EarthCARE MSI imager intercalibration methodology using radiative transfer models

Nils Madenach[1,2], Nicole Docter[1,2], René Preusker[2], Sebastian Bley[1], Anja Hünerbein[1]

[1]Leibniz Institute for Tropospheric Research (TROPOS)

[2]Freie Universität Berlin

Contact: nils.madenach@wew.fu-berlin.de

Outline

I. EarthCARE

II. MSI forward simulation tool

III. Ad-hoc calibration of MSI using FCI

IV. Validation of MSI using ground-based measurements

V. Intercalibration of LEOs above suber-sites using GEOs and RTS as transfer

VI. Summary & Outlook

I. EarthCARE

EarthCARE

Latest ESA Earth explorer mission launched in May 2024

3
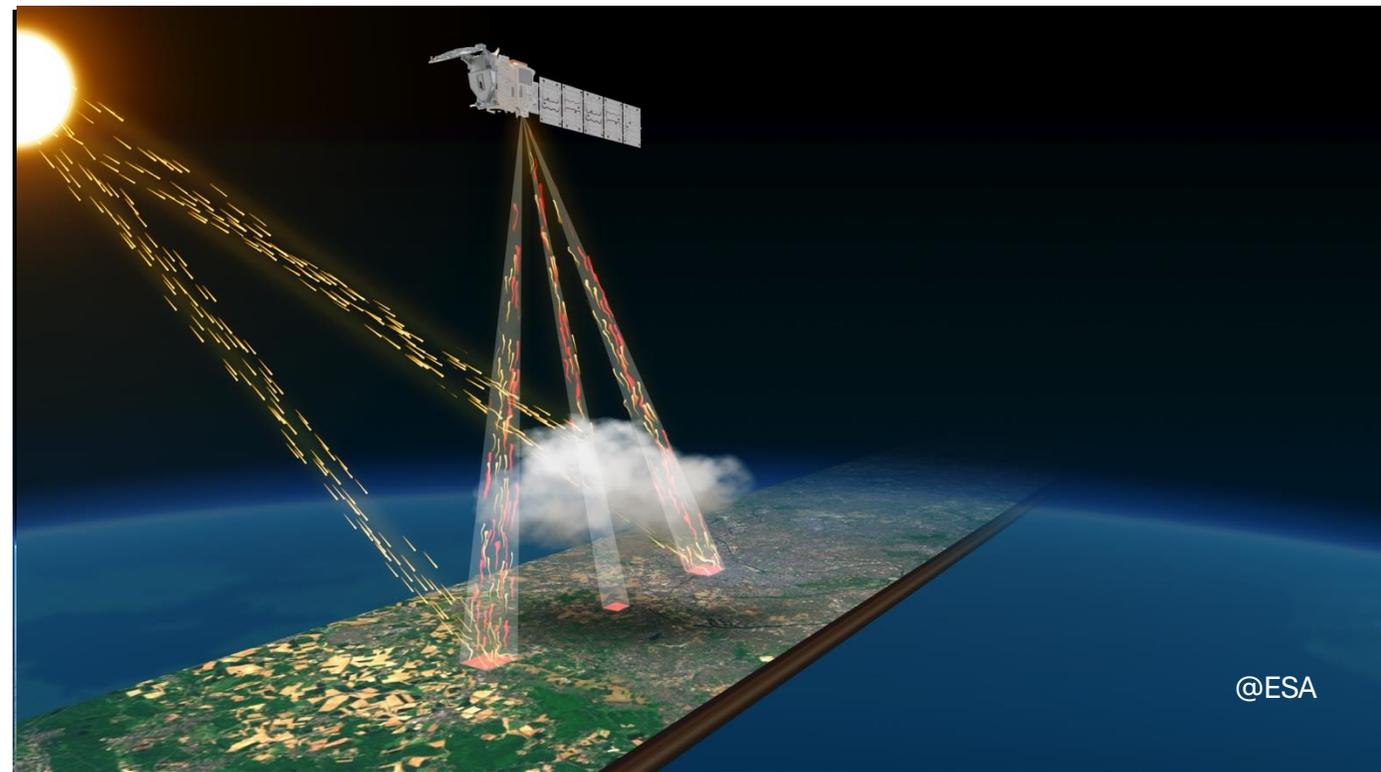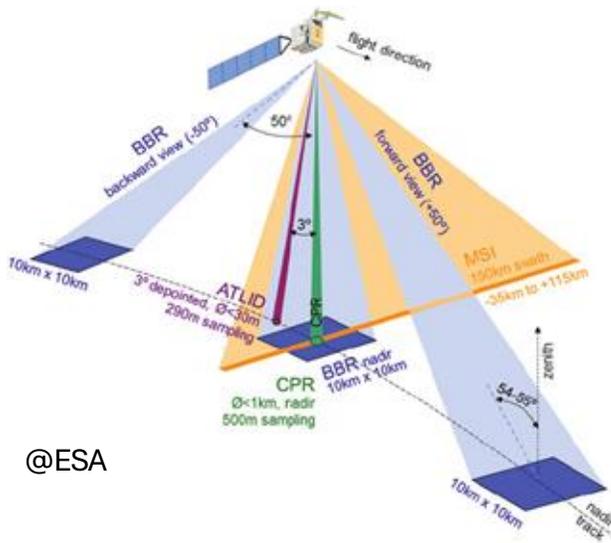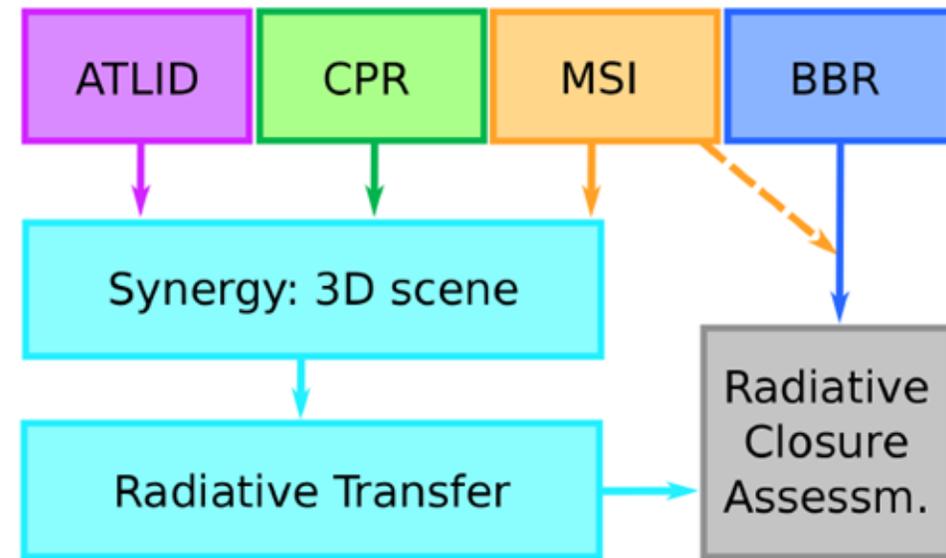
MSI – Multi Spectral Imager

- Main purpose: add horizontal context to active instruments

- push-broom imager with 7 bands

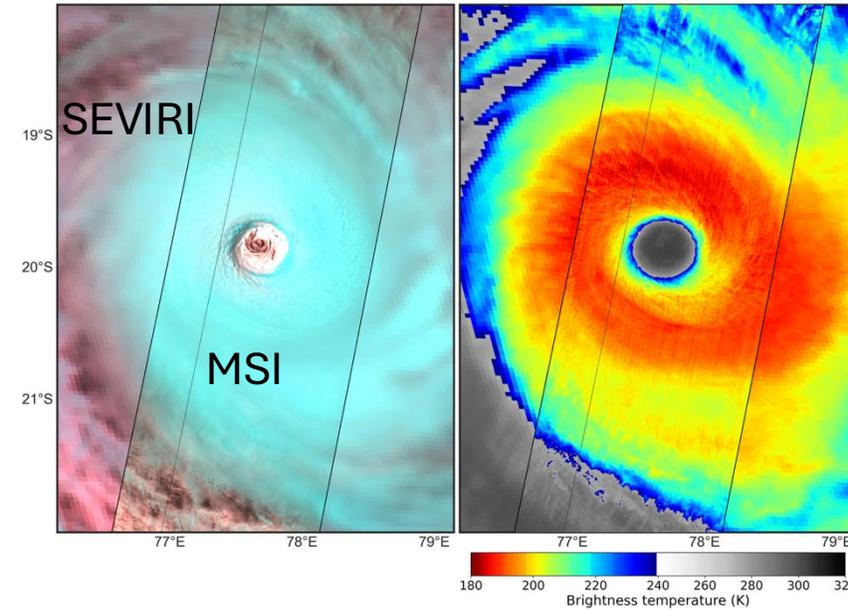- 150 km tilted swath (35km and 115 km)

- 500 m resolution

Table 1: MSI band specifics (Wehr, 2006; Wehr et al., 2023).

| Name	Nominal central wavelength	band width	reference signal	SNR or ΔT for low reference signal	SNR or ΔT for high reference signal	absolute radiometric accuracy
VIS	670 nm	20 nm	30.0 - 444.6 $Wm^{-2}sr^{-1}\mu m^{-1}$	203	2560	2.2 %
NIR	865 nm	20 nm	17.0 - 282.7 $Wm^{-2}sr^{-1}\mu m^{-1}$	137	1620	2.2 %
SWIR1	1650 nm	50 nm	1.5 - 67.9 $Wm^{-2}sr^{-1}\mu m^{-1}$	26	1082	2.2 %
SWIR2	2210 nm	100 nm	0.5 - 24.6 $Wm^{-2}sr^{-1}\mu m^{-1}$	138	5606	2.2 %
TIR1	8.8 μm	0.9 μm	220 - 293 K	0.45 K	0.13 K	0.38-0.60 K
TIR1	10.8 μm	0.9 μm	220 - 293 K	0.25 K	0.10 K	0.36-0.40 K
TIR1	12.0 μm	0.9 μm	220 - 293 K	0.35 K	0.16 K	0.49-0.54 K

VNS camera

TIR camera

4

Current calibration status of MSI VNS channels

- MSI is equipped with 4 diffuser (1 for first 3 channels and 1 for 2.2 μm channel, plus 2 for aging)

- Currently diffusers are not used for calibration due to effects not fully understood yet

- Satellite (FCI) intercomparison is currently used as ad-hoc calibration (parallel vicarious calibration has been initialized via VICALOPS*)

- Interaction with AIRBUS to find root causes ongoing

Bley et al. 2026 in prep.

Results using latest MSI baseline
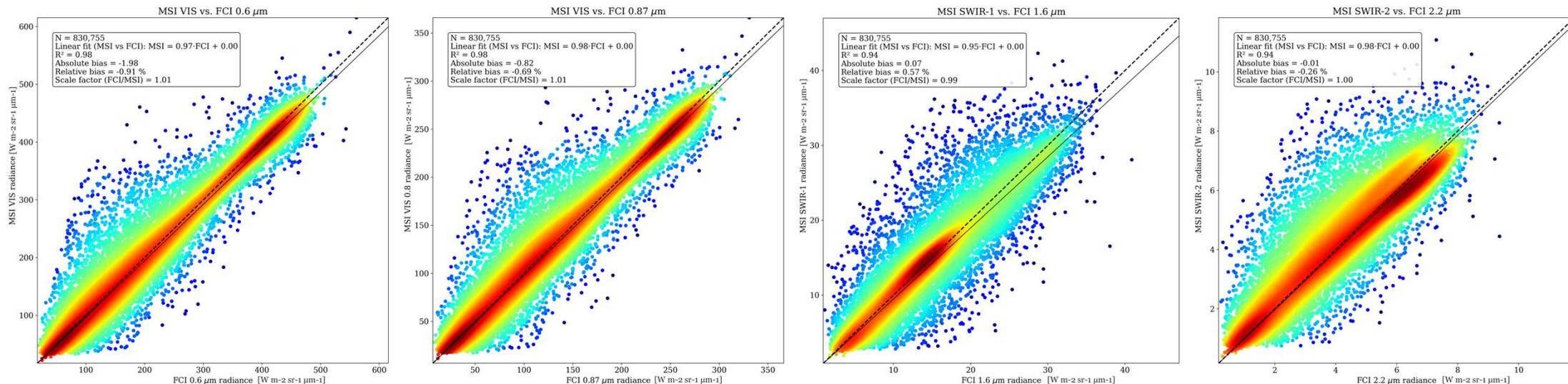
*Vicarious calibration operational service

Validation of MSI L1 data

- EarthCARE L1 validation team (subgroup meetings every 2-3 months)
  - Satellite-satellite, airborne, ground-based
- **Validation Tools:**
Forward simulation tools for **MSI, CPR** and **ATLID** developed within EarthCARE's pre-launch CARDINAL project

CARDINAL

CPR Tool University Cologne	MSI Tool FU Berlin/TROPOS	ATLID Tool KNMI

II. MSI forward simulation tool

# MSI forward simulation tool (MSI-Tool)

- **Python** tool for realistic **simulations** of **EarthCARE MSI radiances**
- Input data can be from **models** or/and **measurements (e.g. campaigns)**
- Consisting of **two modules (RTM solvers)**:
  - **MSI VNS** (FUB): VIS (0.67μm), NIR (0.865), SWIR1 (1.65), SWIR2 (2.21) **-> MORTY-RTS**
  - MSI TIR (TROPOS): TIR1 (8.8), TIR2 (10.8), TIR3 (12.0) -> RTTOV13
- **Flexible** with respect to **input data** (e.g. scattering functions, num. layers etc.)
- **Tailored** for **MSI spectral channels** (accounting for smile* only in VNS)
- **Focus** here only on **VNS**
- **Open source**

https://gitlab.com/wew_fub/msi-tool

*smile: The MSI VIS bands are affected by a shift of the central wavelength depending on the instrument viewing angle. This effect is caused due to imperfections in the bandpass filters on the curved optical lenses (Wehr et al., 2022; Wang et al., 2022).

Structure of MSI-Tool
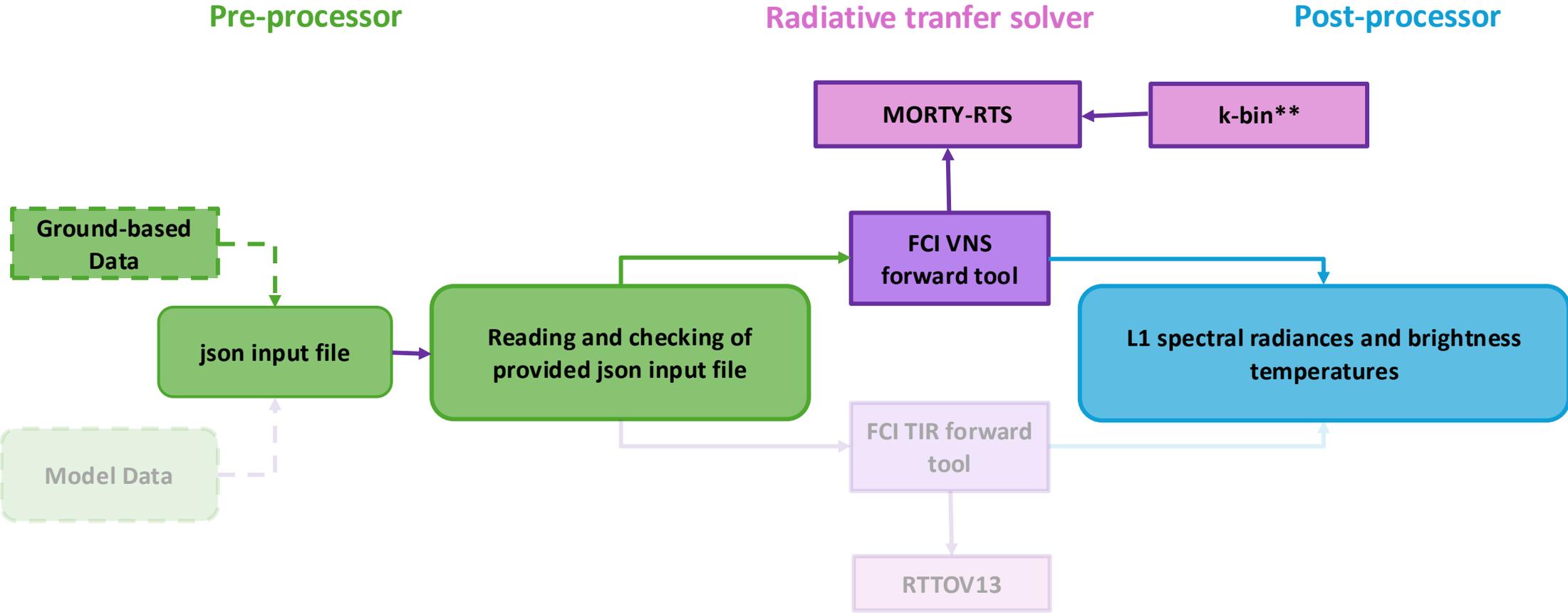
*__MORTY-RTS__: __M__atrix __O__perator __R__adiative __T__ransfer in p__Y__thon – __R__adiative __T__ransfer __S__olver (Preusker et al. 2026 in prep)
**Madenach et al. 2024

III. Ad-hoc calibration of MSI using FCI

Ad-hoc calibration of MSI using FCI

- First **relate FCI** and **MSI** via Spectral Band Adjustment Factors (**SBAFs**)

- **Extension** of **MSI-tool** to **FCI**

- **Forward simulations** of MSI and FCI-like spectral radiances for for variety of **different liquid** and **ice cloud scenarios**

- SBAF $= median(L(fci)/L(msi))$

MSI and FCI response functions
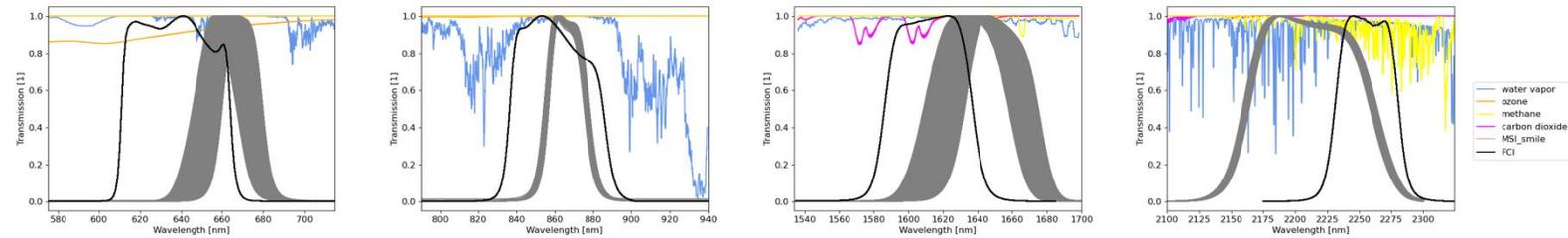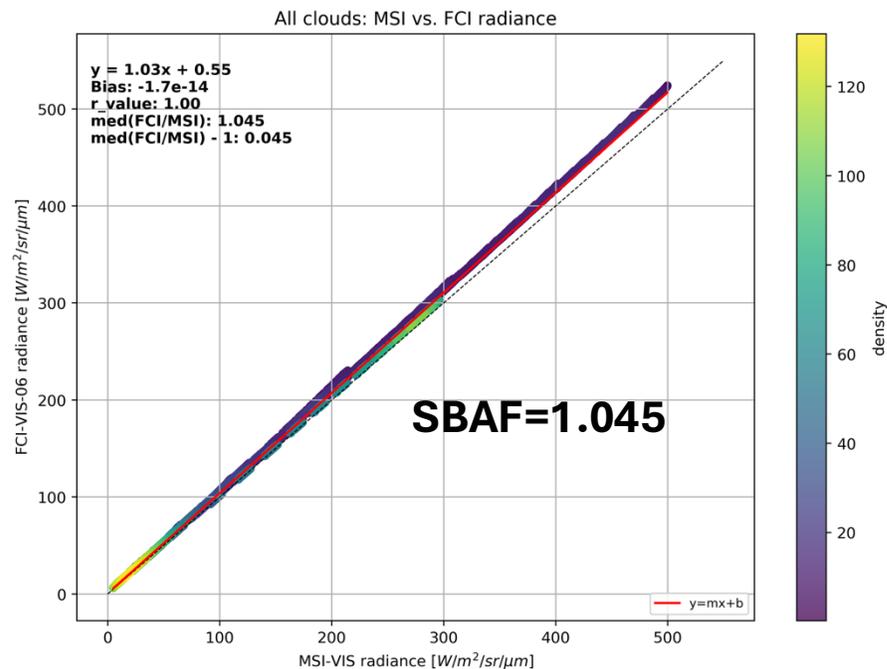
Parameter	Values
COT	0, 0.5, 2, 4, 8, 16, 32, 64, 100
CTP [hPa]	200, 500, 800
VZA [°]	0, 5, 10, 15, 20
SZA [°]	10, 15, 20, 25, 30, 35, 40, 45, 50, 55, 60, 65, 70
RAA [°]	0, 10, 20, 30, 40, 50, 60, 70, 80, 90, 100, 110, 120, 130, 140, 150, 160, 170

Forward simulation setup

Ad-hoc calibration of MSI using FCI

SBAFs

| BAND	MSI-VIS/FCI-VIS-06	MSI-NIR/FCI-VIS-08	MSI-SWIR1/FCI-NIR-16	MSI-SWIR2/FCI-NIR-22
Factors	1.045	0.996	1.06	0.925

- **Applying SBAFs** to MSI radiances
- Using **MSI** with **collocated FCI**, to determine band specific **vicarious calibration factors: mean slope** of the regressions
- **Calibration factors** are **applied** to **MSI L0 gains**
- Only scenes with **VZA<10°** and pixels with **CF=1** are used
- A spatial **homogeneity filtering** (Doelling et al. (2022, 2025)) is applied
- MSI SMILE not yet considered
- Methodology and results will be submitted soon (**Bley et al., 2026 in prep.**)

| Band	MSI-VIS	MSI-NIR	MSI-SWIR1	MSI-SWIR2
Correction factor (c)	0.9596	0.9920	0.8827	0.8970

IV. Validation of MSI using ground-based measurements

Input Data MSI-Tool

- Atmospheric **vertical profiles** based on **ACTRIS Cloudnet** data
- ACTRIS Radar, Lidar and microwave radiometer
  - LWC (*_ lwc-scaled-adiabatic.nc)
  - IWC (*_iwc-Z-T-method.nc)
  - IER (*_ier.nc)
  - DER (*_der.nc)
  - T, P (*_ categorize.nc)
  - h (*_hatpro*.nc)
- **Gas** absorption cross-section from **CKDMIP** dataset (Hogan and Matricardi, 2020, based on LBLRTM 12.8)
- **Spectral aerosol optical thickness** from Aeronet and microphysics from HETEAC* (comprises spherical and non-spherical particles)
- **Cloud microphysics** via **Mie** for liquid and **Baum** general habit mixture for ice
- Land **surface reflectance** based on **BRDF** reconstructed using **MODIS MYD09A1** (7 days) dataset and PCs from **Vidot and Borbás, 2014**
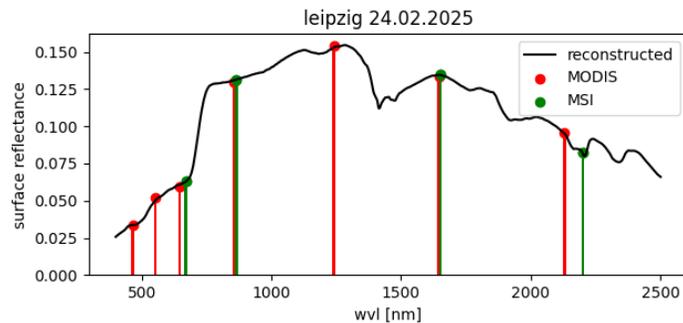
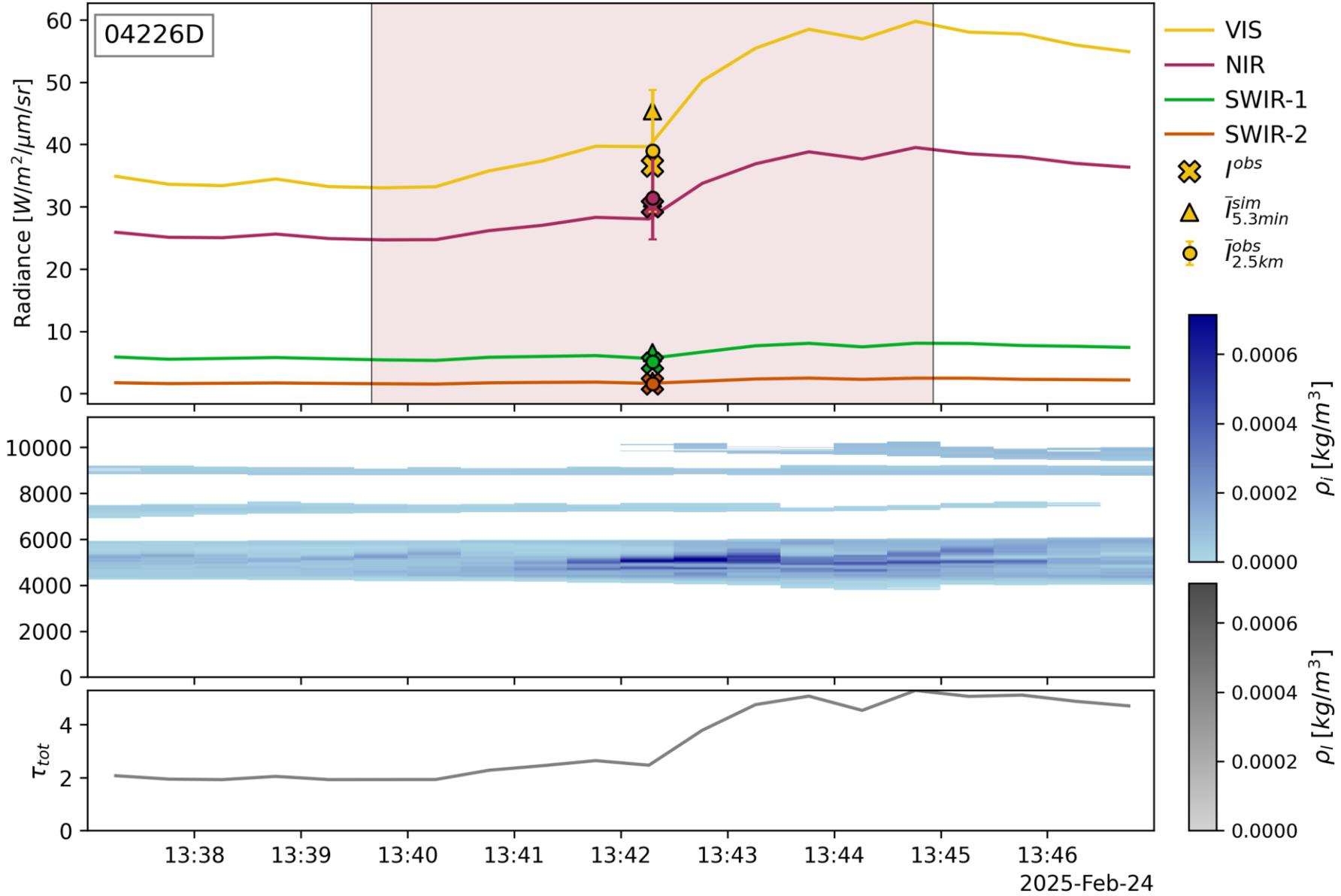*HETEAC: Hybrid End-to-End Aerosol Classification (HETEAC)
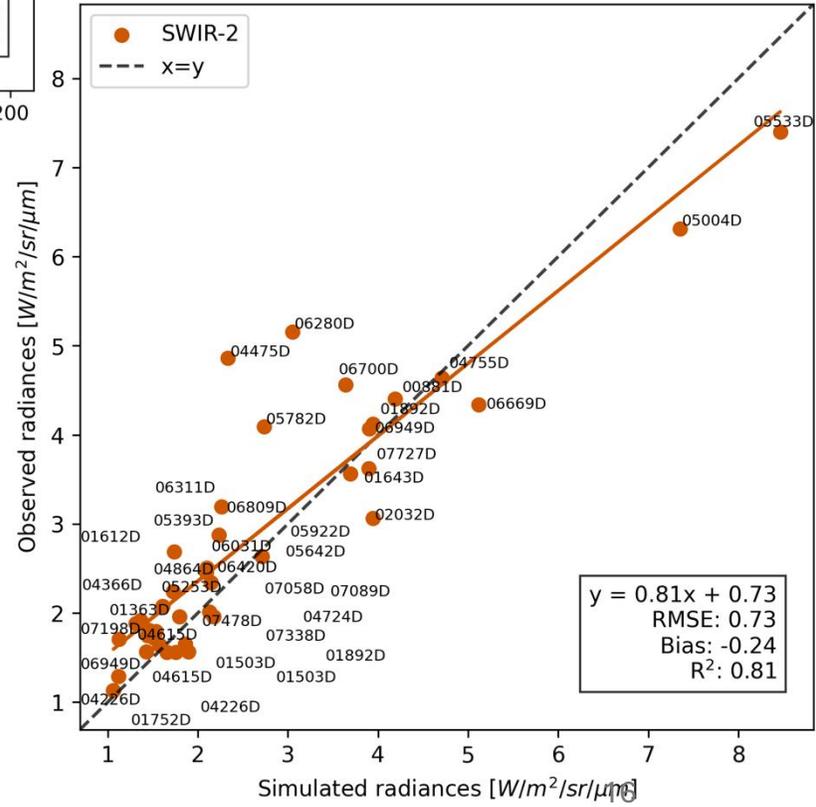

14
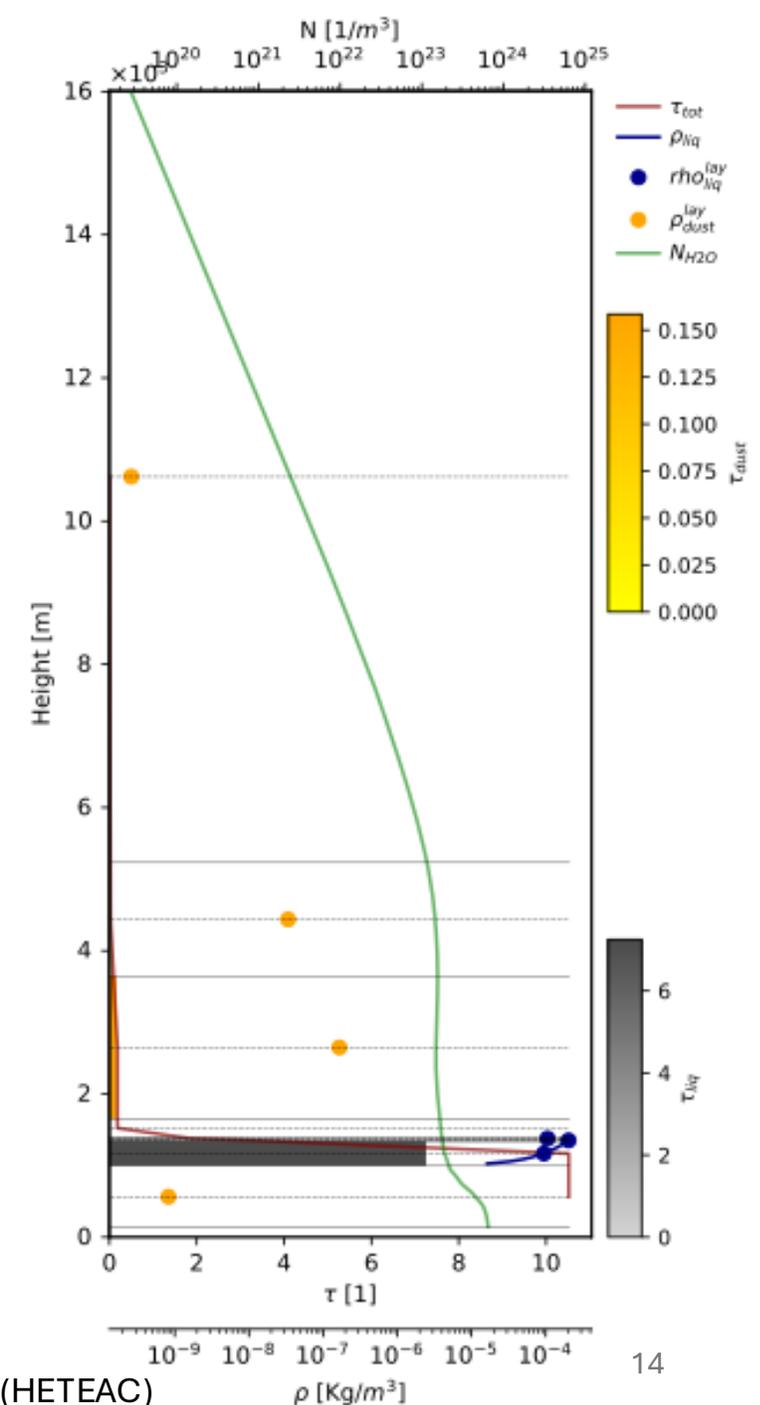
Example

Station: **Leipzig,** 24.02.25, 13: 42 UTC
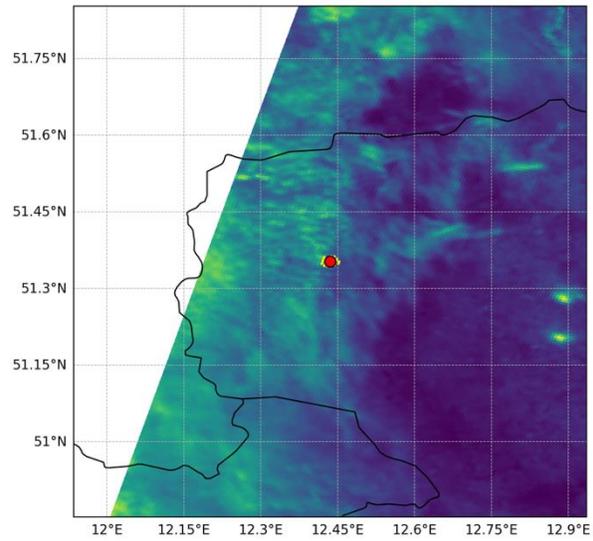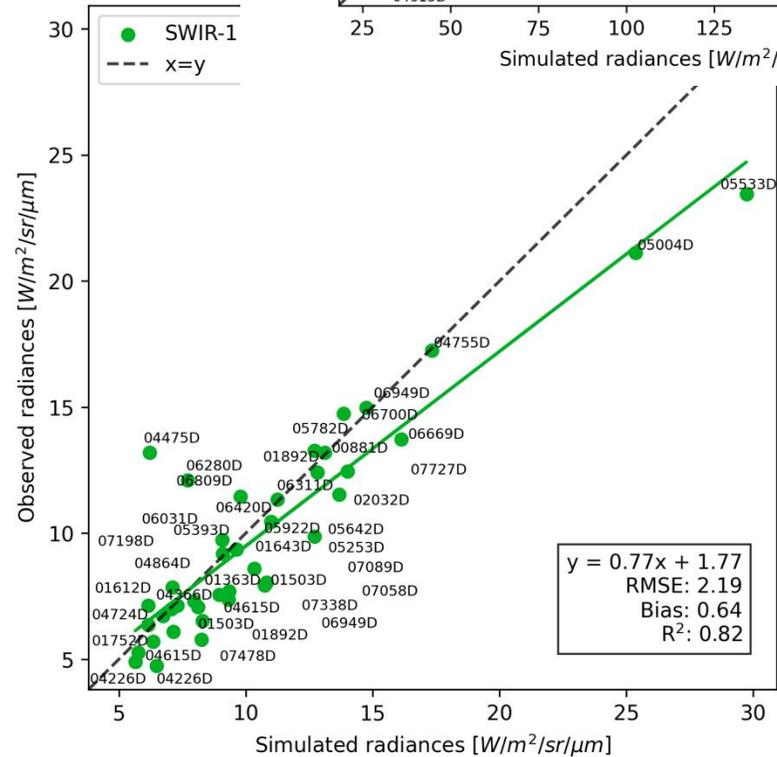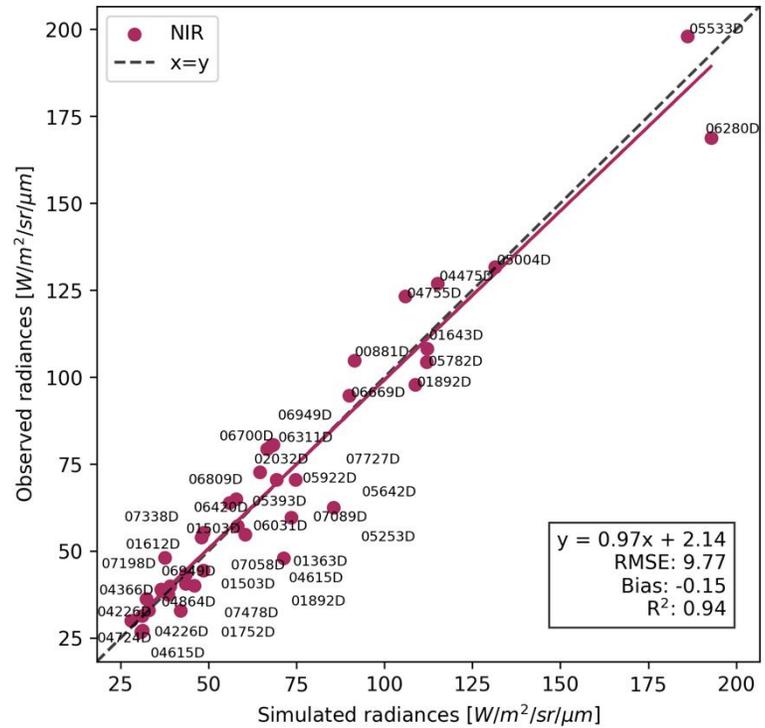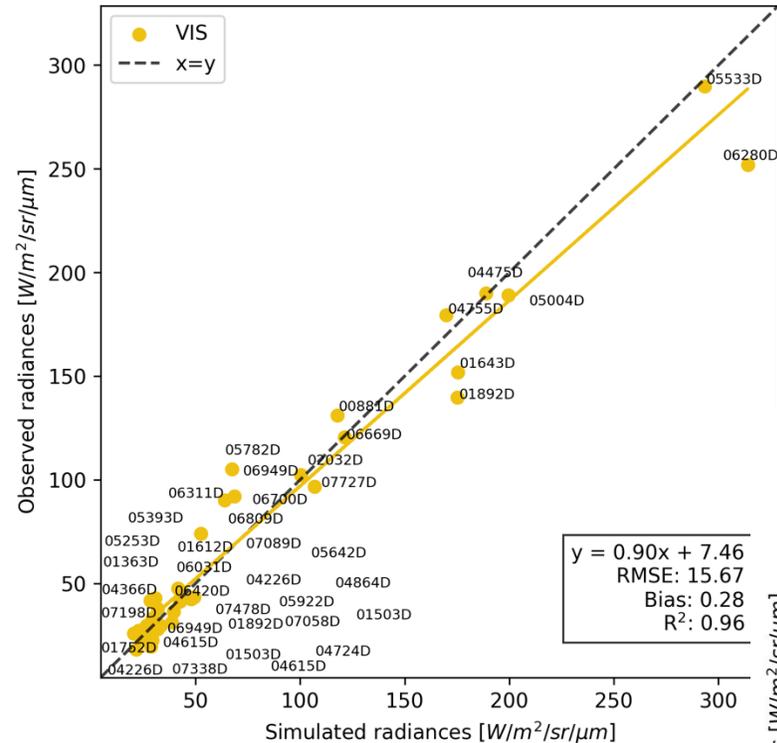
Deviation %: **VIS**: 8.5, **NIR**: 6.5, **SWIR 1** : -15.0, **SWIR 2** : -6.2

First results

- First statistics using **41 matchups**
- Stations: **Leipzig** and **Lindenberg**
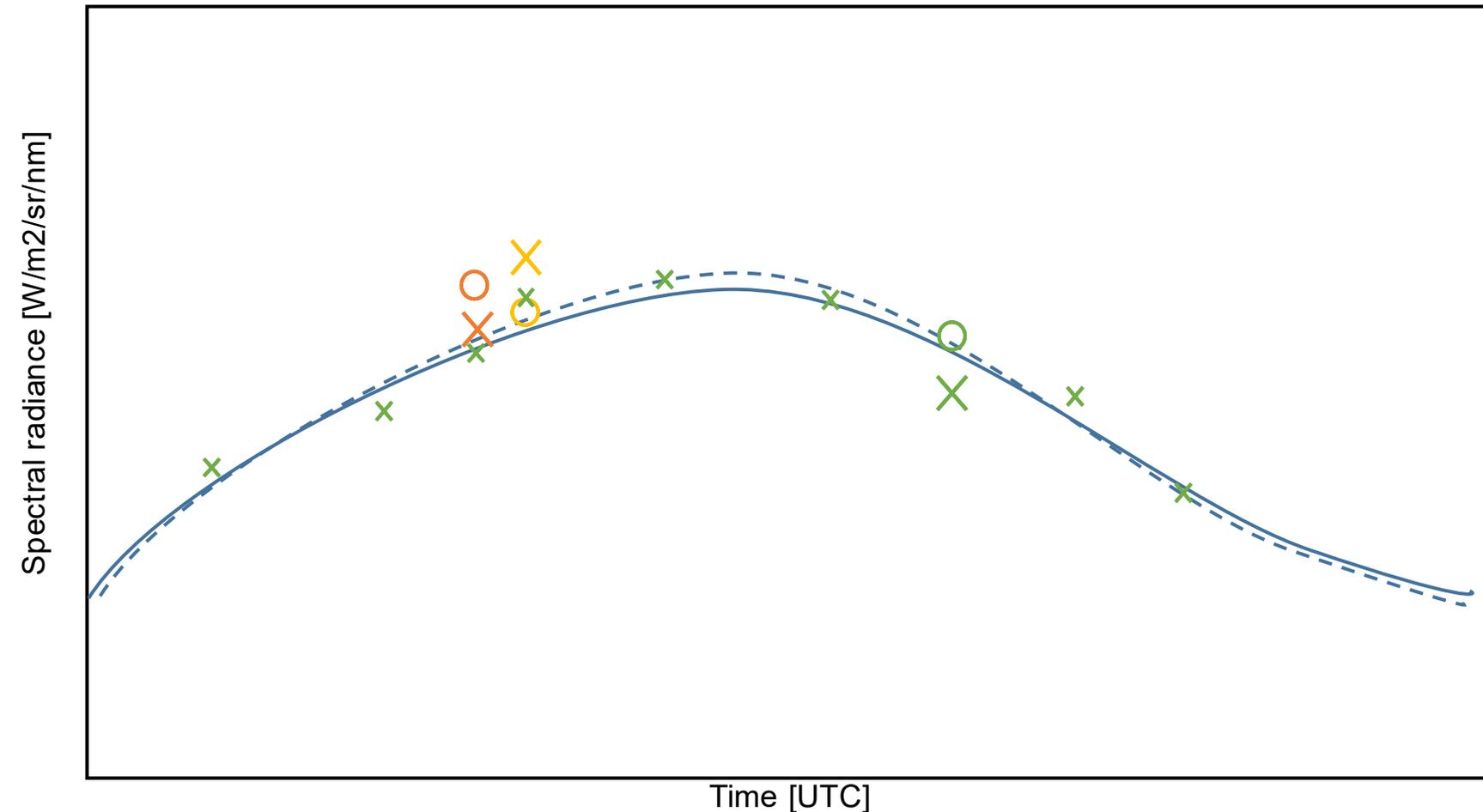- **Period:** July 2024 – November 2025

V. Intercalibration of LEOs above suber-sites using GEOs and RTS as transfers

Concept

Intercalibration Methodology

- Using MSI tool to cross-link EC **radiances** and **BT** measurements with MSG-SEVIRI/MTG-FCI
- Possibility to use other polar orbiting satellites (e.g. OLCE or METImage) without the need of temporal match-ups
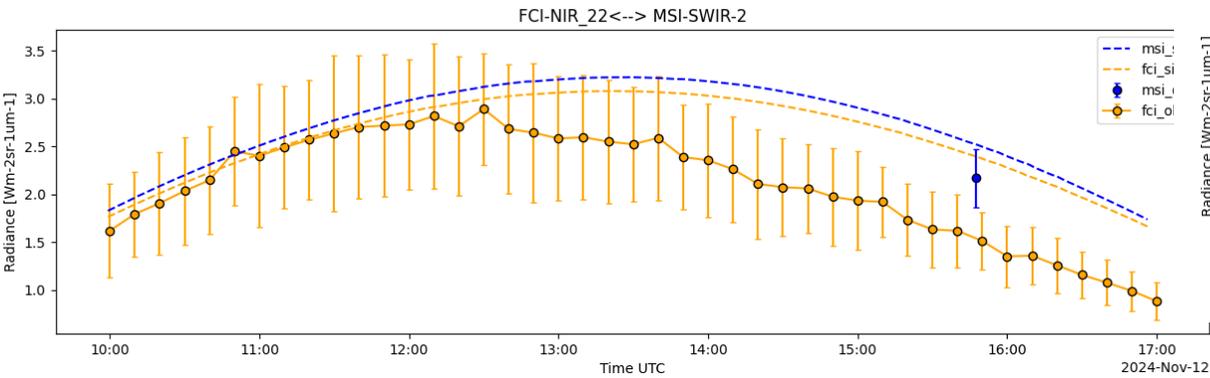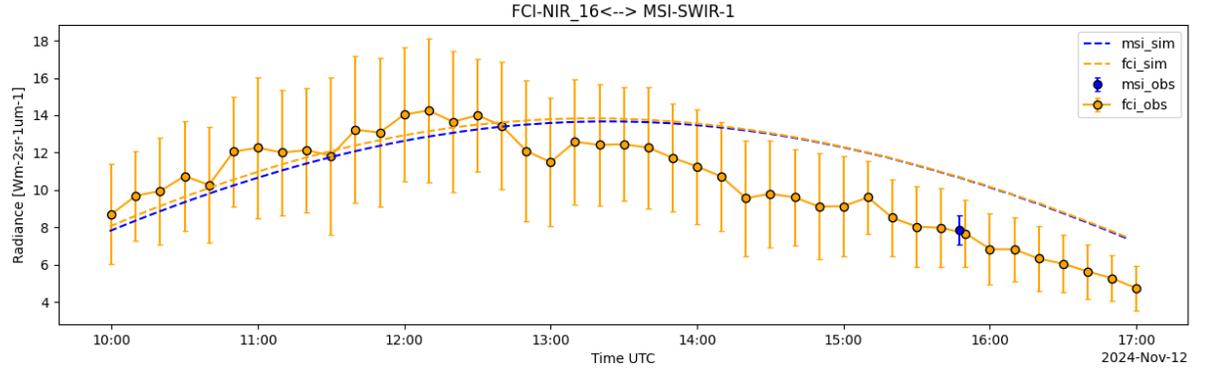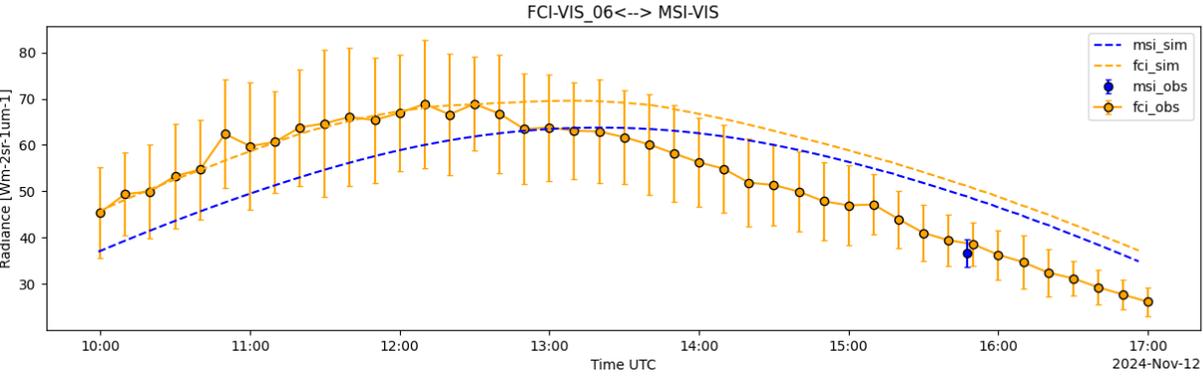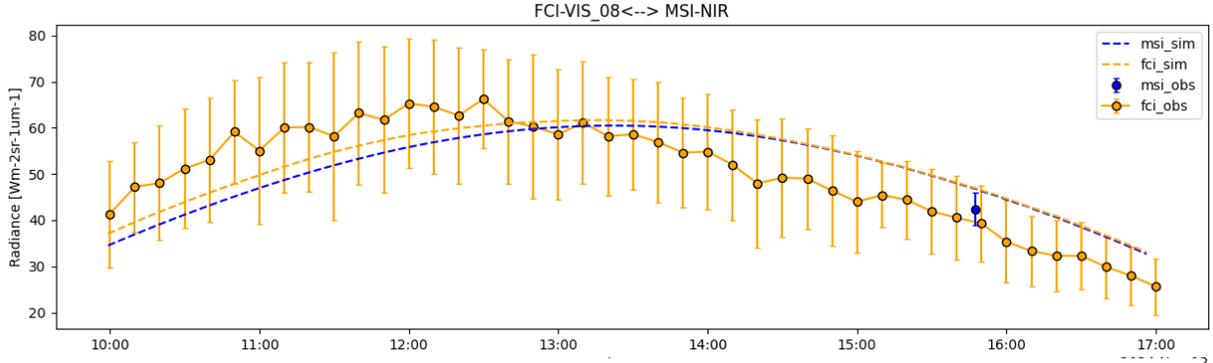- Adaption of the MSI-Tool to simulate, e.g. FCI and/or OLCI, METimage
- Using SBAFs to align all imagers

Ground-based station XYZ, lat, lon

MSI
Observation
Tool simulation
MTG observation
MTG tool simulation
OLCI-A
OLCI-B

Spectral radiance [W/m2/sr/nm]

Time [UTC]

First FCI-MSI intercomparison
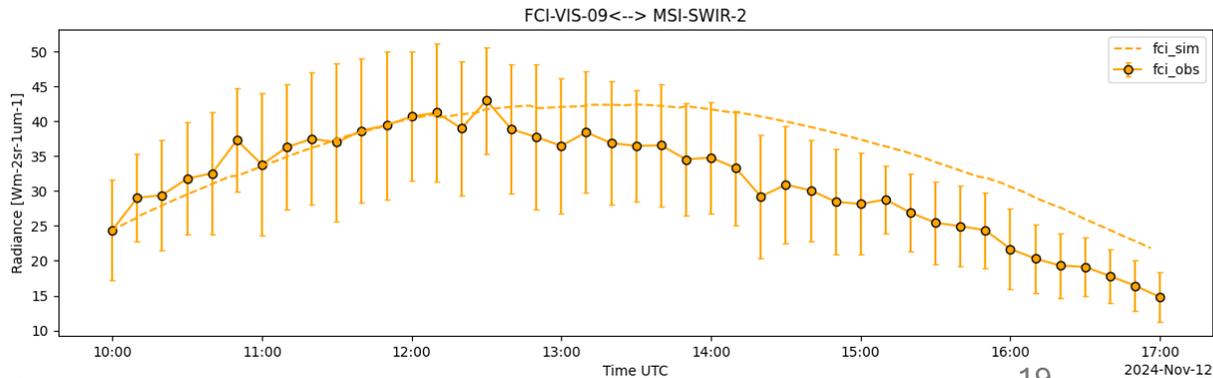
VI. Summary & Outlook

- **MSI/FCI-Tool** used to calculate **SBAFs** for **ad-hoc calibration**

- Usage of MSI-tool to **validate MSI L1**, based on ground-based **ACTRIS measurements**

- Need of further **screening** of data, such as, **spatial homogeneity filter**, surface reflectance, viewing geometry, drizzle, radar/lidar signal attenuation

- **Tool** will be **extended** for other imagers to explore **cross-validation** of different **polar orbiting imagers**

- Use of **ESA reference** sites such as, Gobabeb site in Namibia (**clear sky**)

- **Evaluate integration** of forward simulations to **ACTRIS**

Thanks for your attention!