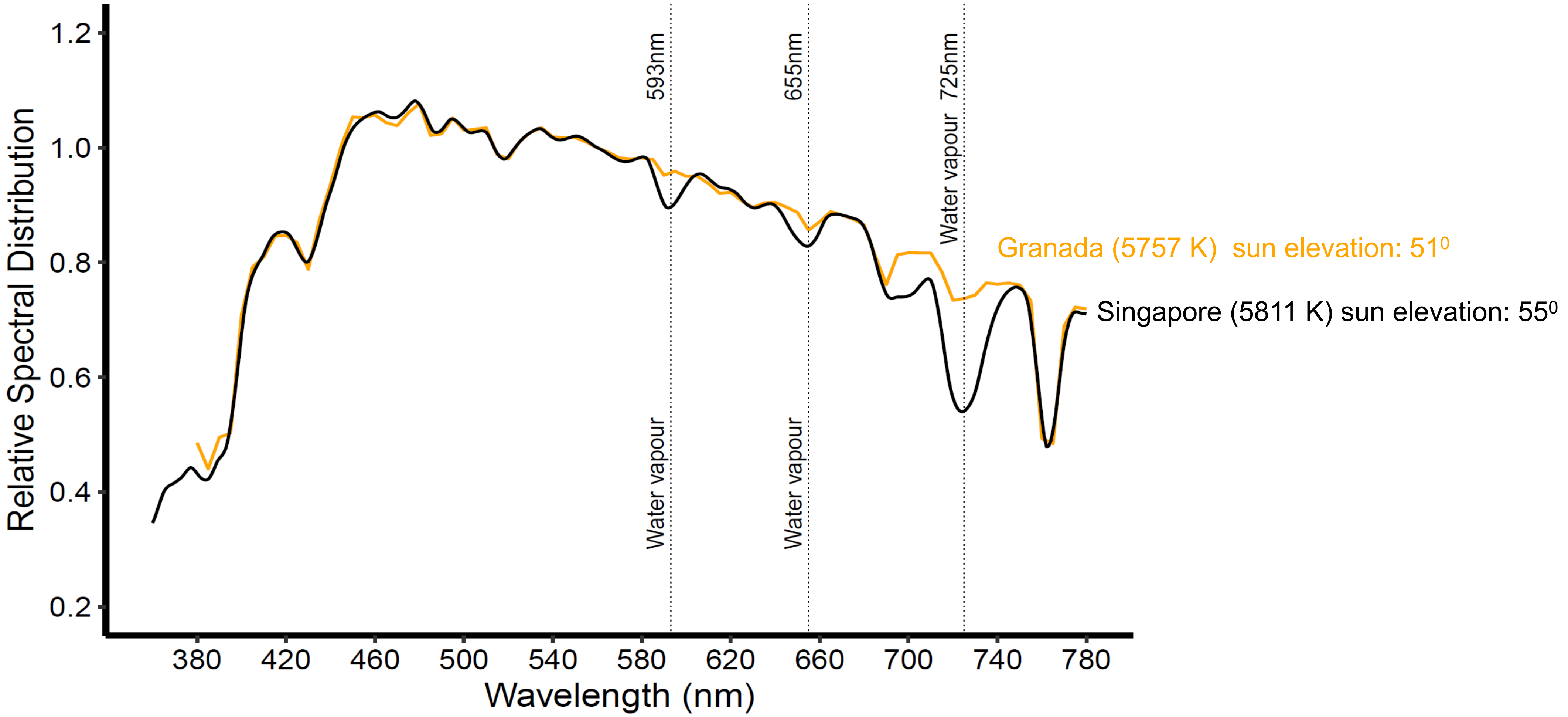
Based on inputs of measured or other available spectral daylight data in the Tregenza sky patch format.

No sun measurement patch included.

Different blue skies in different cities?

- Proportions of atmospheric constituents can change with location, seasons and even time of the day.

Different blue skies in different cities? – Singapore and Granada clear skies



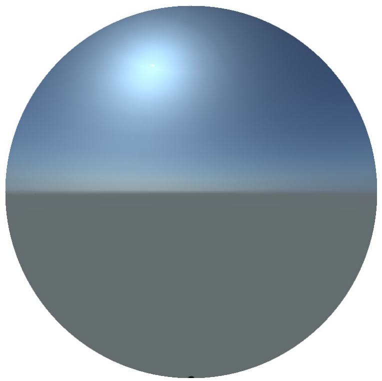
Currently used spectral sky models in spectral daylight simulation tools

LARK
SPECTRAL LIGHTING

Based on CIE and Perez sky model with inputs of measured global spectral irradiances or CCT.

Sun is not coloured, it is equal energy white source

ALFA



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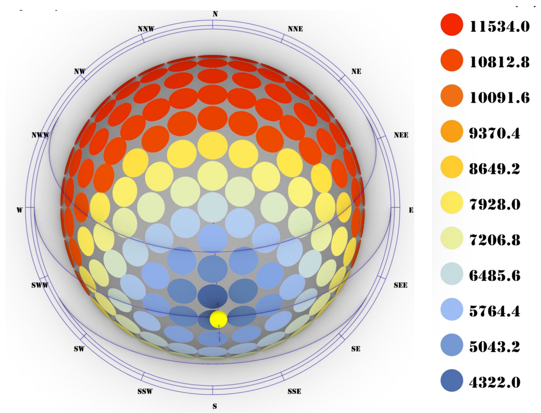
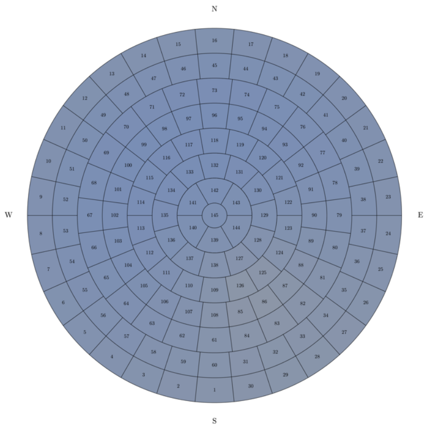


Based on CIE and Perez sky models. Using conversion models from luminance to CCT.

LUMOS



Based on inputs of measured or other available spectral daylight data in the Tregenza sky patch format.

Generating local spectral skies with radiative transfer simulations

Radiative transfer simulations: libRadtran

Atmospheric files

- Midlatitude summer
- Midlatitude winter
- Subarctic summer
- Subarctic winter
- Tropical

Atmospheric description

- Trace gas profiles (O_3, CO_2, NO_2 etc)
- Pressure profile
- Water vapour
- Temperature profile
- Aerosols
- Surface properties (albedo)
- Cloud descriptions
- ….

Solar spectrum (extraterrestrial)

Location/time/solar geometry

- Latitude
- Longitude
- Altitude
- Solar zenith angle
- Solar azimuth angle

Inputs

Outputs

- Broadband irradiances (global, direct, diffuse)
- Spectral irradiances (global, direct, diffuse)
- Spectral radiances

Framework of generating local spectral skies

Location specific atmospheric parameters (measured)

- Atmospheric pressure
- Ozone
- Nitrogen dioxide
- Water vapour
- Aerosols

Atmospheric parameters that effect the visual spectrum of solar radiation

→

Radiative transfer simulations

libRadtran

→

Outputs

- Broadband irradiances (global, direct, diffuse)
- Spectral irradiances (global, direct, diffuse)
- Spectral radiances

→

Comparison with measurements

- Broadband irradiances (global, direct, diffuse)
- Spectral irradiances (global, direct)

↓

Implement local spectral skies in spectral simulation engines

Framework of generating local spectral skies

Location specific atmospheric parameters (measured)

- Atmospheric pressure
- Ozone
- Nitrogen dioxide
- Water vapour
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Atmospheric parameters that effect the visual spectrum of solar radiation

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Radiative transfer simulations

libRadtran

→

Outputs

- Broadband irradiances (global, direct, diffuse)
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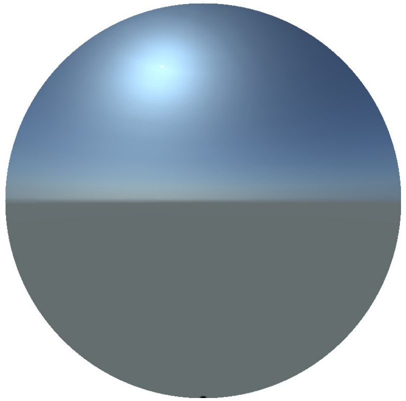
Comparison with measurements

- Broadband irradiances (global, direct, diffuse)
- Spectral irradiances (global, direct)

↓



Implement local spectral skies in spectral simulation engines

Measurement site and data source: Lindenberg, Germany

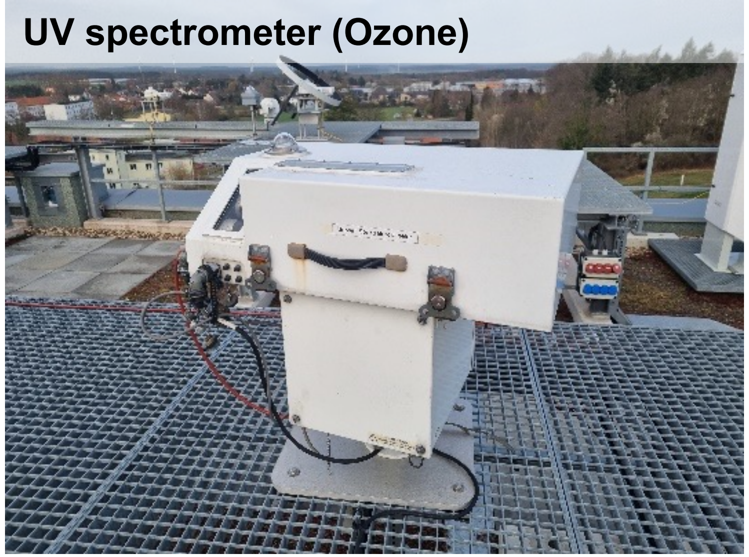
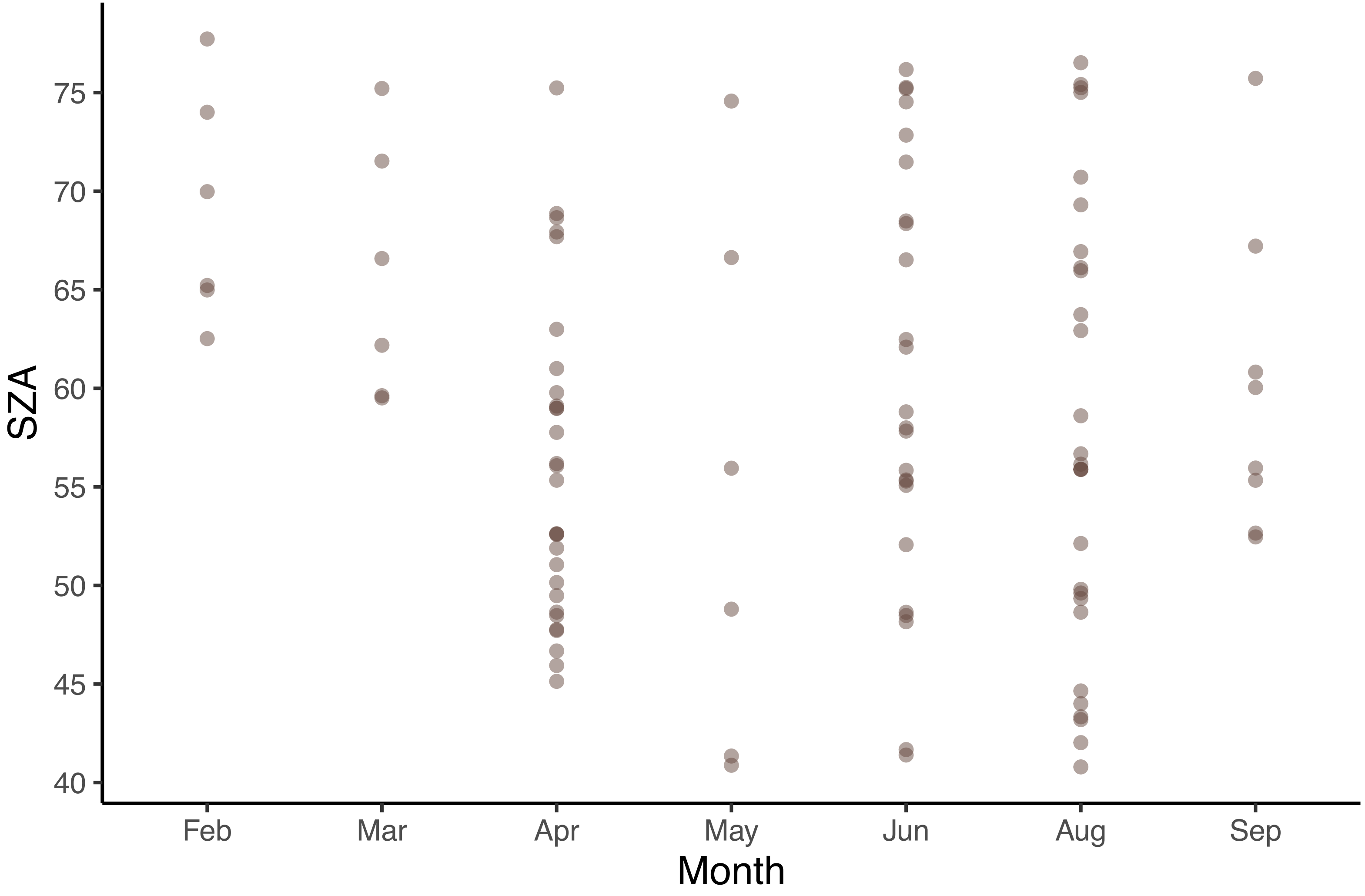


Photo credit: Lionel Doppler, MOL-RAO

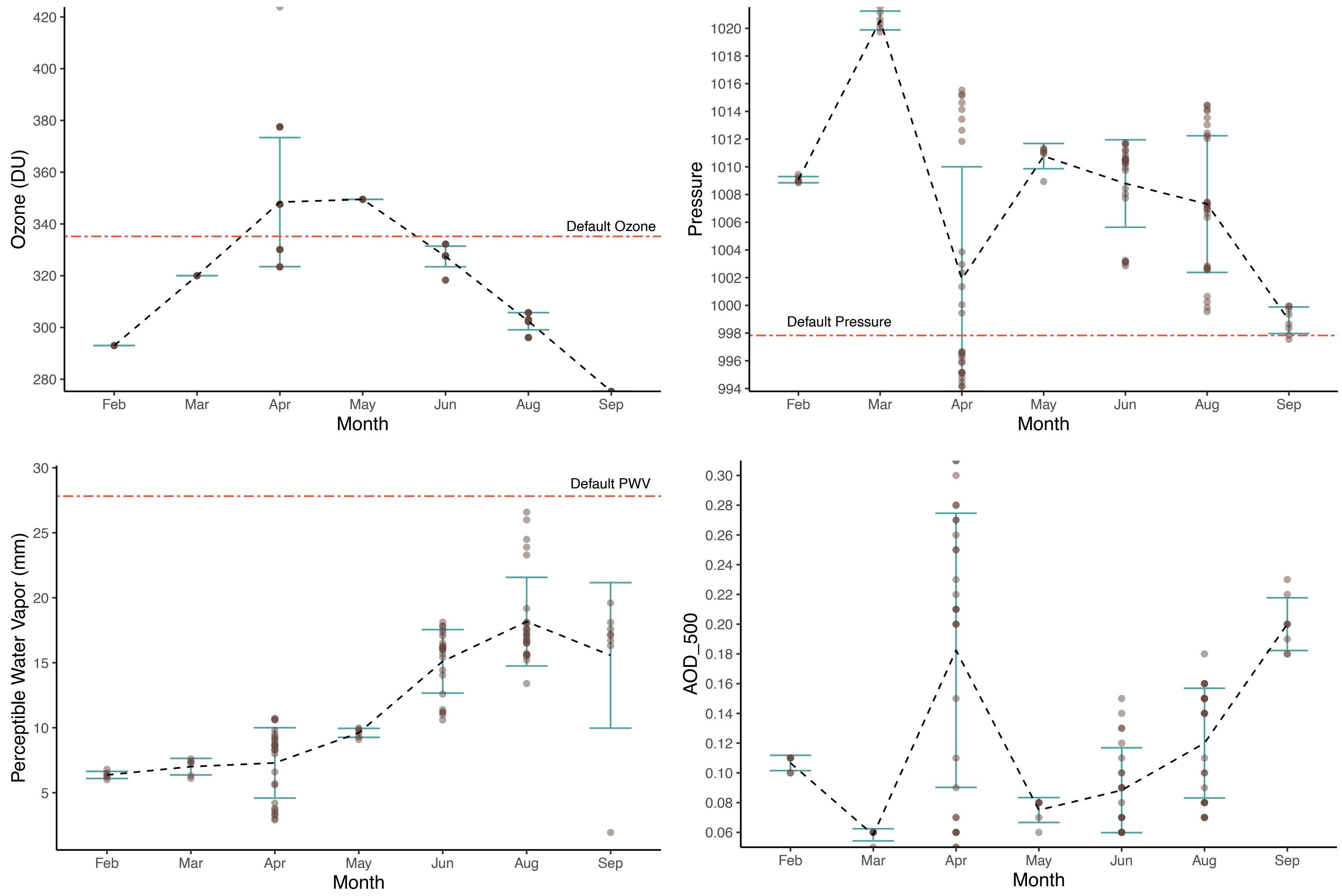
- Both the atmospheric data and data for validation is from Meteorological Observatory Lindenberg - Richard Aßmann Observatory affiliated with the German Meteorological Service (DWD)
- Atmospheric data for location-specific atmospheric profile
  - aerosols (aerosol optical depth, single scattering albedo)
  - Ozone
  - Water vapour (precipitable water vapour)
- Data for validation:
  - Global, diffuse and direct irradiances
  - Spectral global and direct irradiances

About the dataset: cloud-free clear sky dataset



- Cloud-free, clear sky dataset with 101 timestamps throughout the year
- Dataset spans from February to September
- SZA ranges from 41 to 78 degrees
- A subset of this dataset used for direct solar irradiances. 39 timestamps with SZA ranging from 43 to 75 degrees

About the dataset: cloud-free clear sky dataset



- Pressure ranges from 994 to 1021 mbar
- Total ozone column ranges from 275 to 424 DU
- Aerosol optical depth at 500 nm ranges from 0.05 to 0.31
- Single scattering albedo ranges from 0.78 to 0.99
- In the default profile, these are constant values throughout the year.

Simulations procedures for comparison

Radiative transfer simulations with location-specific atmospheric parameters.

libLOC

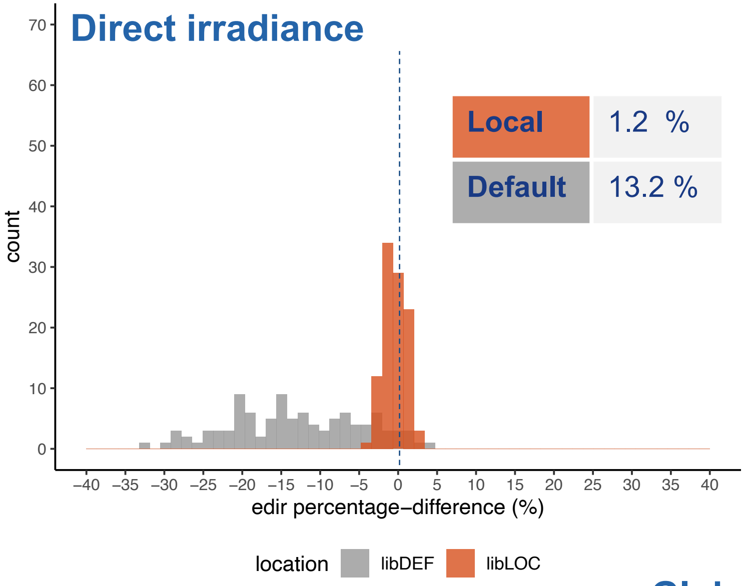
Radiative transfer simulations with default atmospheric parameters

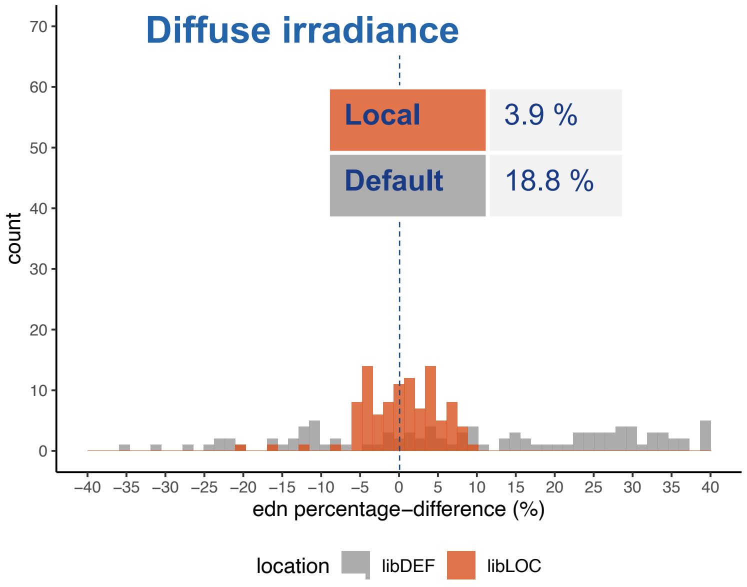
libDEF

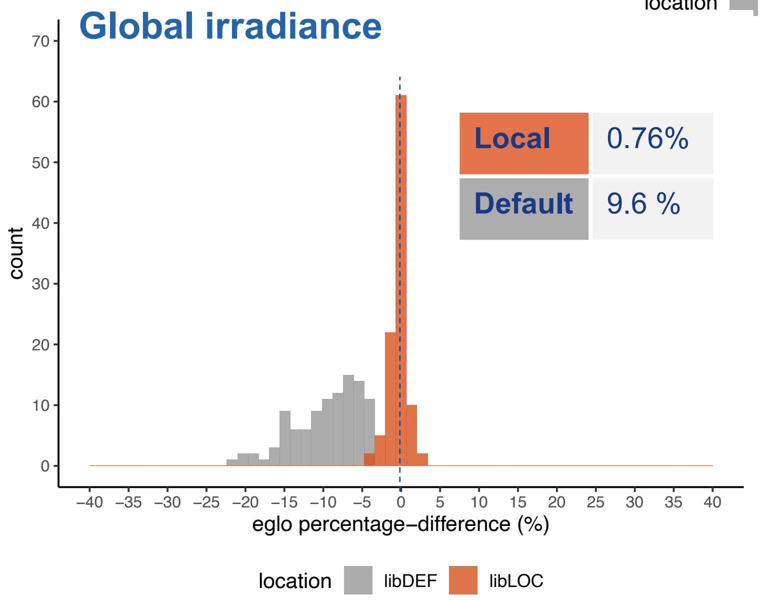
- For the libRadtran simulations, midlatitude summer profile is used since our location is in Europe.
- ALFA also uses the midlatitude summer profile for all locations
- For simulations to generate local spectral skies, measured atmospheric inputs are used.
- Simulations are also run with just the default profile as used in ALFA

Comparing local and default simulations with measured data

Analysis 1: Broadband irradiances (global, diffuse, direct) – percentage differences



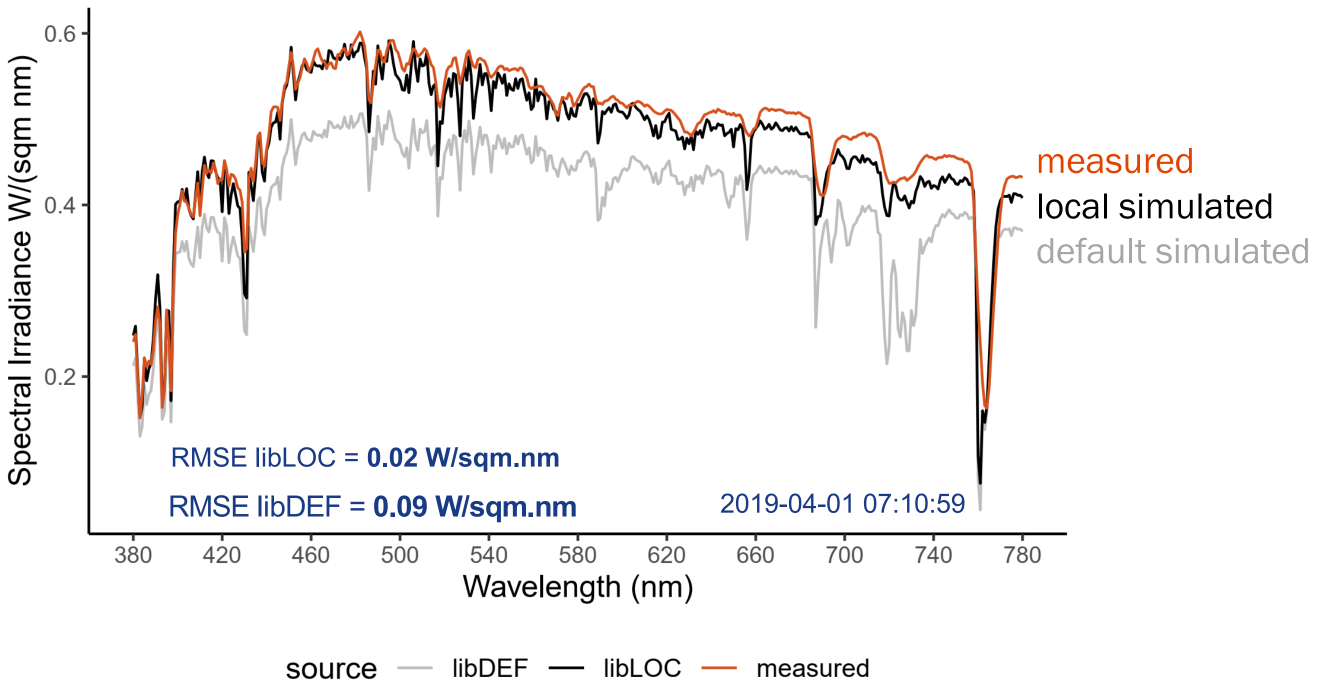




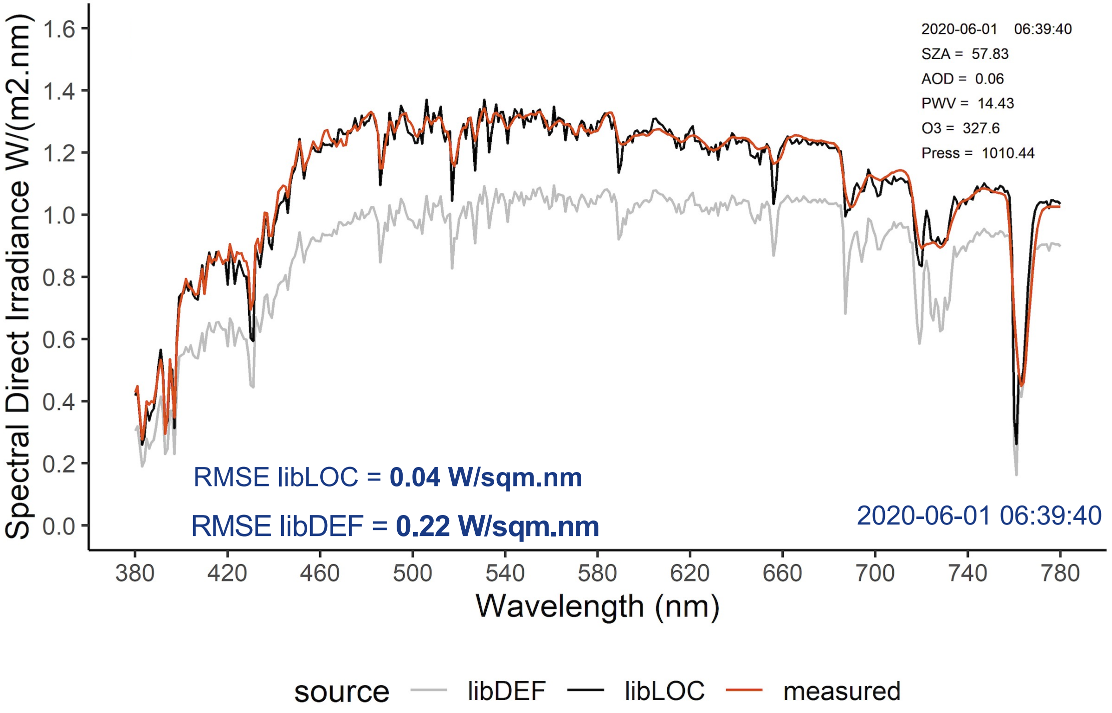
- For broadband irradiance simulations, the simulations are conducted for wavelength 285 to 4000 nm
- libLOC are within 4% (average) error range for all irradiances and as low as 0.8 % for global irradiances
- libDEF errors are within 19% (average) for all irradiances
- libDEF underestimates both the direct and global irradiances

Analysis 2: Spectral irradiances (global and direct)

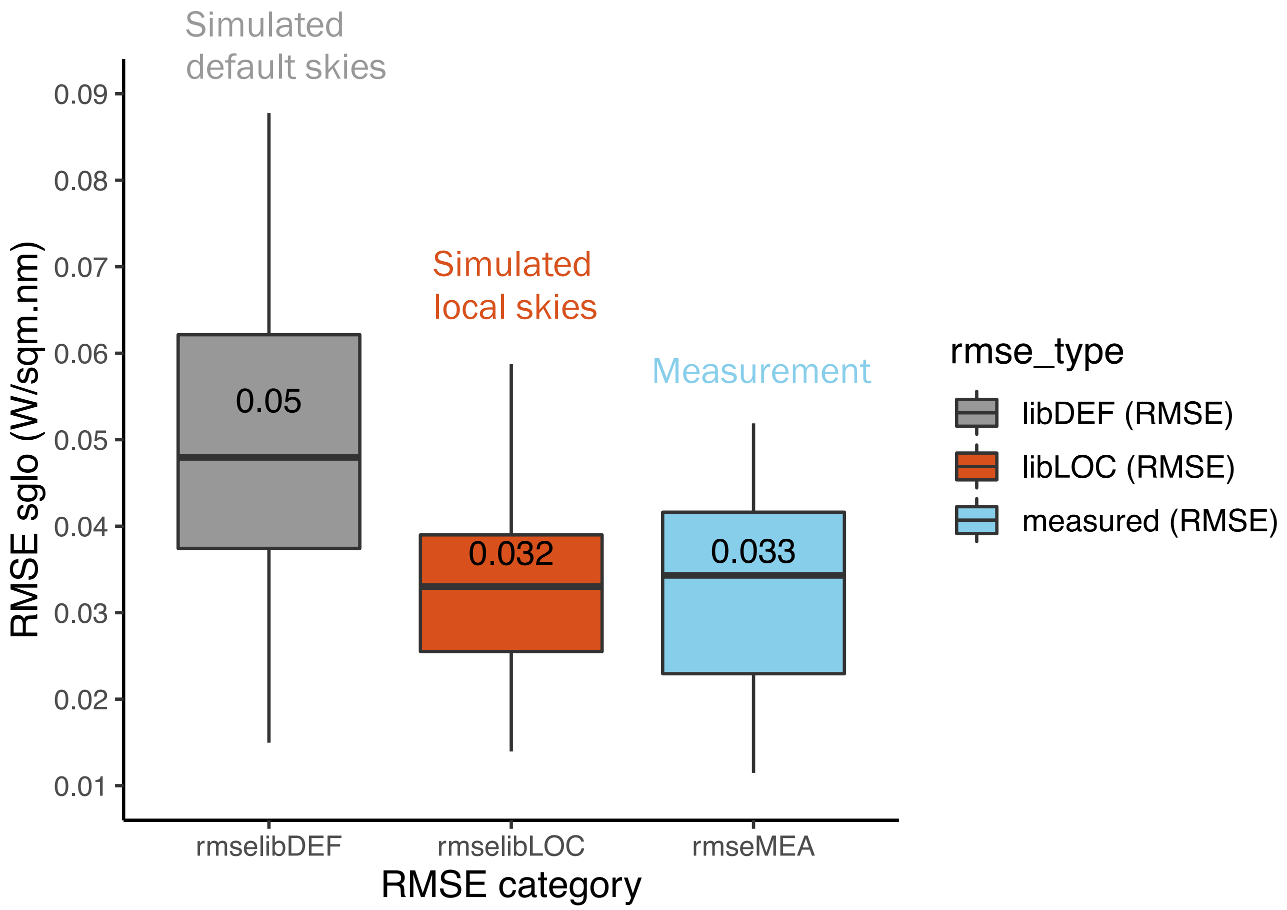
Spectral global irradiance (sun + sky)



Spectral direct irradiance (sun)



Analysis 2: Spectral global irradiances – Root Mean Square Errors



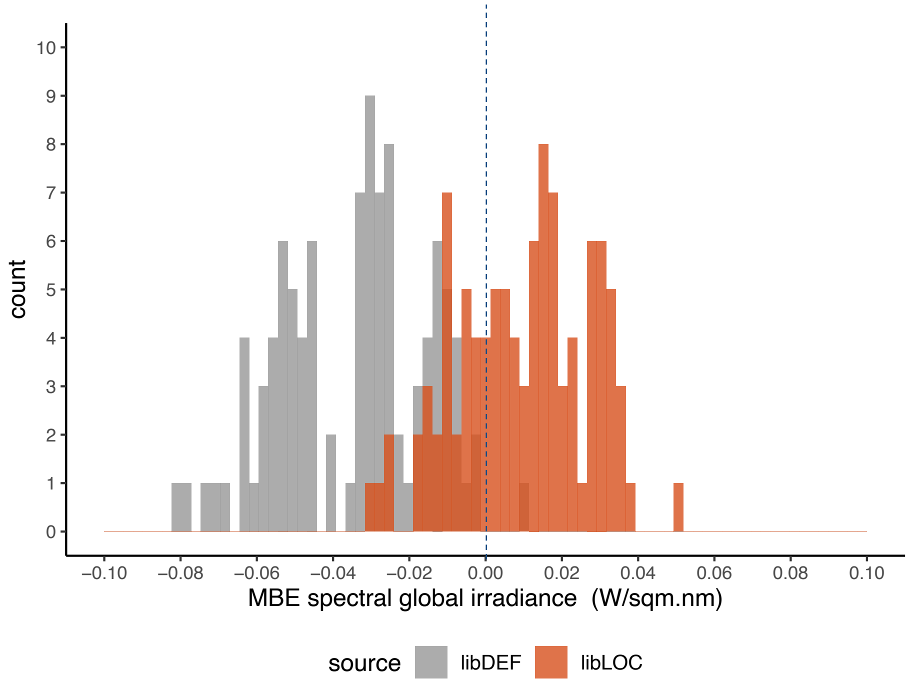
- libLOC has an RMSE error of 0.03
- Using measurement uncertainty percentage of a JETI specbos 1201, which is ± 2.4%, we calculate error bounds for the measurement dataset. RMSE errors of these bounds are 0.03
- Location-specific atmospheric profile has the potential to produce high accuracy spectral skies (alteast for clear skies!)

Analysis 2: Spectral Irradiances (global and direct) – Mean Bias and Root Mean Square Errors

Spectral global irradiance (sun + sky)

RMSE

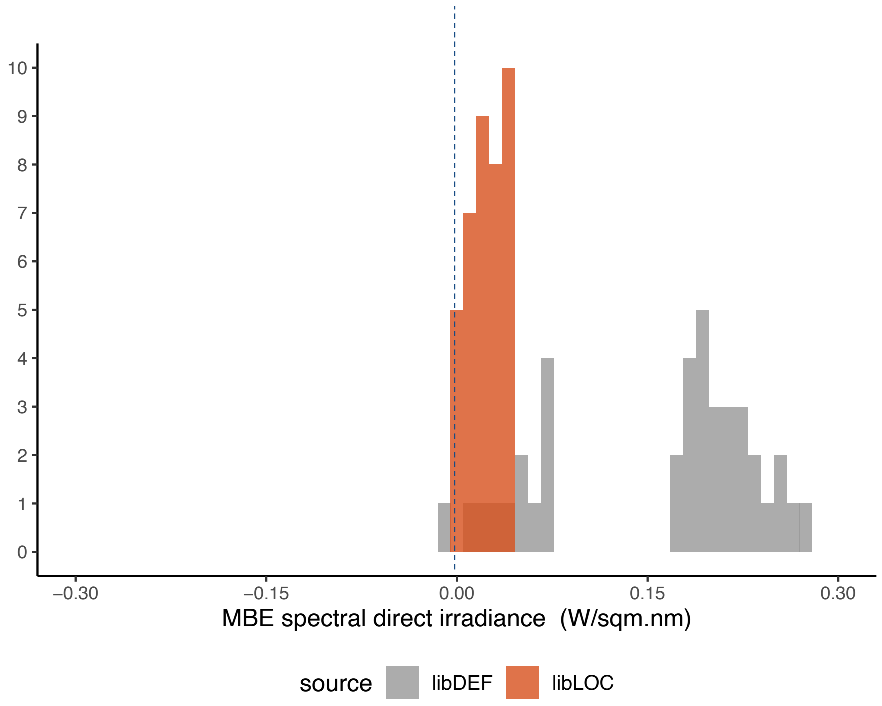
Local	0.03 W/sq.nm
Default	0.05 W/sq.nm



Spectral direct irradiance (sun)

RMSE

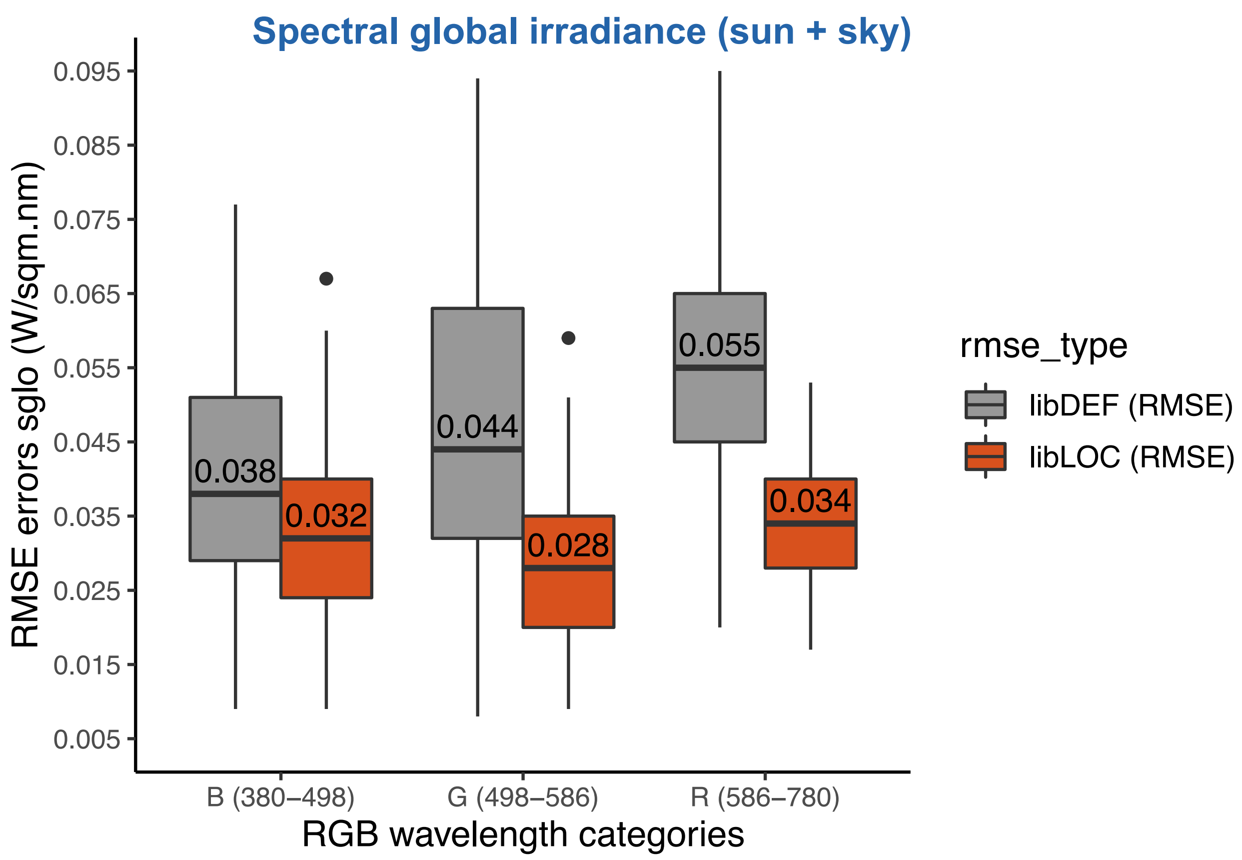
Local	0.05 W/sq.nm
Default	0.19 W/sq.nm

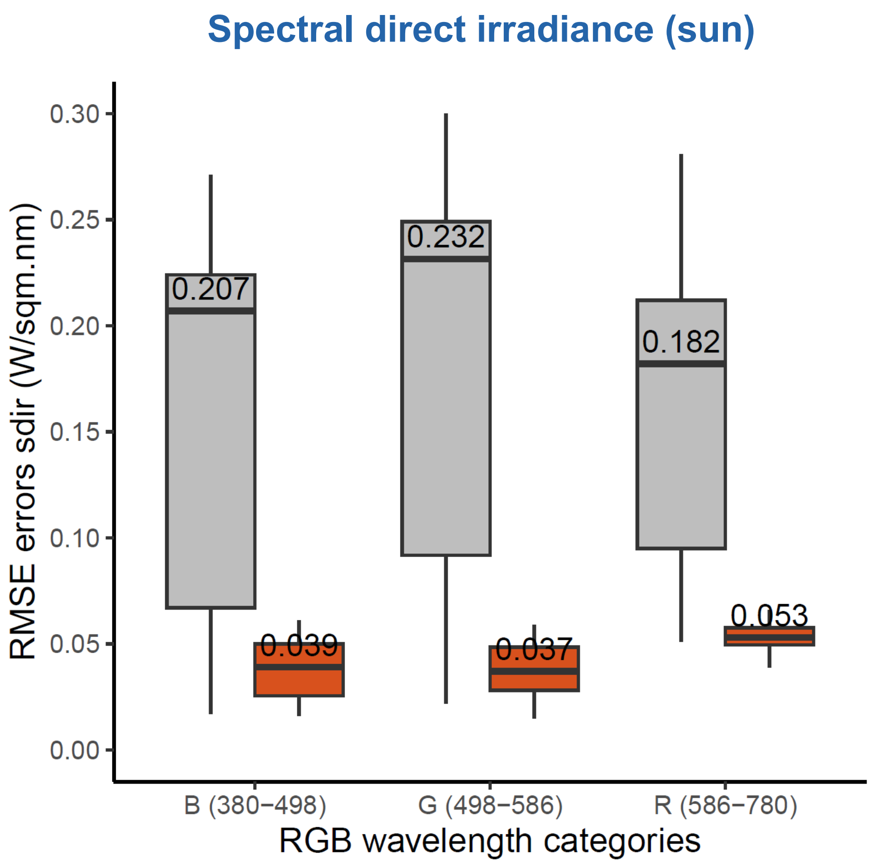


- libDEF has a much higher RMSE error for spectral direct irradiance.
- libDEF underpredicts spectral global irradiance and overpredicts the direct solar irradiance

Analysis 3: RMSE errors in the RGB channel

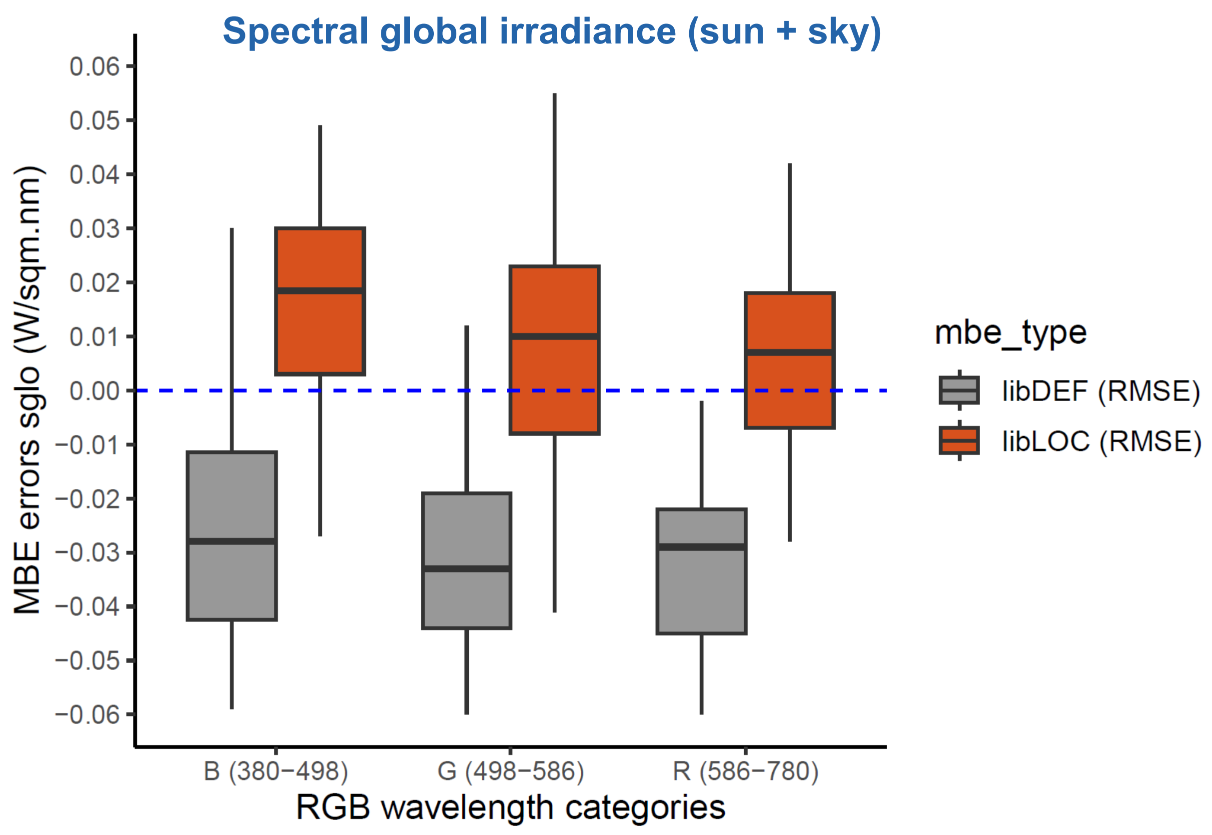
- libDEF has larger errors in the green and red channels for spectral global irradiances.

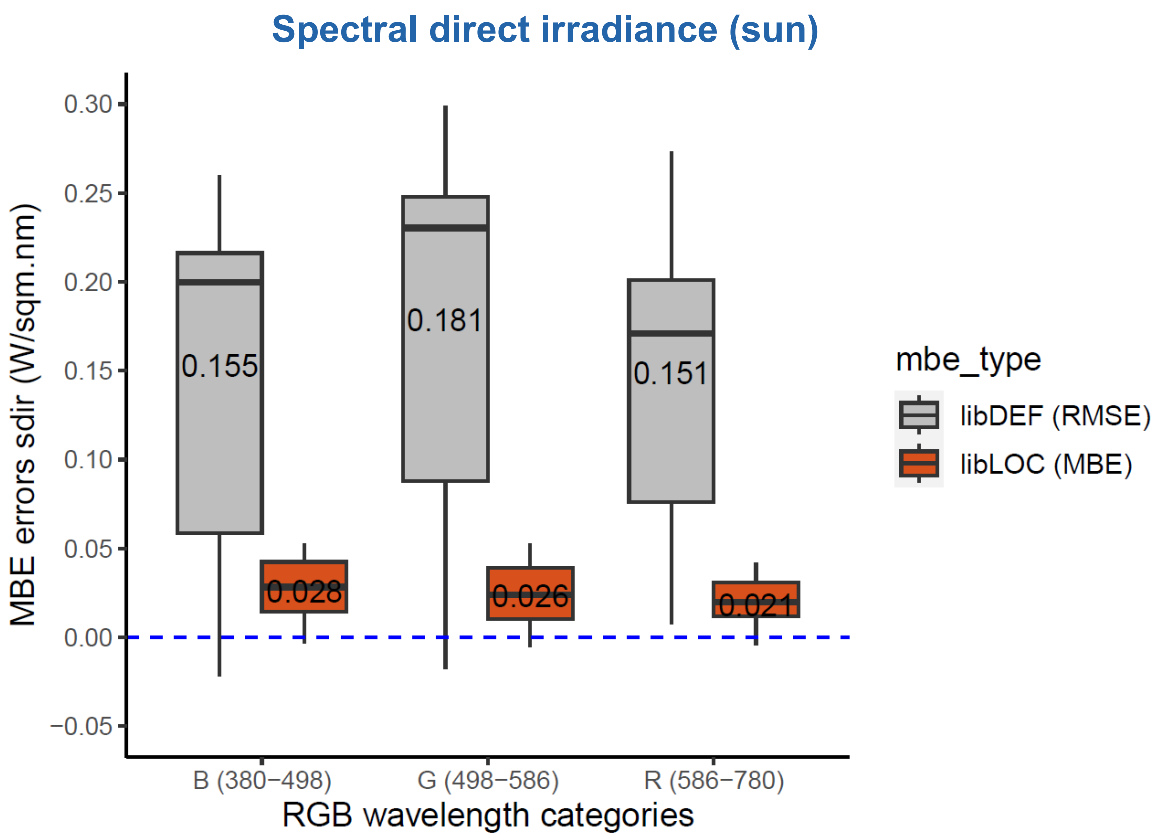




Analysis 3: MBE errors in the RGB channel

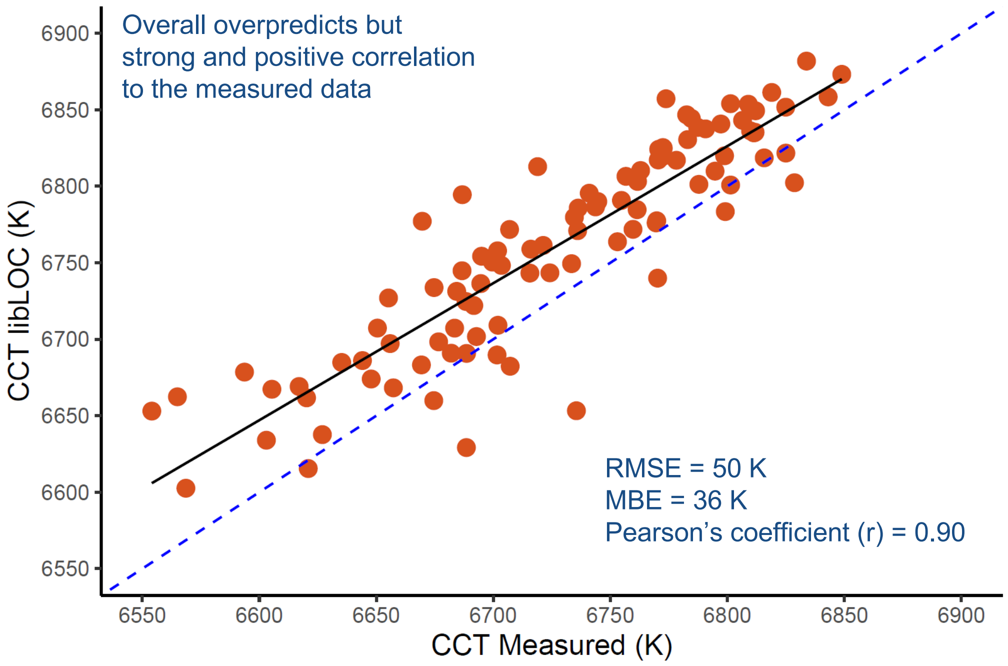
- libDEF underpredicts spectral global irradiances and significantly over predicts spectral direct irradiances in all three channels



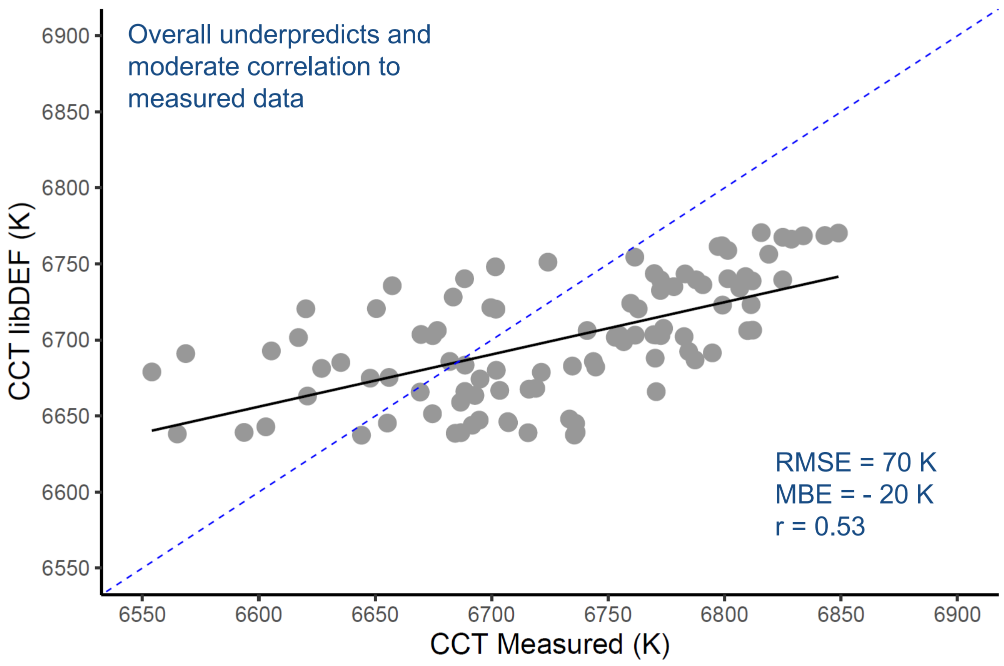


Analysis 3: CCT comparison of spectral global irradiances

libLOC – local profile simulations

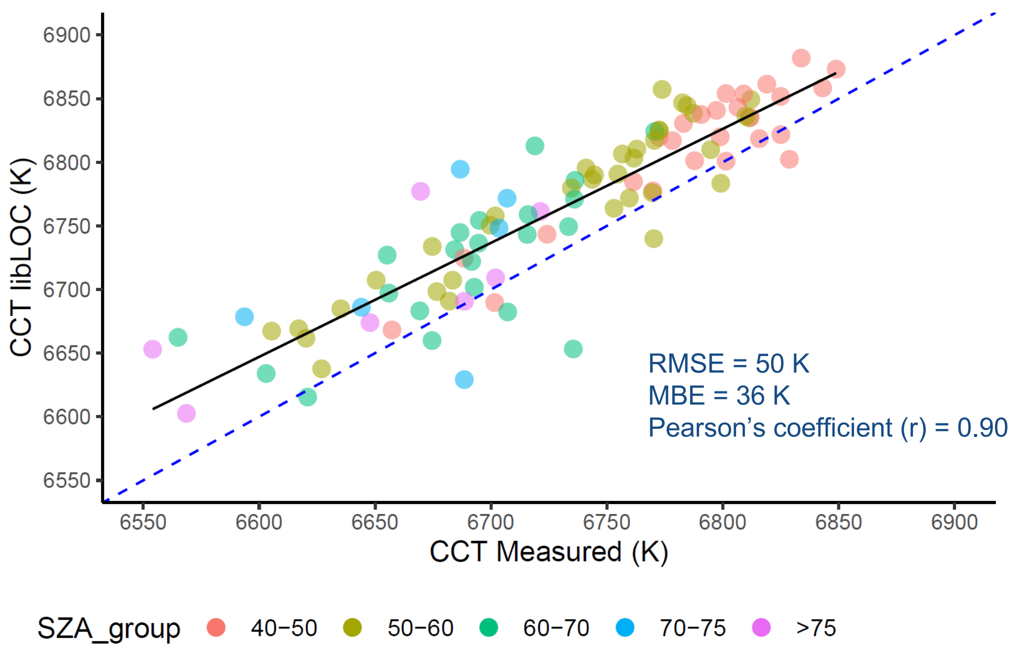


libDEF – default profile simulations

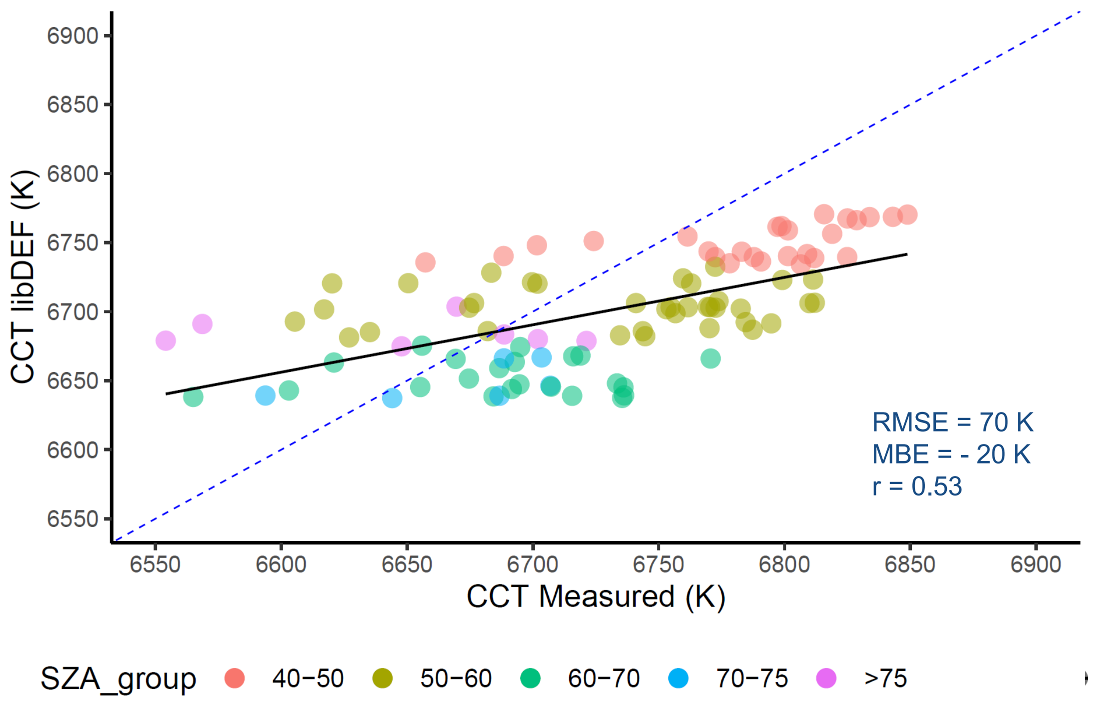


Analysis 3: CCT comparison of spectral global irradiances

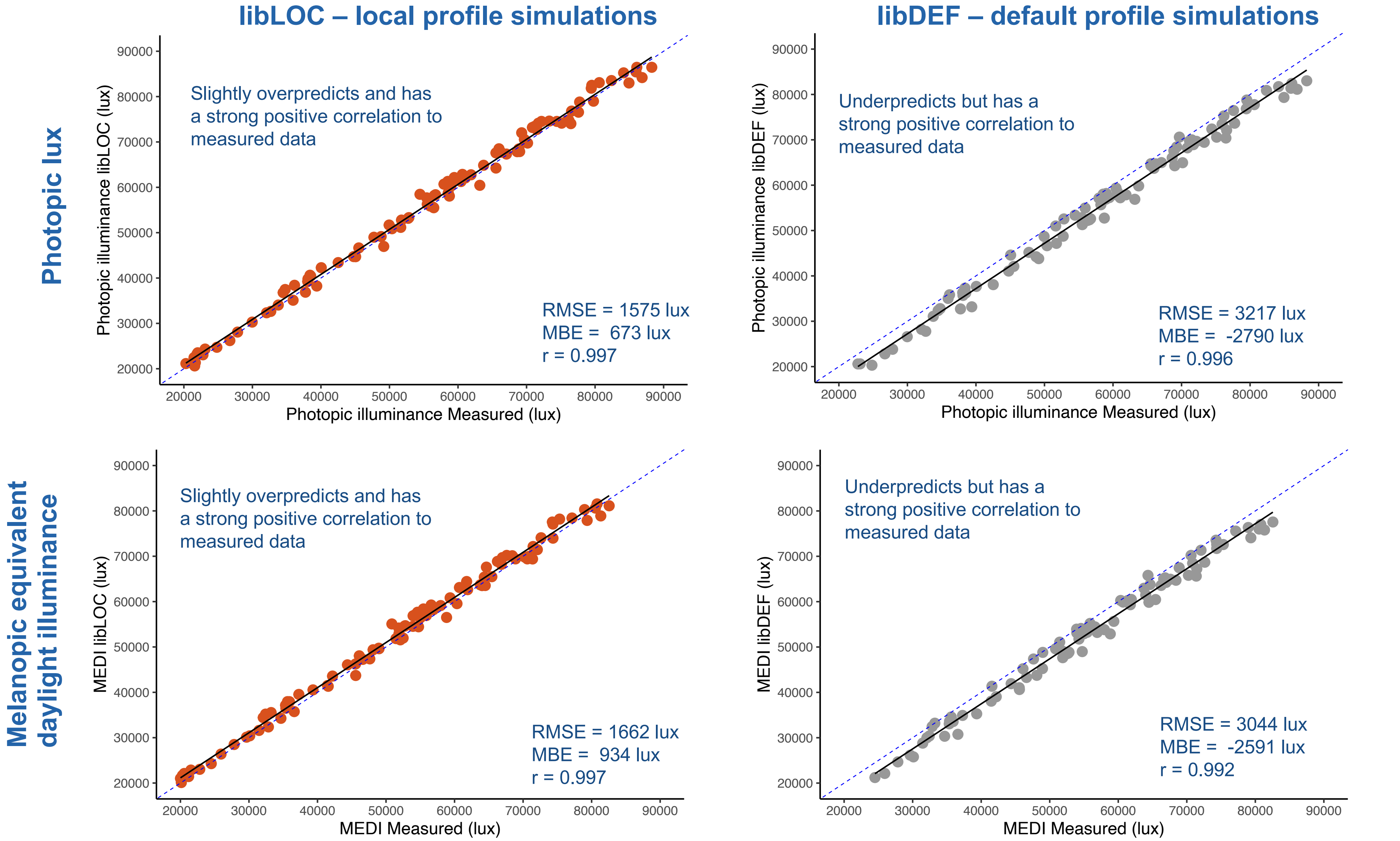
libLOC – local profile simulations



libDEF – default profile simulations



Analysis 3: Comparison of Photopic and melanopic lux



Conclusions

- Location-specific set-up, libLOC, produces broadband irradiances and spectral irradiances with lower errors than the default set-up libDEF
- Default profiles outputs large errors when it comes to direct solar irradiances.
- Default errors are still low compared to using other methods to create spectral skies.
- The framework seems promising for clear skies, especially where high accuracy spectral sky data is required.
- Framework requires knowledge of radiative transfer simulations and computation time is involved.
- Using default profile (midlatitude summer profile) for other locations like in ALFA could lead to larger errors.
- More work is required to implement the work for spectral radiances and other sky conditions.

Conclusions

Paper at the CISBAT conference in September 2023

With Martine Knoop and Lionel Doppler

CISBAT : IOP Publishing
Journal of Physics: Conference Series

A framework to generate local spectral skies for spectral daylight simulations

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Abstract. Spectral daylight simulations are becoming increasingly important in predicting non-visual responses to light and more accurate daylight colour and temporal patterns. However, the availability of locally measured spectral sky data is limited and current spectral sky models do not capture the local colour variability of skies. This paper presents a novel framework for

Promoting the use and application of location-specific daylight

Open source data package of worldwide measured spectral daylight (for now 7 locations)

Release at the CIE conference September 2023

SKYSPECTRA: AN OPENSOURCE DATA PACKAGE OF WORLDWIDE SPECTRAL DAYLIGHT

Balakrishnan, P.[1], Diakite, A.K.[1], Dumortier, D.[2], Hernández-Andrés, J.[3], Kenny, P.[4], Maskarenj, M.[5], Pierson, C.[6], Thorseth, A.[7], Xue, P.[8], Knoop, M.[1]
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Abstract

This paper introduces SKYSPECTRA, an open-source data package comprising spectral daylight measurements of the sun and the sky collected from various sources worldwide. The dataset encompasses measurements from both long-term measurement sites and specific

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