Atmospheric correction for turbid and complex waters

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2026 IOCCG Summer Lecture Series

Turbid and complex waters

Issues with atmospheric correction

Solutions?

Turbid and complex waters

Complex waters are perhaps best described as complex conditions that invalidate processing assumptions

Venice
S2C/MSI
2026-03-28

~15x15 km
ρs RGB

Rhone Plume
S2B/MSI
2026-02-17

~15x15 km
ρs RGB

Suriname
S2B/MSI
2026-06-20

~15x15 km
ρs RGB

Kaliyakheri
S2B/MSI
2026-02-06

~15x15 km
ρs RGB

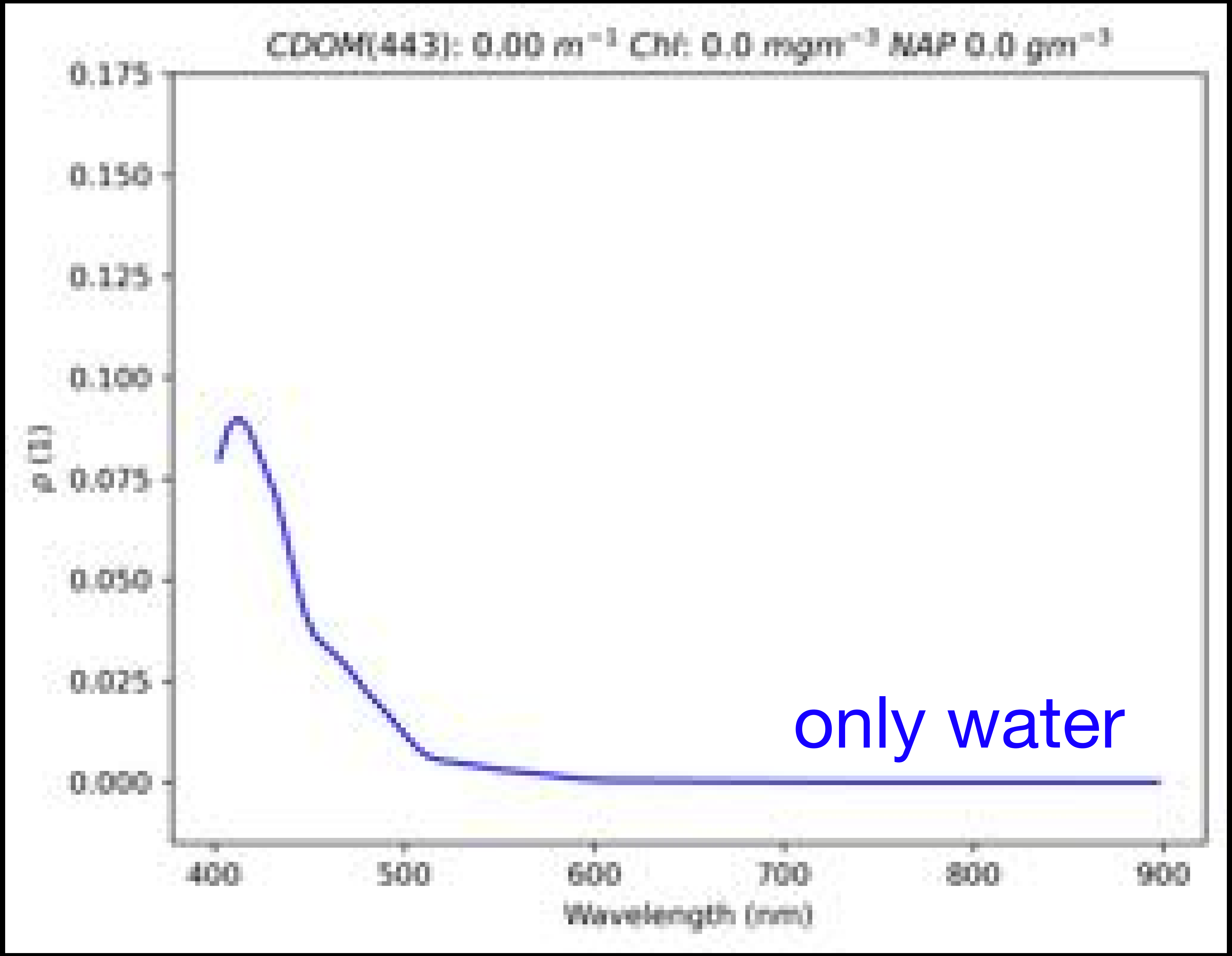
Turbid and complex waters

- Reflectance of a water target varies as a result of the Inherent Optical Properties (IOPs) of different components present in the water (and the bottom reflectance if not optically deep)

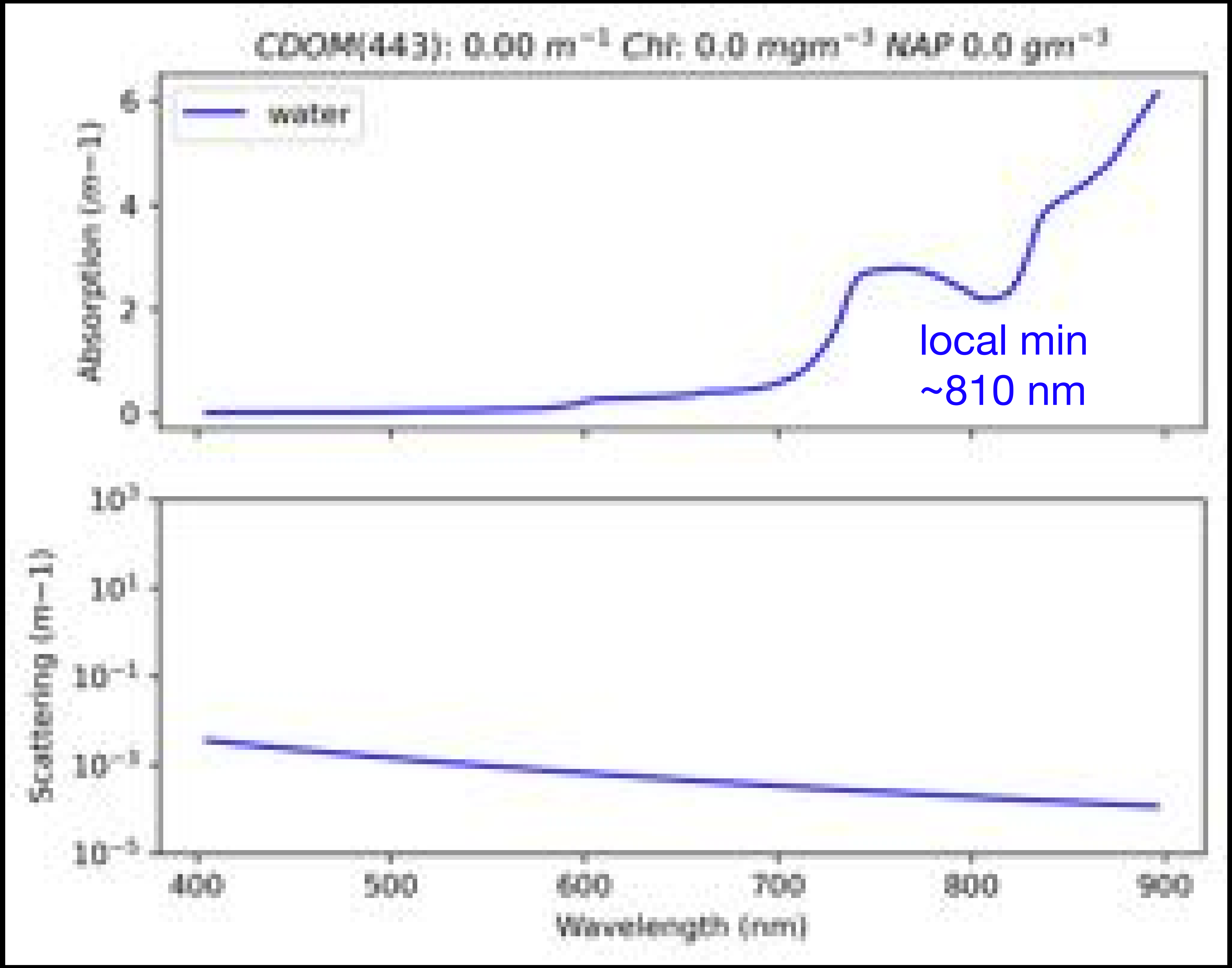
- The water reflectance can be modeled by including four components: water, phytoplankton pigments (e.g. chlorophyll a, CHL), coloured dissolved organic matter (CDOM), and non-algal particles (NAP)




ρw = π x Rrs

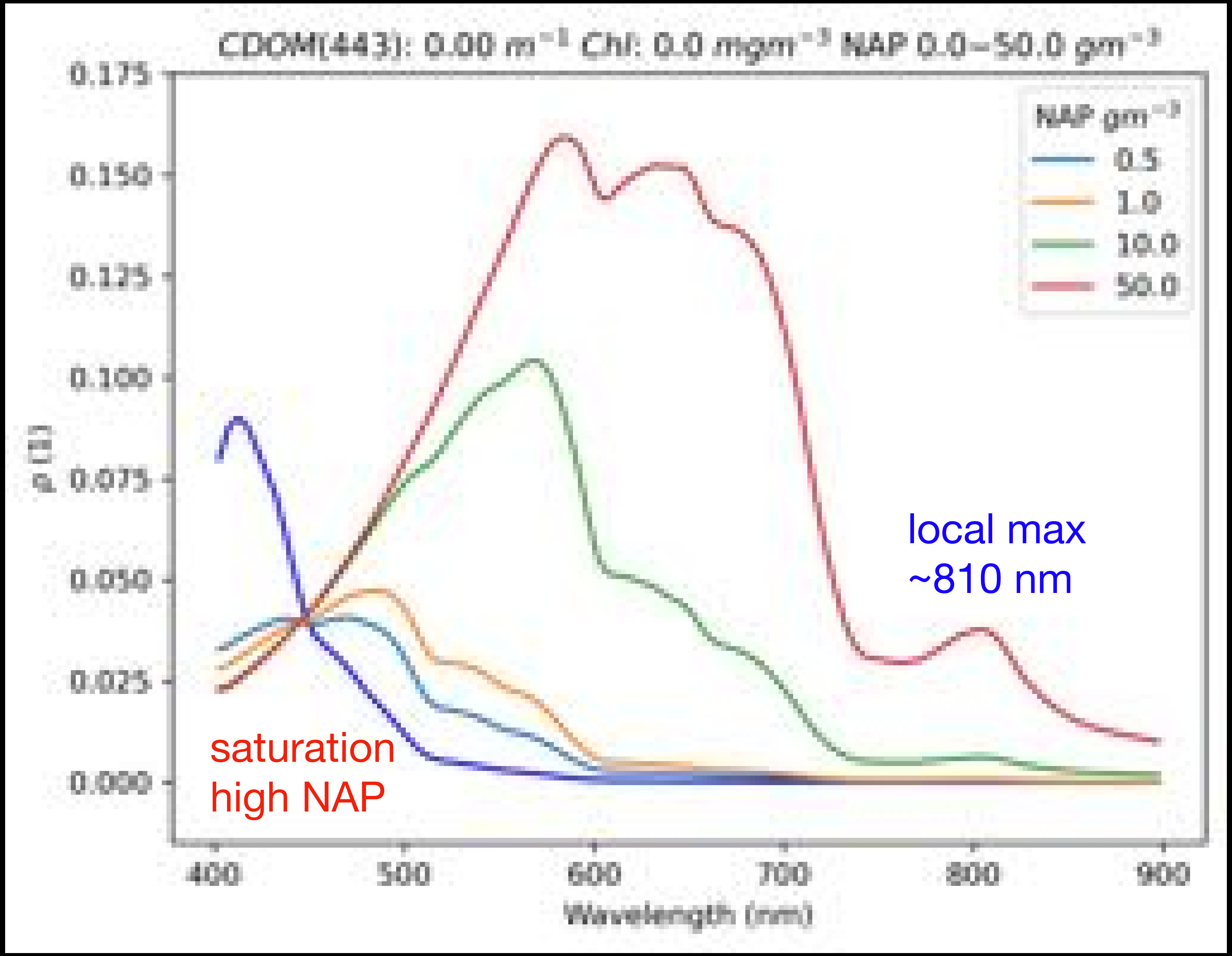


a and b

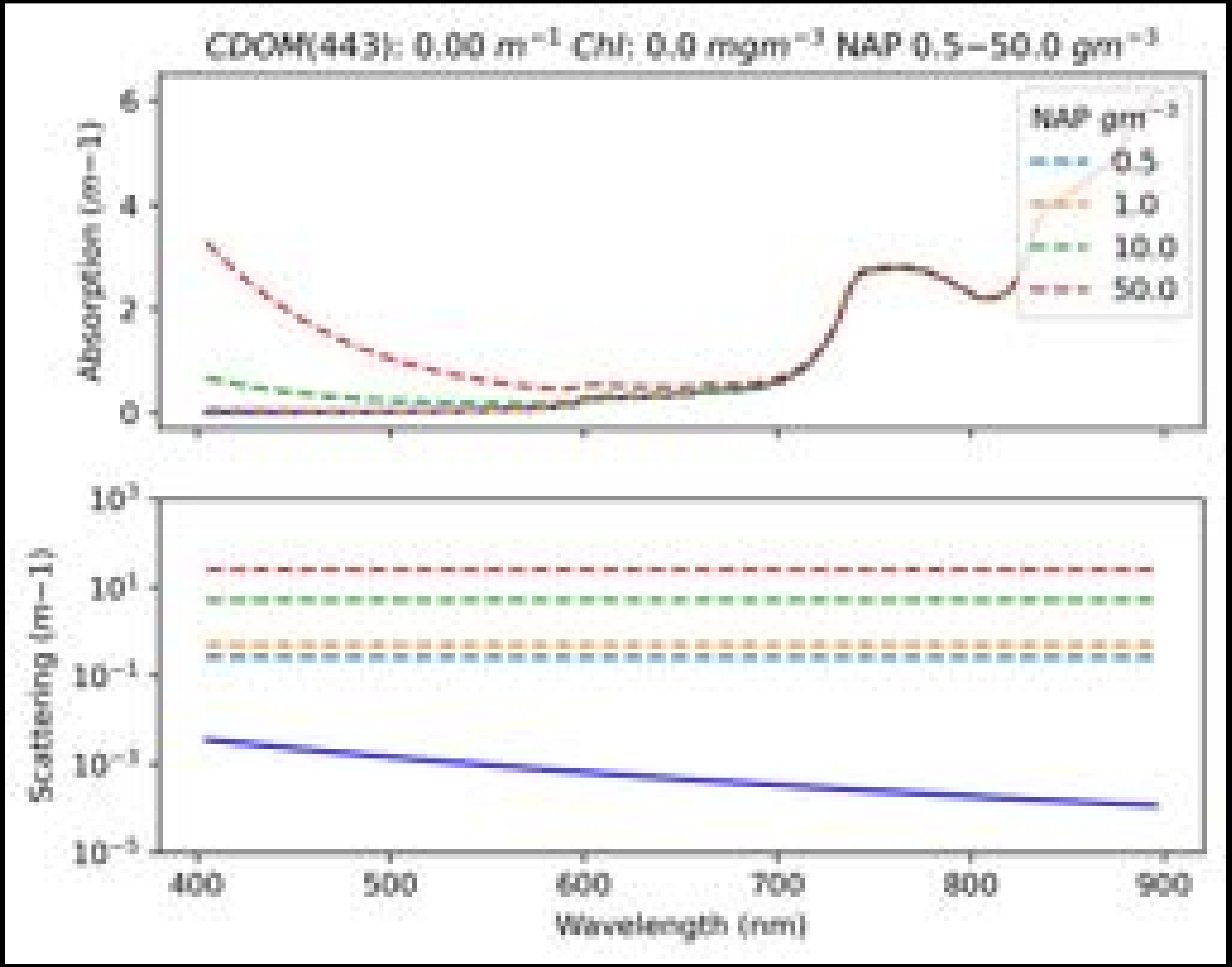


HYDROLIGHT

ρw = π x Rrs

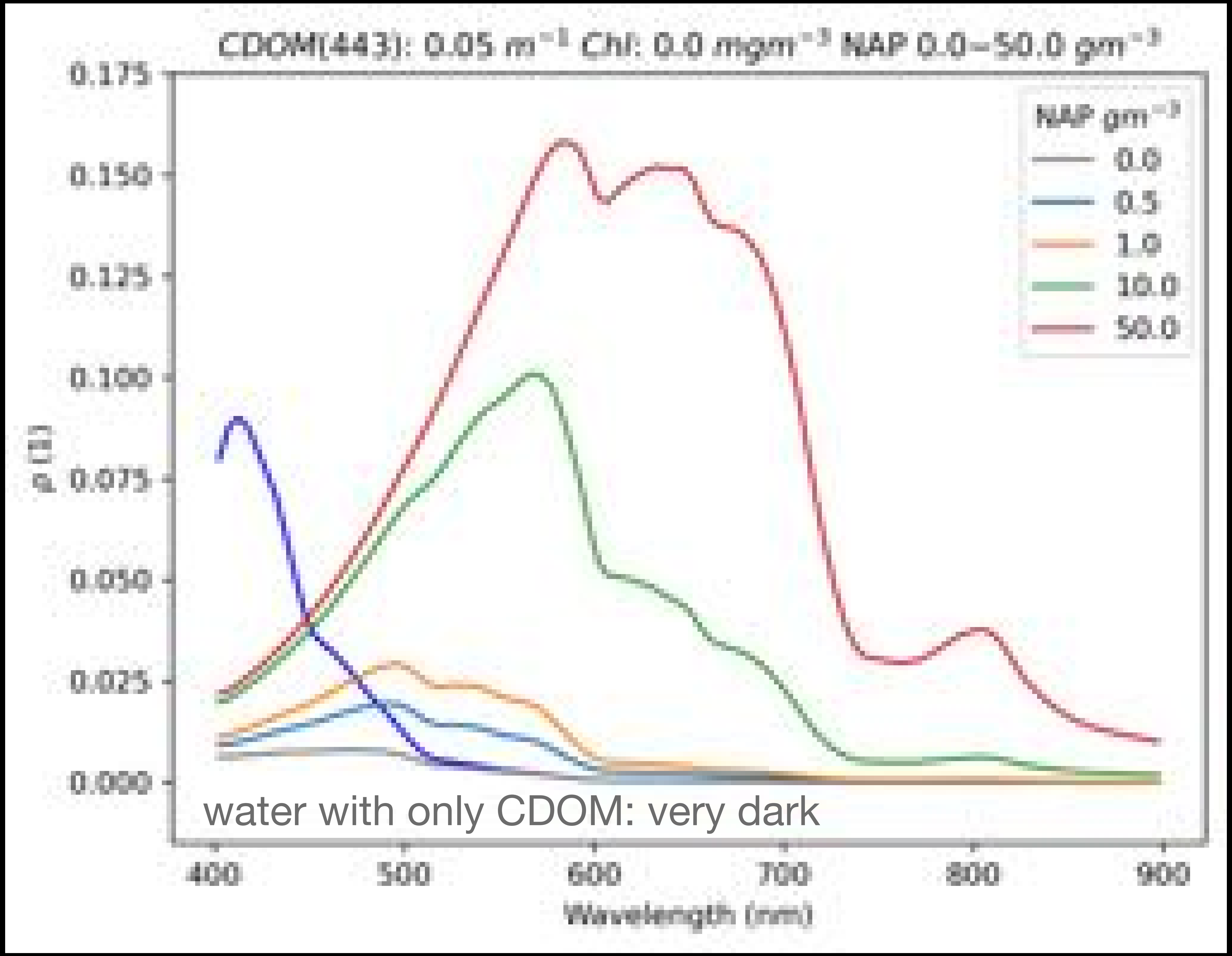


a and b

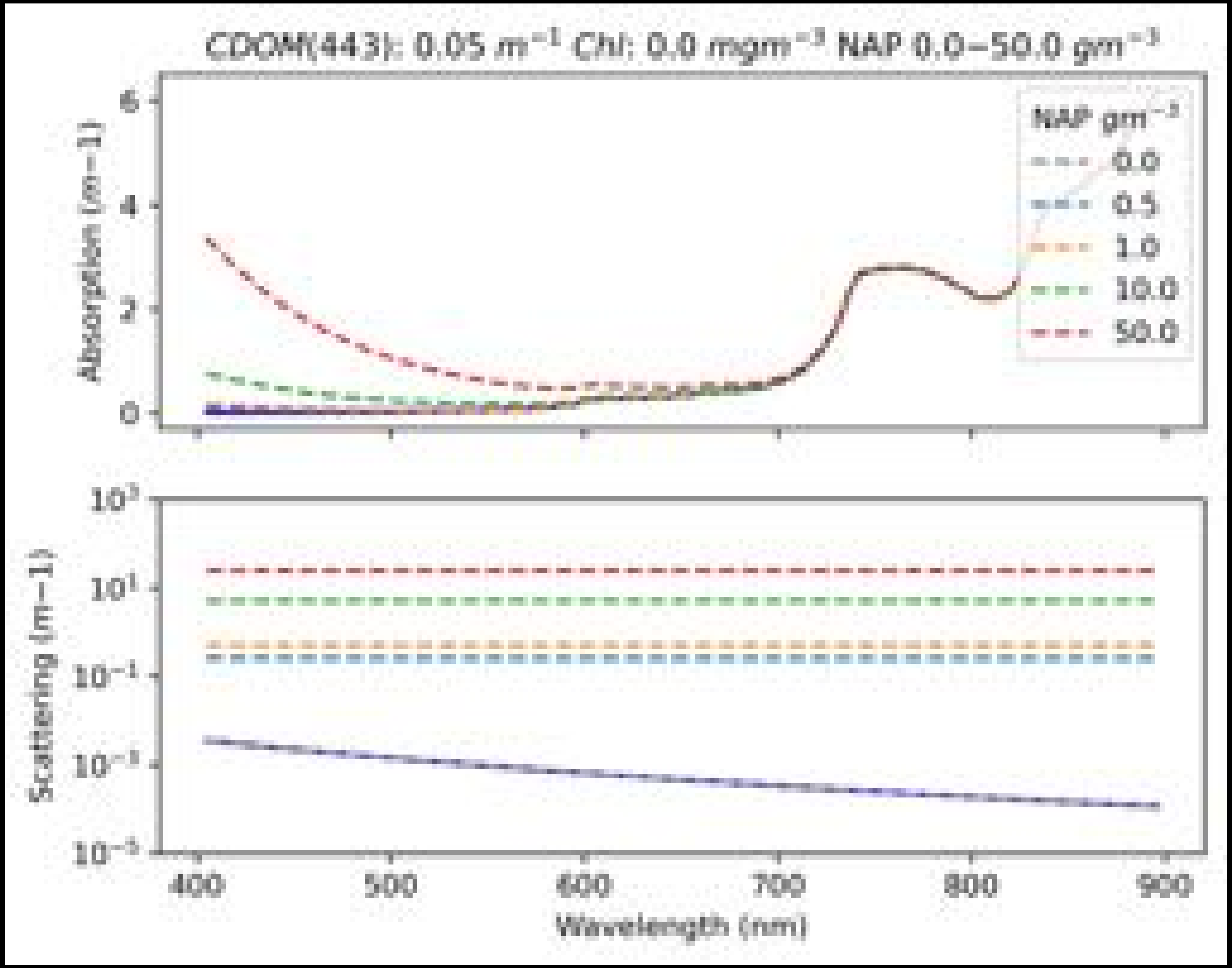


HYDROLIGHT, NAP range

ρw = π x Rrs

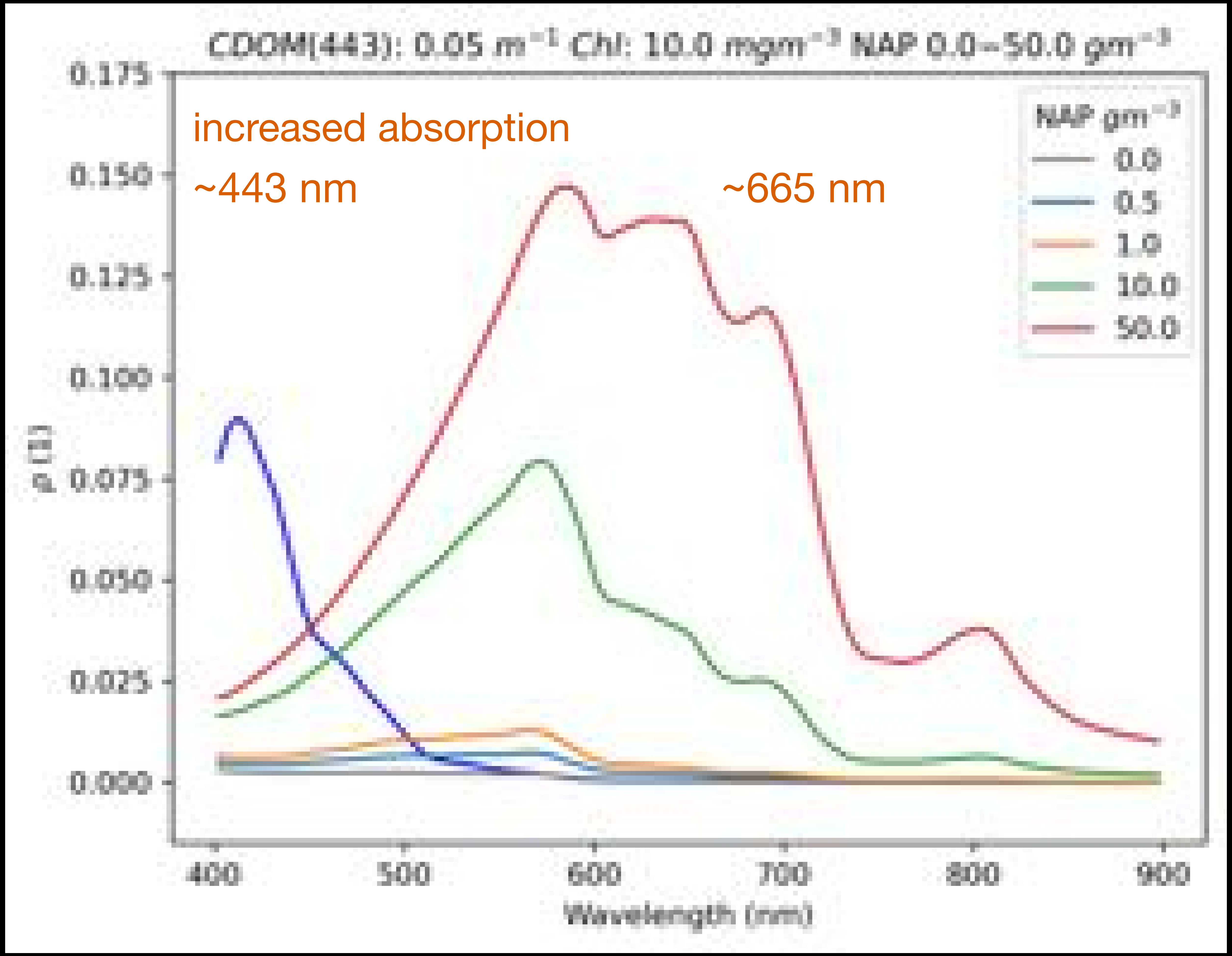


a and b

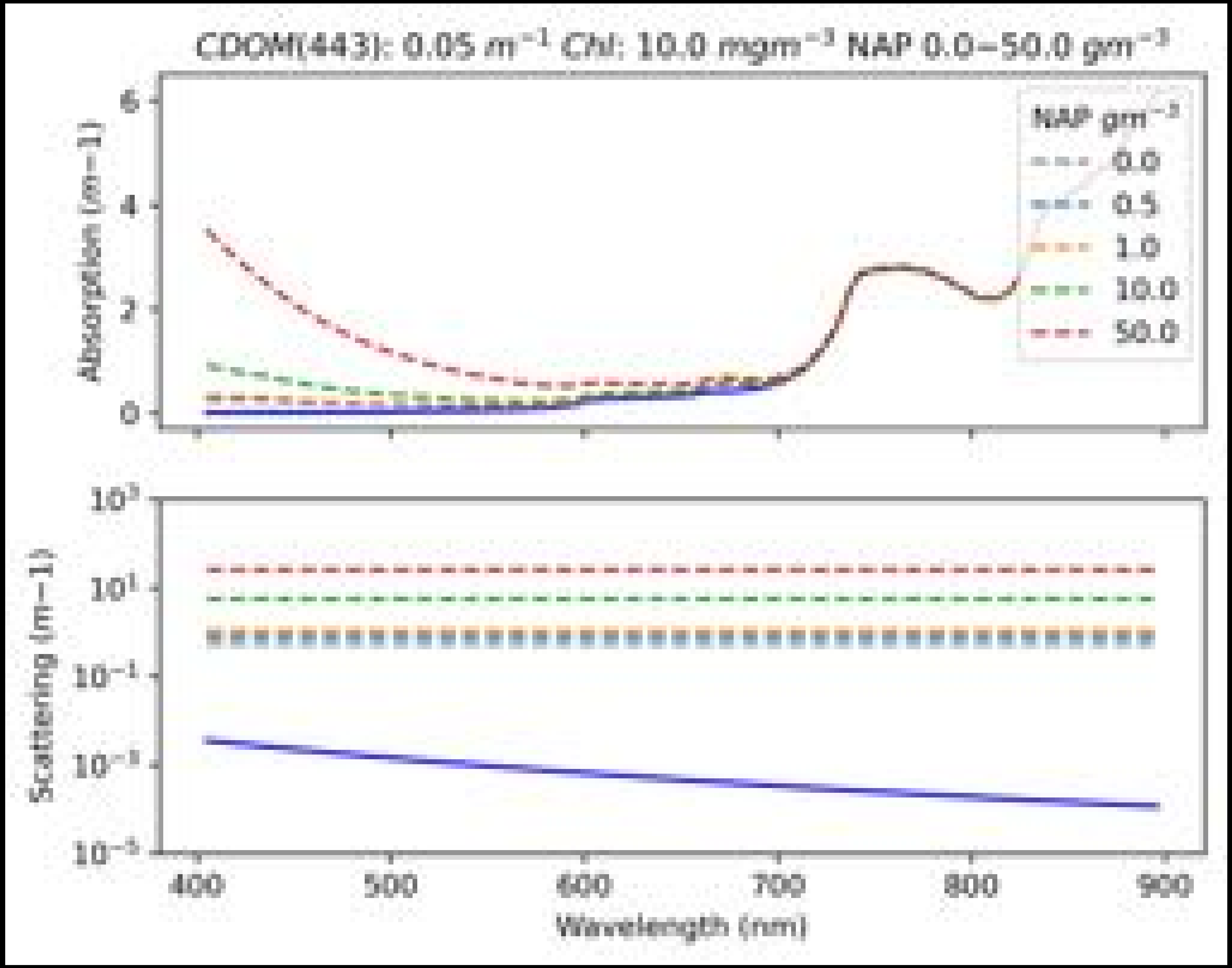


HYDROLIGHT, NAP range, CDOM 0.05

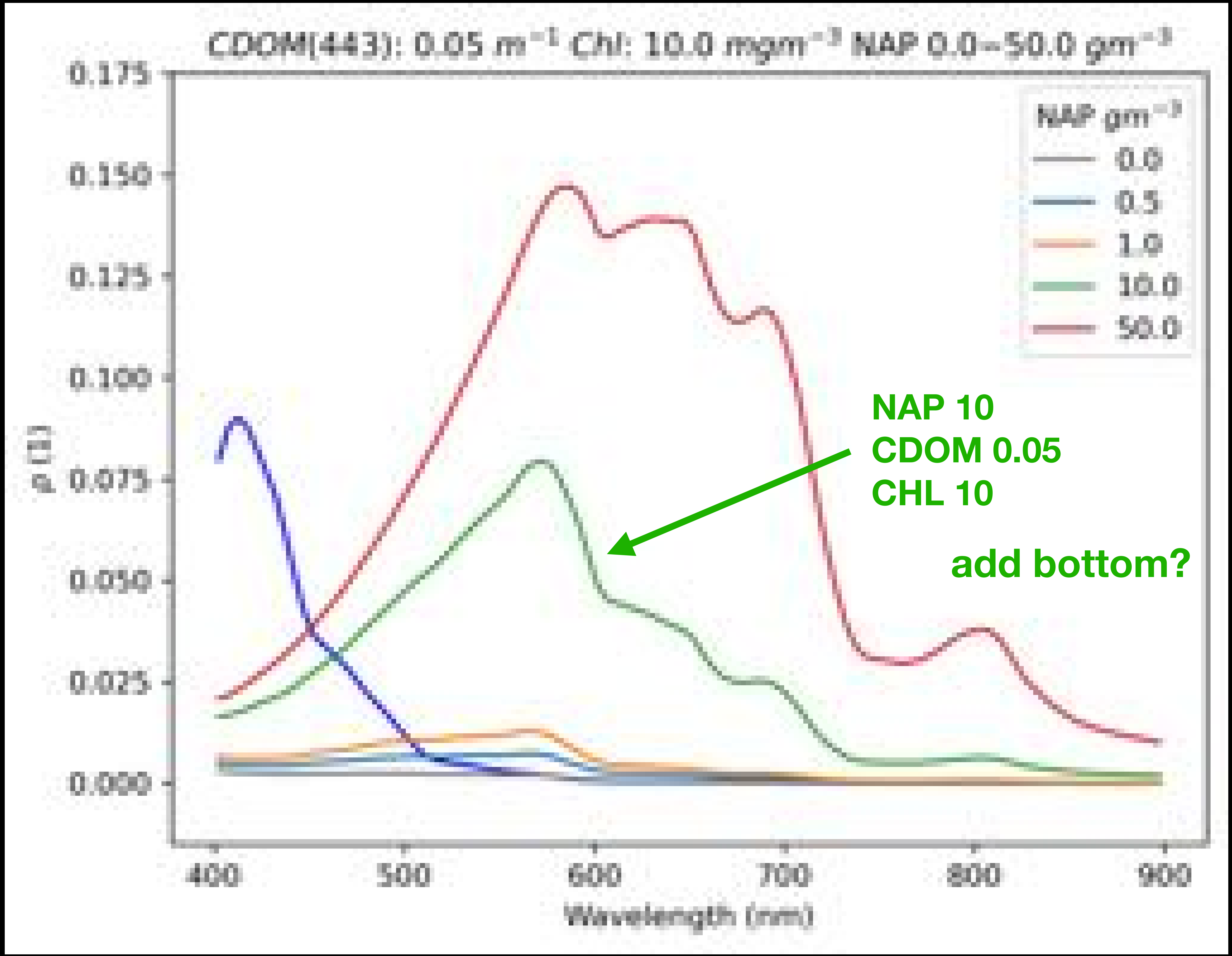
ρw = π x Rrs



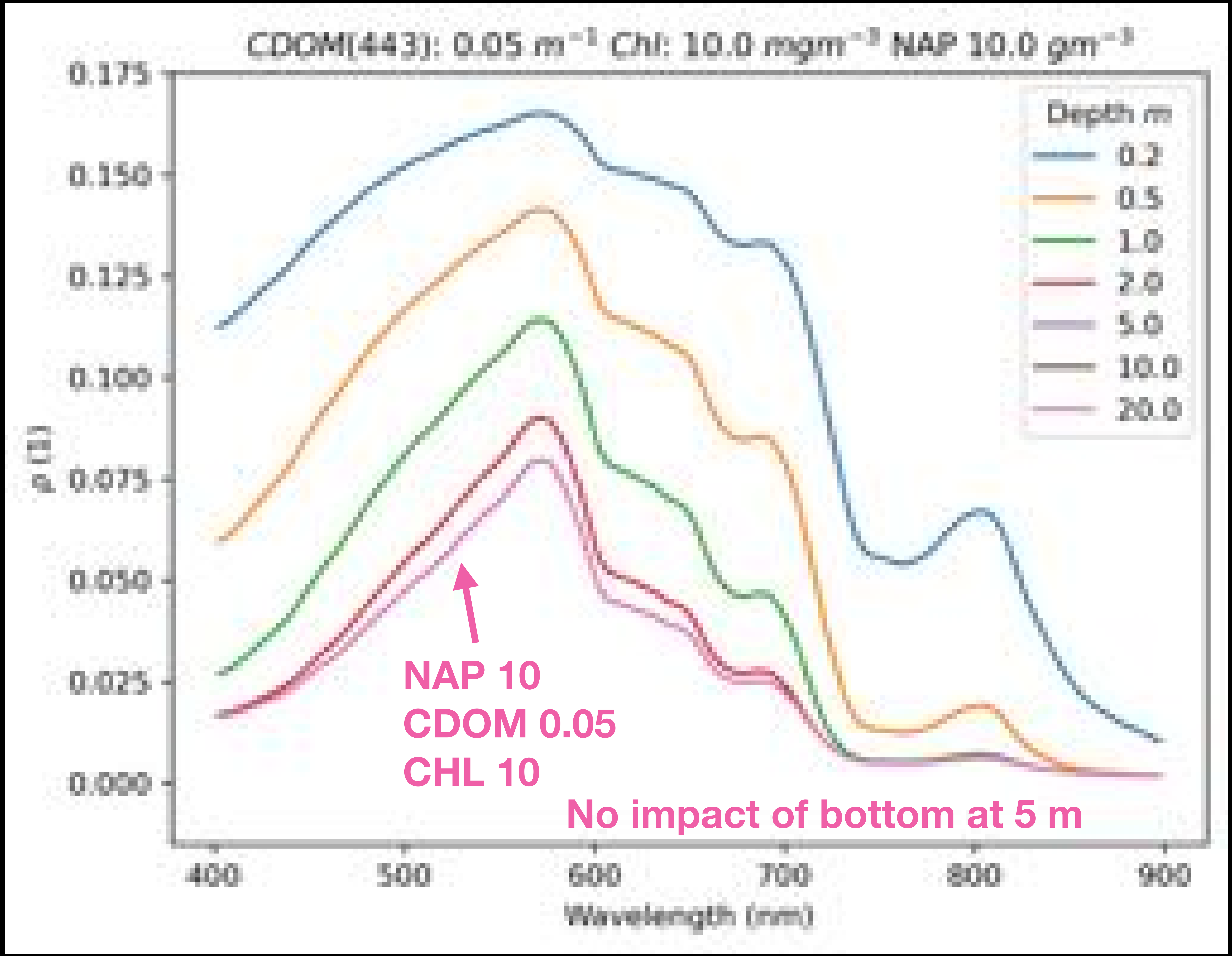
a and b



HYDROLIGHT, NAP range, CDOM 0.05, CHL 10



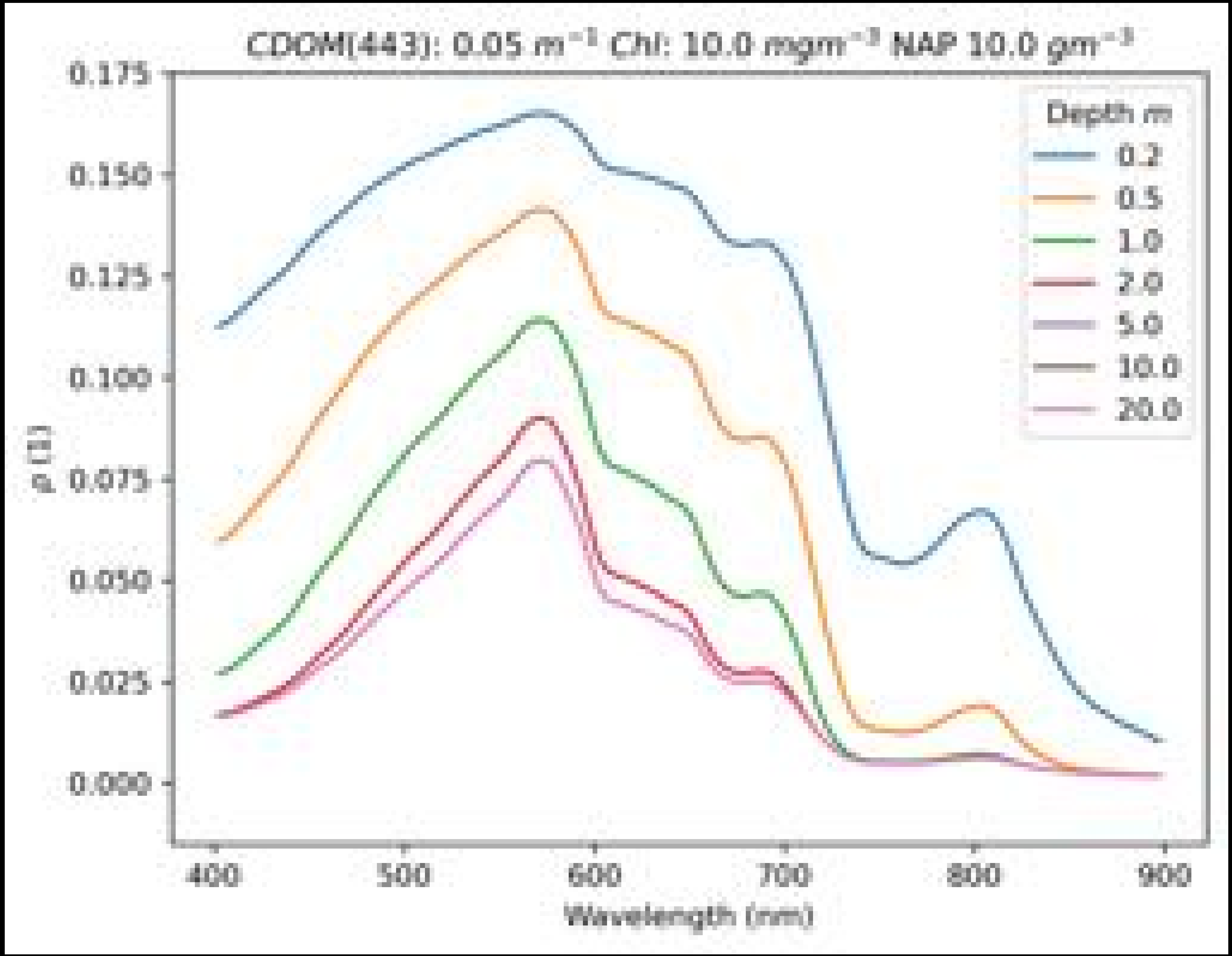
HYDROLIGHT, NAP range, CDOM 0.05, CHL 10



ρbottom: 0.3

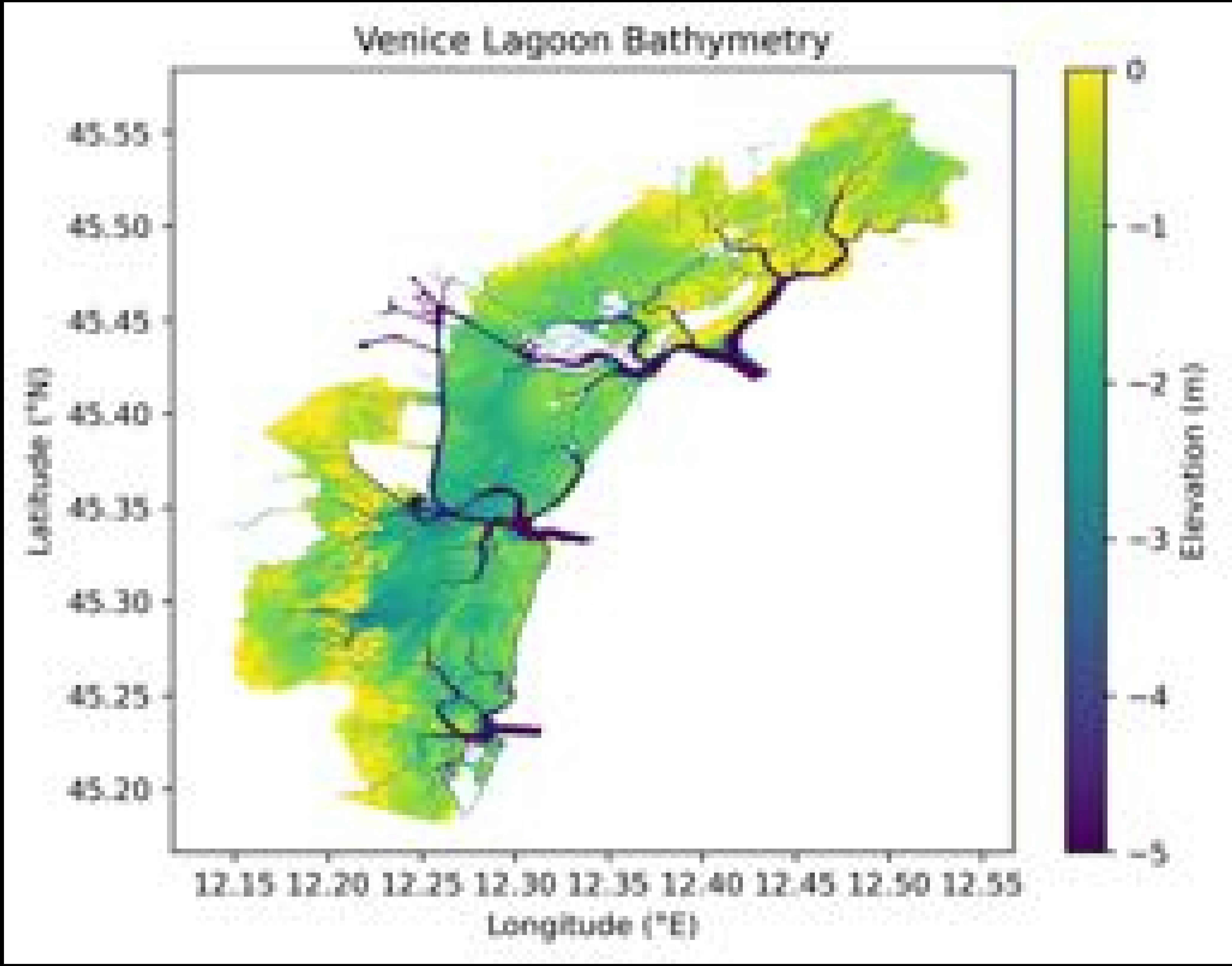
HYDROLIGHT, NAP range, CDOM 0.05, CHL 10, bottom 0.2-20 m

> bottom influence
for shallower depth



ρbottom: 0.3

HYDROLIGHT, NAP range, CDOM 0.05, CHL 10, bottom 0.2-20 m



~7% > 5 m depth

~82% < 2 m depth

~43% < 1 m depth

~15% < 0.5 m depth

source: downloads.emodnet-bathymetry.eu/high_resolution/1528_Venice_lagoon_IB_128.emo.zip

Issues with atmospheric correction

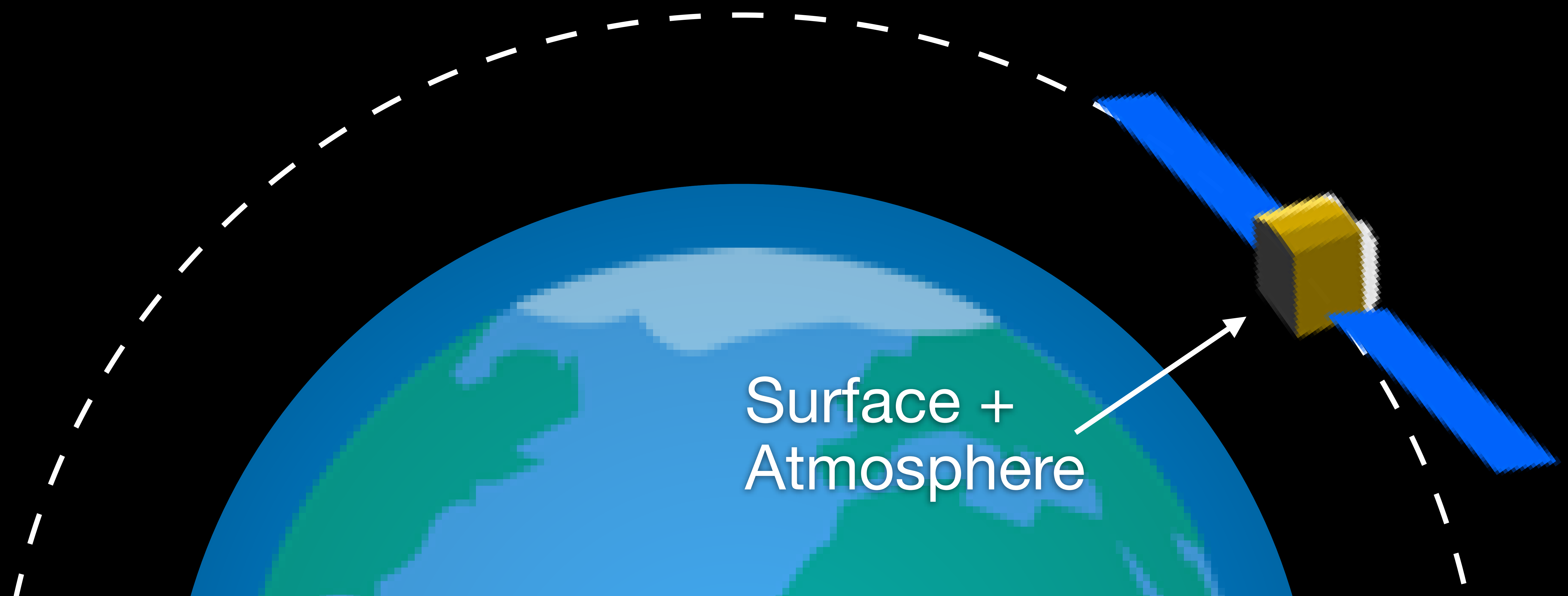
Atmospheric correction algorithms are complex, and assumptions and limitations are not always obvious

Atmospheric correction

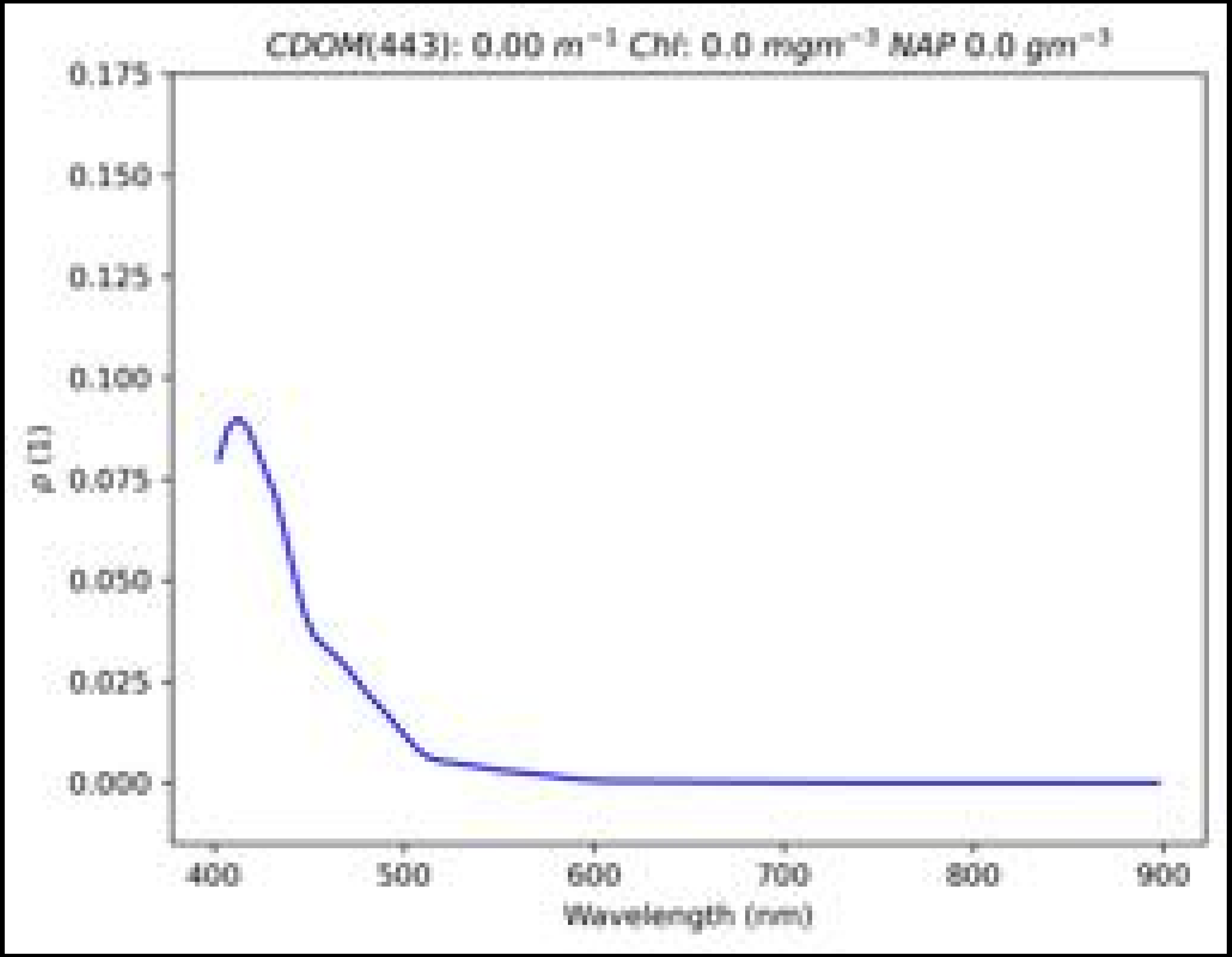
Need for atmospheric correction:

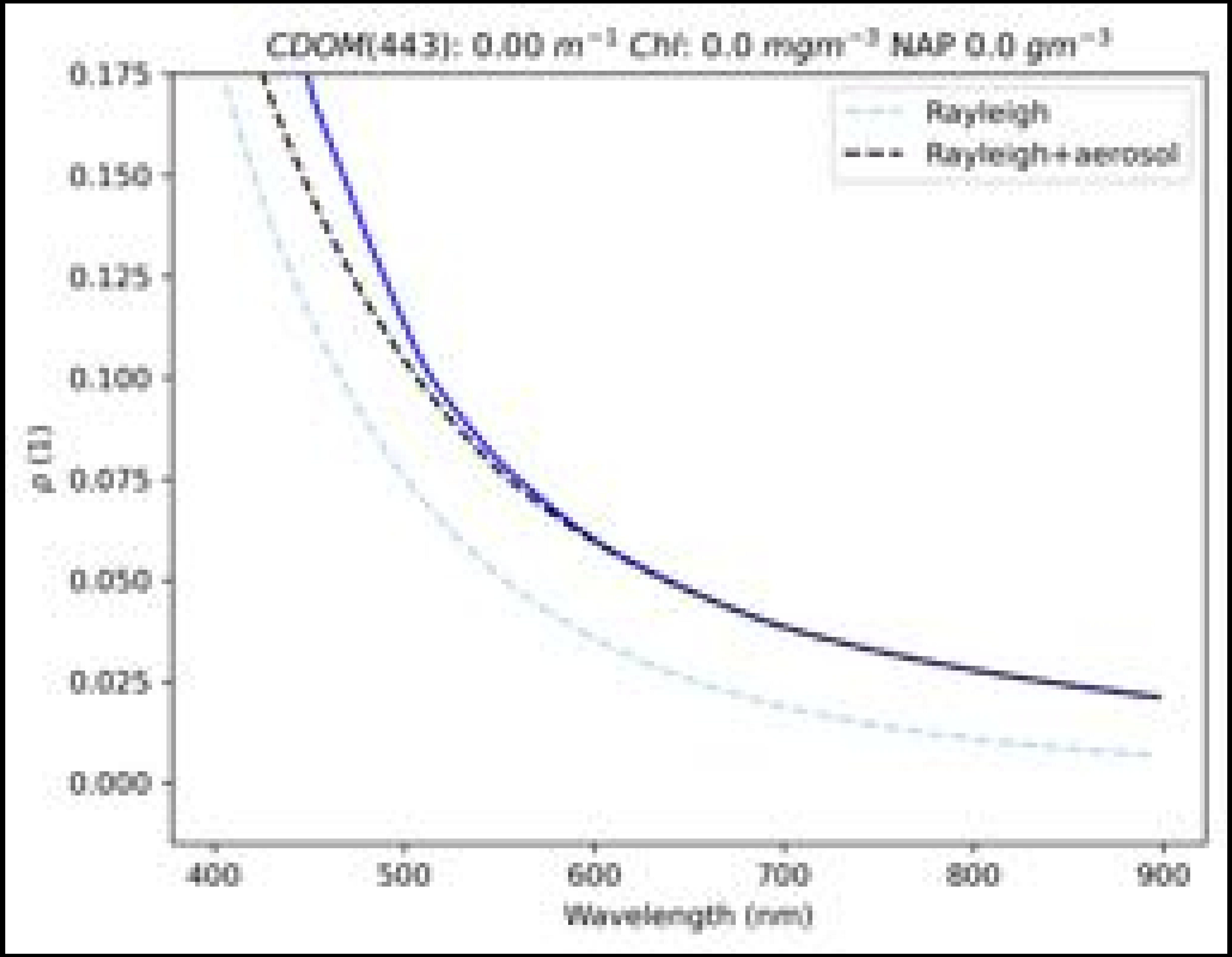
- remote observation combines the signals from the target, the atmosphere, and the interface between target and atmosphere

- for near surface sensors the effect of atmosphere between the sensor and the target is minimal, but for airborne, or top-of-atmosphere (TOA) sensors the atmosphere can dominate the signal



θs 60° θv 40° τa 550 nm = 0.1

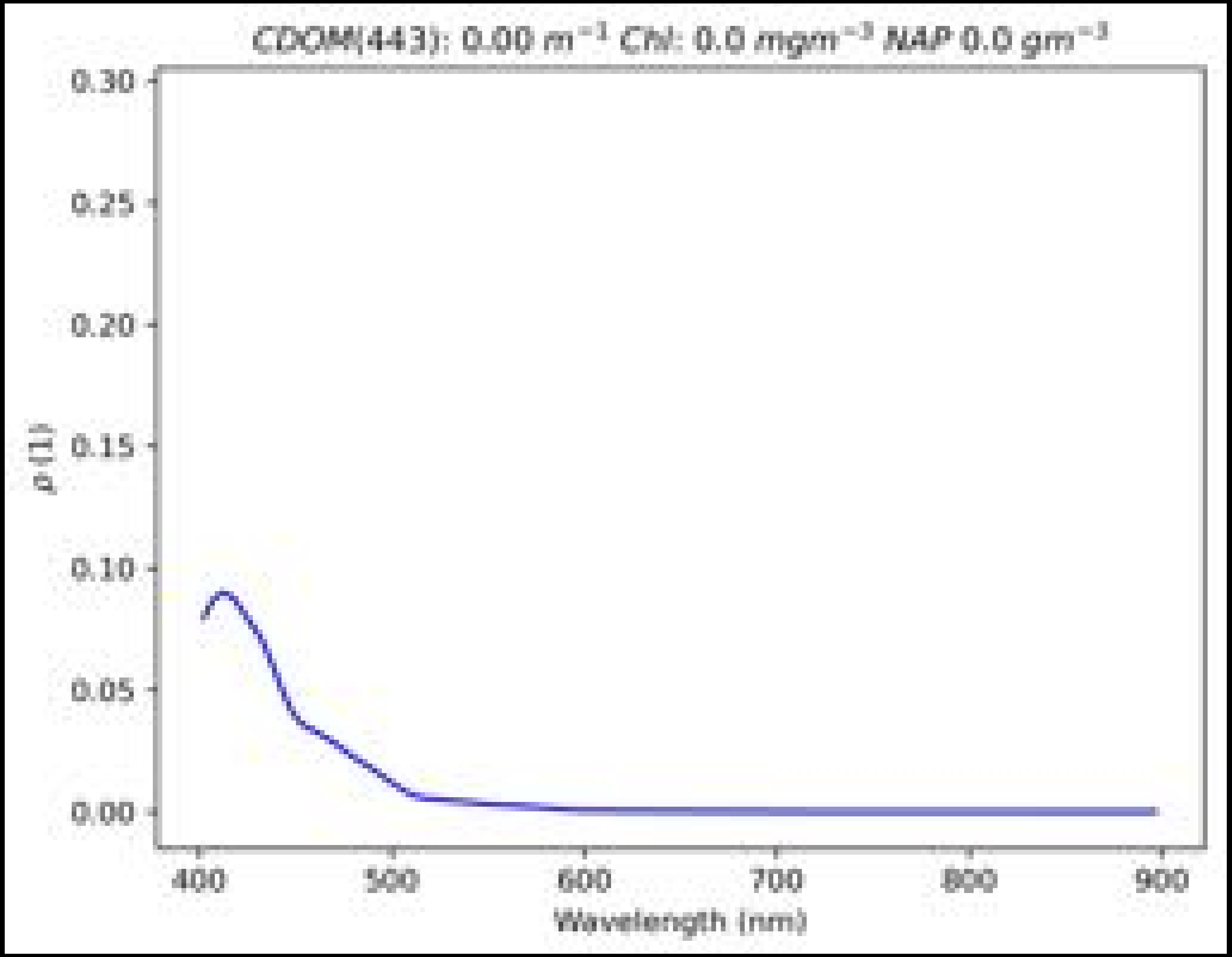


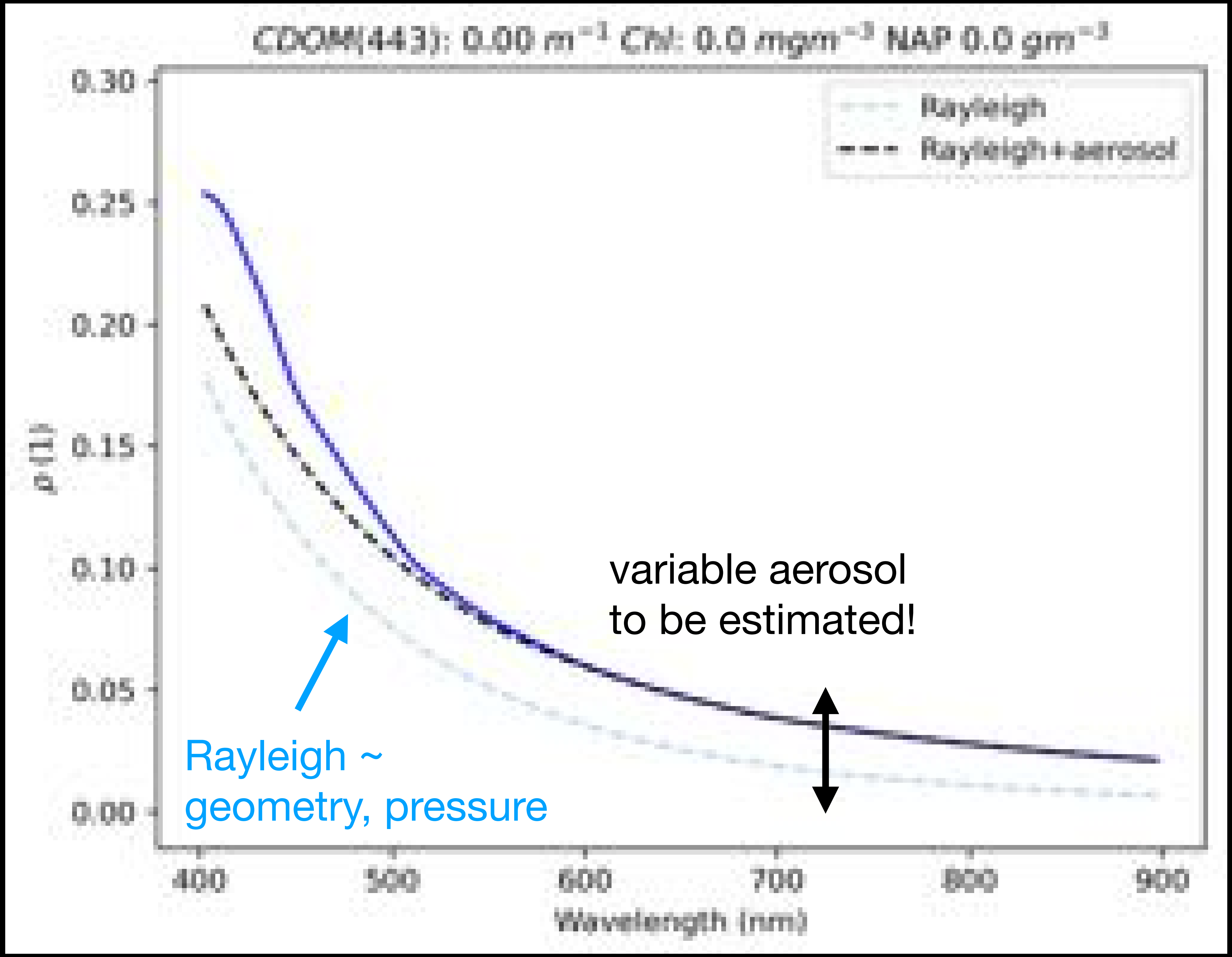


BOA

TOA

θs 60° θv 40° τa 550 nm = 0.1





BOA

TOA

Atmospheric correction

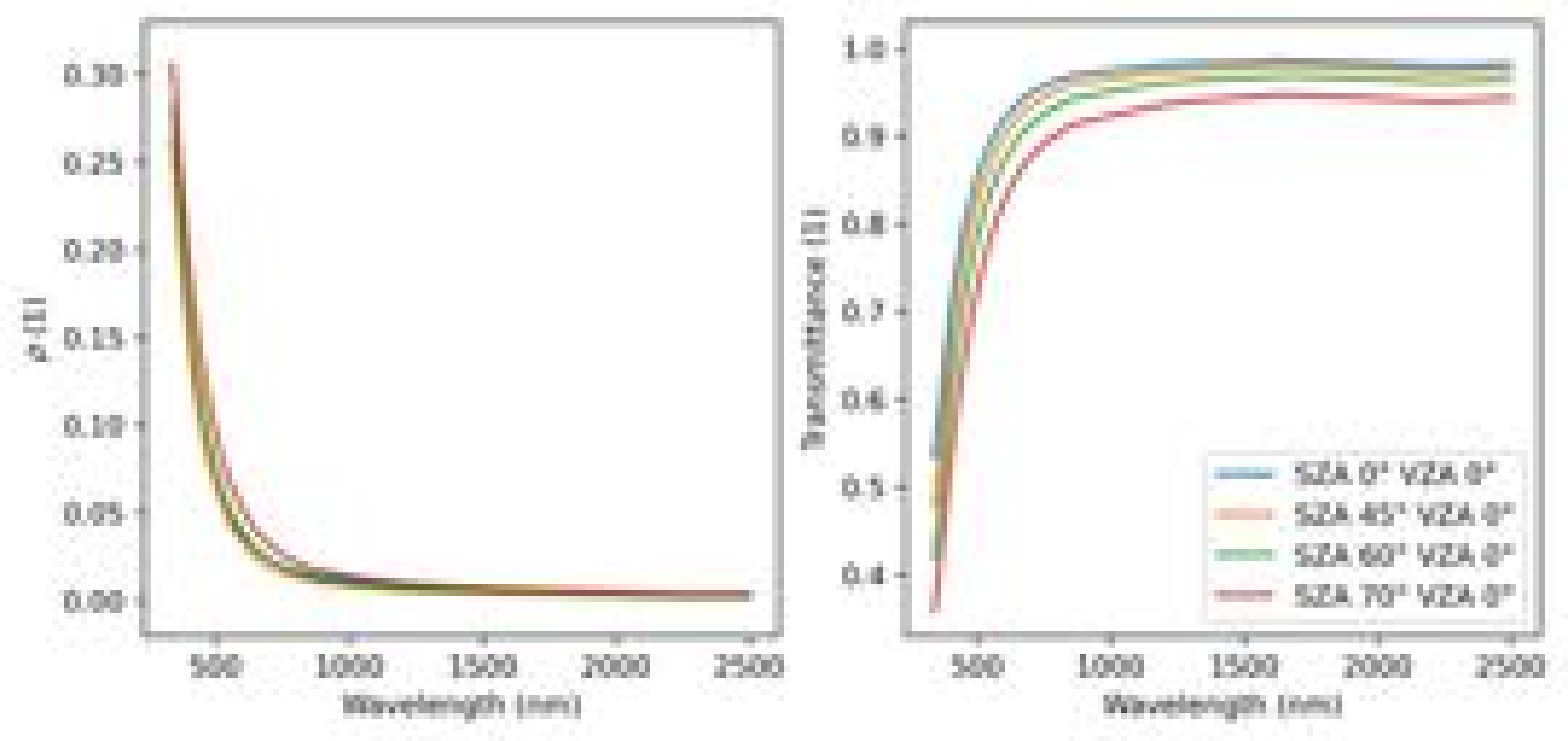
Need for atmospheric correction:

- **the atmospheric path reflectance and transmittance varies with illumination and observation geometry, scaling with atmospheric path length, simplified as 1/cos(vza) + 1/cos(sza)**

- **the extraterrestrial solar irradiance (F0) varies throughout the year with the sun-earth distance (d), and is scaled from reference irradiance value by d^2**

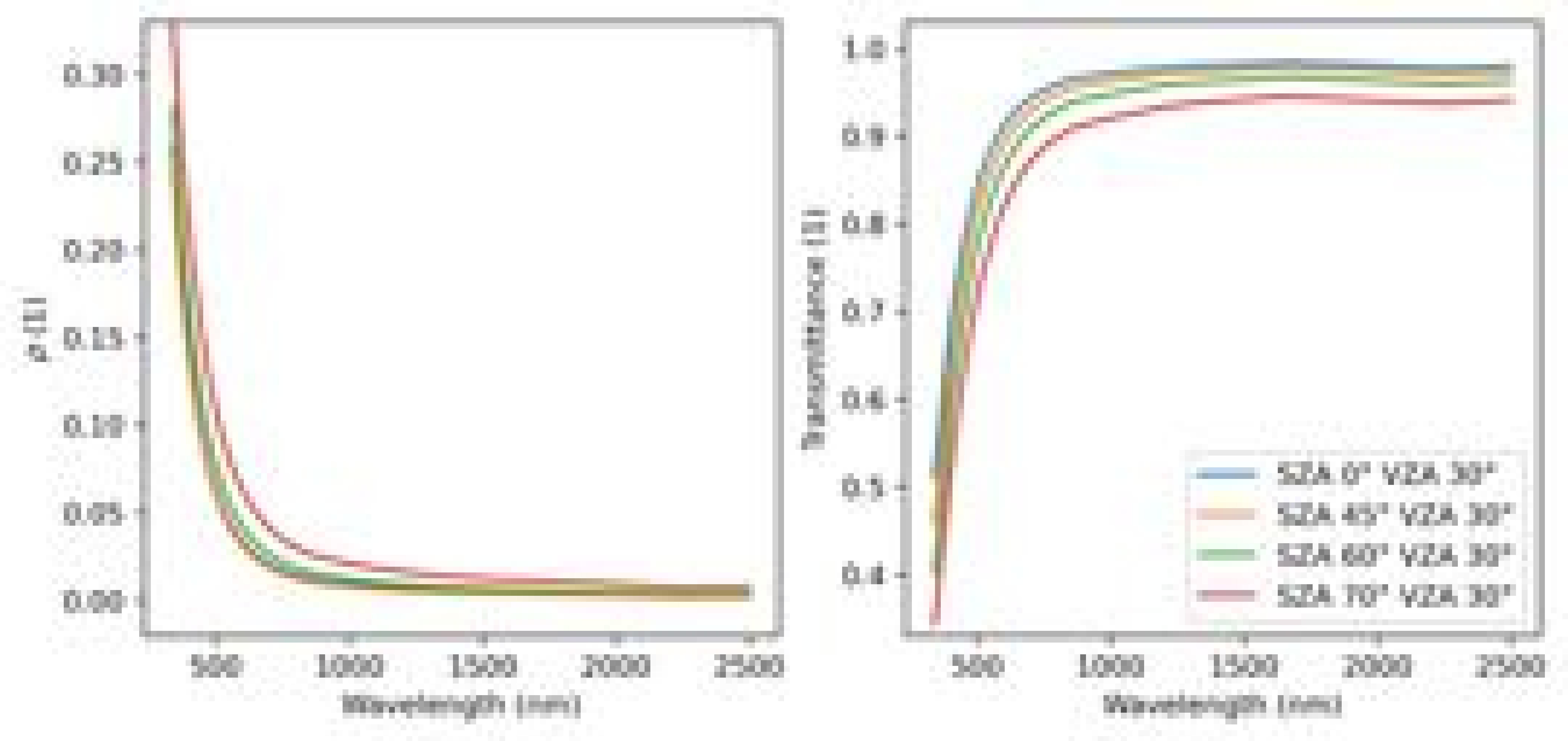
https://commons.wikimedia.org/wiki/File:Sunset_from_Echo_Point_(50659650521).jpg

Path reflectance and transmittance



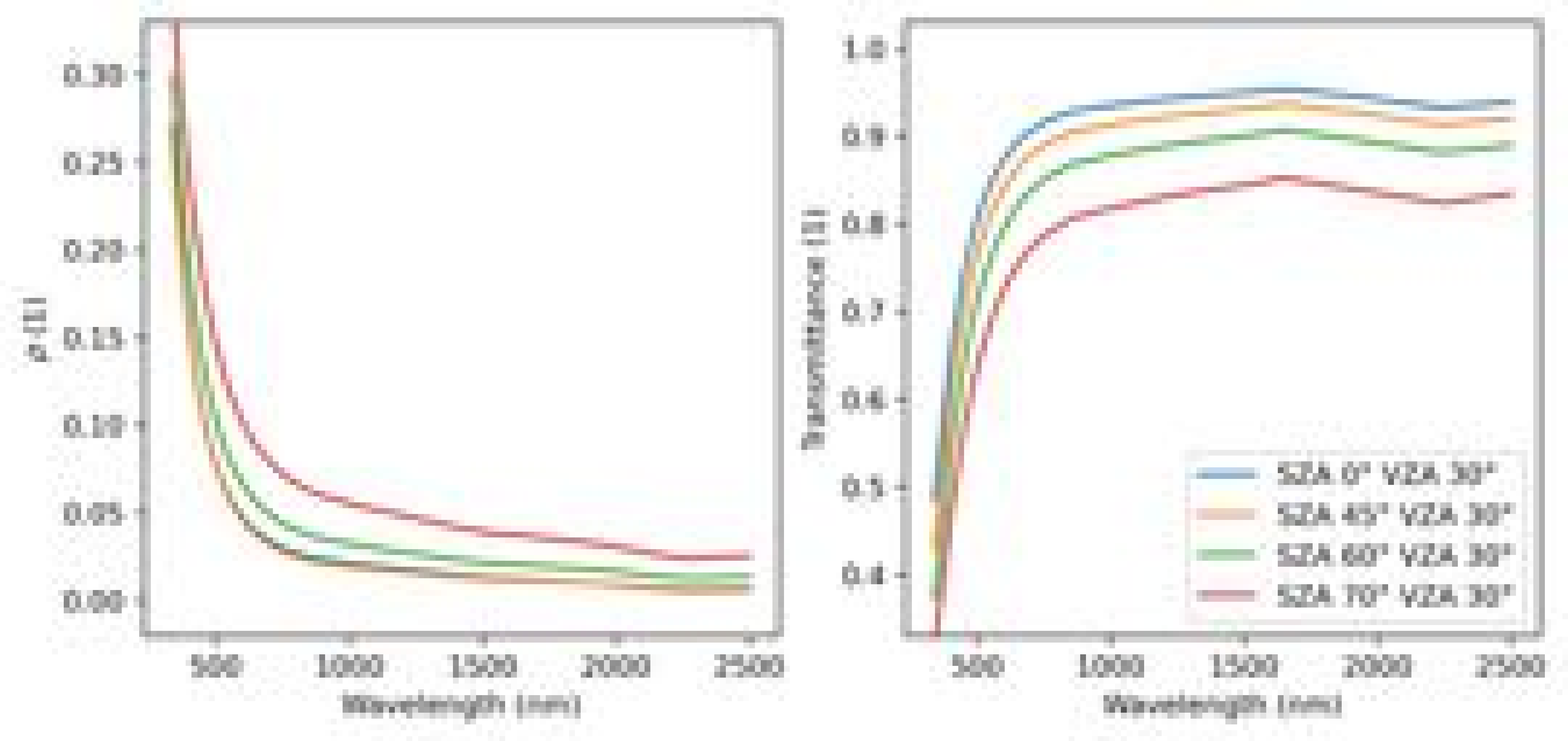
6SV model, τa 550 nm 0.1, maritime aerosol

Path reflectance and transmittance



6SV model, τa 550 nm 0.1, maritime aerosol

Path reflectance and transmittance



6SV model, τa 550 nm 0.3, maritime aerosol

Atmospheric correction

Required for atmospheric correction:

- absorption by atmospheric gases (O_3, H_2O, but many others) ~ concentration, geometry
- scattering and absorption by air molecules (Rayleigh) ~ air pressure, geometry
- scattering and absorption by particles (aerosol) ~ particle type and concentration, geometry
- air-water interface: sky and sun glint, whitecaps, foam ~ wind speed, geometry

Pressure, wind speed, atmospheric gas concentration

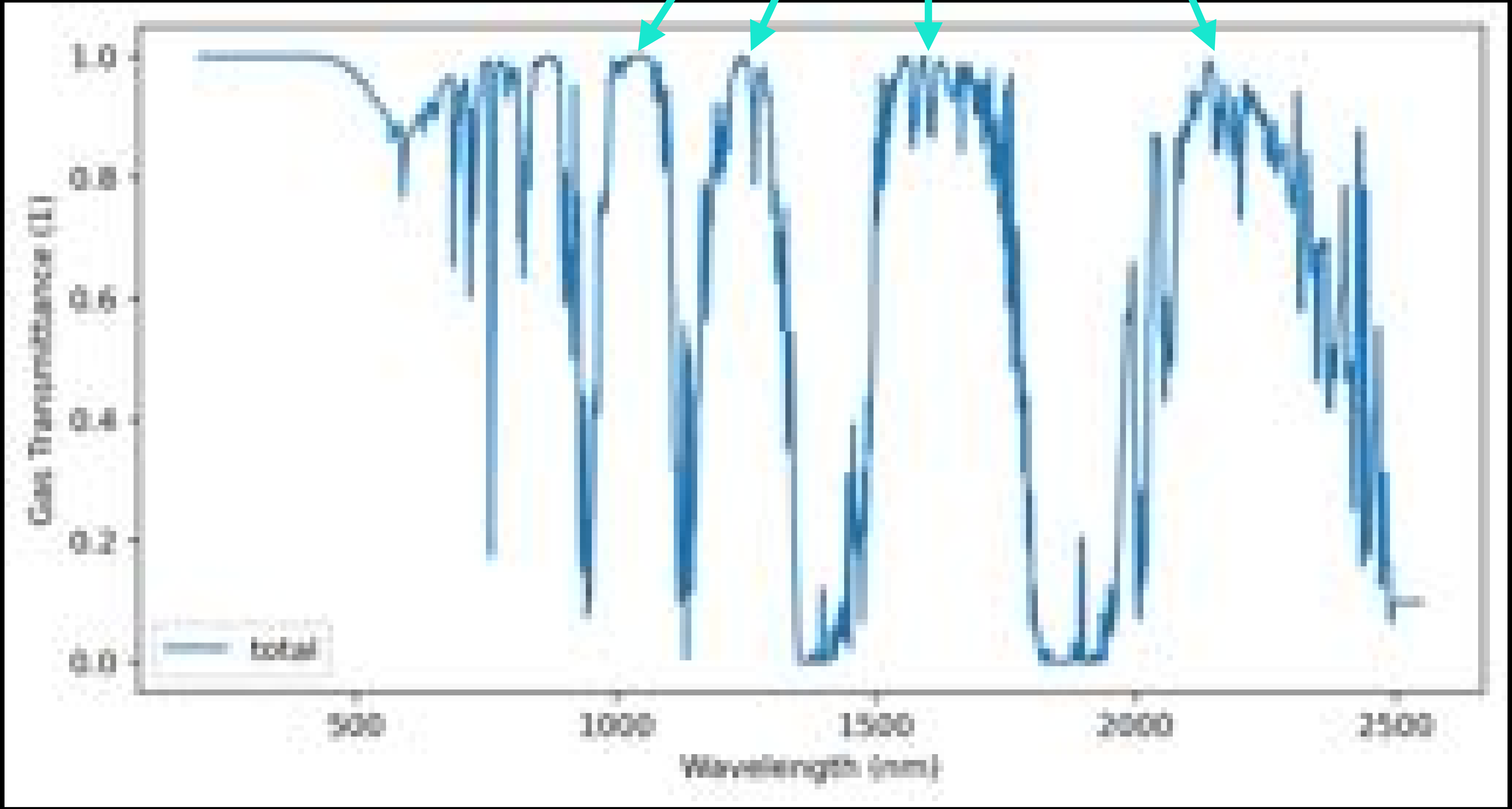
- ancillary data, global climatologies or reasonable defaults

Aerosol information

- from ancillary data or measurements (uncommon)
- estimated from the image, either directly or indirectly

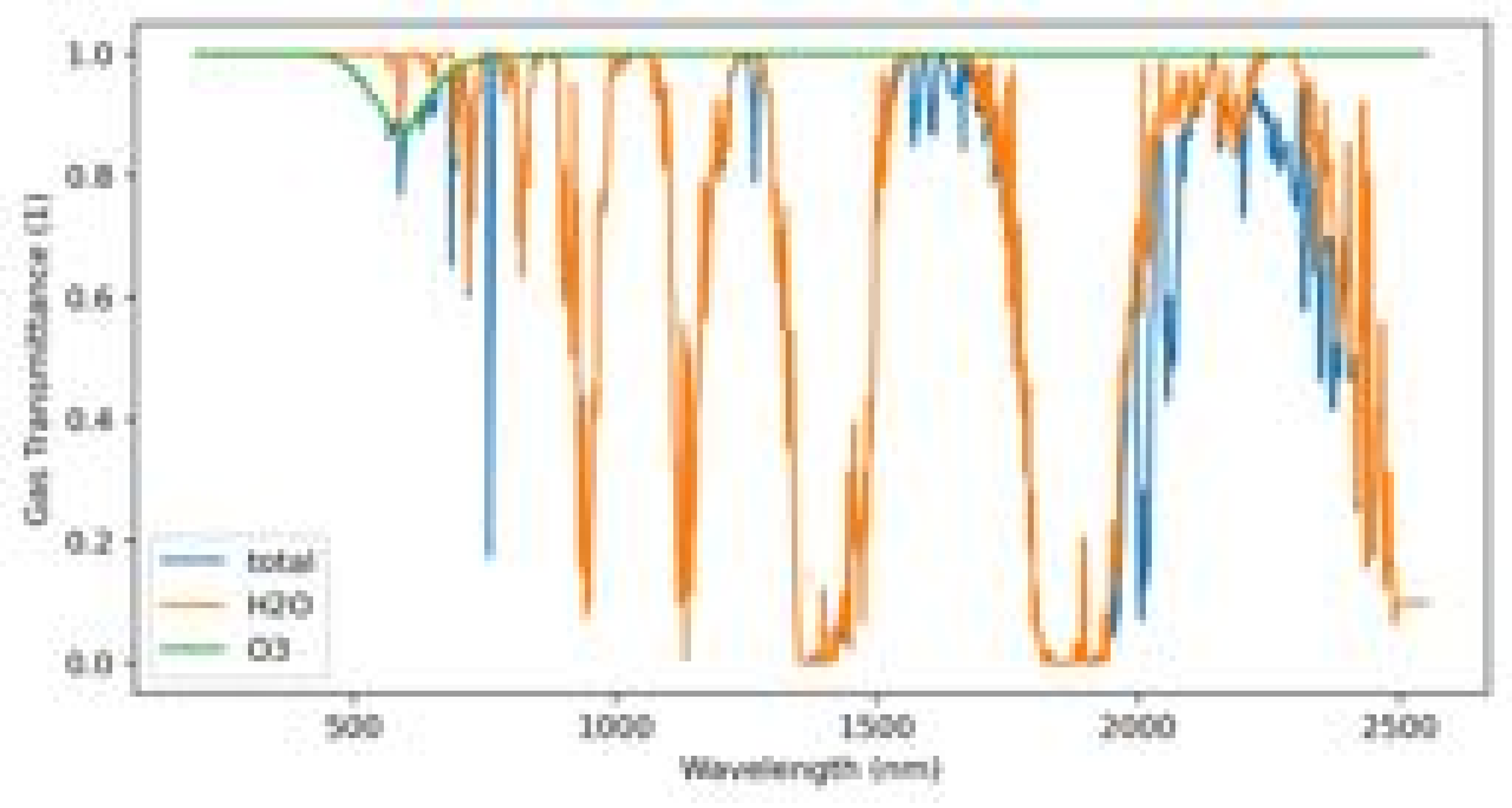
Gas transmittance

Atmospheric “windows”
Gas transmittance ~ 1



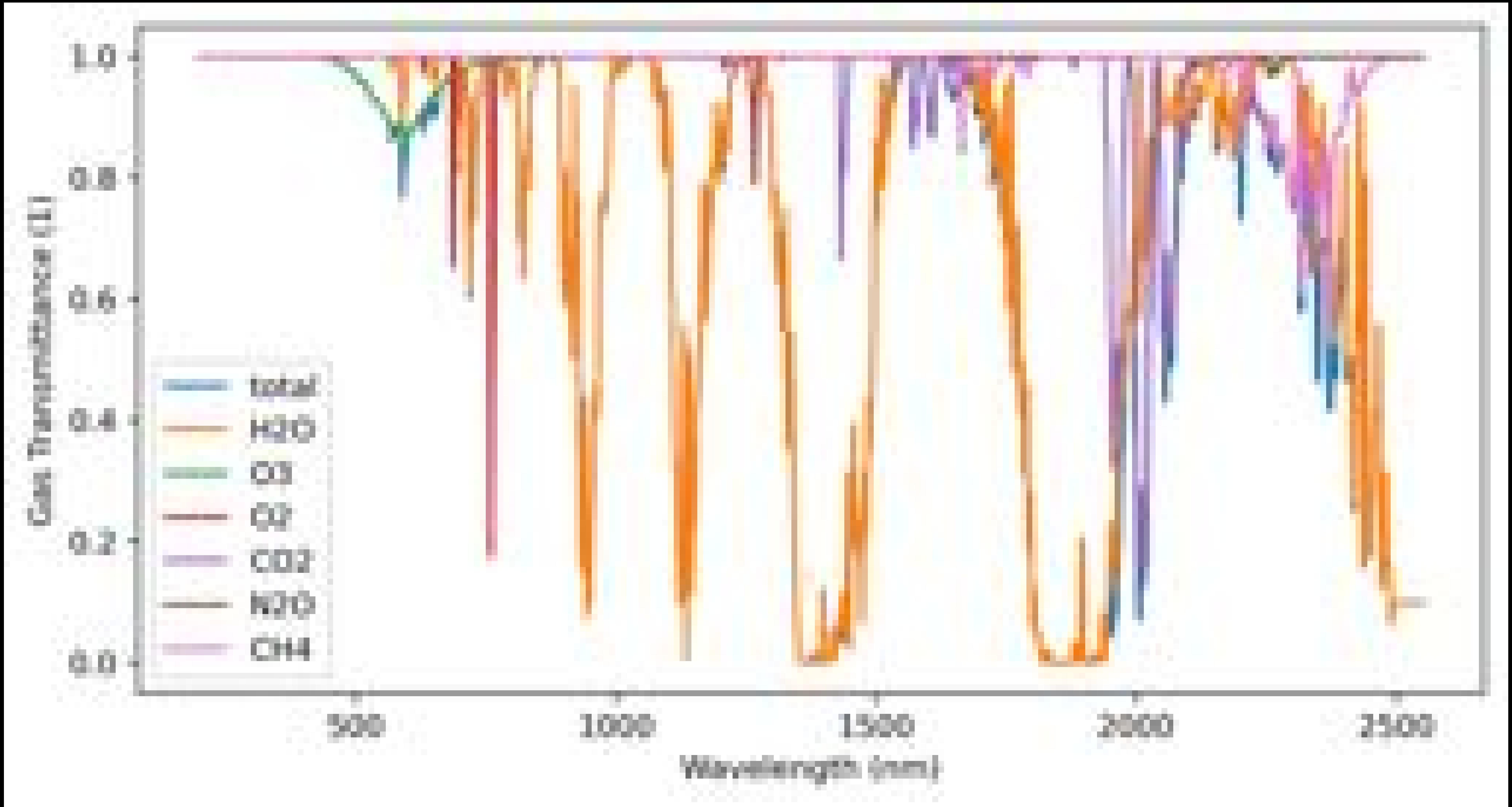
6SV model, 2.5 nm, θs 60°, θv 40°, ozone 0.3 cm-atm, water 1.5 g/cm2

Gas transmittance



6SV model, 2.5 nm, θs 60°, θv 40°, ozone 0.3 cm-atm, water 1.5 g/cm2

Gas transmittance



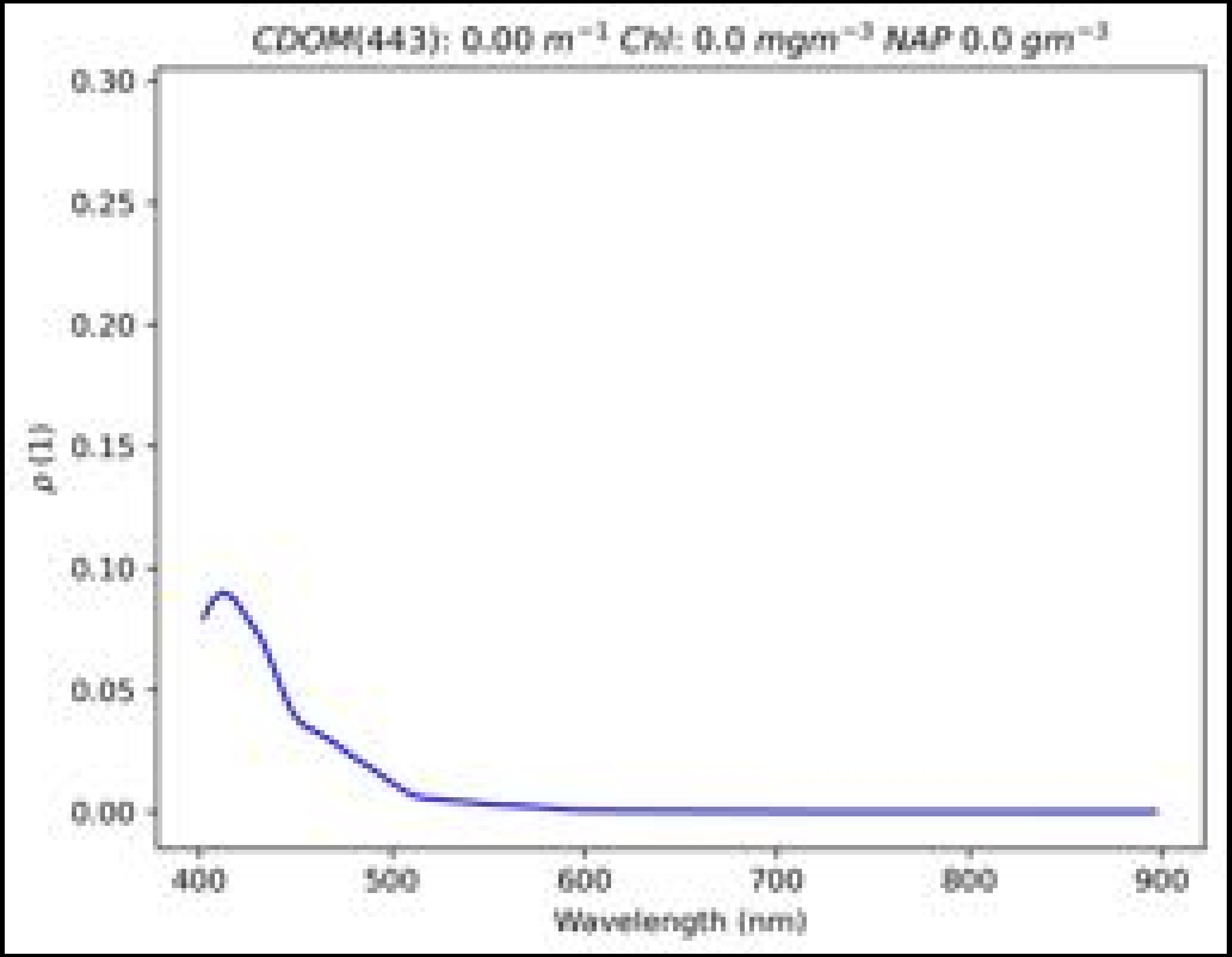
6SV model, 2.5 nm, θs 60°, θv 40°, ozone 0.3 cm-atm, water 1.5 g/cm2

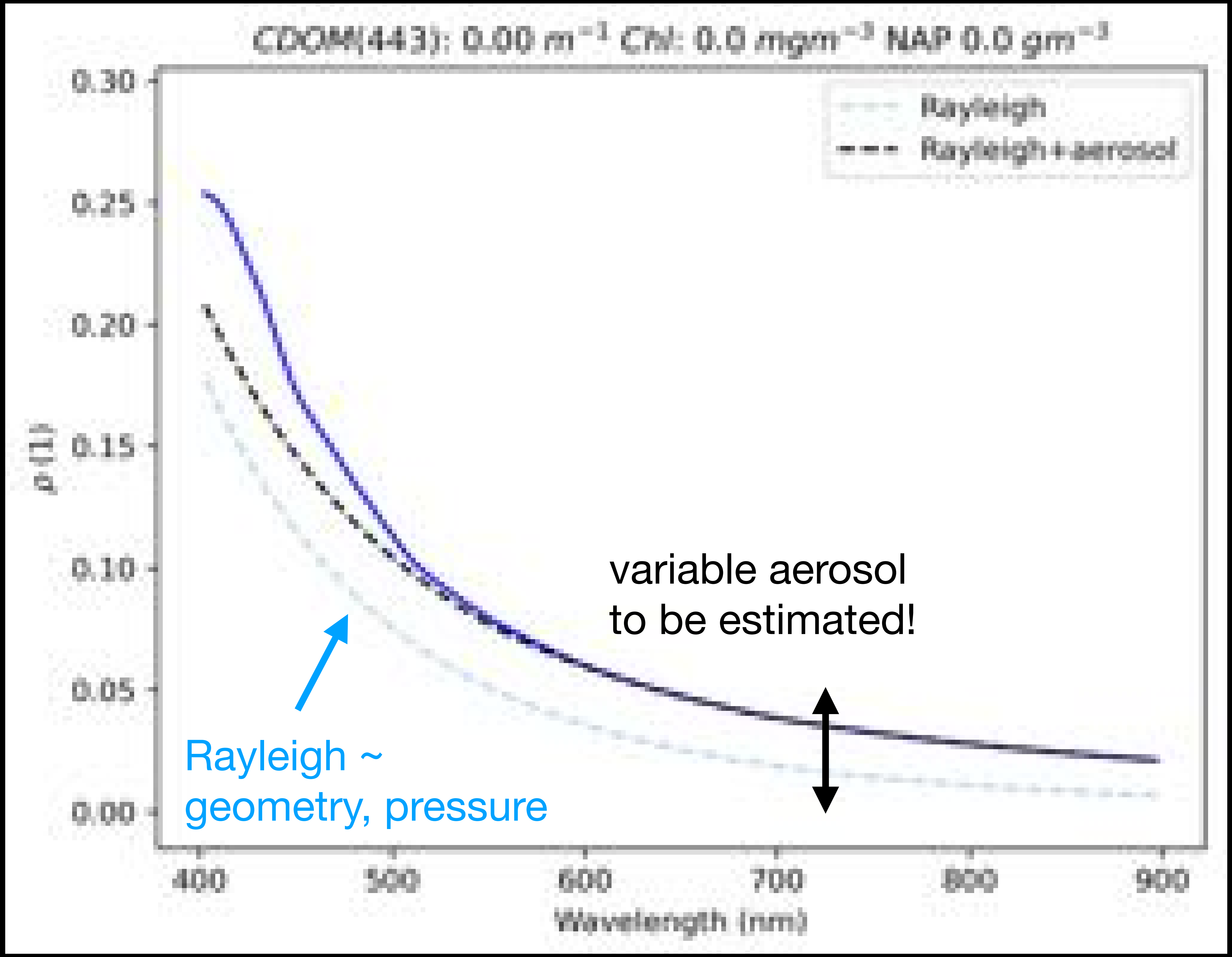
Aerosol estimation

1) Traditional ocean colour approach ~ dark NIR over water

- SeaDAS/l2gen, NASA/NOAA, Gordon and Wang (1994)
- ESA MERIS/OLCI, Antoine et al. (1997)

θs 60° θv 40° τa 550 nm = 0.1

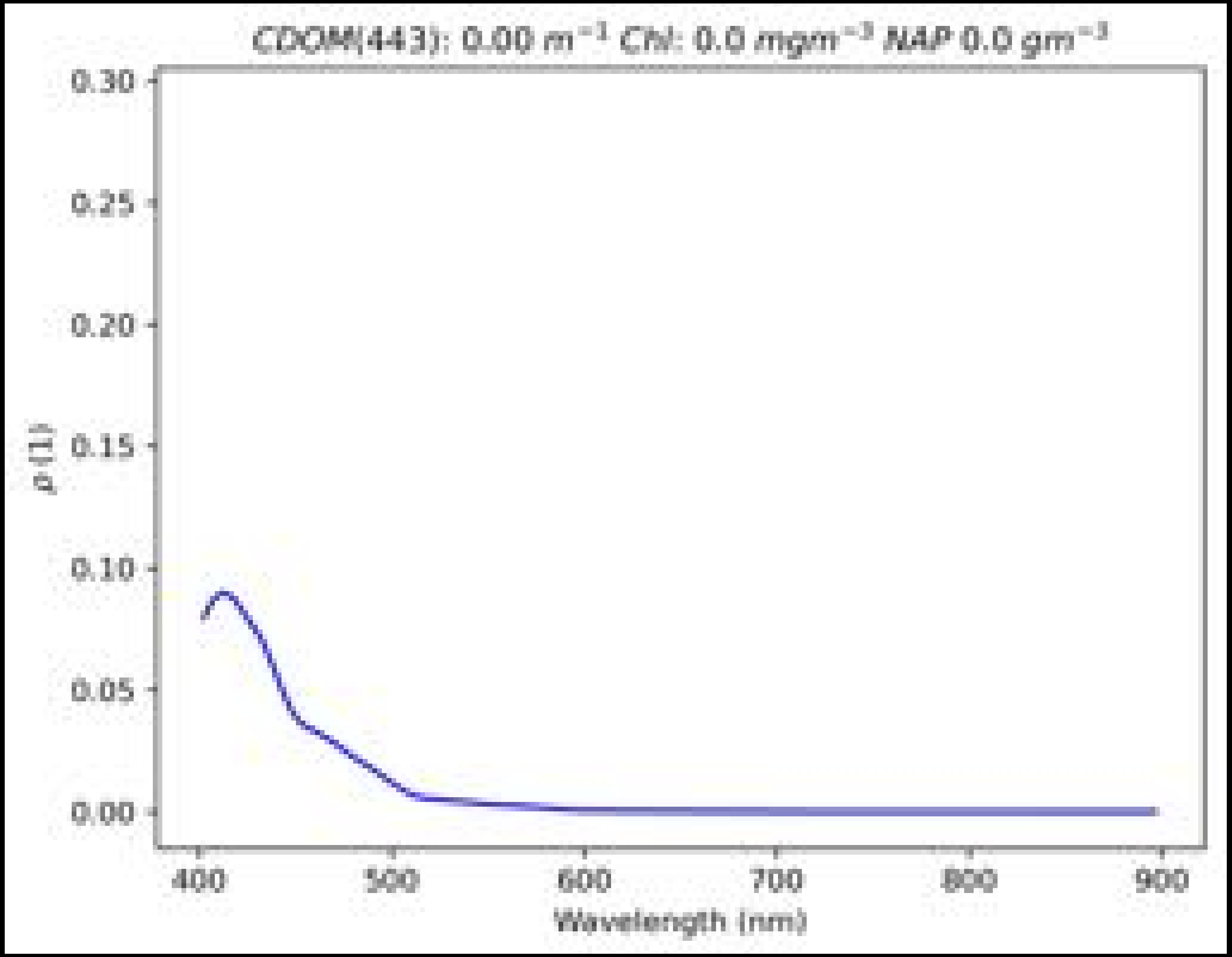


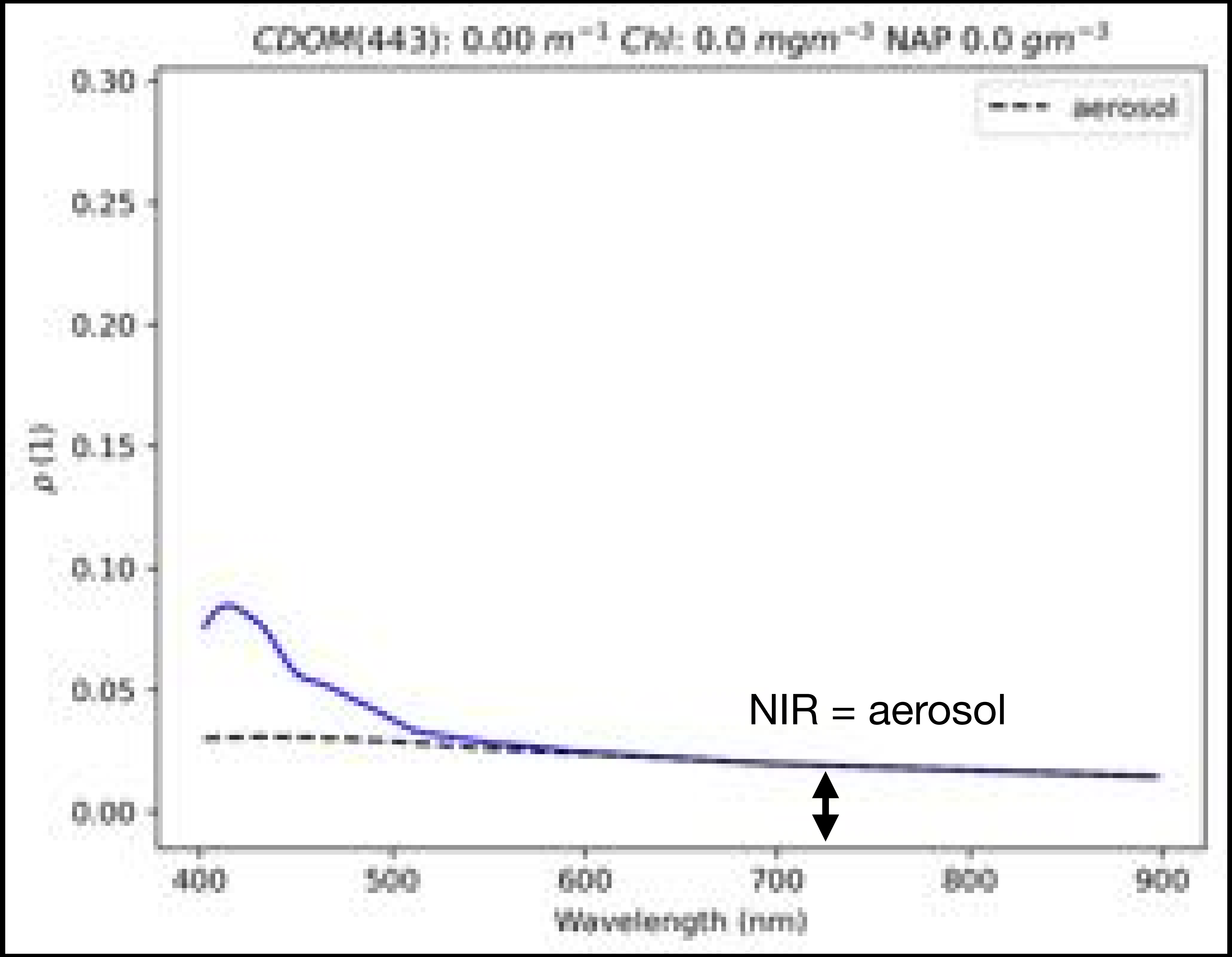


BOA

TOA

θs 60° θv 40° τa 550 nm = 0.1

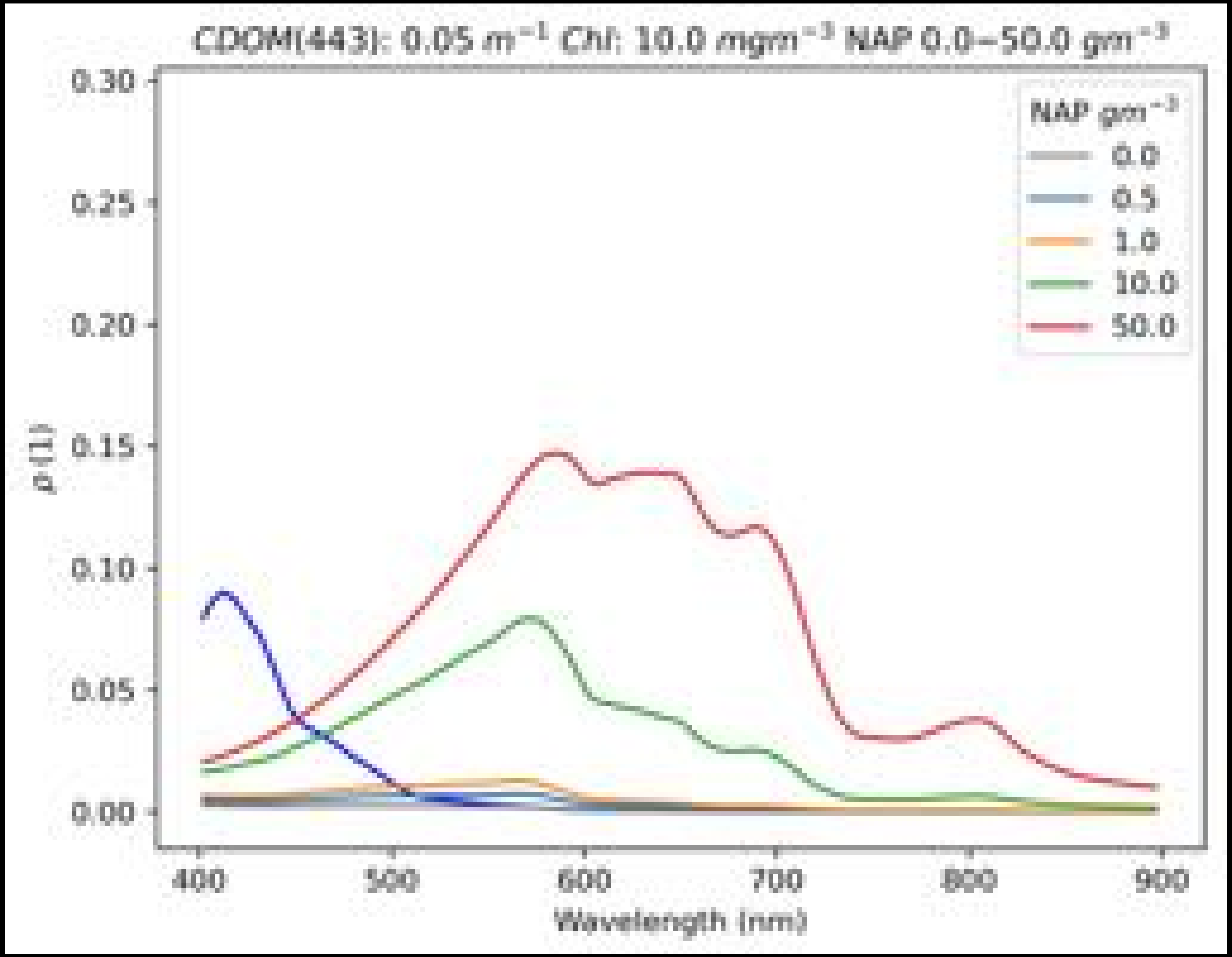


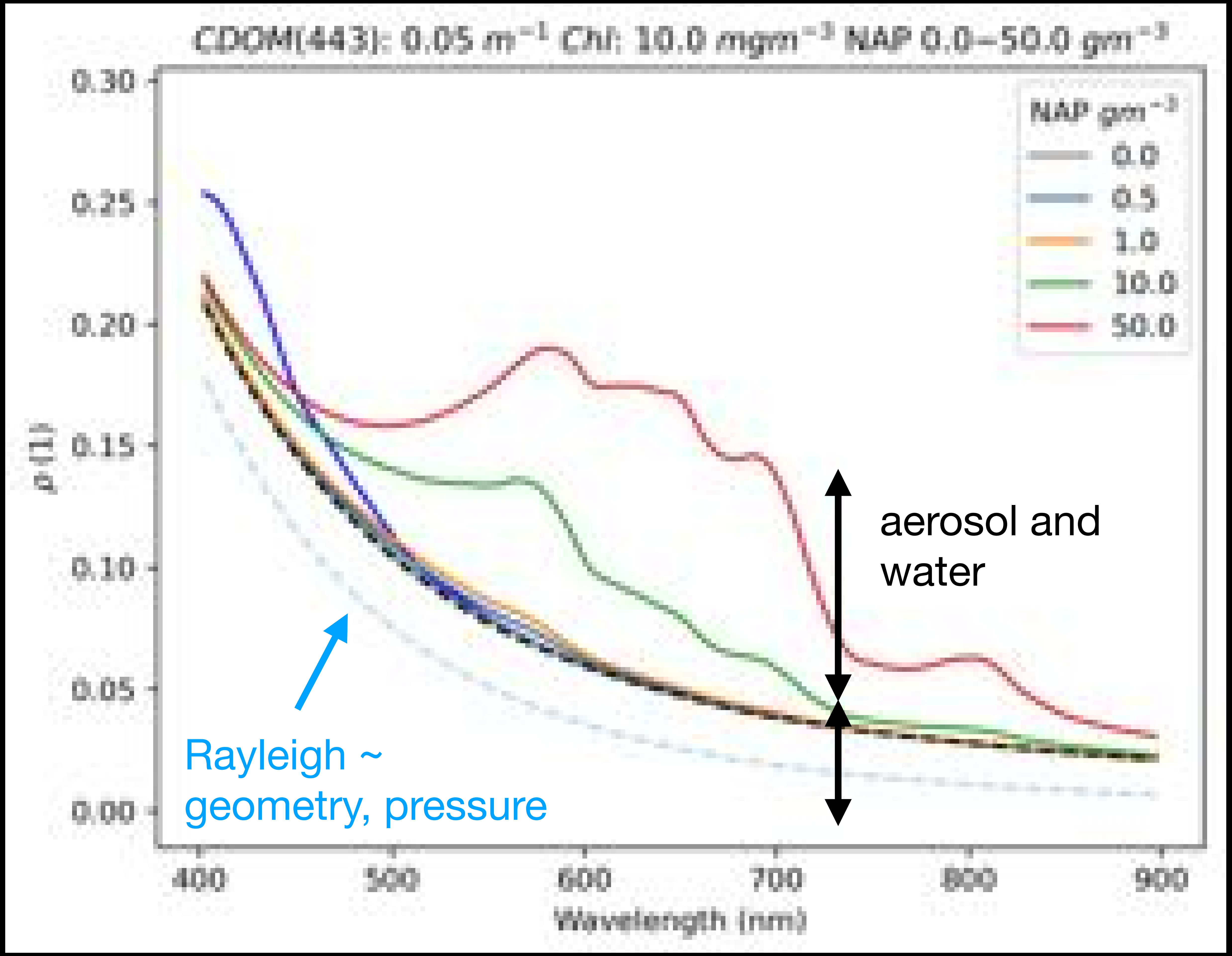


BOA

TOA-Rayleigh

θs 60° θv 40° τa 550 nm = 0.1

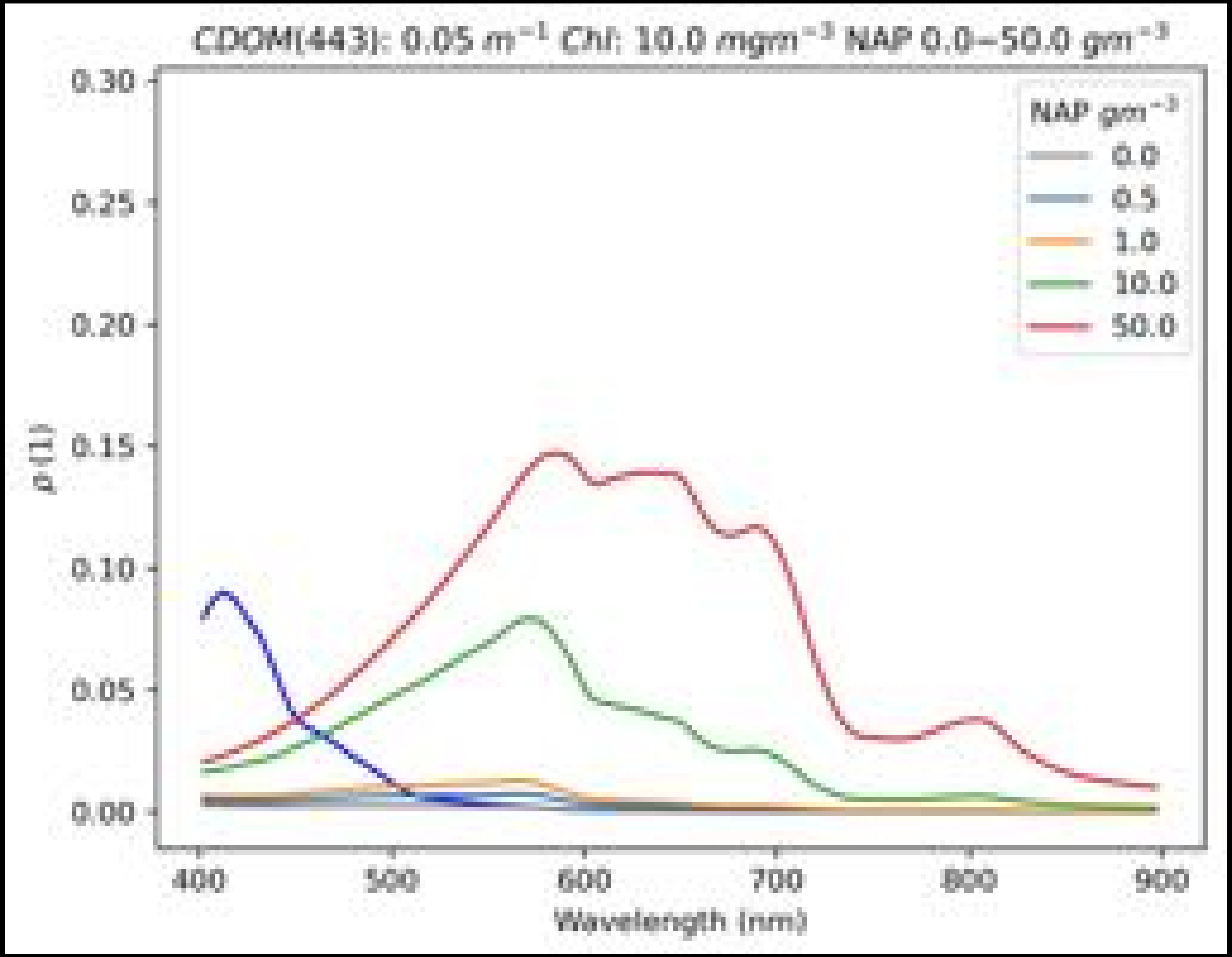




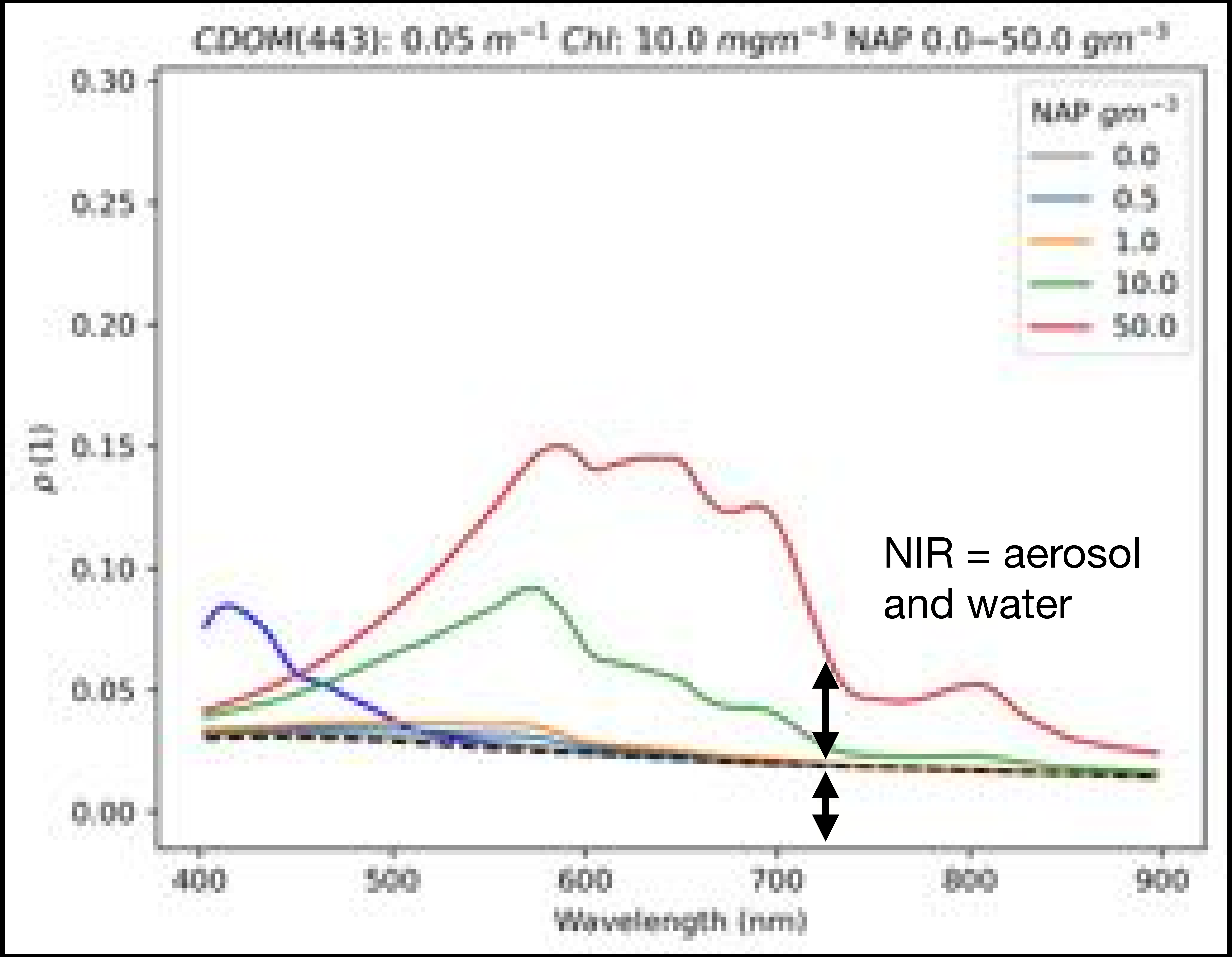
BOA

TOA

θs 60° θv 40° τa 550 nm = 0.1



BOA



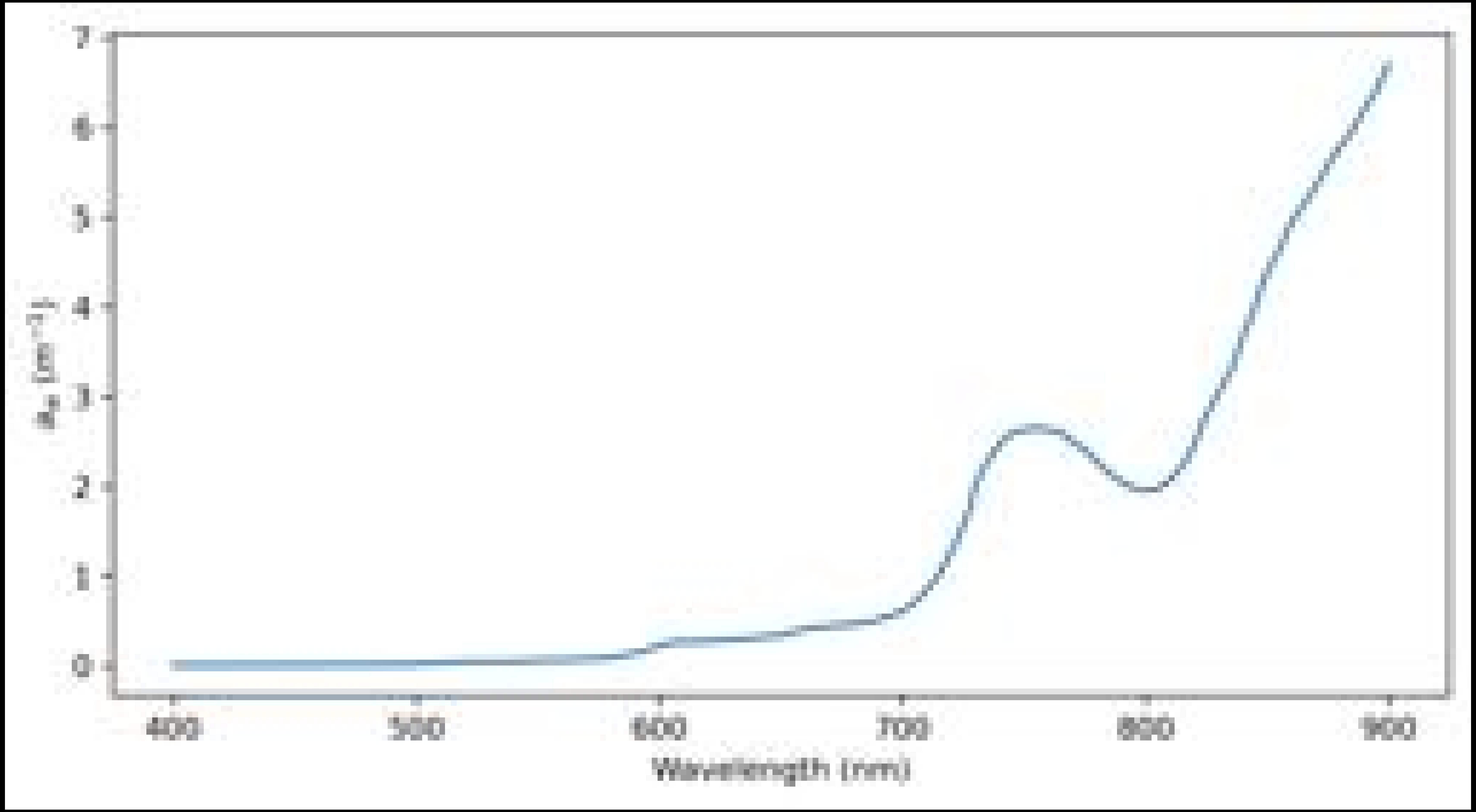
TOA-Rayleigh

Aerosol estimation

2) Modified ocean colour approach, e.g.

- Hu et al. (2000), Ruddick et al. (2000) ~ spatial context/stability of aerosol
- DSF - Vanhellemont and Ruddick (2018) ~ spatial context, use of VIS-SWIR, potentially land
- RAdCor - Castagna and Vanhellemont (2025) ~ generalisation to heterogeneous surface
- SeaDAS/l2gen, Bailey et al. (2010) ~ non-zero NIR from chl
- BPAC, MERIS/OLCI (Moore et al. 1999, 2017)
- SeaDAS/l2gen, NOAA/msl12, Wang and Shi (2007) ~ zero SWIR

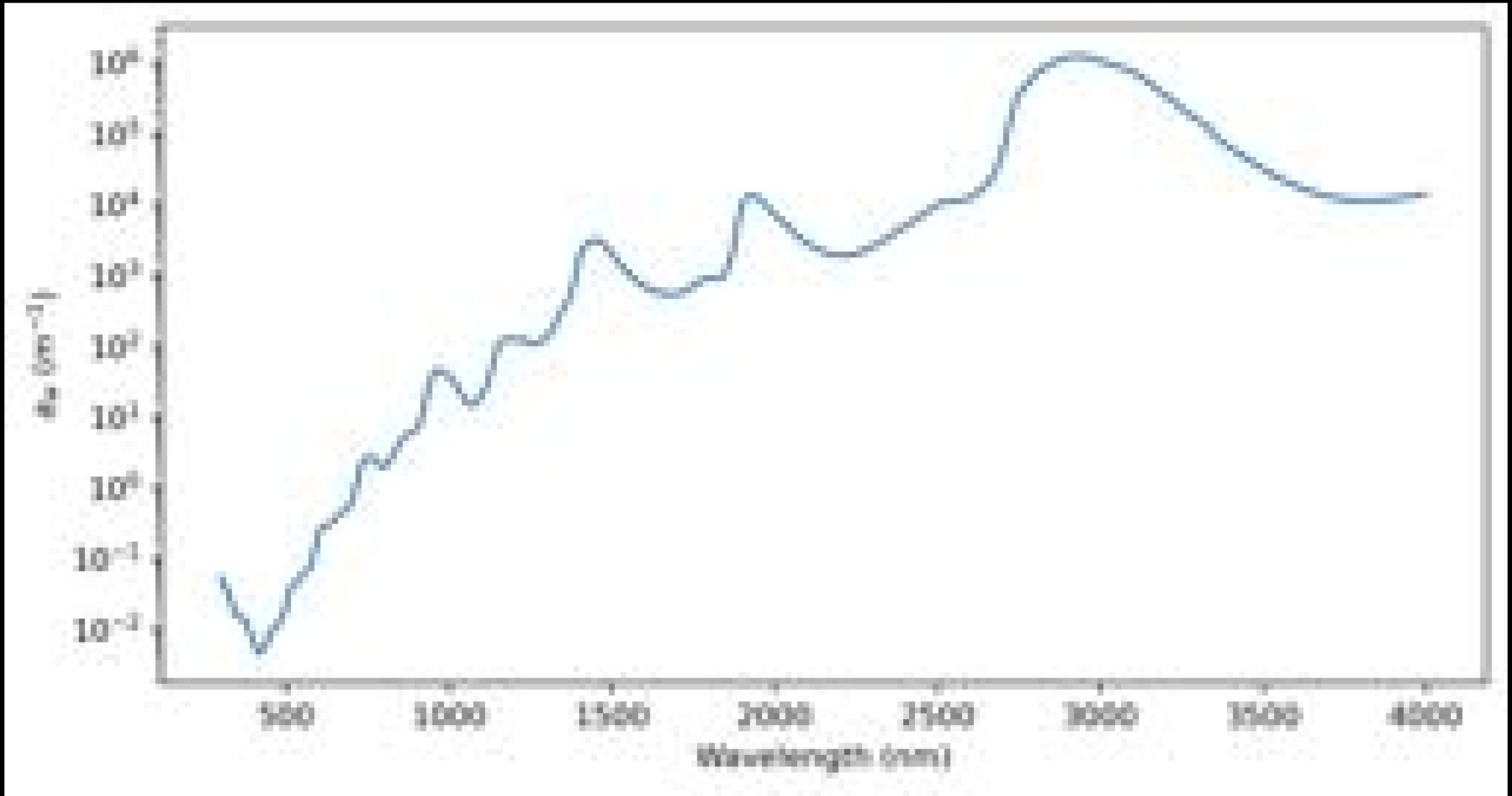
Water absorption



WOPP, Röttgers et al. (2011), T 20°C, S 34 PSU

Water absorption

aw orders of magnitude greater
at ~1600 and ~2200 nm



WOPP, Röttgers et al. (2011), T 20°C, S 34 PSU

Aerosol estimation

3) Approaches which include or rely on water models, e.g.

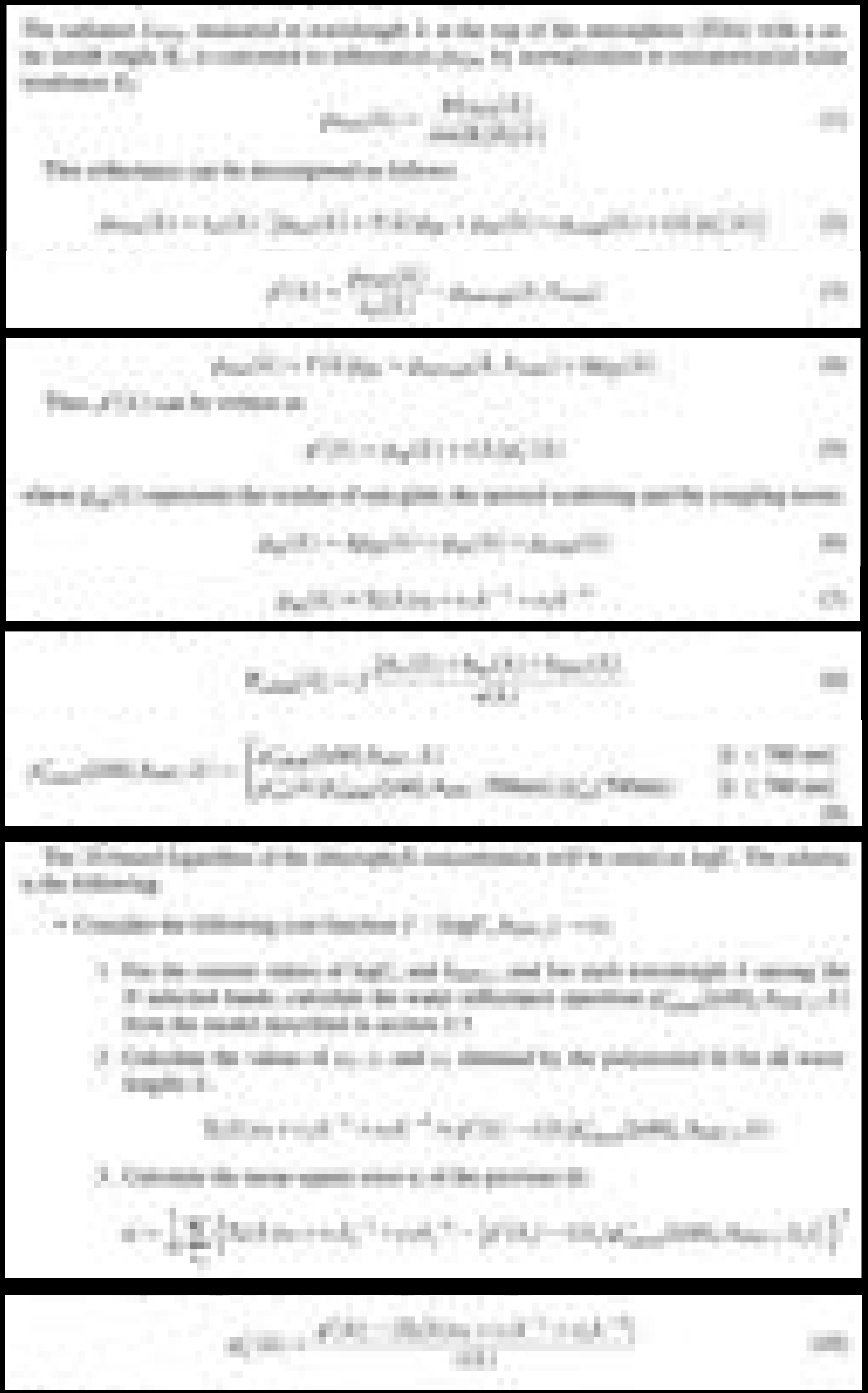
- POLYMER, Steinmetz et al. (2011)
- C2RCC, Roland Doerffer and Helmut Schiller 1990s-2000s, Müller et al. (2025)
- OC-SMART, Fan et al. (2021)

POLYMER

Part 1

Part 2

Part 3



Steinmetz et al. (2011)

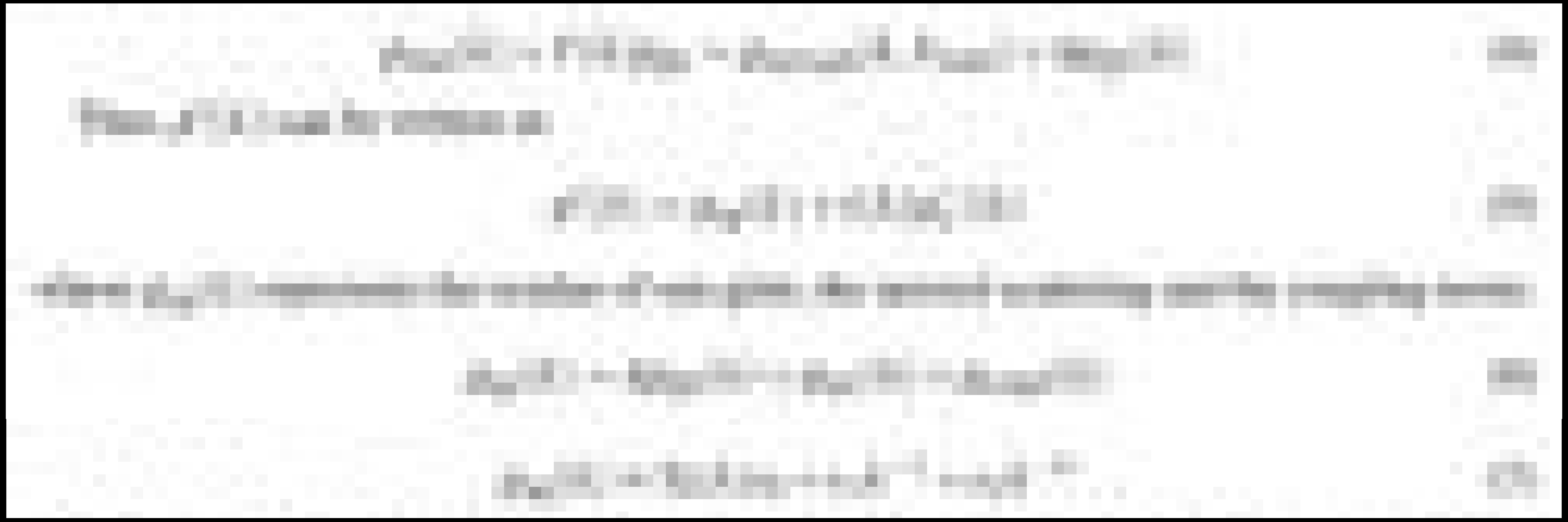
POLYMER

Step 1 ~ ρTOA
ρ' : ρTOA - ρRayleigh

Steinmetz et al. (2011)

POLYMER

Step 2 ~ model
ρag + ρw



ρag : coupled residual aerosol
and glint reflectance

ρw : function of Chl and b_b

Steinmetz et al. (2011)

Step 3 ~ optimise

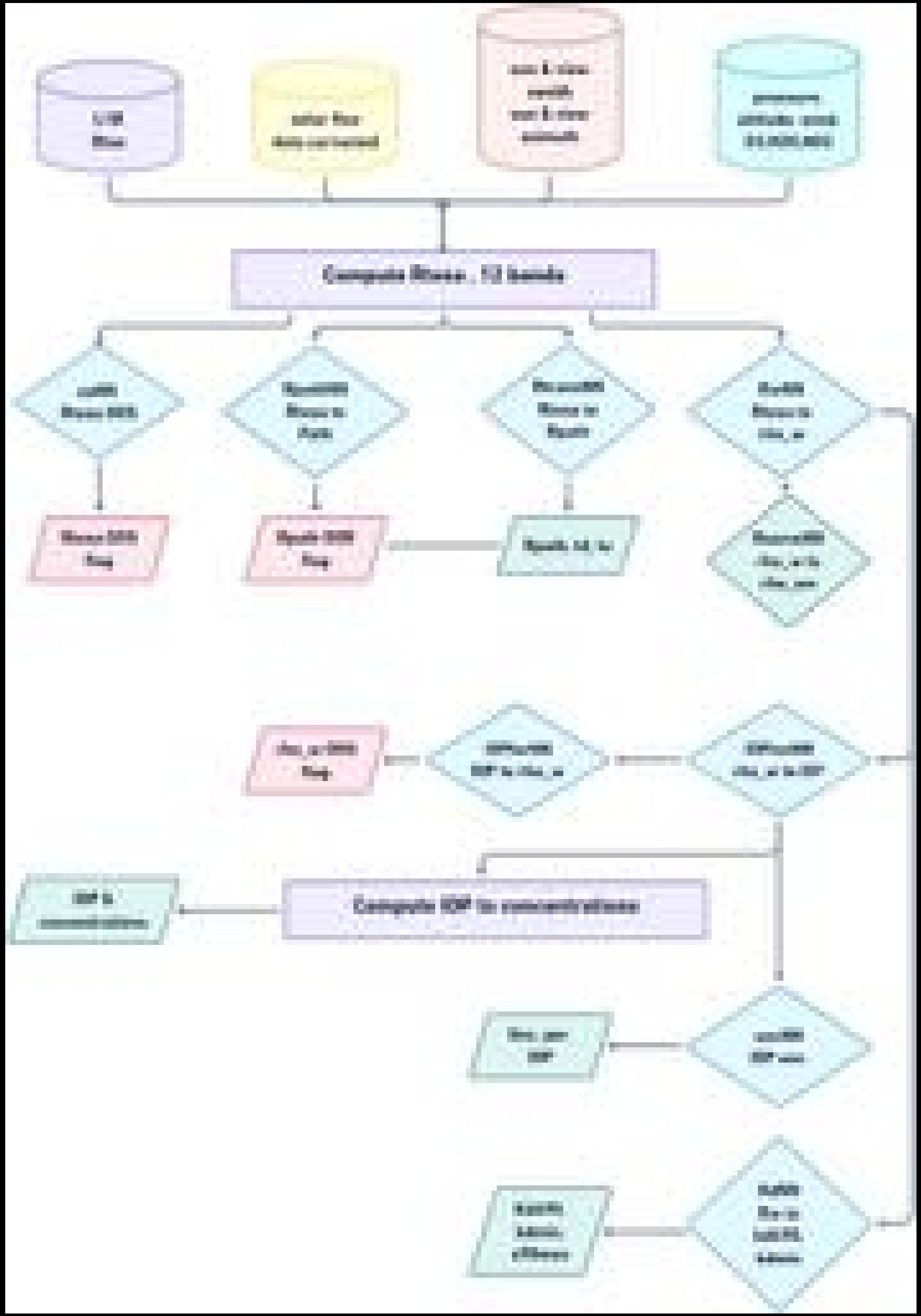
ρag + ρw

iterate over Chl, b_b, c_0, c_1, c_2

ρw computed using final c_0, c_1, c_2

Steinmetz et al. (2011)

C2RCC



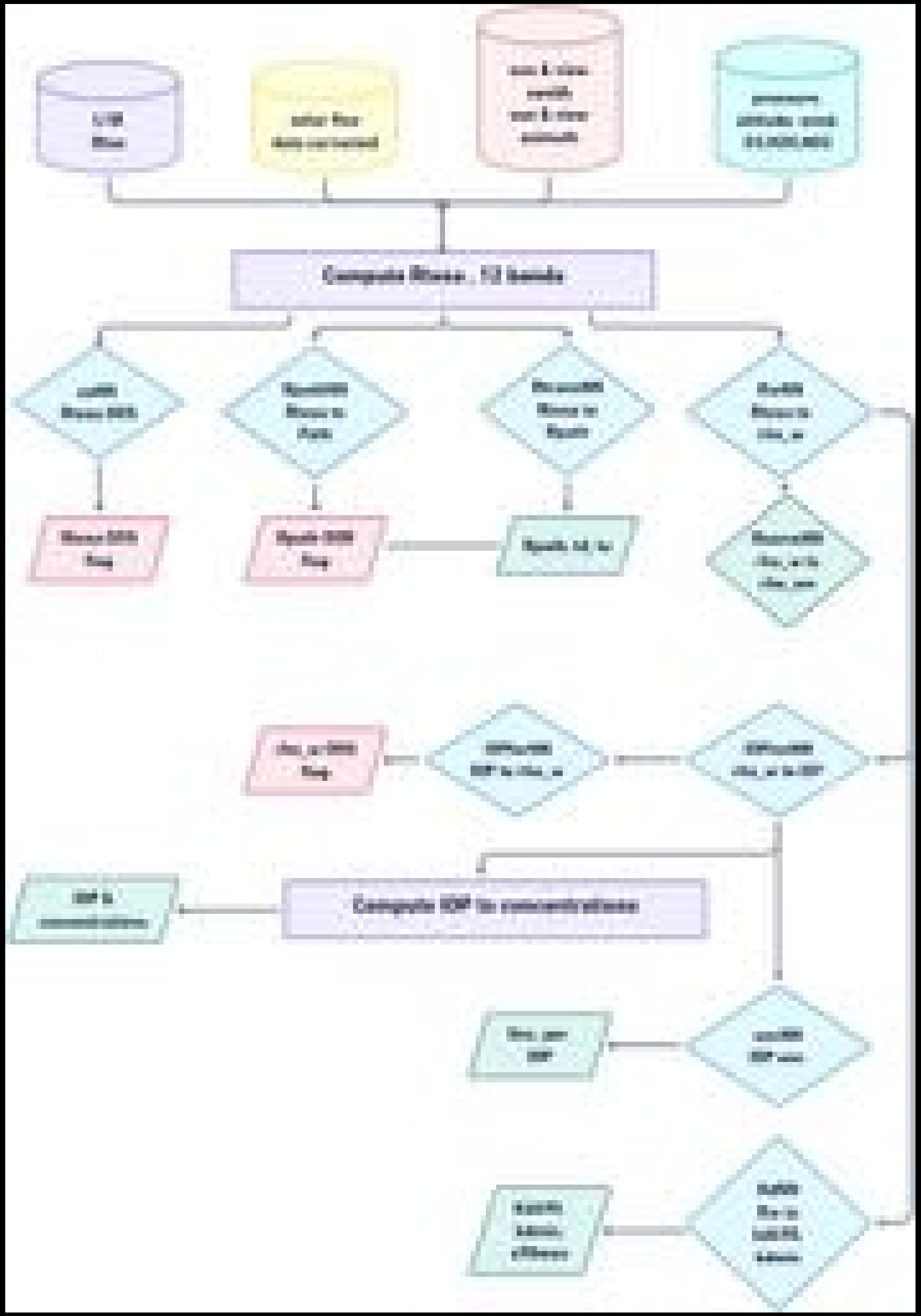
Müller et al. (2025)

C2RCC

Part 1

Part 2

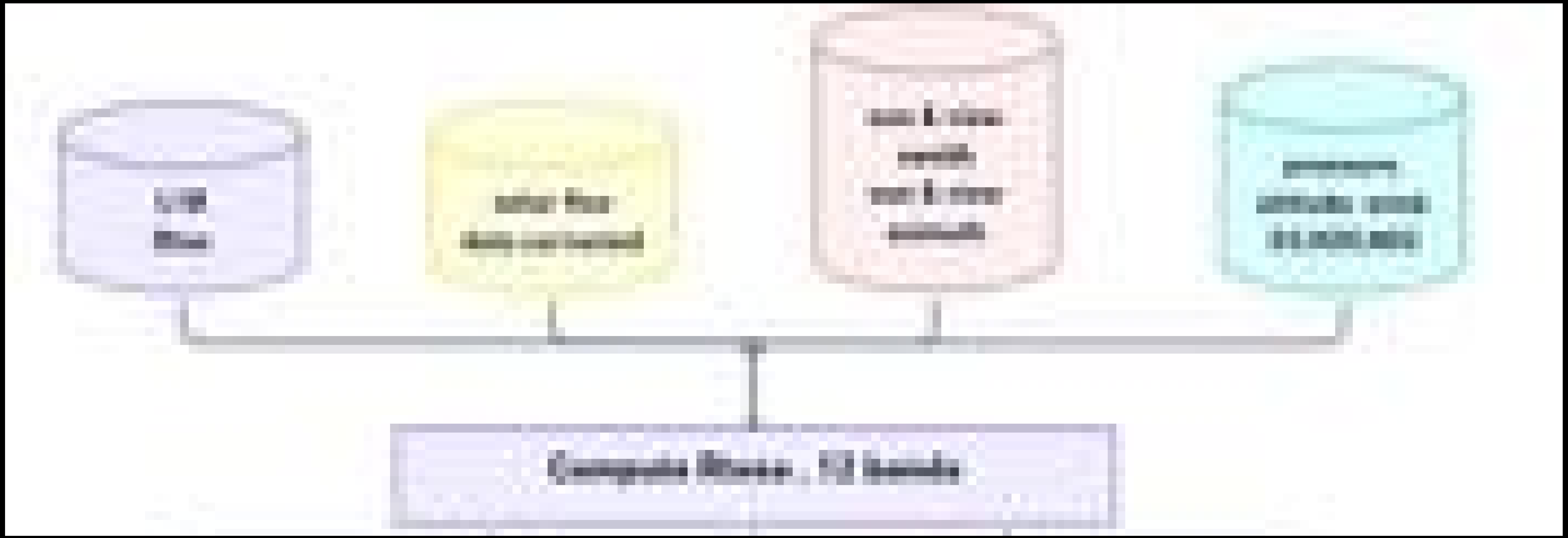
Part 3



Müller et al. (2025)

C2RCC

Part 1 ~ standard ocean colour

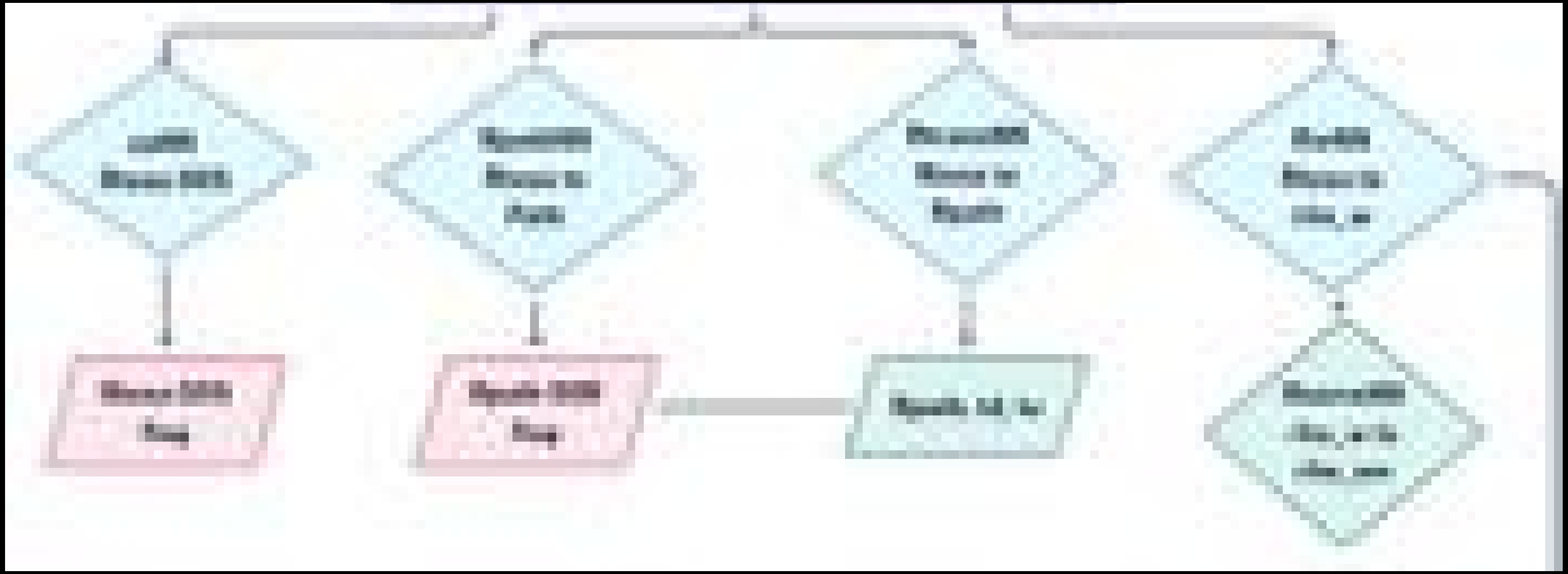


Rtosa = Reflectance at Top-Of-Standard-Atmosphere

Müller et al. (2025)

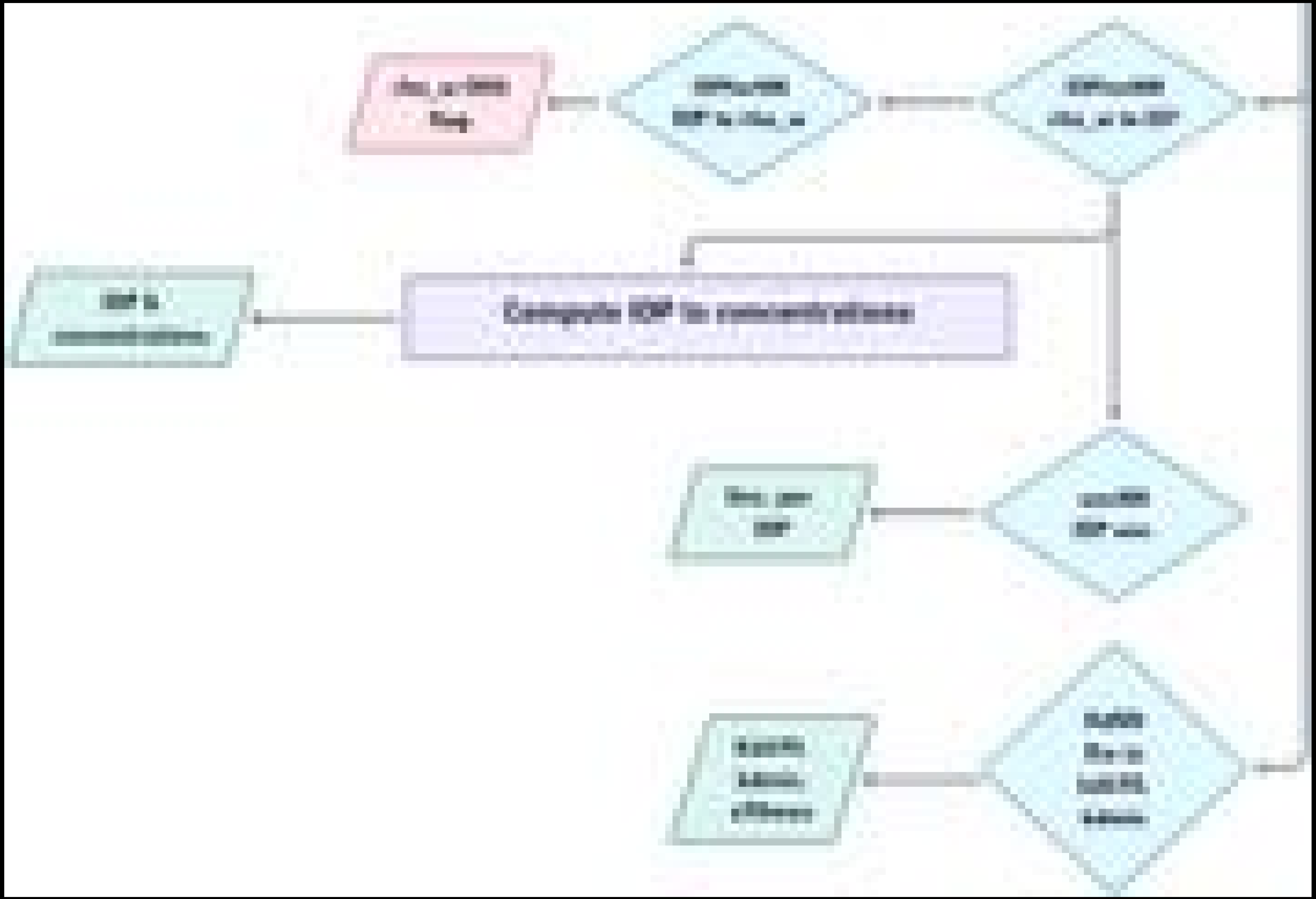
C2RCC

Part 2 ~
Rtosa -> NN ρw(n)



Müller et al. (2025)

C2RCC



Part 3 ~
ρw -> NN IOP

Müller et al. (2025)

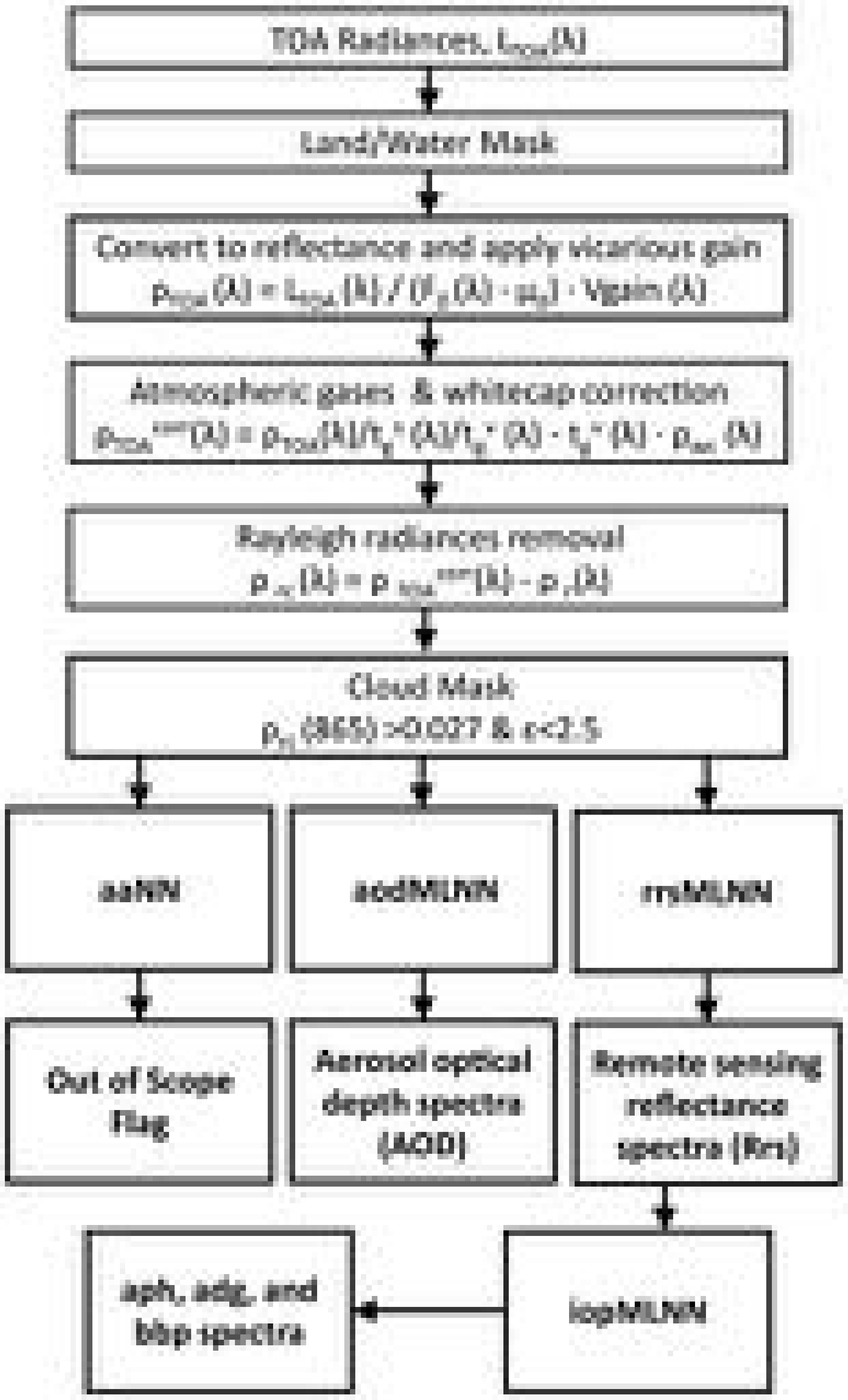
OC-SMART

Part 1

Part 2

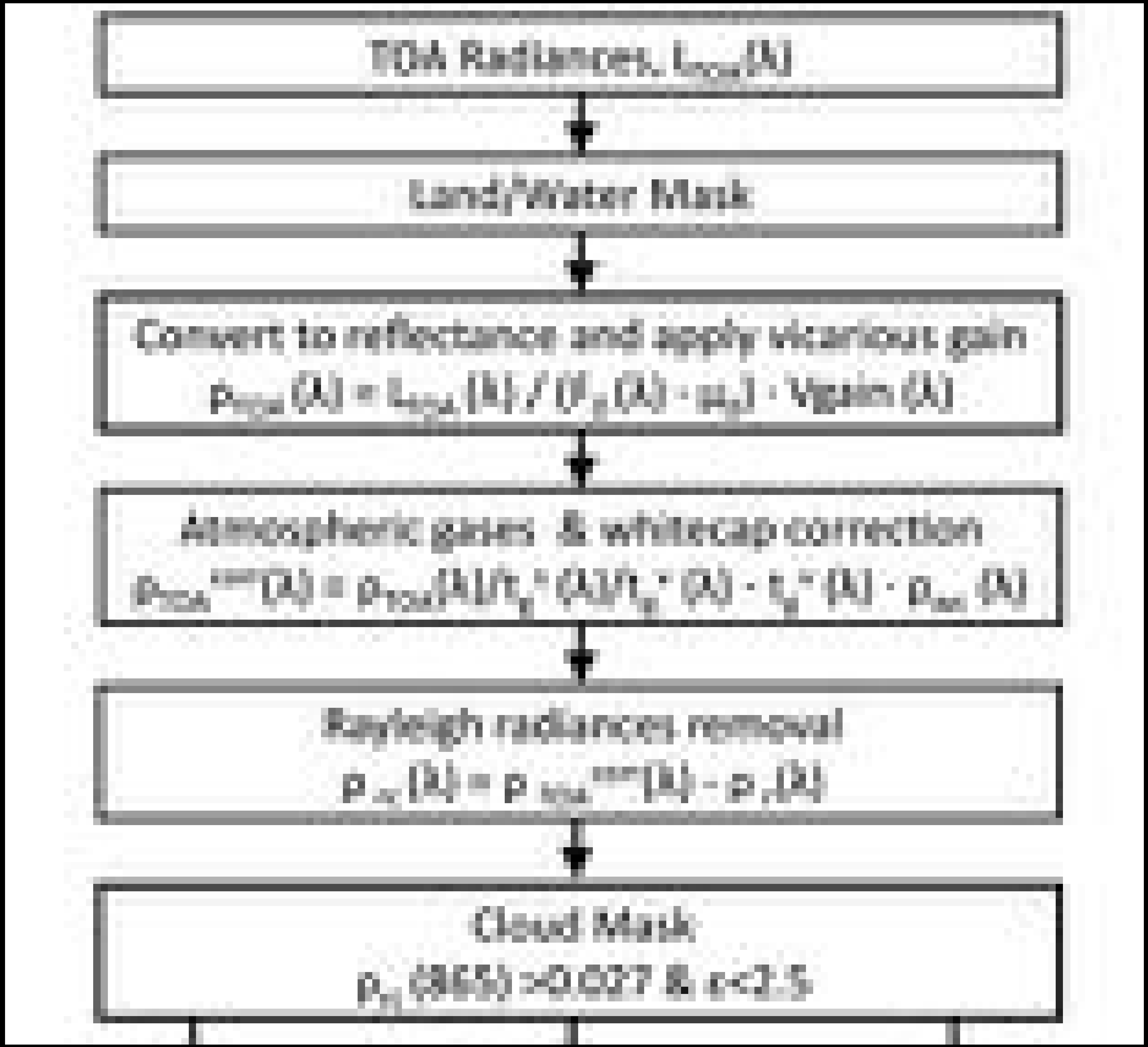
Part 3

Fan et al. (2021)



OC-SMART

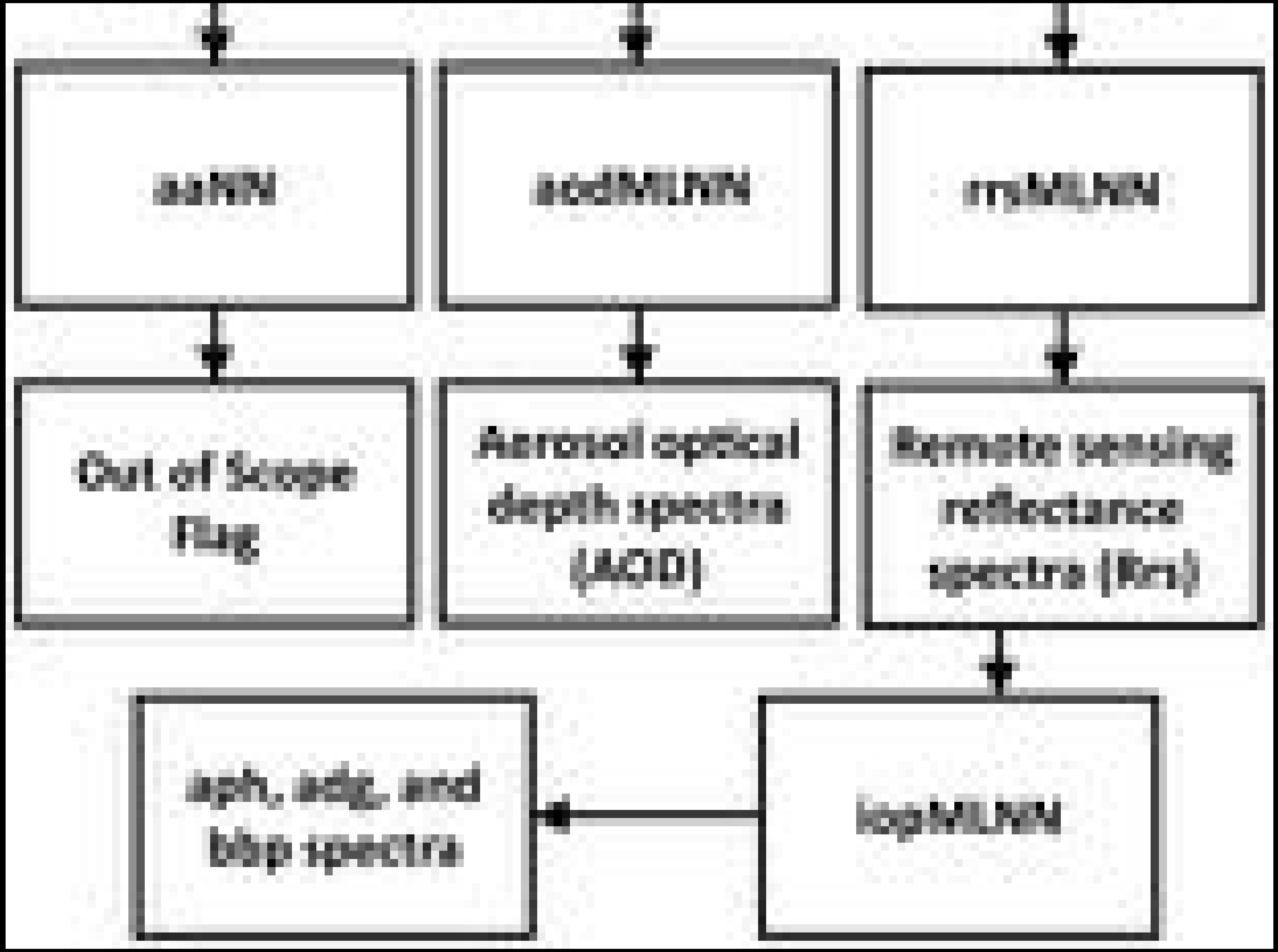
Part 1 ~ standard ocean colour



Fan et al. (2021)

OC-SMART

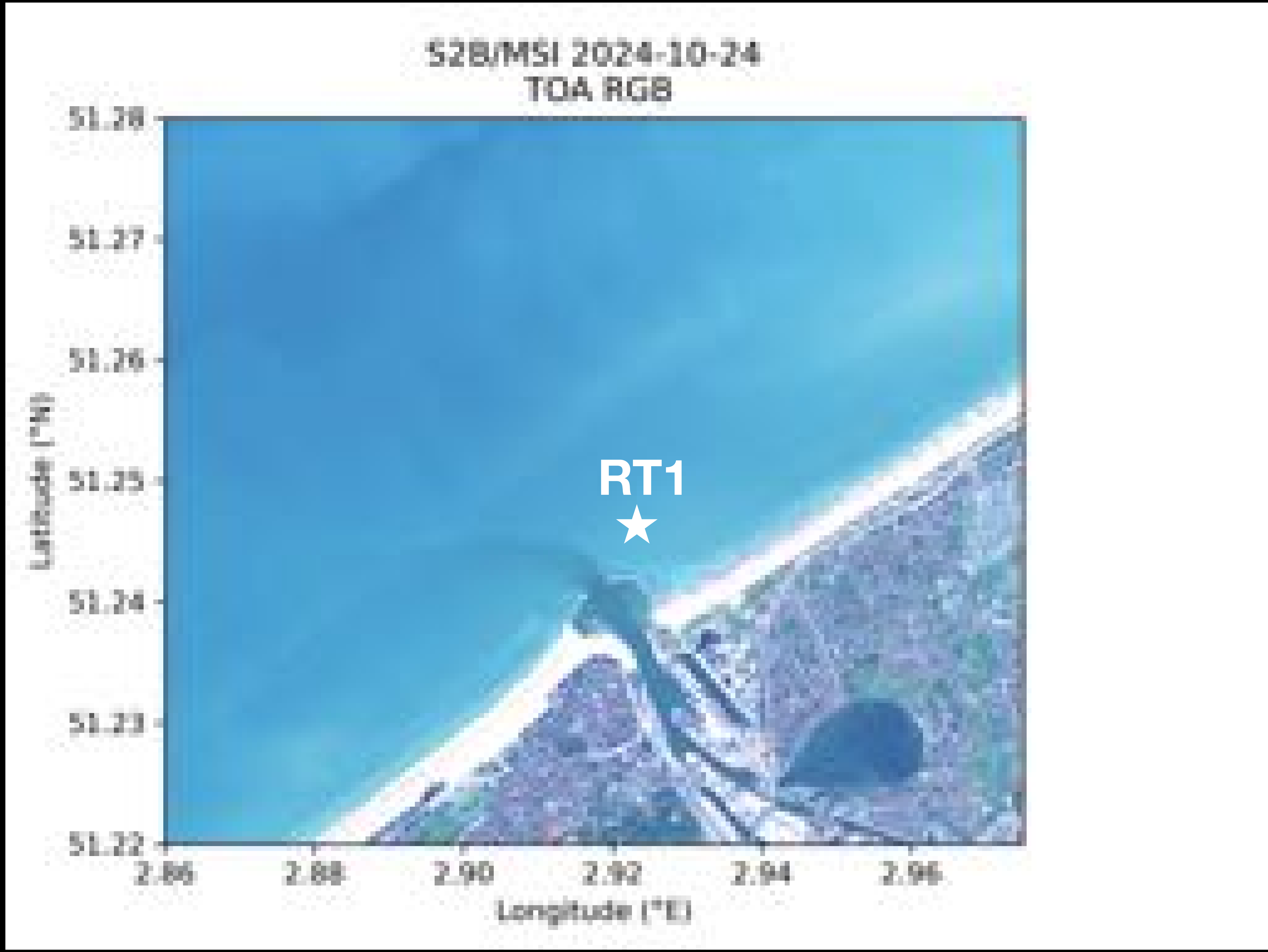
Part 2 ~ ρrc -> NN Rrs



Part 3 ~ Rrs -> NN IOP

Fan et al. (2021)

Example - Belgian Coastal Zone



TOA

PI: Dieter Vansteenwegen (VLIZ)

Research Tower 1
~900 m from shore

PANTHYR
autonomous
hyperspectral
radiometer

PANTHYR

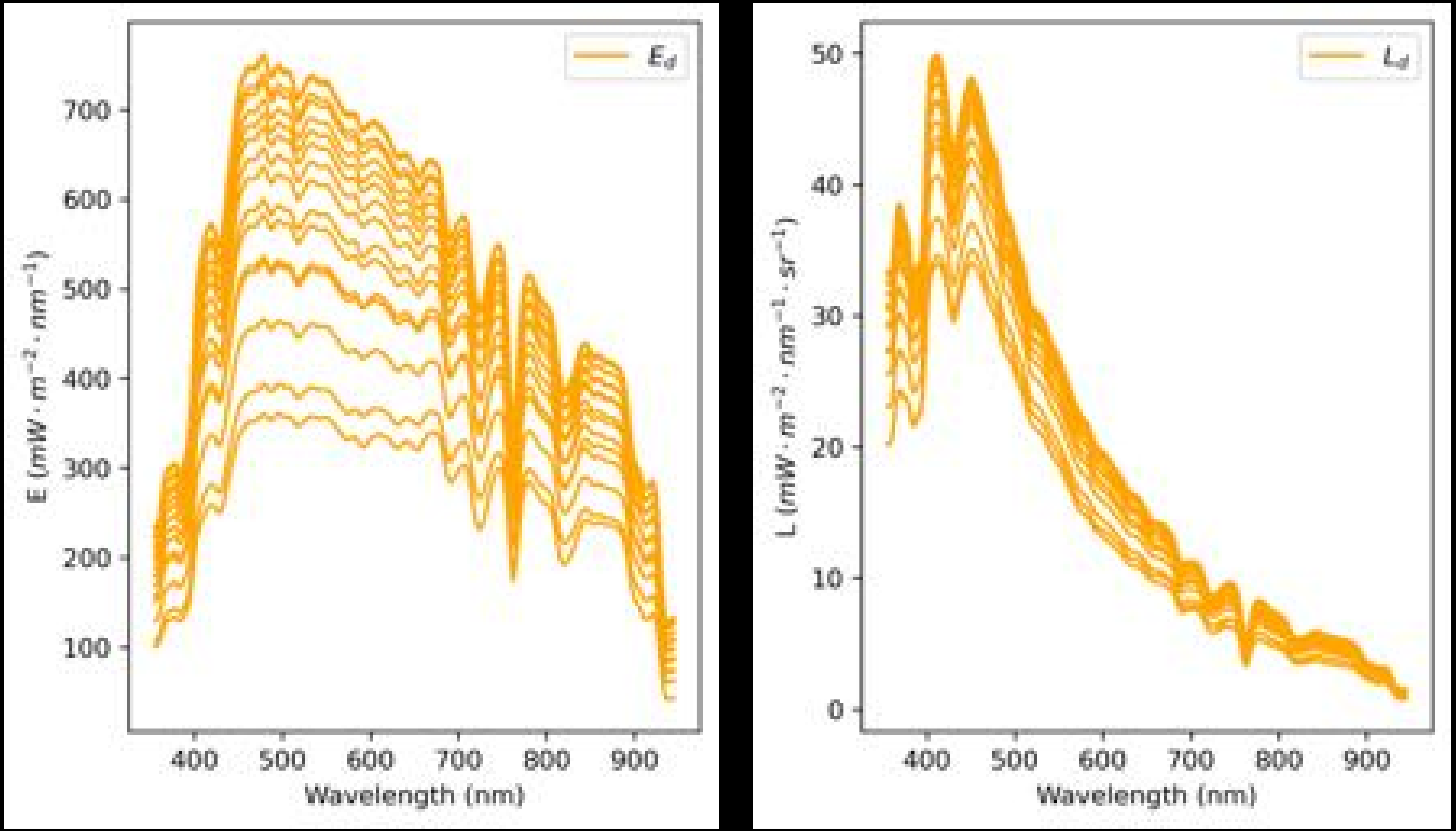
- Two TriOS RAMSES (L, E)
- Mounted on pan and tilt head
- Measurements every 20 minutes
- RAA 90/135/225/270° VNA 40°
- 3x Ed, 3x Ld, 11x Lu, 3x Ld, 3x Ed
- Valid 5/6 Ed and Ld 9/11 Lu
- Effective Fresnel using Mobley 1999
- QC using Ruddick et al. 2005/2006, custom

https://waterhypernet.org/equipment/

Vansteenwegen et al. (2019)

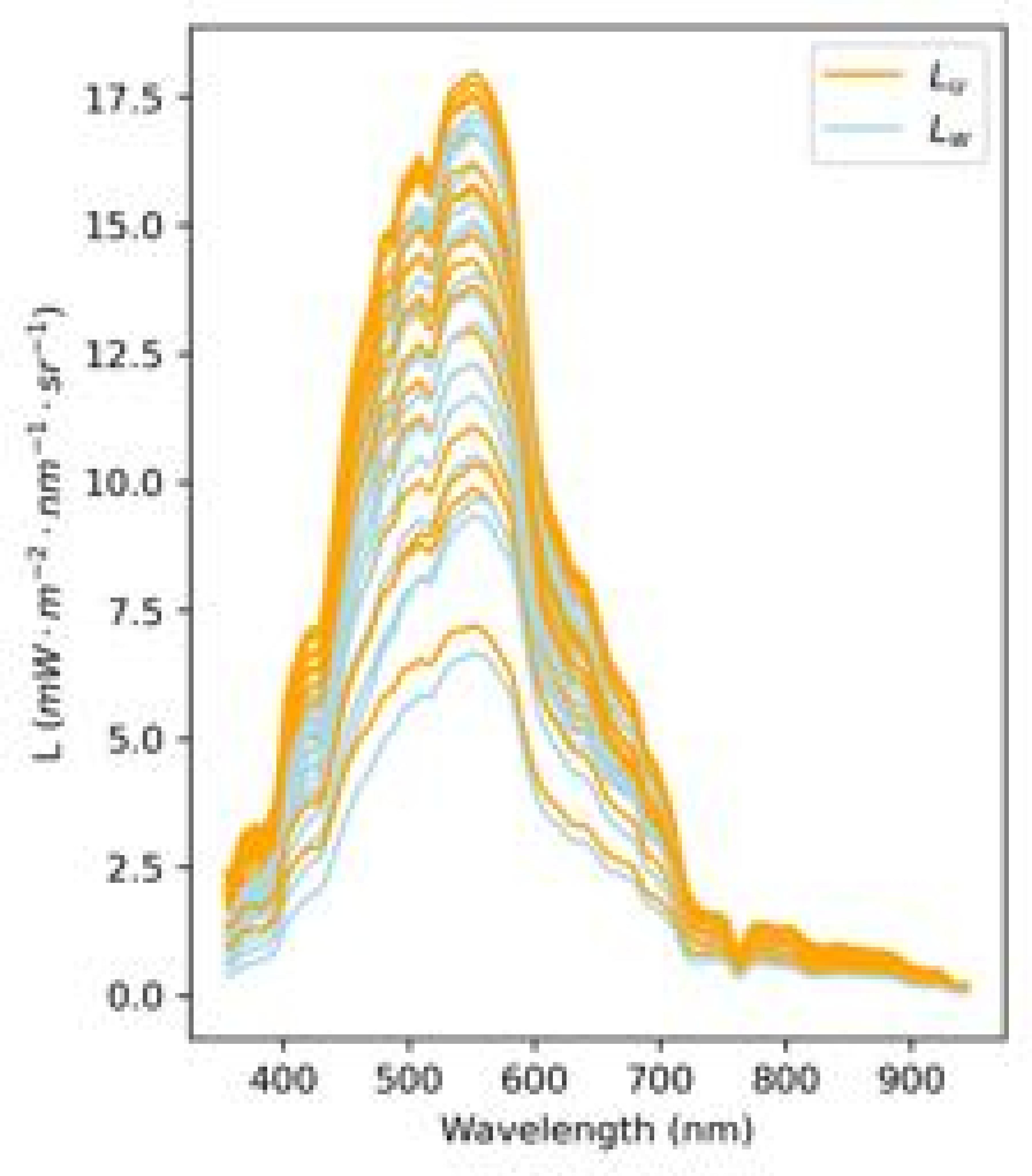
2024-10-24

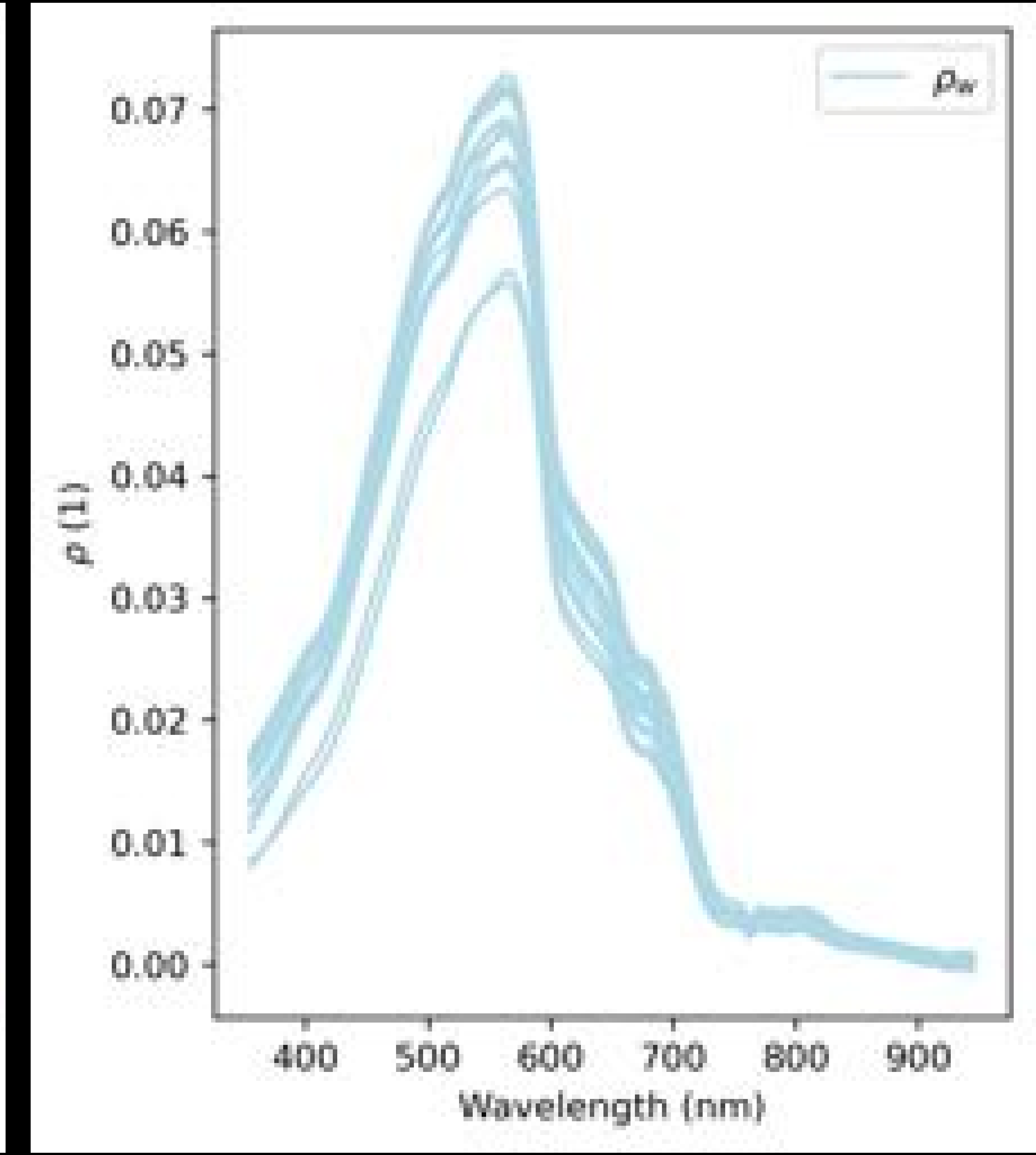
PANTHYR



17 measurements at 270° relative azimuth passing QC (8:30 - 14:40UTC)

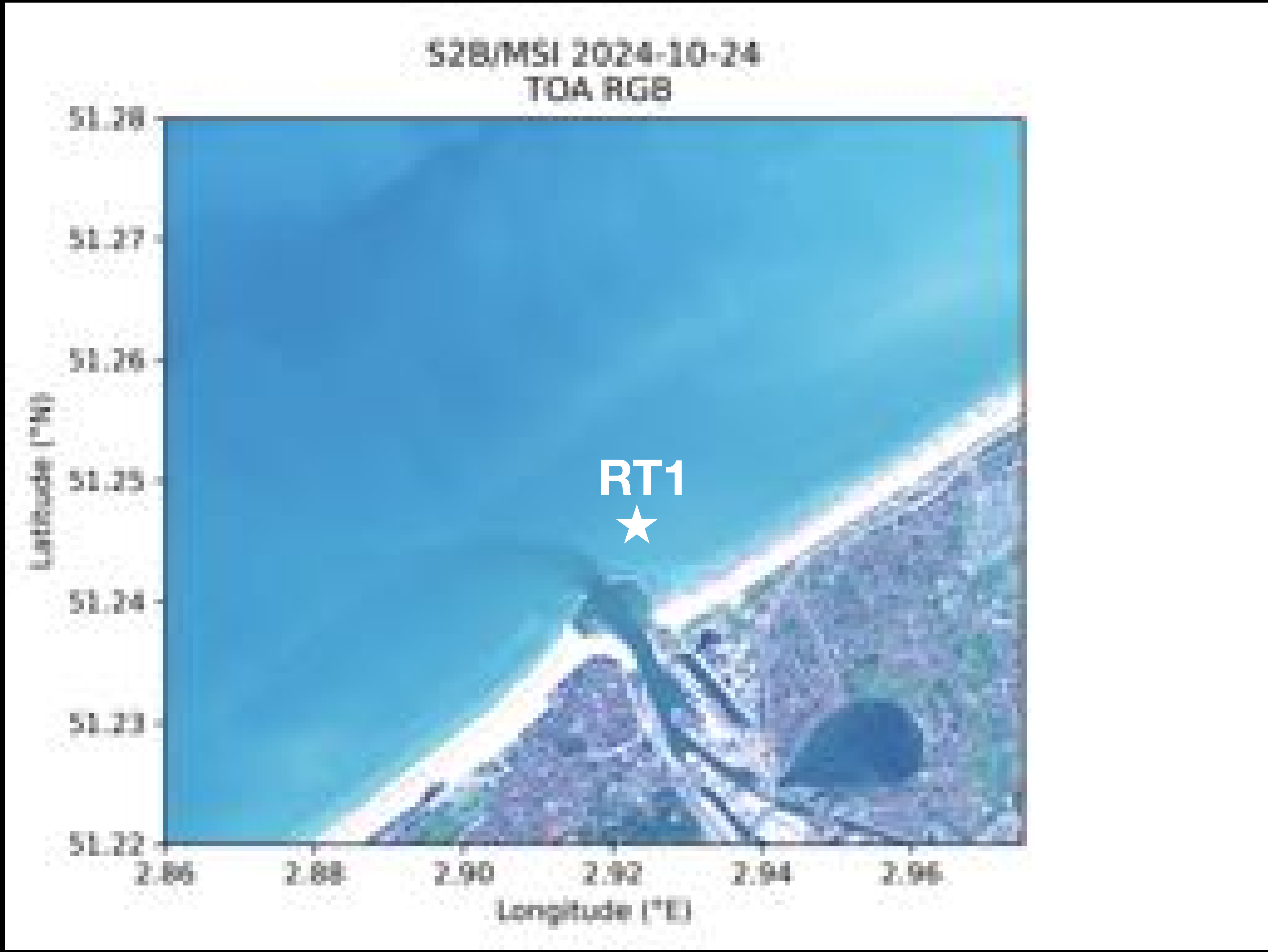
2024-10-24 PANTHYR

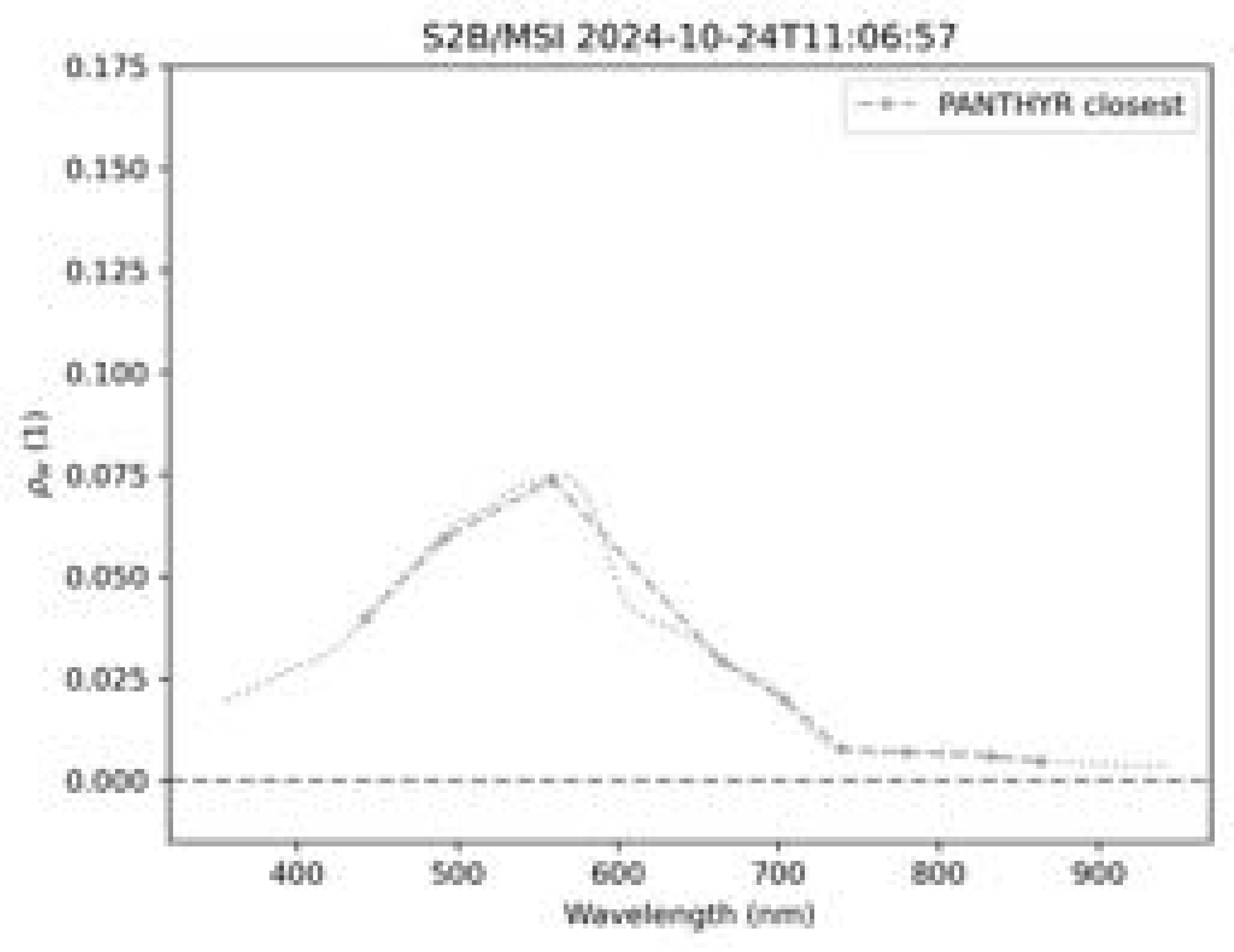




17 measurements at 270° relative azimuth passing QC (8:30 - 14:40UTC)

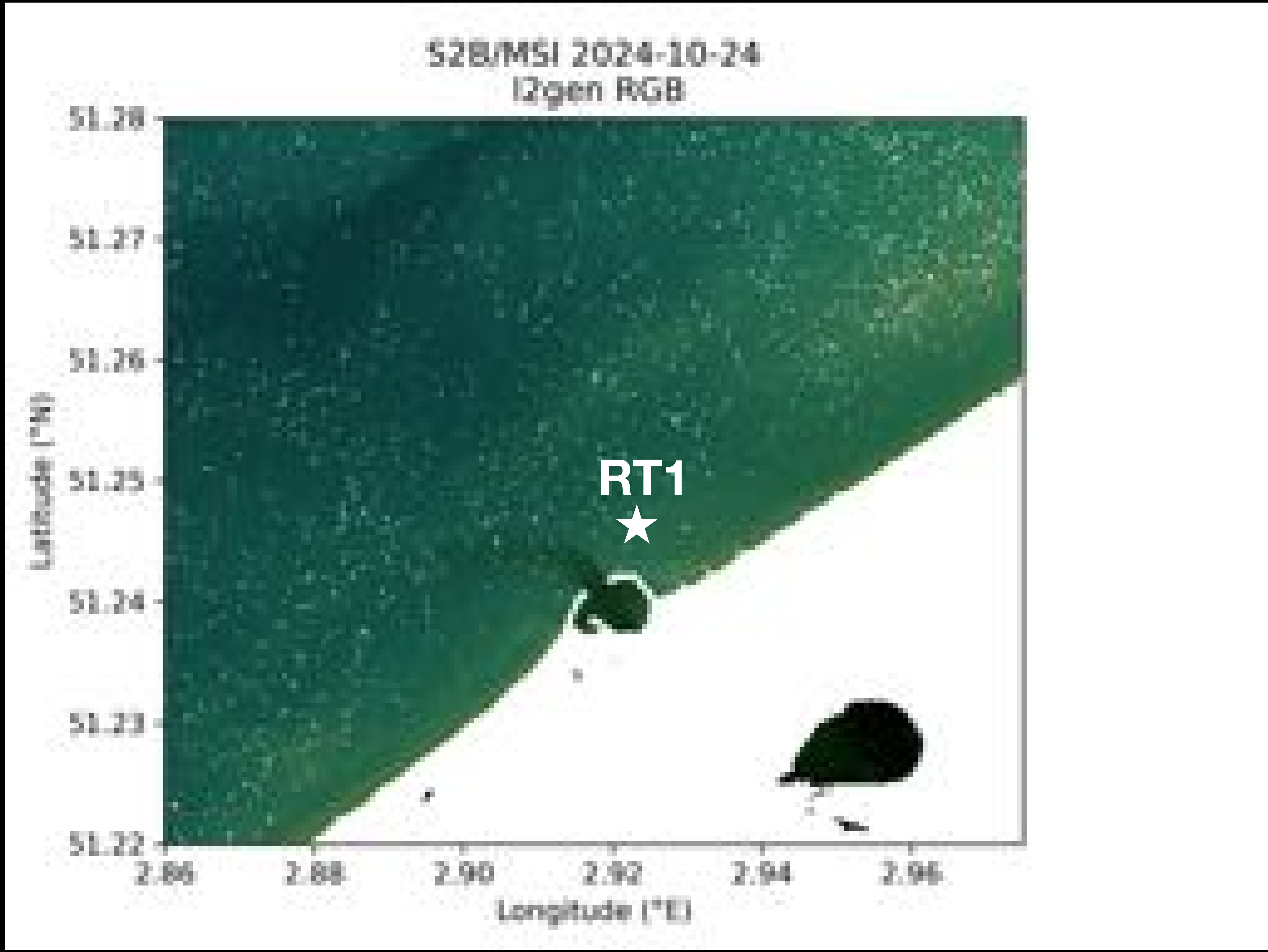
TOA 2024-10-24 PANTHYR

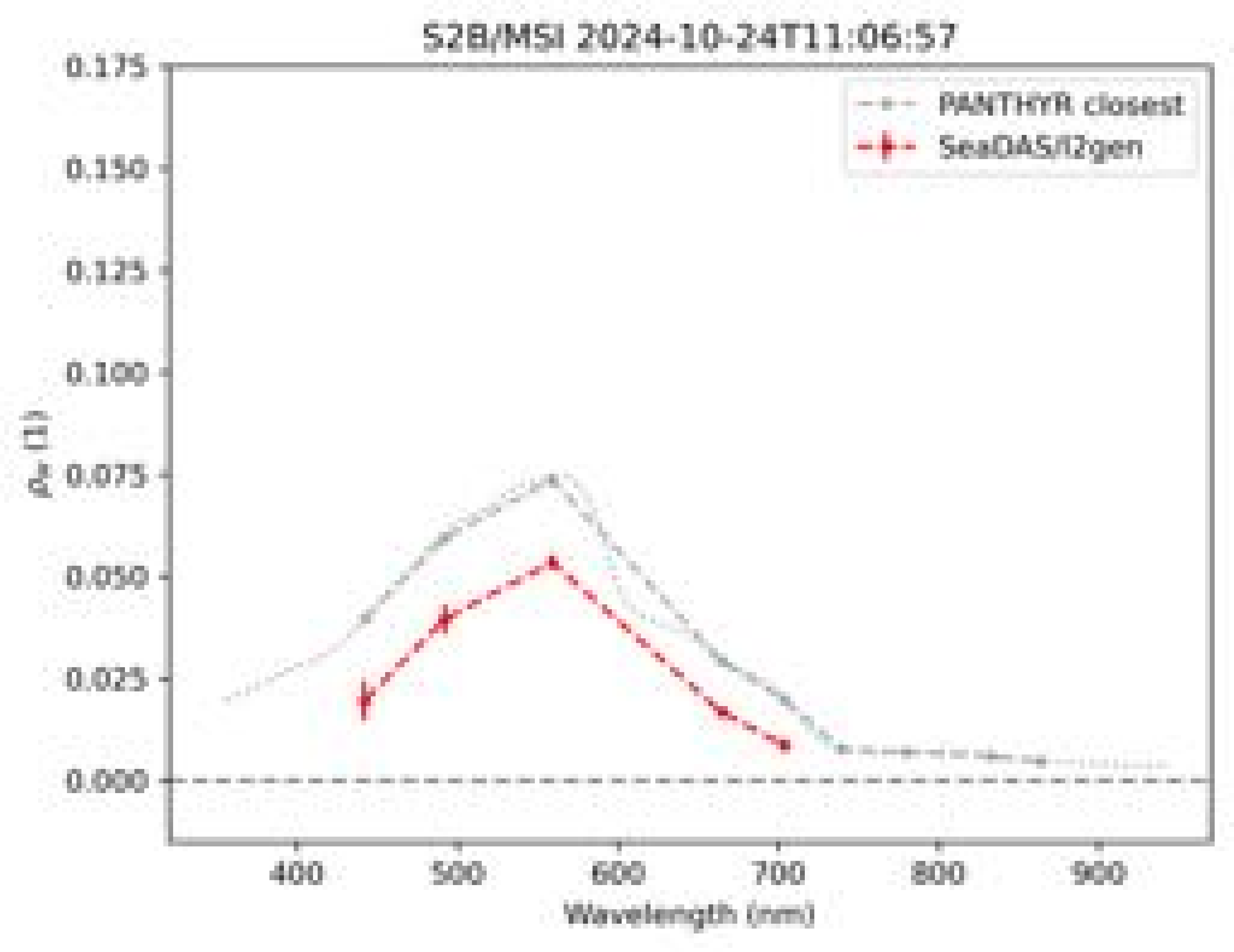




Moderately turbid, no high Chla (665 nm dip absent)

l2gen

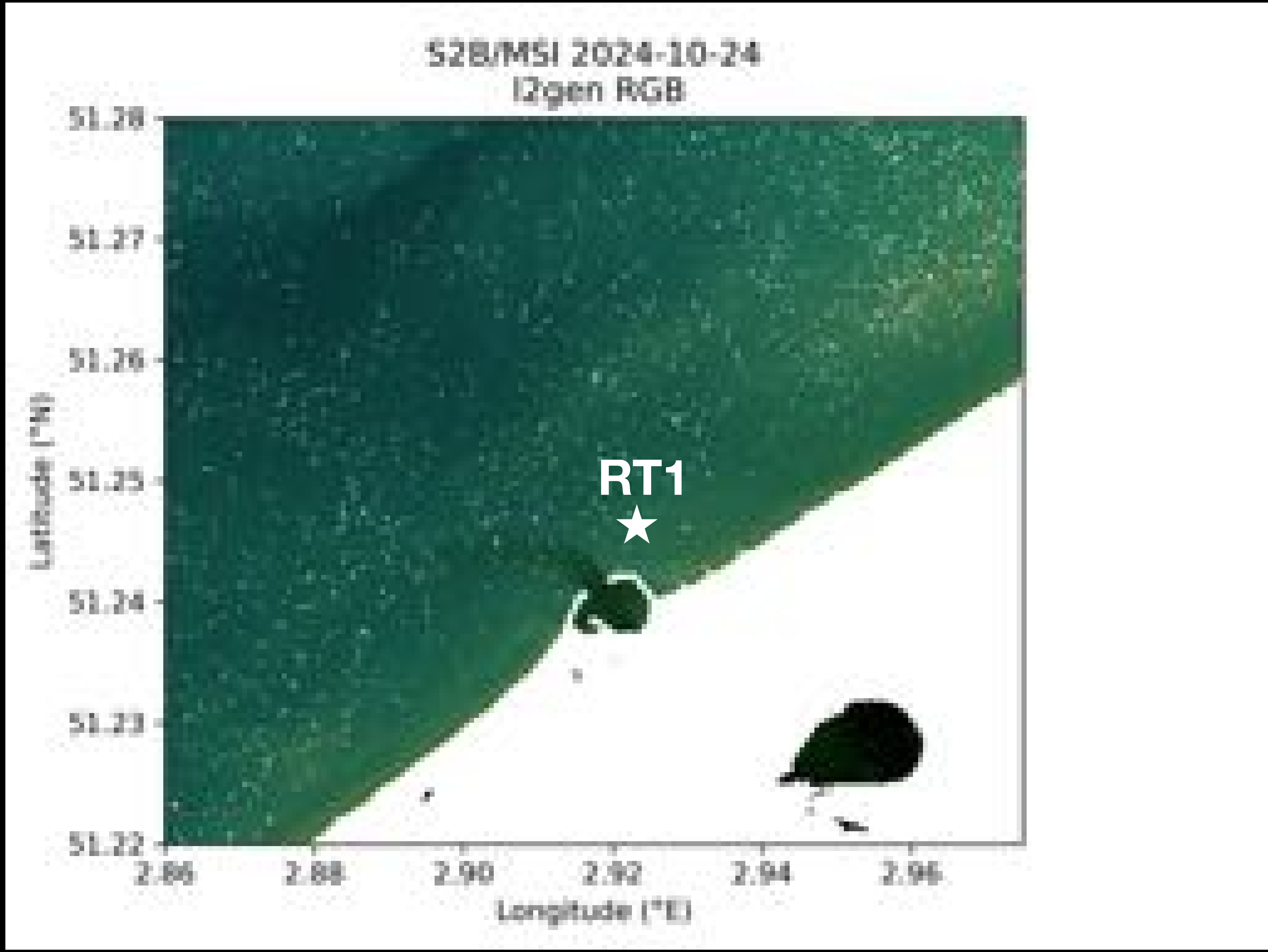


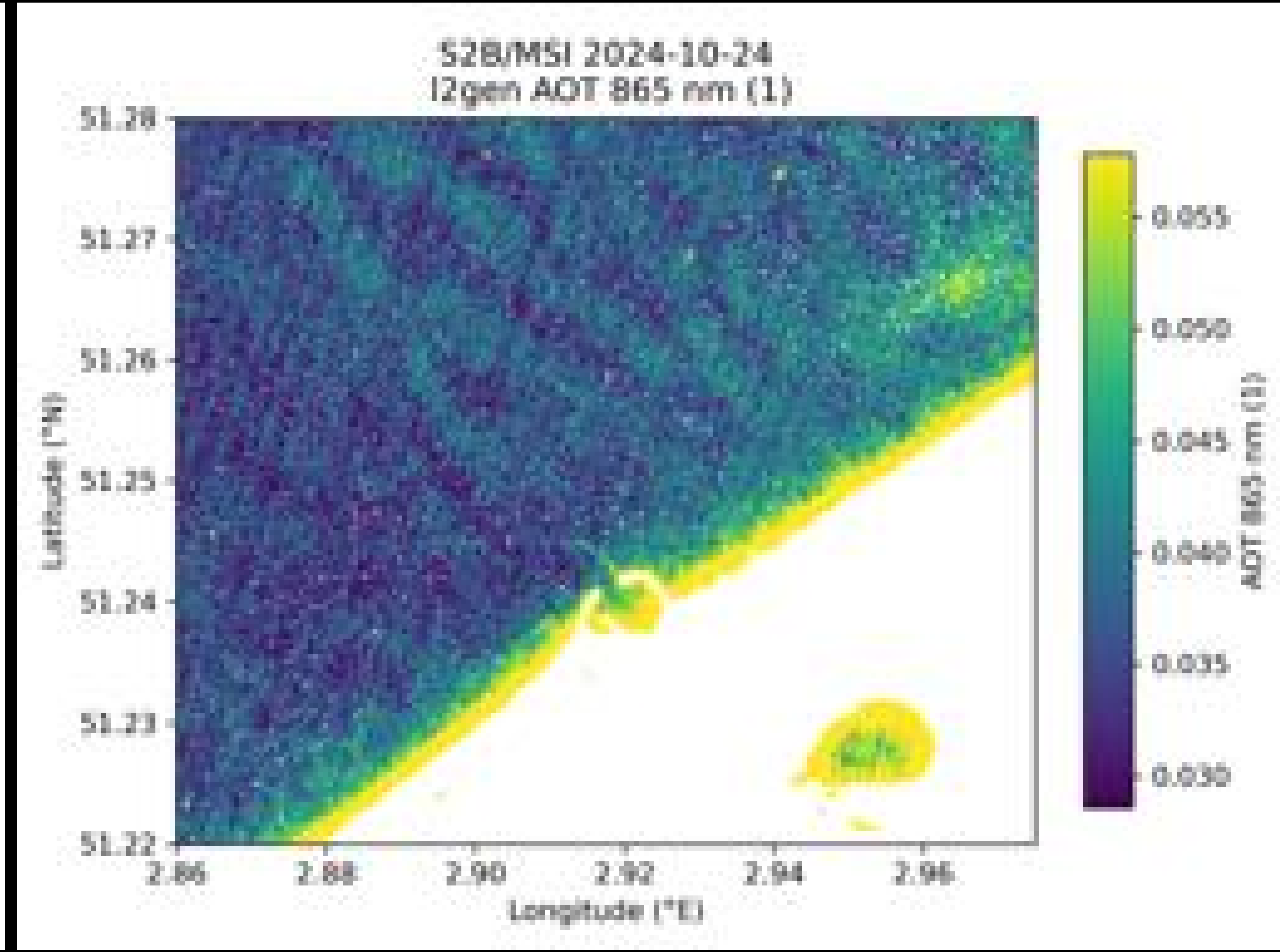


green-blueish appearance, some scattered pixels masked (ATMFAIL)

fairly flat overcorrection

l2gen

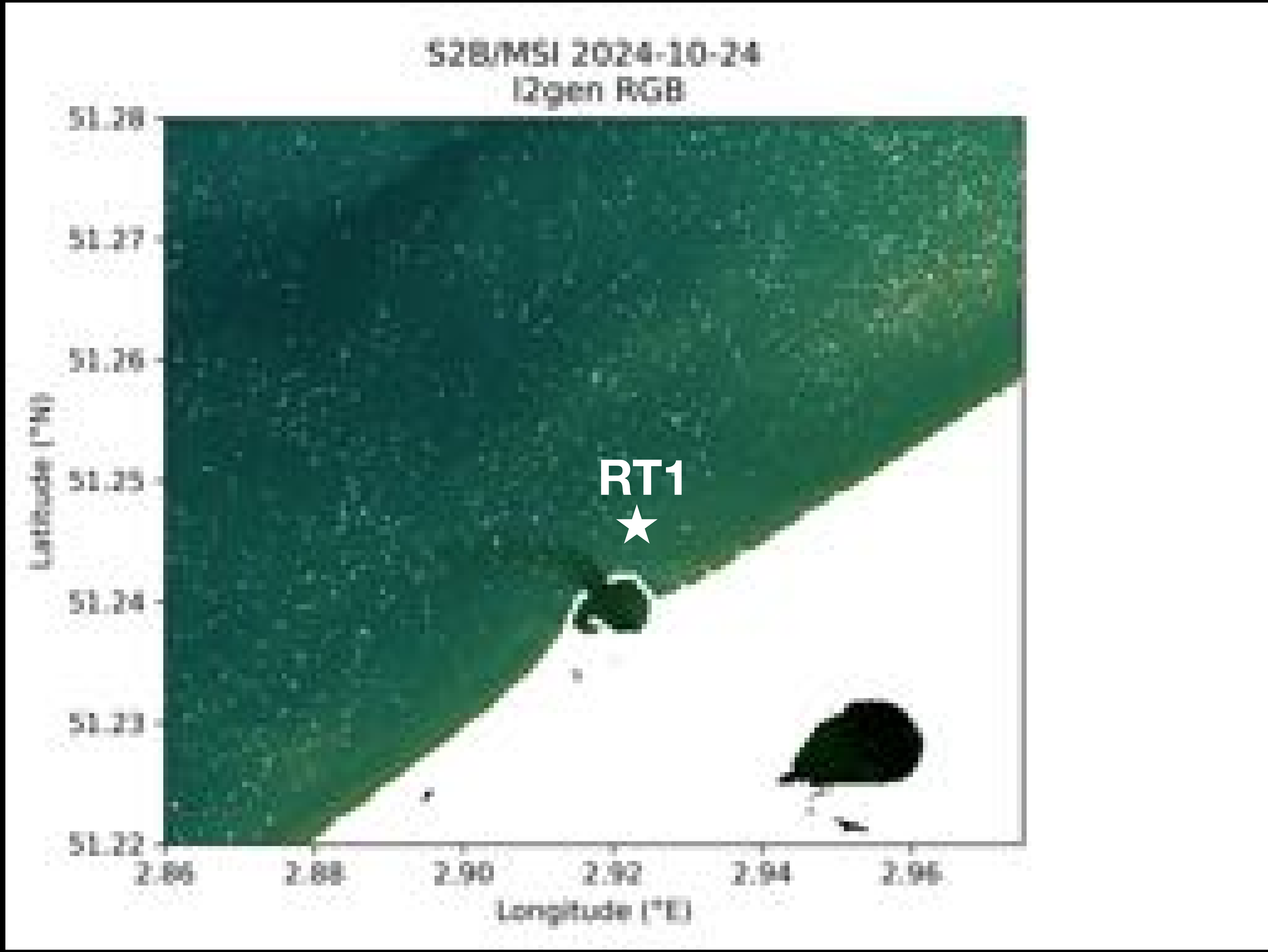


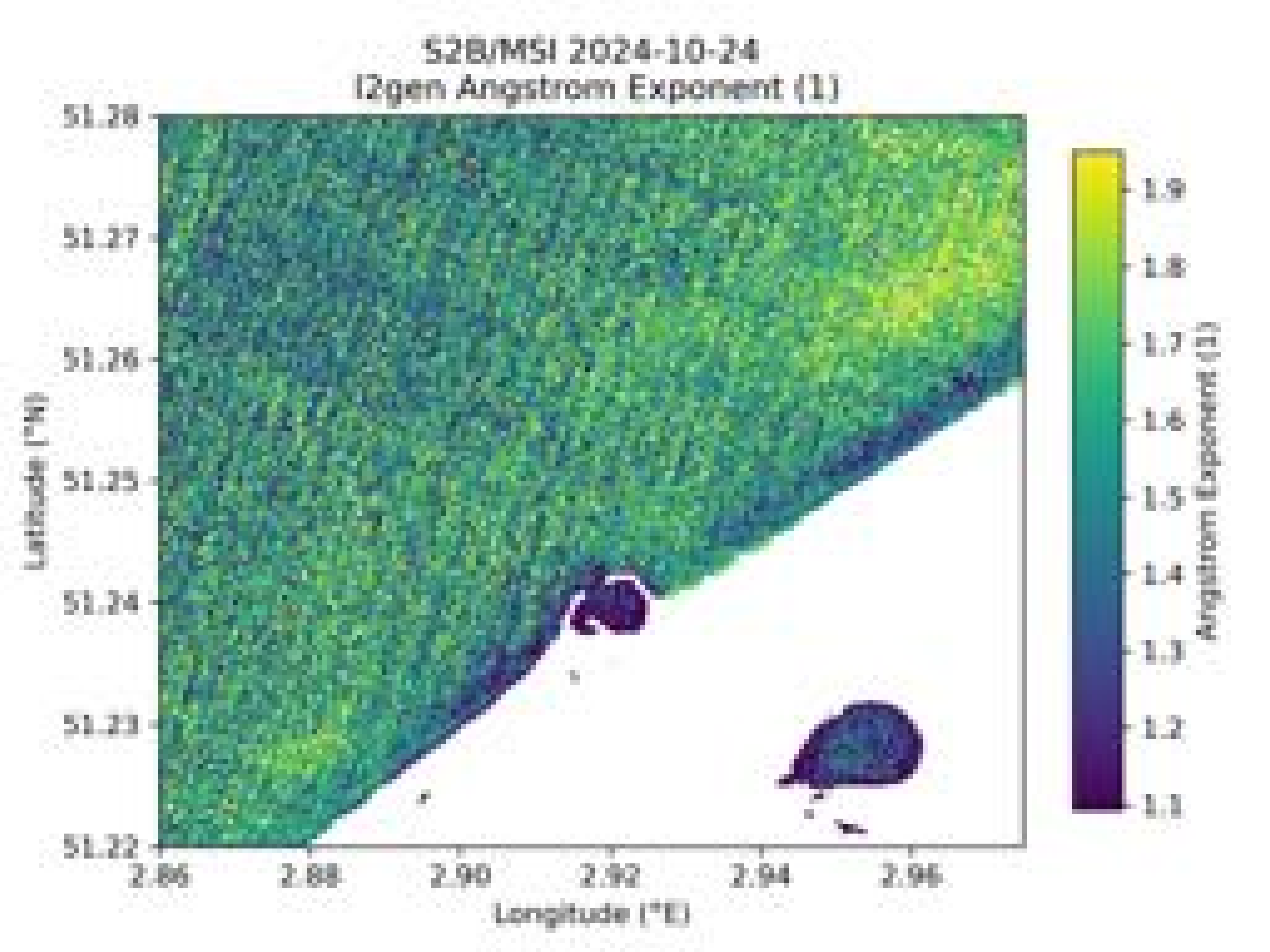


noisy aerosol products -> noisy Rrs

aerosol optical depth ~ increase towards shore, in port and lake

l2gen

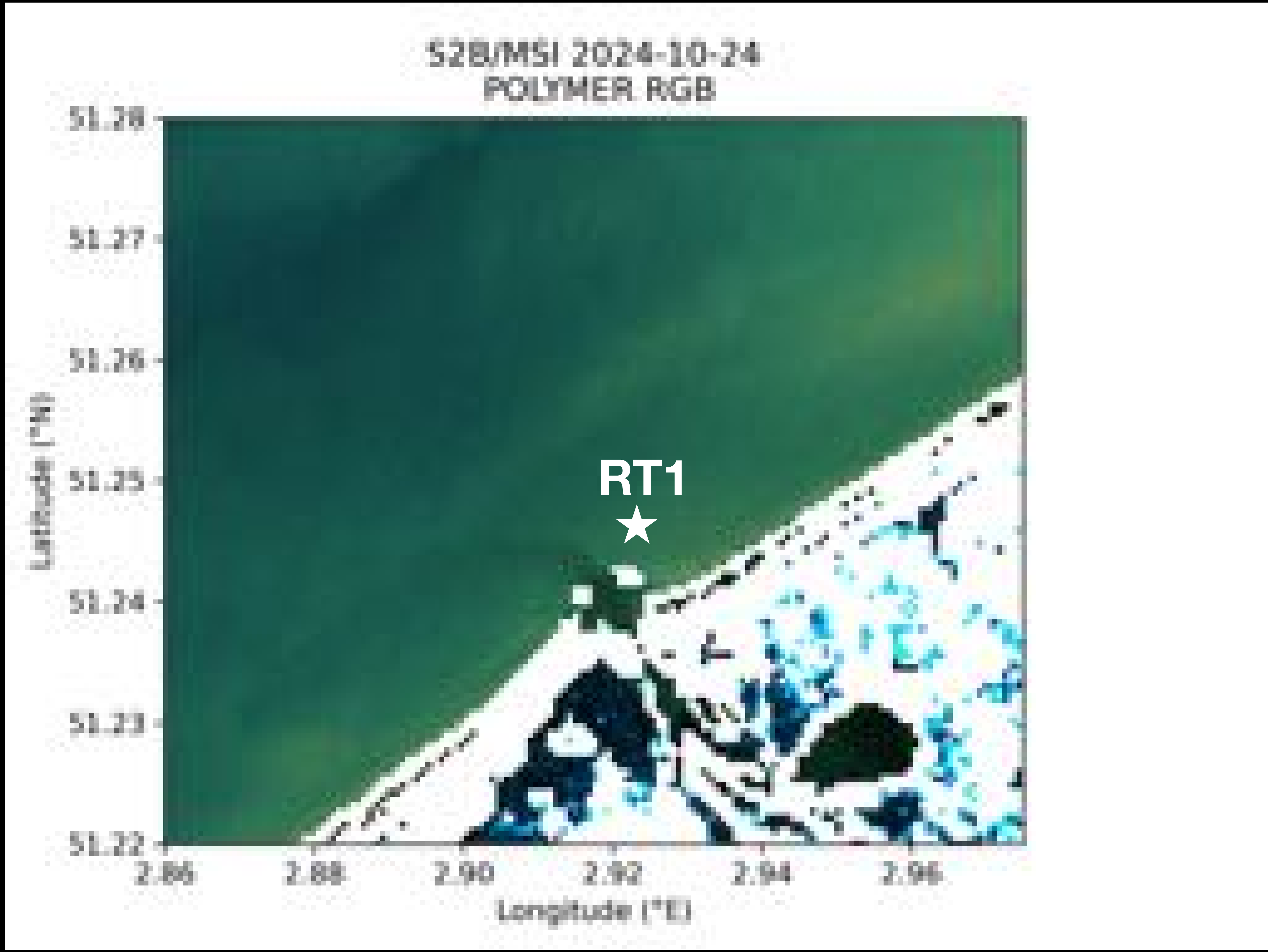


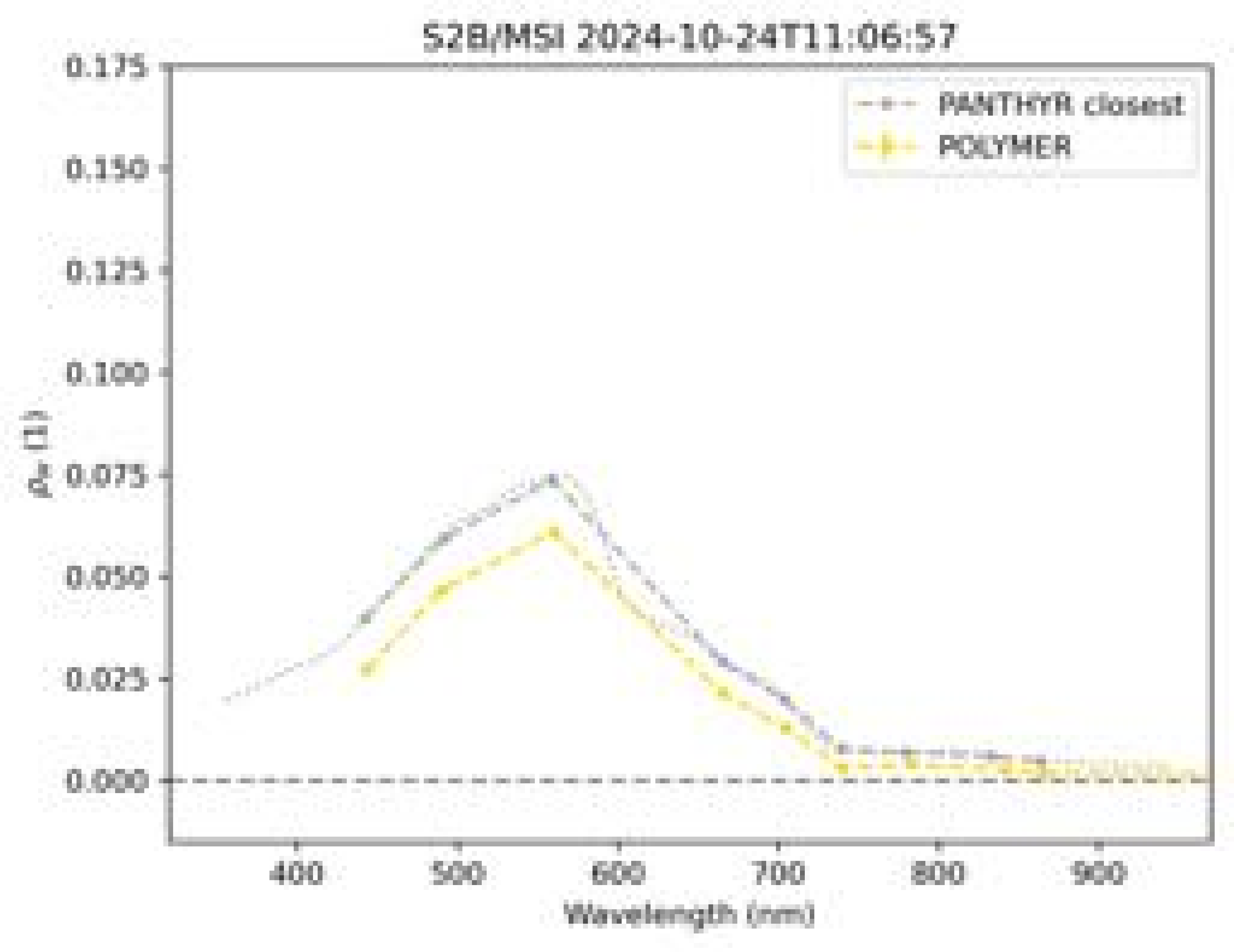


noisy aerosol products -> noisy Rrs

Angstrom ~ water turbidity, port and lake have low angstrom

POLYMER

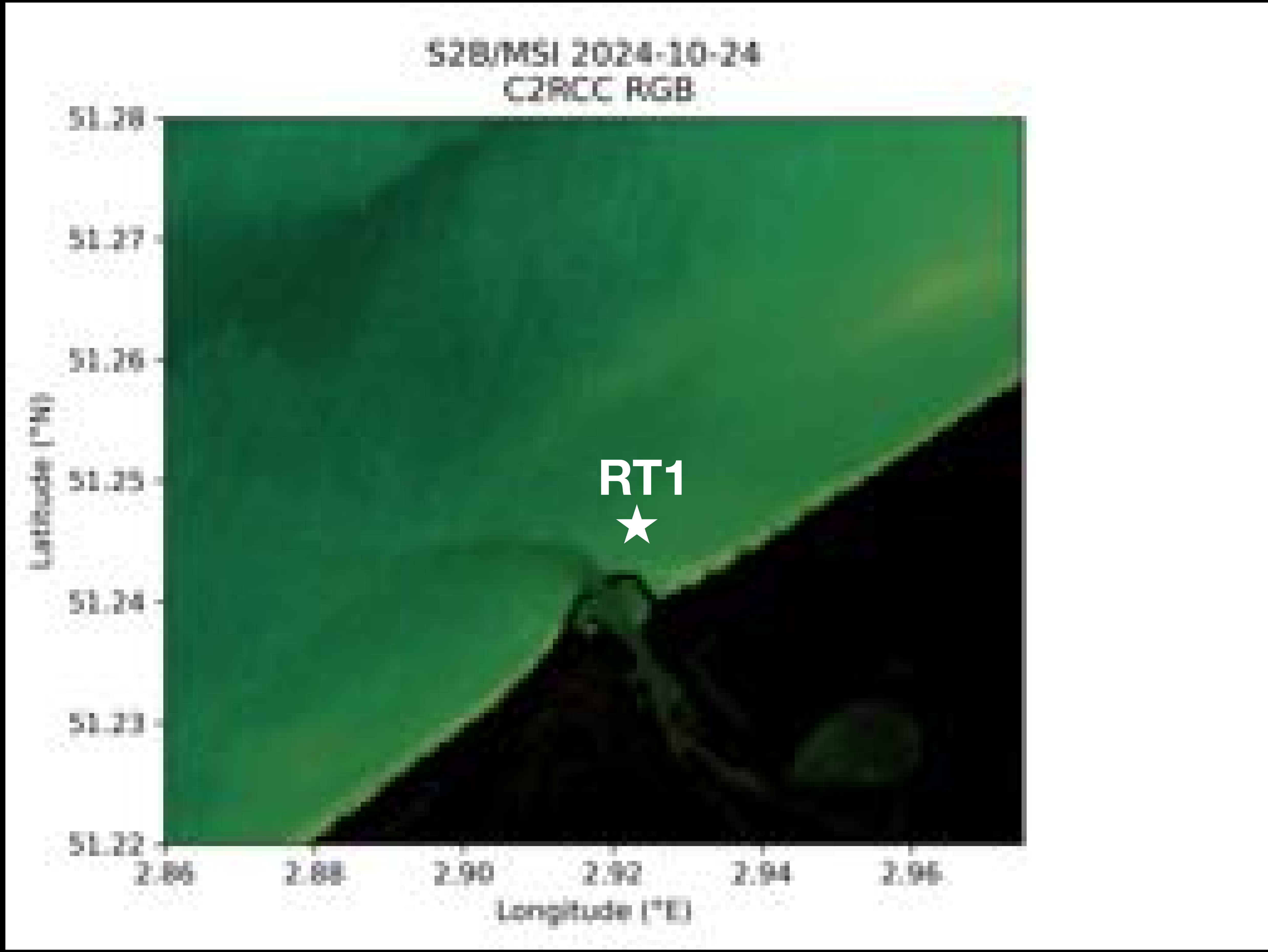


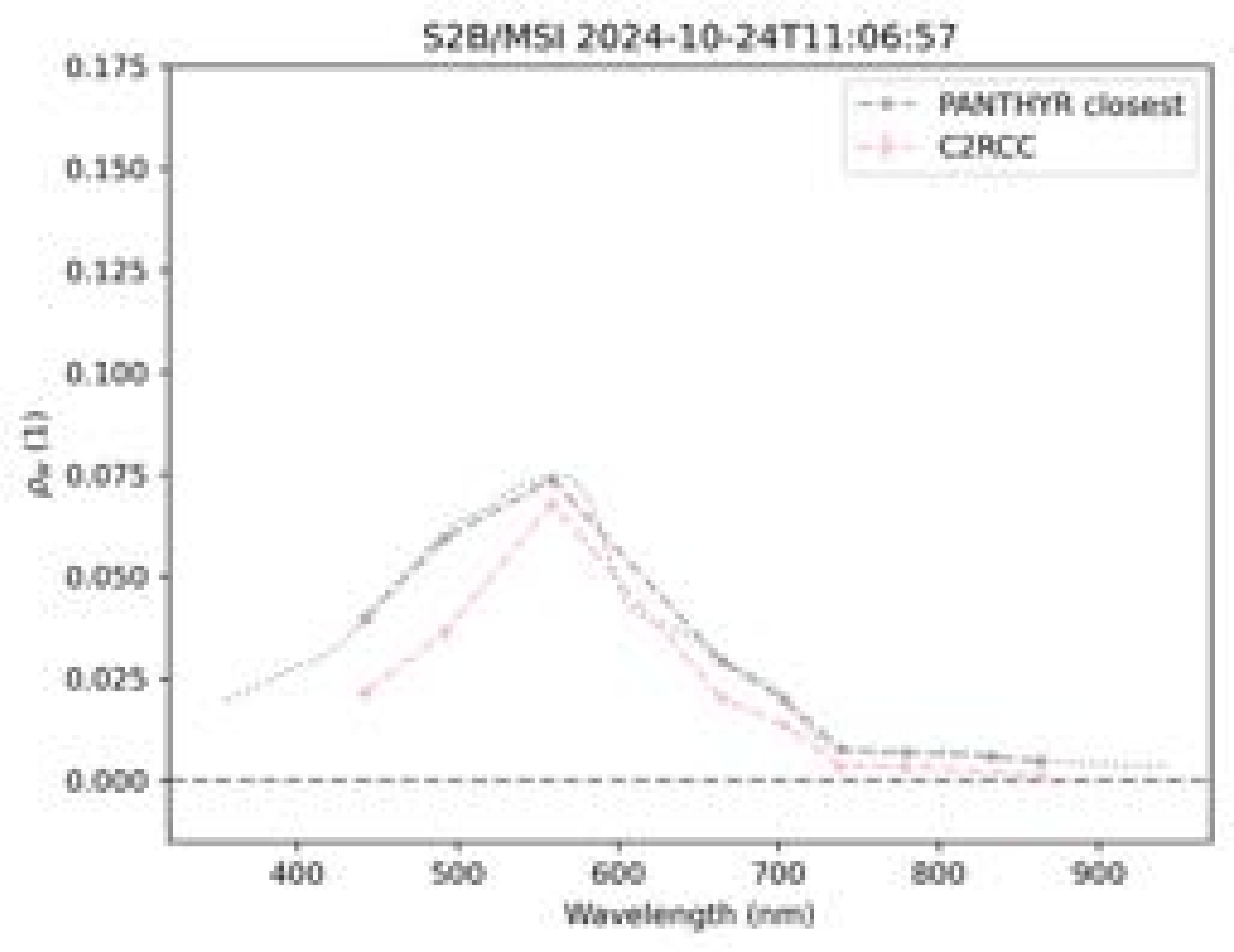


similar colour compared to l2gen, slightly noisier, but no failures

overcorrection, slightly brighter compared to l2gen

C2RCC

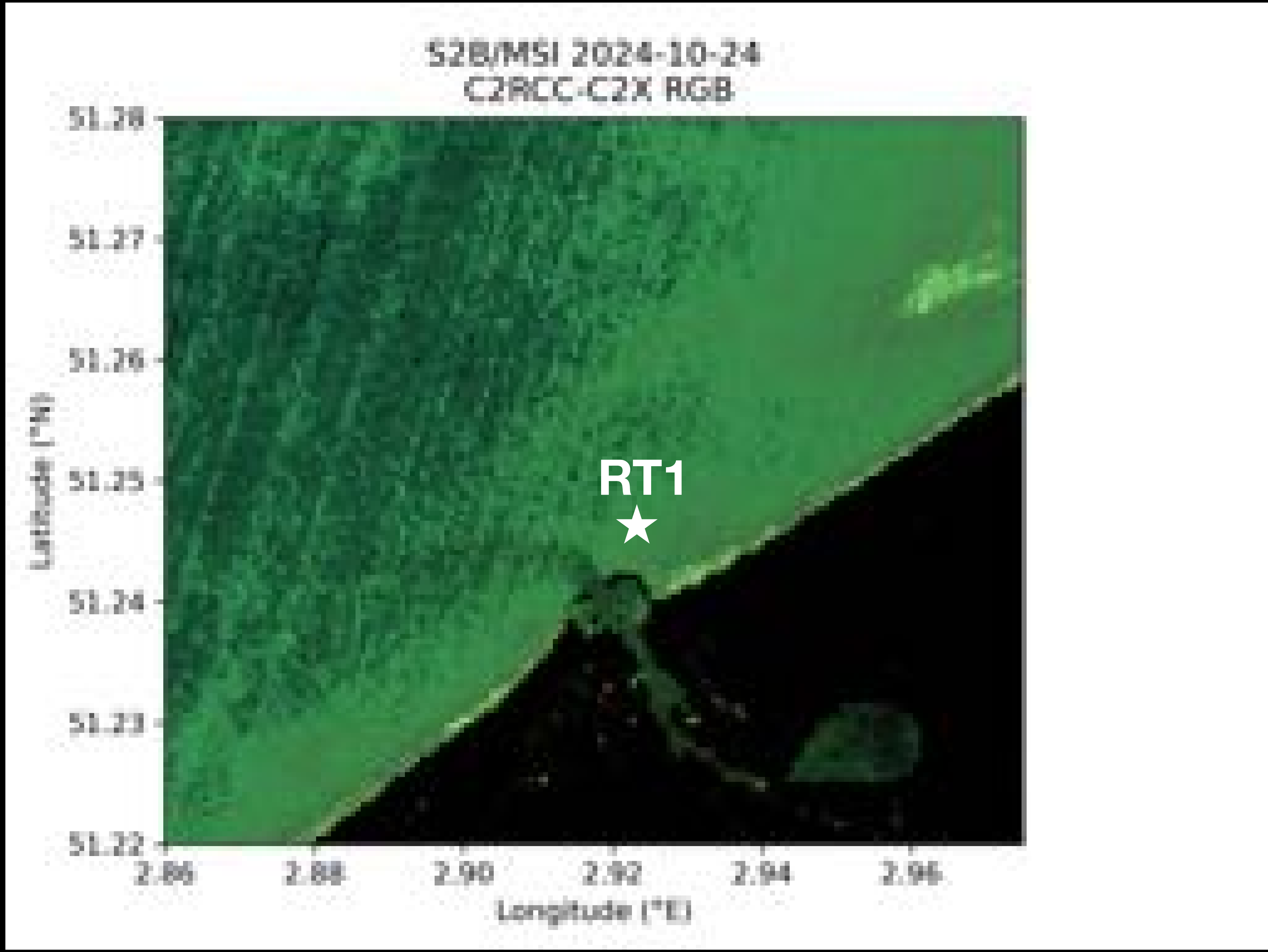


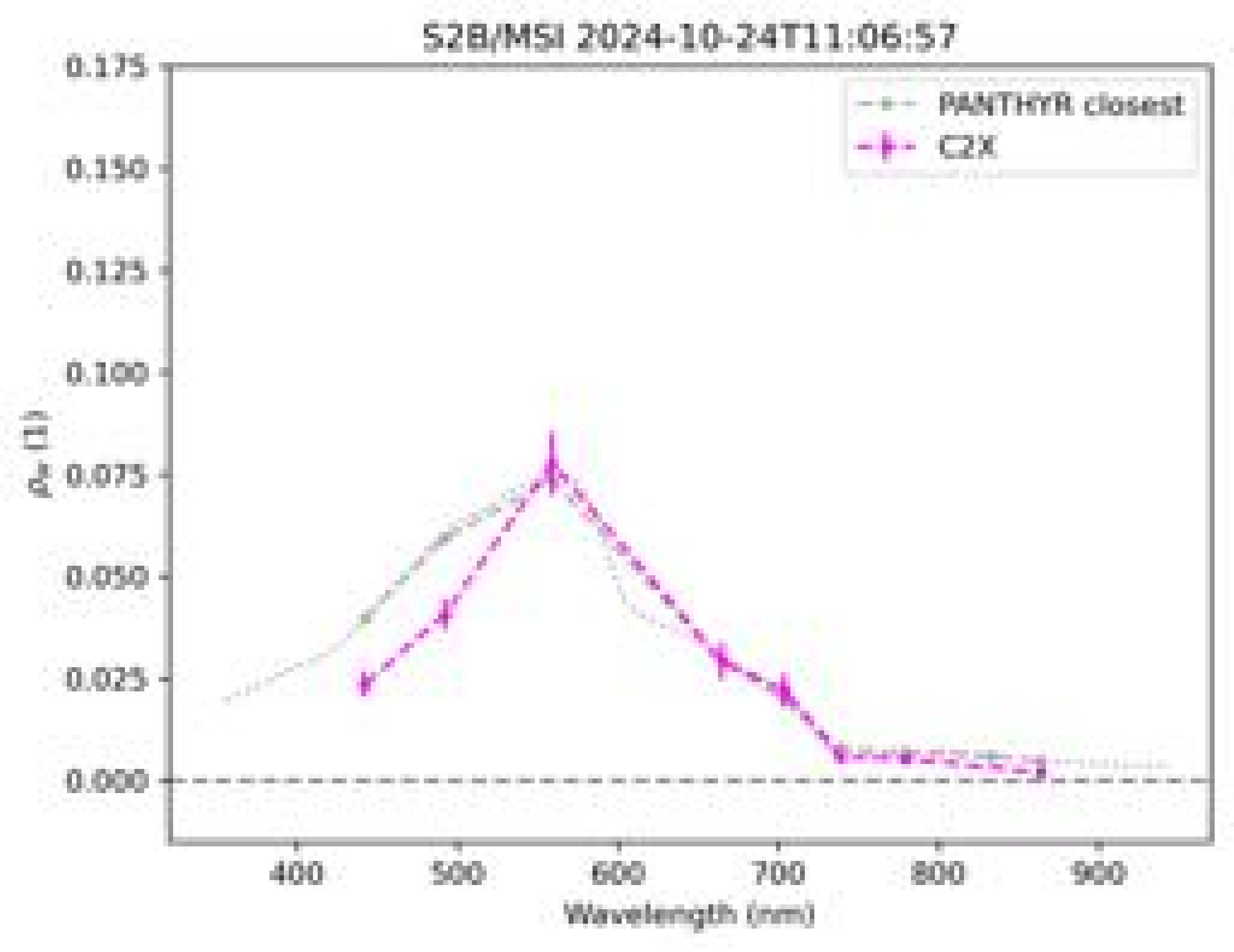


a bit brighter than l2gen/POLYMER, greener appearance

higher reflectance than l2gen/POLYMER, difference in blue shape

C2RCC-C2X

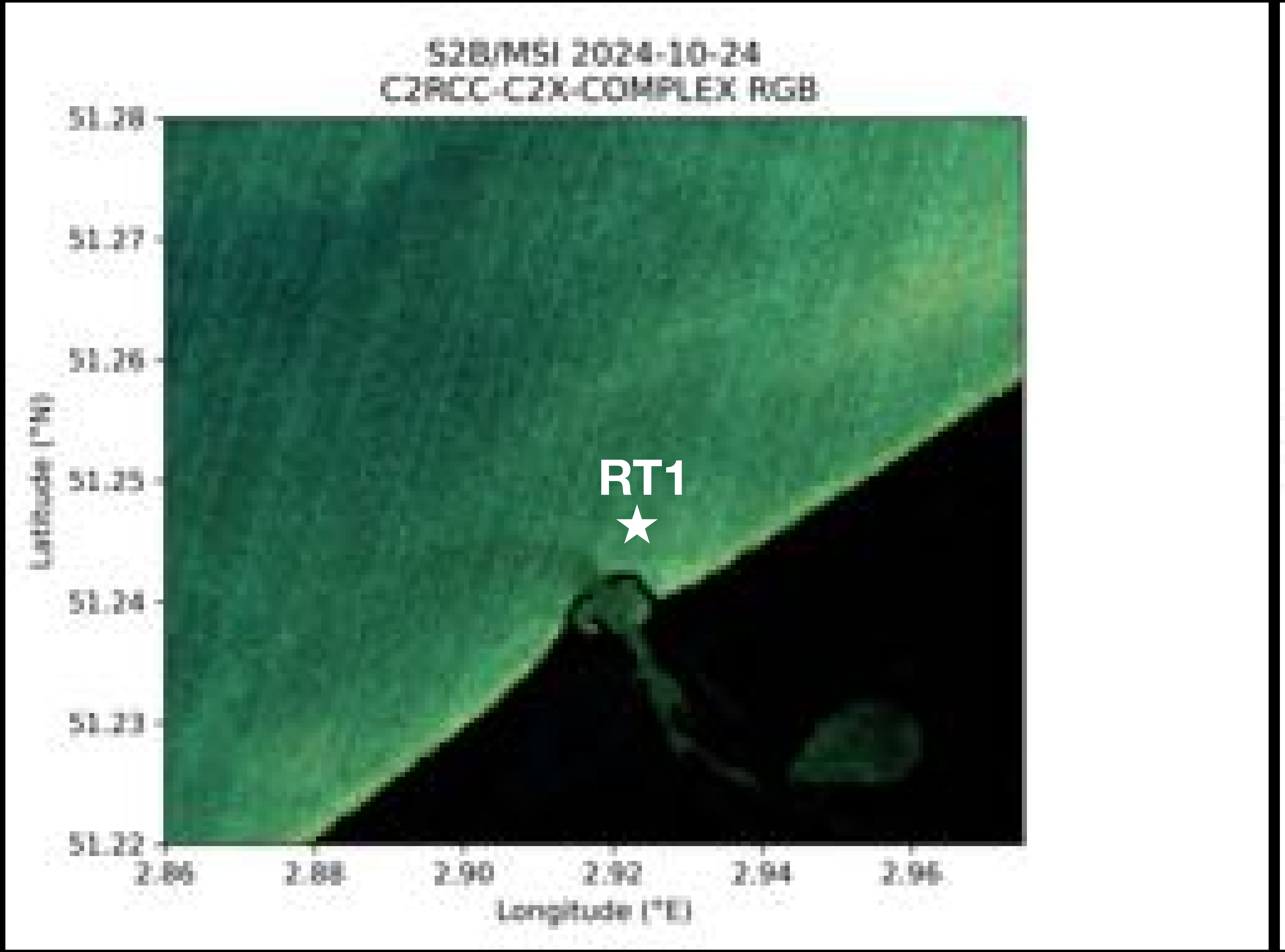


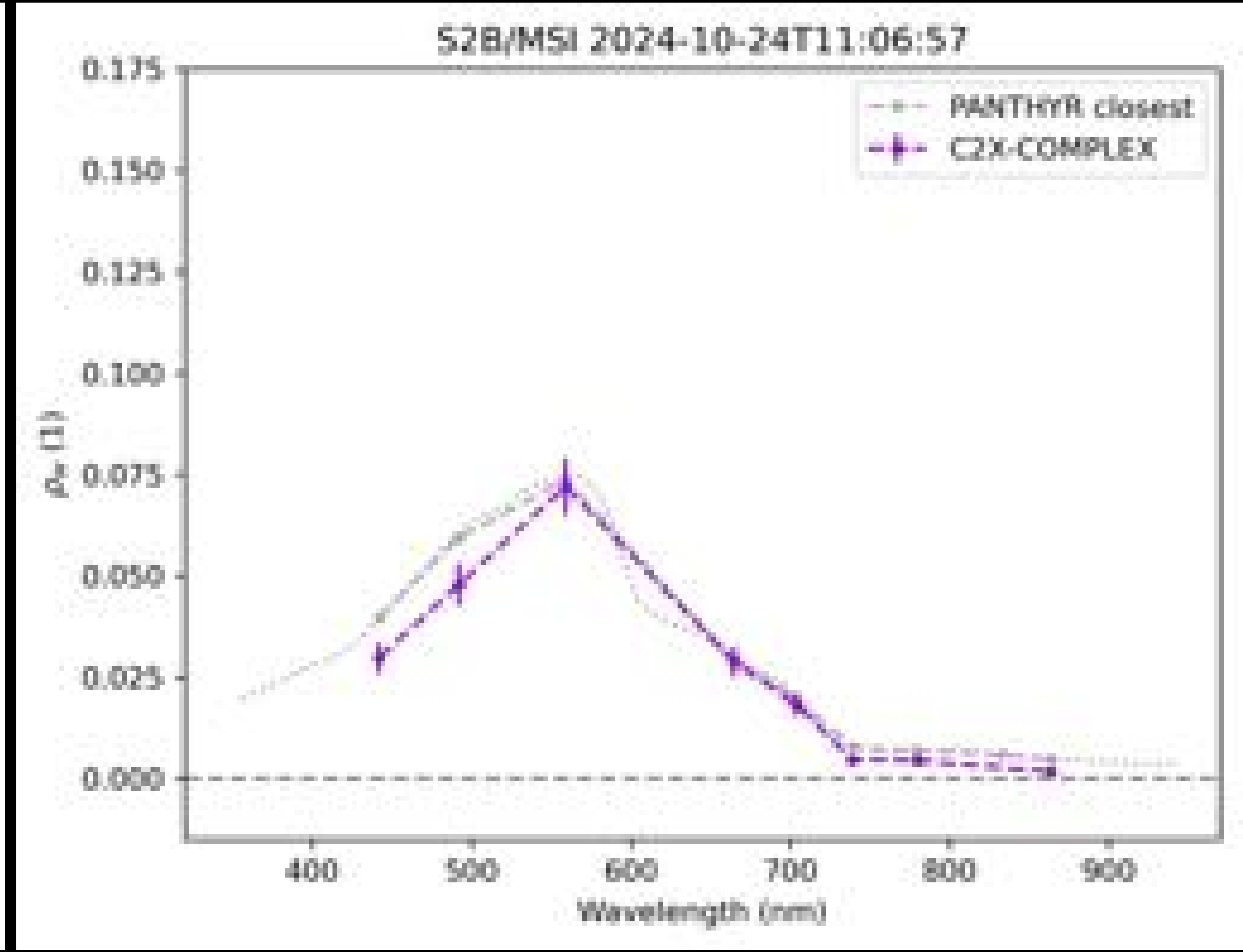


a bit brighter than C2RCC, more noise, spatial variability reduced

better fit compared to C2RCC in green-NIR

C2RCC-COMPLEX

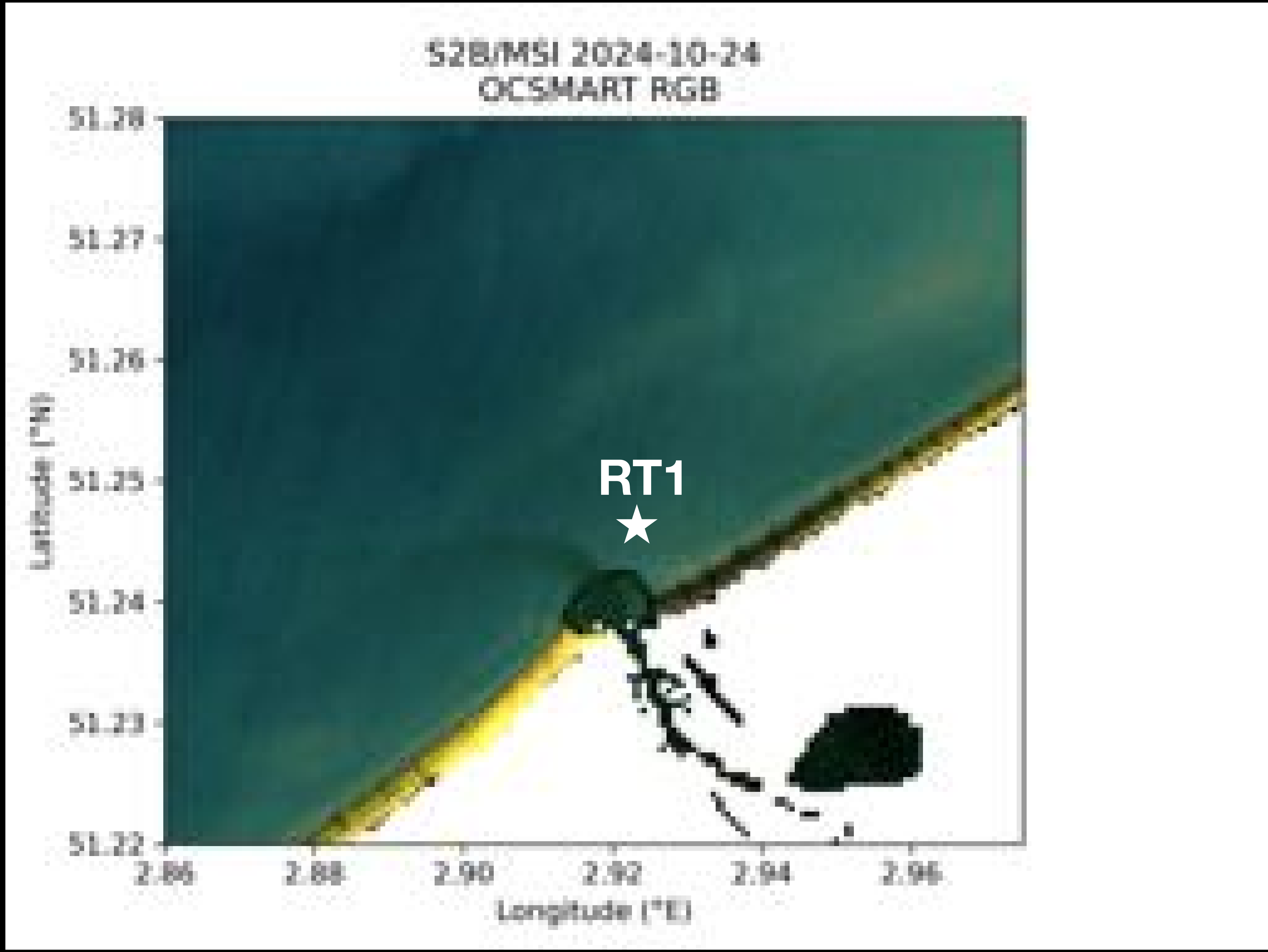


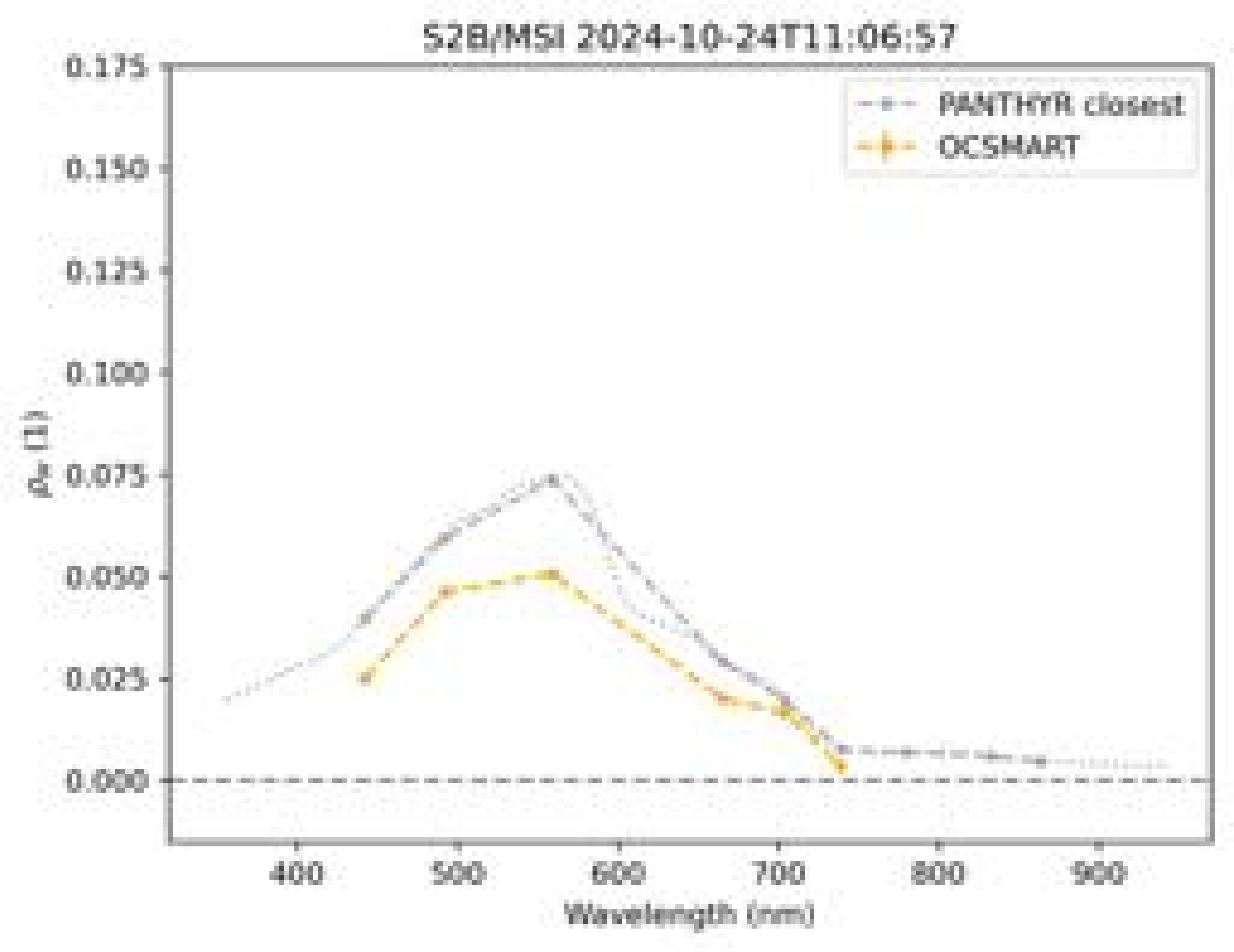


a bit brighter than C2RCC, more noise, spatial variability reduced

better fit compared to C2RCC and C2X, slight under-correction in Blue

OC-SMART

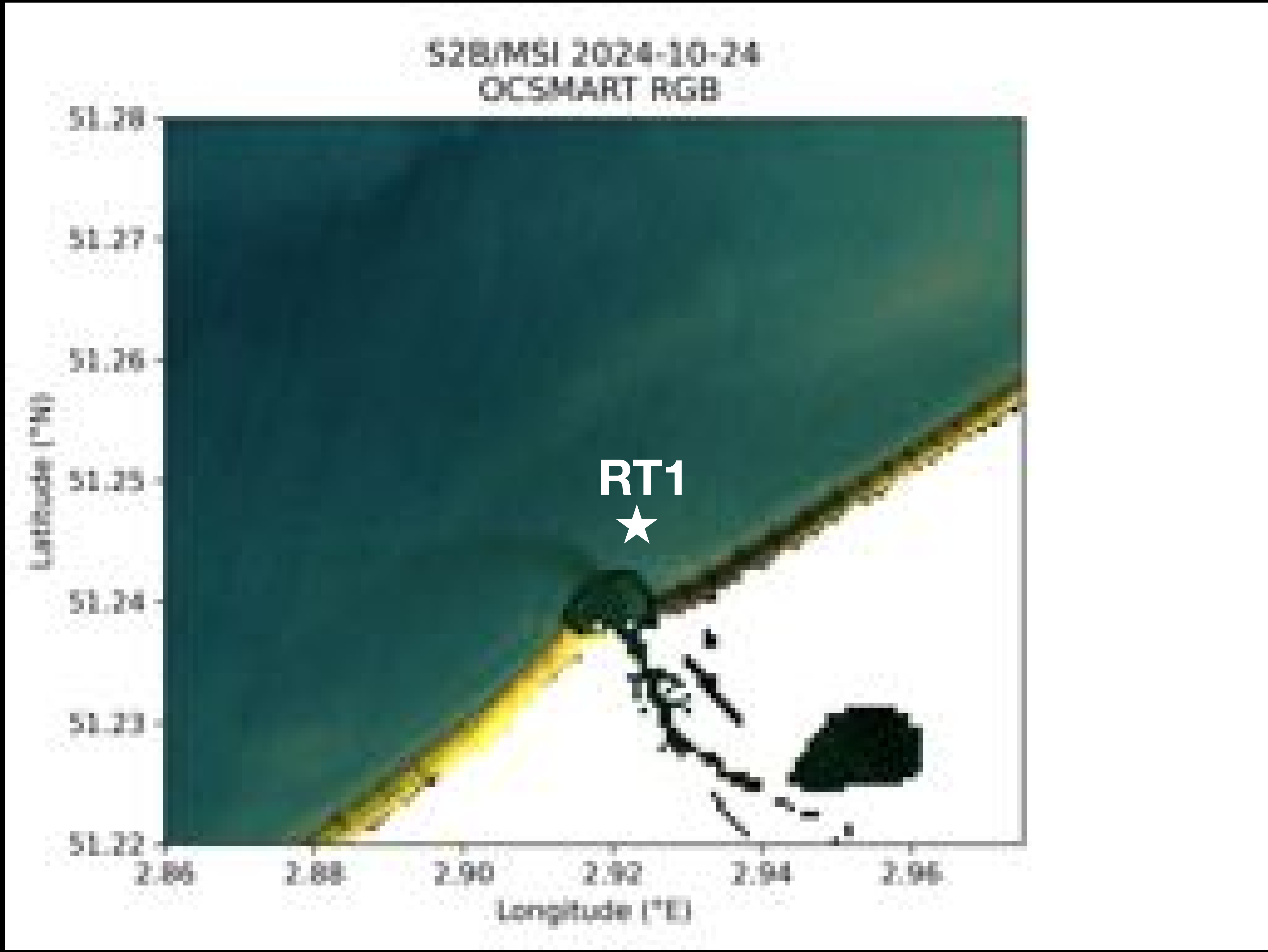


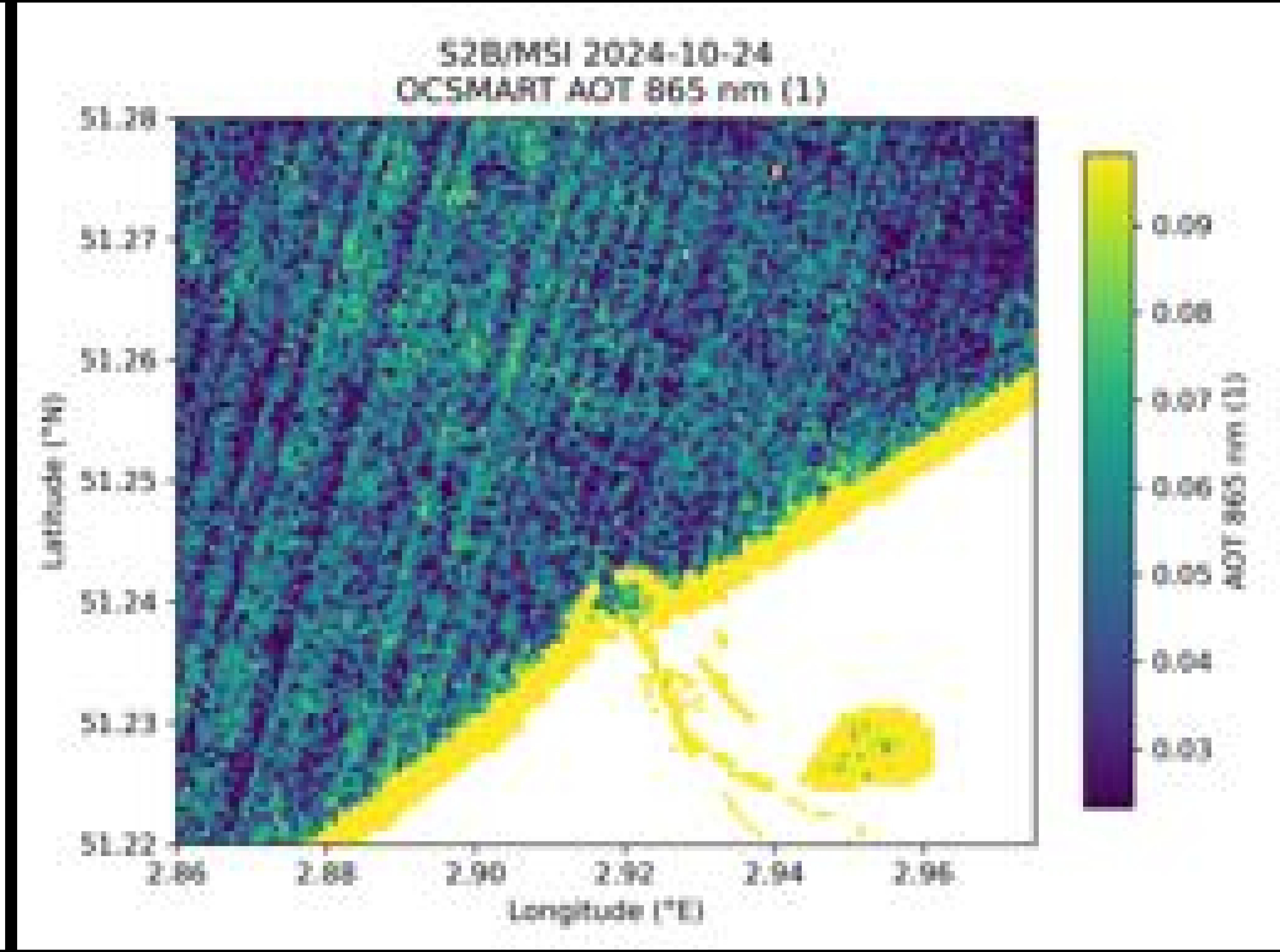


lower reflectance, a bit less green

overcorrection in VIS, slight red absorption feature introduced

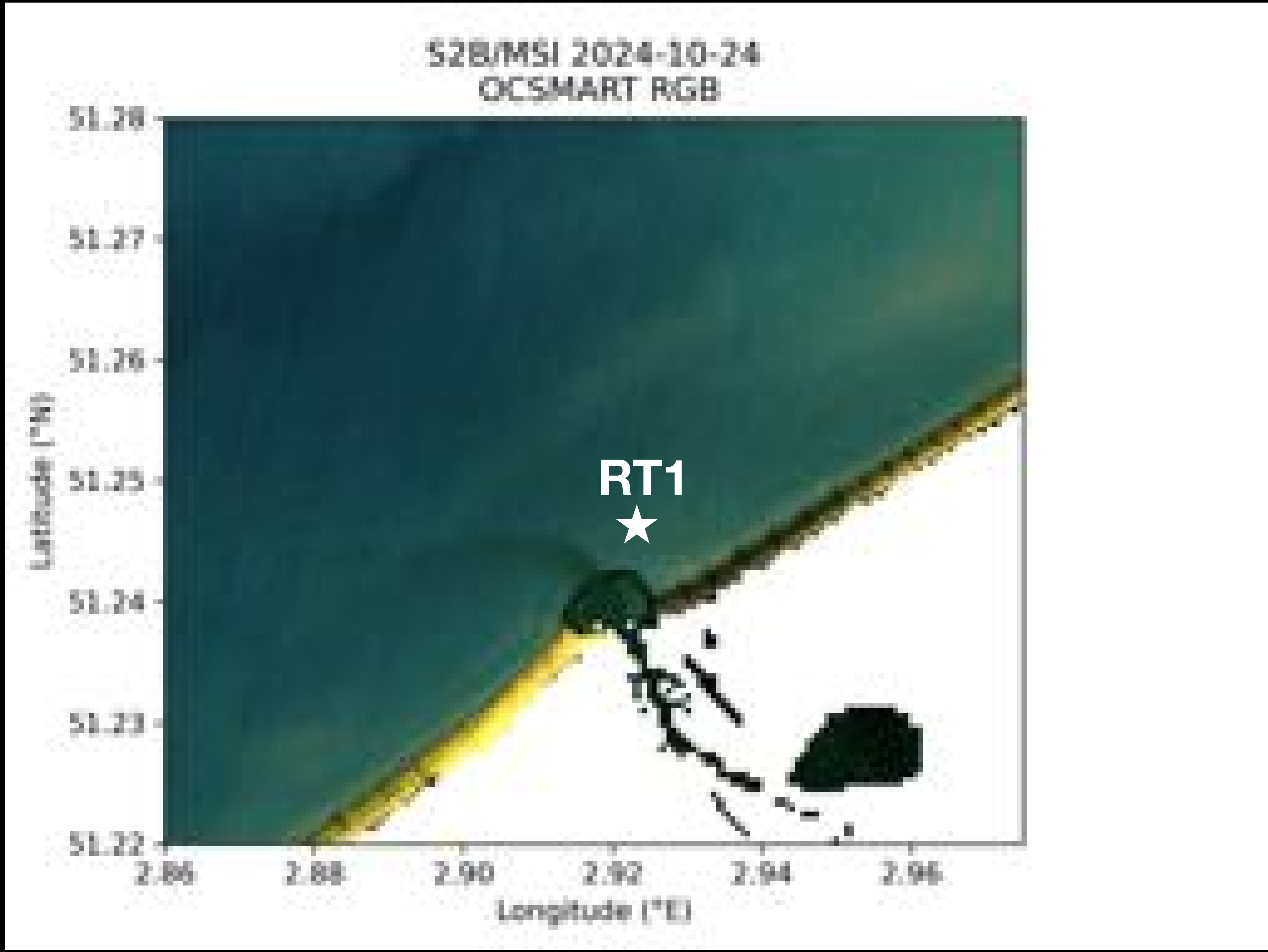
OC-SMART

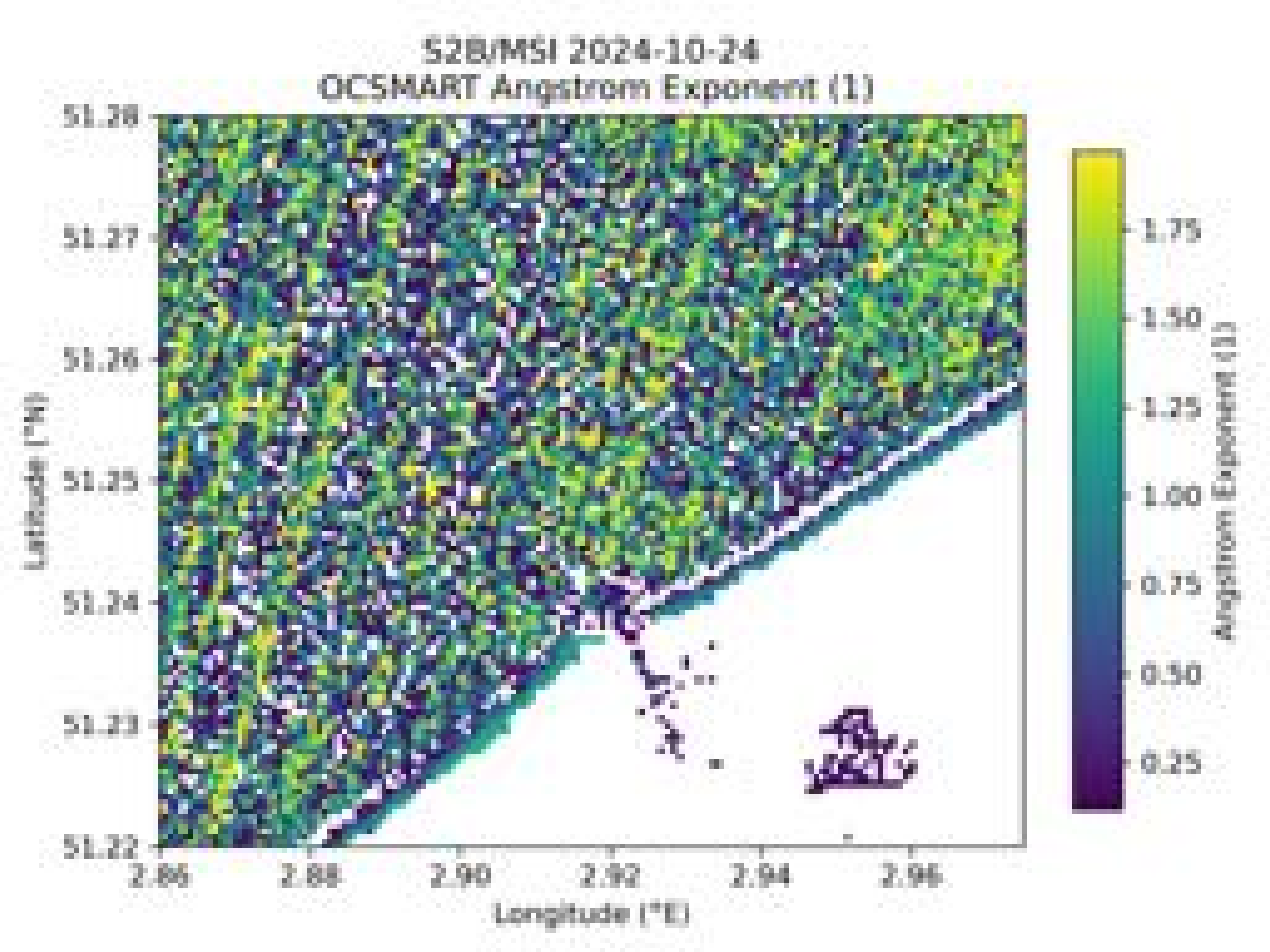




aerosol optical depth ~ noisy, high in the port and lake

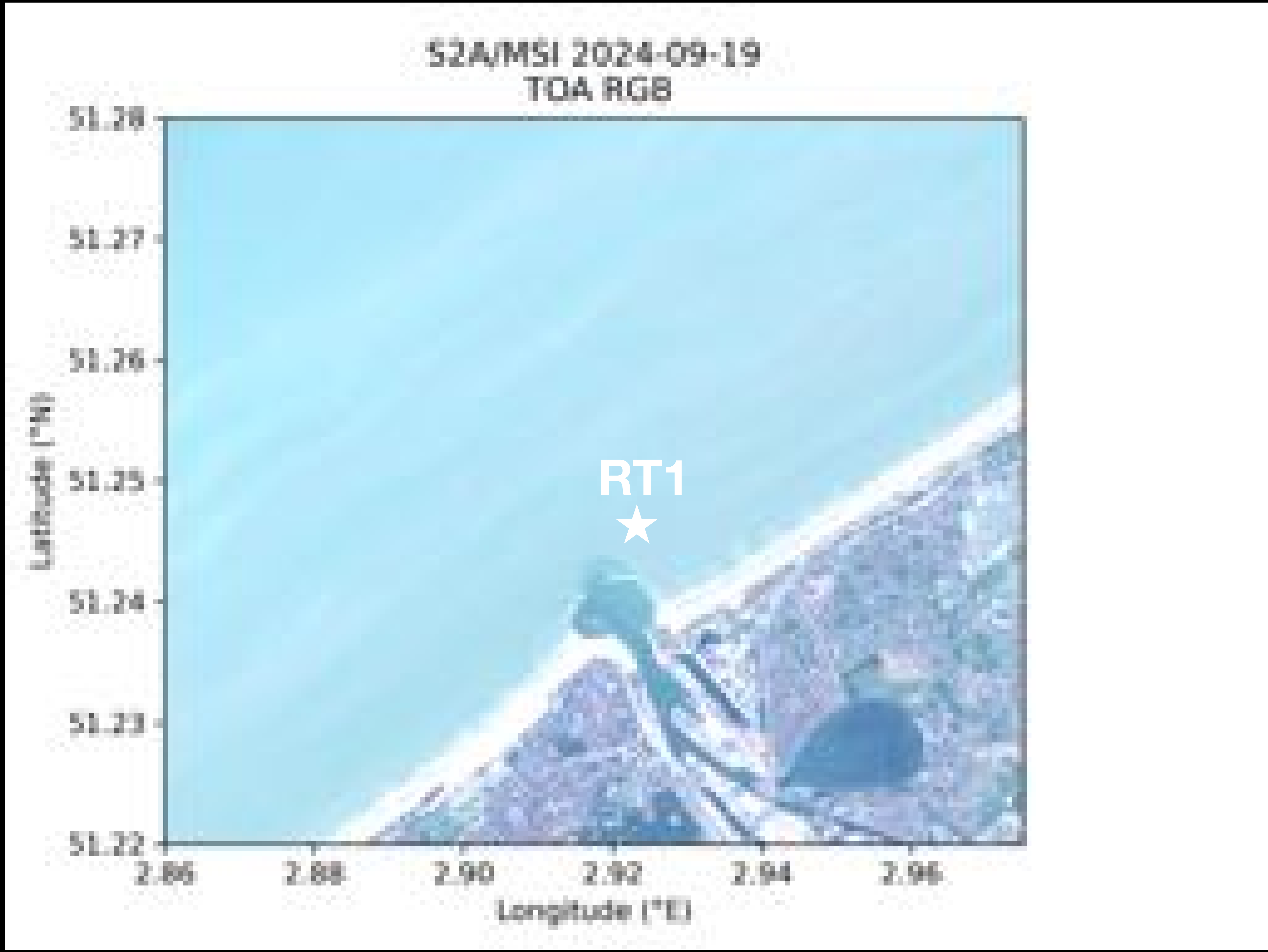
OC-SMART

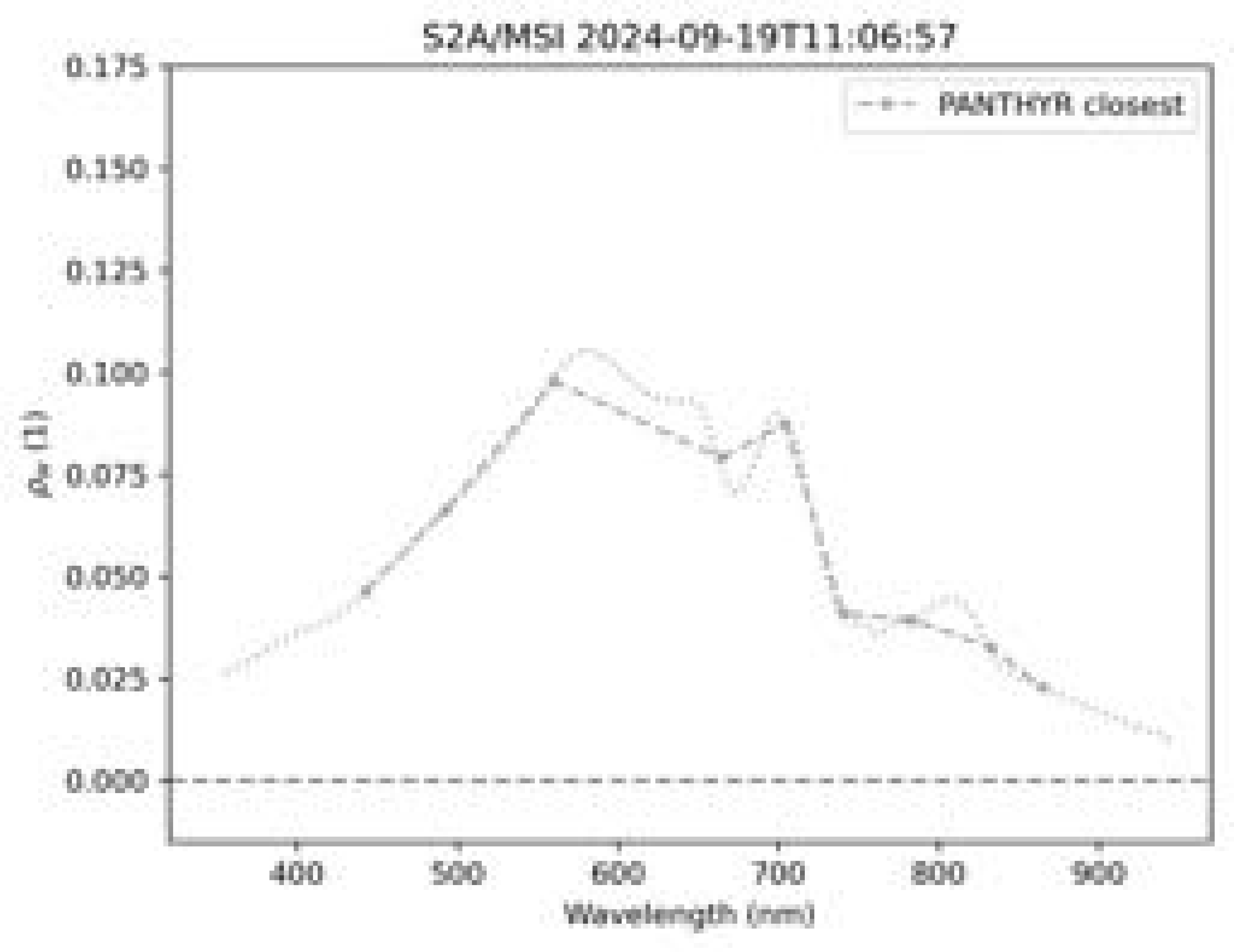




Angstrom ~ noisy!

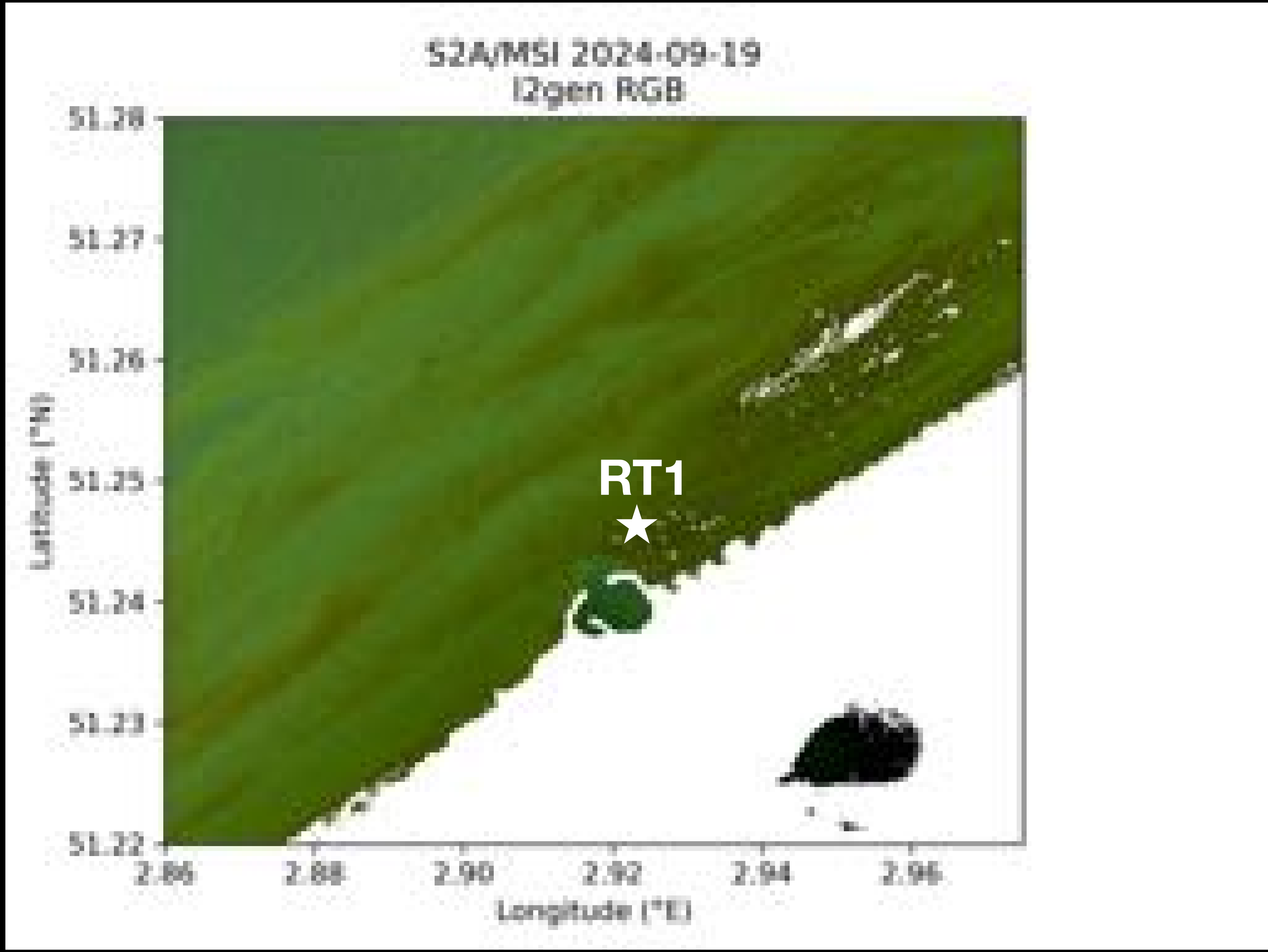
TOA 2024-09-19 PANTHYR

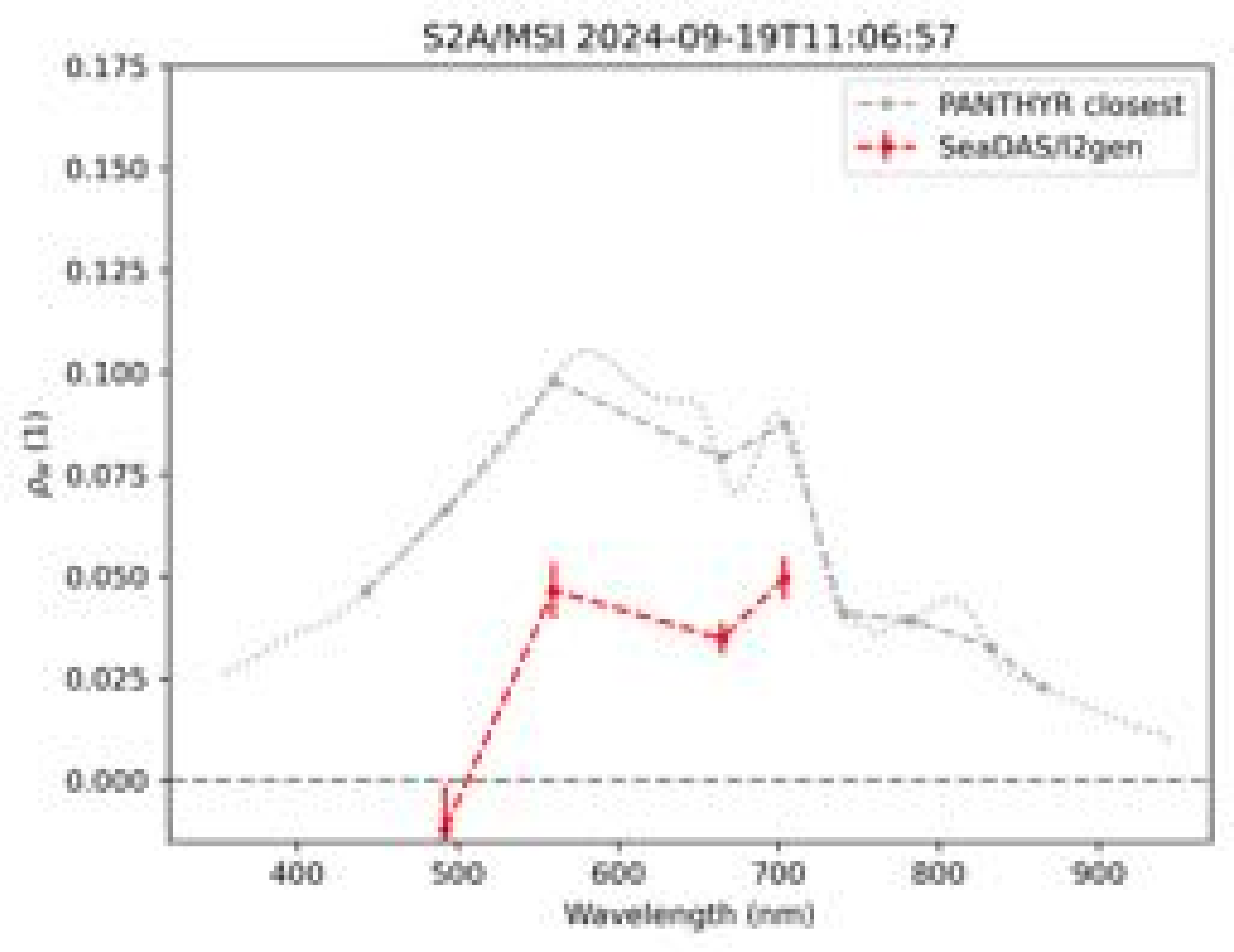




quite turbid, some Chla (665 nm dip)

l2gen

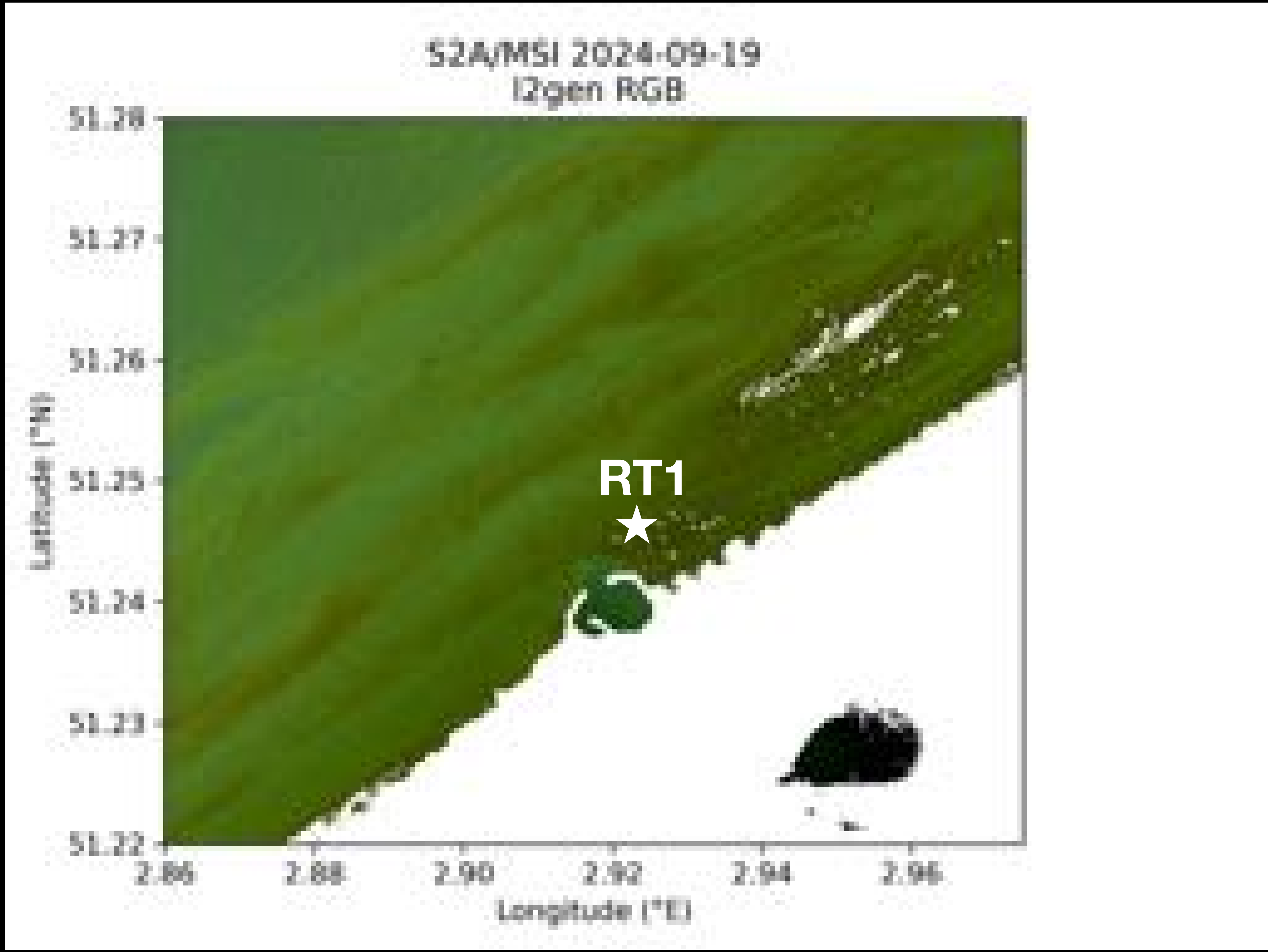


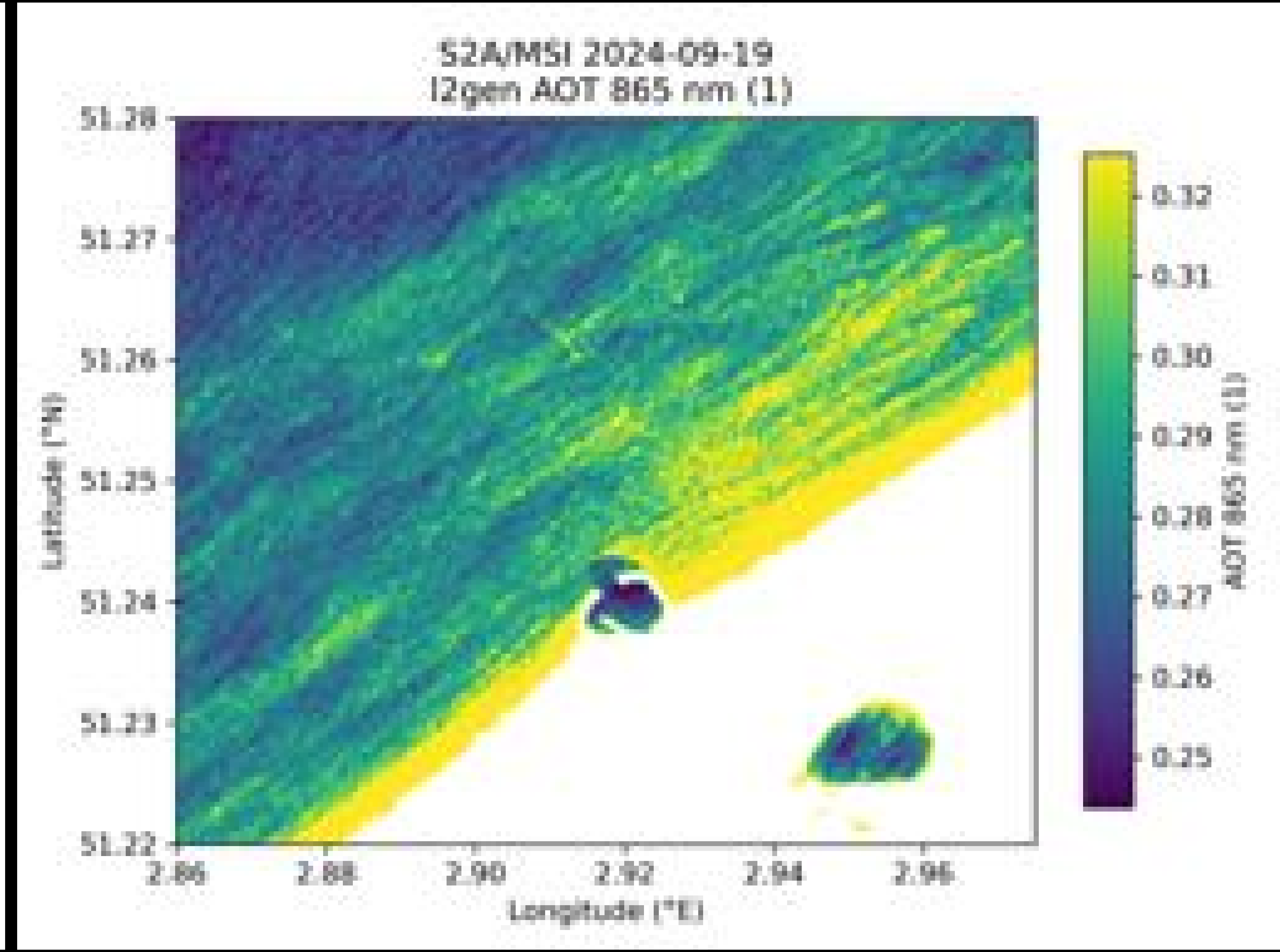


greenish appearance, more turbid ~ more red/brown, some pixels masked (Blue << 0)

overcorrection, especially in Blue

l2gen

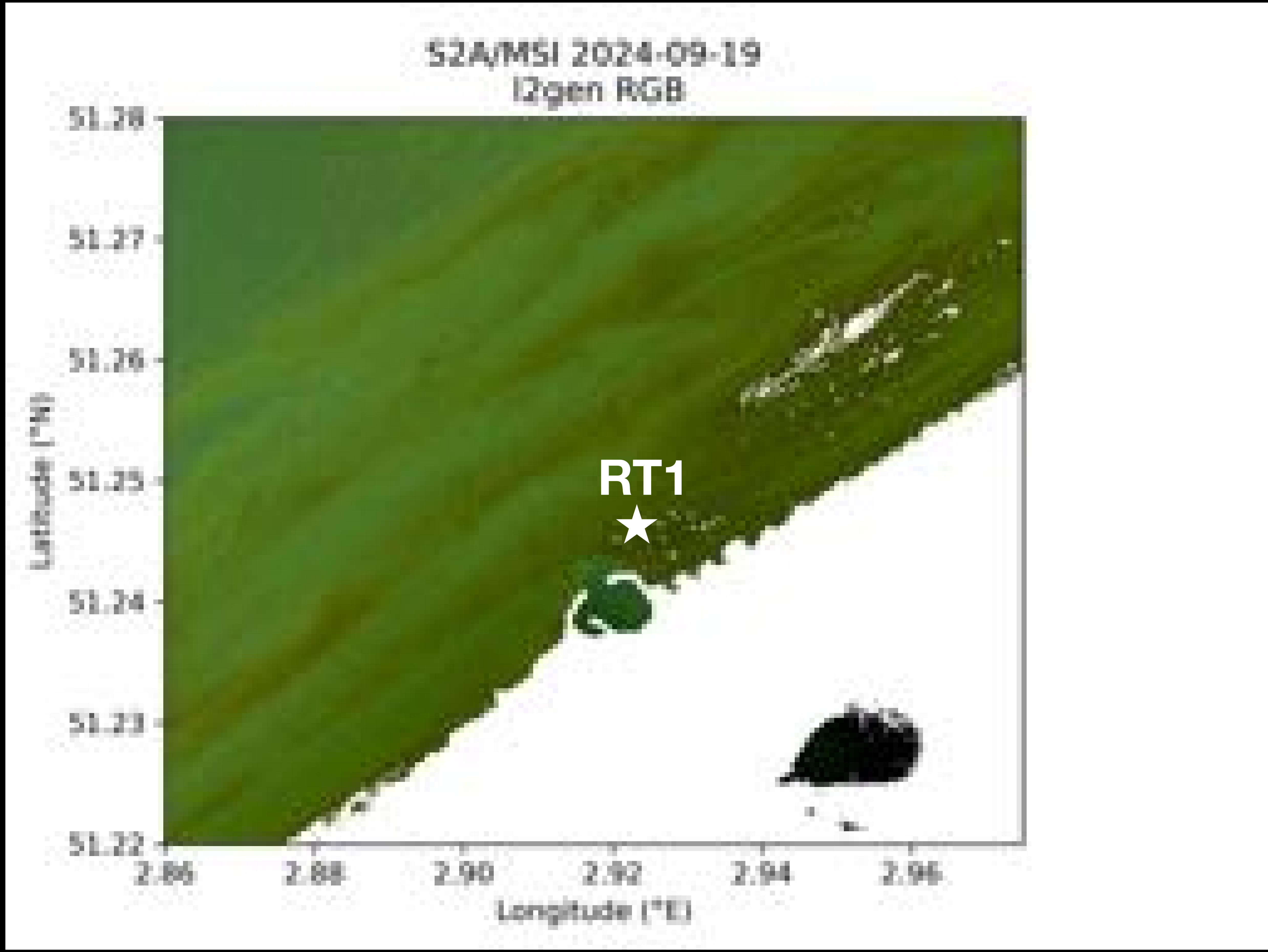


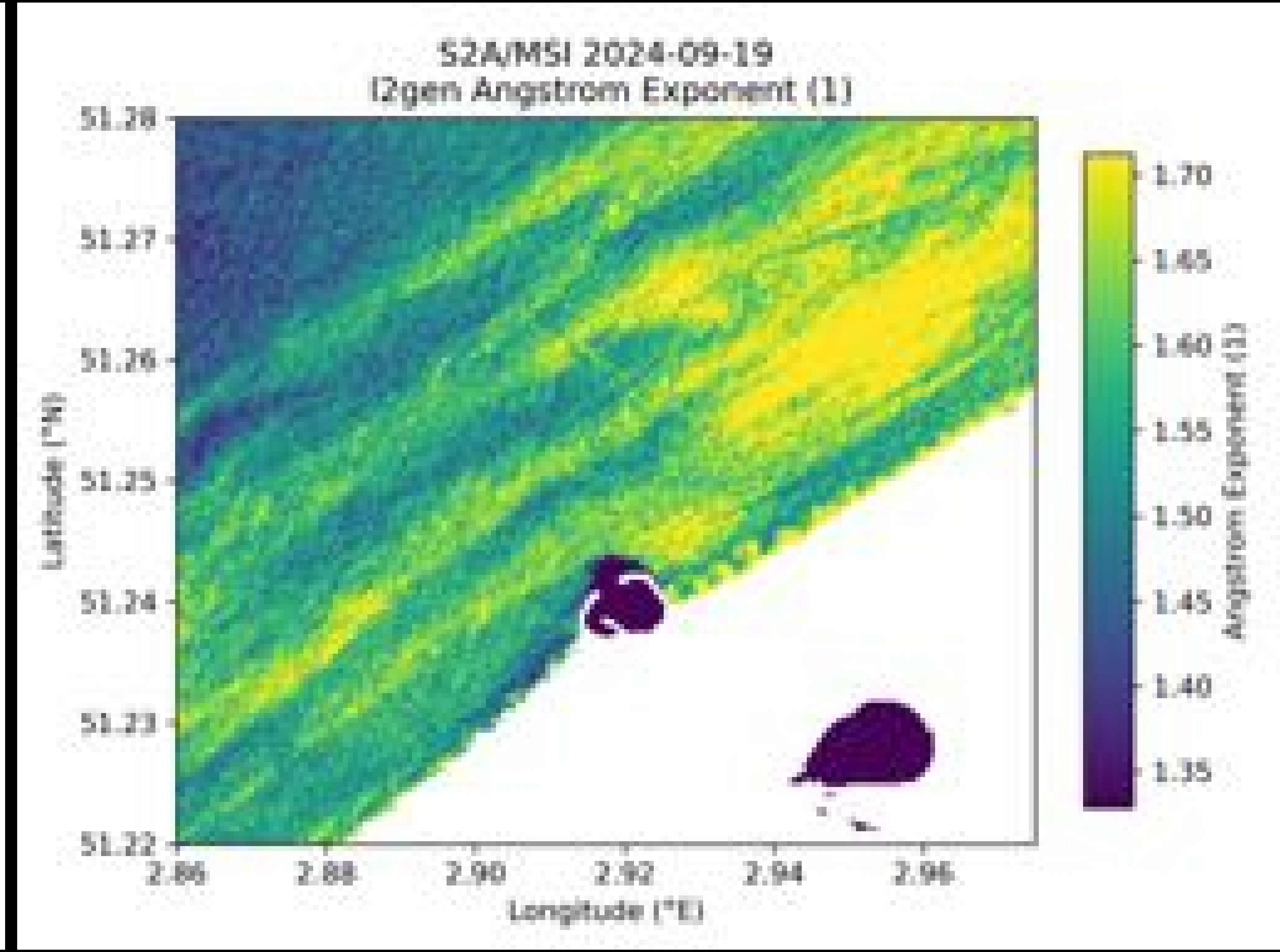


masking (blue band << 0) ~ high aerosol optical depth

aerosol optical depth ~ water turbidity

l2gen

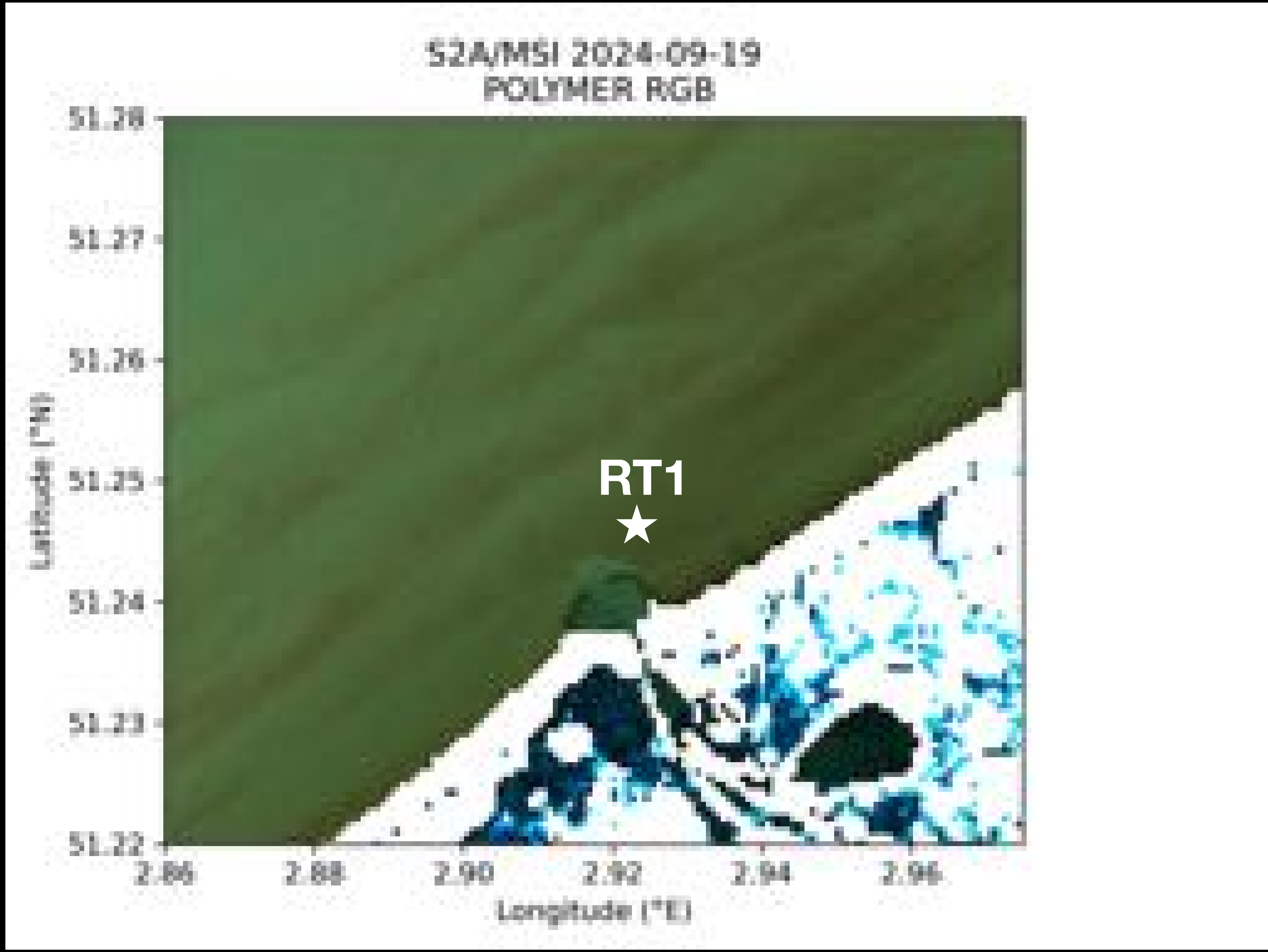


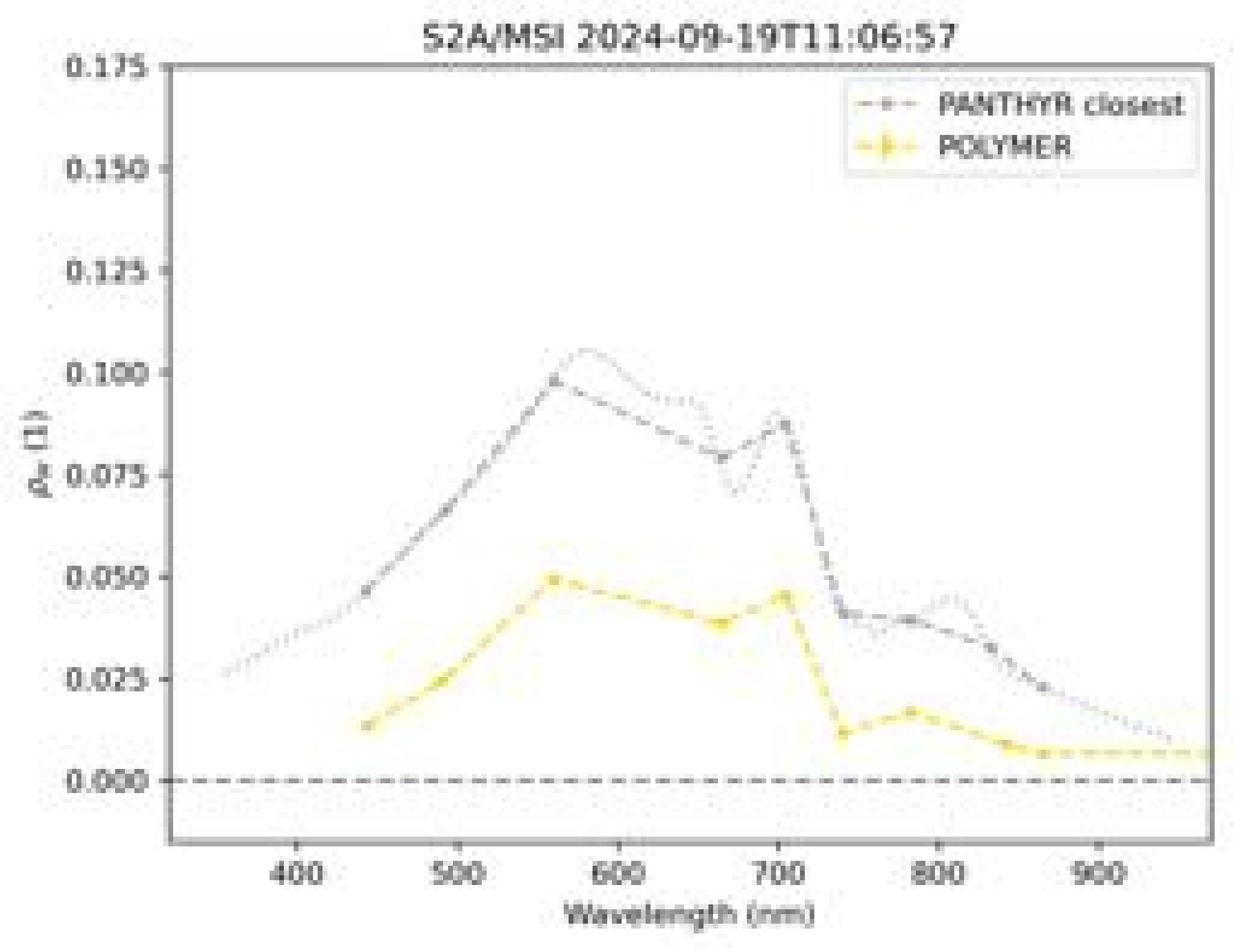


masking (blue band << 0) ~ high aerosol Angstrom

Angstrom ~ water turbidity, port and lake have low angstrom

POLYMER

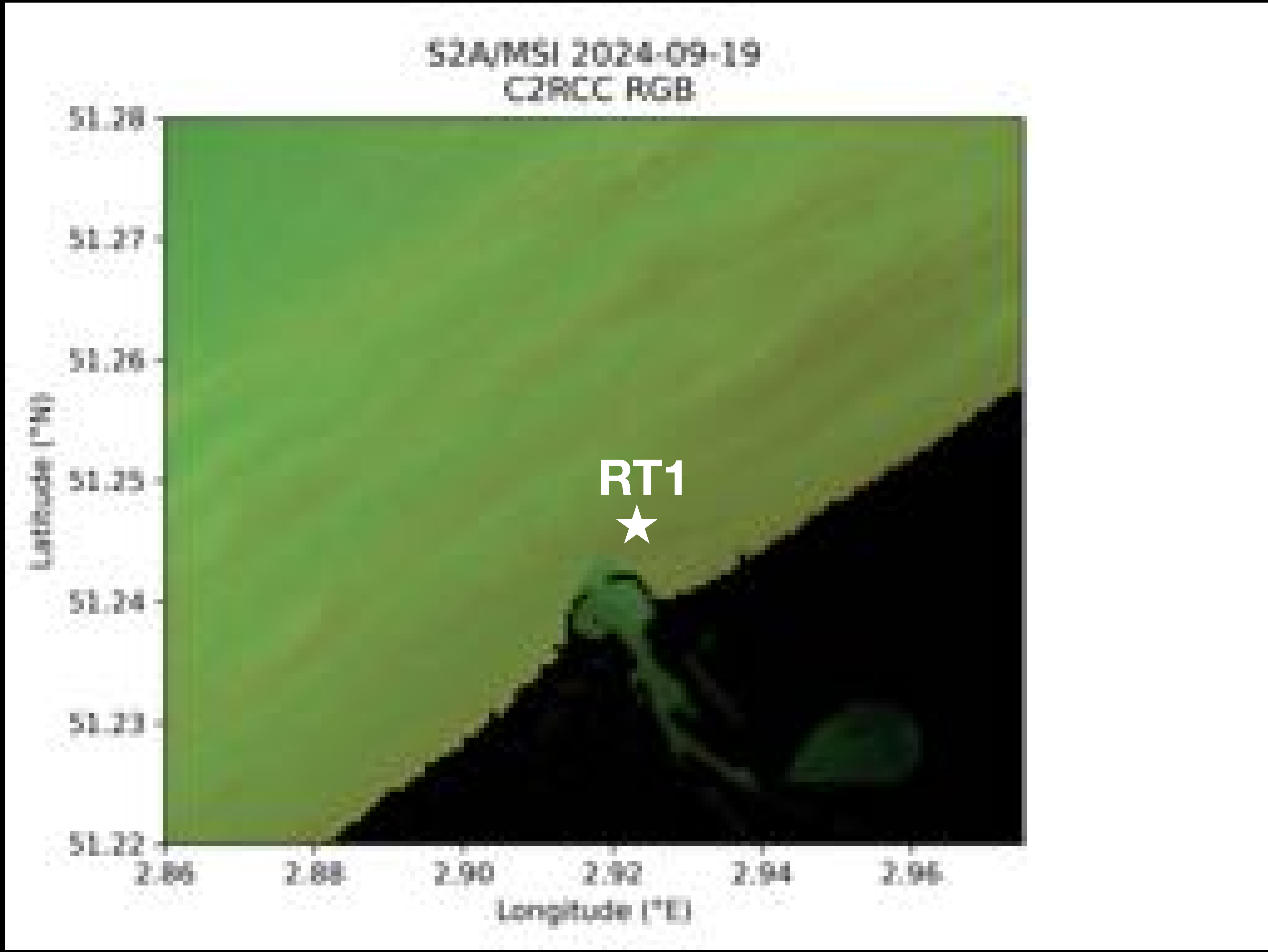


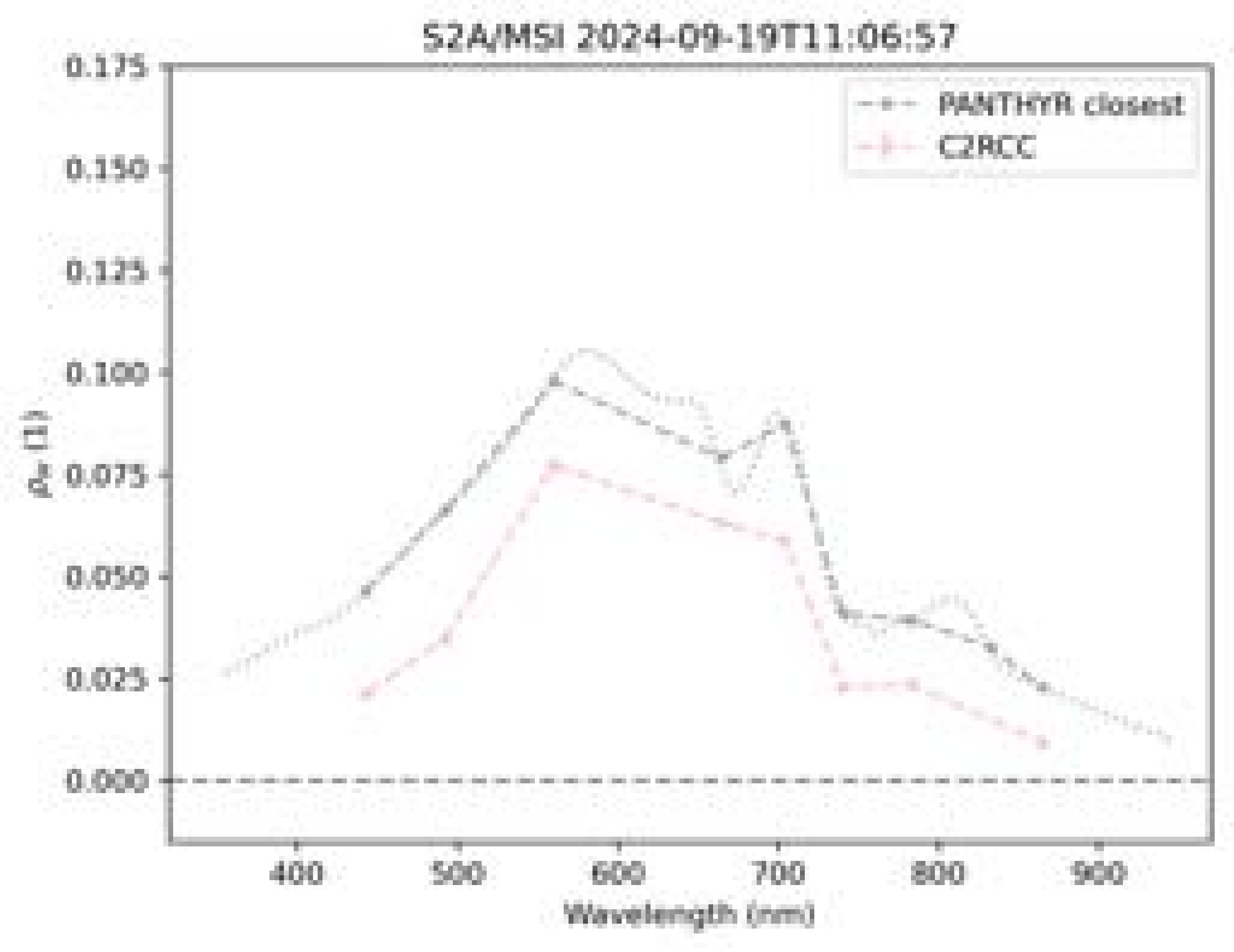


less green and a bit darker than l2gen, brown over most turbid areas

overcorrection, more flat compared to l2gen

C2RCC

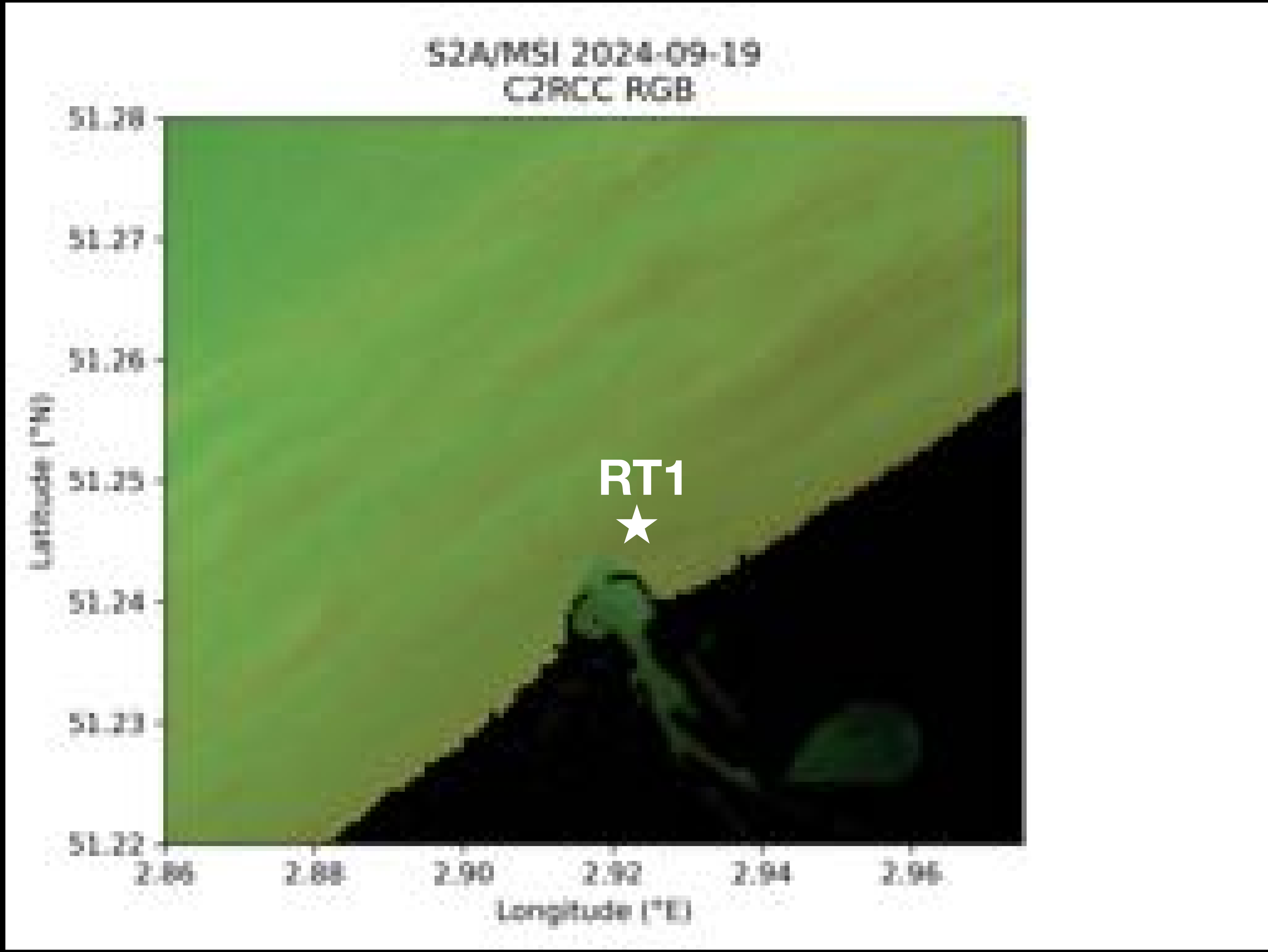


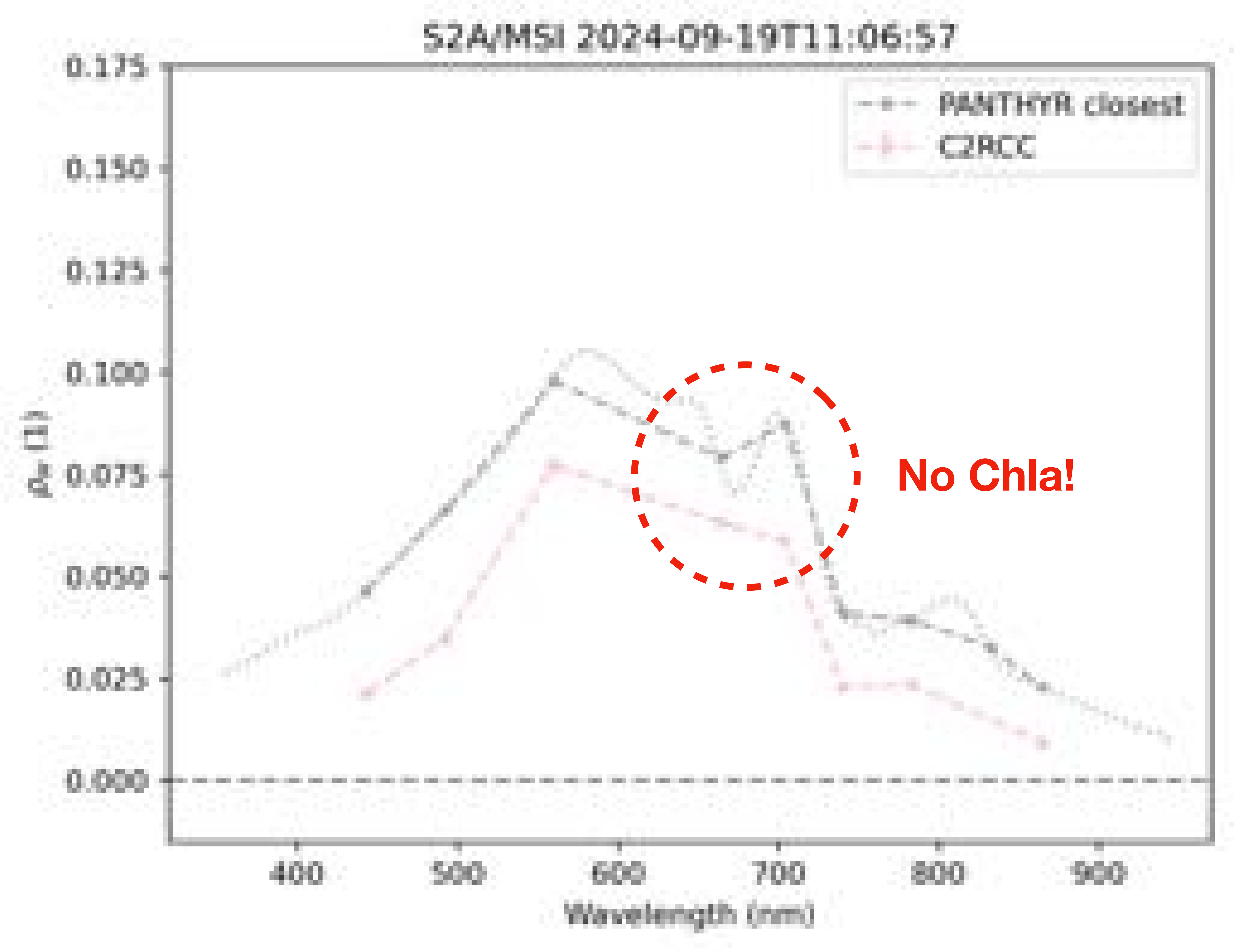


a bit brighter than l2gen/POLYMER, brown over most turbid areas

higher reflectance than l2gen/POLYMER, but red absorption feature has disappeared

C2RCC

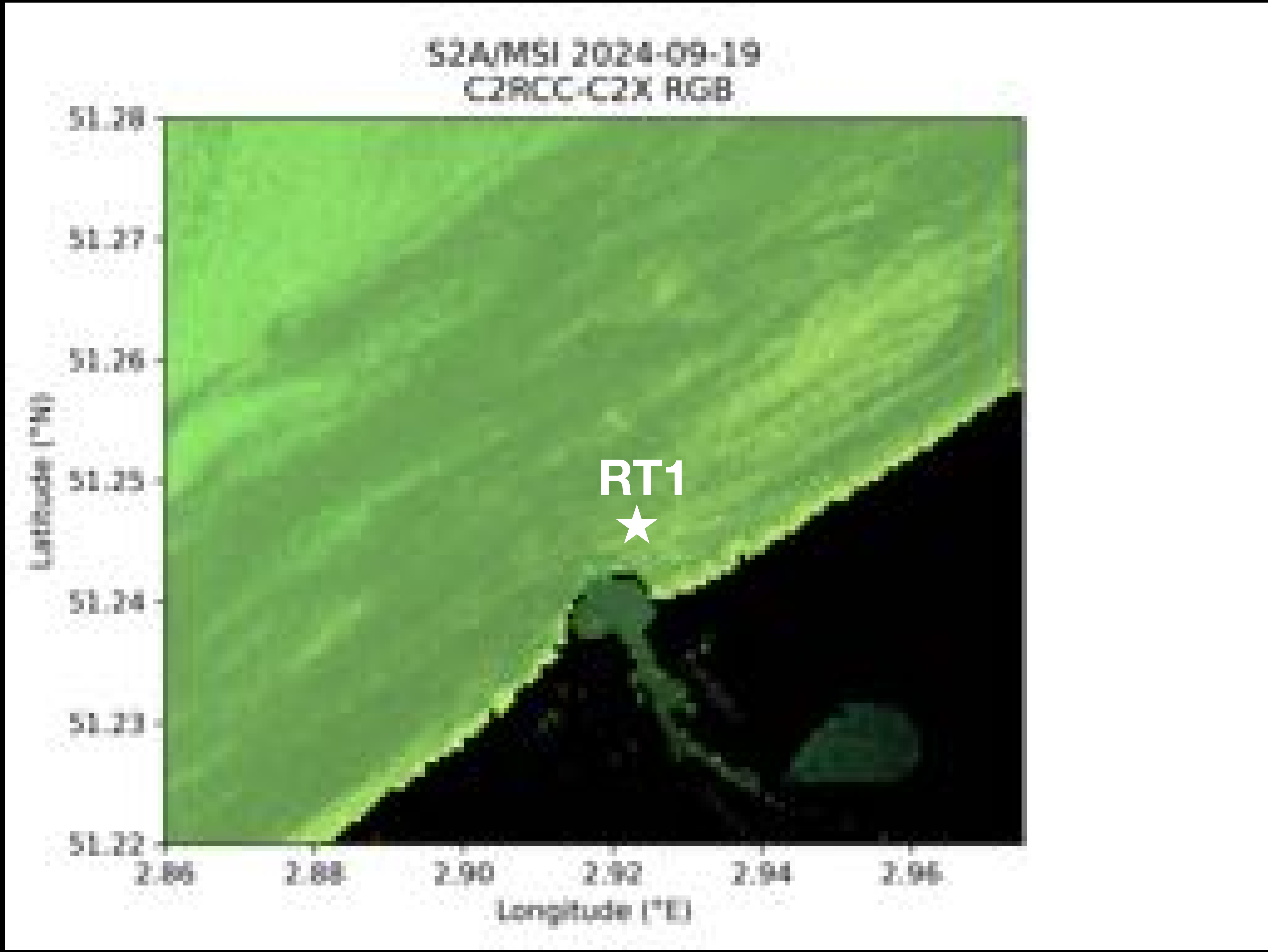


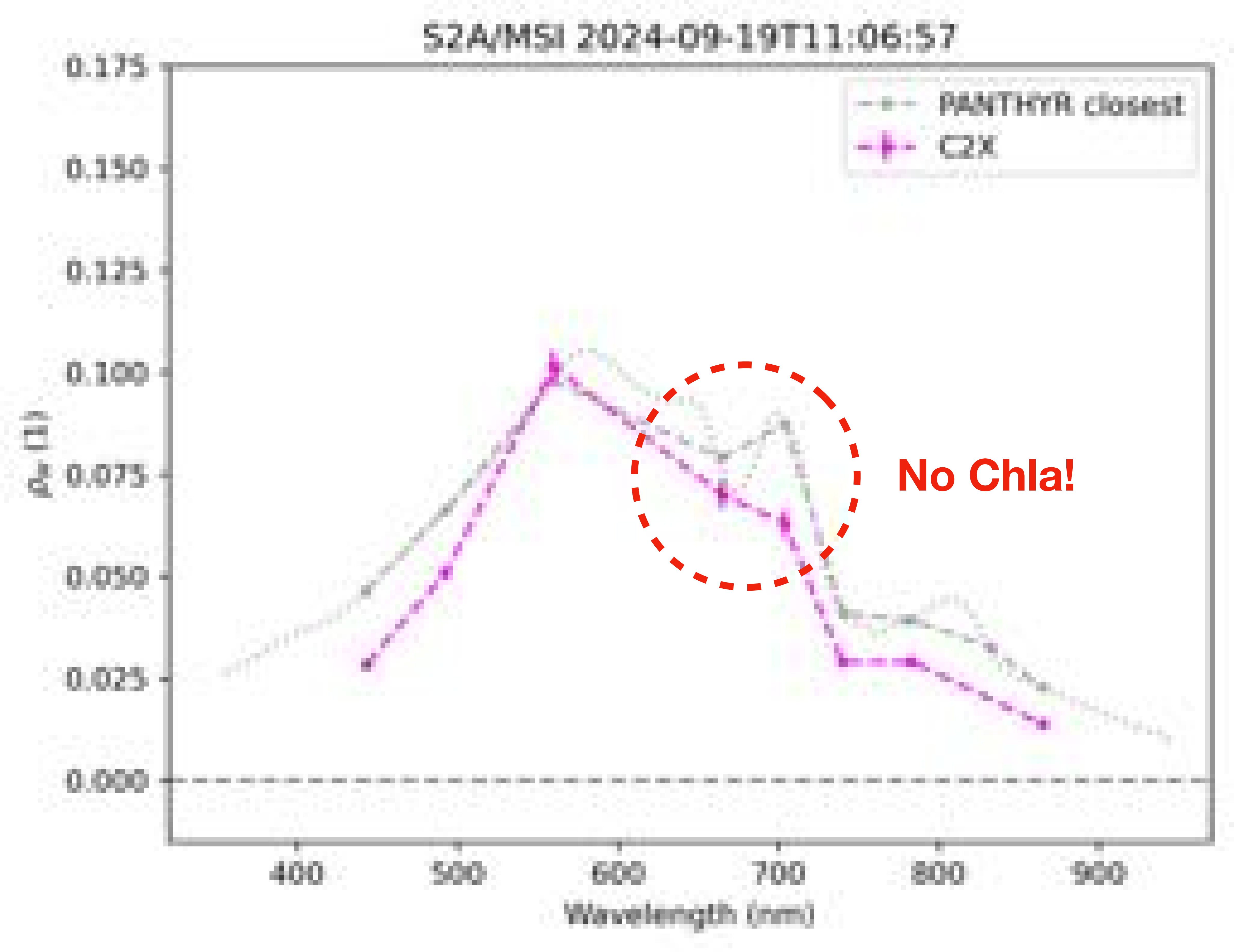


a bit brighter than l2gen/POLYMER, brown over most turbid areas

higher reflectance than l2gen/POLYMER, but red absorption feature has disappeared

C2RCC-C2X

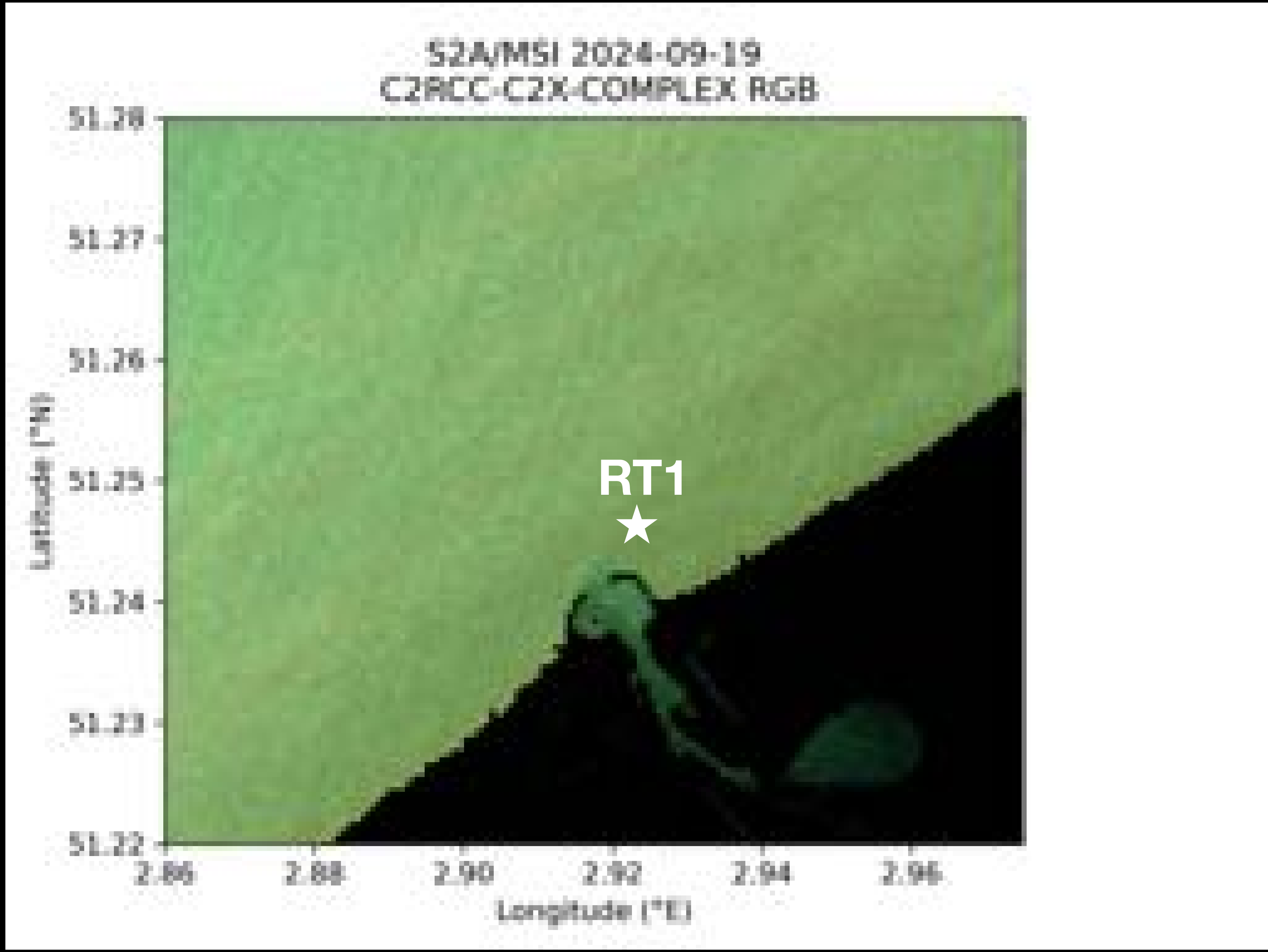


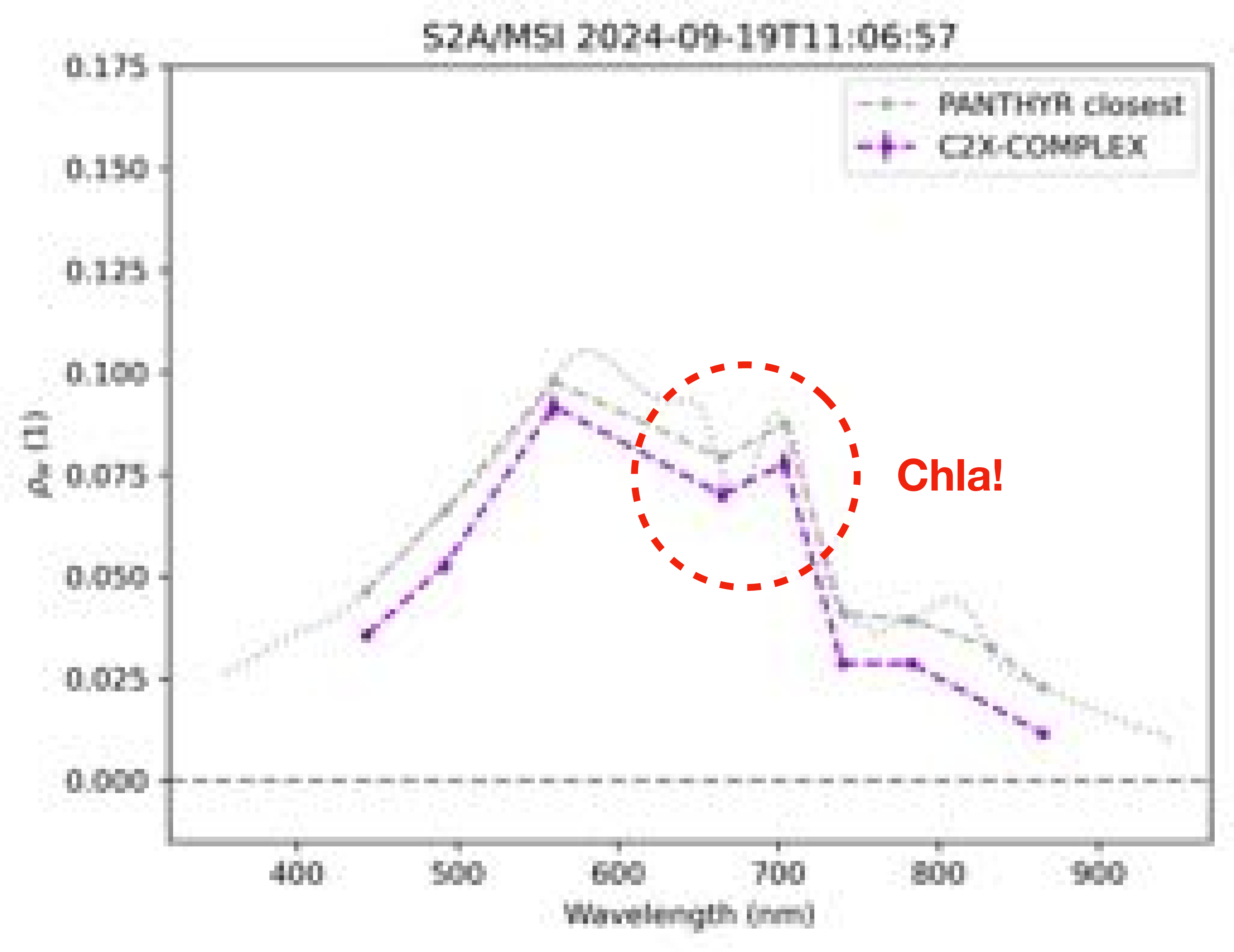


a bit brighter than C2RCC, more patchy, more noise

better fit compared to C2RCC , but red absorption feature missing

C2RCC-COMPLEX

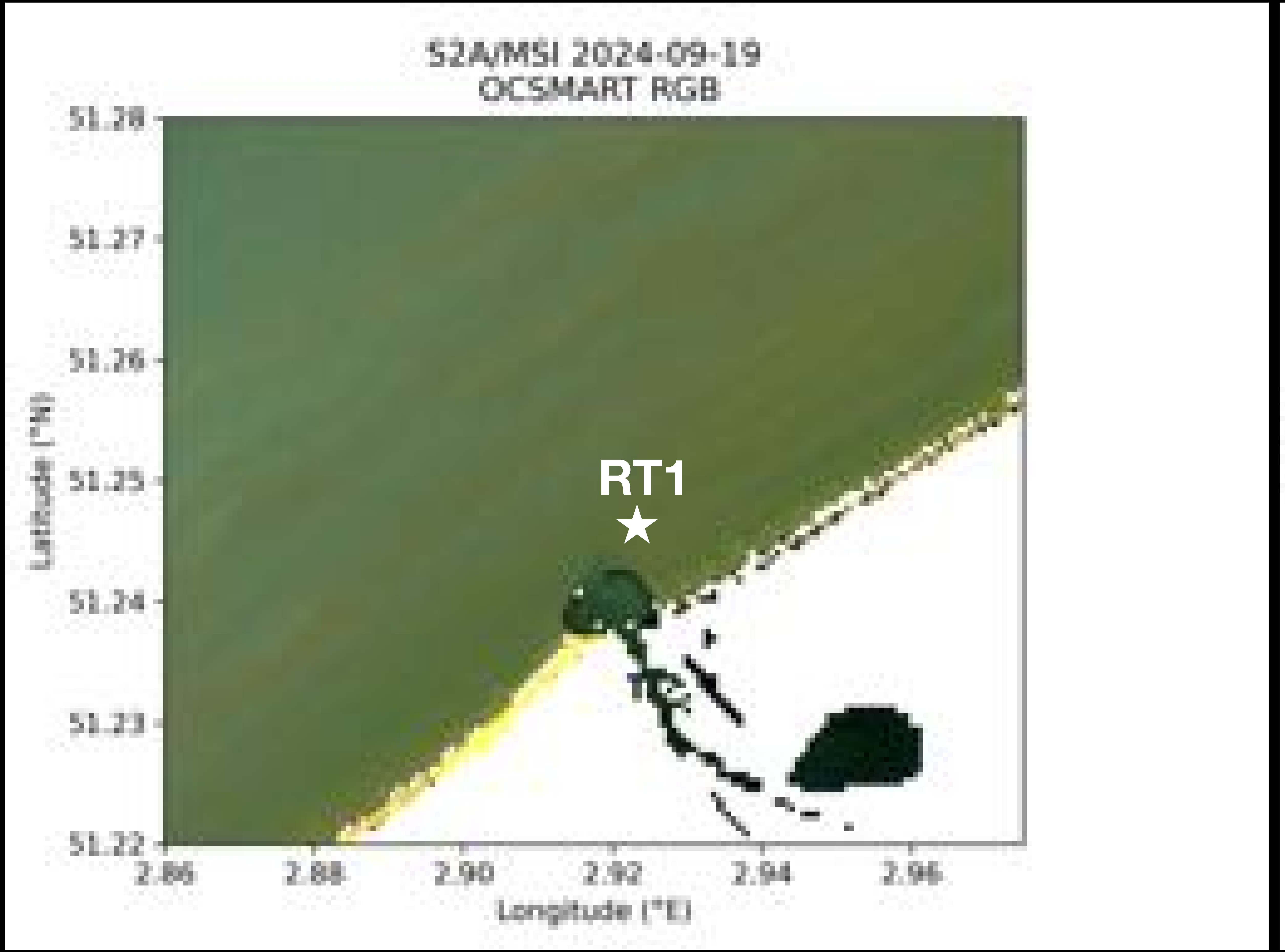


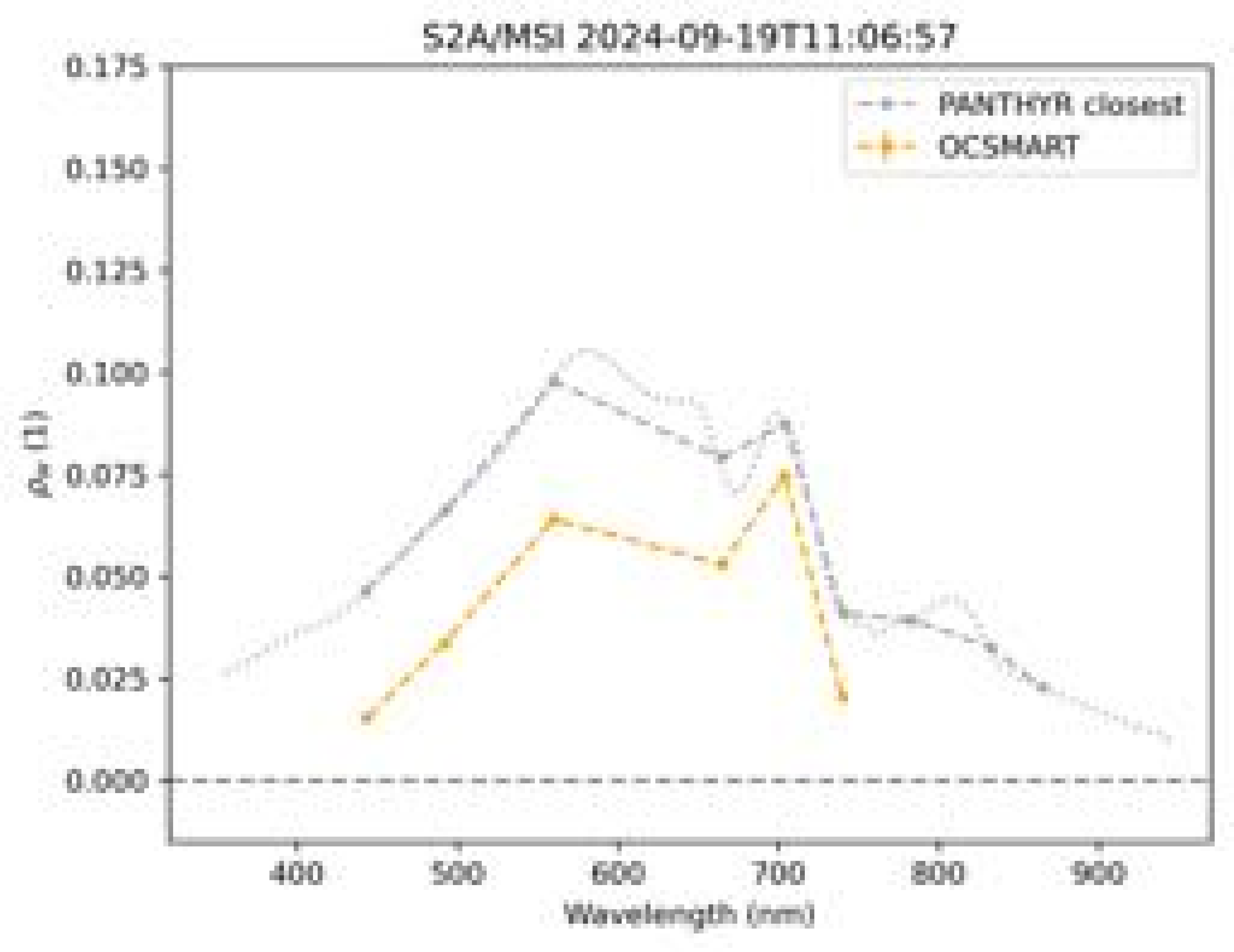


a bit brighter than C2RCC, more noise, spatial variability reduced

better fit compared to C2RCC and C2X, red absorption feature reappears

OC-SMART

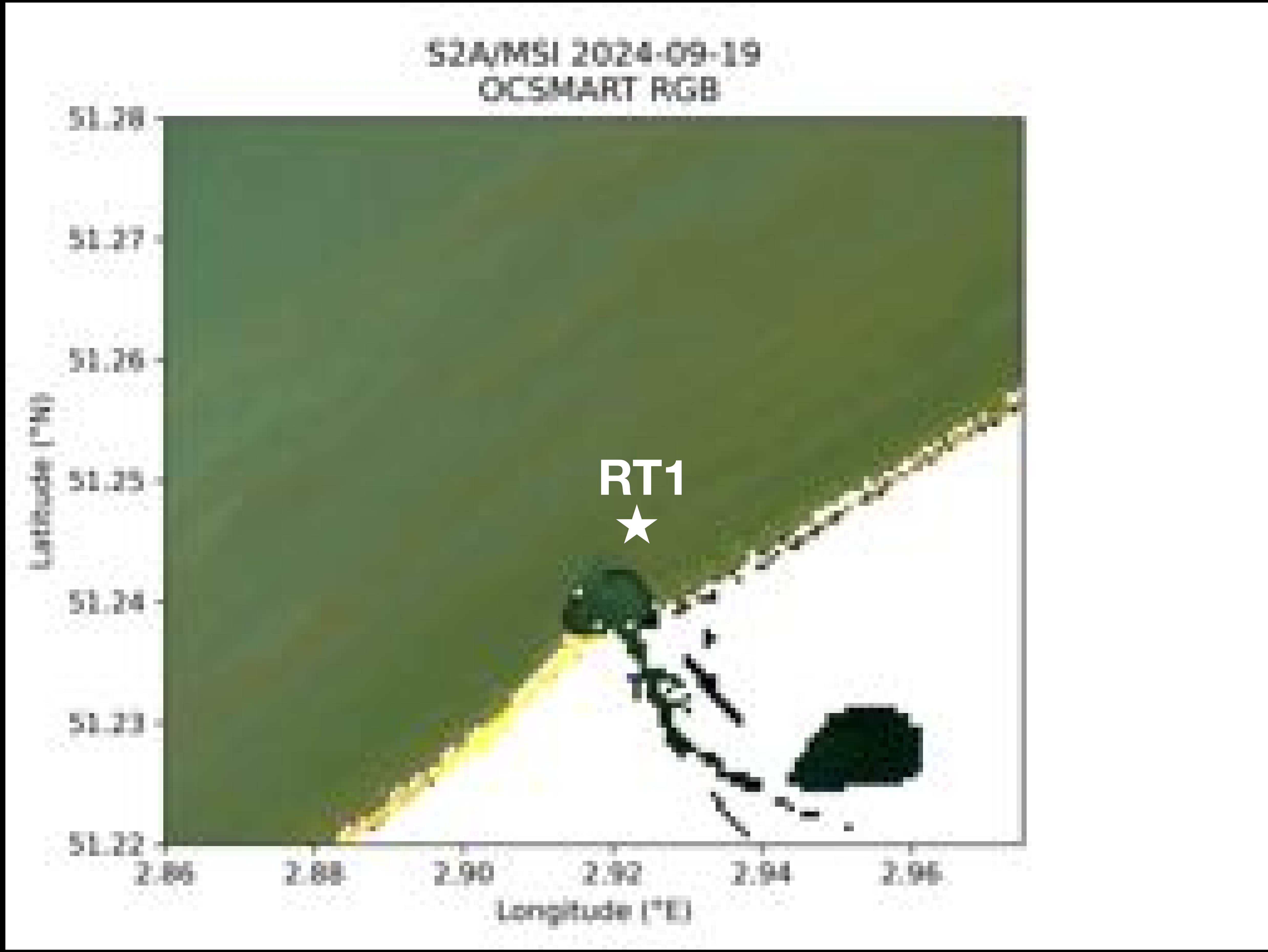


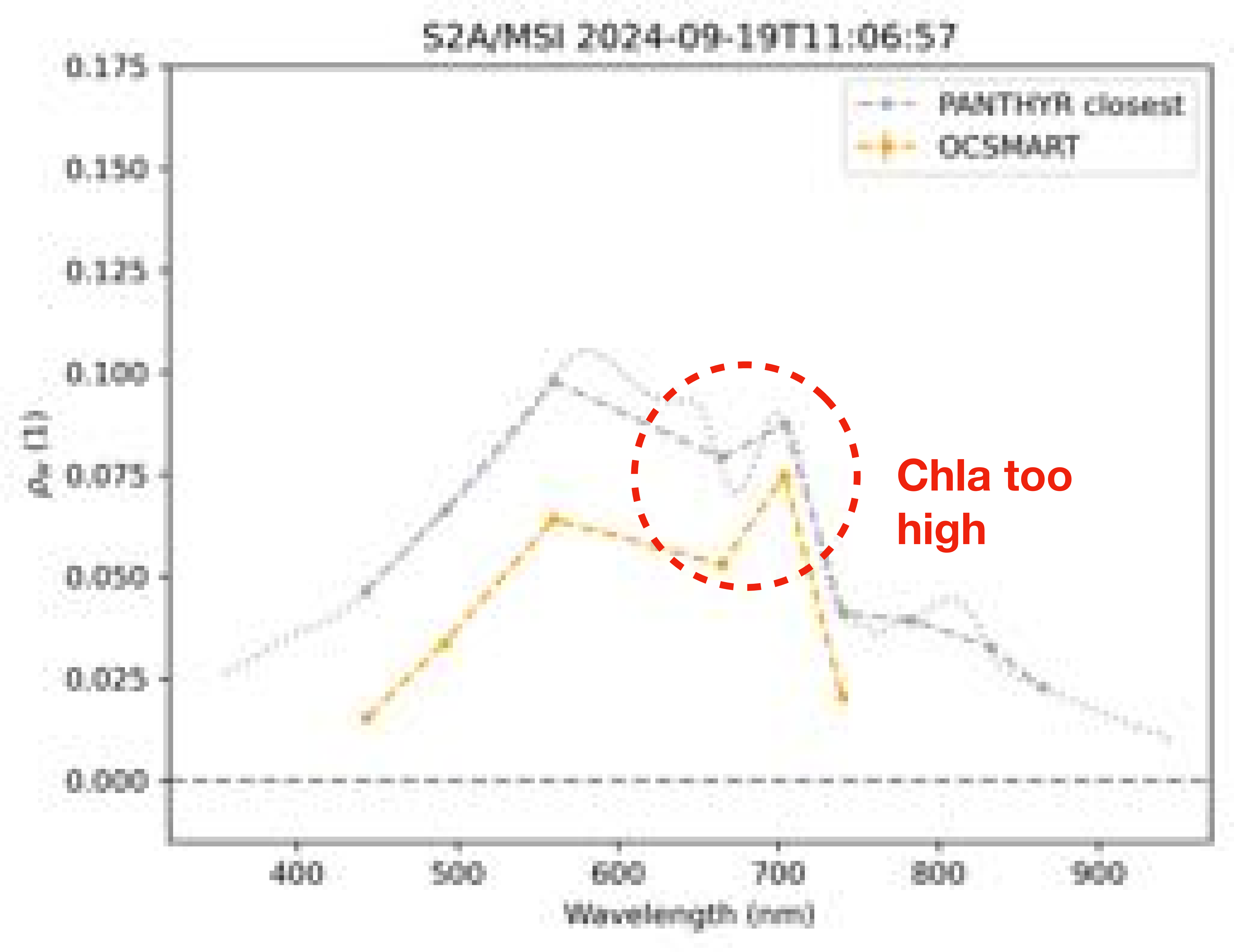


lower reflectance, comparable to POLYMER, less difference over most turbid waters

overcorrection in VIS , red absorption feature exaggerated

OC-SMART

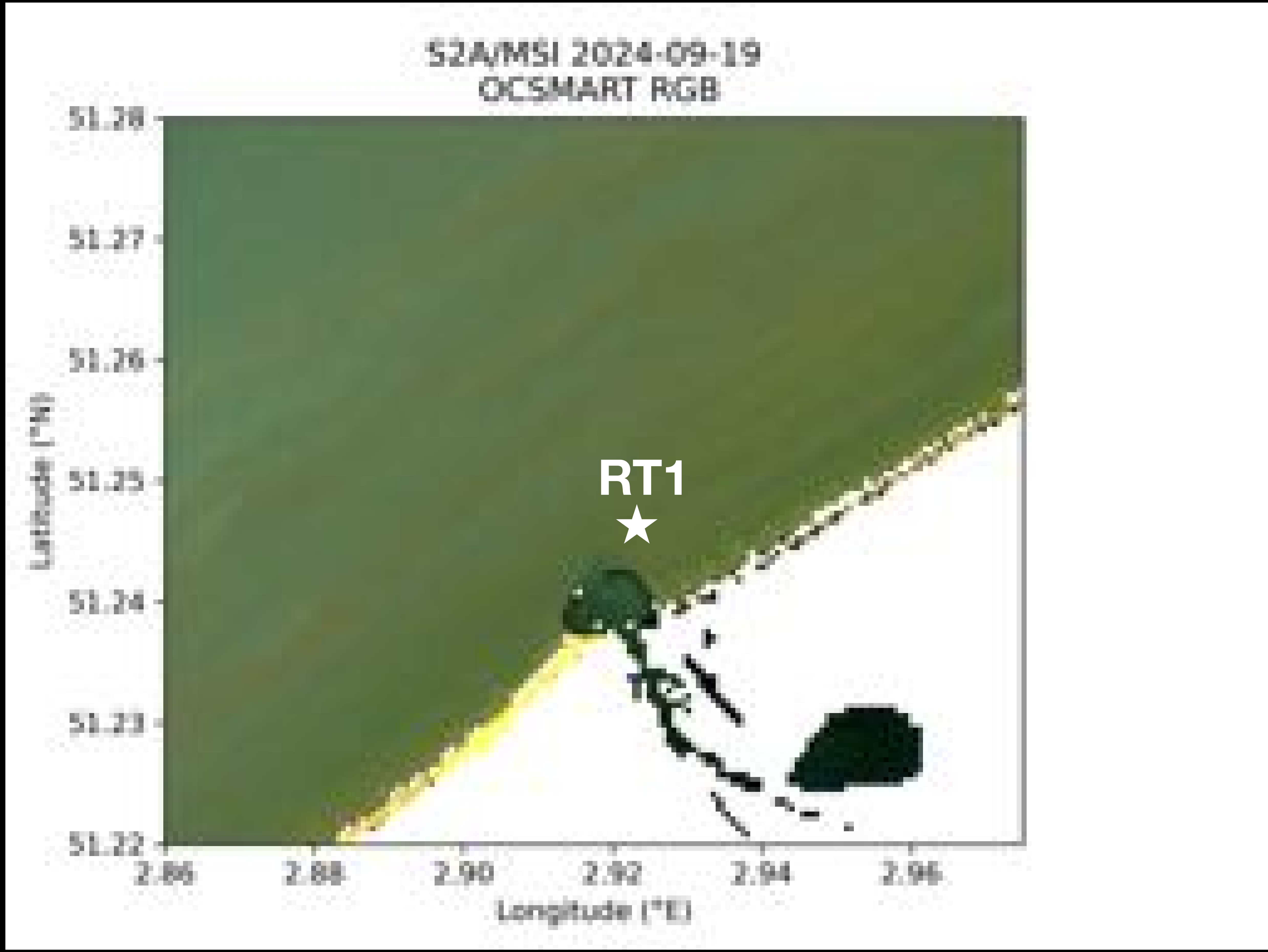


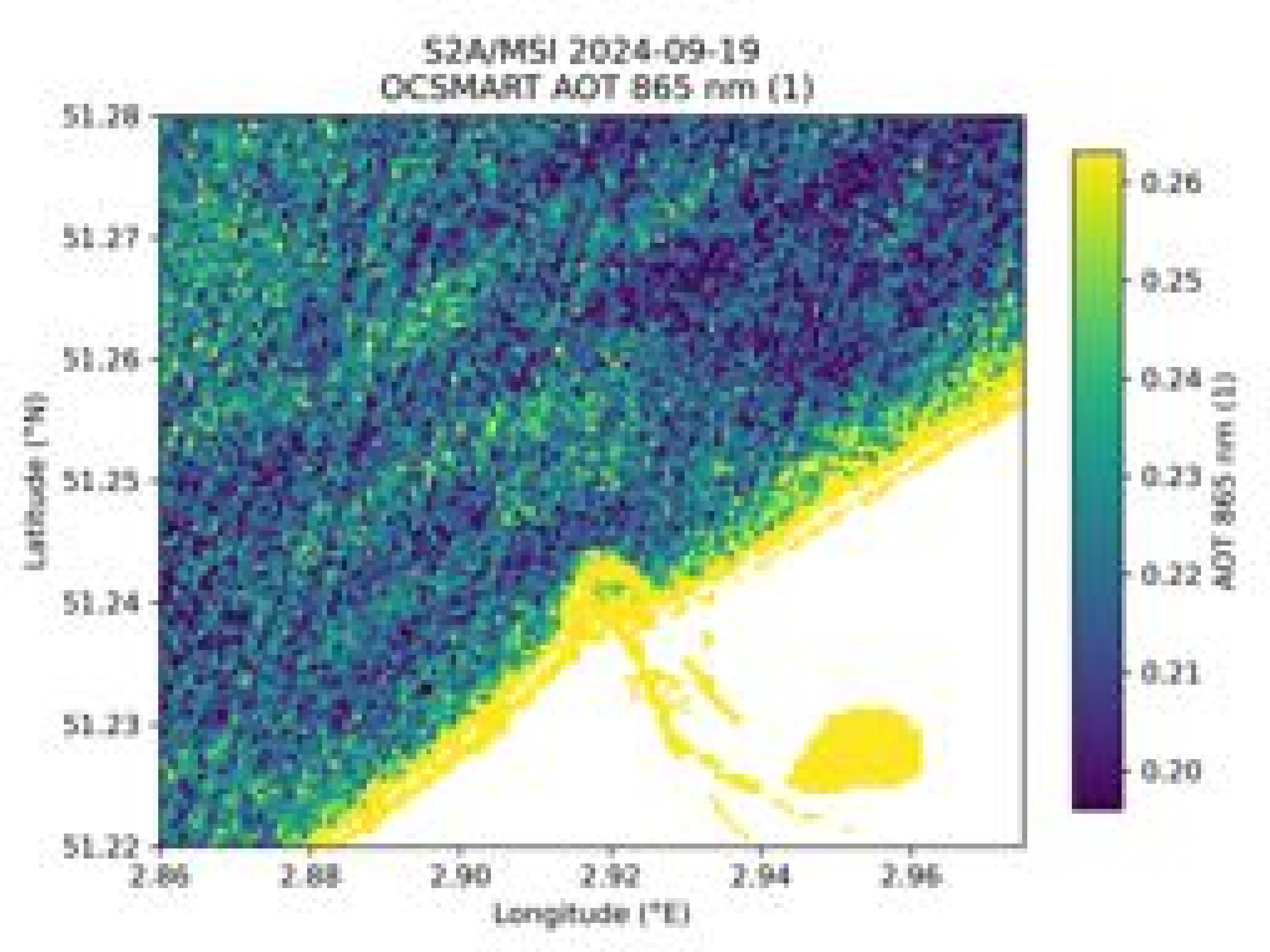


lower reflectance, comparable to POLYMER, less difference over most turbid waters

overcorrection in VIS , red absorption feature exaggerated

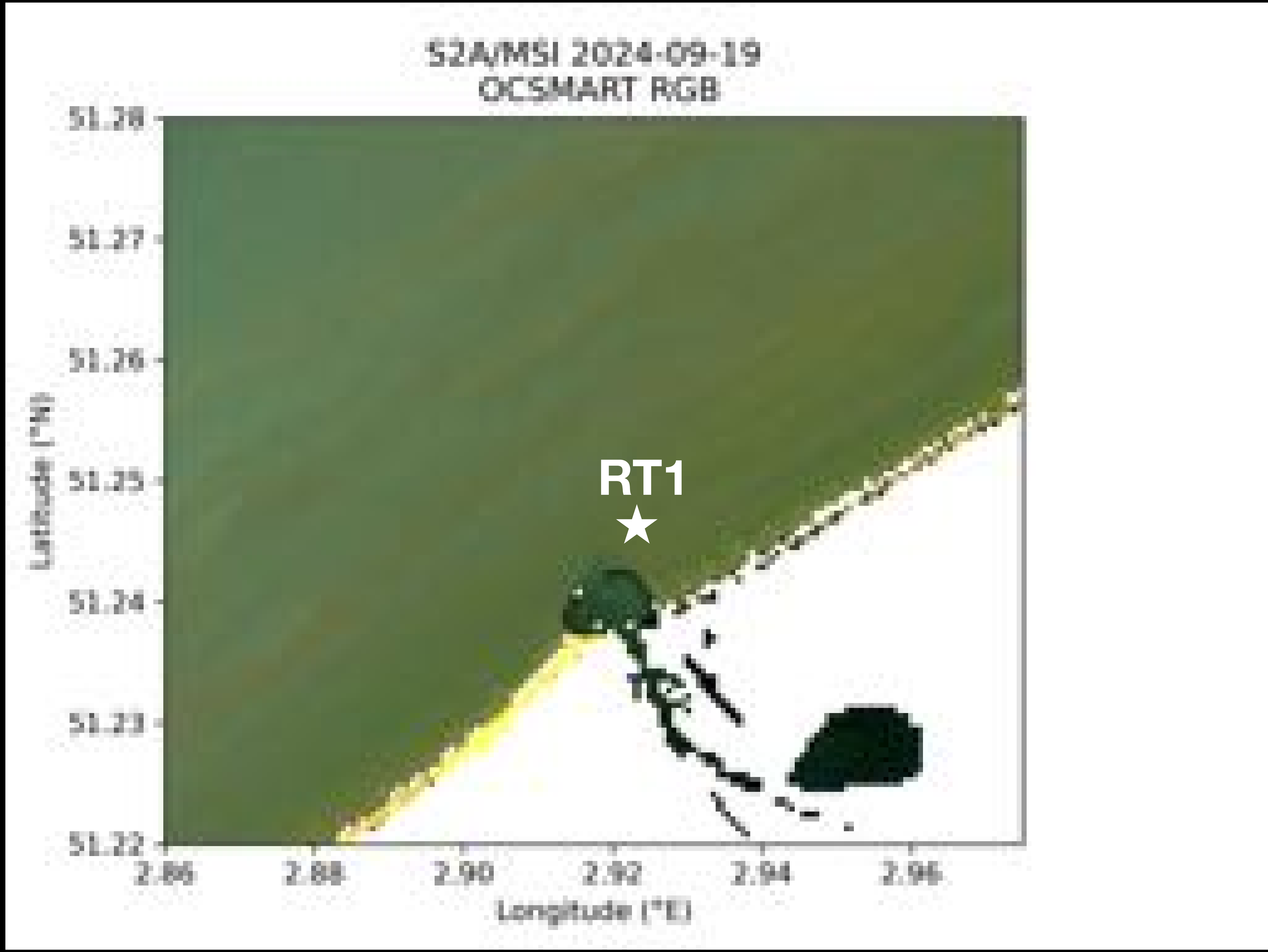
OC-SMART

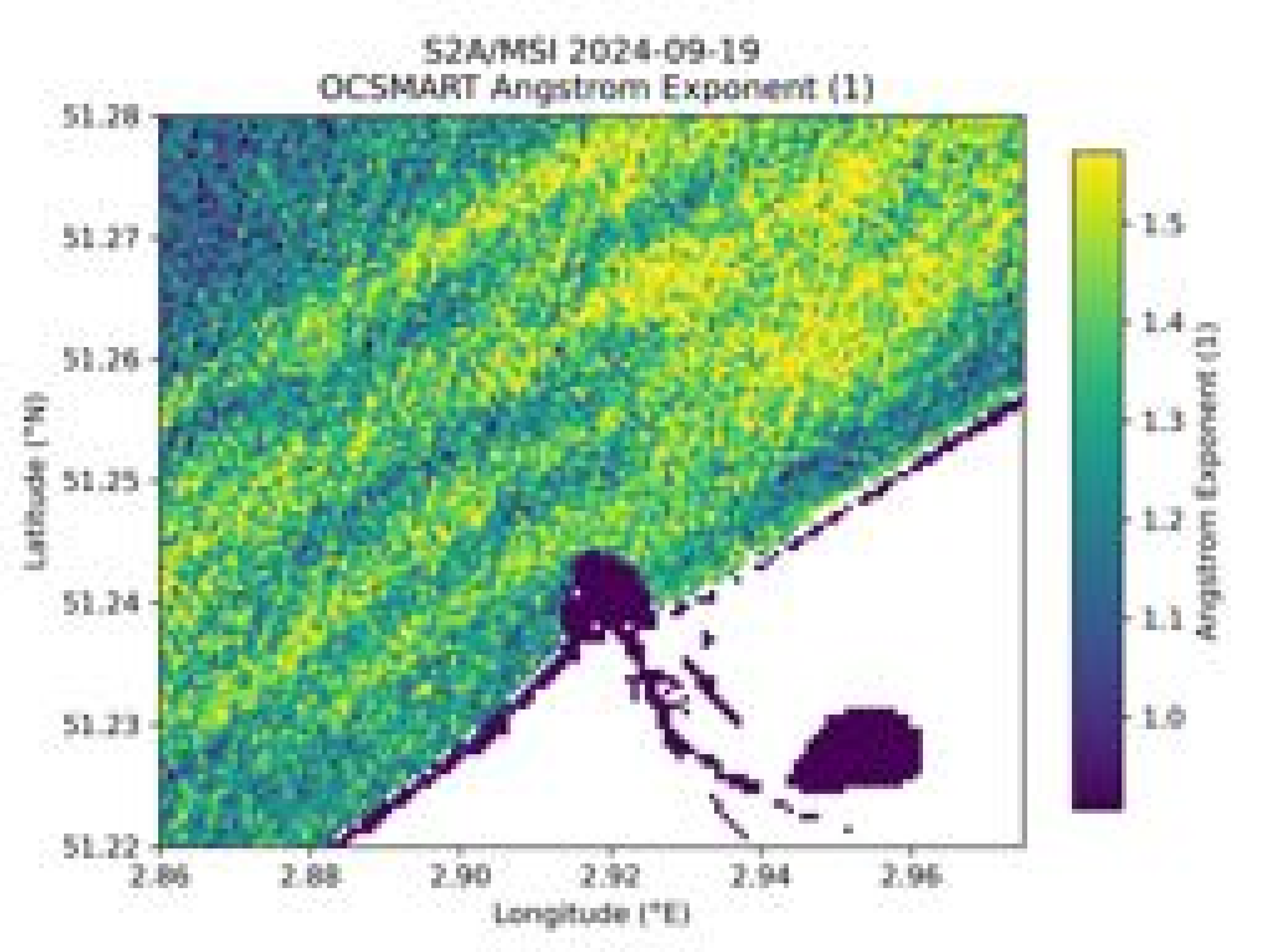




aerosol optical depth ~ some water patterns, noisy, high in the port and lake

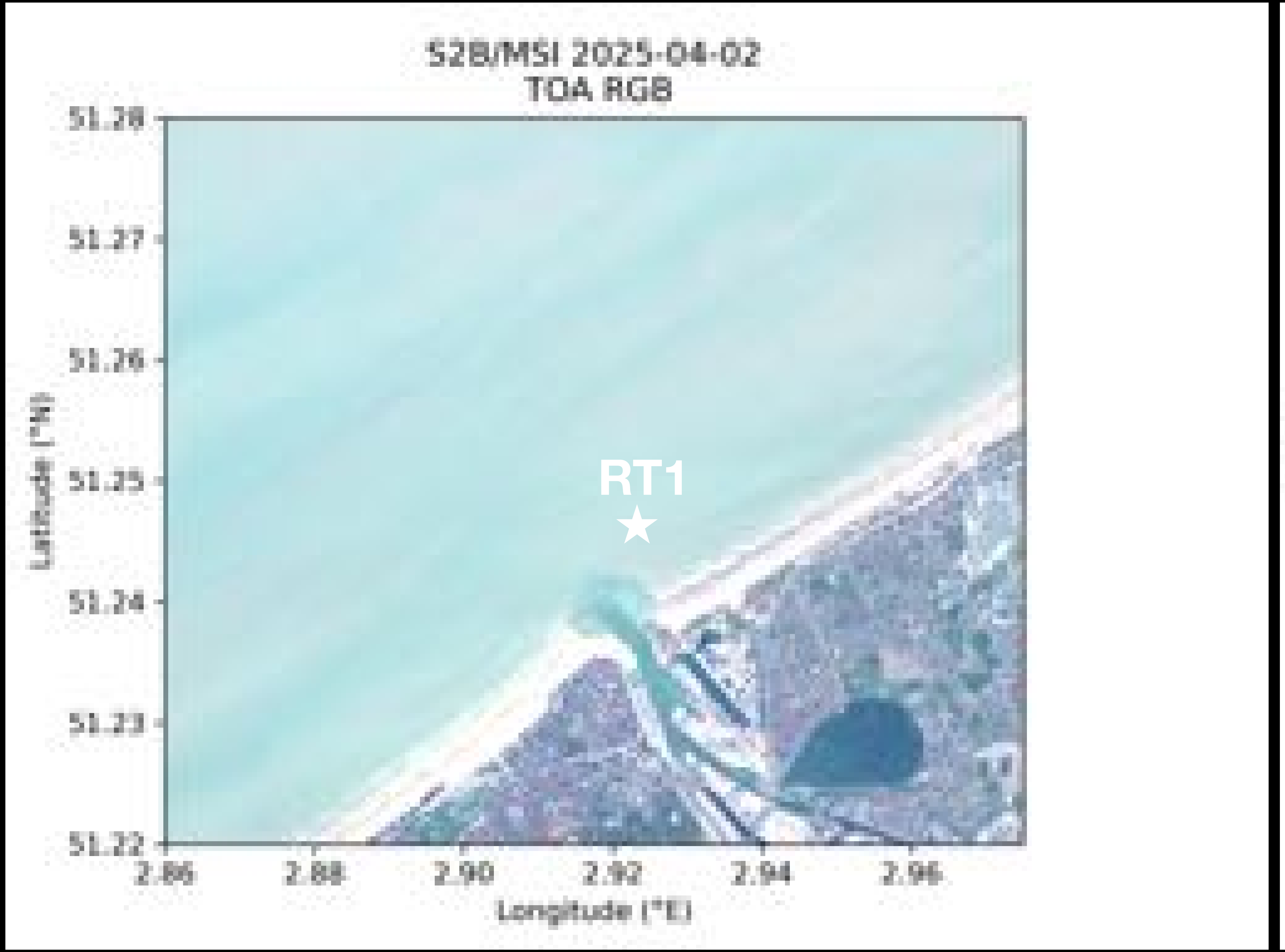
OC-SMART

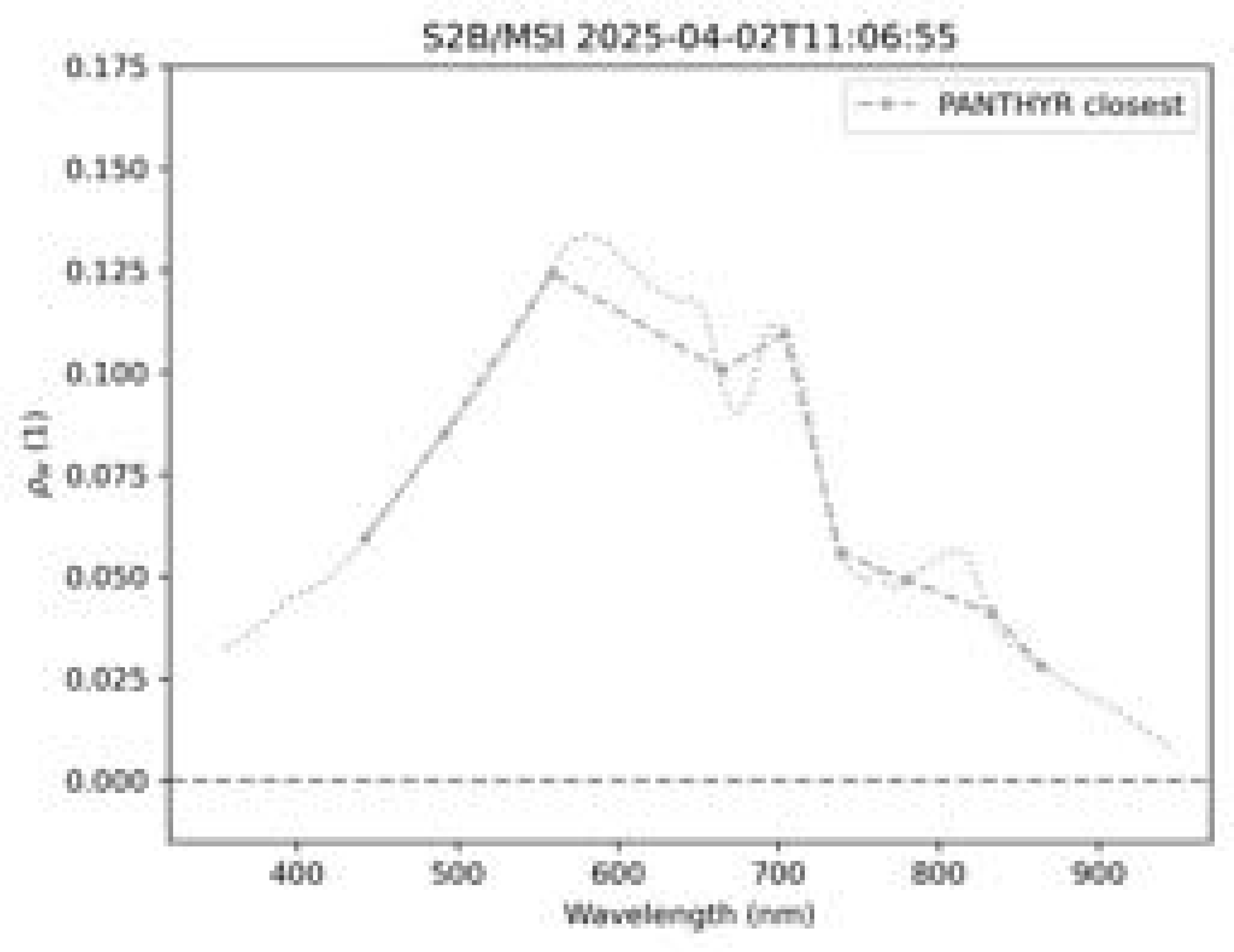




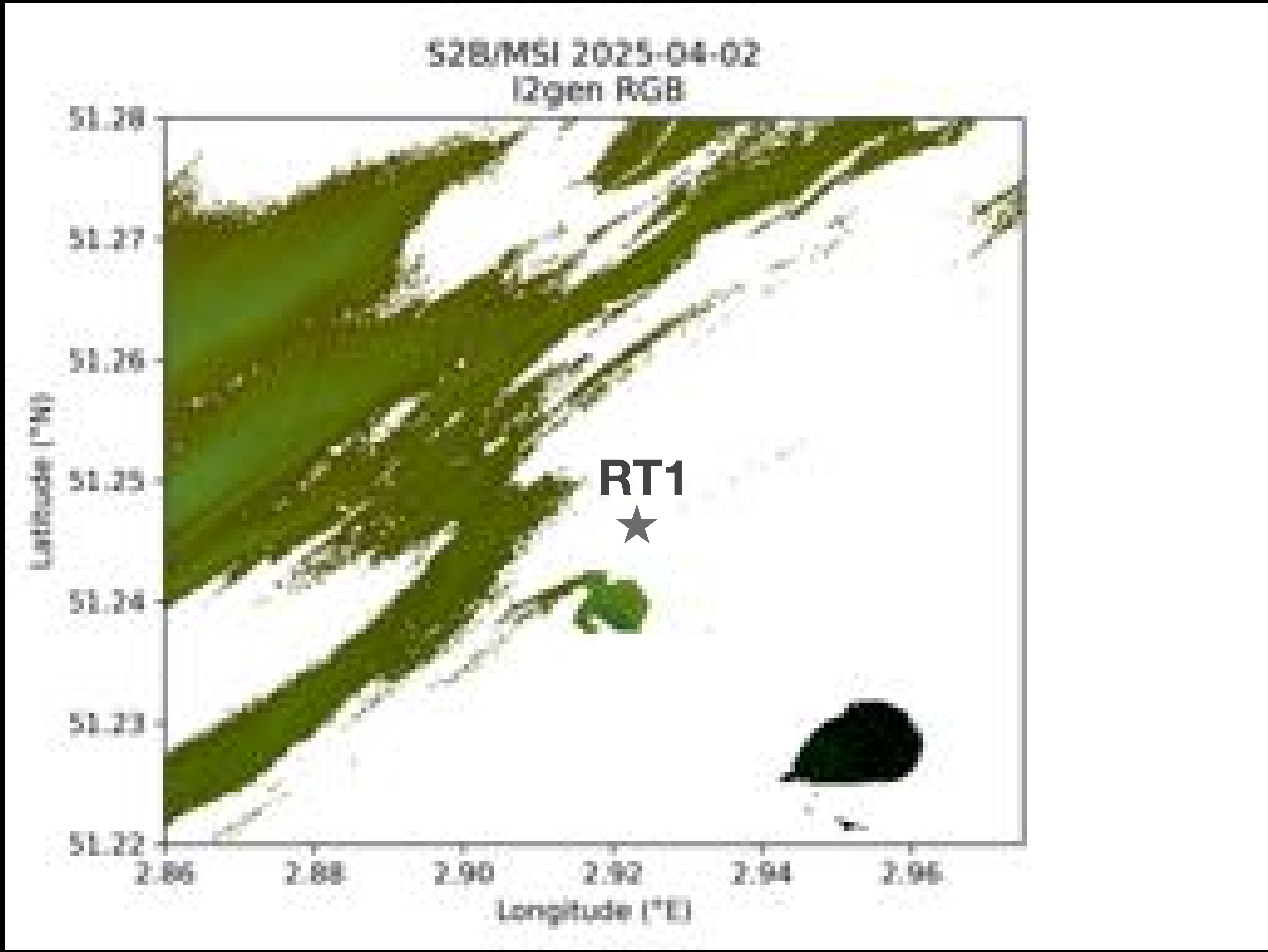
Angstrom ~ some water patterns, very low in port and lake

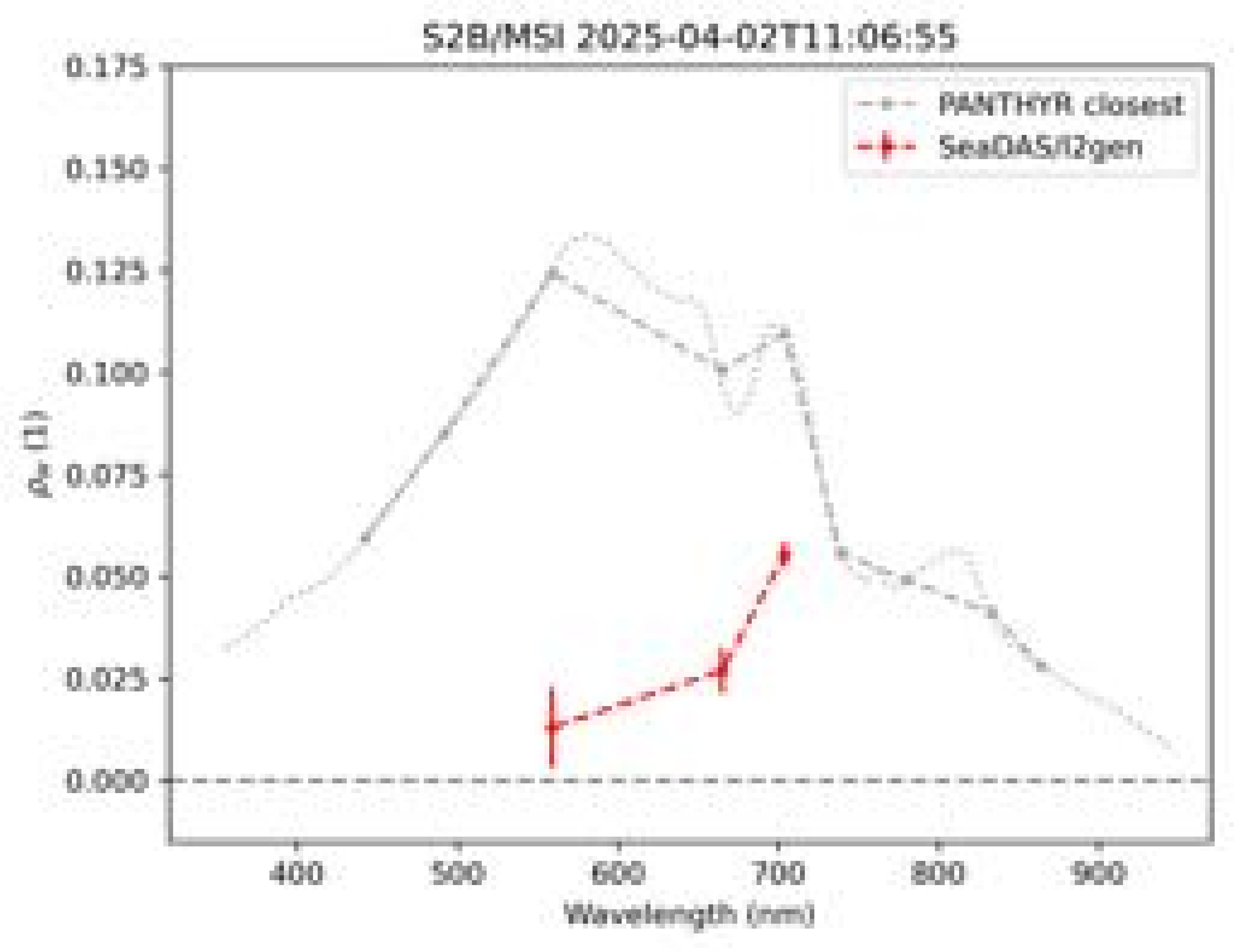
TOA 2025-04-02 PANTHYR





l2gen

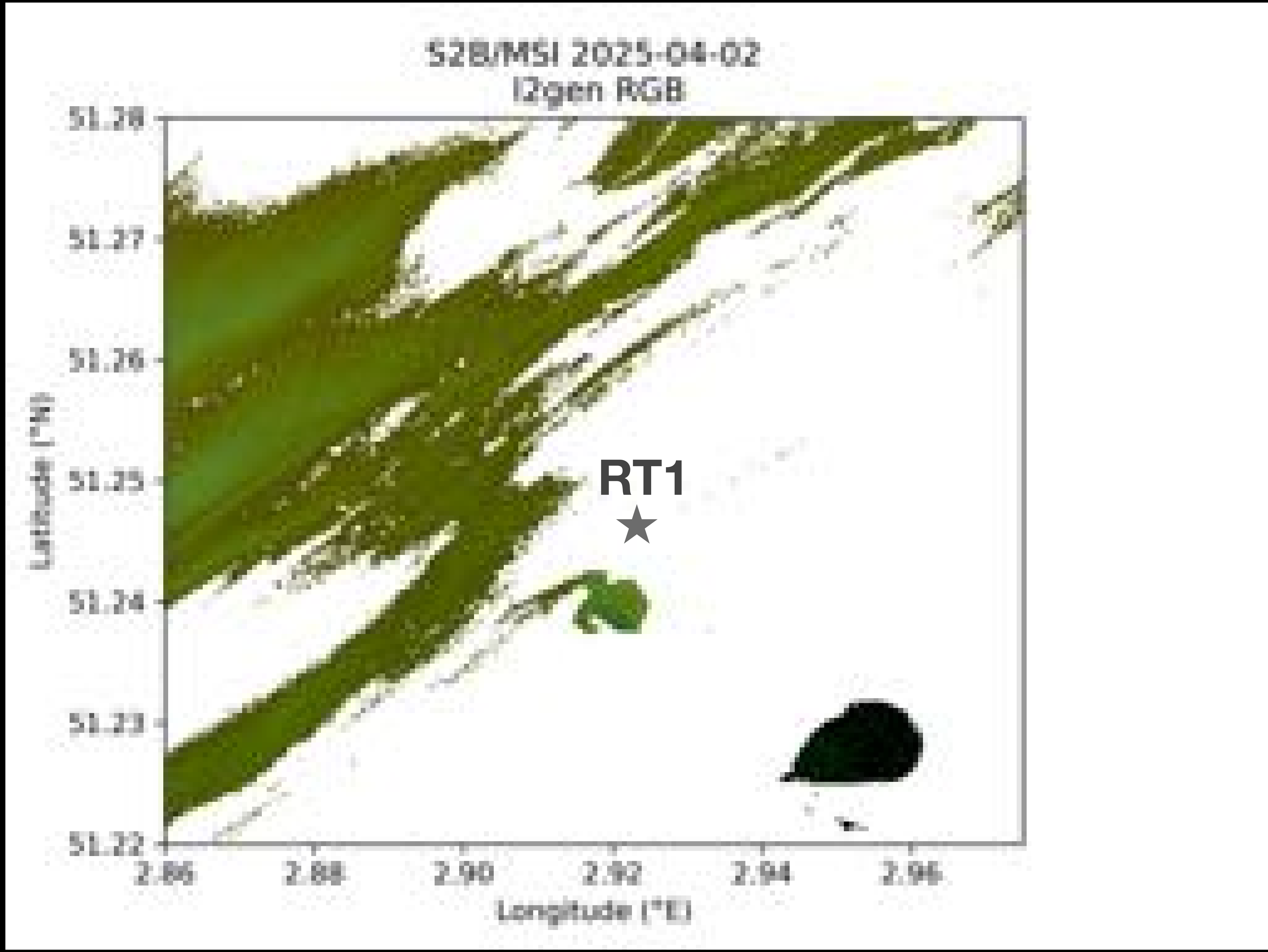


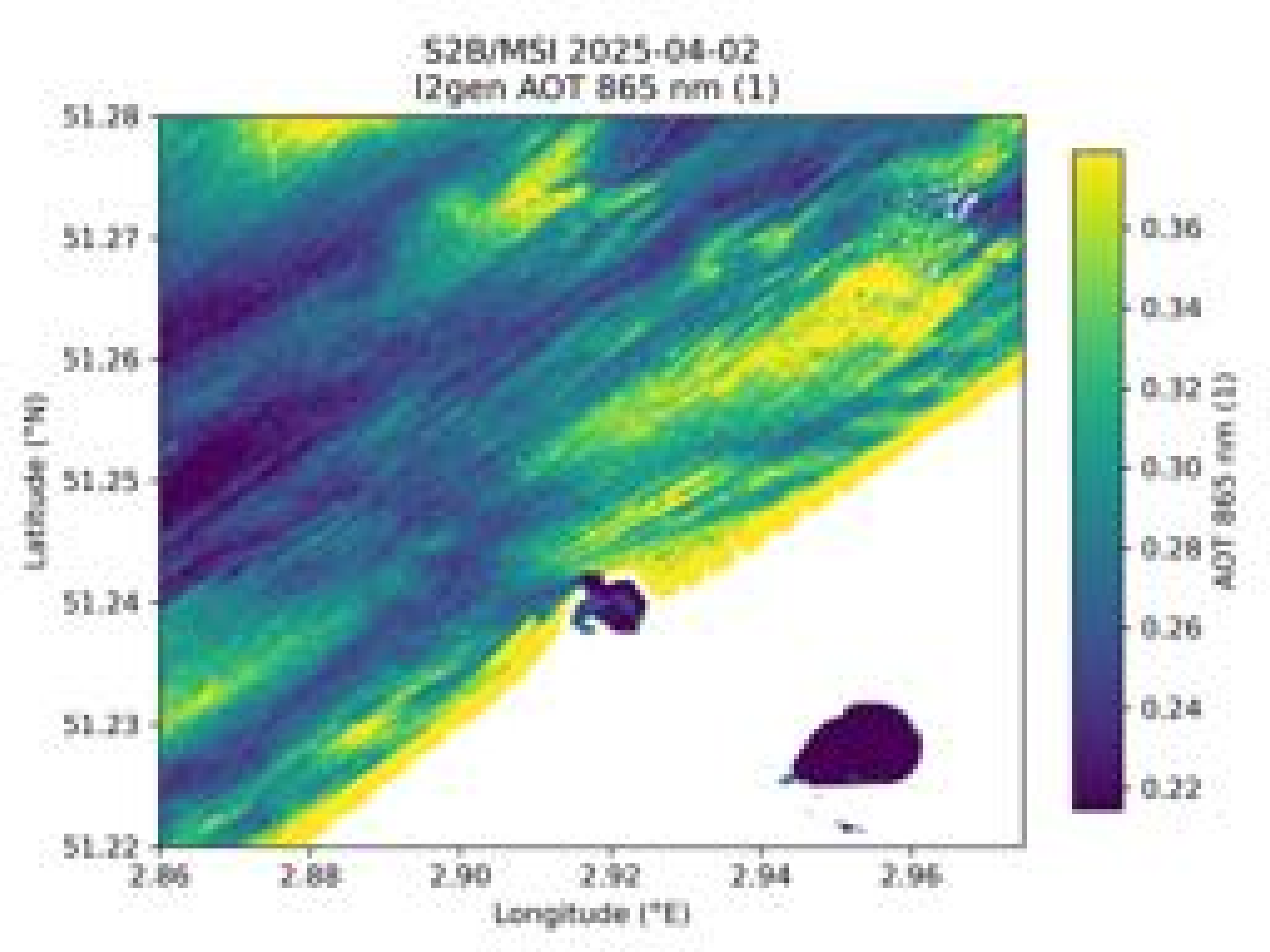


green/brown appearance, many pixels masked (Blue band << 0)

significant overcorrection

l2gen

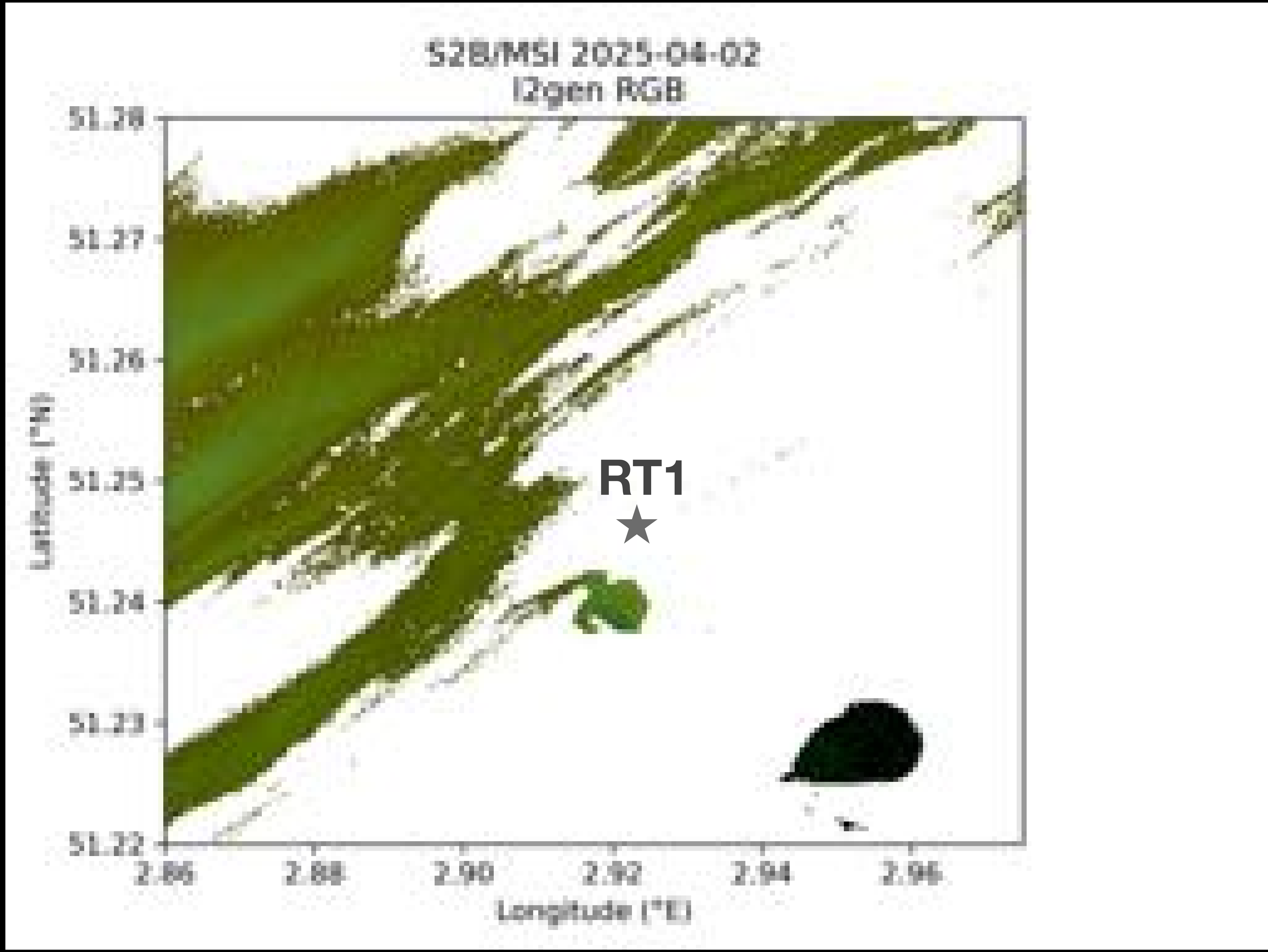


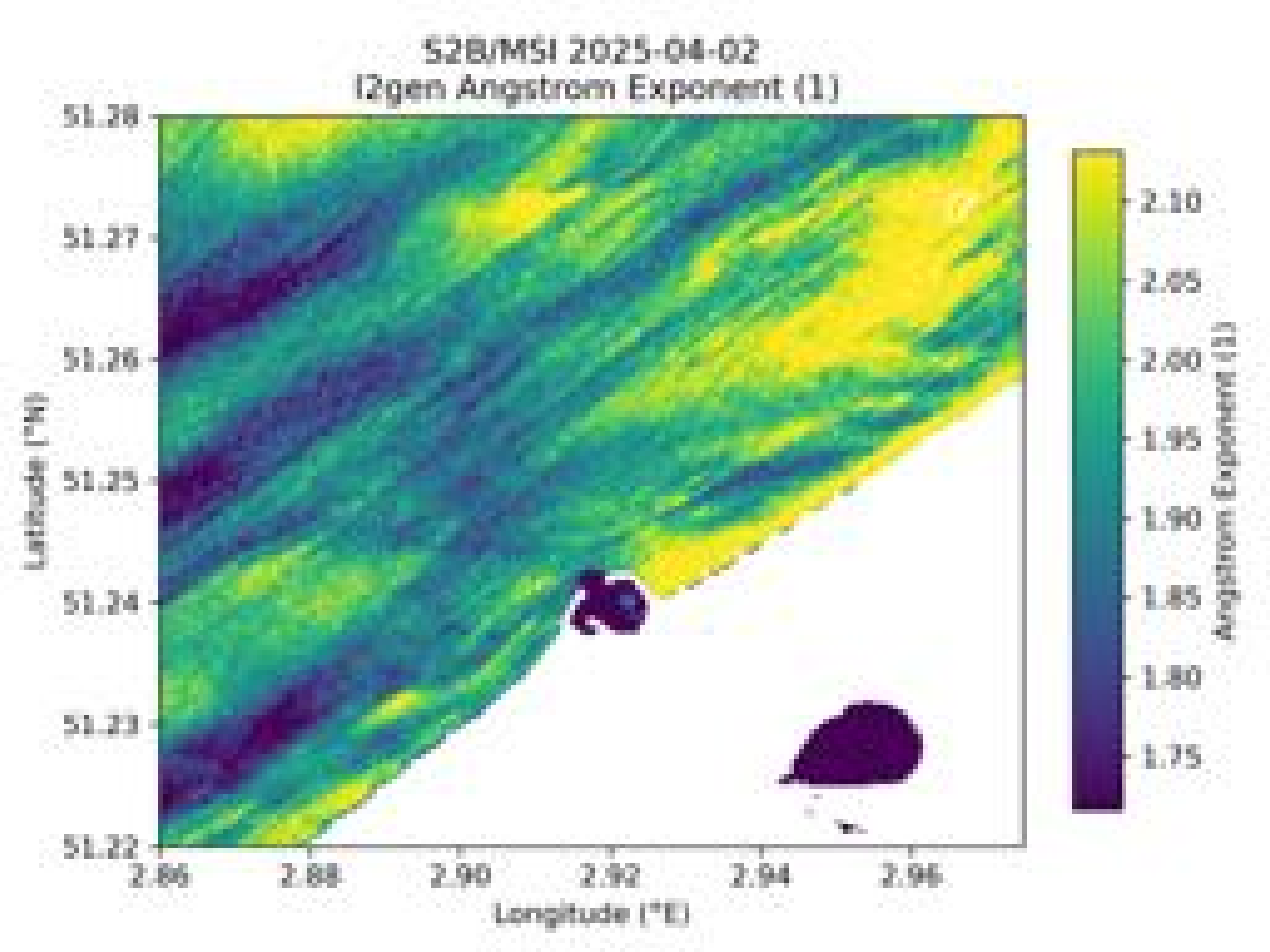


masking (blue band << 0) ~ high aerosol optical depth

aerosol optical depth ~ water turbidity

l2gen

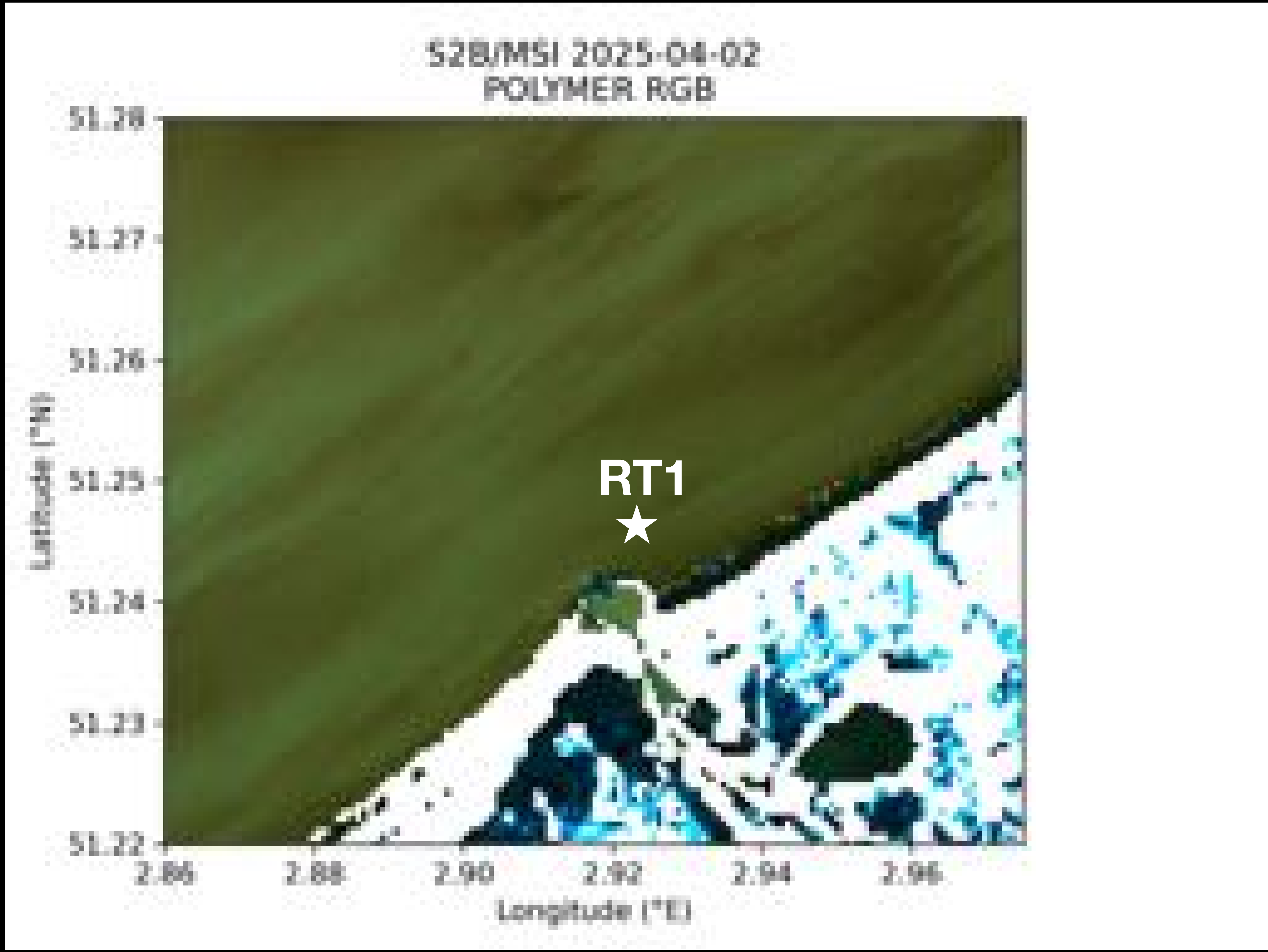


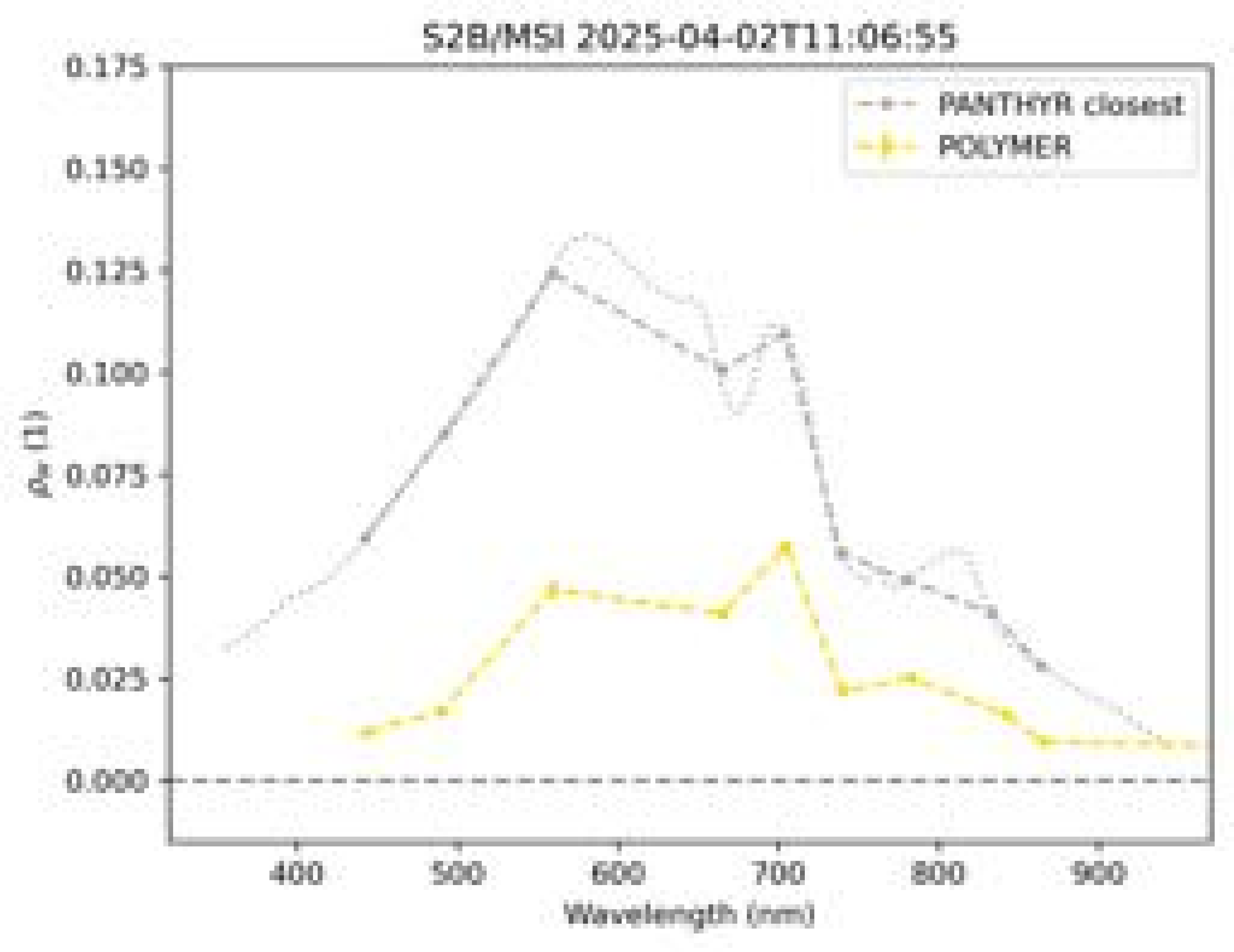


masking (blue band << 0) ~ high aerosol angstrom

Angstrom ~ water turbidity

POLYMER

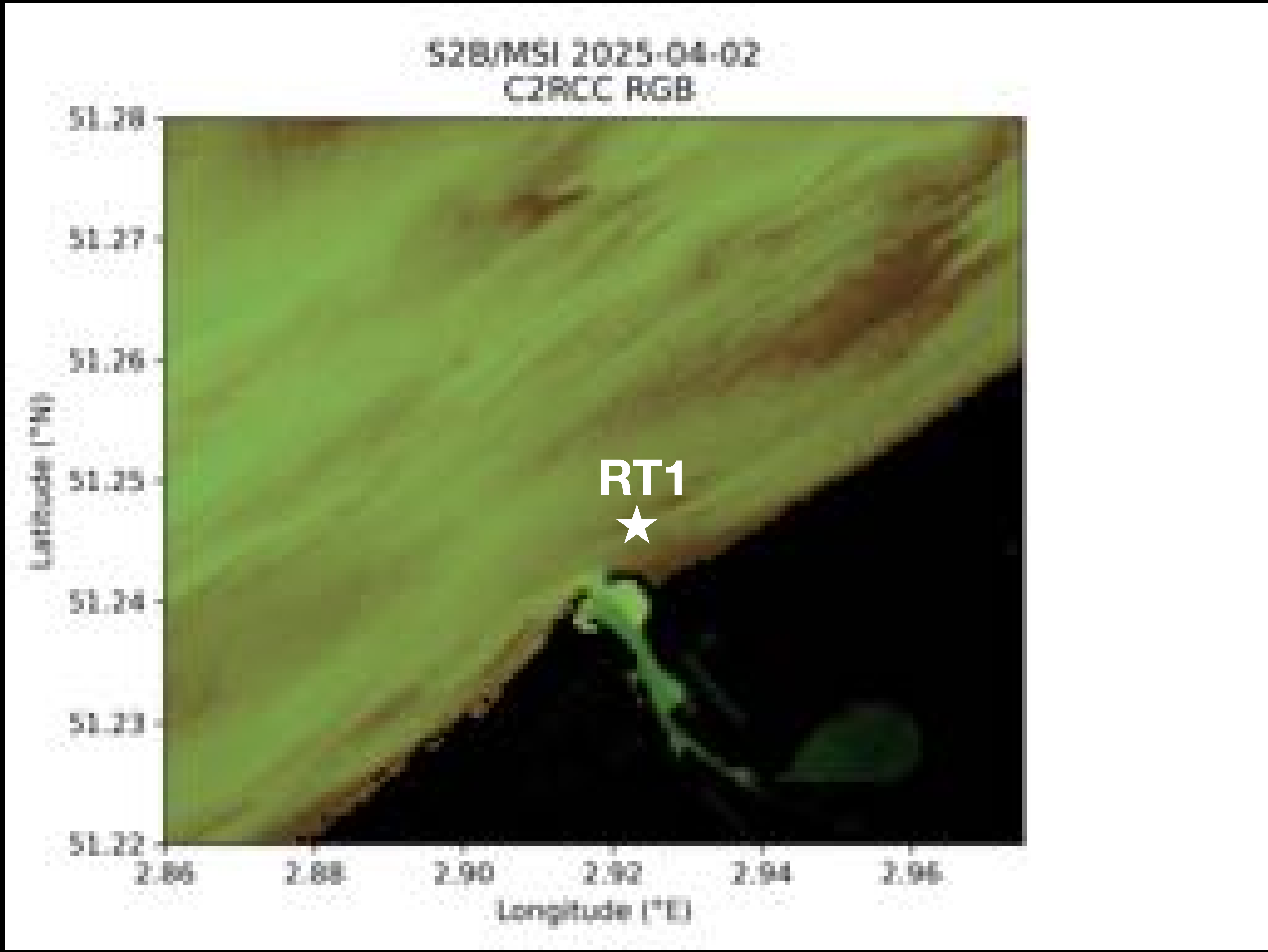


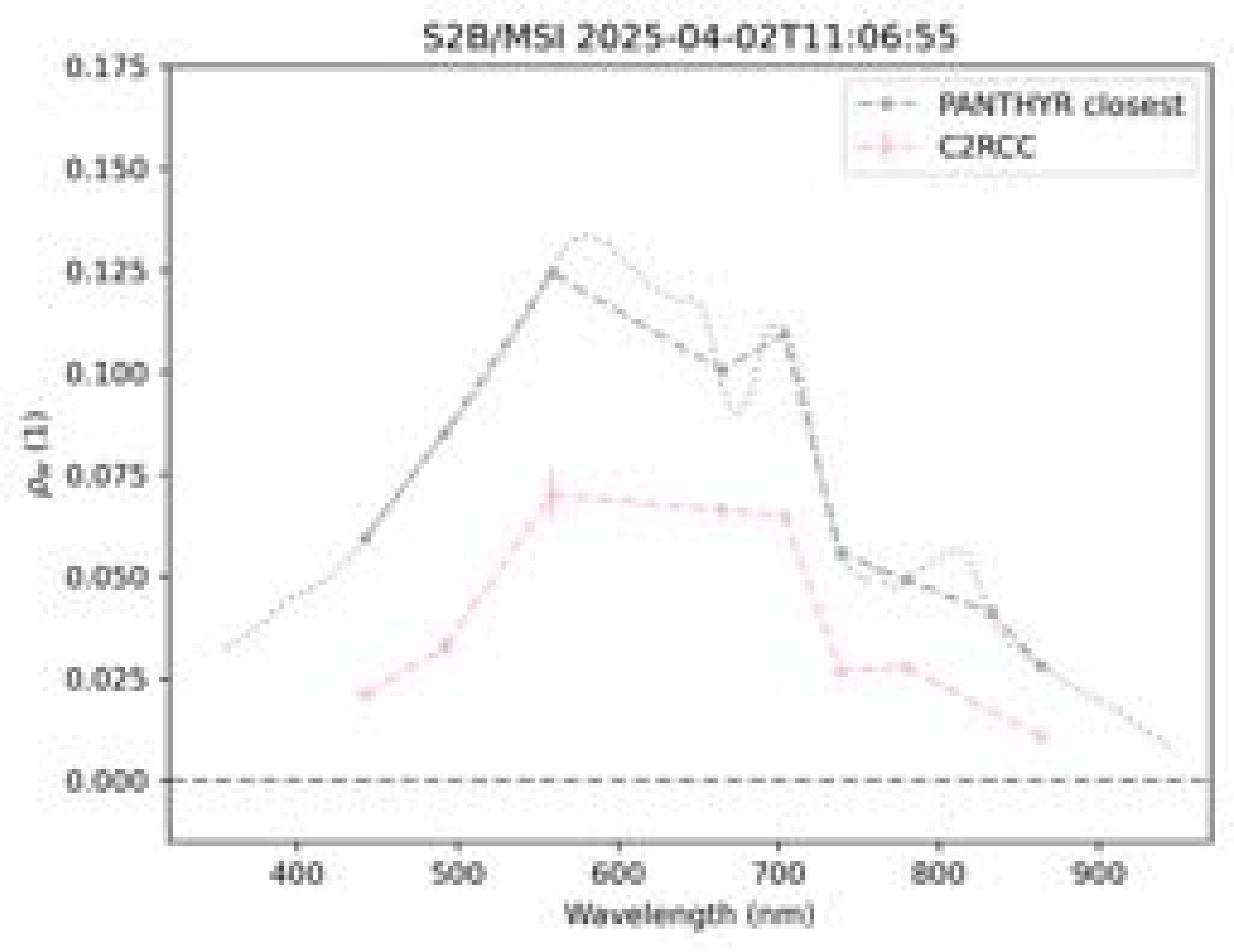


quite dark, mostly green and brown areas

overcorrection, more bands output compared to l2gen

C2RCC

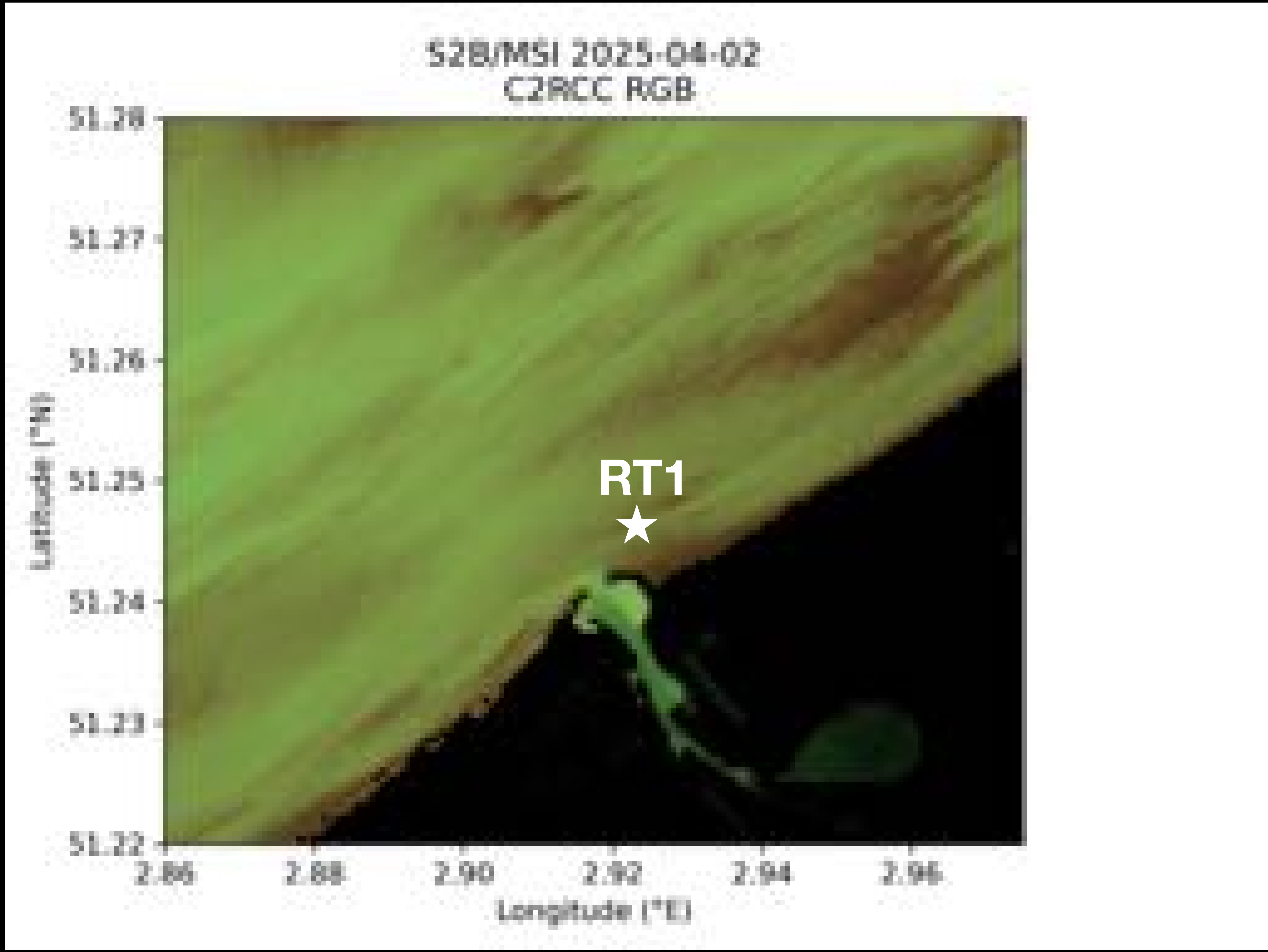




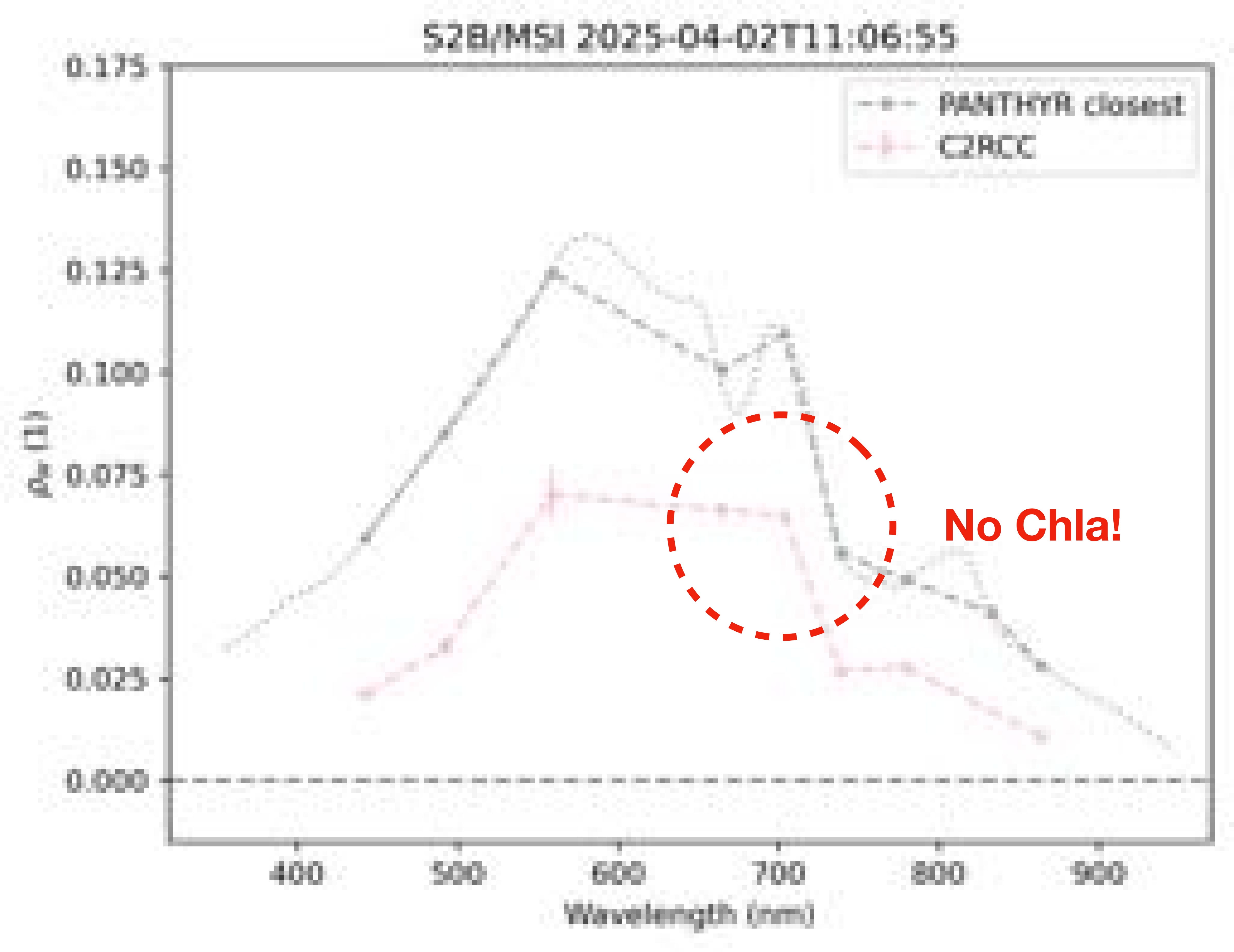
a bit brighter than l2gen/POLYMER, brown over most turbid areas

higher reflectance than l2gen/POLYMER, but red absorption feature has disappeared

C2RCC

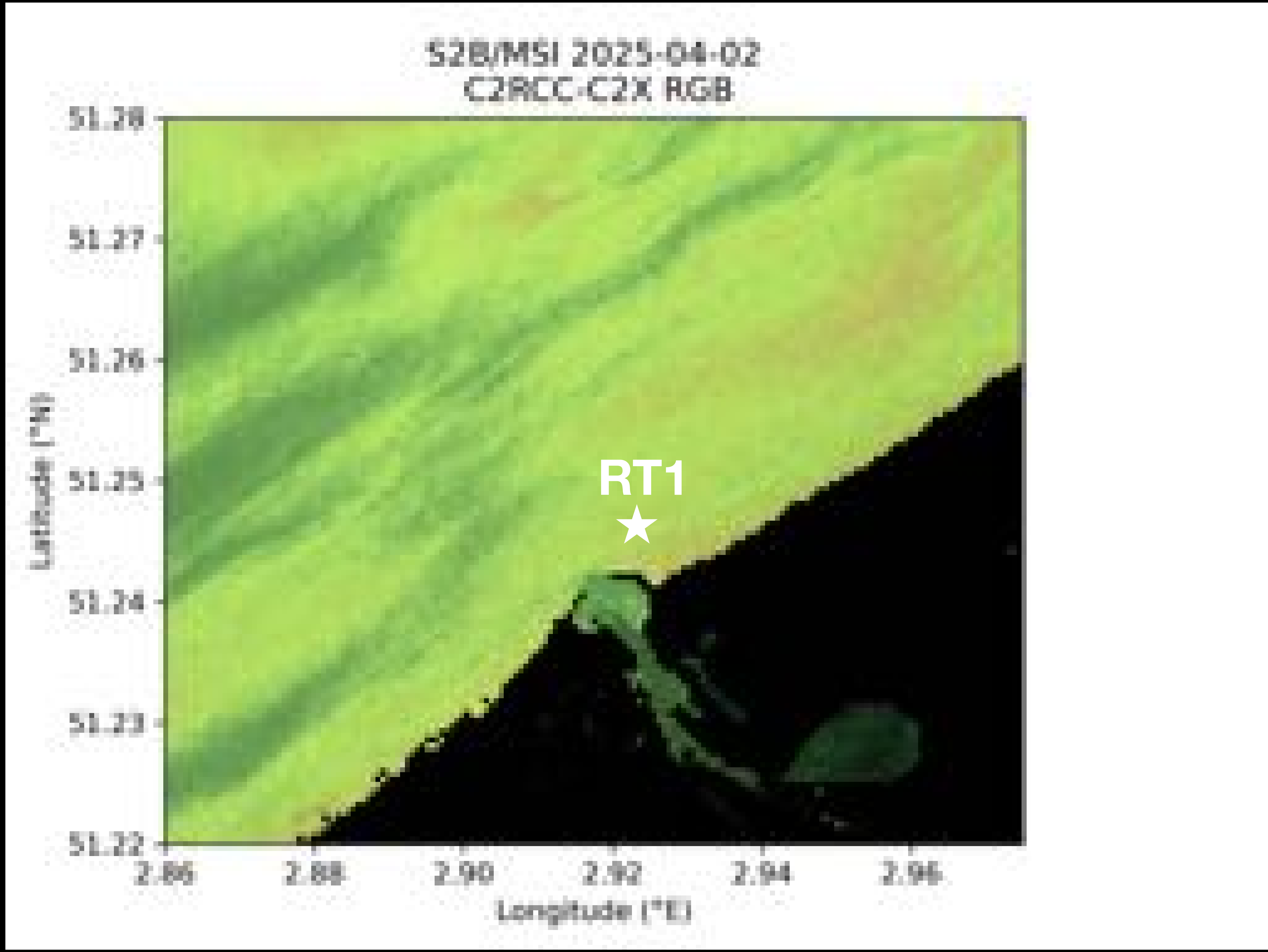


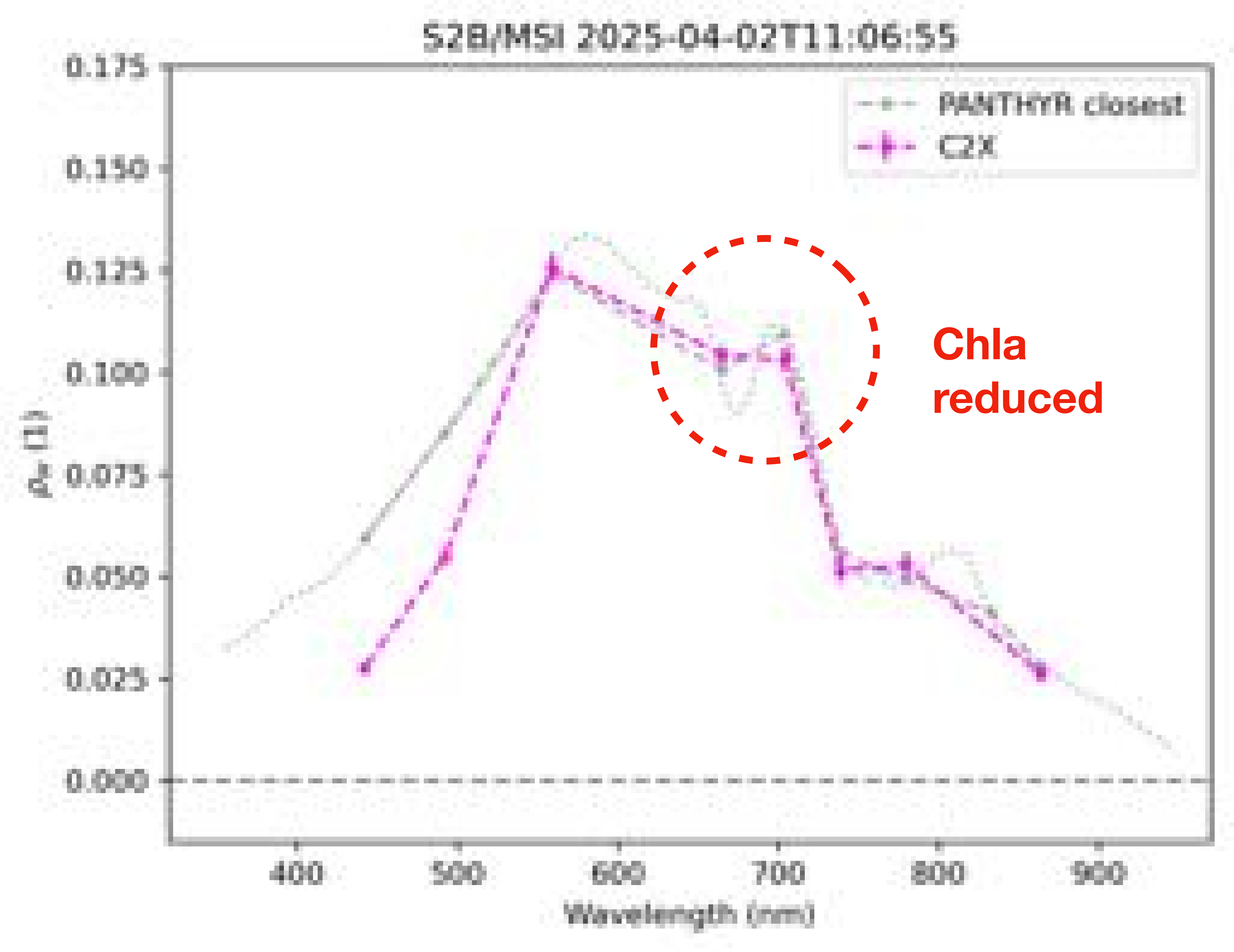
a bit brighter than l2gen/POLYMER, brown over most turbid areas



higher reflectance than l2gen/POLYMER, but red absorption feature has disappeared

C2RCC-C2X

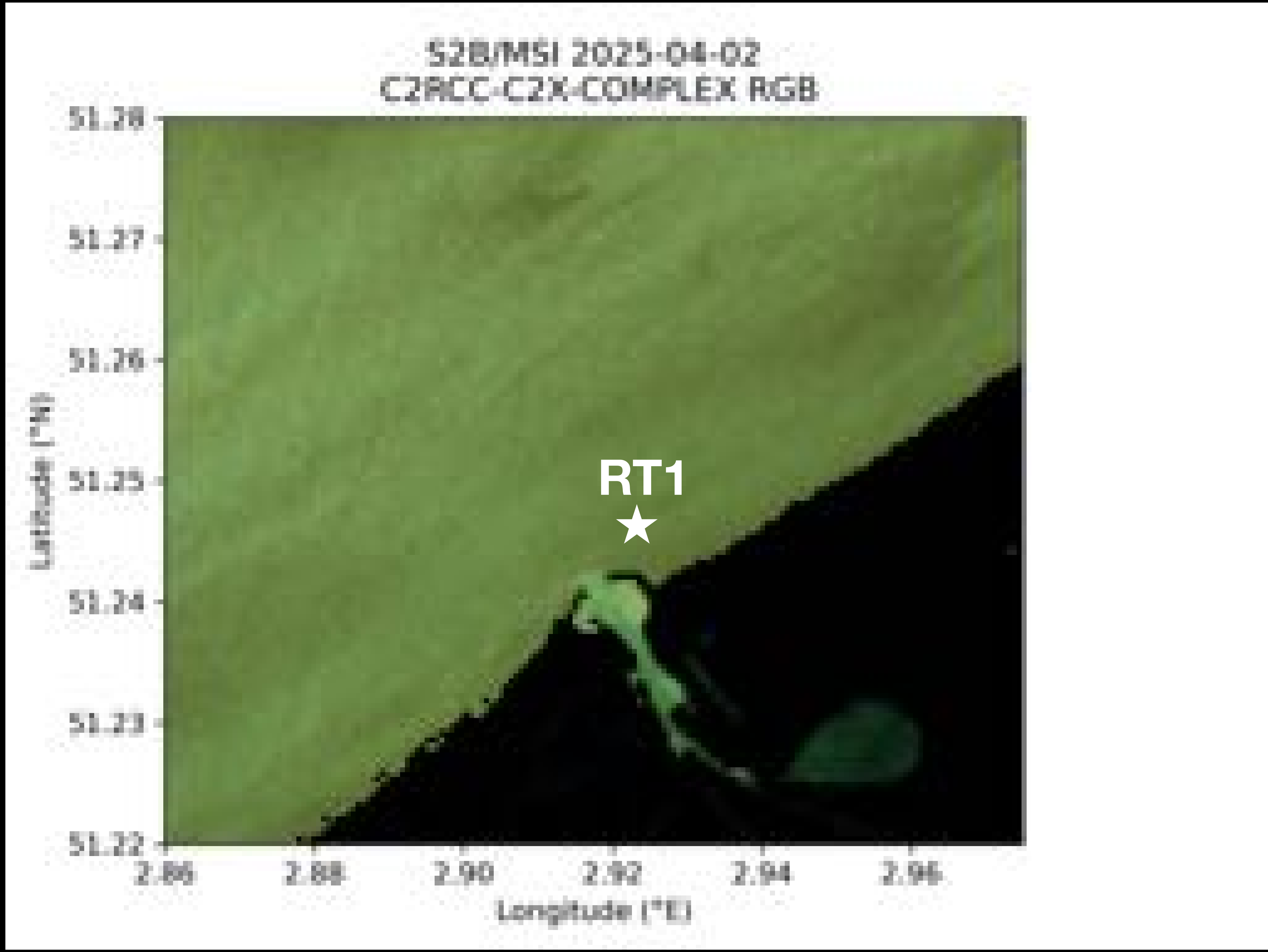


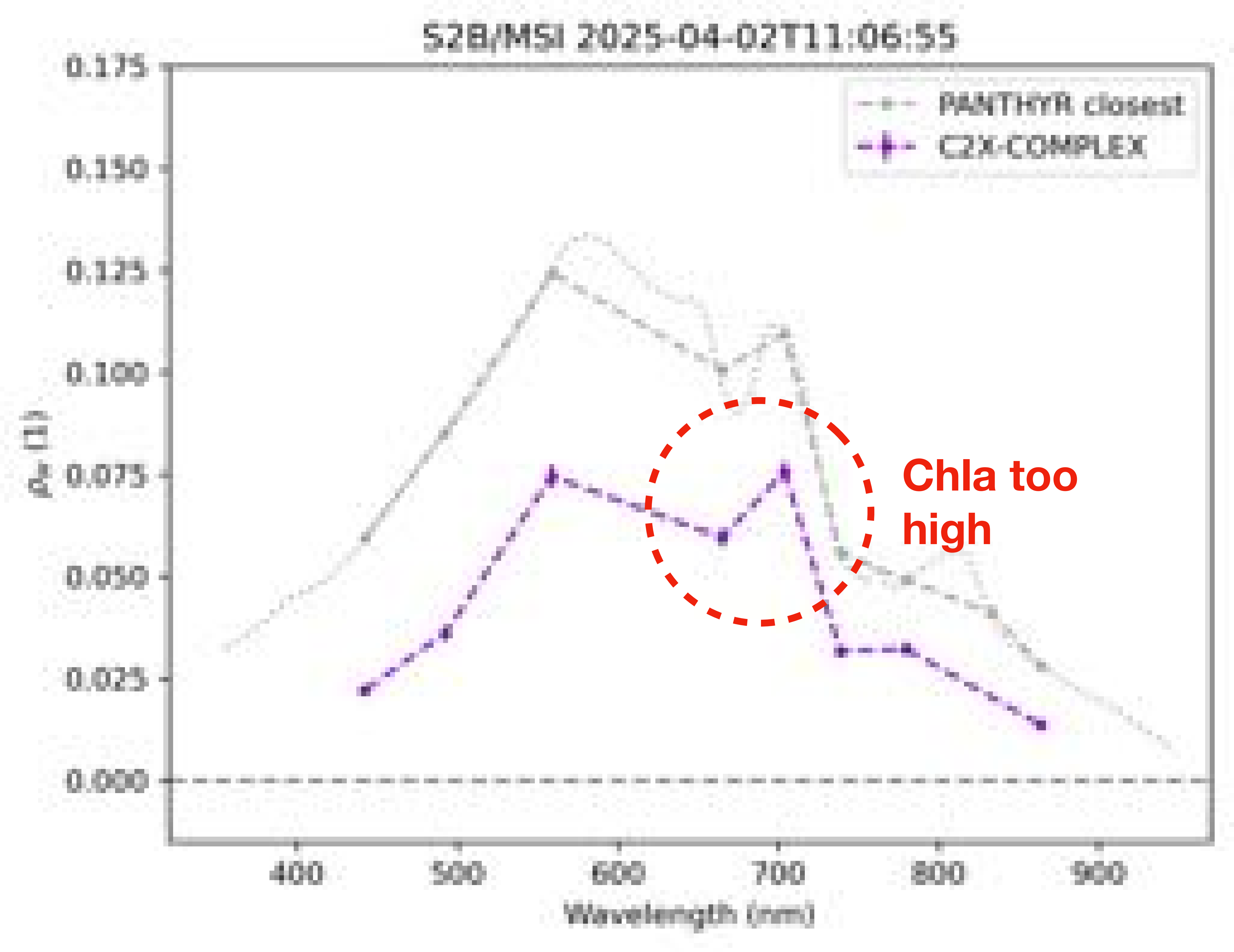


brighter than C2RCC, more noise, spatial variability reduced

better fit compared to C2RCC , but red absorption feature missing

C2RCC-COMPLEX

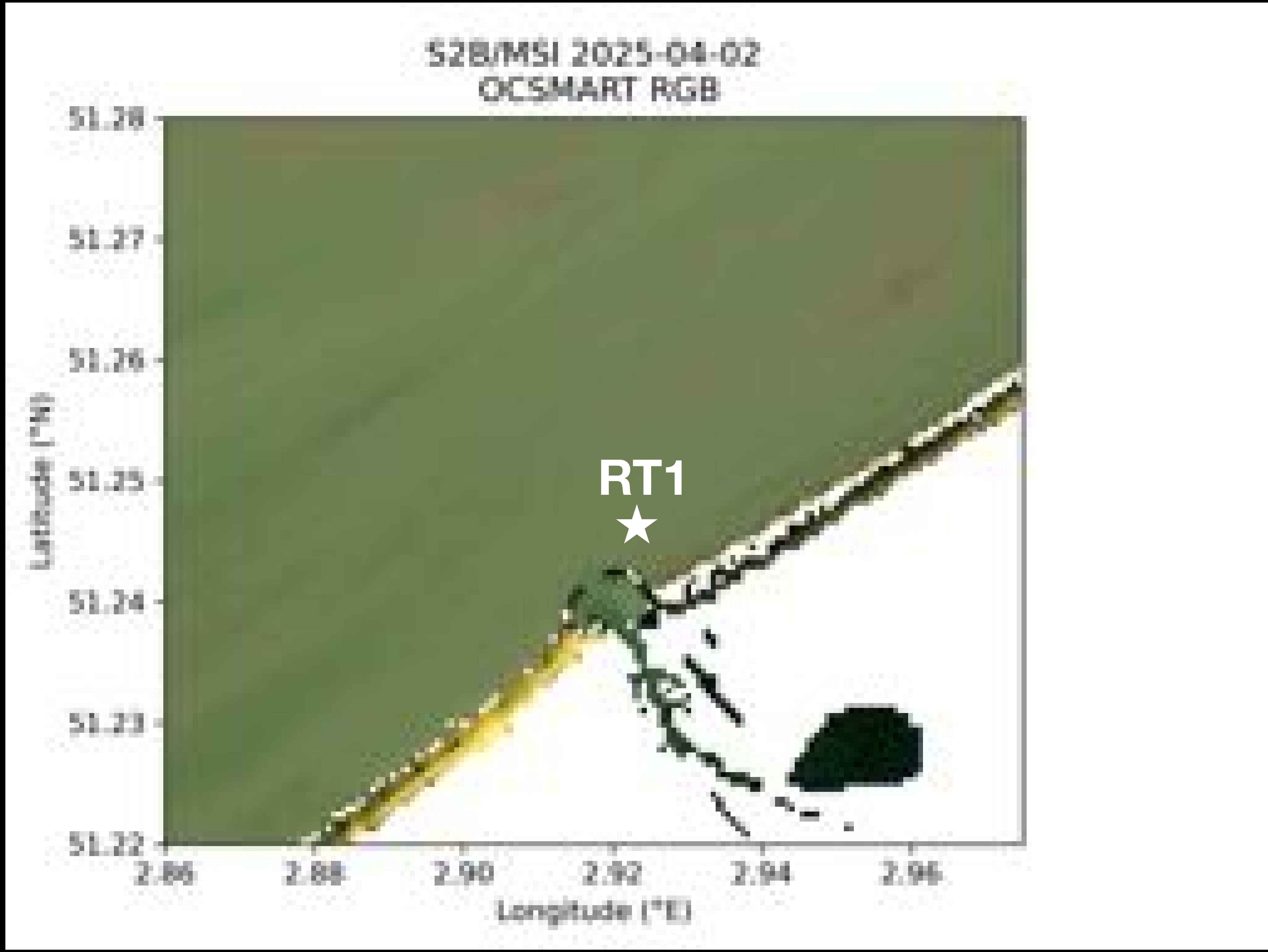


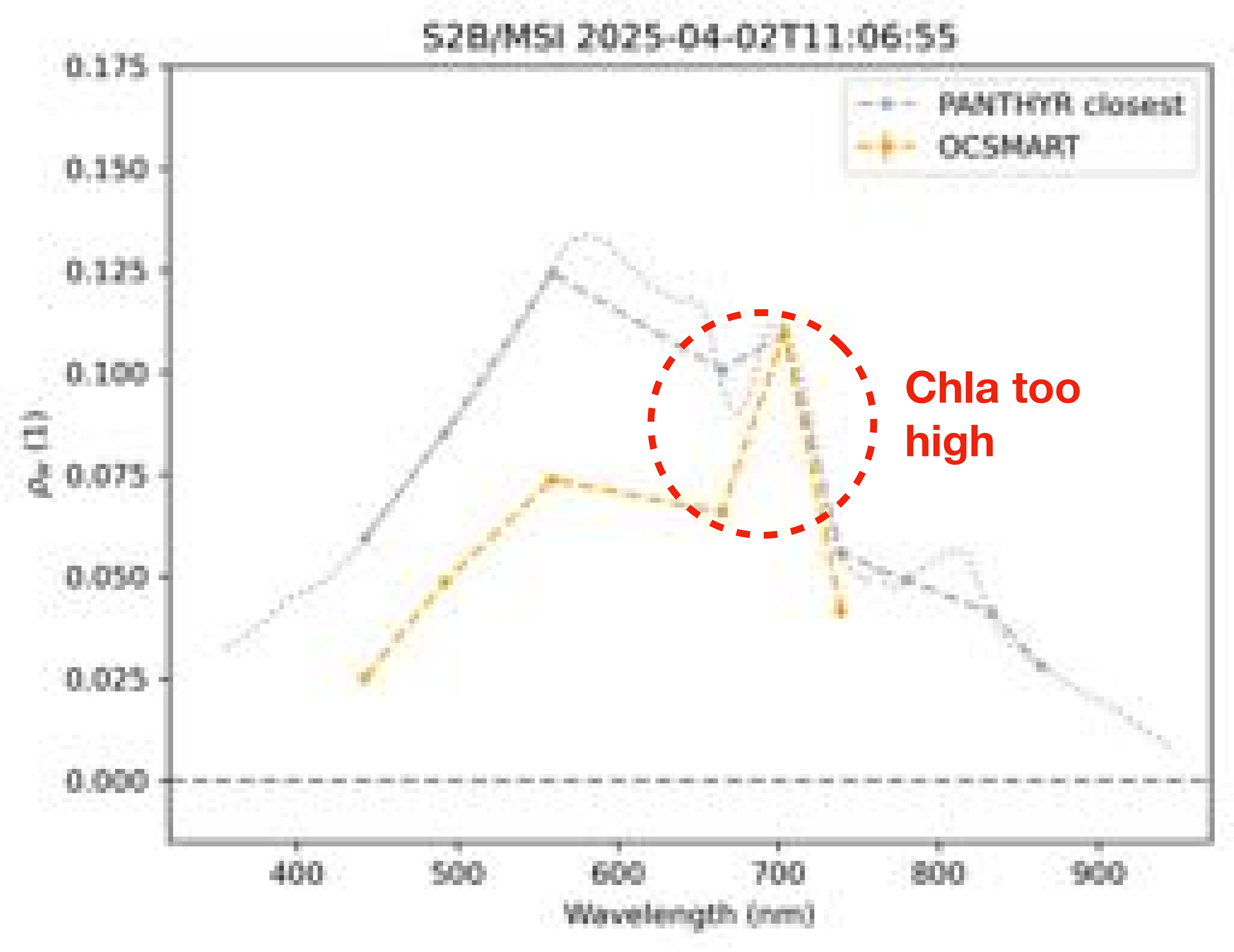


a bit darker than C2RCC, more noise, spatial variability reduced

~ C2RCC and lower than C2X, red absorption feature reappears (too sharply?)

OC-SMART

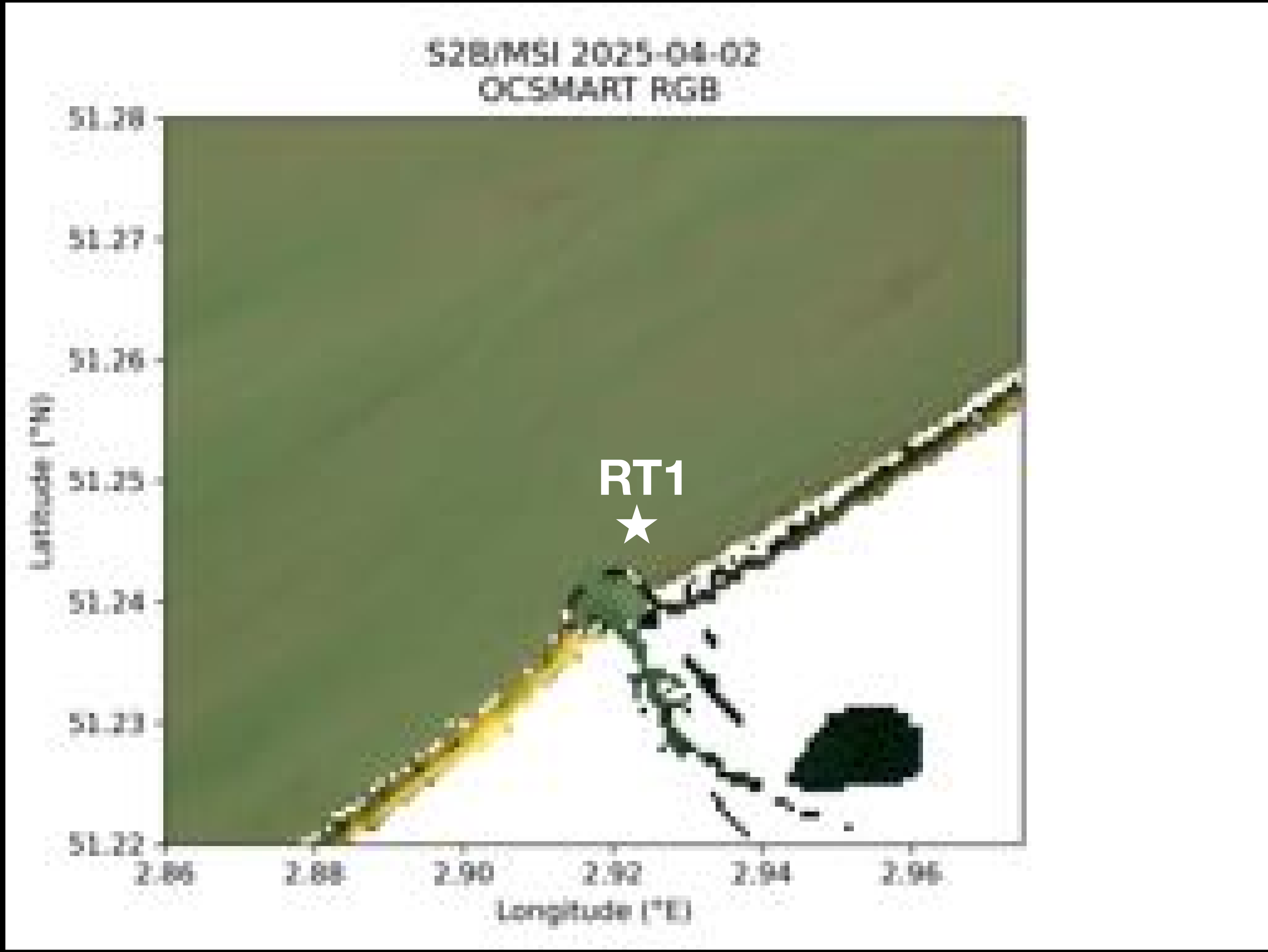


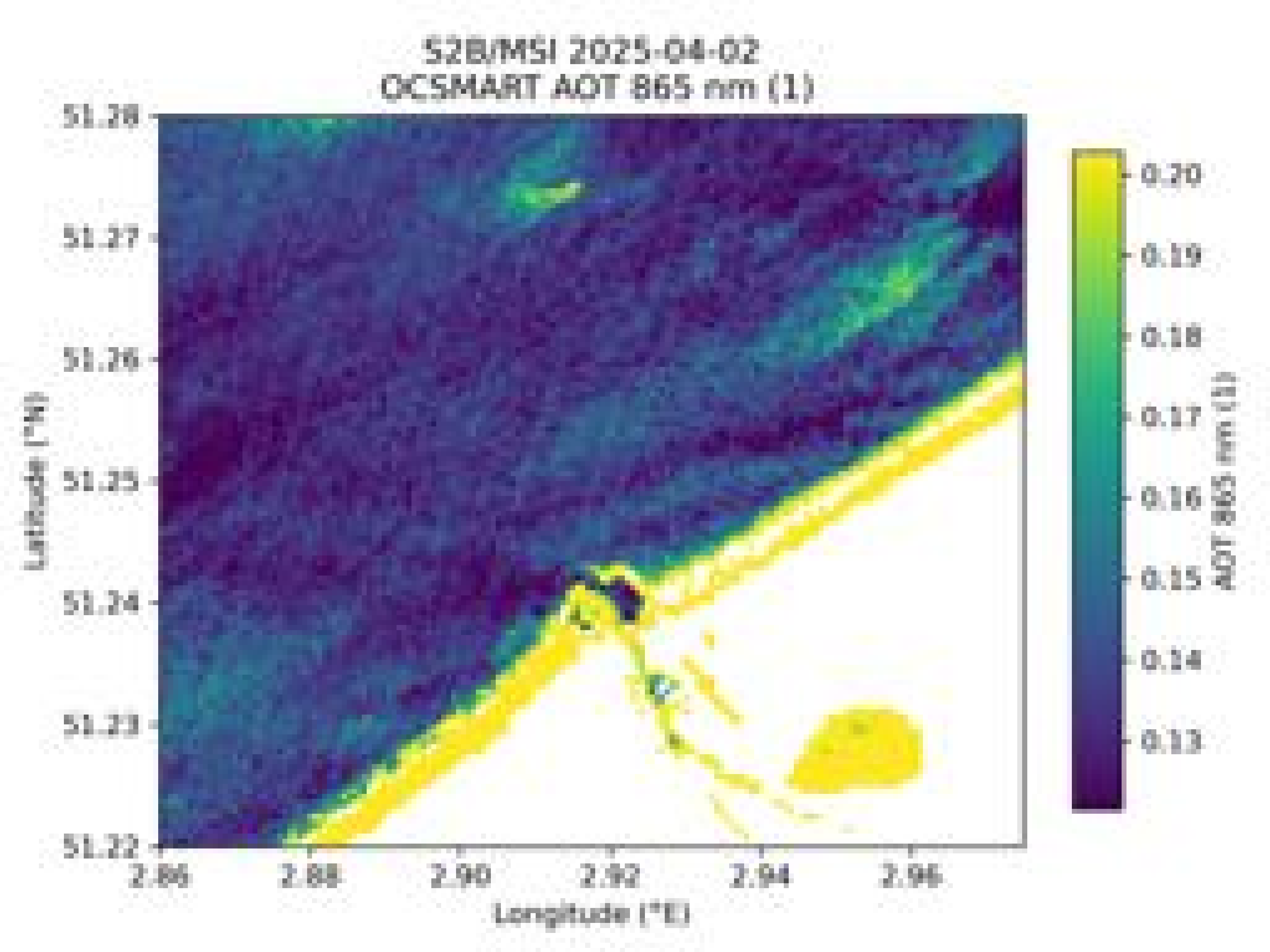


lower reflectance, brighter than POLYMER, less difference over most turbid waters

overcorrection in VIS , red absorption feature exaggerated

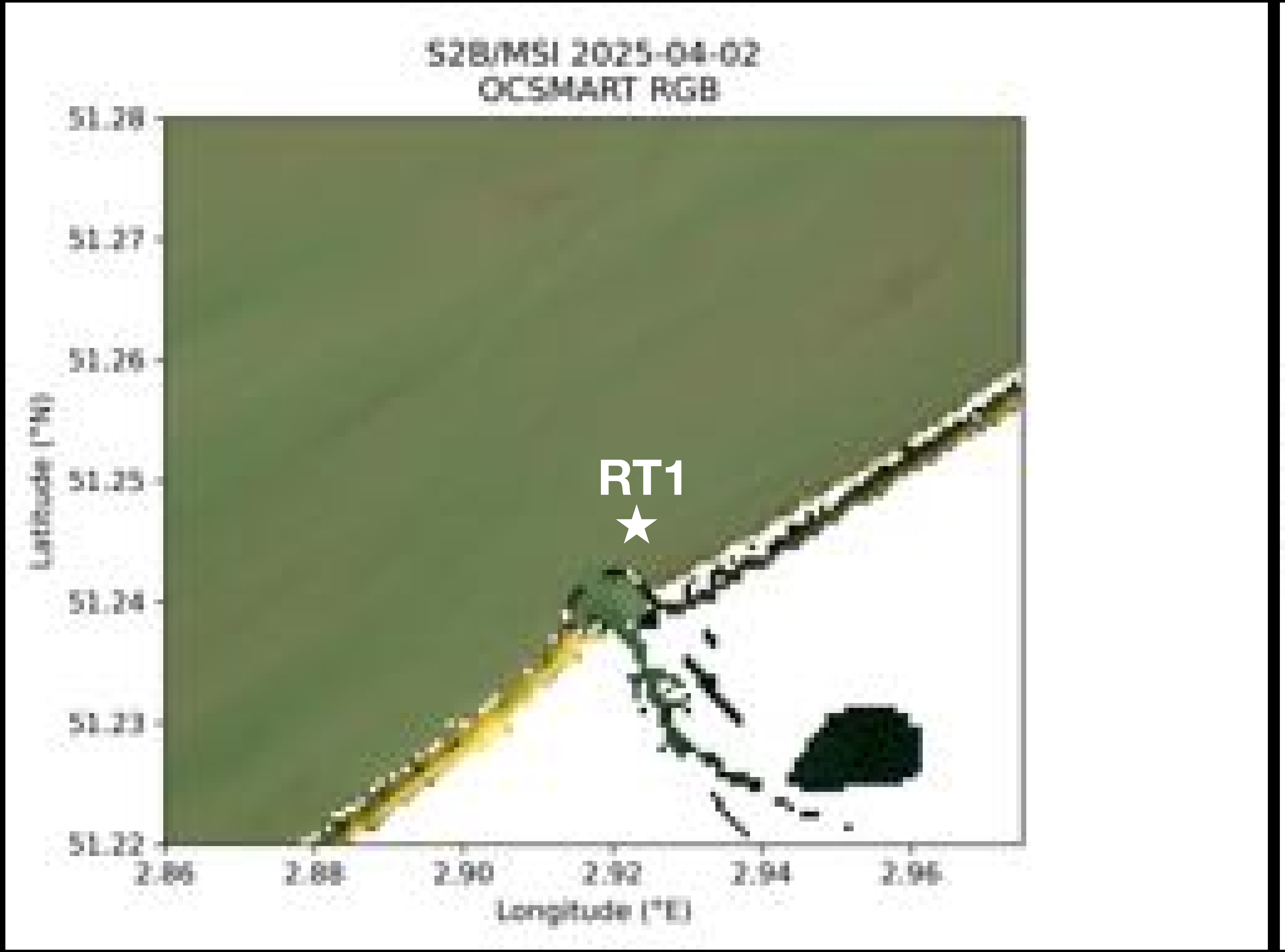
OC-SMART

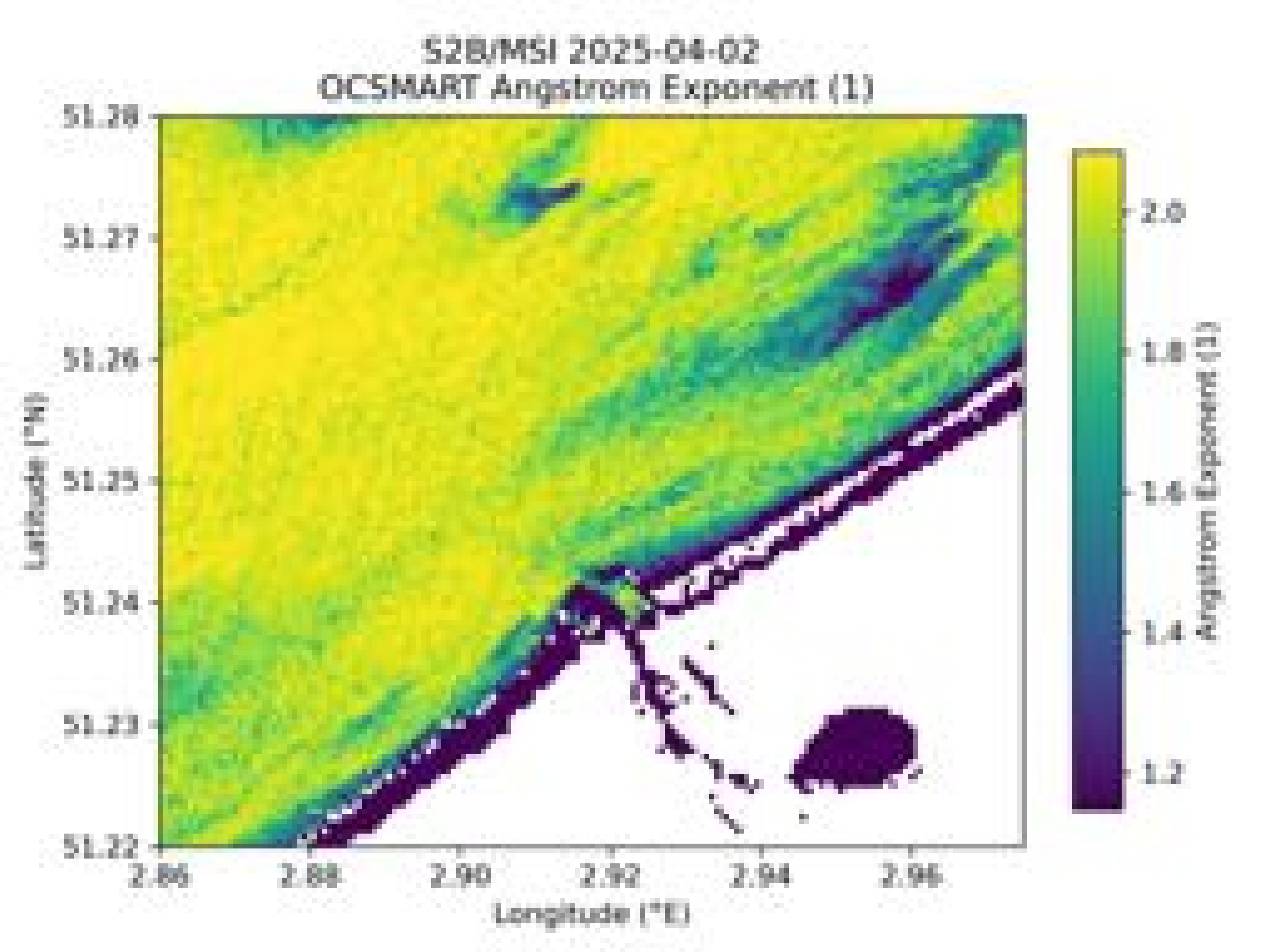




aerosol optical depth ~ some water patterns, noisy, high in the port and lake

OC-SMART



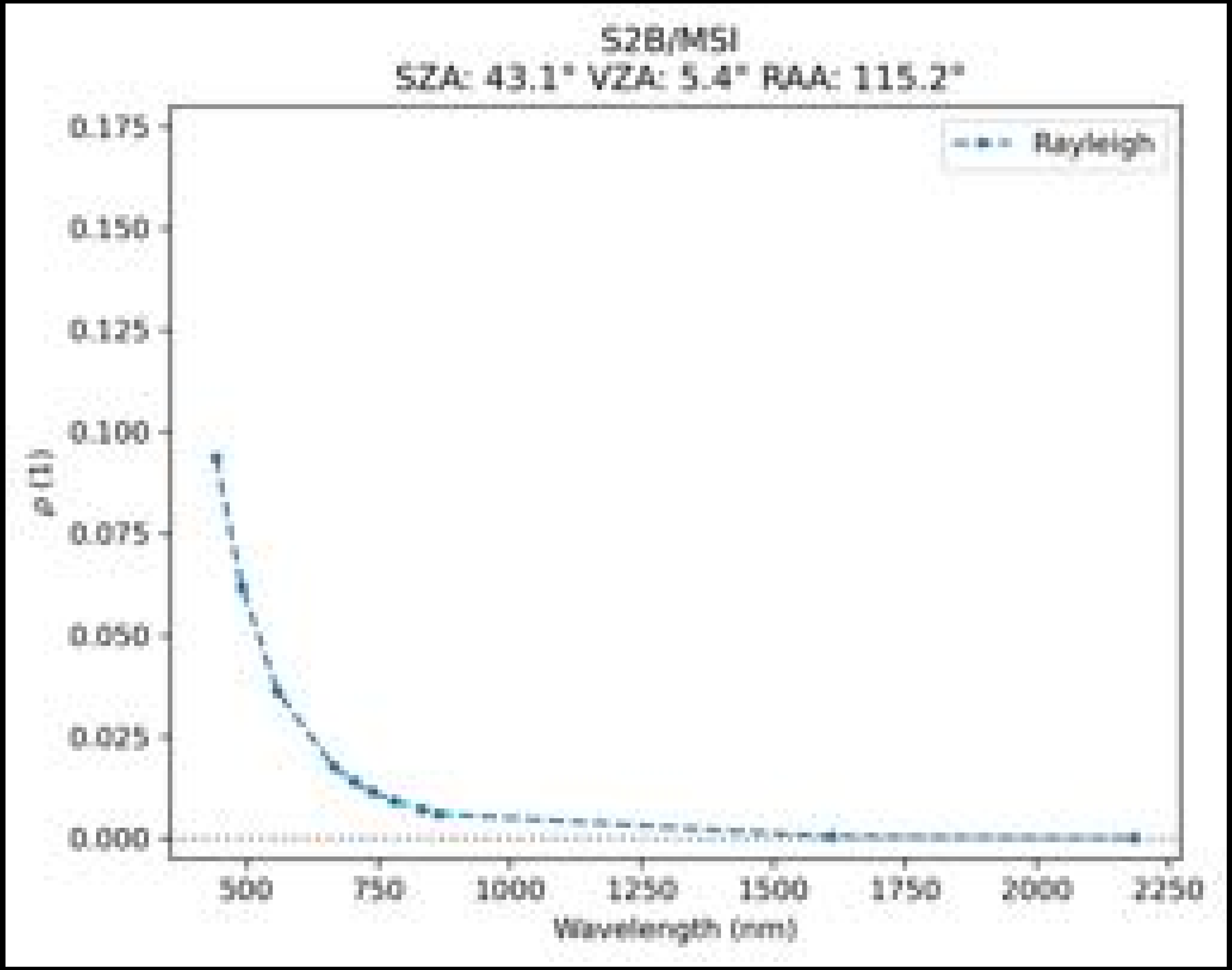


Angstrom ~ some water patterns, very low in port and lake, in some of the more turbid patches

Solutions?

No single algorithm seems to perform well everywhere, but for specific targets certain algorithms may be more suitable

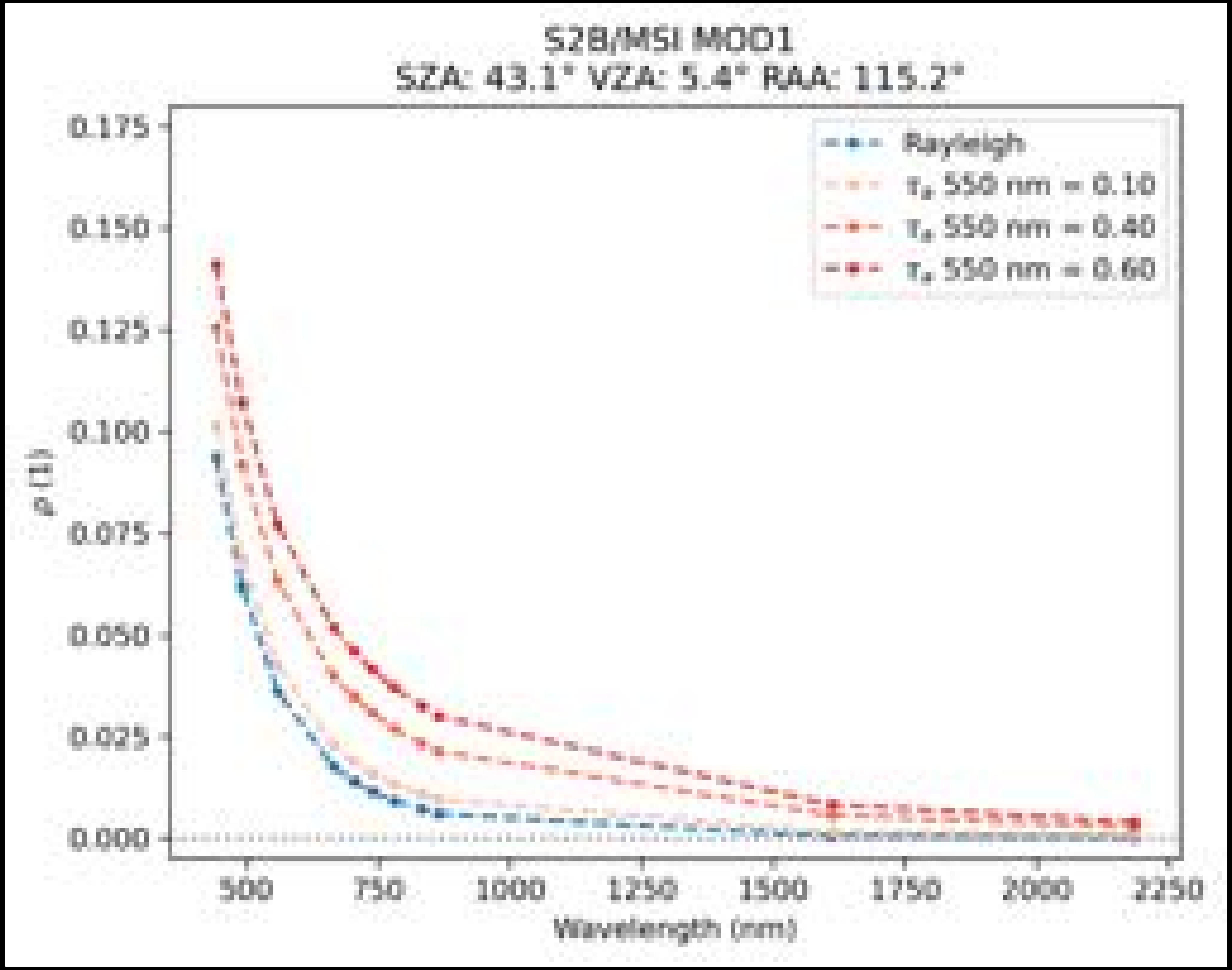
ACOLITE/DSF



1) extract geometry

TOA

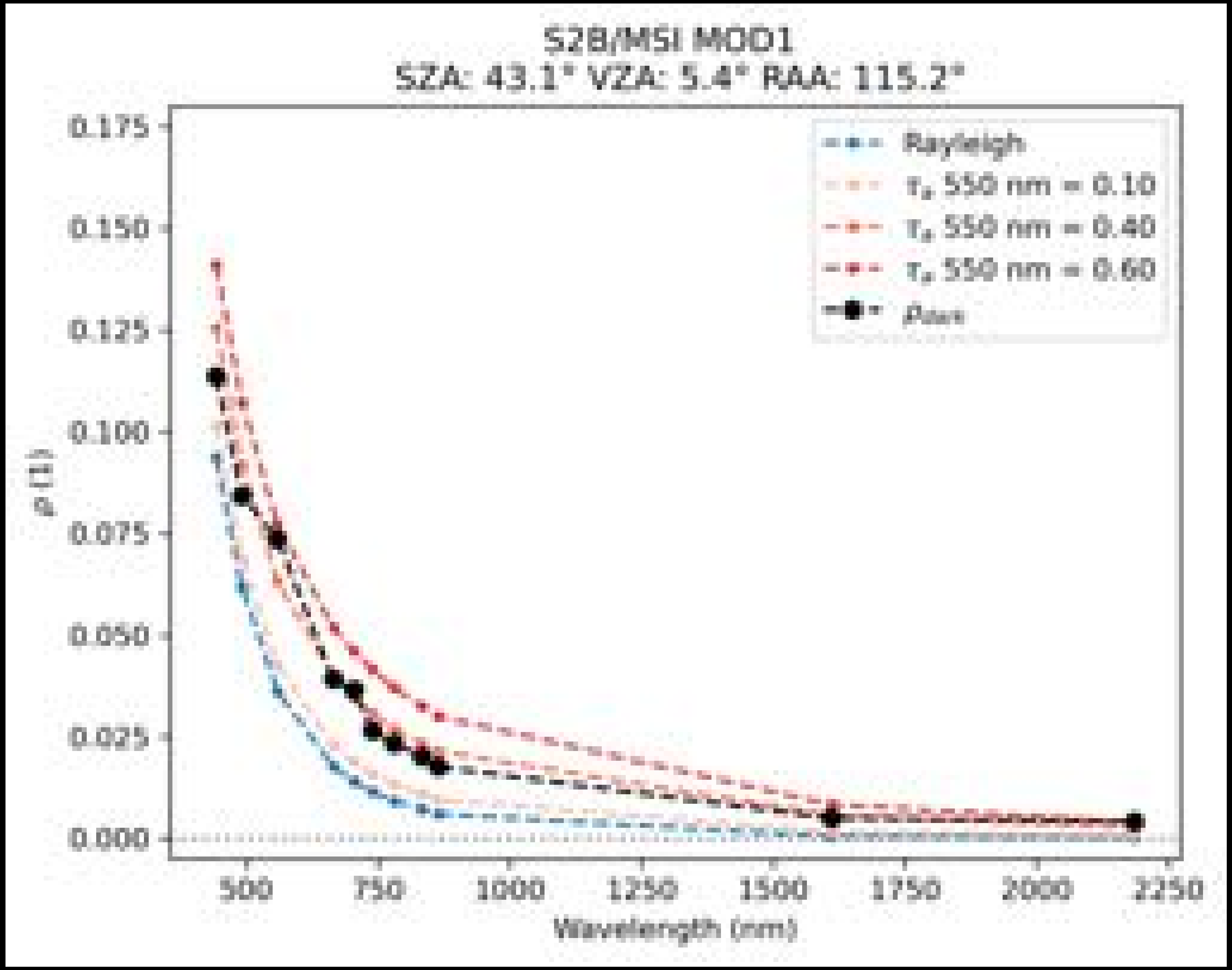
ACOLITE/DSF



2) load LUTs

TOA

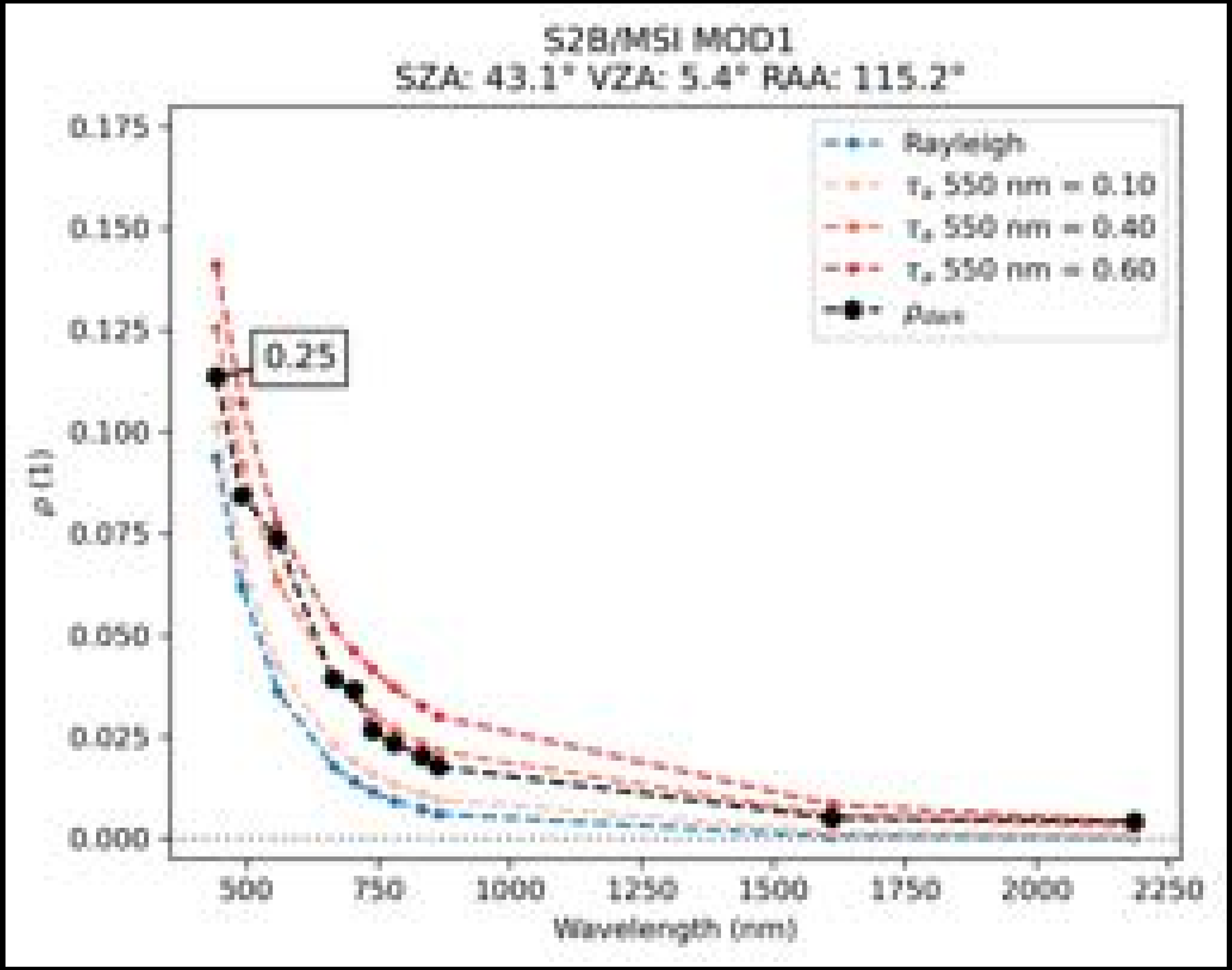
ACOLITE/DSF



3) get ρdark spectrum (here 2.275%)

TOA

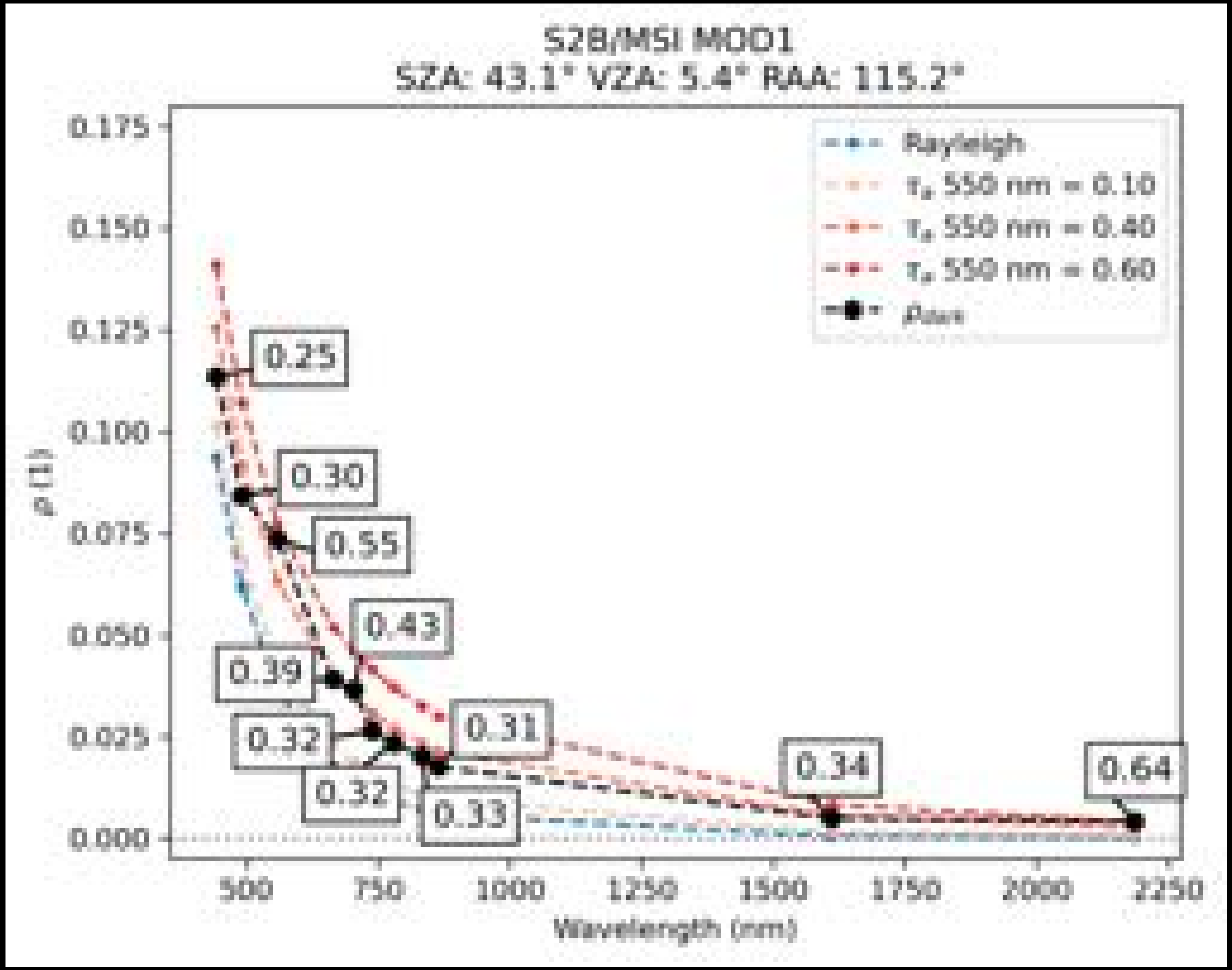
ACOLITE/DSF



4) estimate τa for ρdark

TOA

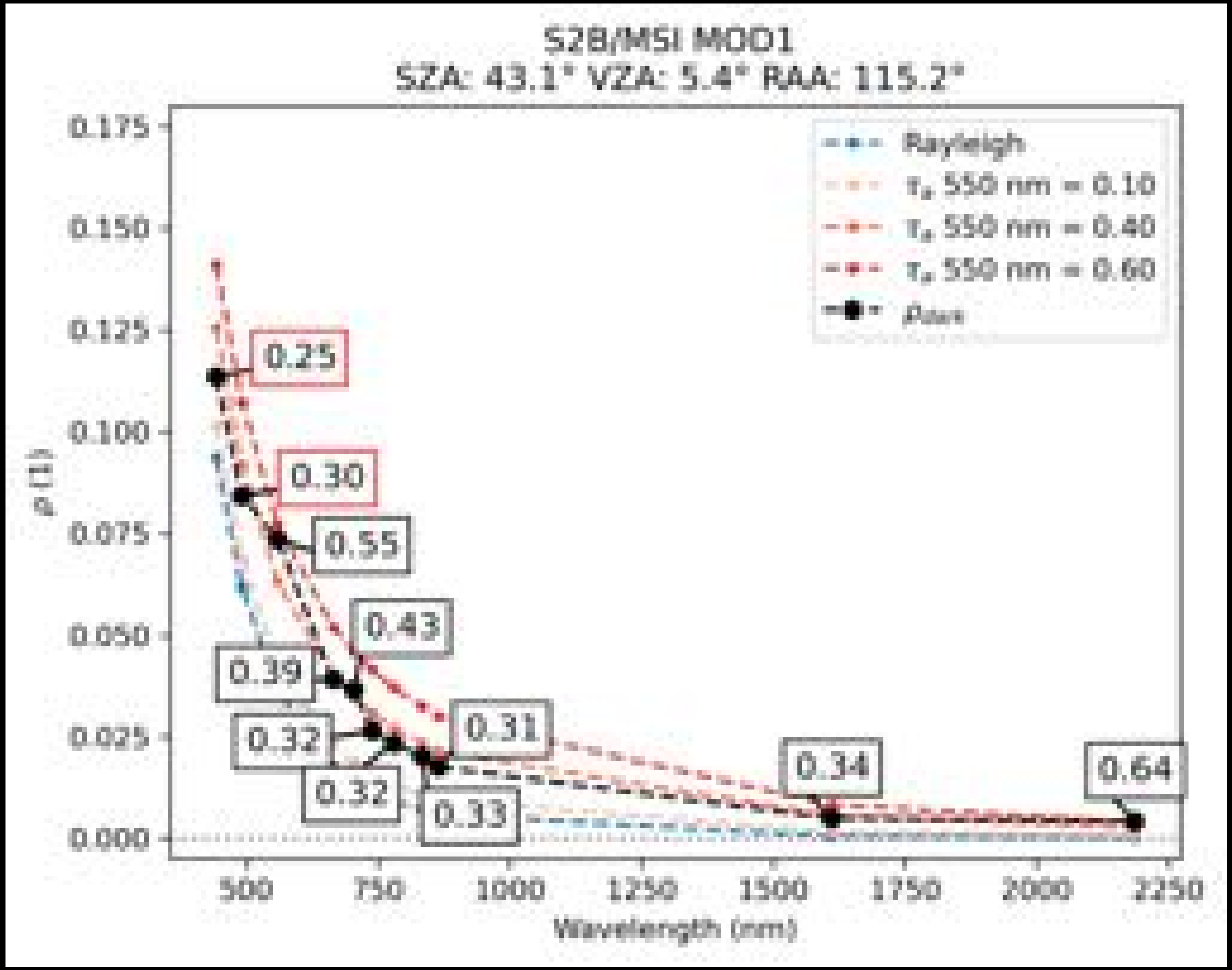
ACOLITE/DSF



4) estimate τa for ρdark

TOA

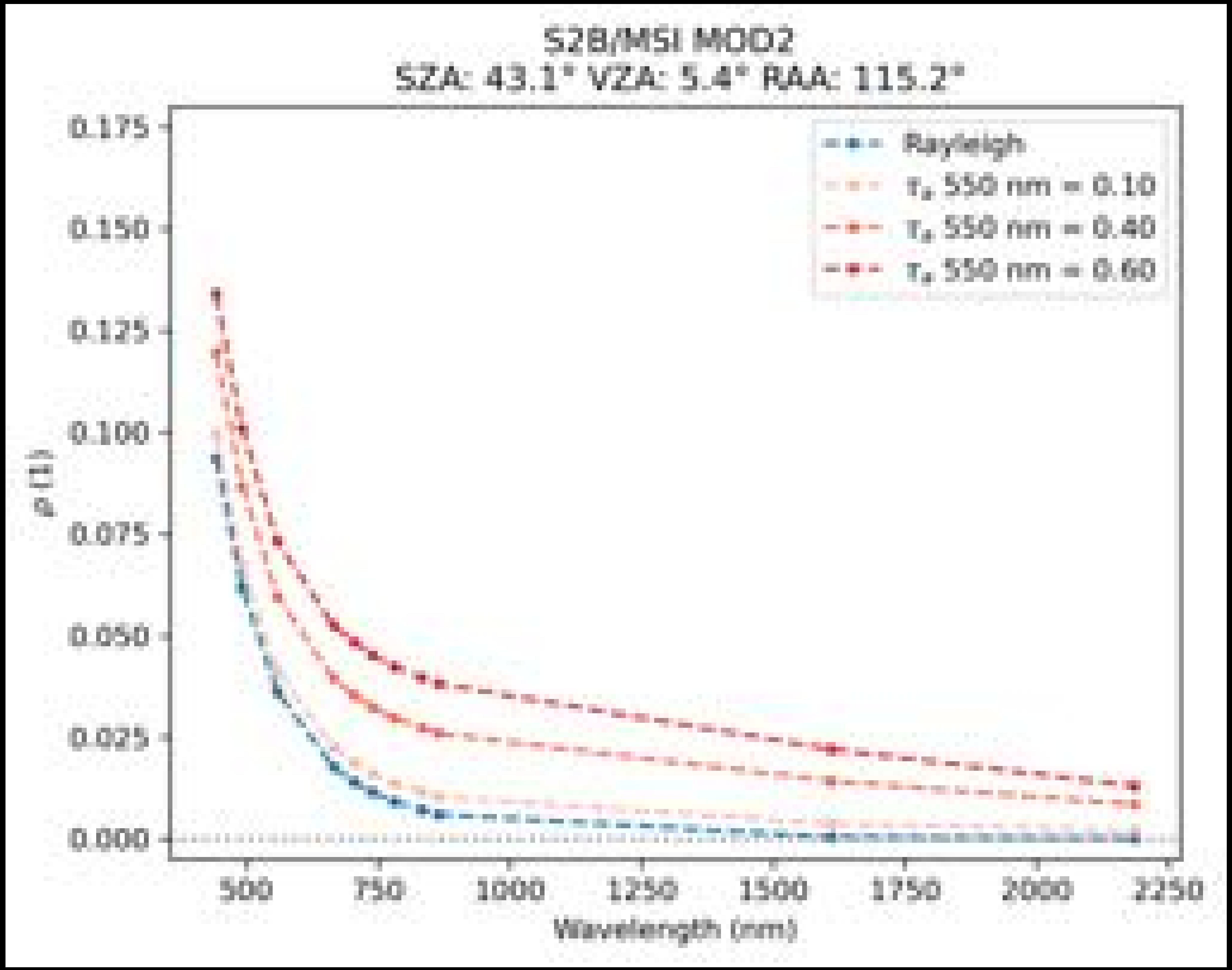
ACOLITE/DSF



5) find lowest τa - here B1 and B2

TOA

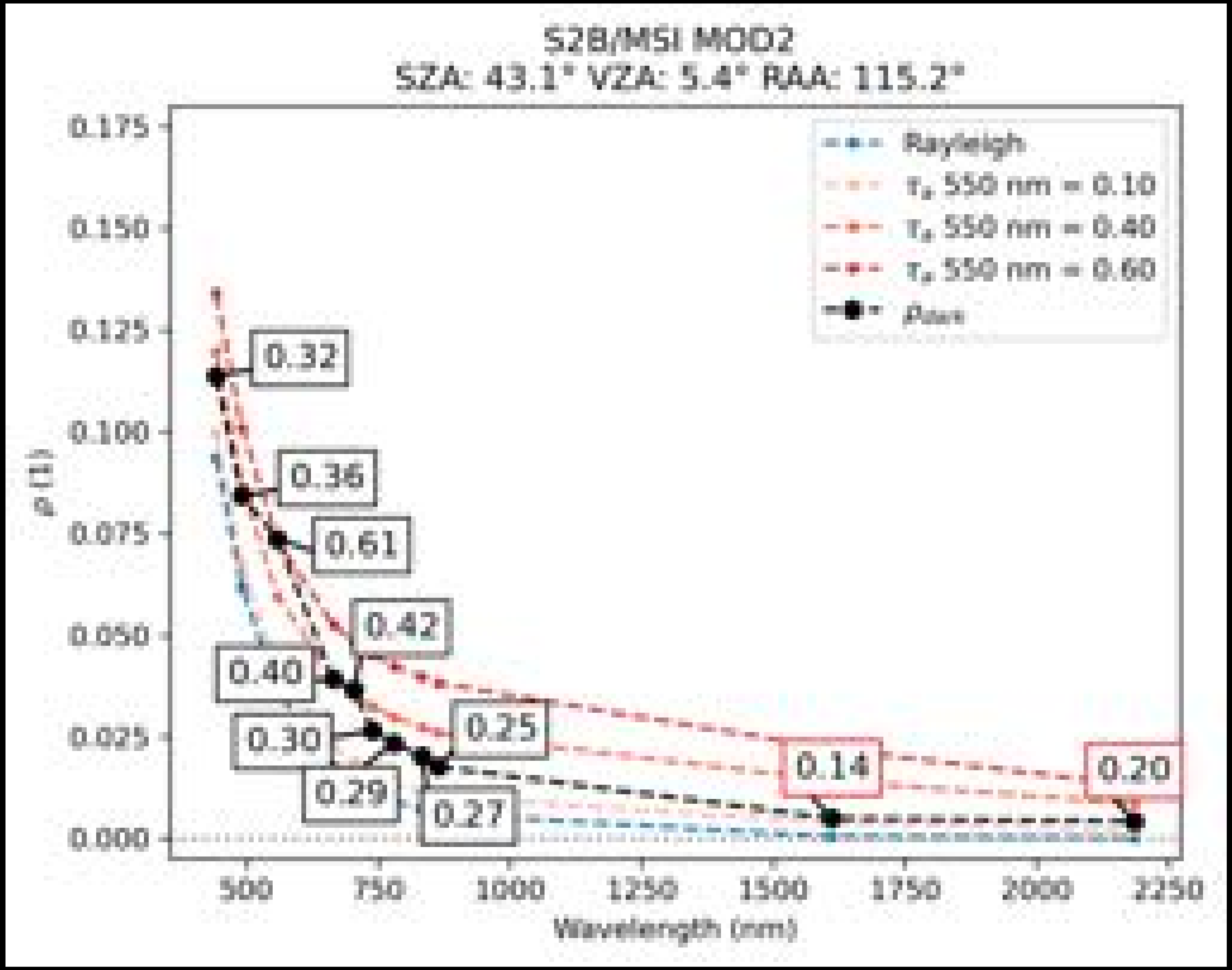
ACOLITE/DSF



6) repeat for other model

TOA

ACOLITE/DSF



6) here B11 and B12

TOA

ACOLITE/DSF

TOA reflectance

Surface reflectance

Two-way atmospheric transmittance

$$\frac{\rho_t}{T_g} = \rho_{path} + \frac{\rho_s \cdot T_d T_u}{1 - \rho_s \cdot S}$$

Gas transmittance (O2, O3, H2O)

Atmospheric path reflectance (Rayleigh+aerosol)

Spherical albedo of the atmosphere

6SV formulation e.g. Vermote et al. 1997

TOA

7) select model, and compute ρs

ACOLITE/DSF

TOA reflectance

Surface reflectance

Two-way atmospheric transmittance

$$\frac{\rho_t}{T_g} = \rho_{path} + \frac{\rho_s \cdot T_d T_u}{1 - \rho_s \cdot S}$$

Gas transmittance (O2, O3, H2O)

Atmospheric path reflectance (Rayleigh+aerosol)

Spherical albedo of the atmosphere

6SV formulation e.g. Vermote et al. 1997

7) select model, and compute ρs

BOA

ACOLITE/DSF

$$\frac{\rho_t}{T_g} = \rho_{path} + \frac{\rho_s \cdot T_d T_u}{1 - \rho_s \cdot S}$$

low contrast / homogeneous surface: ρe = ρs

ACOLITE/DSF

$$\frac{\rho_t}{T_g} = \rho_{path} + T_d \cdot T_u \cdot \frac{\rho_s}{1 - \rho_s \cdot S}$$

low contrast / homogeneous surface: ρe = ρs

ACOLITE/DSF

$$\frac{\rho_t}{T_g} = \rho_{path} + T_d \cdot \frac{T_u^{dir} \cdot \rho_s}{1 - \rho_e \cdot S} + T_d \cdot \frac{T_u^{dif} \cdot \rho_e}{1 - \rho_e \cdot S}$$

low contrast / homogeneous surface: ρe = ρs

ACOLITE/RAdCor

$$\frac{\rho_t}{T_g} = \rho_{path} + T_d \cdot \frac{T_u^{dir} \cdot \rho_s}{1 - \rho_e \cdot S} + T_d \cdot \frac{T_u^{dif} \cdot \rho_e}{1 - \rho_e \cdot S}$$

high contrast / heterogeneous surface: ρe != ρs

ACOLITE/RAdCor

$$\frac{\rho_t}{T_g} = \rho_{path} + T_d \cdot \frac{\rho_s}{1 - \rho_s \circledast SAF} \circledast PSF$$

high contrast / heterogeneous surface: ρe != ρs

after some “generous approximations”

$\circledast$ image convolution

SAF spherical albedo function

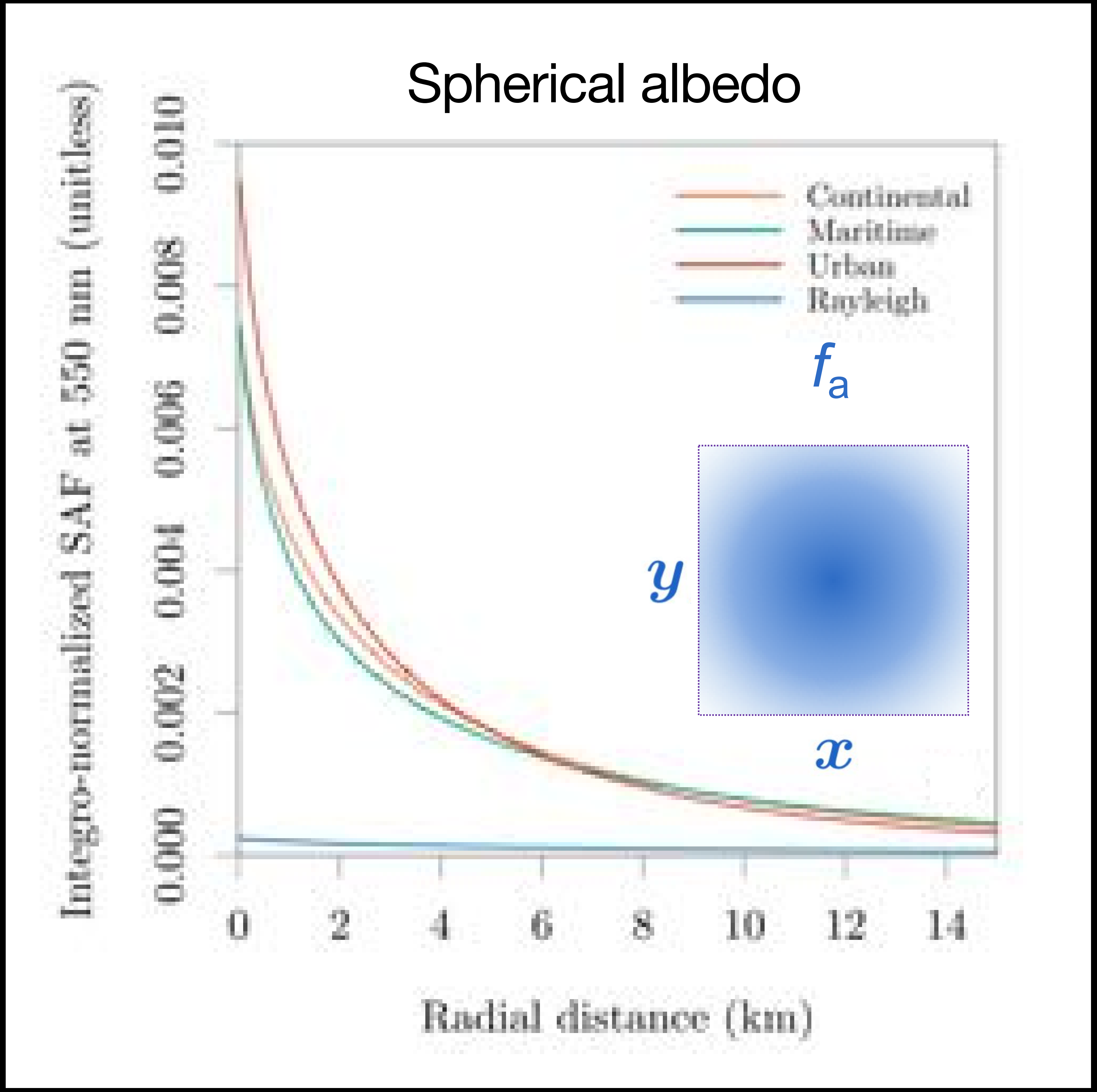
PSF point spread function

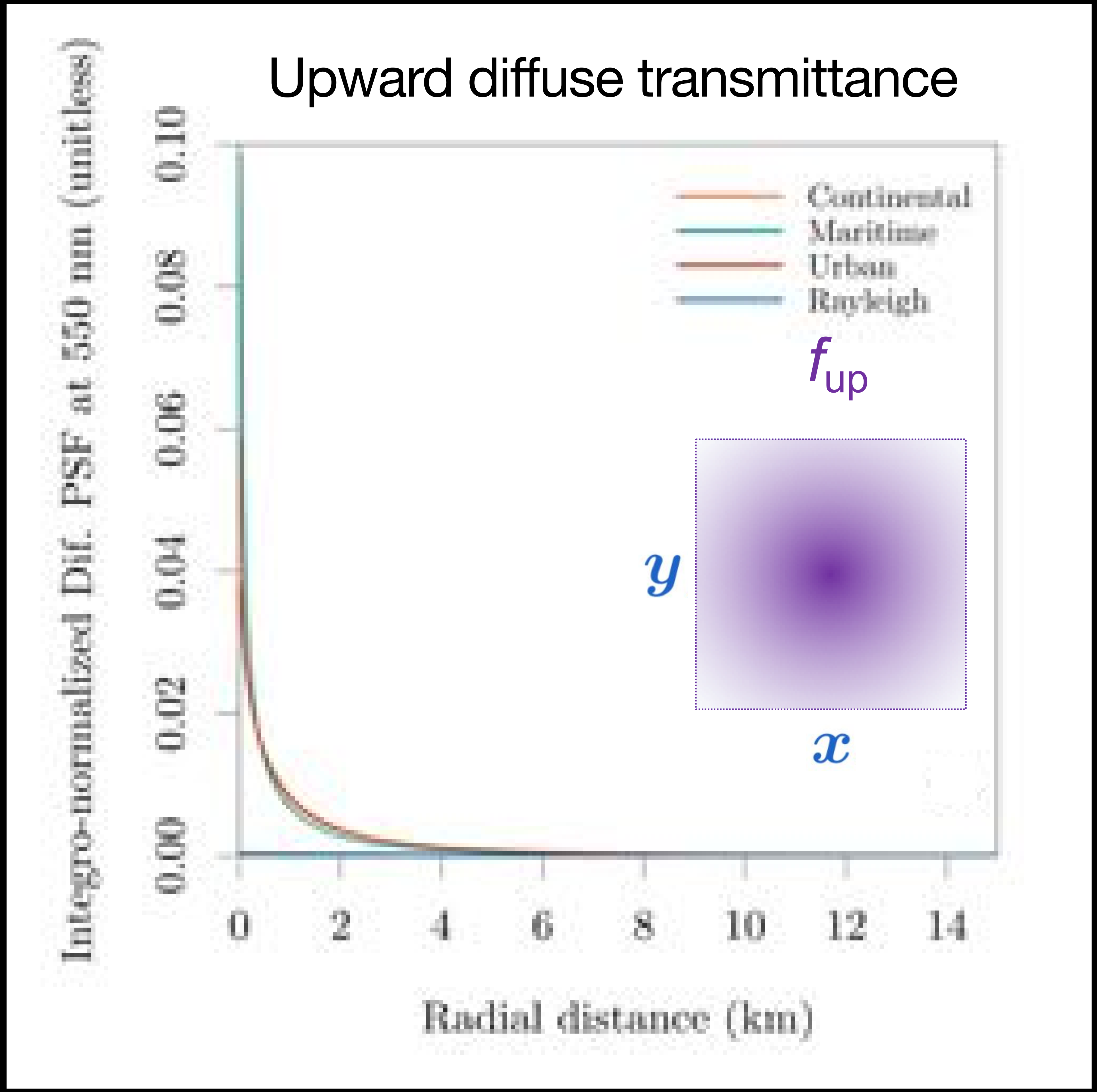
ACOLITE/RAdCor

(default kernel size 5 km)

$\circledast \ SAF$

$\circledast \ PSF$





ACOLITE/RAdCor

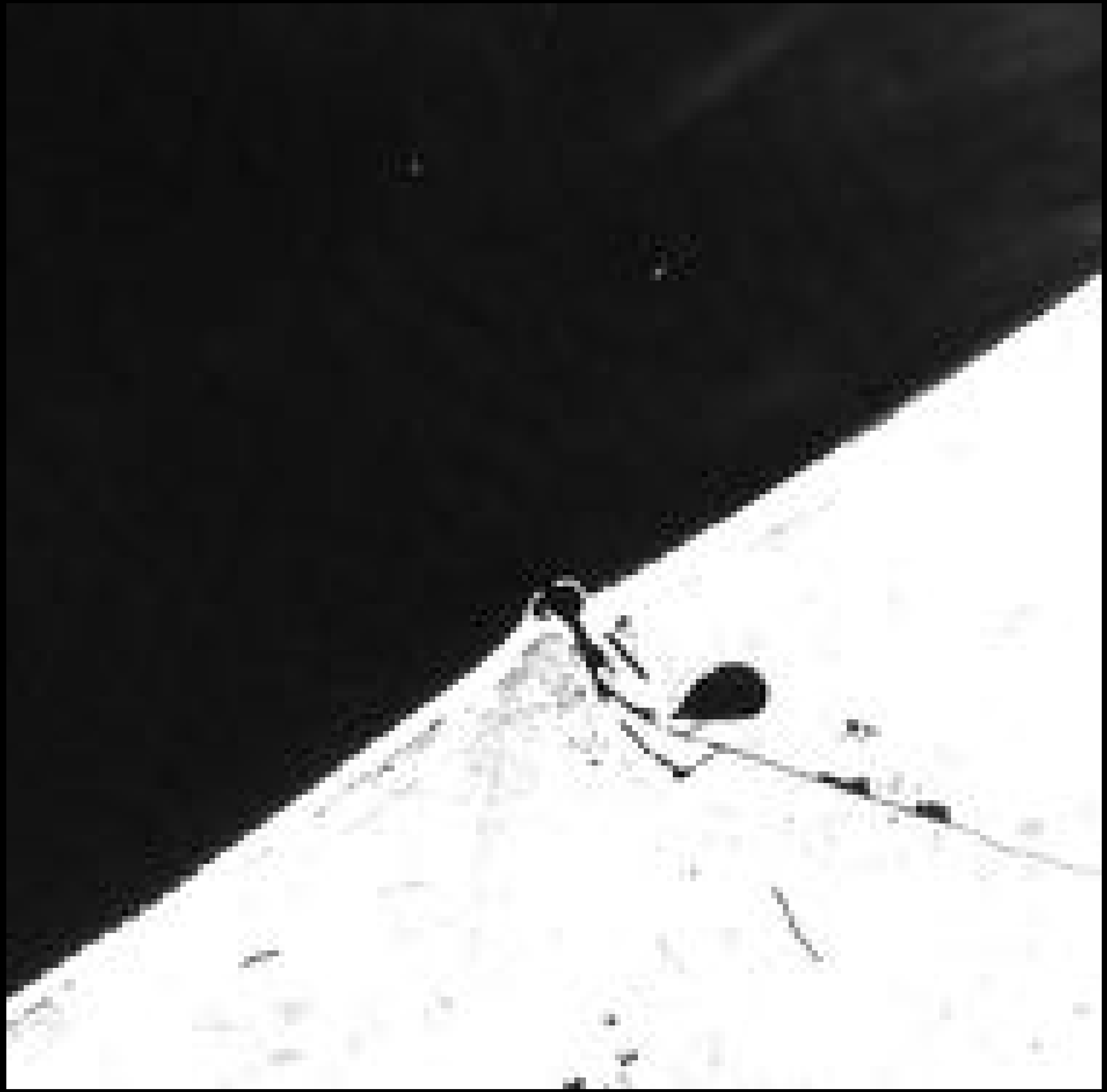
ρe estimate RGB

homogeneous

heterogeneous

ACOLITE/RAdCor

ρe estimate NIR

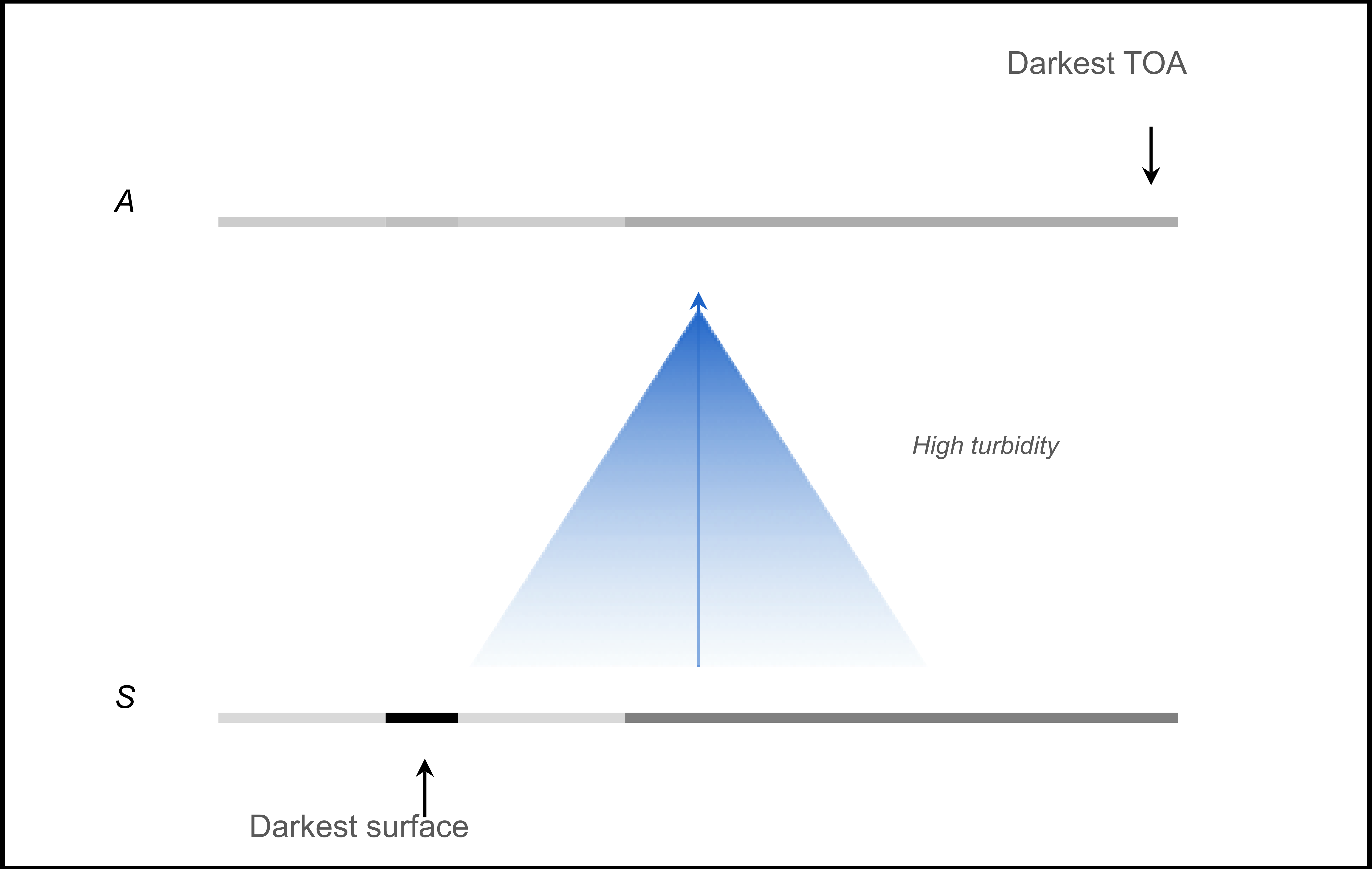


homogeneous

heterogeneous

ACOLITE/RAdCor

DSF estimation ~ ρdark at TOA | **TSDSF estimation ~ ρdark at BOA**



ACOLITE/RAdCor

TSDSF estimation ~ ρdark at BOA

1) compute hypothetical quantity ρ_t^{HYP}

TOA if all upward transmittance diffuse, estimated ρt for high aerosol optical depth (ta 550 = 1.0) :

$$\rho_t^{HYP} = \rho_t \circledast PSF$$

For dark pixels at surface (ρs = 0) the ratio determines the diffuse fraction of the upward transmittance:

$$\frac{\rho_t - \rho_{path}}{\rho_t^{HYP} - \rho_{path}} = \frac{T_u^{dif}}{T_u^{tot}}$$

ACOLITE/RAdCor

TSDSF estimation ~ ρdark at BOA

2) detection of dark pixels at surface using heuristic

$$min[\frac{\rho_t \cdot \rho_t}{\rho_t^{HYP}}]$$

The ratio of TOA to hypothetical quantity is proportional to the ratio of target to environmental reflectance.

Small values indicate upscaling adjacency, large values indicate downscaling adjacency, scaled by TOA to account for absolute reflectance.

ACOLITE/RAdCor

TSDSF estimation ~ ρdark at BOA

3) find τa that minimises difference between modeled and estimated diffuse fraction

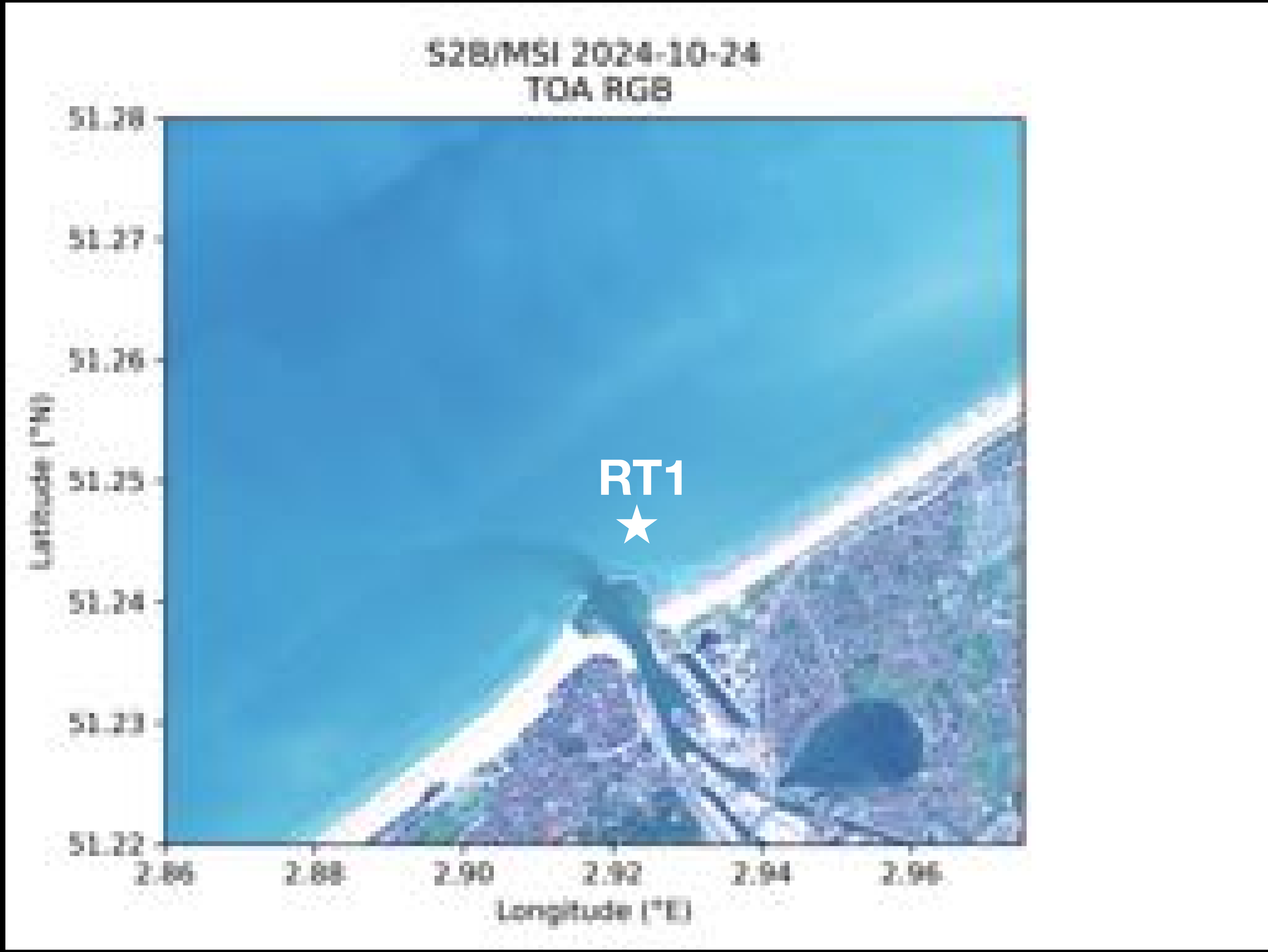
$$\frac{T_u^{dif}}{T_u^{tot}}$$

$$\frac{\rho_t - \rho_{path}}{\rho_t^{HYP} - \rho_{path}} = \frac{T_u^{dif}}{T_u^{tot}}$$

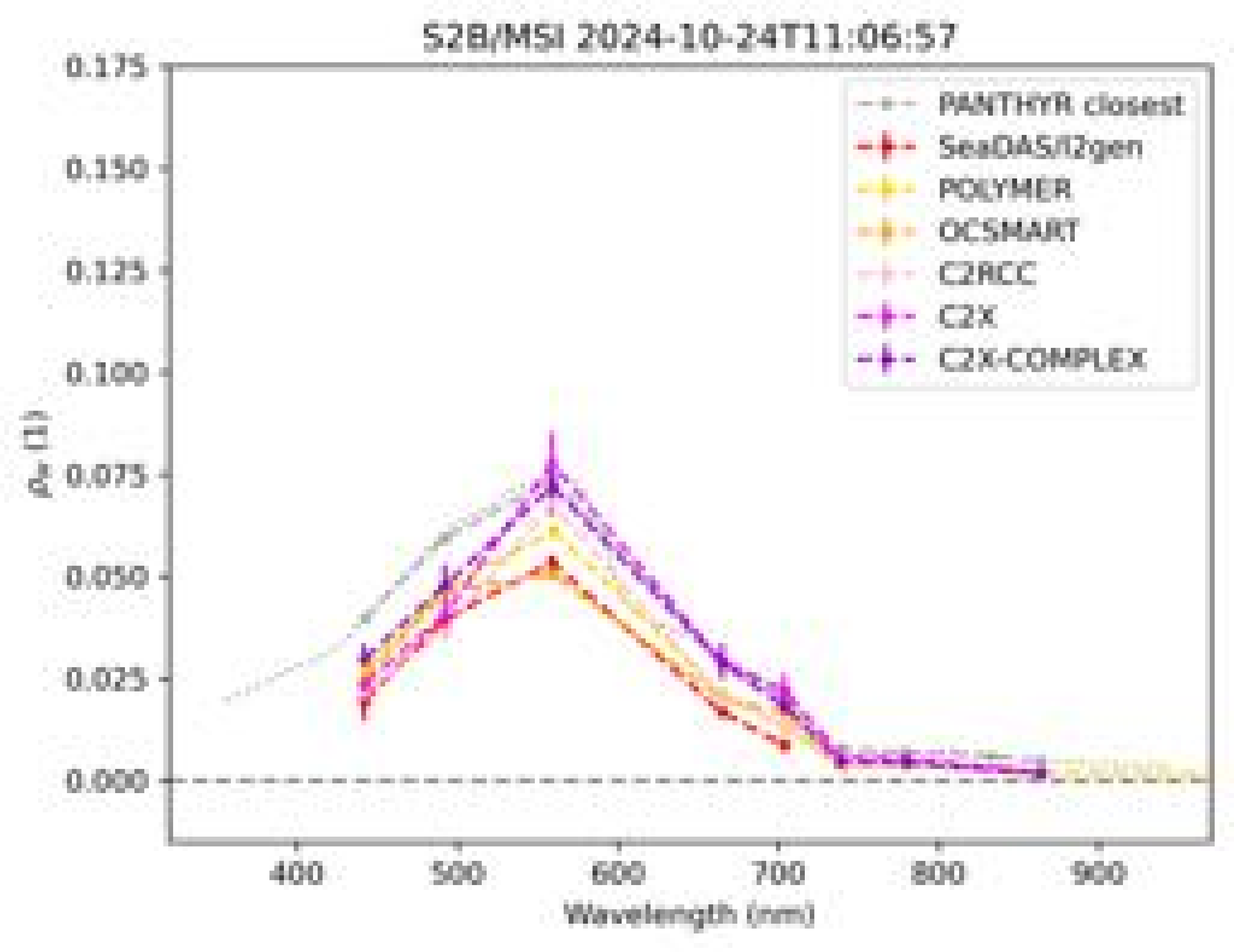
Modeled by RTM

Estimated from image using high τa

2024-10-24

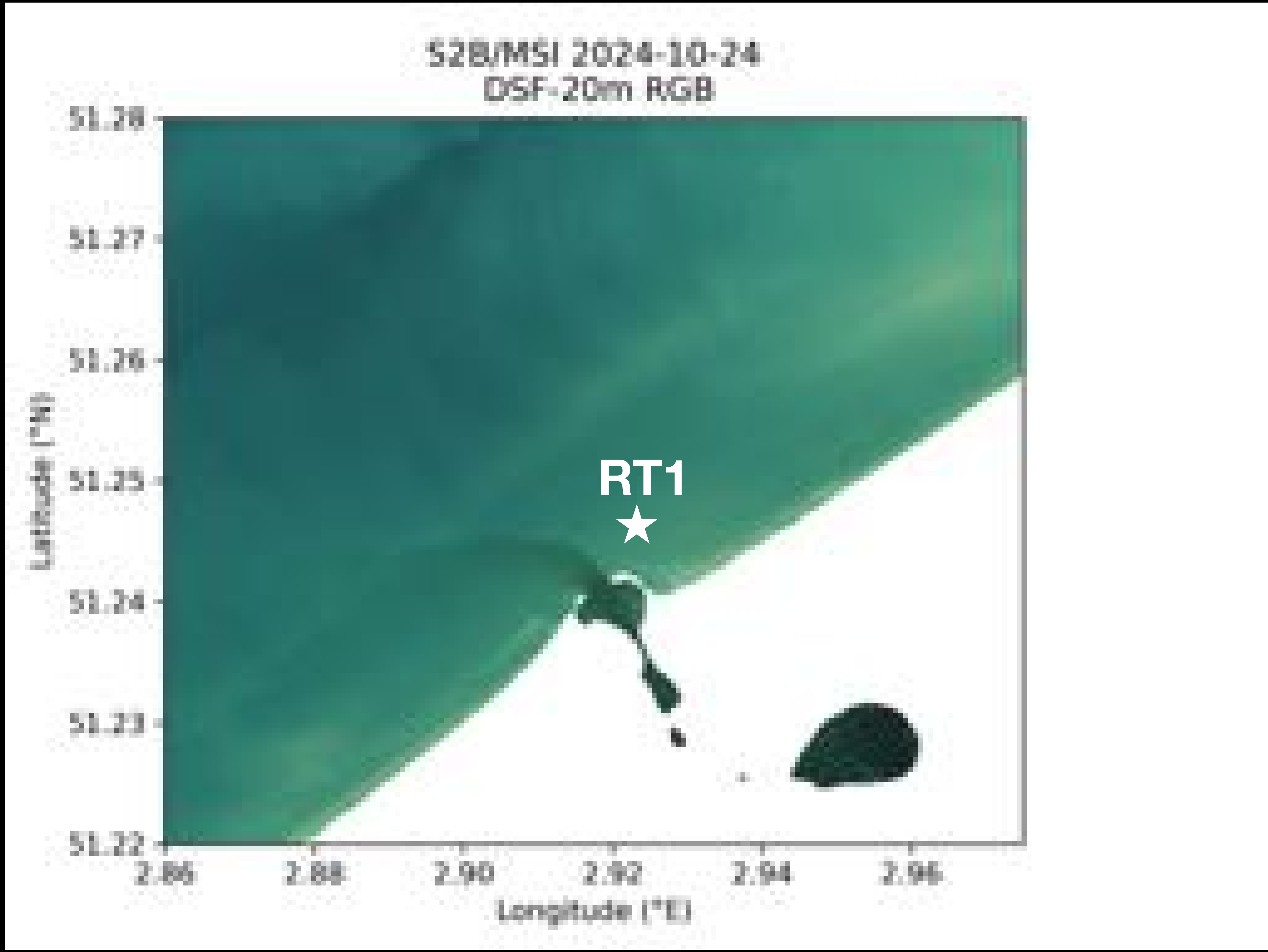


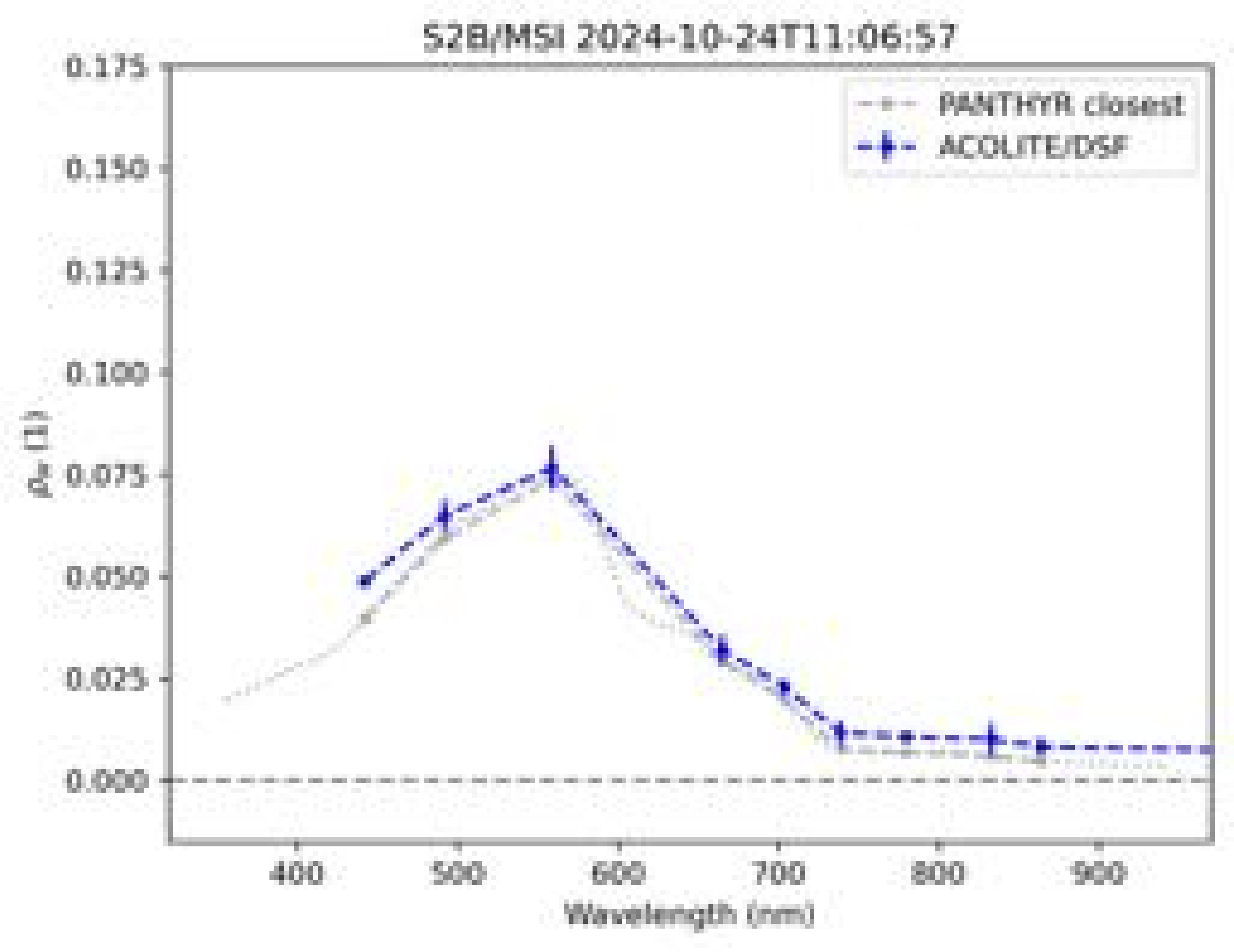
S2B/MSI 2024-10-24
TOA RGB
51.28
51.27
51.26
51.25
51.24
51.23
51.22
Latitude (°N)
2.86
2.88
2.90
2.92
2.94
2.96
Longitude (°E)
RT1



S2B/MSI 2024-10-24T11:06:57
0.175
0.150
0.125
0.100
0.075
0.050
0.025
0.000
ρ_w (1)
400
500
600
700
800
900
Wavelength (nm)
PANTHYR closest
SeaDAS/l2gen
POLYMER
OCSMART
C2RCC
C2X
C2X-COMPLEX

DSF

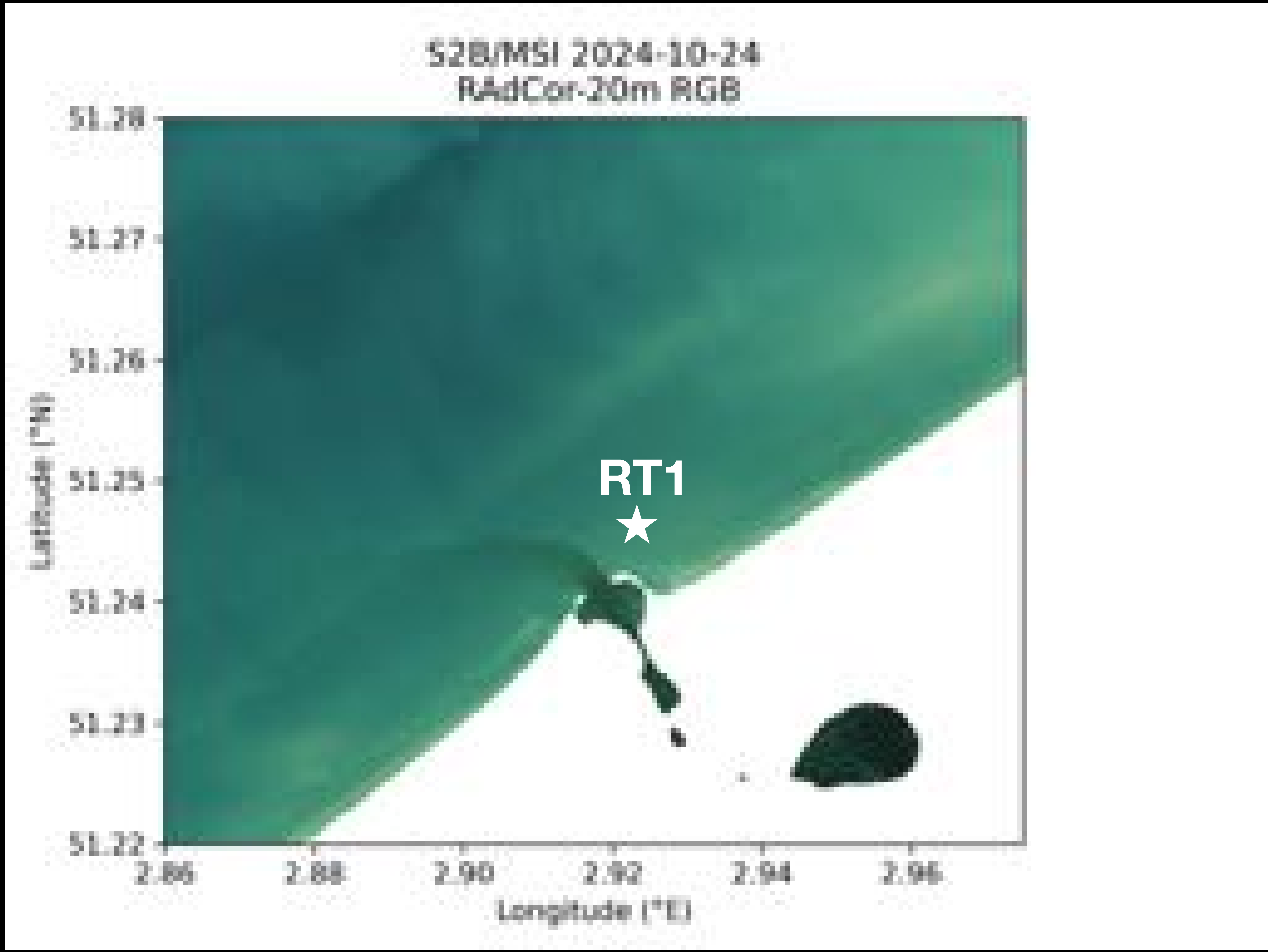


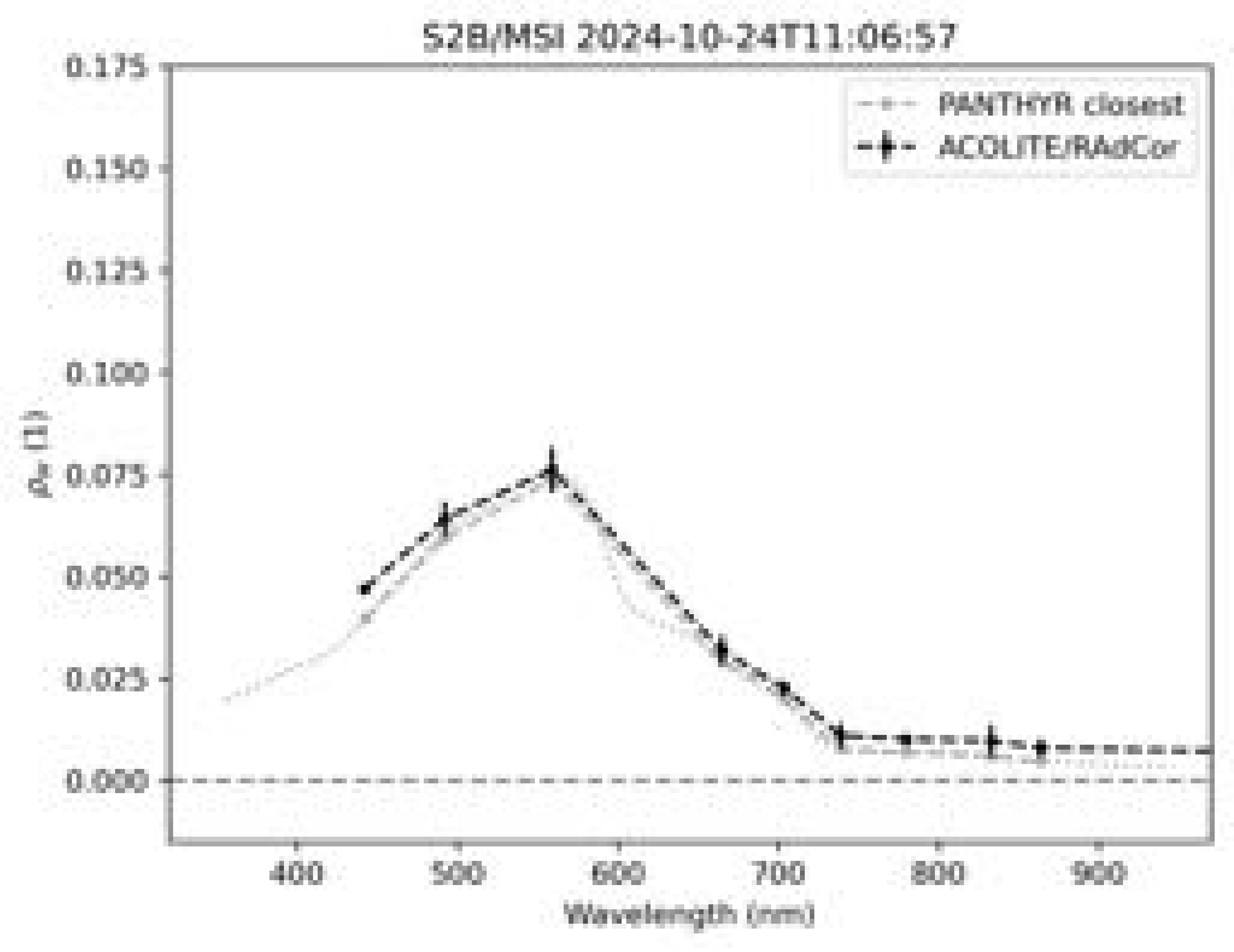


brighter reflectance, less pronounced green

undercorrection, slightly higher in Blue and NIR

RAdCor

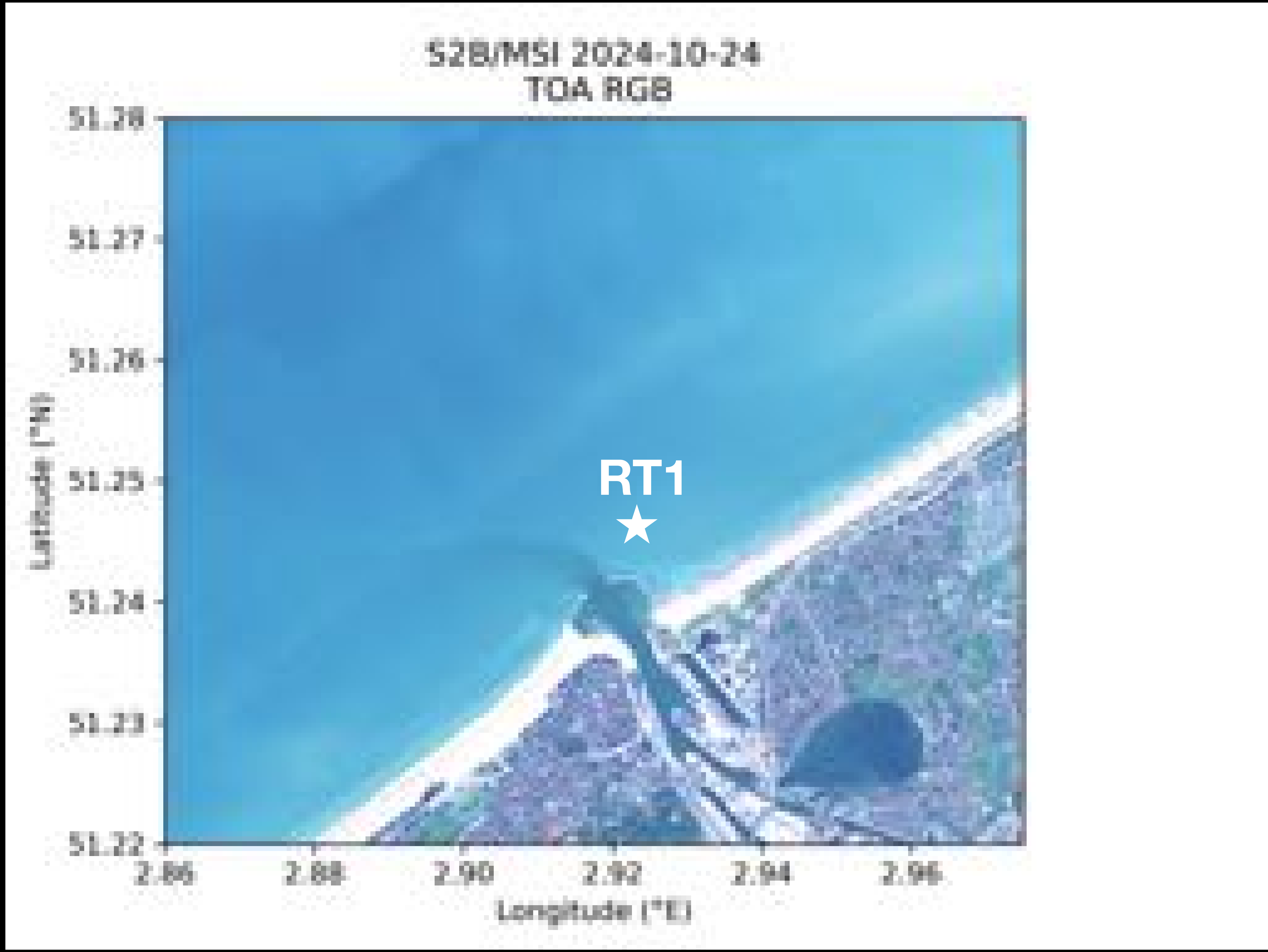


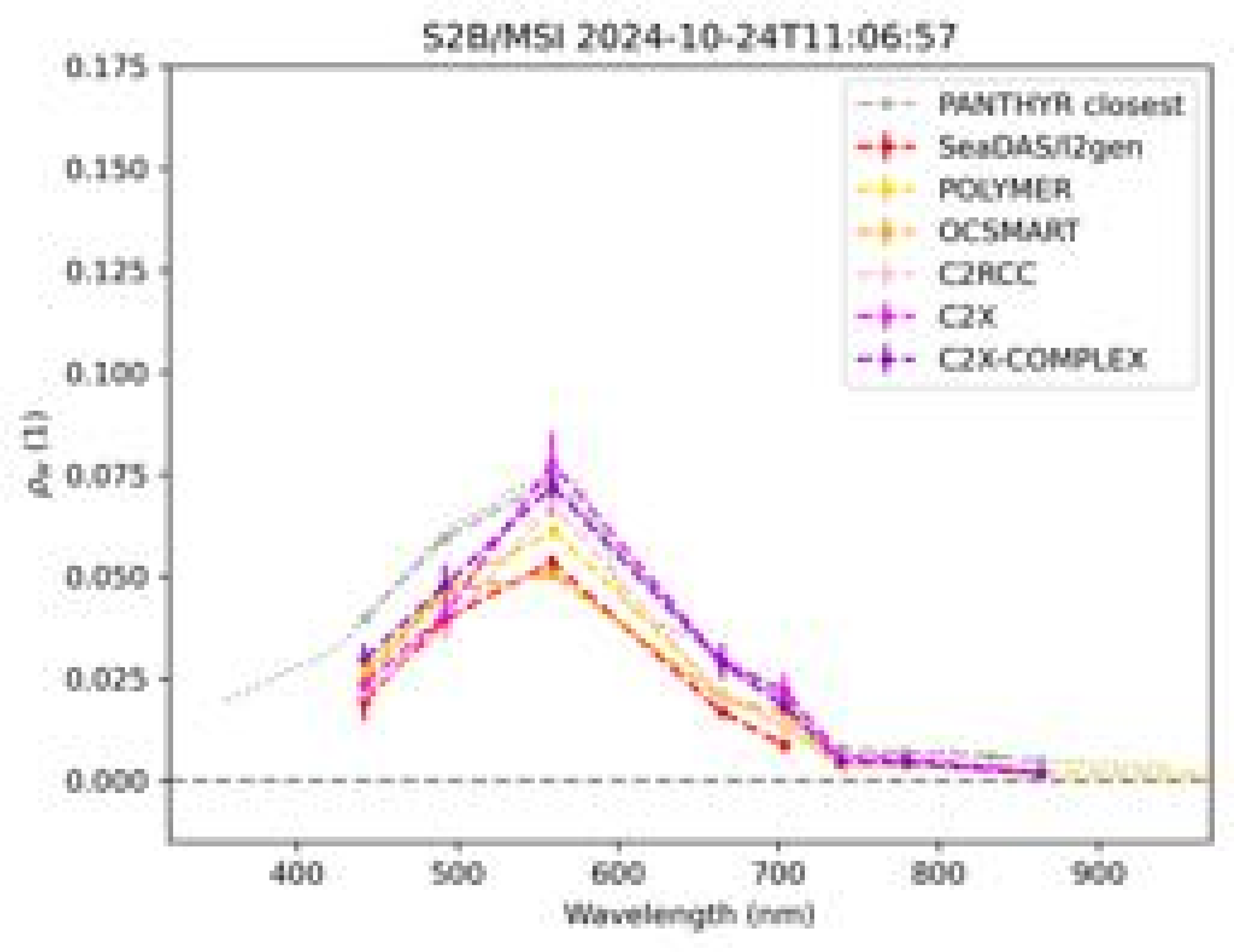


very similar to DSF, lower reflectance in port and lake, slightly sharper appearance

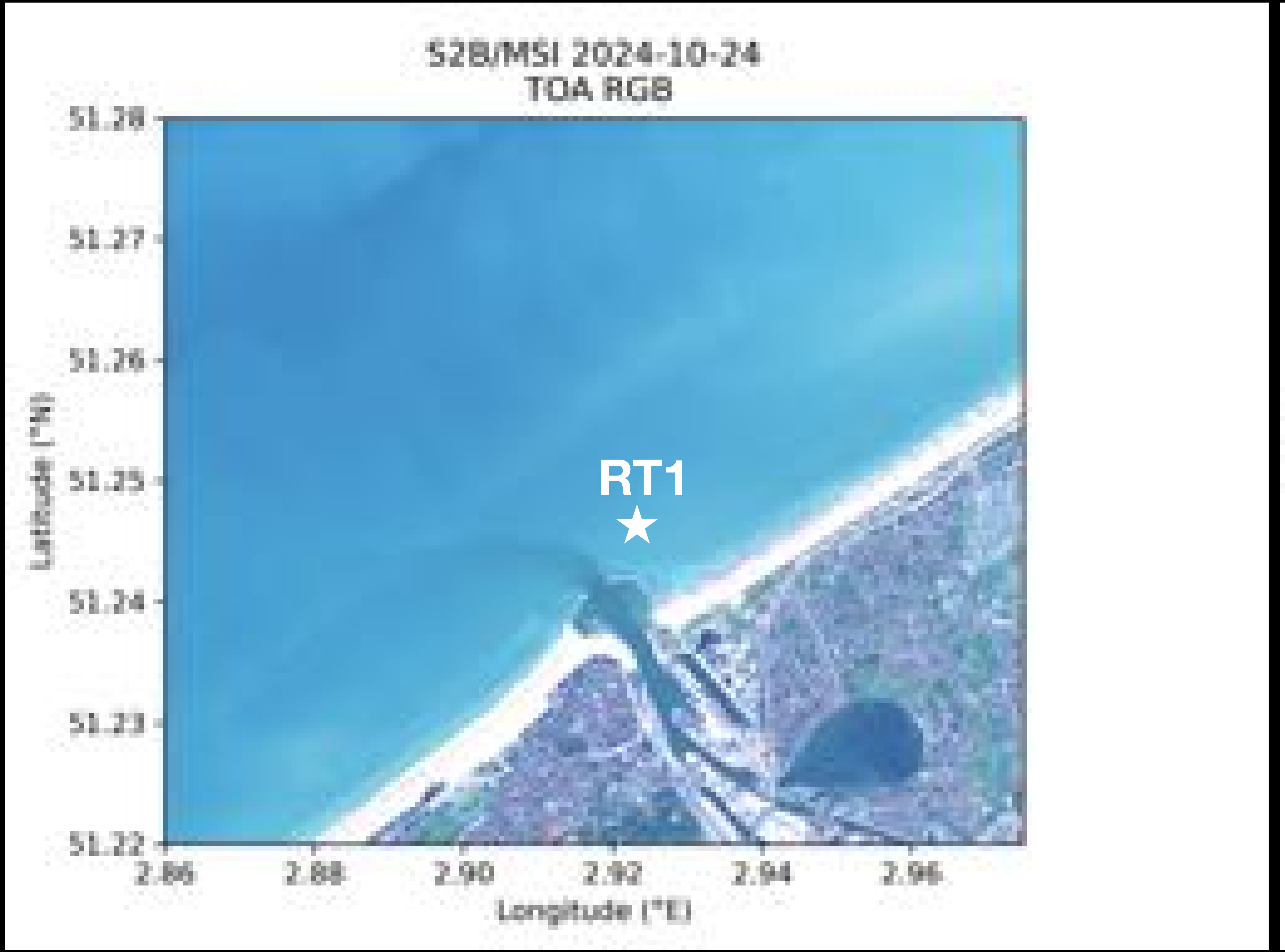
undercorrection, slight improvement to spectral shape compared to DSF

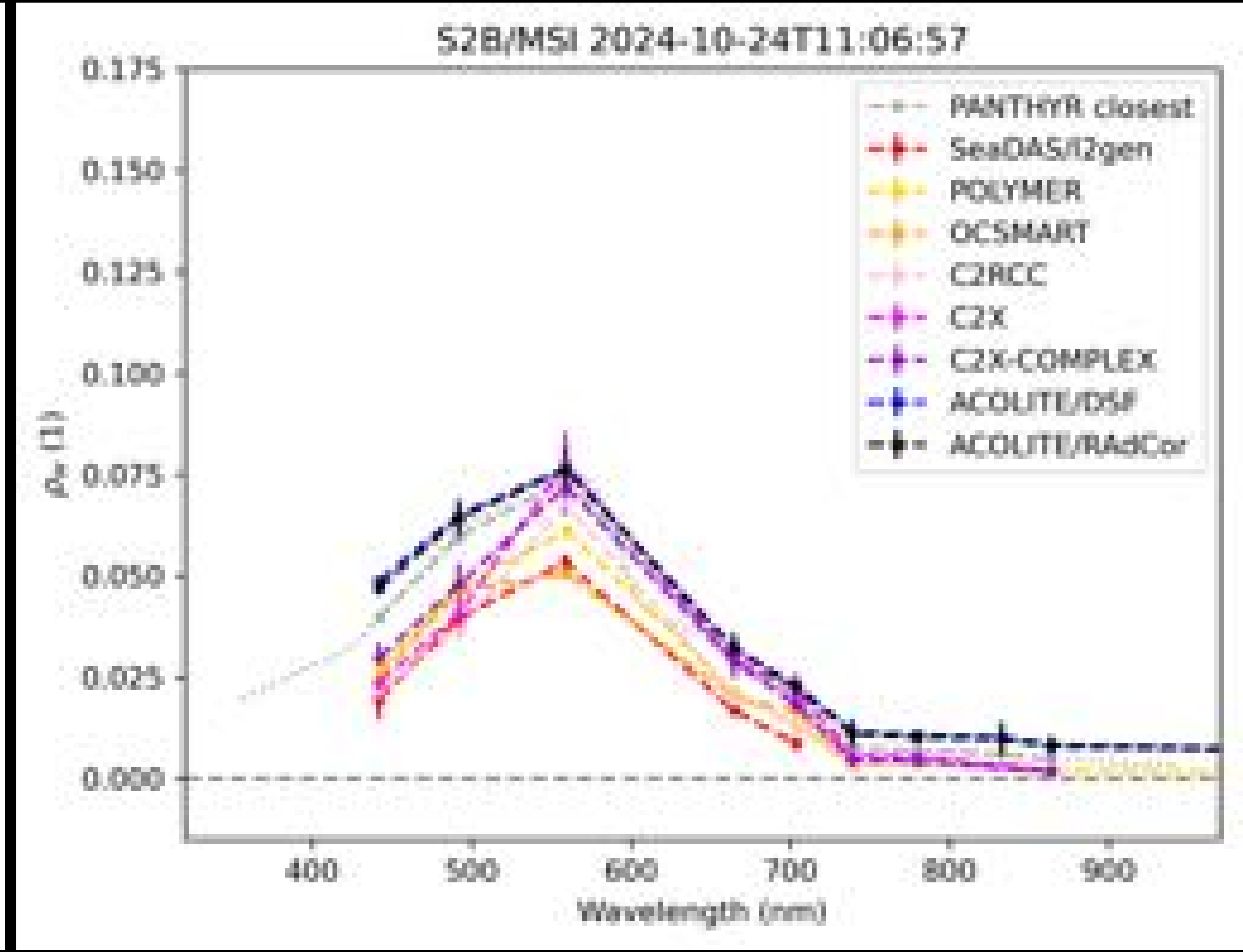
2024-10-24


S2B/MSI 2024-10-24
TOA RGB
51.28
51.27
51.26
51.25
51.24
51.23
51.22
Latitude (°N)
RT1
2.86
2.88
2.90
2.92
2.94
2.96
Longitude (°E)

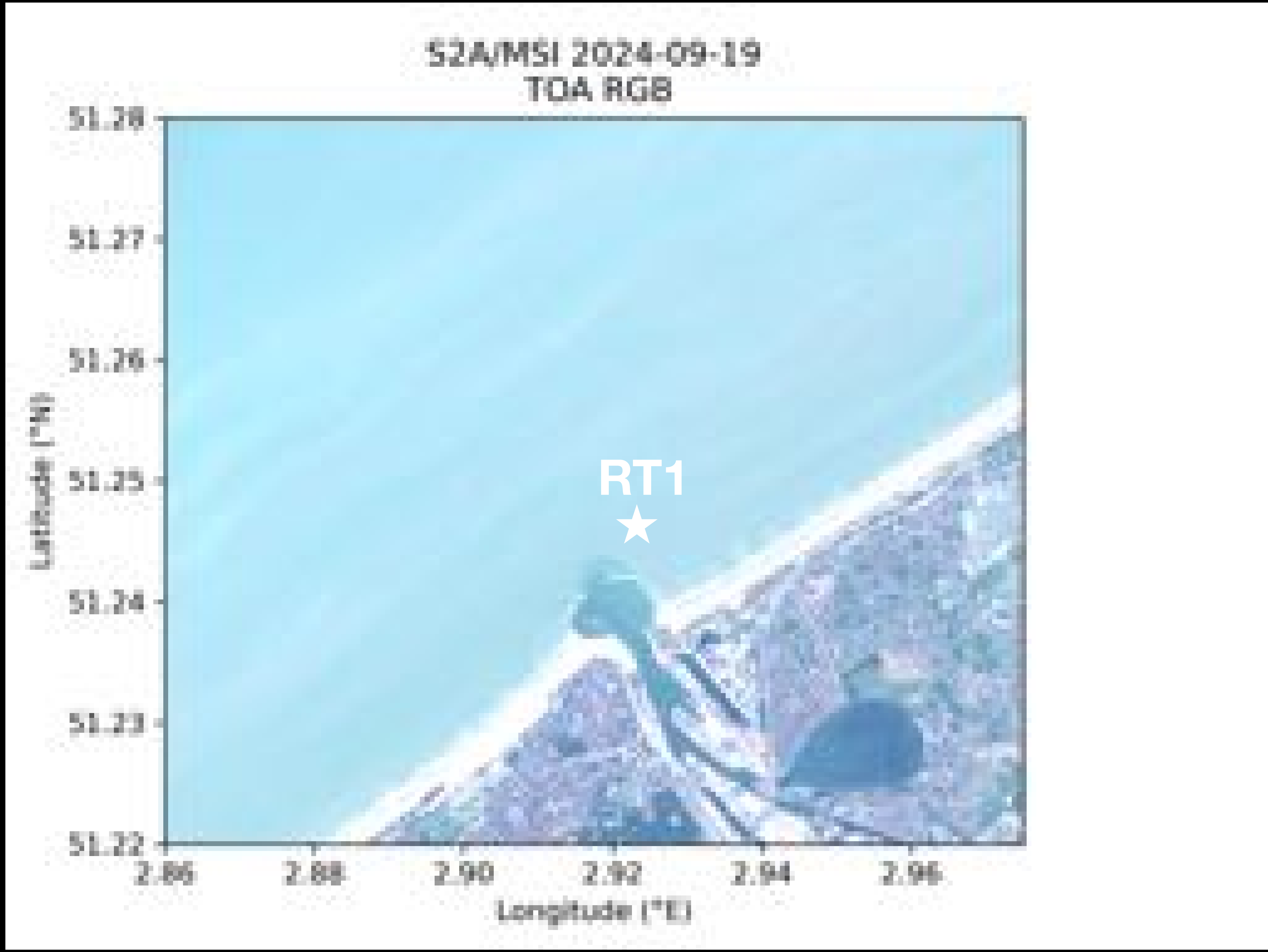

S2B/MSI 2024-10-24T11:06:57
0.175
0.150
0.125
0.100
0.075
0.050
0.025
0.000
400
500
600
700
800
900
Wavelength (nm)
PANTHYR closest
SeaDAS/l2gen
POLYMER
OCSMART
C2RCC
C2X
C2X-COMPLEX

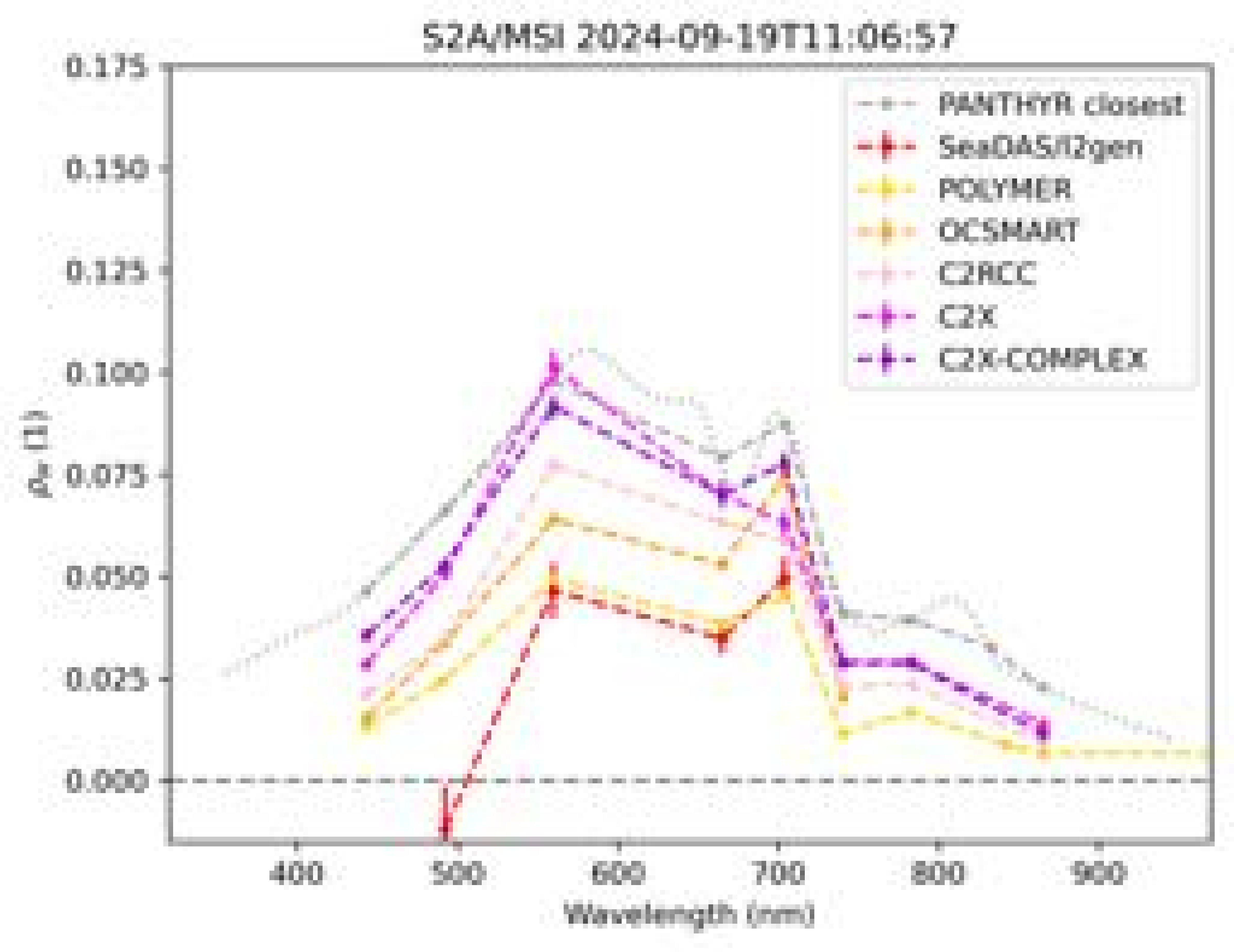
2024-10-24


S2B/MSI 2024-10-24
TOA RGB
51.28
51.27
51.26
51.25
51.24
51.23
51.22
Latitude (°N)
2.86
2.88
2.90
2.92
2.94
2.96
Longitude (°E)
RT1

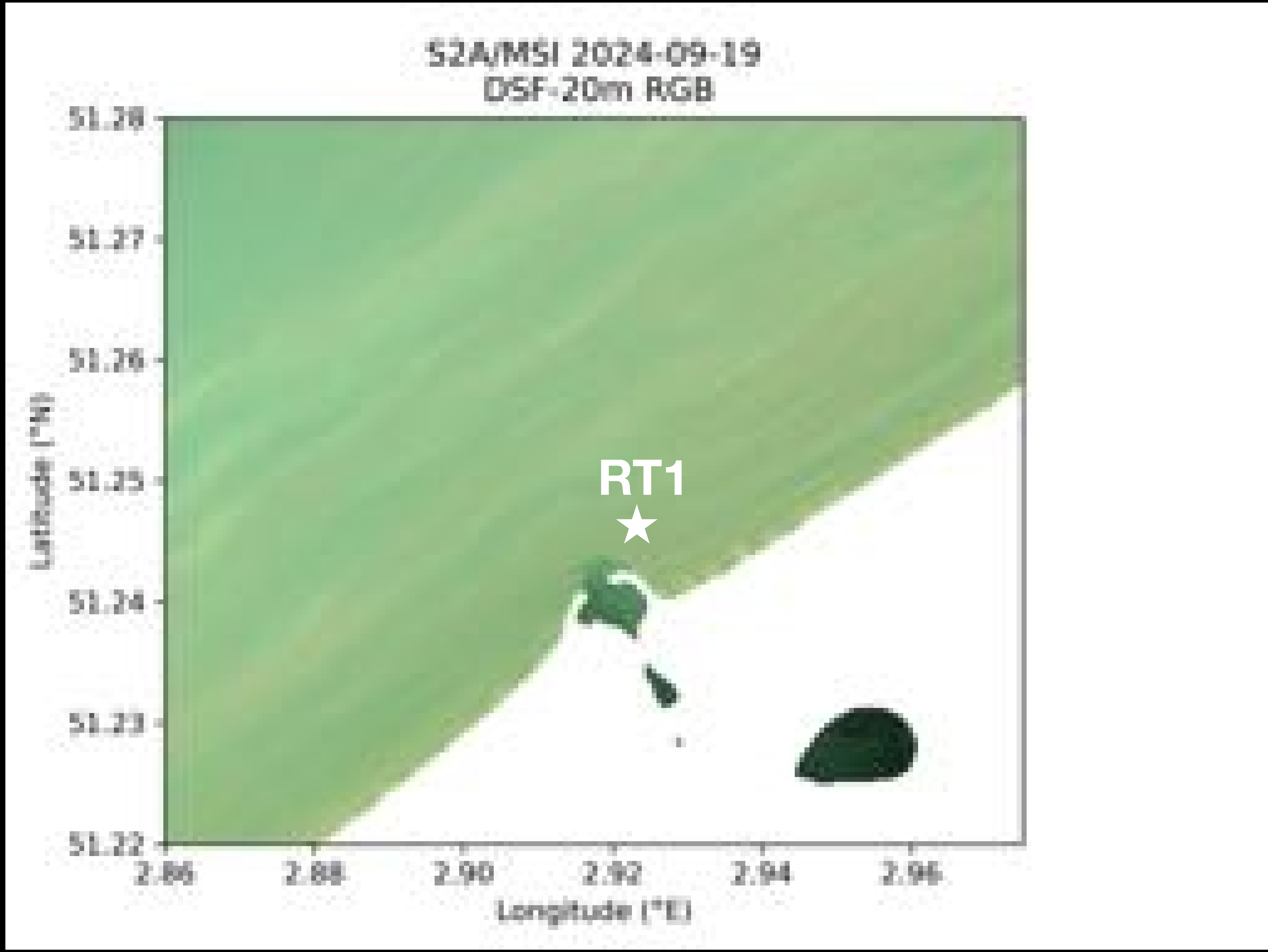

S2B/MSI 2024-10-24T11:06:57
0.175
0.150
0.125
0.100
0.075
0.050
0.025
0.000
400
500
600
700
800
900
Wavelength (nm)
PANTHYR closest
SeaDAS/l2gen
POLYMER
OCSMART
C2RCC
C2X
C2X-COMPLEX
ACOLITE/DSF
ACOLITE/RAdCor

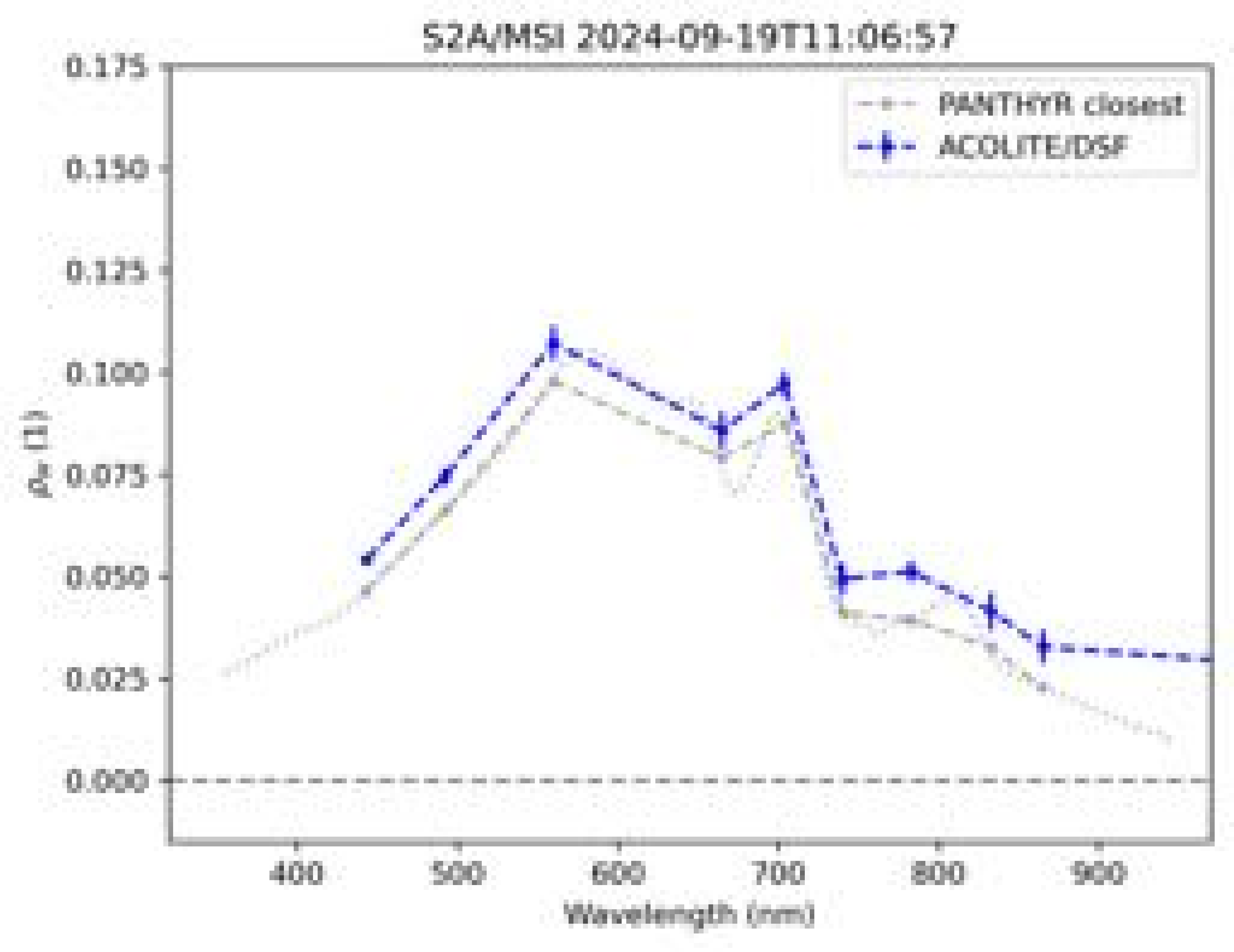
2024-09-19


S2A/MSI 2024-09-19
TOA RGB
RT1
Latitude (°N)
Longitude (°E)
51.28
51.27
51.26
51.25
51.24
51.23
51.22
2.86
2.88
2.90
2.92
2.94
2.96


S2A/MSI 2024-09-19T11:06:57
PANTHYR closest
SeaDAS/l2gen
POLYMER
OCSMART
C2RCC
C2X
C2X-COMPLEX
0.175
0.150
0.125
0.100
0.075
0.050
0.025
0.000
400
500
600
700
800
900
Wavelength (nm)

DSF

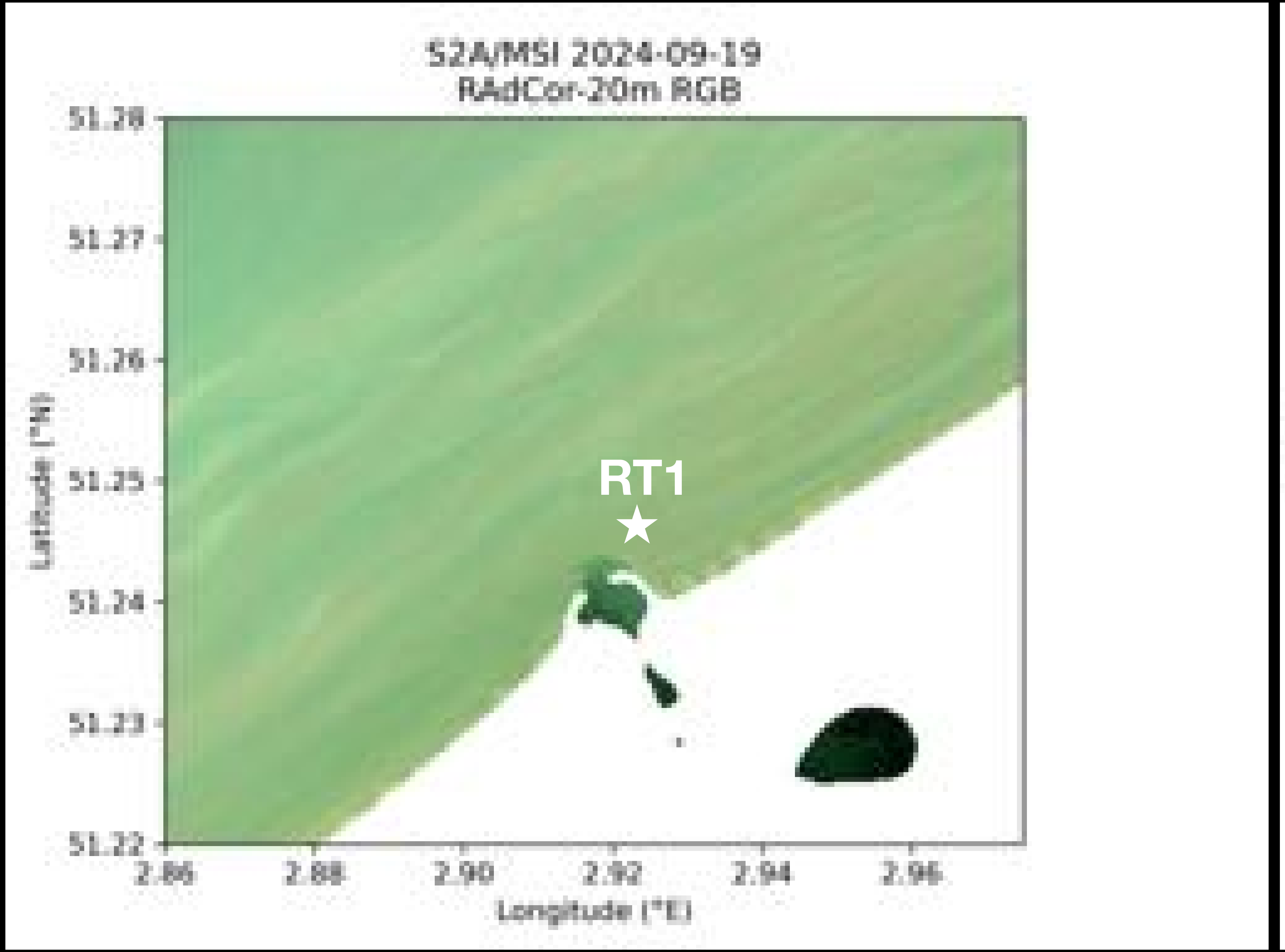


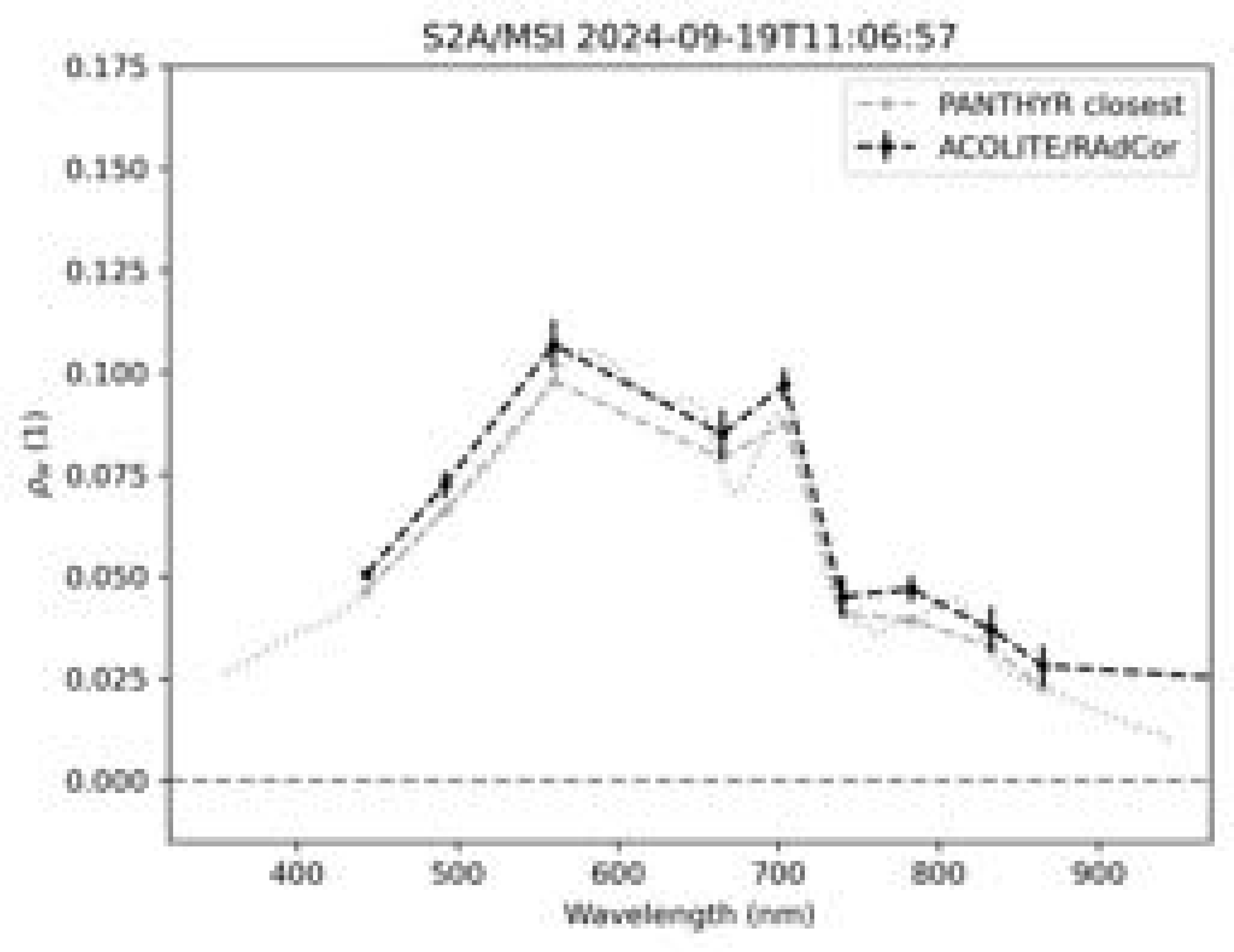


brighter reflectance, more grey/white coloured

undercorrection, rather good spectral shape

RAdCor

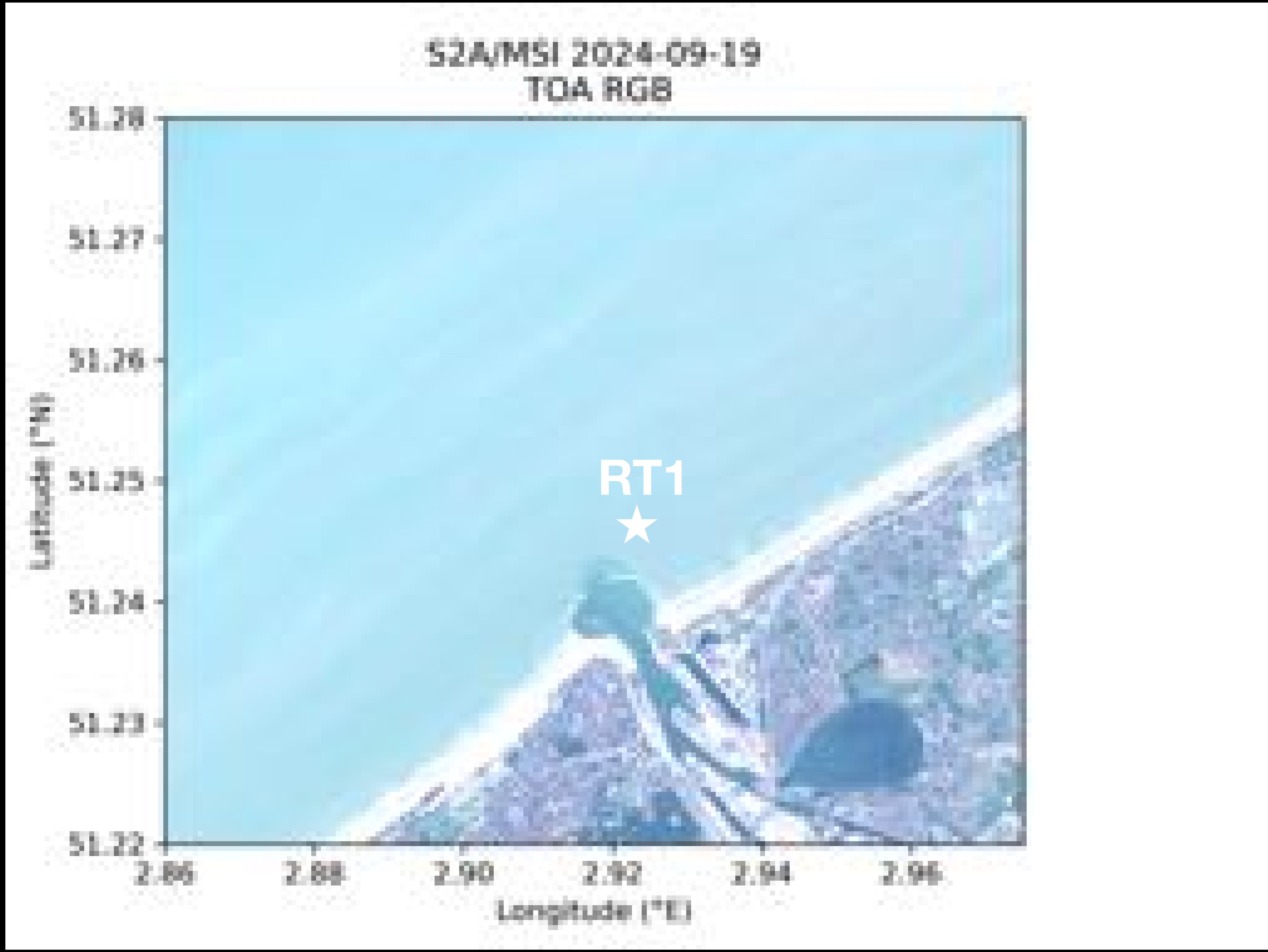


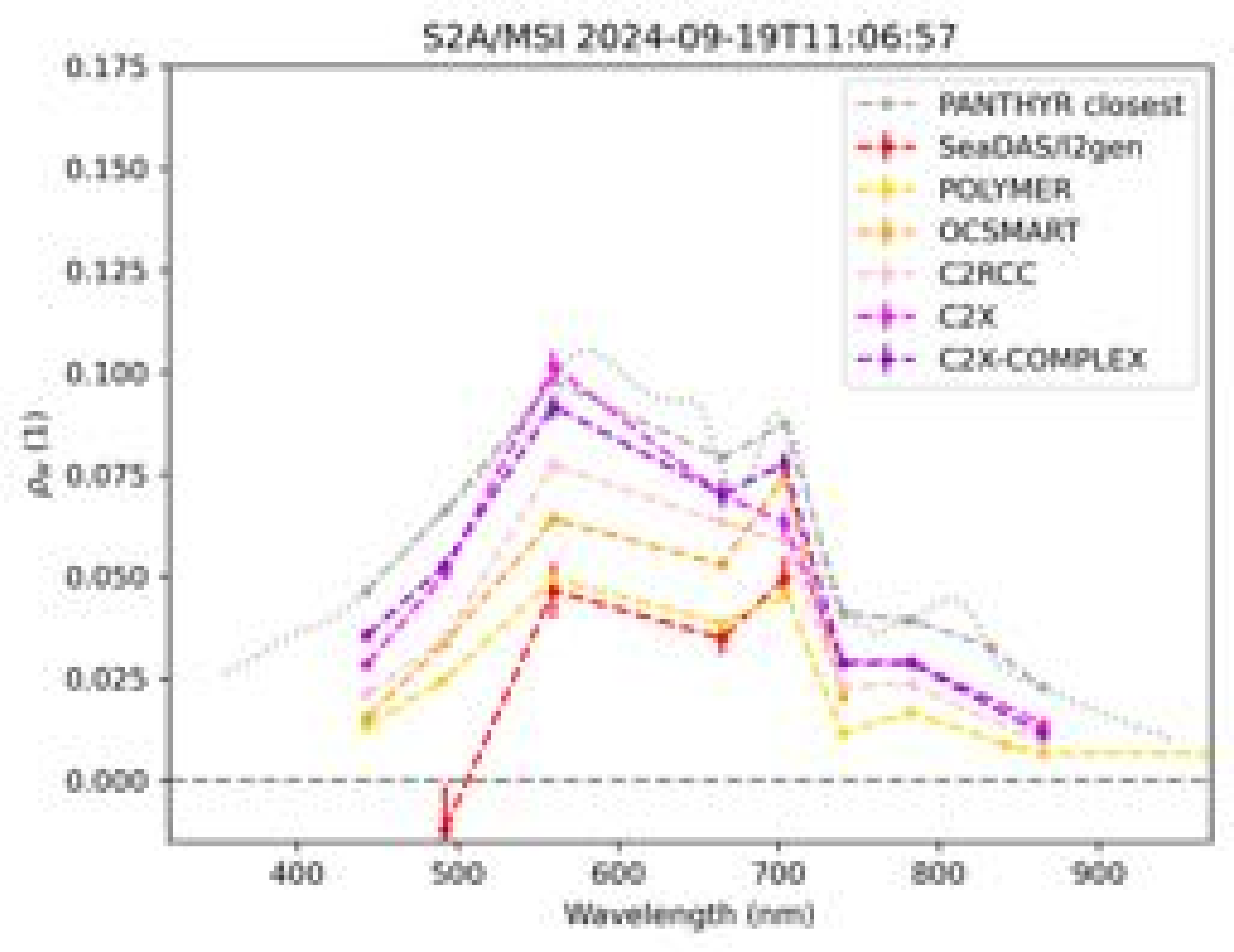


very similar to DSF, lower reflectance in port and lake, slightly sharper appearance

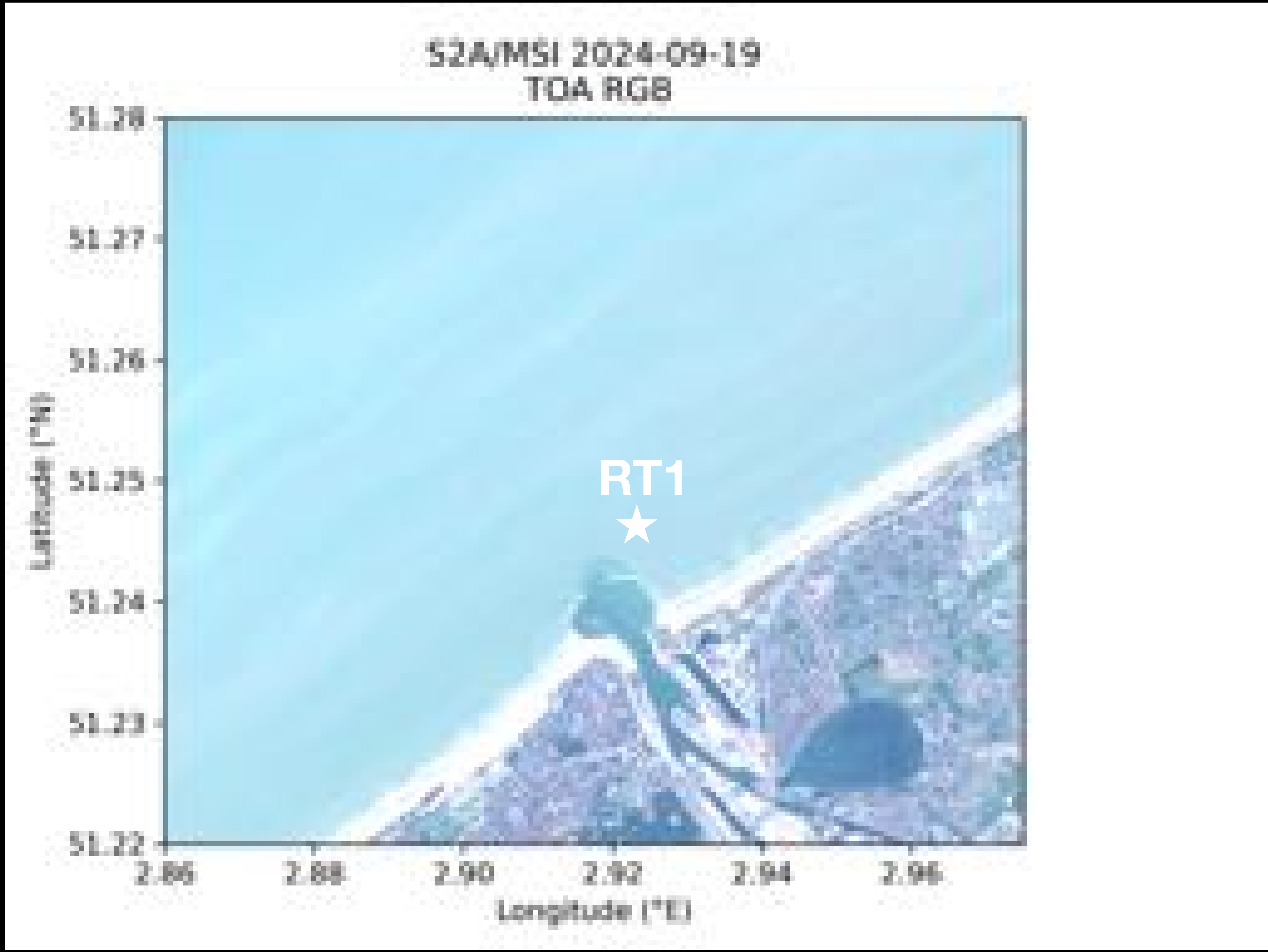
undercorrection, slight improvement to spectral shape compared to DSF

2024-09-19

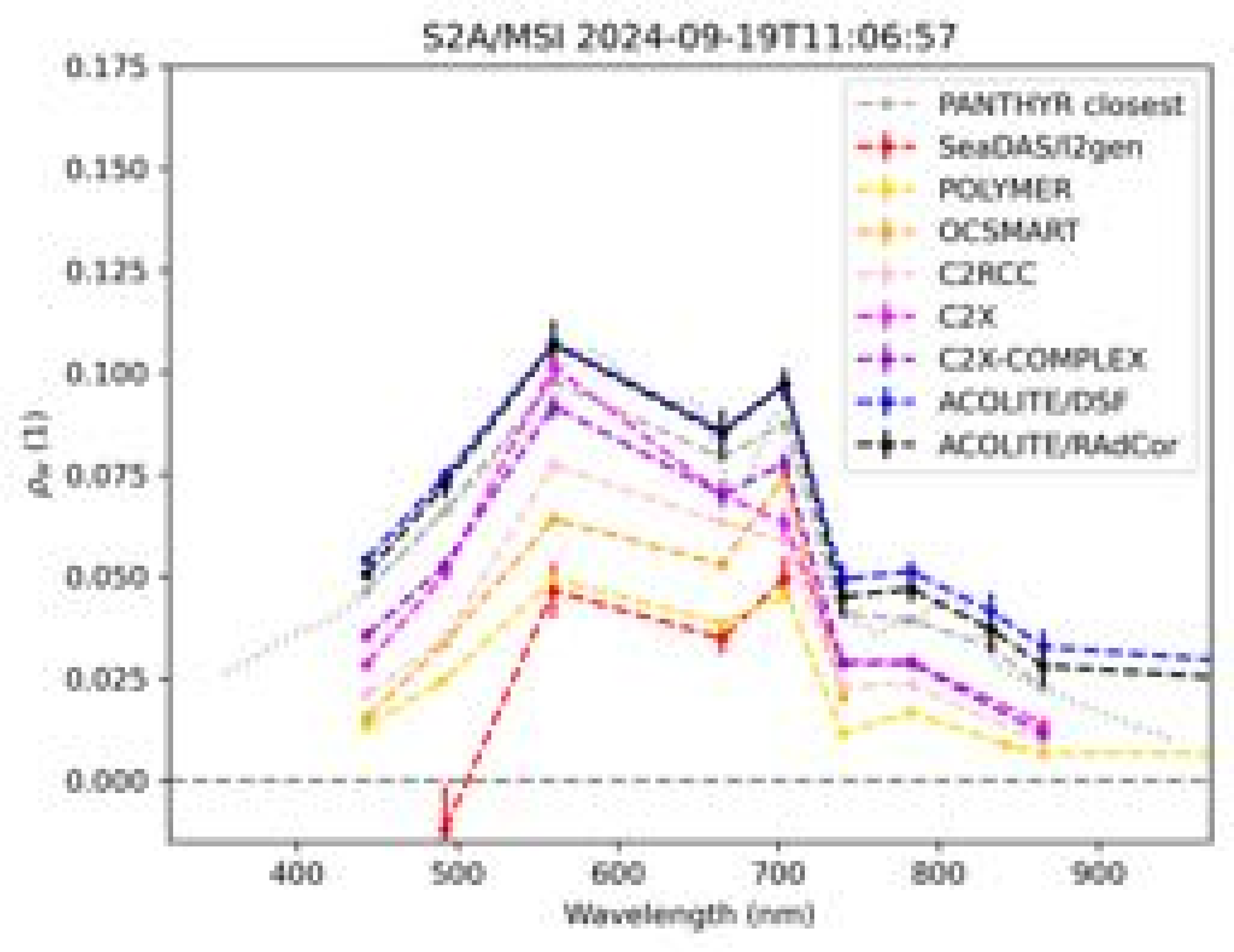

S2A/MSI 2024-09-19
TOA RGB
51.28
51.27
51.26
51.25
51.24
51.23
51.22
Latitude (°N)
2.86
2.88
2.90
2.92
2.94
2.96
Longitude (°E)
RT1


S2A/MSI 2024-09-19T11:06:57
0.175
0.150
0.125
0.100
0.075
0.050
0.025
0.000
400
500
600
700
800
900
Wavelength (nm)
PANTHYR closest
SeaDAS/l2gen
POLYMER
OCSMART
C2RCC
C2X
C2X-COMPLEX

2024-09-19

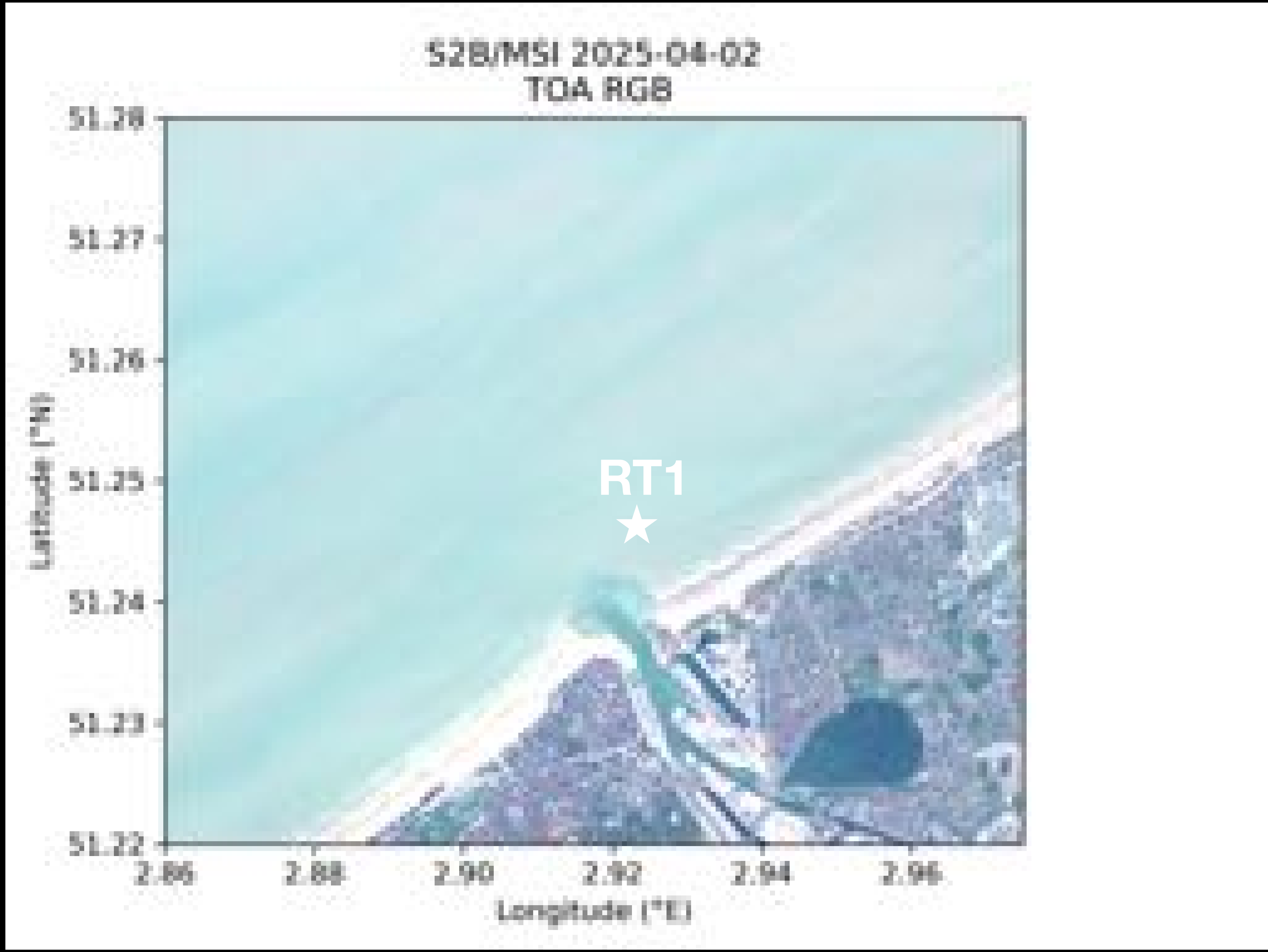


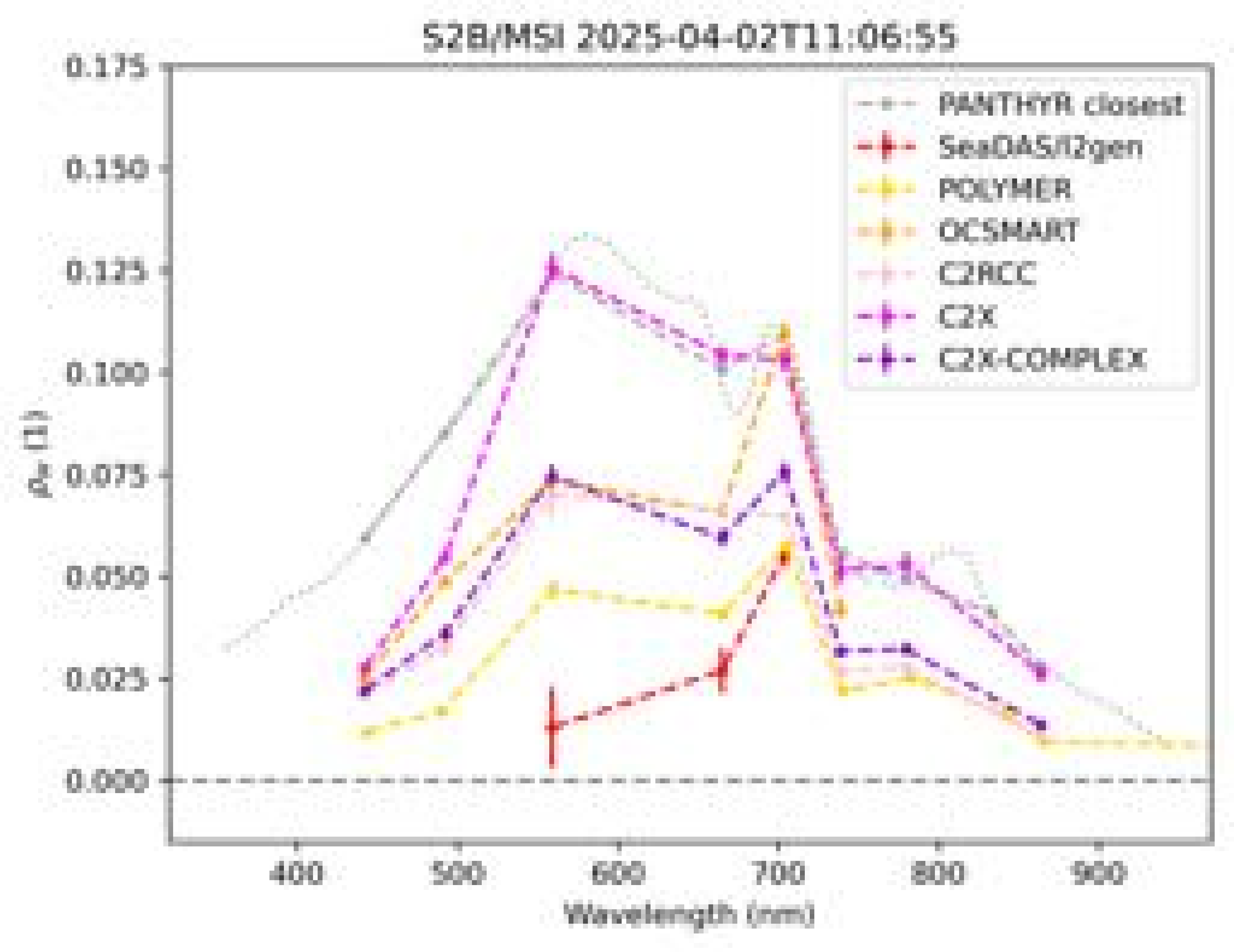
S2A/MSI 2024-09-19
TOA RGB
RT1
Latitude (°N)
Longitude (°E)
51.28
51.27
51.26
51.25
51.24
51.23
51.22
2.86
2.88
2.90
2.92
2.94
2.96



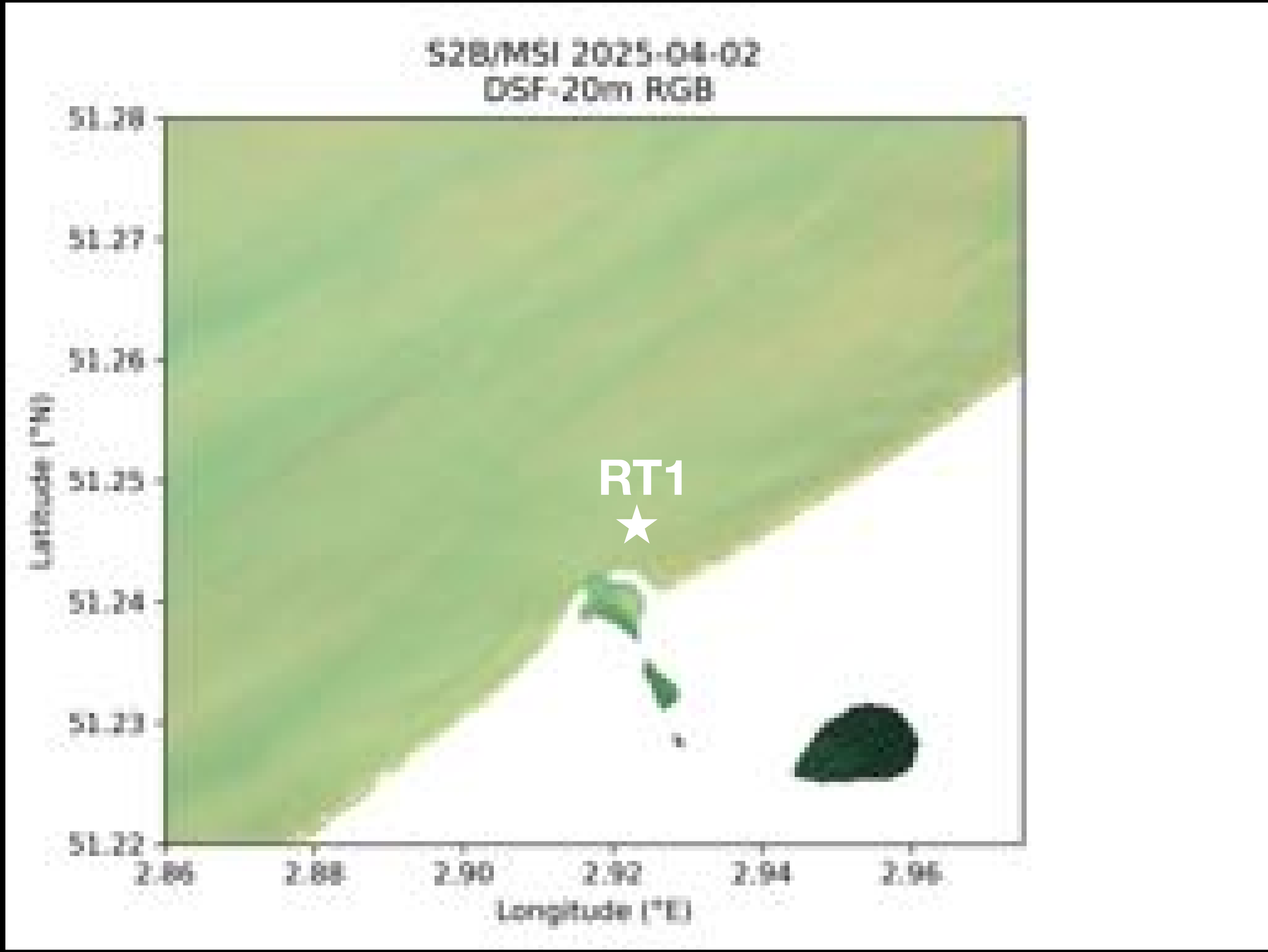
S2A/MSI 2024-09-19T11:06:57
PANTHYR closest
SeaDAS/l2gen
POLYMER
OCSMART
C2RCC
C2X
C2X-COMPLEX
ACOLITE/DSF
ACOLITE/RAdCor
0.175
0.150
0.125
0.100
0.075
0.050
0.025
0.000
400
500
600
700
800
900
Wavelength (nm)

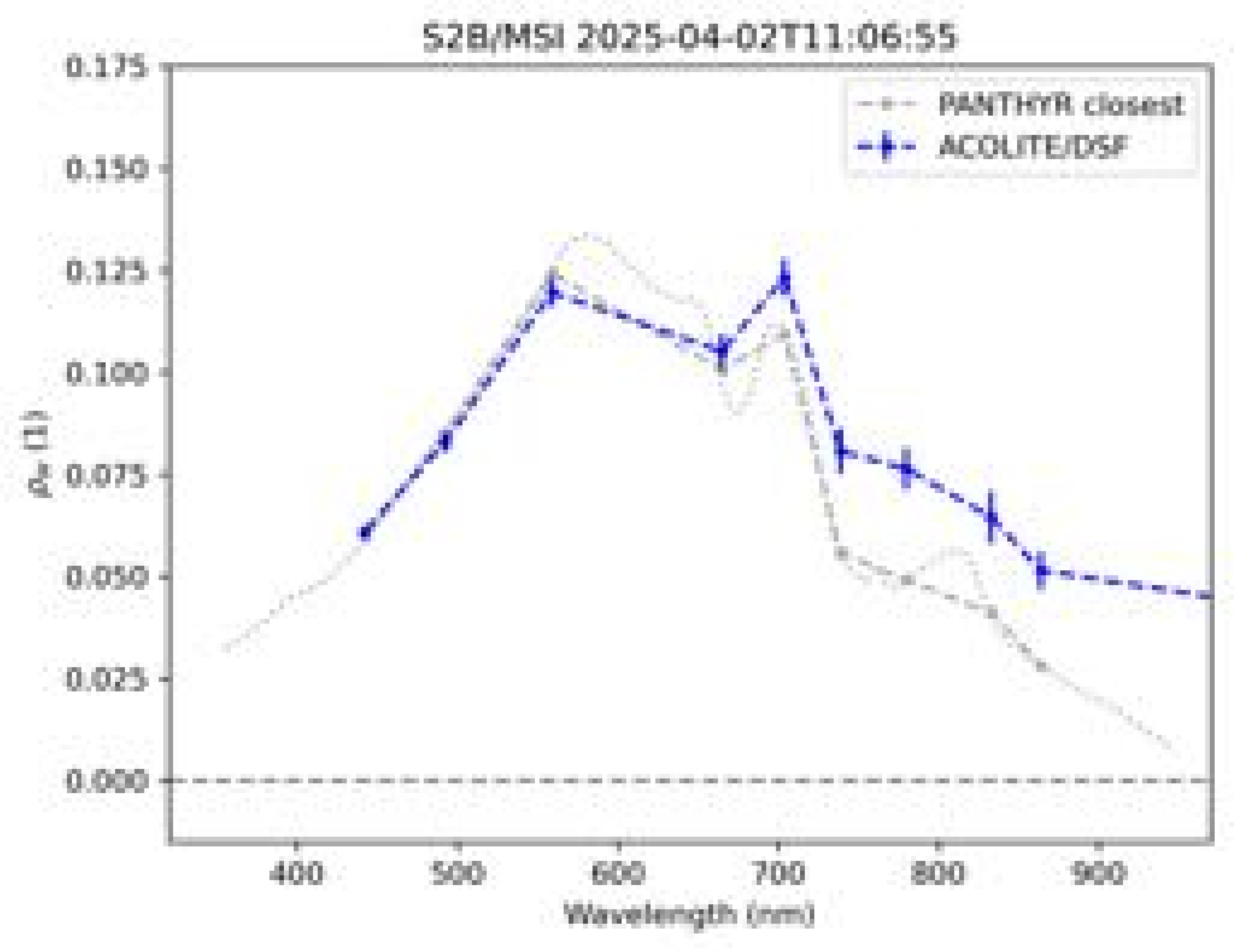
2025-04-02


S2B/MSI 2025-04-02
TOA RGB
Latitude (°N)
Longitude (°E)
RT1
51.28
51.27
51.26
51.25
51.24
51.23
51.22
2.86
2.88
2.90
2.92
2.94
2.96


S2B/MSI 2025-04-02T11:06:55
PANTHYR closest
SeaDAS/l2gen
POLYMER
OCSMART
C2RCC
C2X
C2X-COMPLEX
0.175
0.150
0.125
0.100
0.075
0.050
0.025
0.000
400
500
600
700
800
900
Wavelength (nm)

DSF

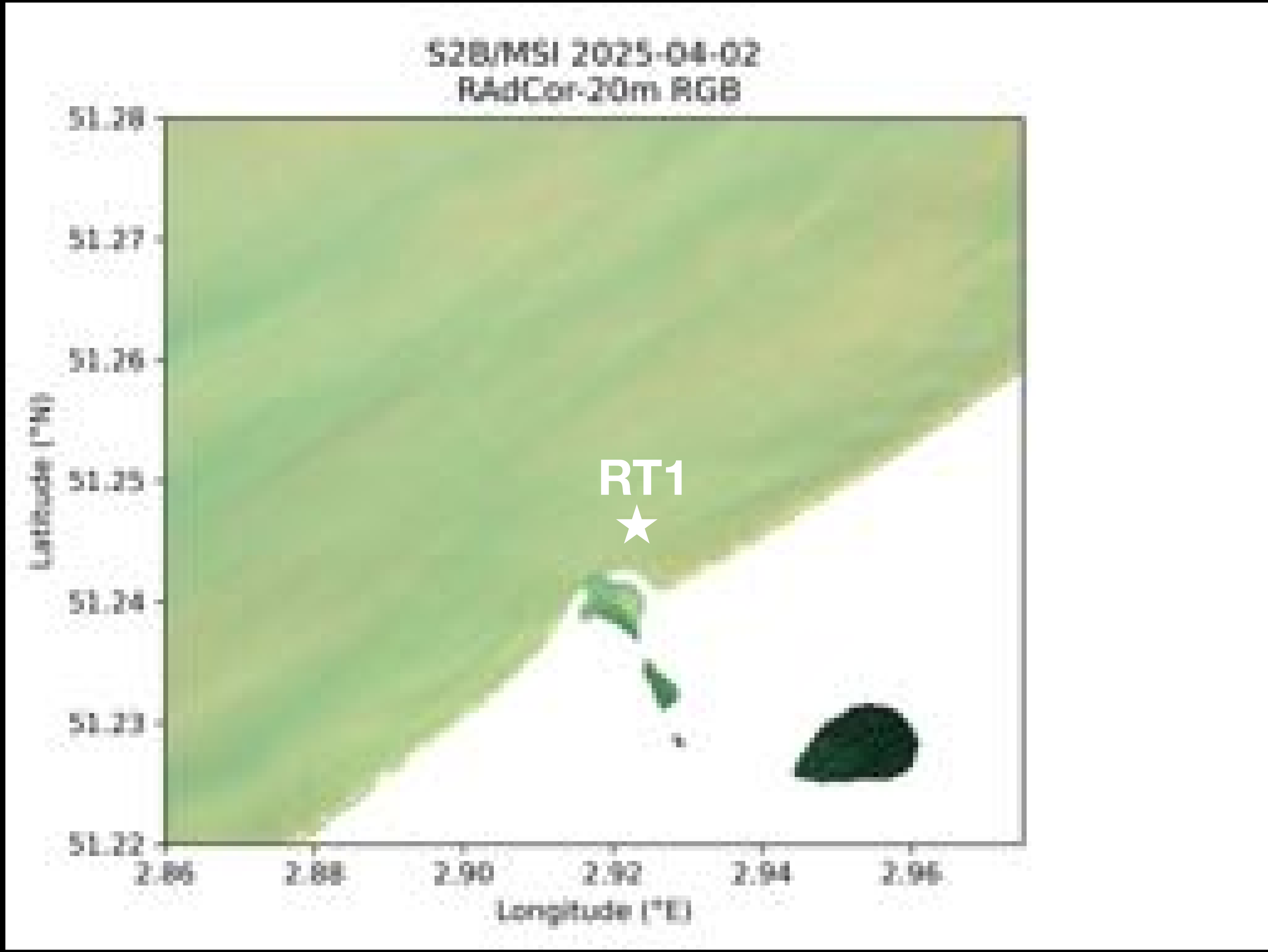


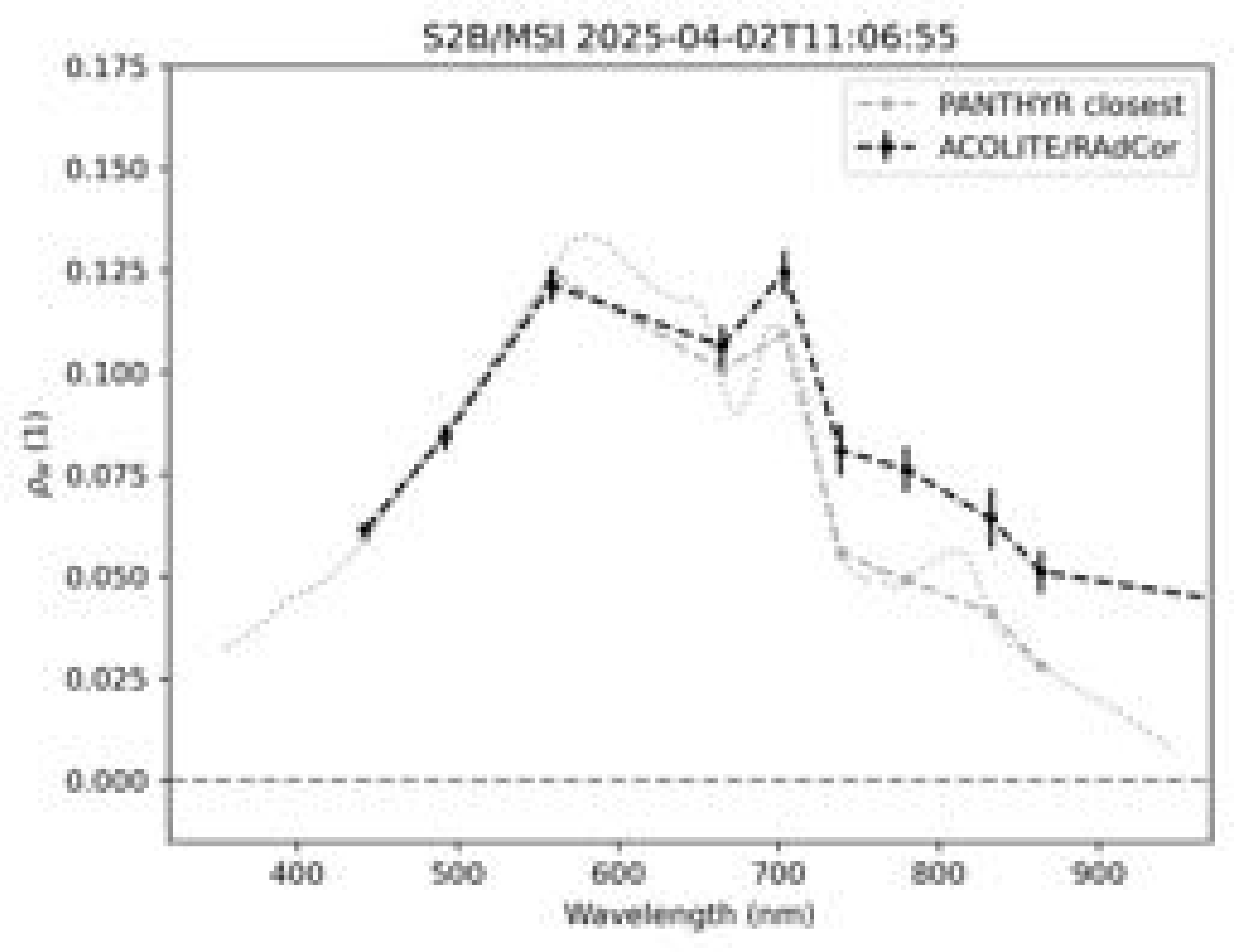


brighter reflectance, more grey/white coloured

good match in VIS, rather good spectral shape, under-correction in NIR

RAdCor

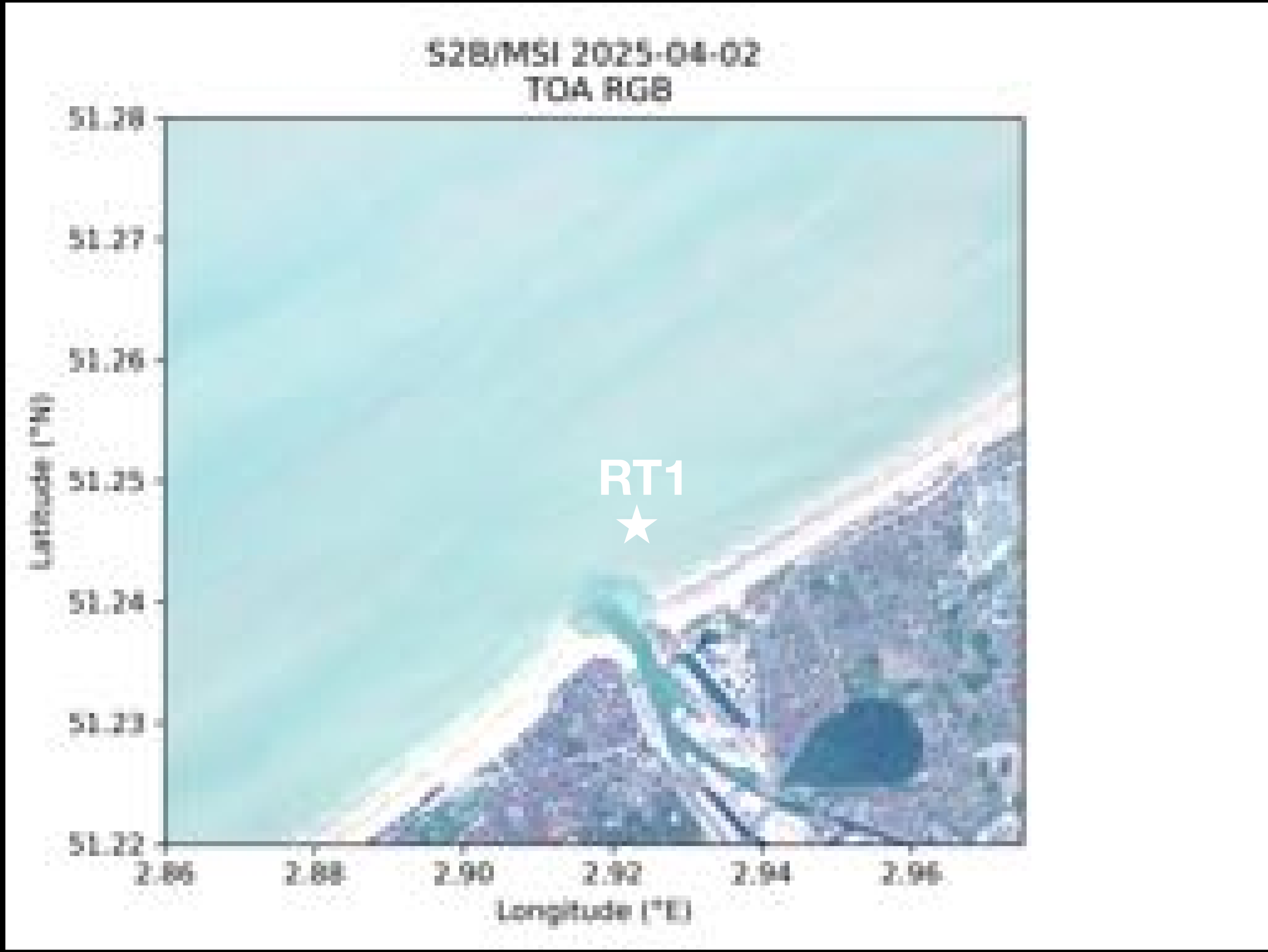


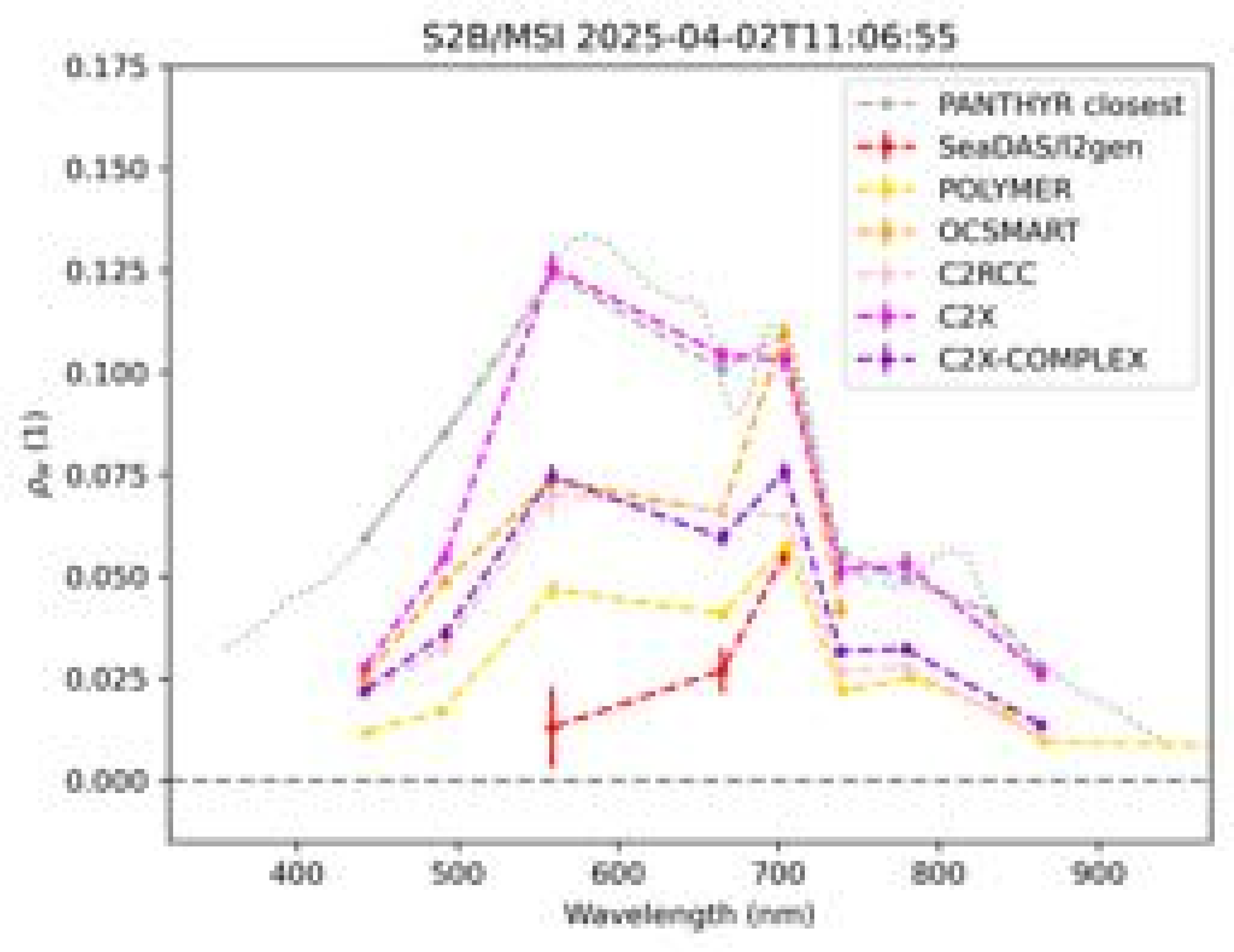


very similar to DSF, lower reflectance in port and lake, slightly sharper appearance

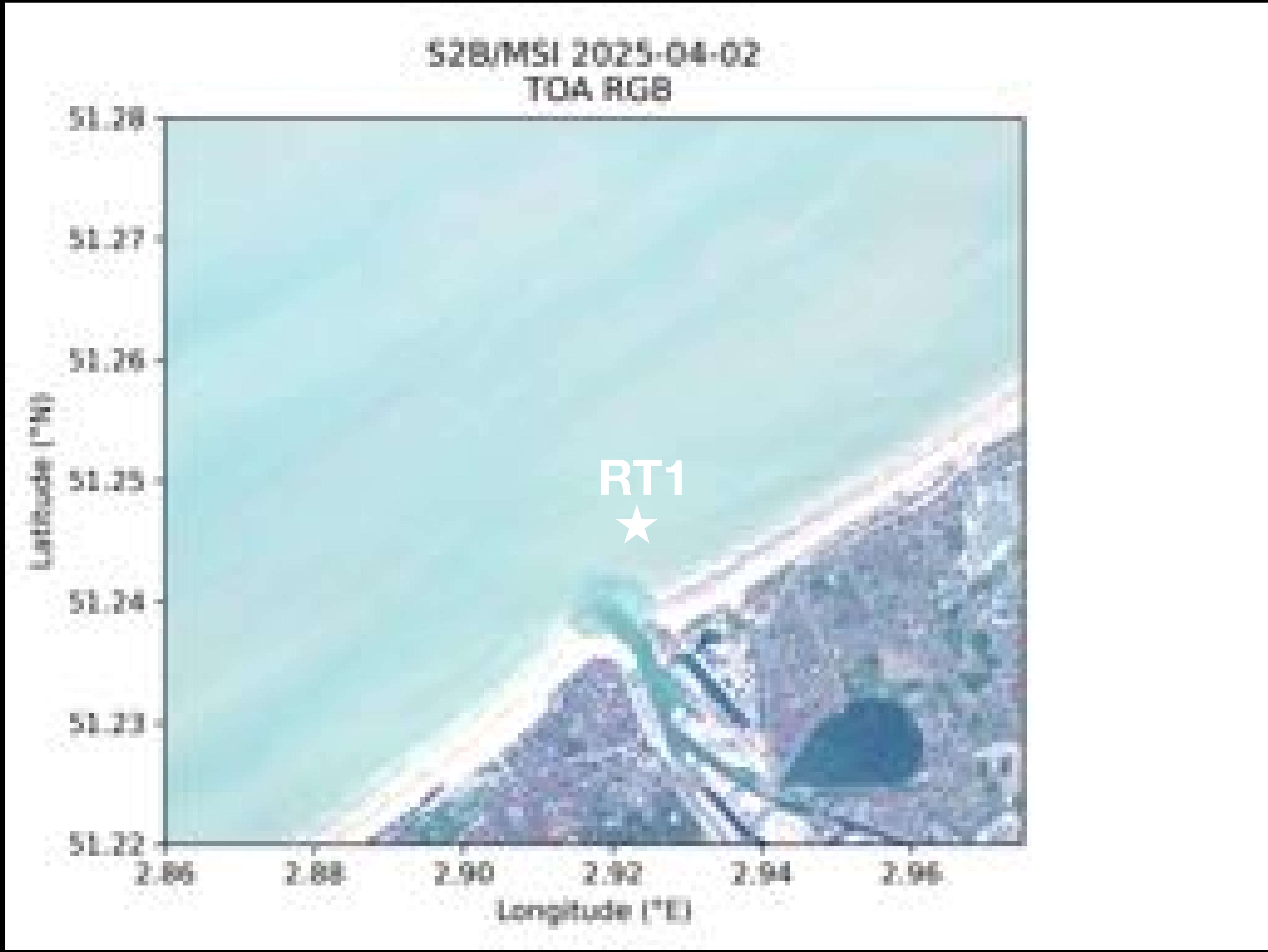
see DSF, still too high in NIR

2025-04-02

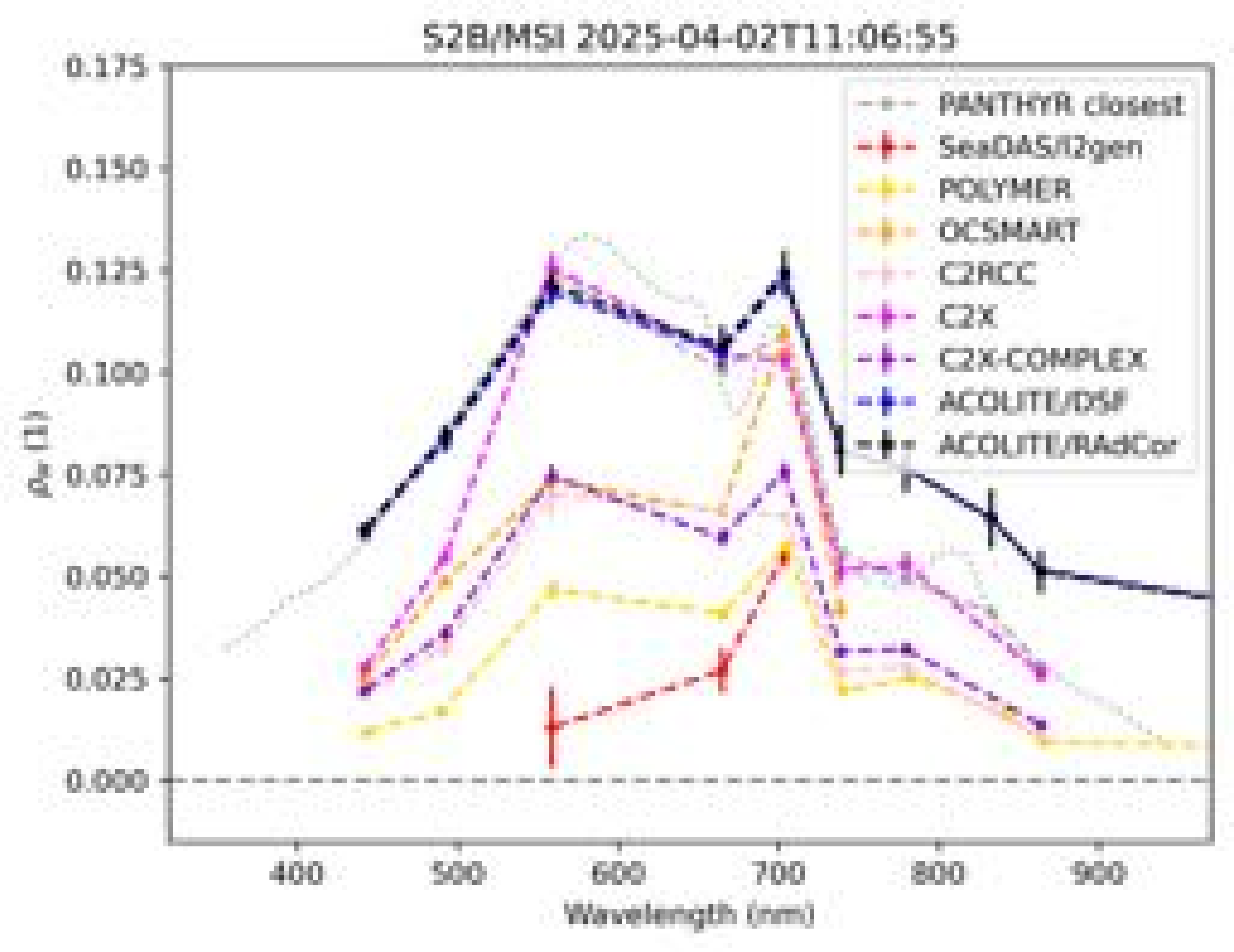

S2B/MSI 2025-04-02
TOA RGB
RT1
Latitude (°N)
Longitude (°E)
51.28
51.27
51.26
51.25
51.24
51.23
51.22
2.86
2.88
2.90
2.92
2.94
2.96


S2B/MSI 2025-04-02T11:06:55
PANTHYR closest
SeaDAS/l2gen
POLYMER
OCSMART
C2RCC
C2X
C2X-COMPLEX
0.175
0.150
0.125
0.100
0.075
0.050
0.025
0.000
400
500
600
700
800
900
Wavelength (nm)

2025-04-02

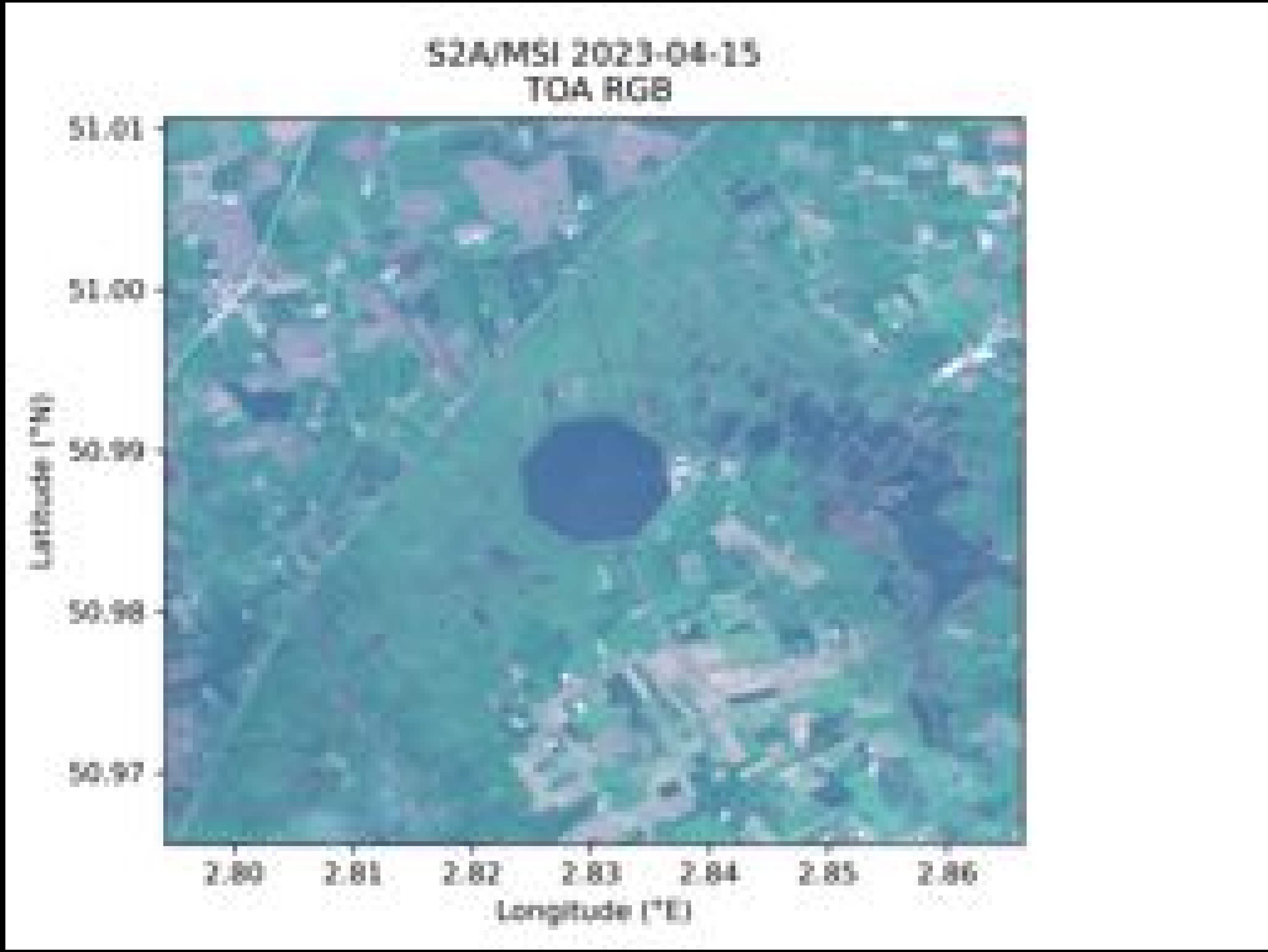


S2B/MSI 2025-04-02
TOA RGB
51.28
51.27
51.26
51.25
51.24
51.23
51.22
Latitude (°N)
2.86
2.88
2.90
2.92
2.94
2.96
Longitude (°E)
RT1



S2B/MSI 2025-04-02T11:06:55
0.175
0.150
0.125
0.100
0.075
0.050
0.025
0.000
ρ_w (1)
400
500
600
700
800
900
Wavelength (nm)
PANTHYR closest
SeaDAS/l2gen
POLYMER
OCSMART
C2RCC
C2X
C2X-COMPLEX
ACOLITE/DSF
ACOLITE/RAdCor

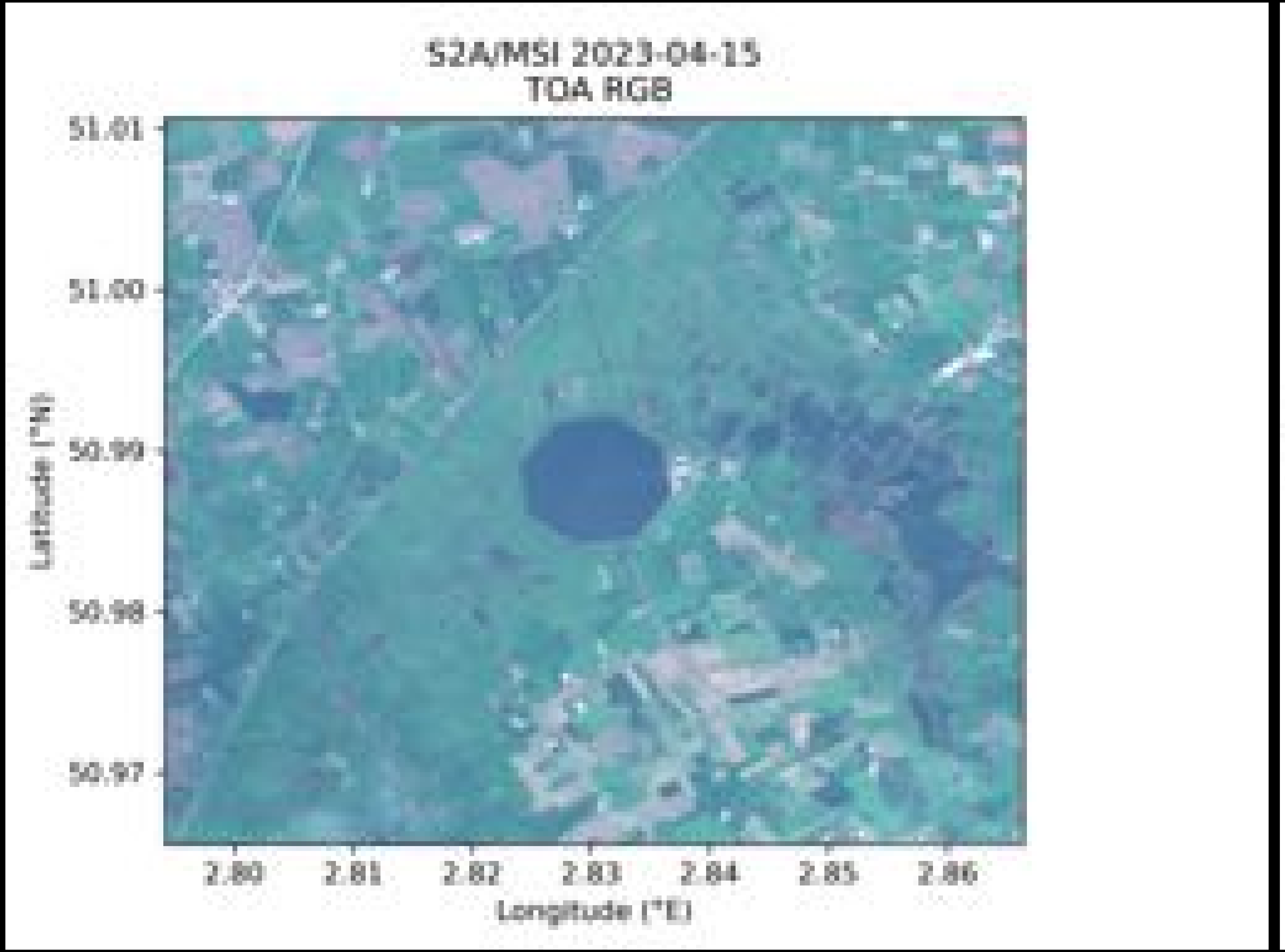
Small inland waters

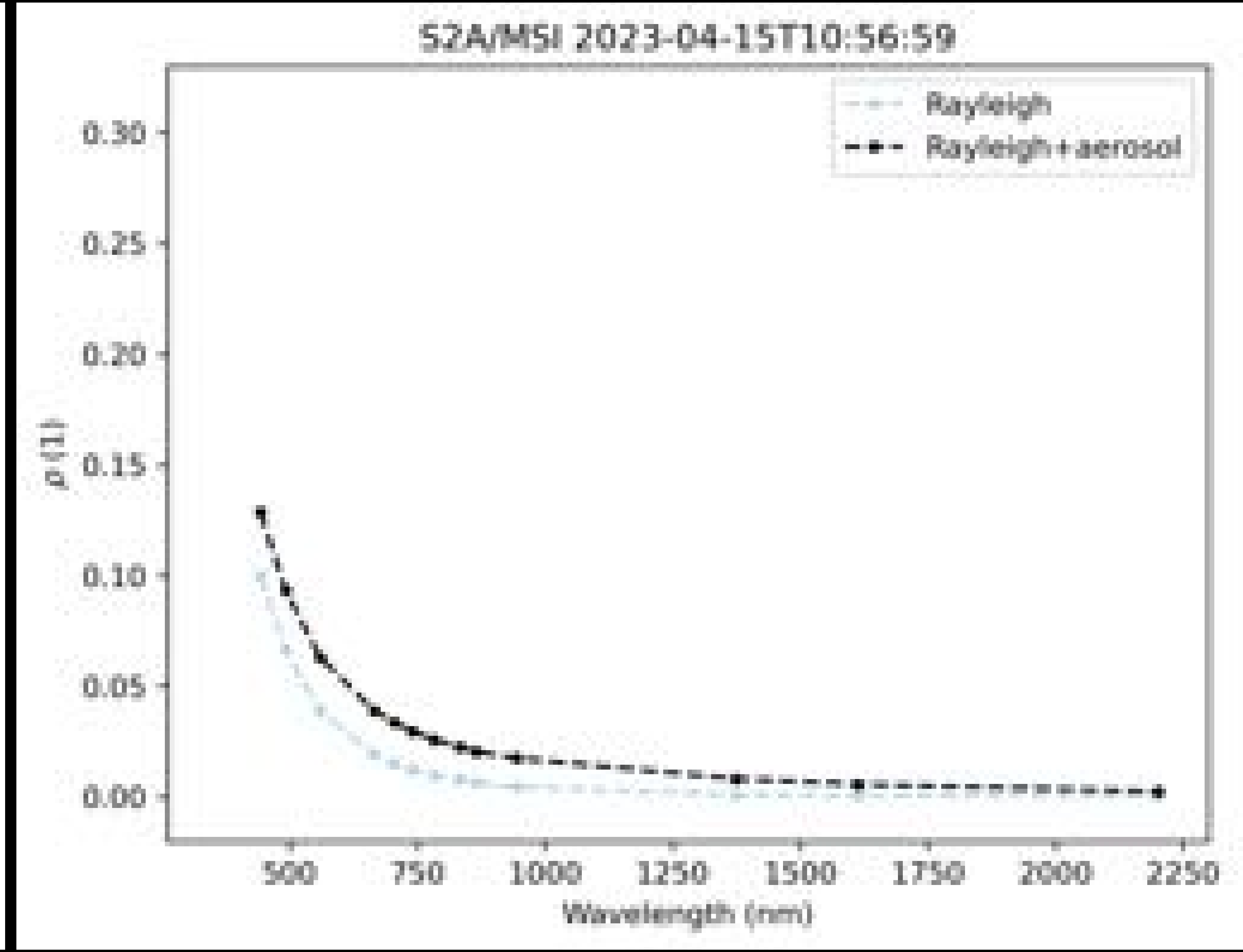


~3x3 km subset

Blankaart drinking water reservoir ~800 m diameter

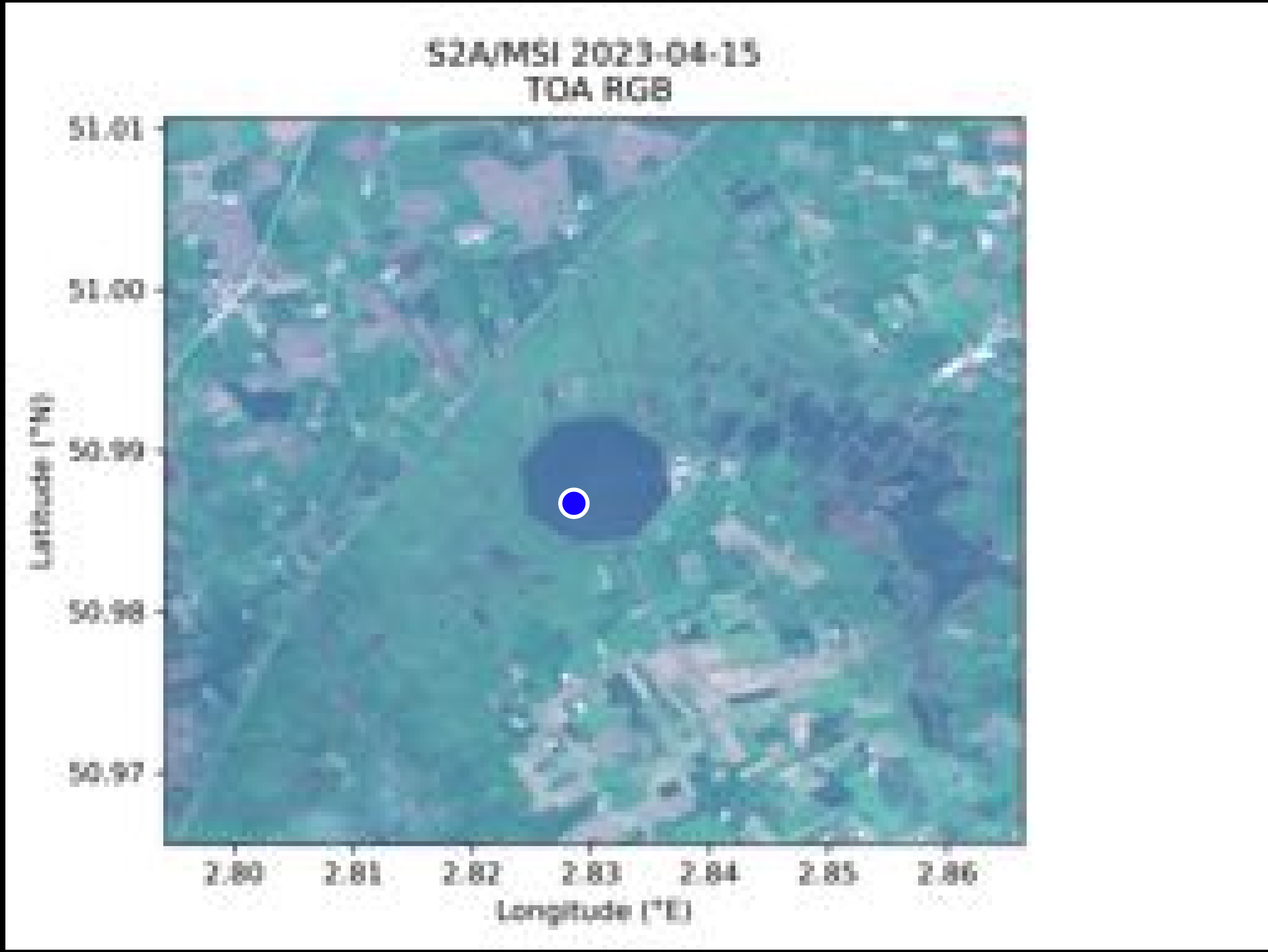
Small inland waters

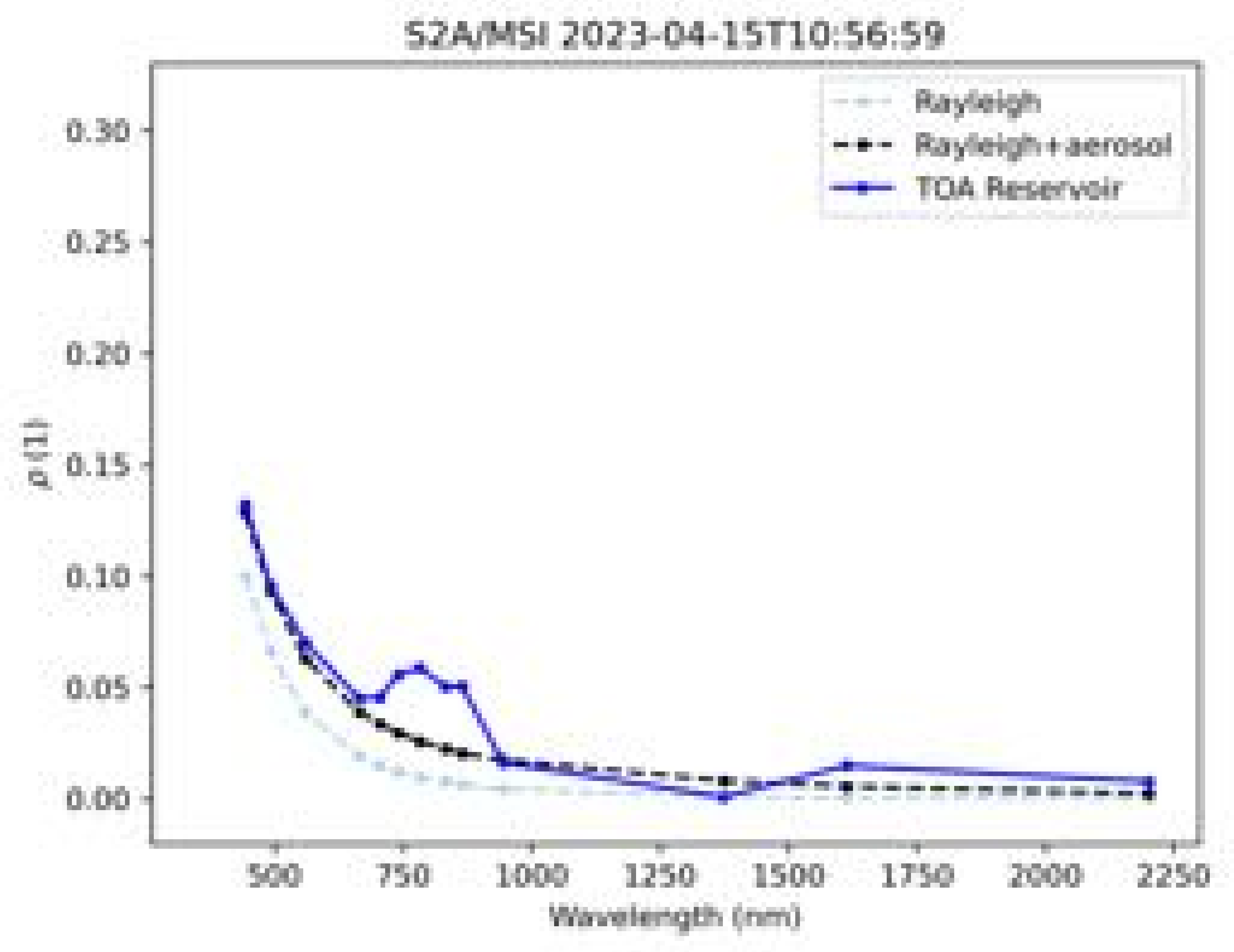




~3x3 km subset

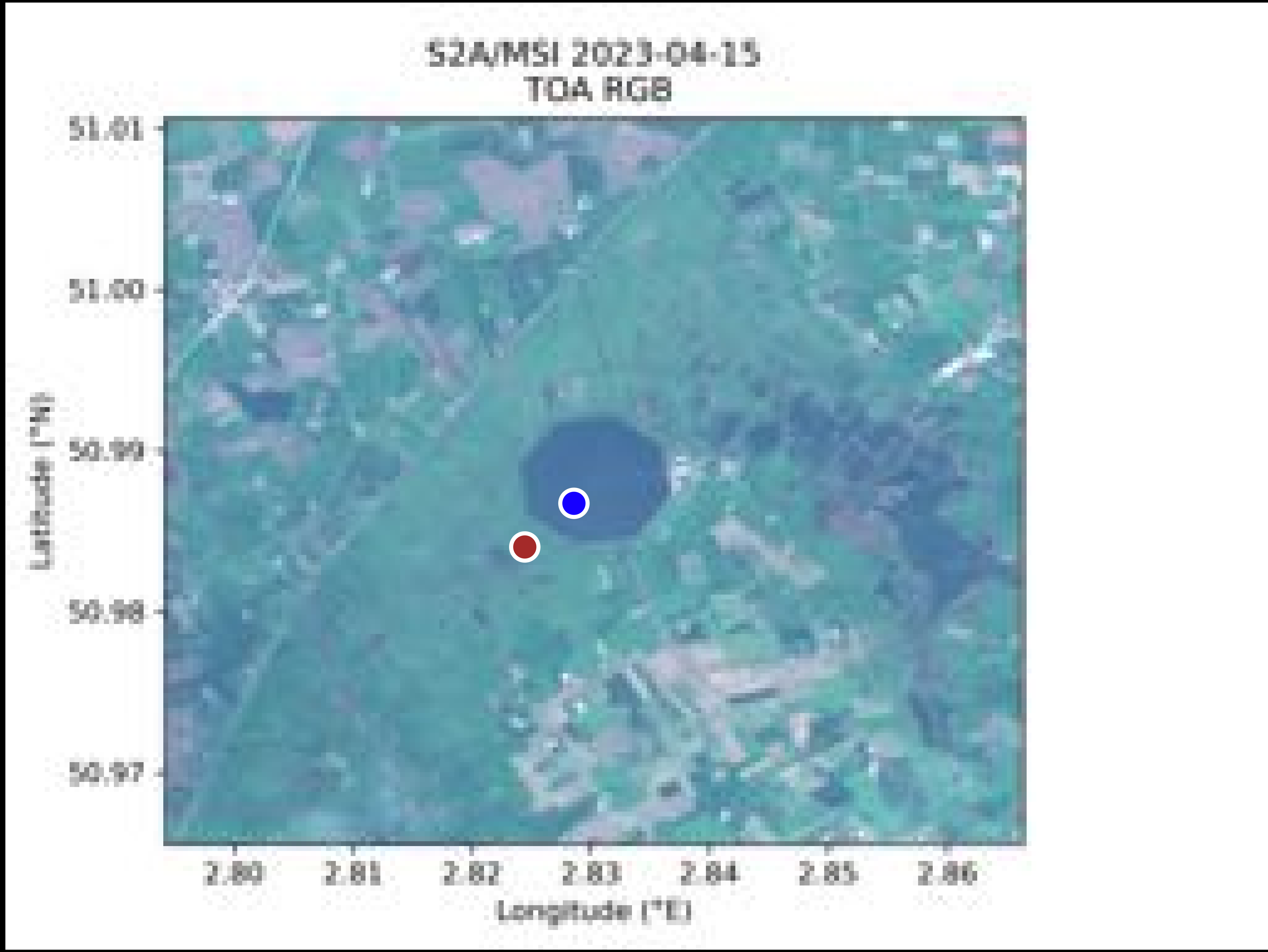
Small inland waters

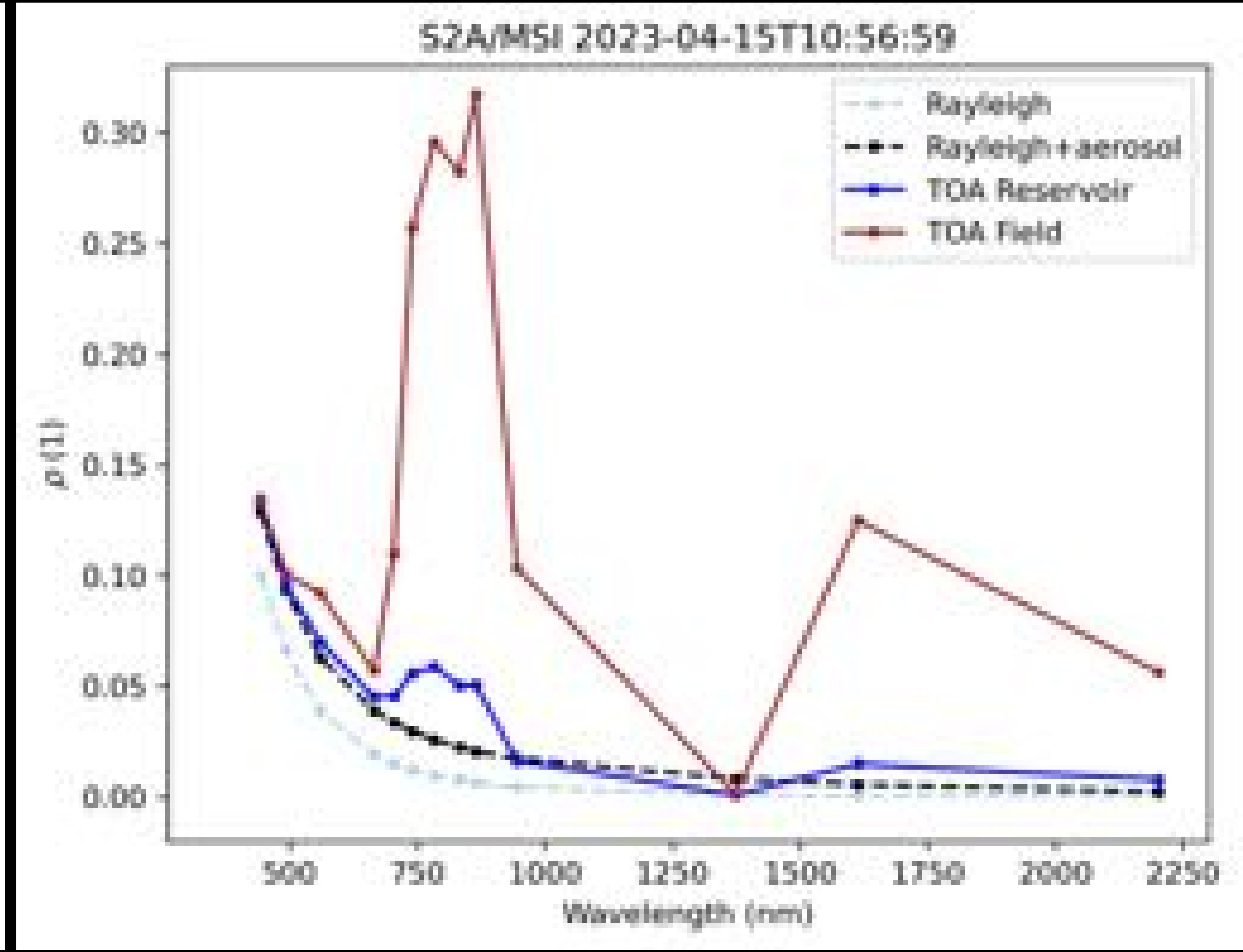




~3x3 km subset

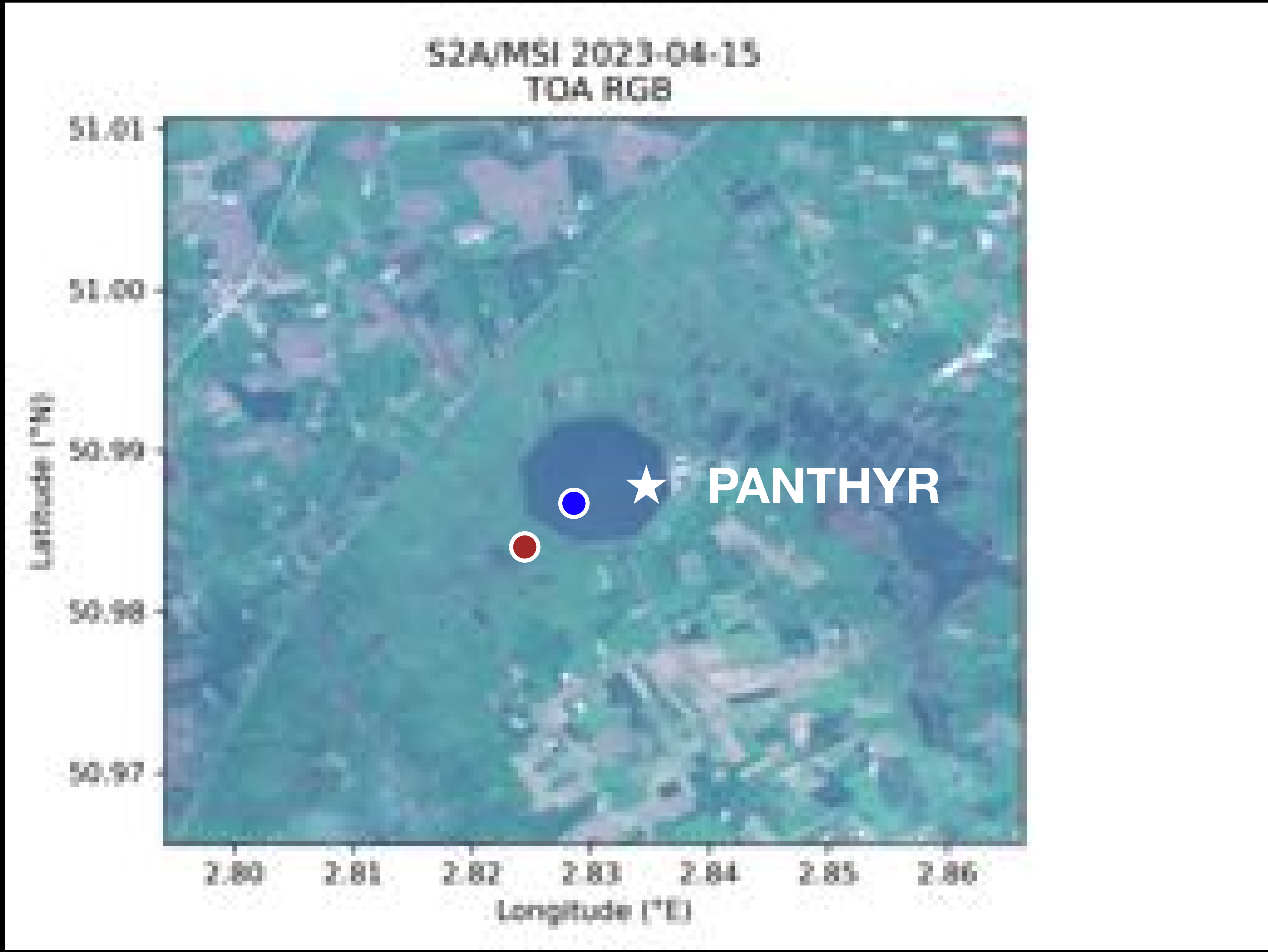
Small inland waters

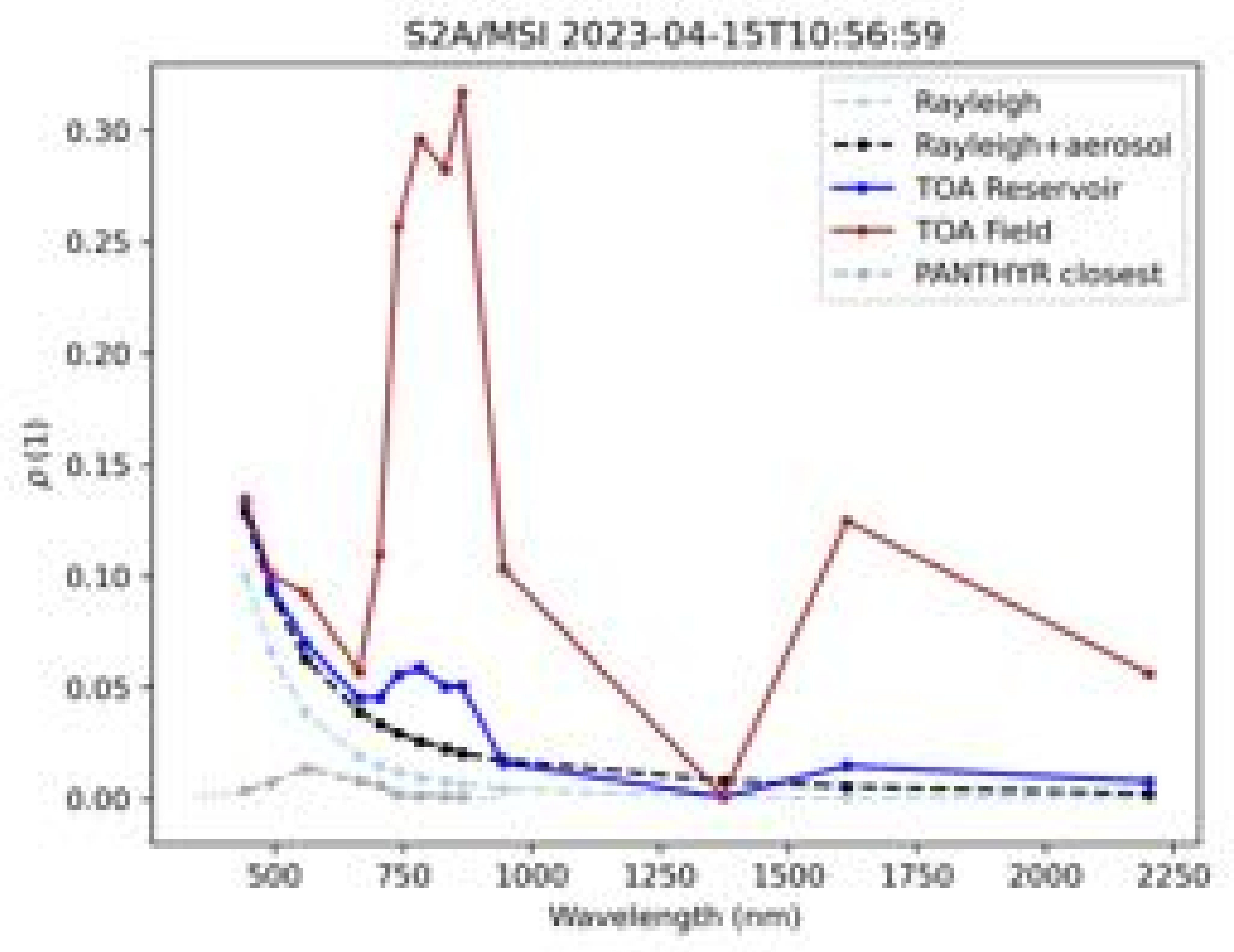




~3x3 km subset

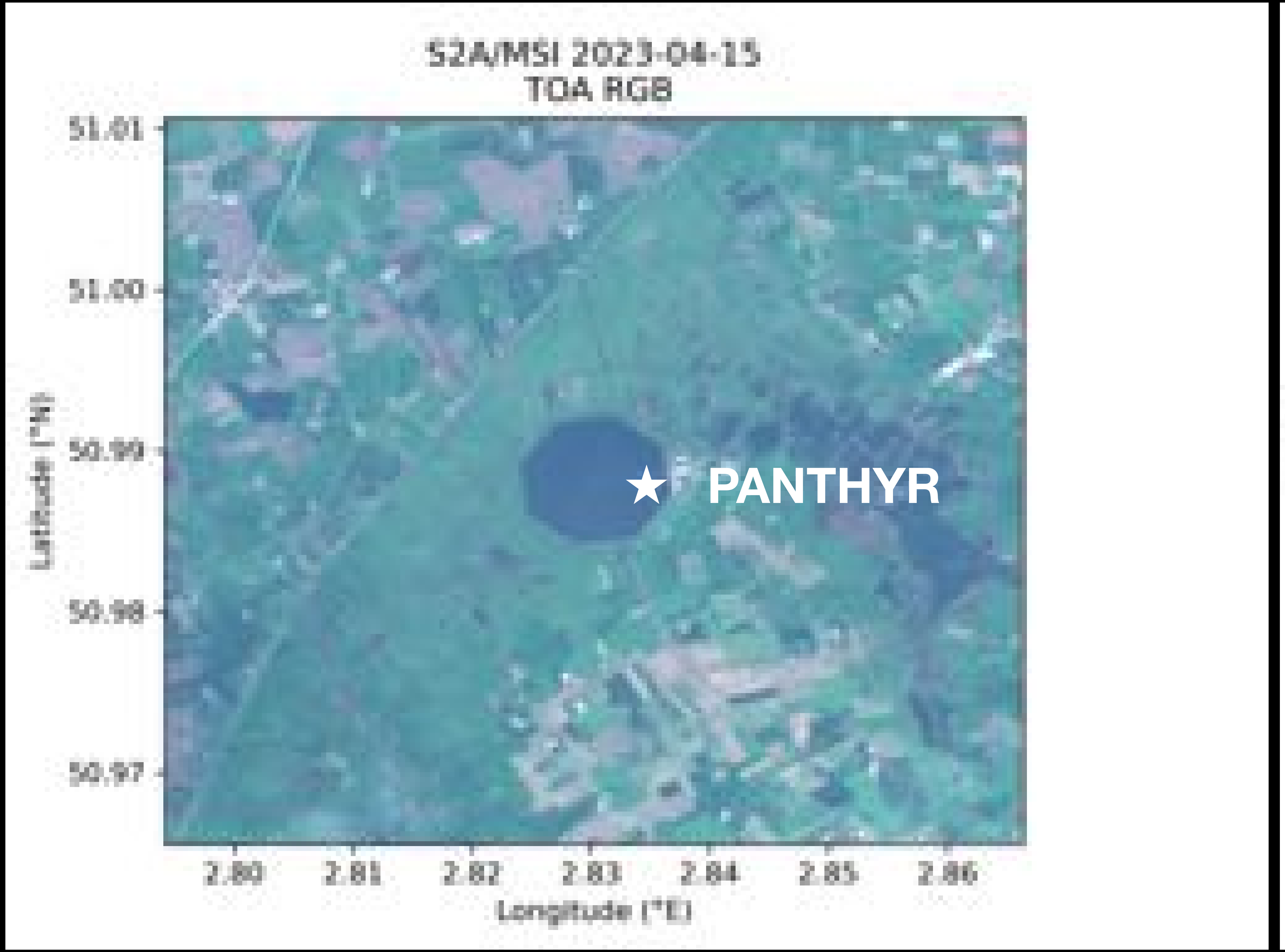
Small inland waters

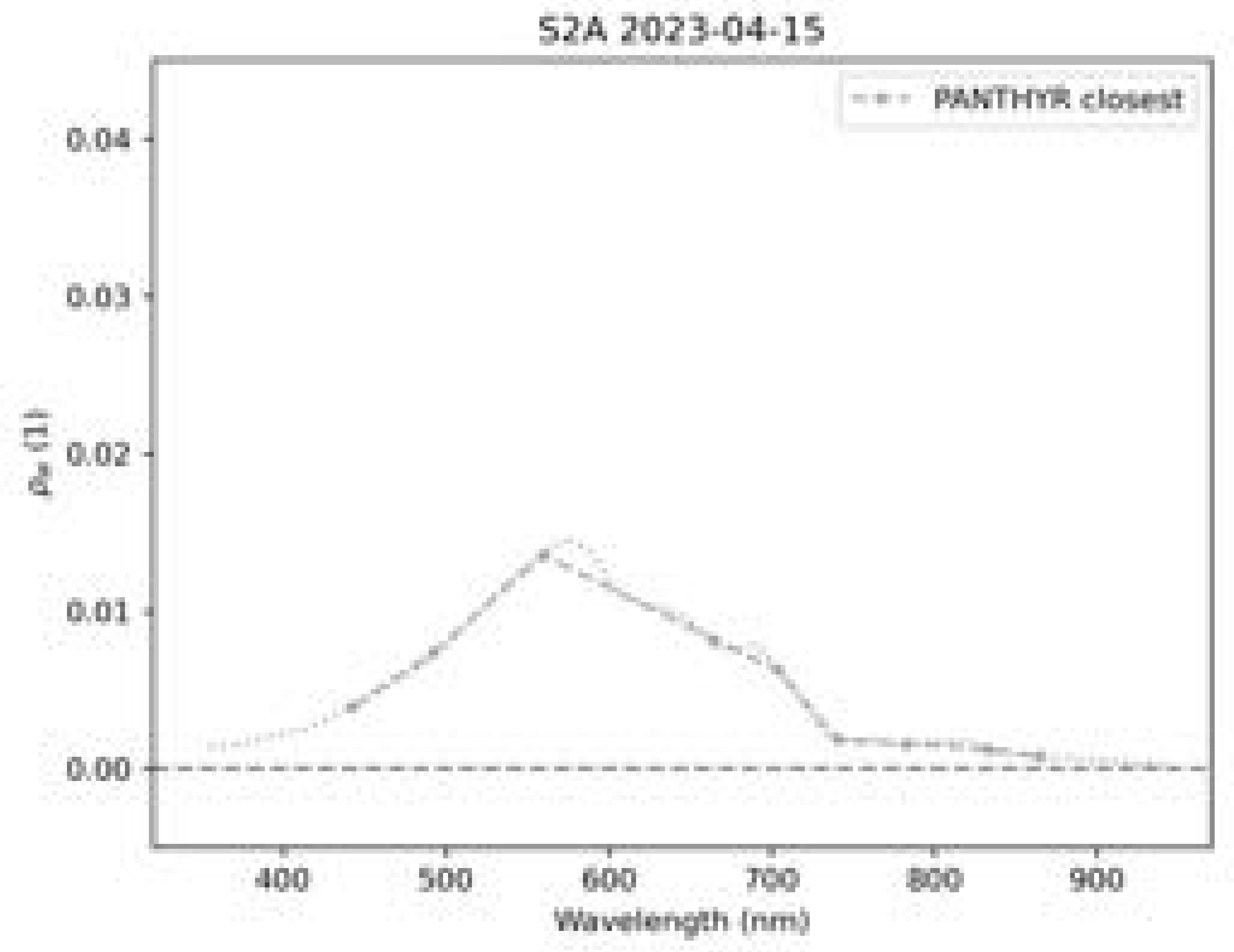




~3x3 km subset

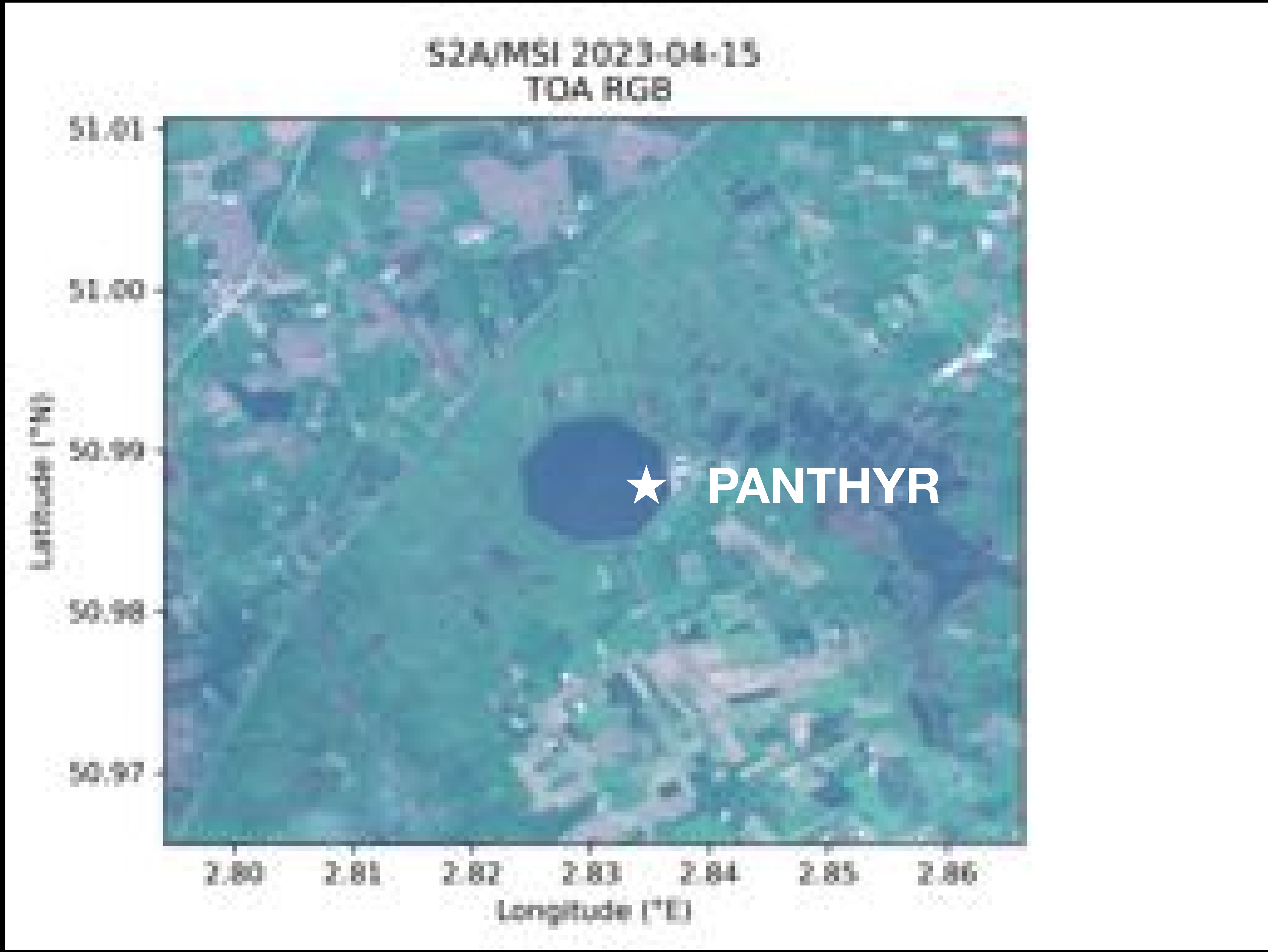
Small inland waters

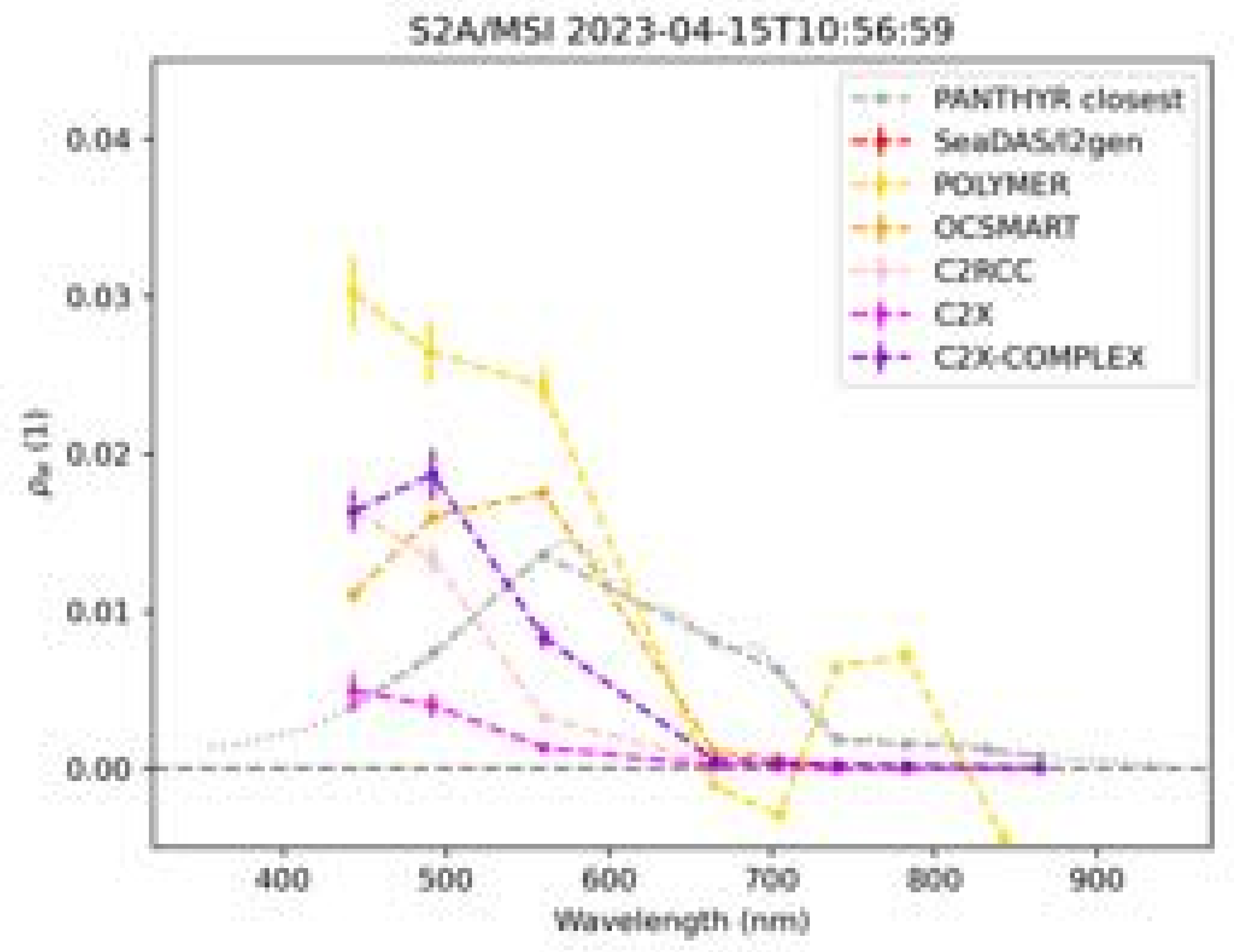




~3x3 km subset

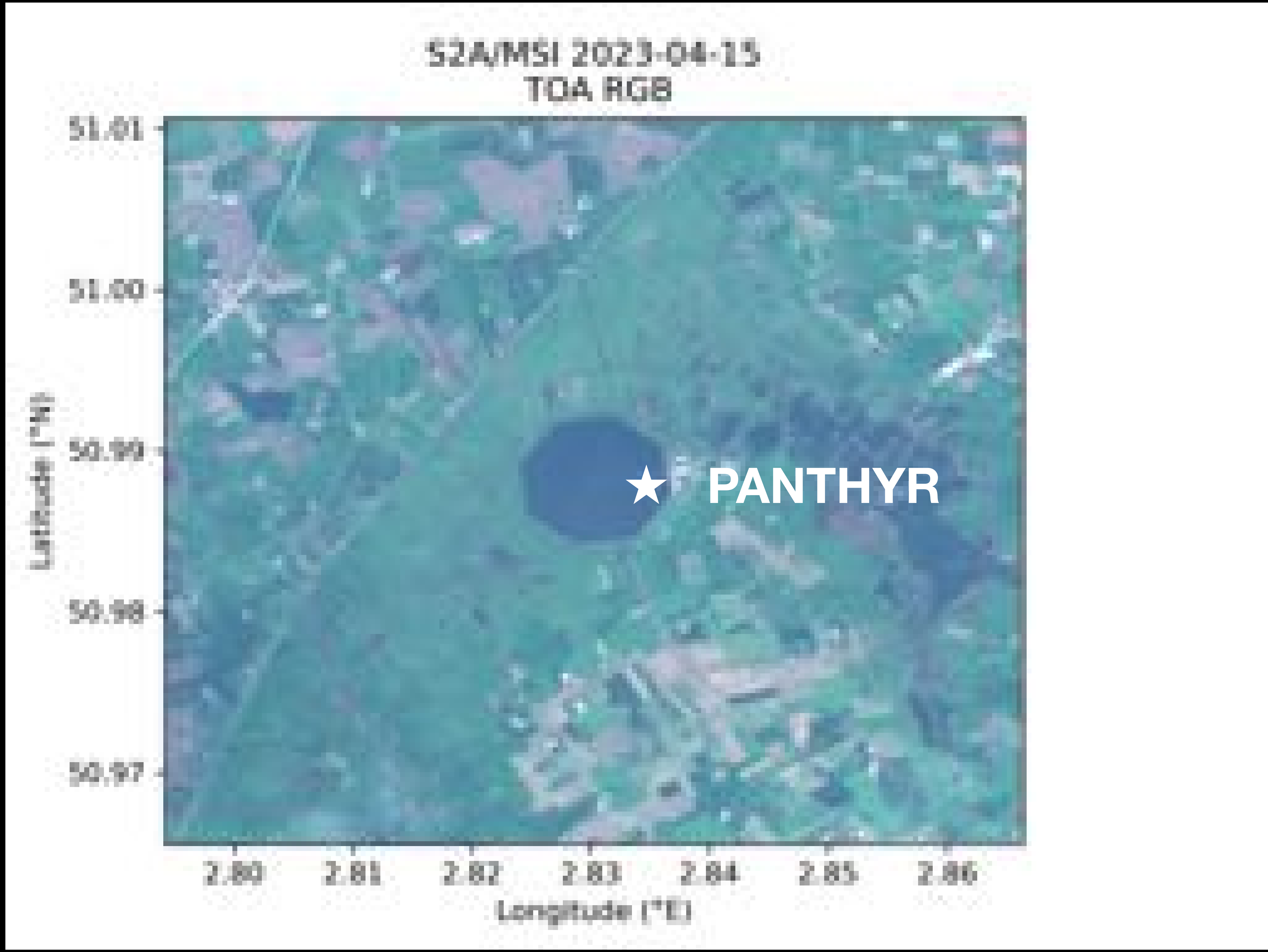
Small inland waters

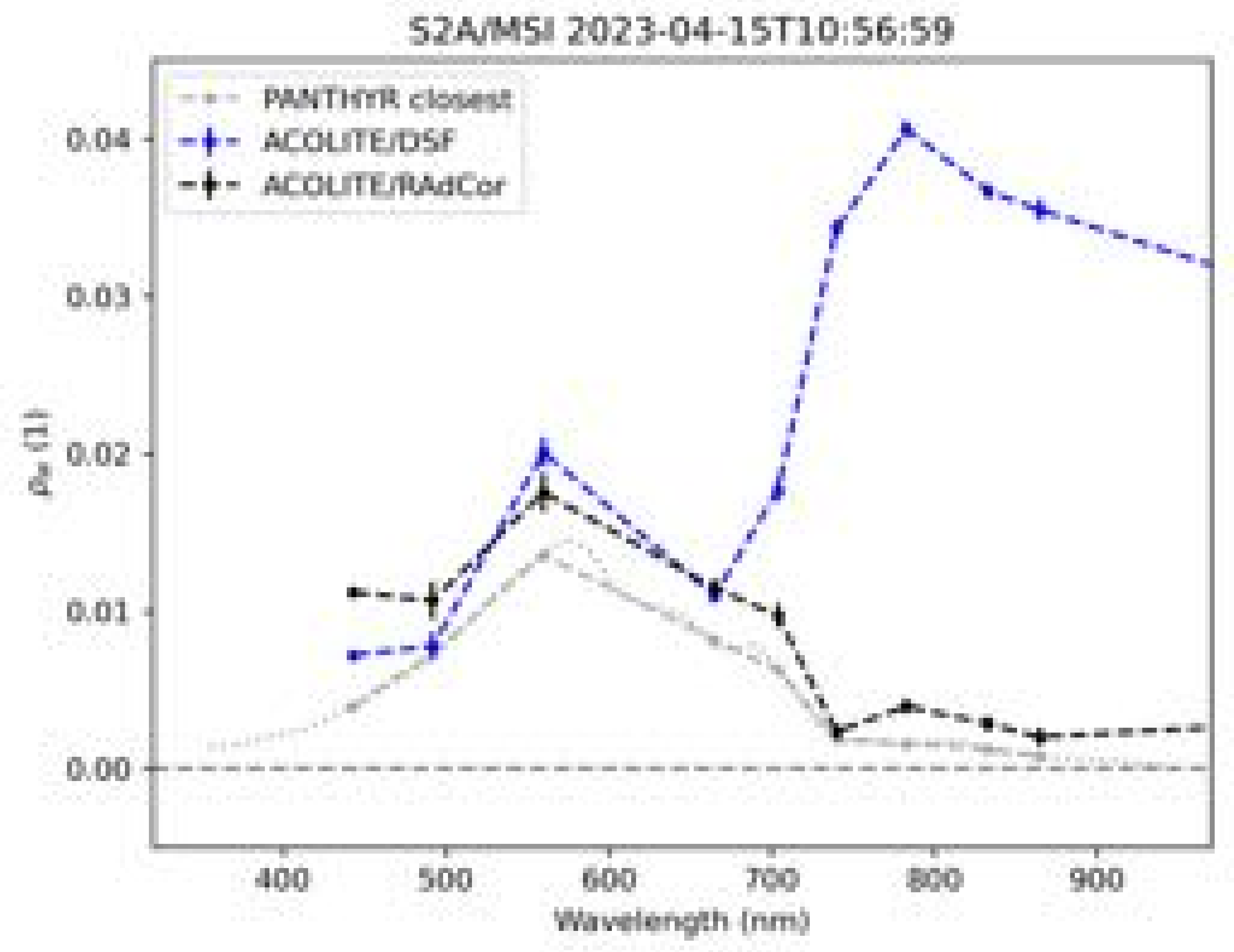




~3x3 km subset

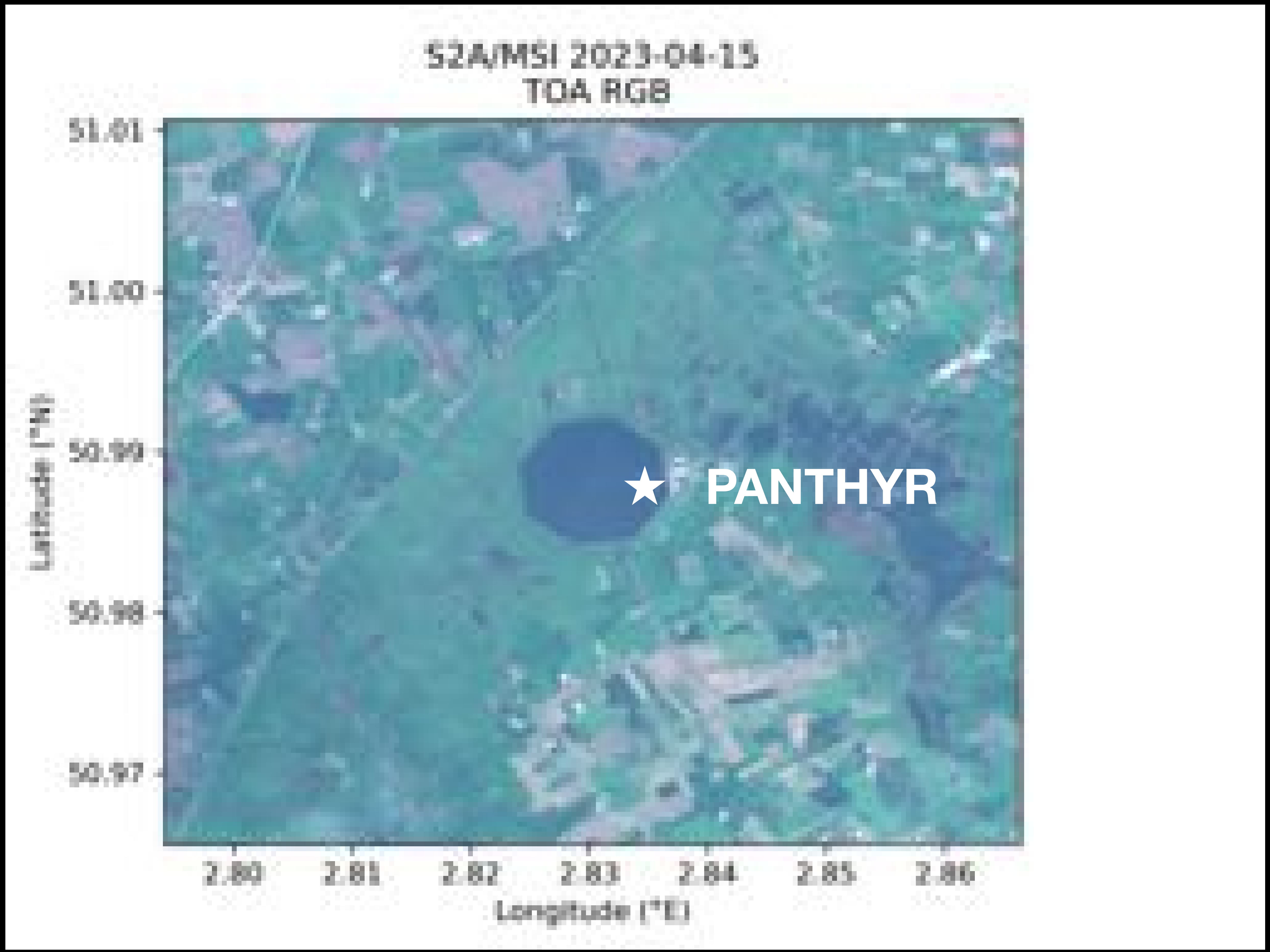
Small inland waters

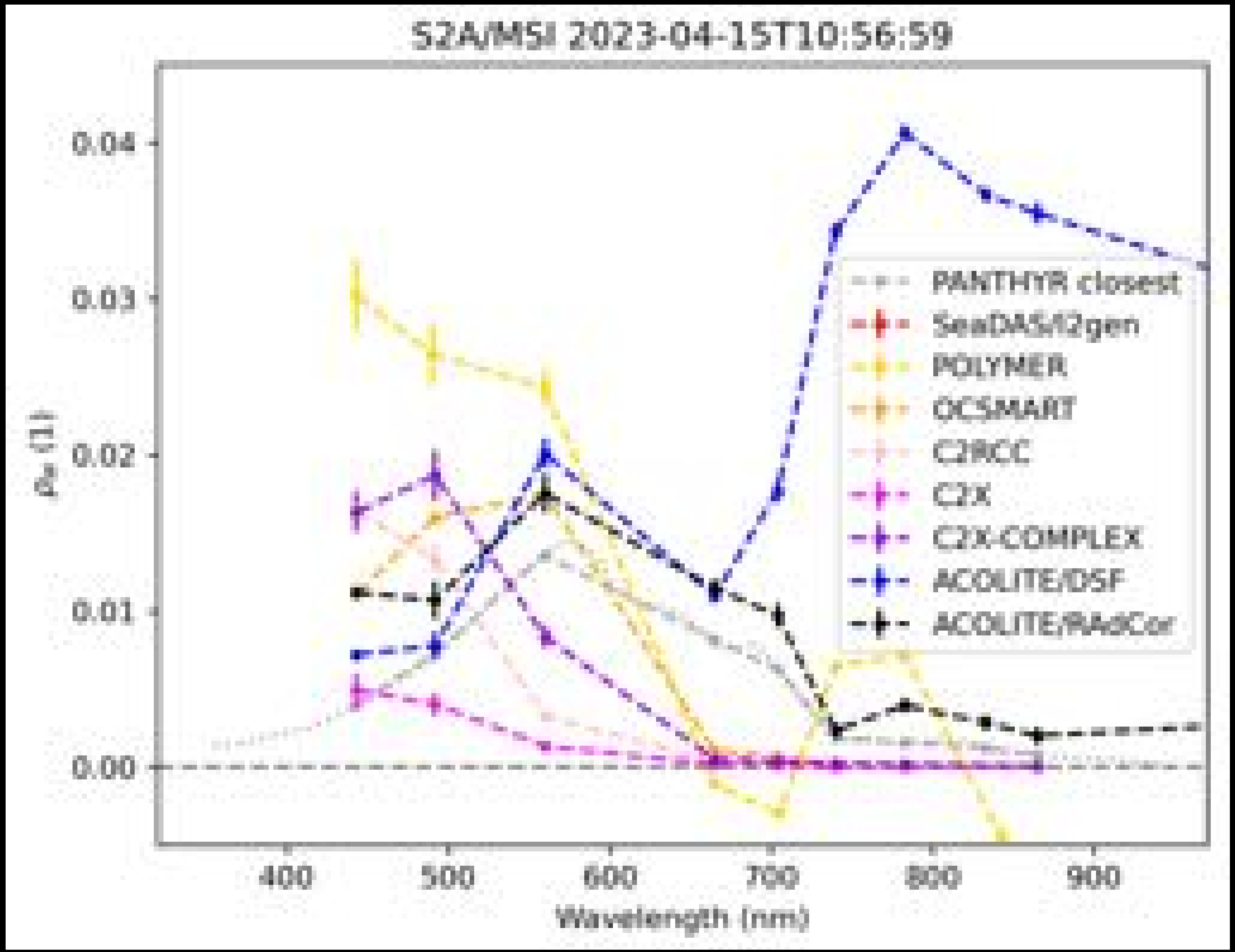




~3x3 km subset

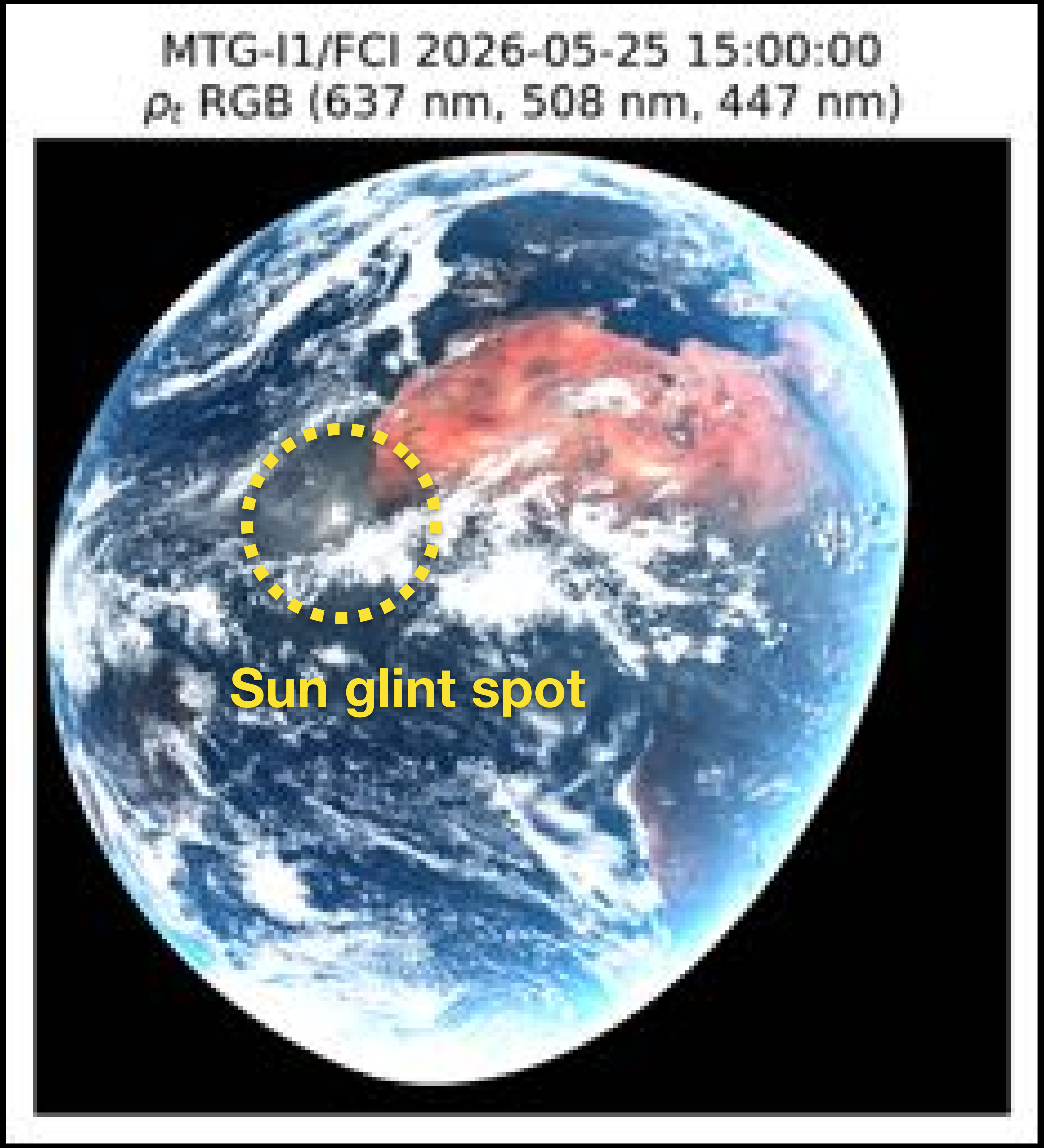
Small inland waters

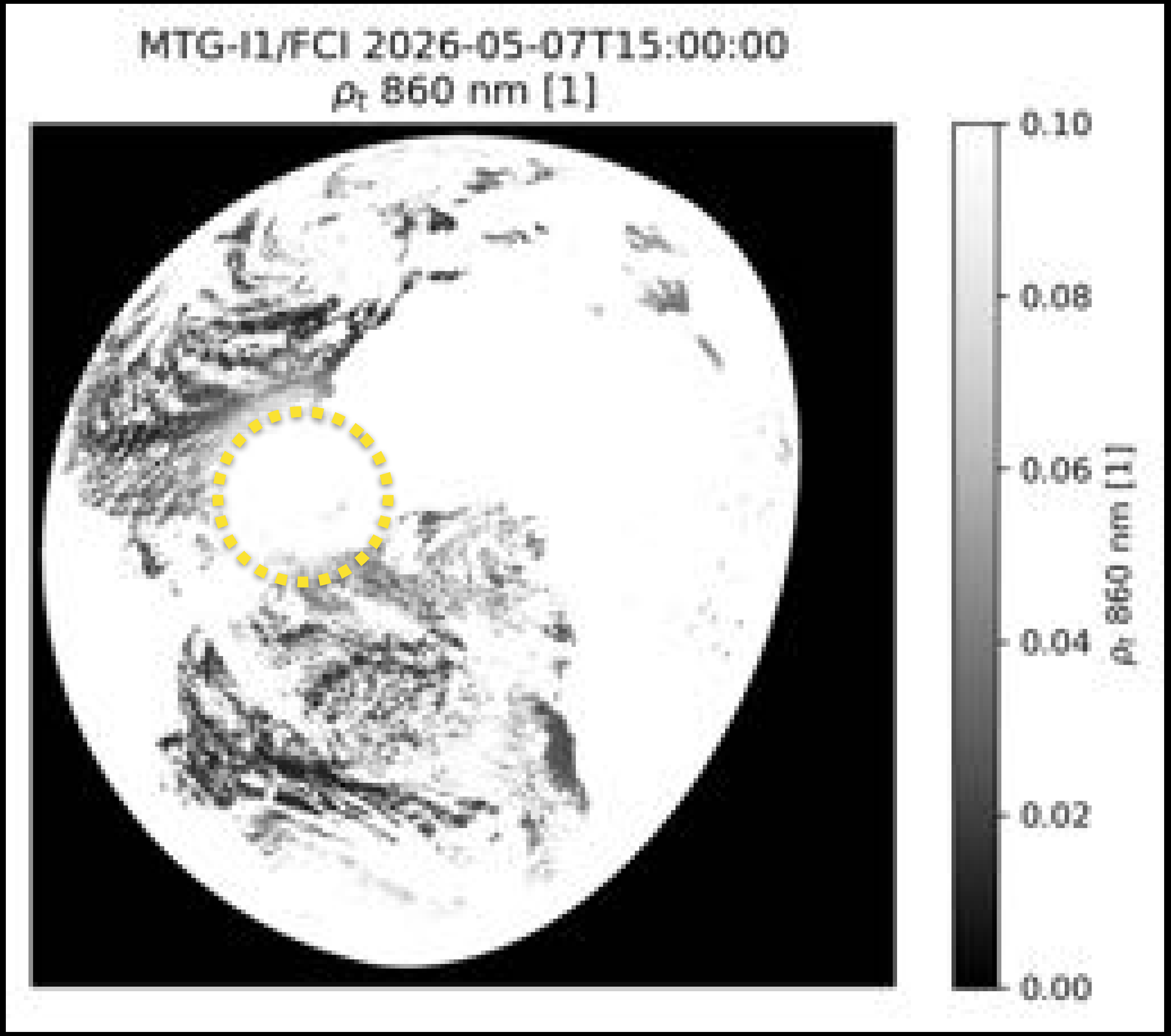




~3x3 km subset

Glint correction

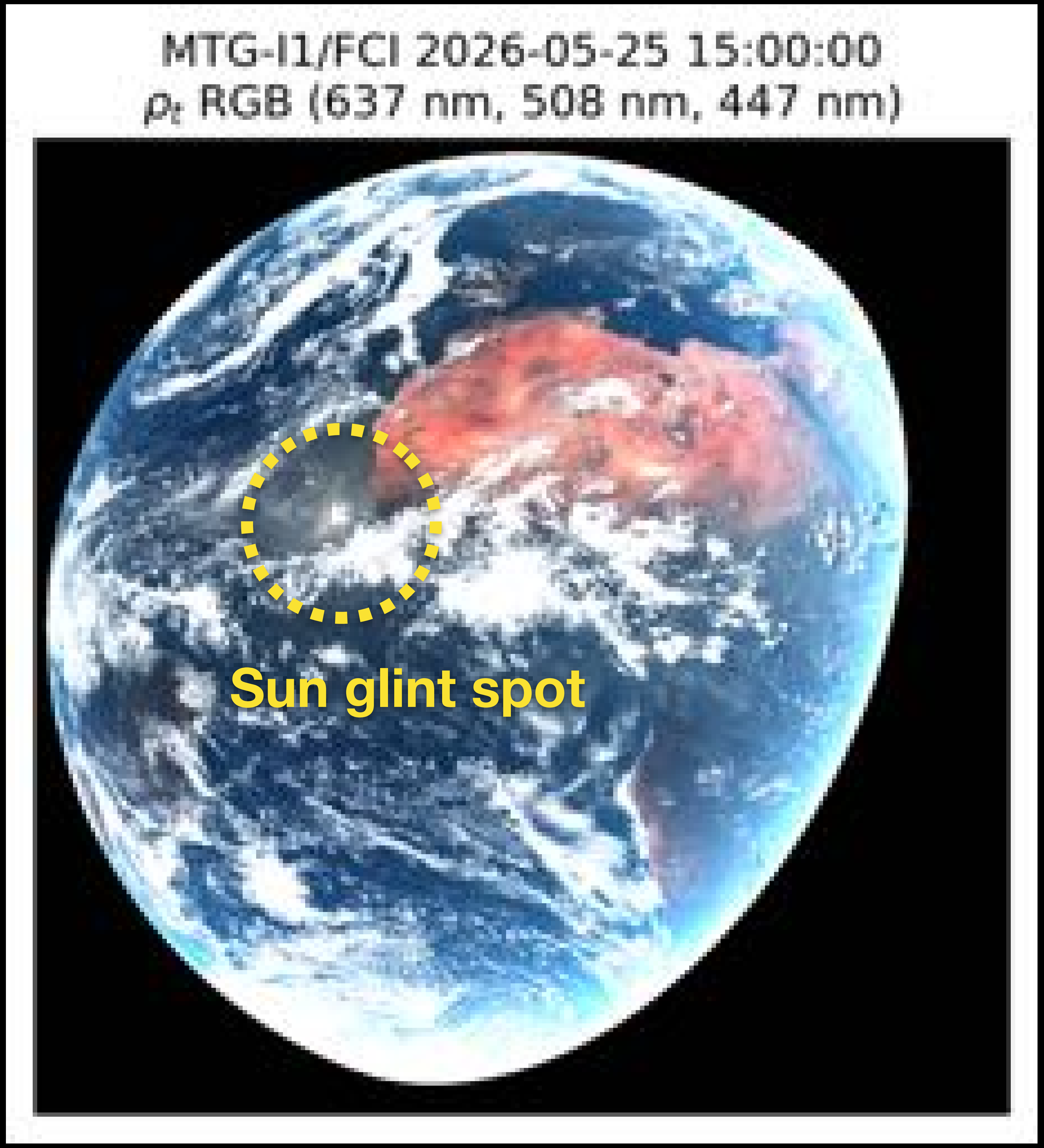


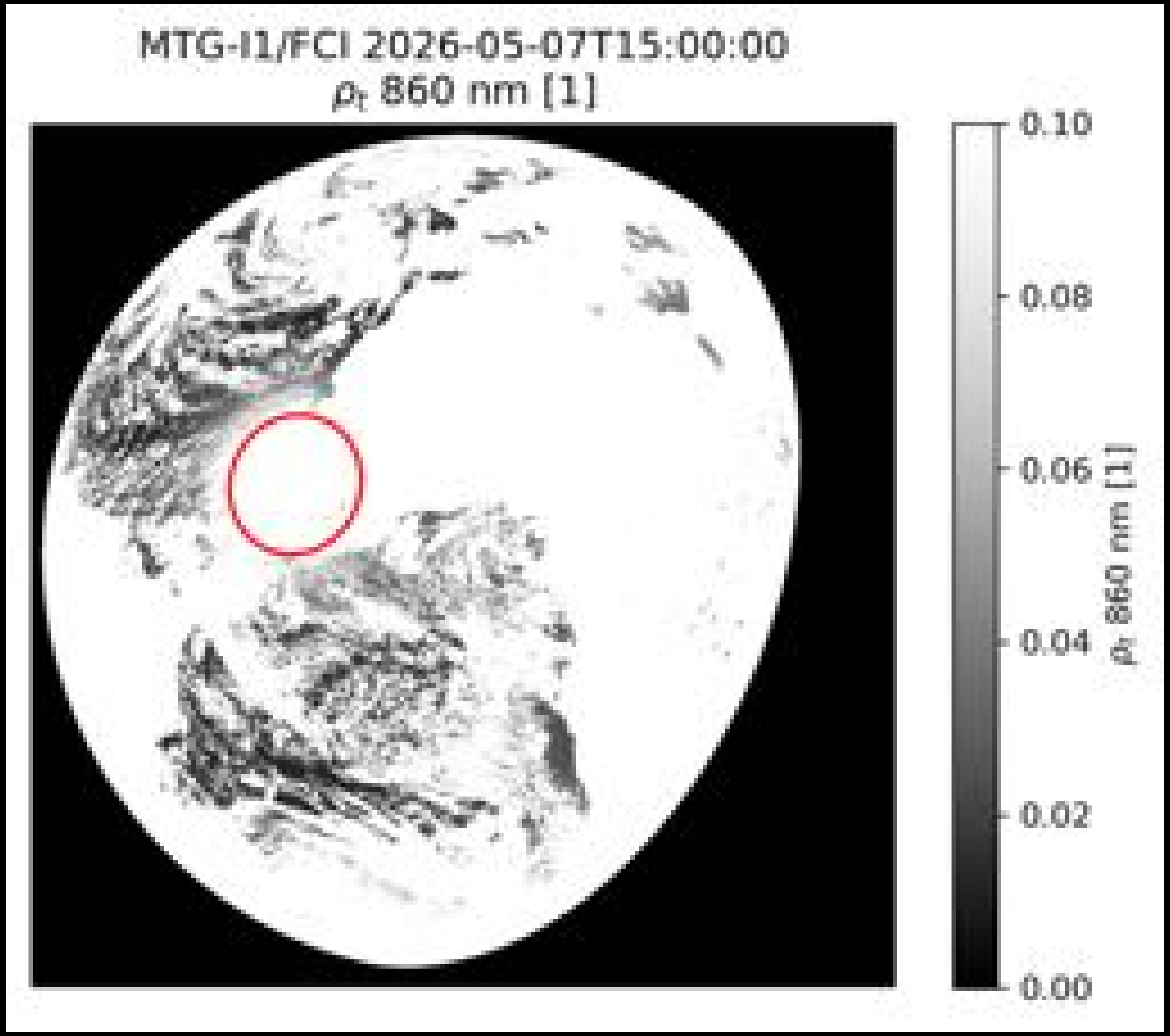


Glint correction

Geometry + wind speed

Cox and Munk **1 m/s**

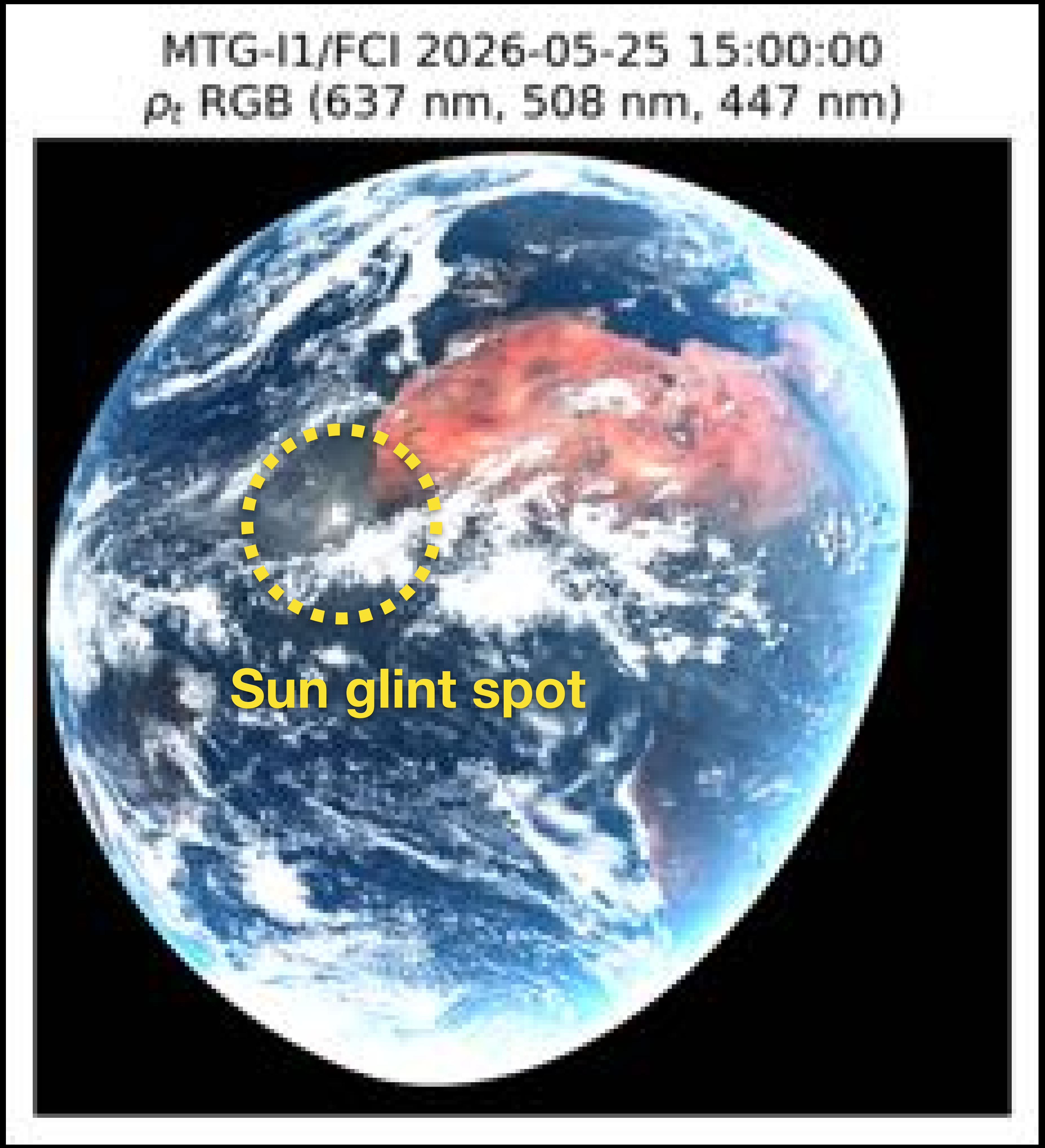


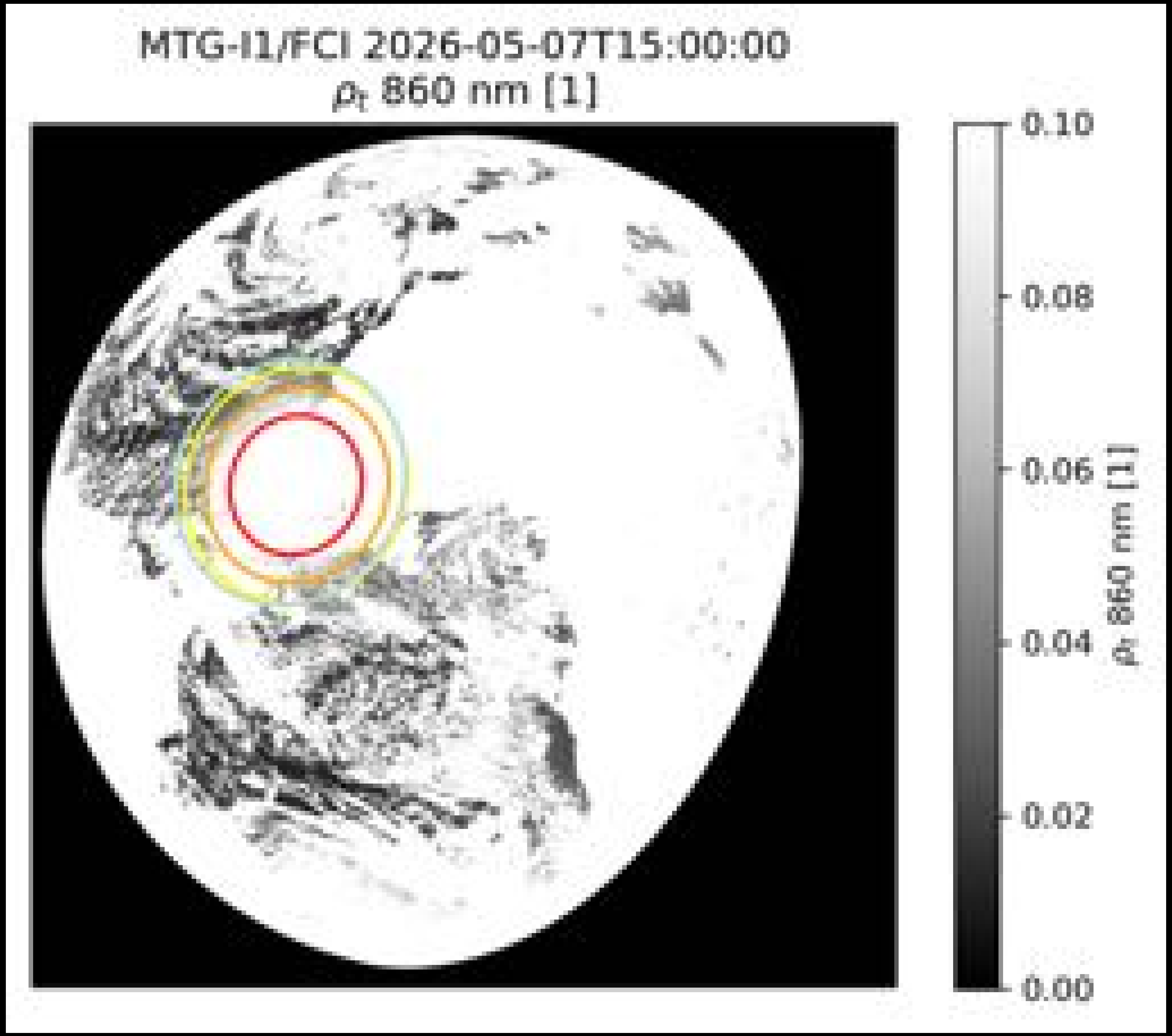


Glint correction

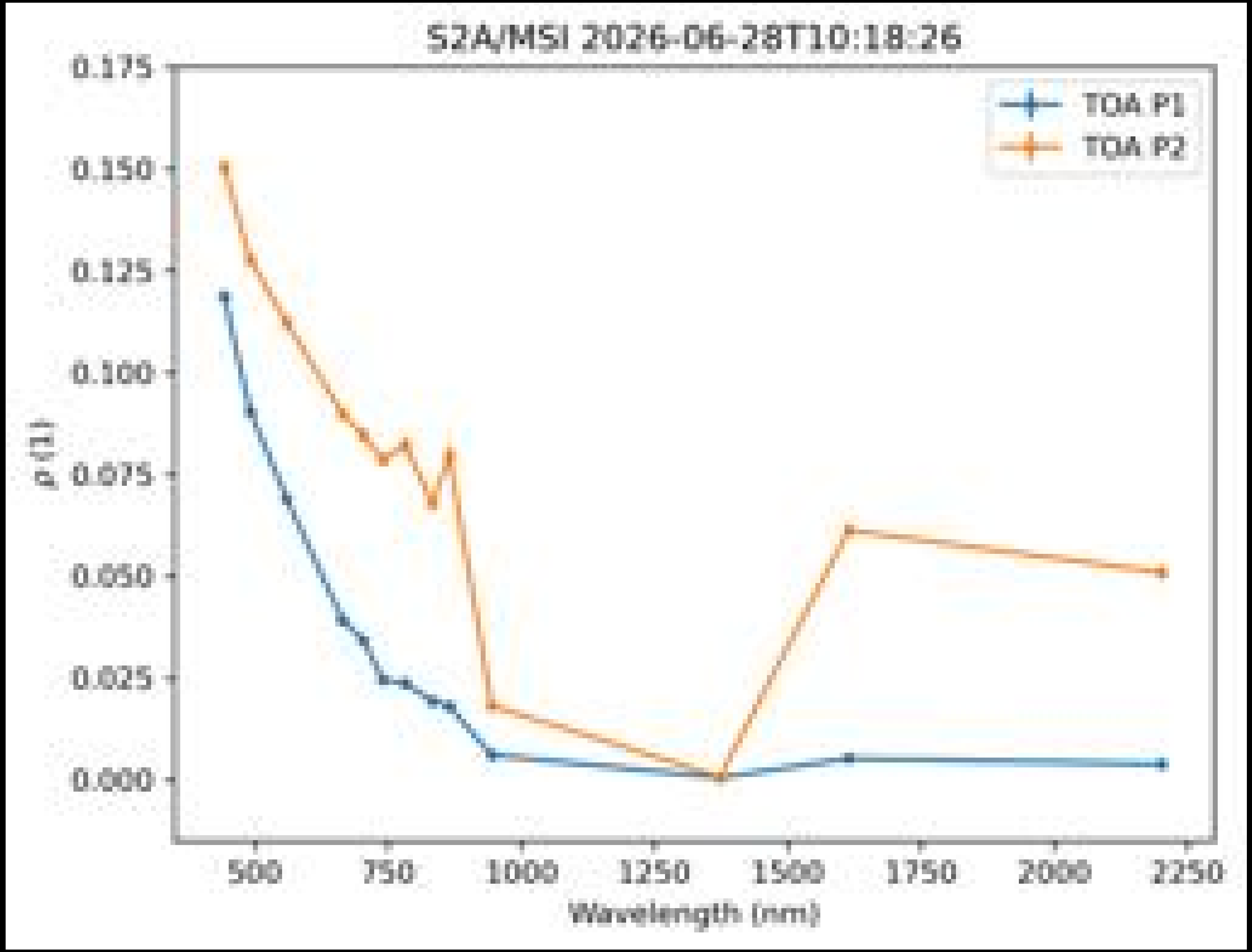
Geometry + wind speed

Cox and Munk 1 m/s 4 m/s 10 m/s 20 m/s

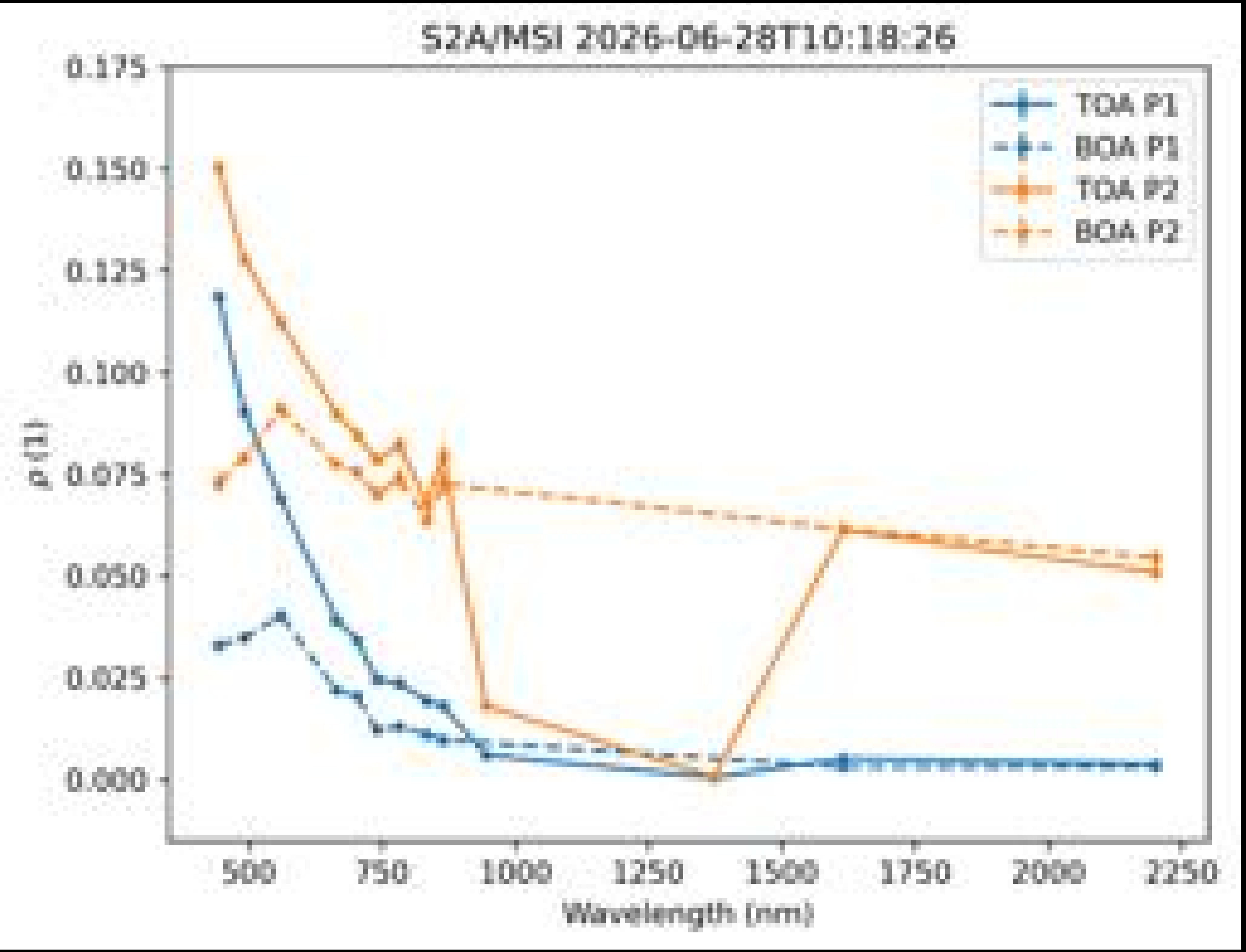




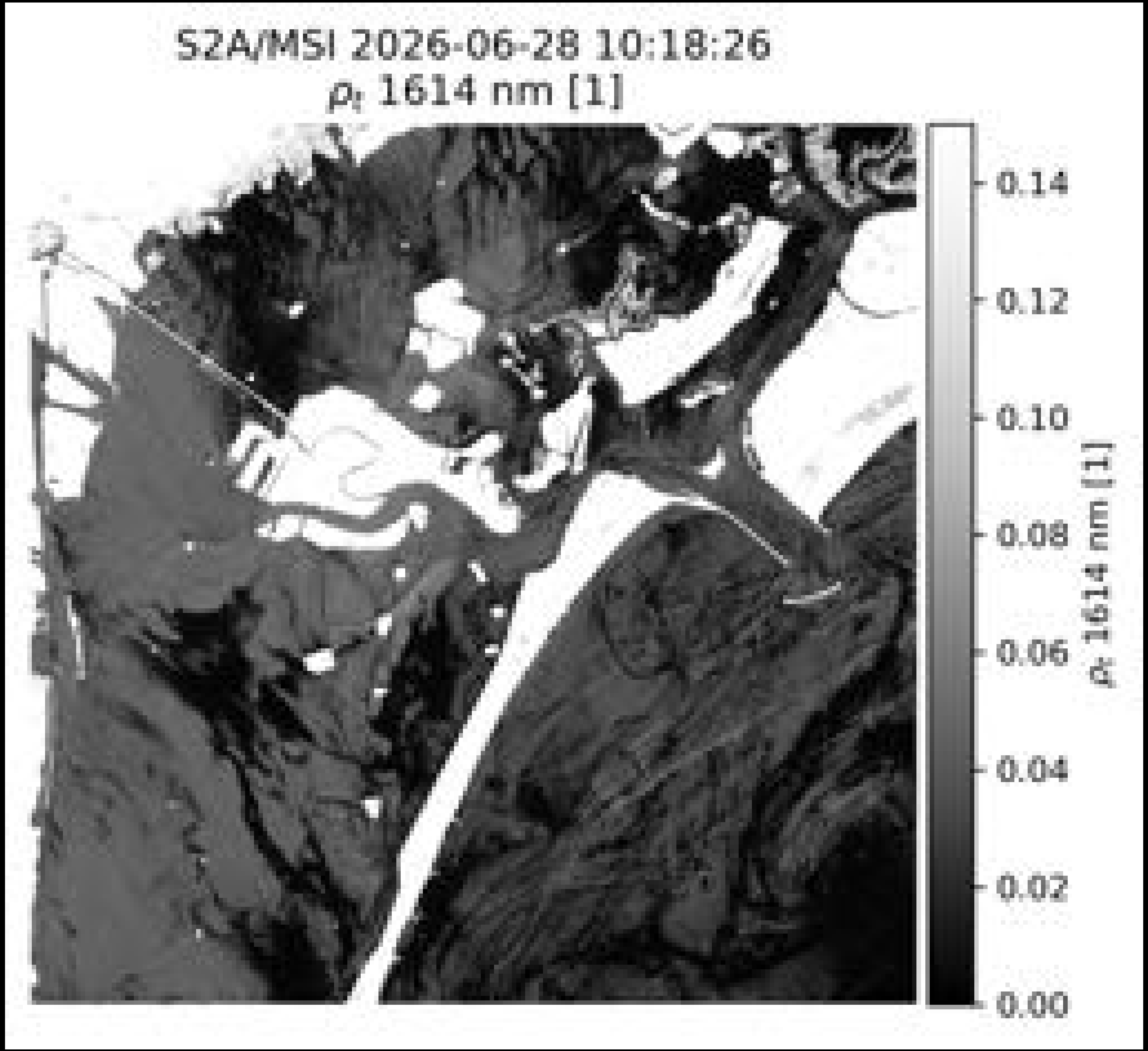
Glint correction



Glint correction

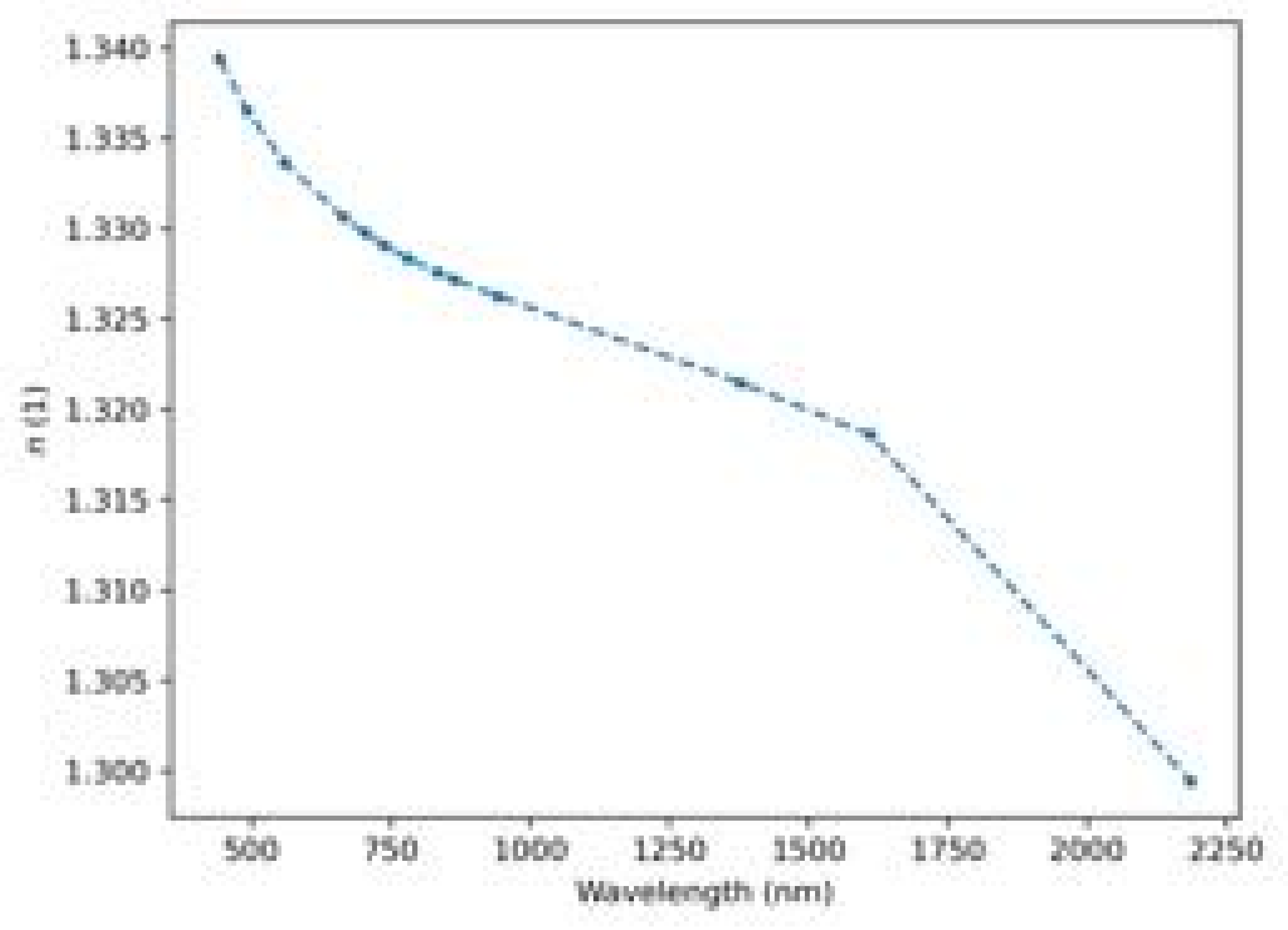


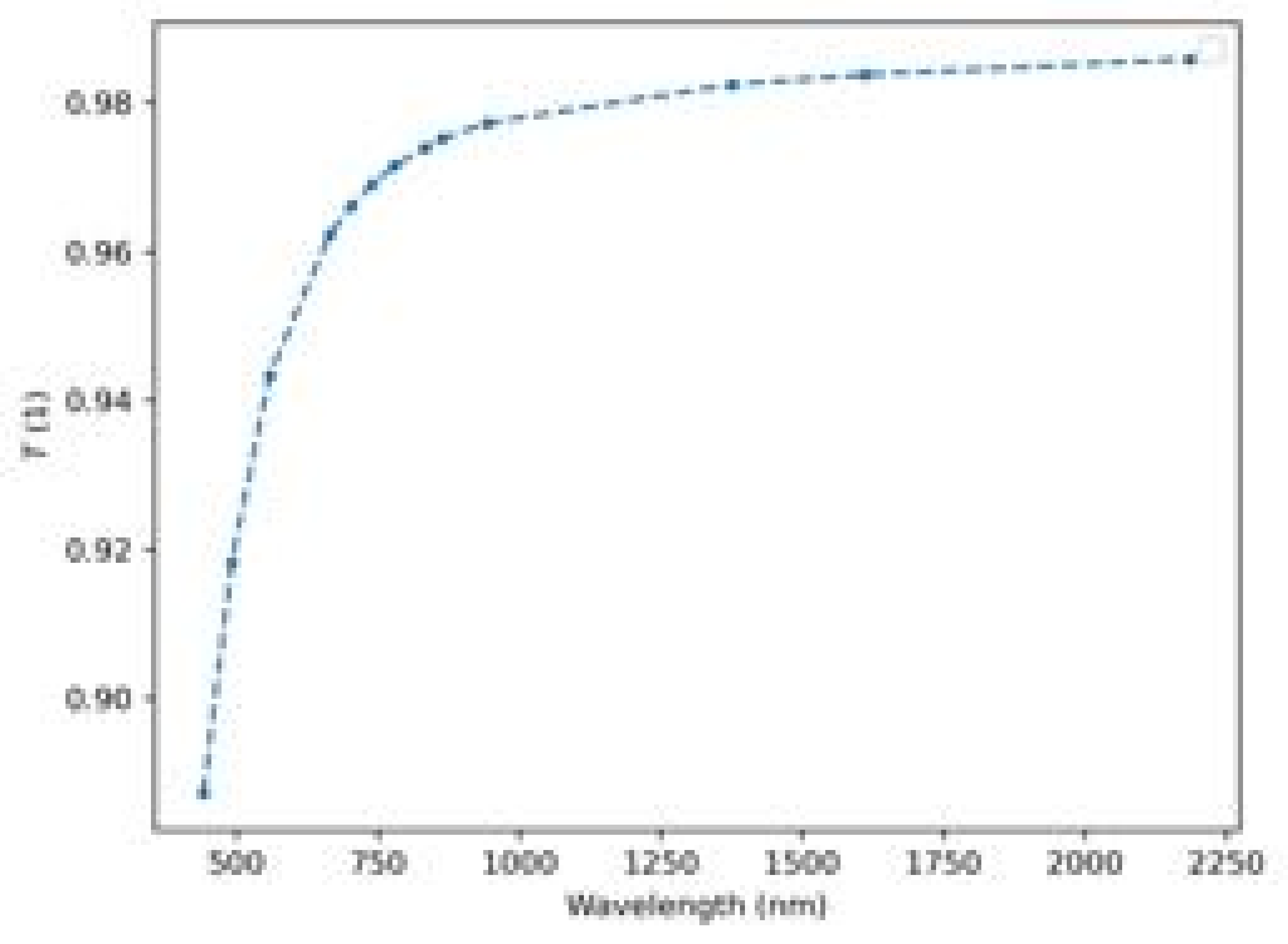
Glint correction



Glint correction

$$\rho_{glint} = \rho_{SWIR} \cdot \frac{n}{n_{SWIR}} \cdot \frac{T}{T_{SWIR}}$$

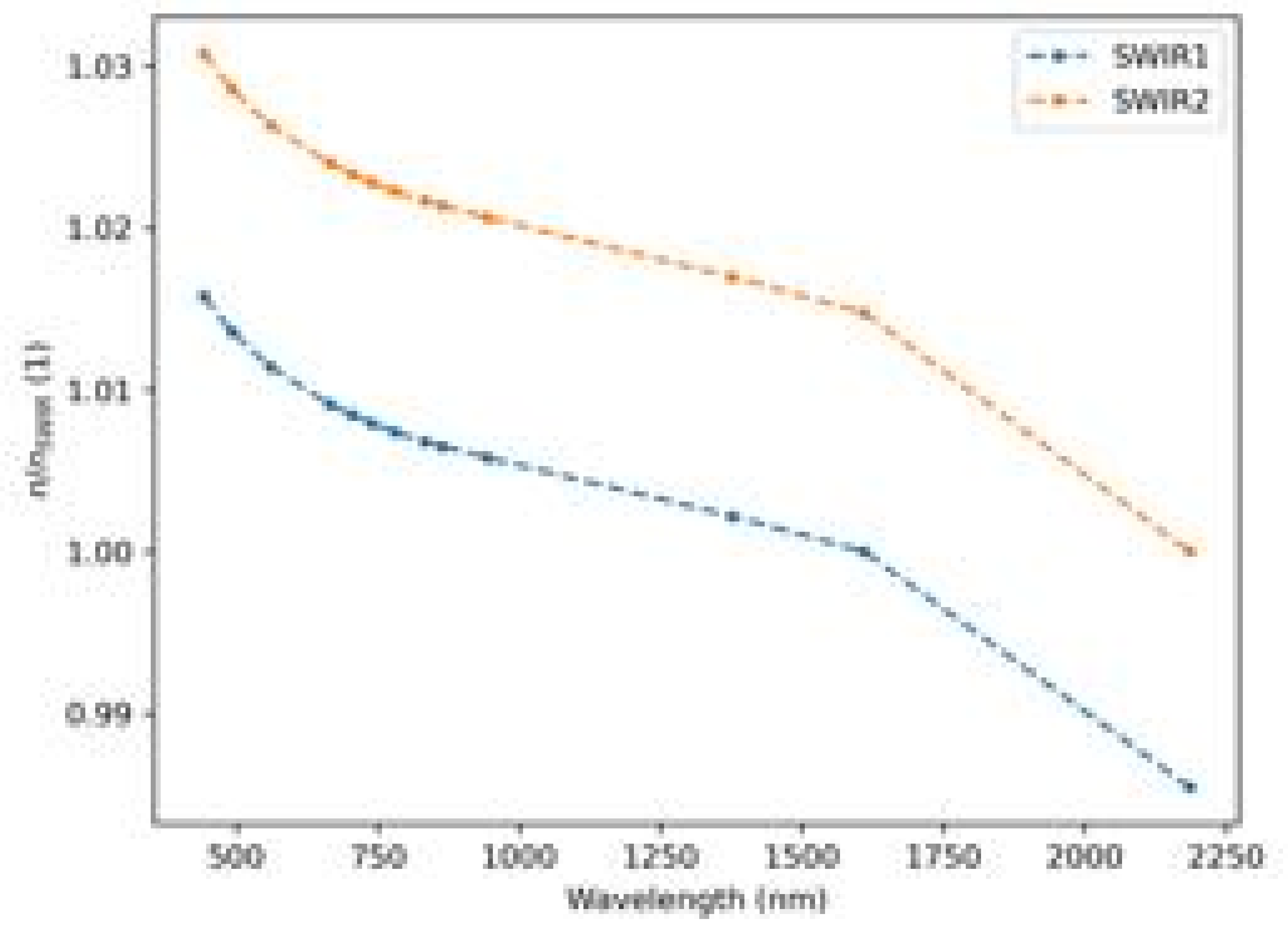


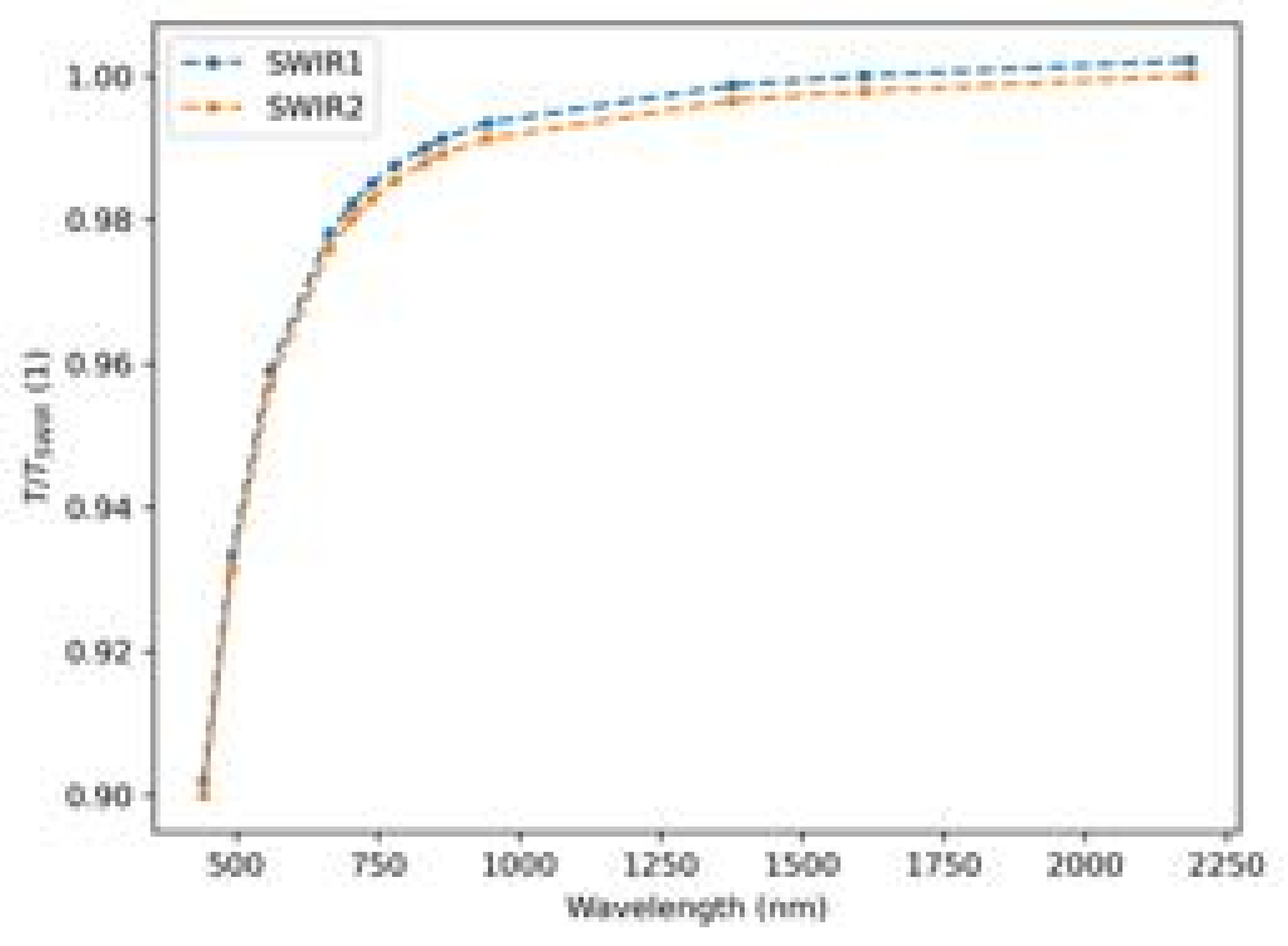


Harmel et al. (2018)

Glint correction

$$\rho_{glint} = \rho_{SWIR} \cdot \frac{n}{n_{SWIR}} \cdot \frac{T}{T_{SWIR}}$$





Harmel et al. (2018)

Glint correction

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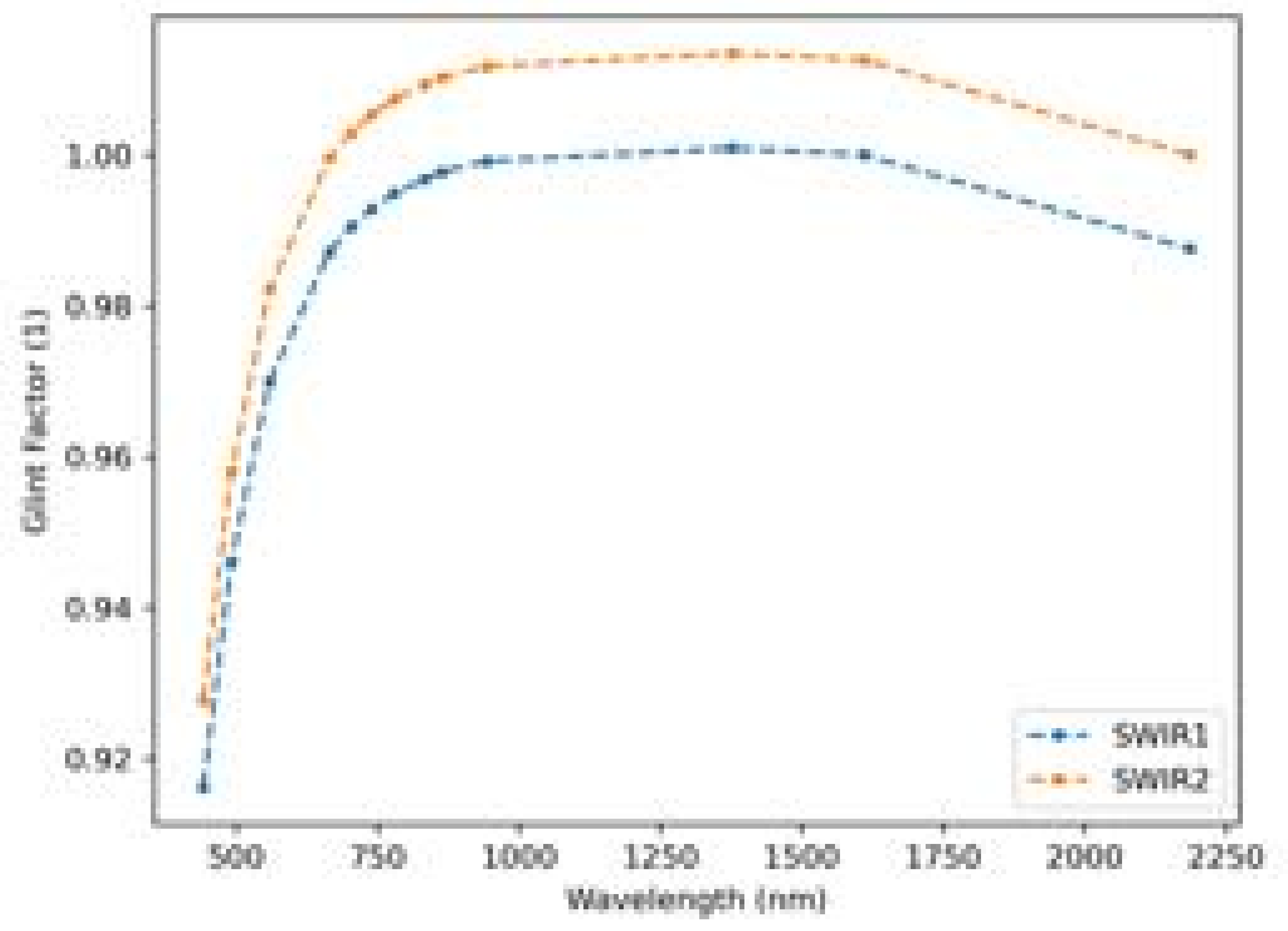
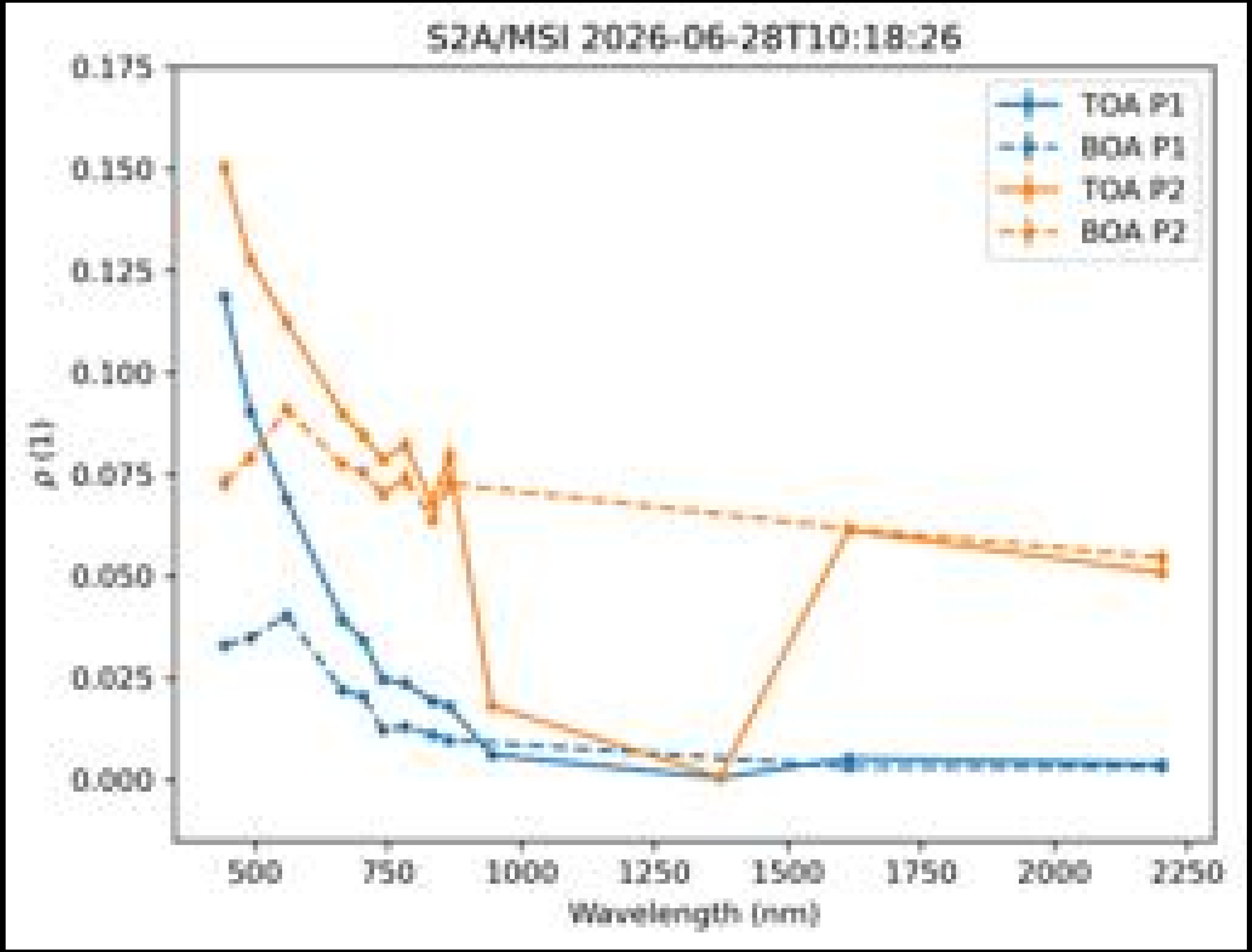


(ACOLITE: Choose SWIR band which gives lowest ρglint in Band 1)

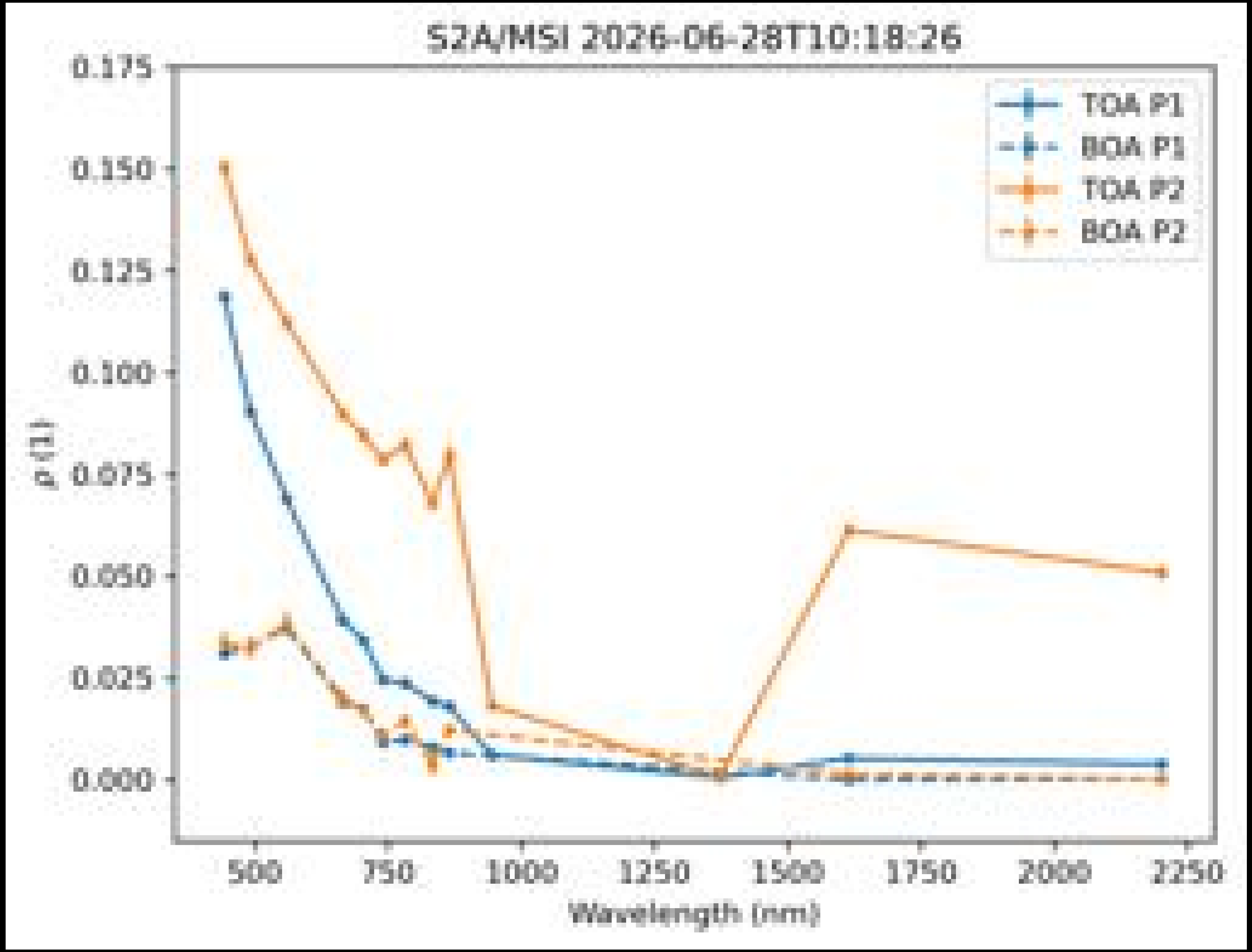
Harmel et al. (2018)

Glint correction

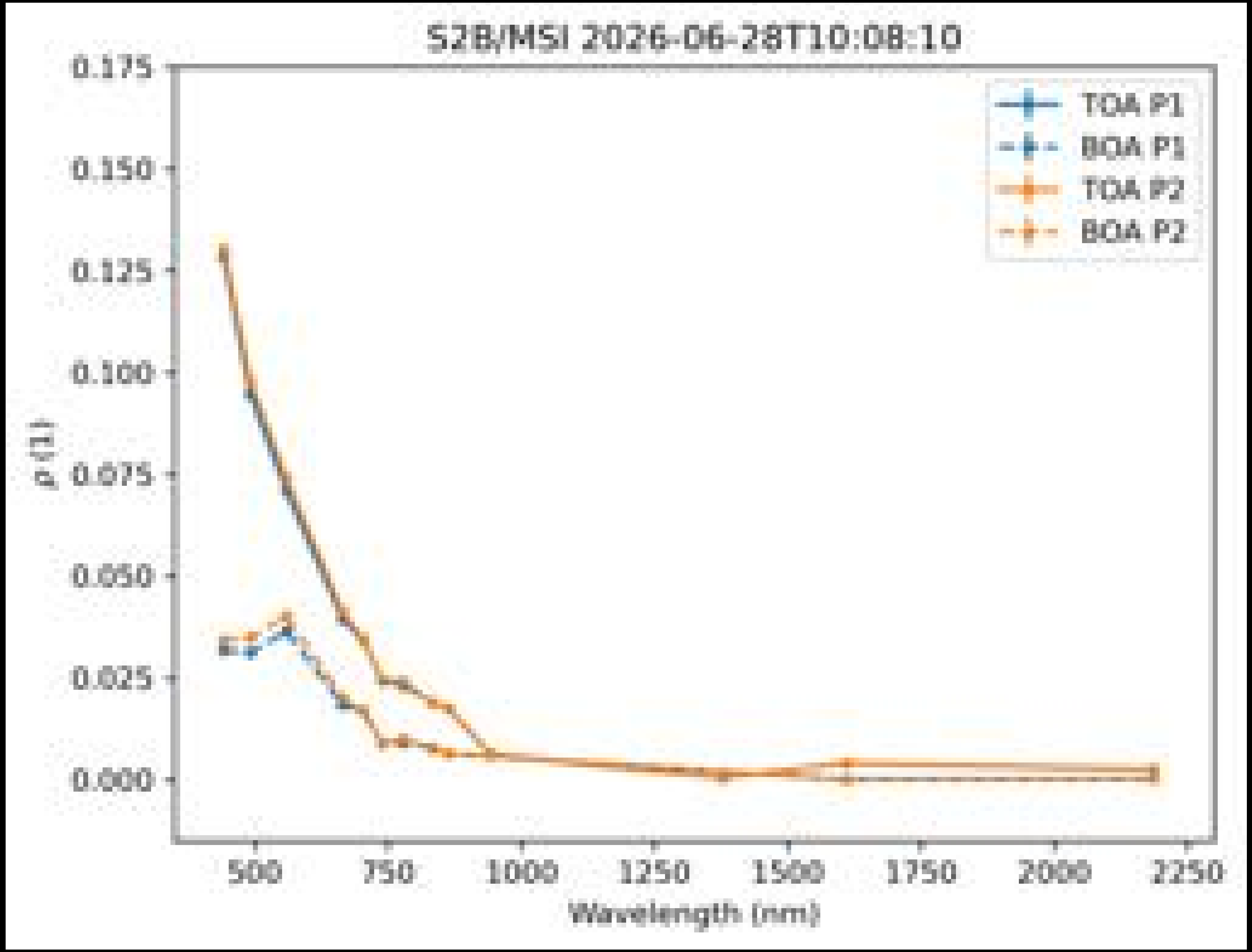
Glint correction



Glint correction



Glint correction



Conclusions

Atmospheric correction over complex waters, is determined by conditions that invalidate algorithm assumptions.

Many algorithms struggle in the presence of high NIR ρt, for example high turbidity, glint, and adjacency effects, which invalidates assumptions or exceeds training/model range.

ACOLITE/DSF and RAdCor show fairly robust retrievals under conditions where other algorithms fail, but may perform worse for low reflectance waters.