Verification of MSI Low Radiance Calibration Over Coastal Waters, Using AERONET-OC Network

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Rayference

Radiometric Calibration Workshop for European Missions

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This work is founded by the ESA S2 RadVal project

Overview

- Developing and inter-comparing algorithms for validating low radiances of Sentinel-2 Level 1C products;
- Based on a comparison of low-radiance Sentinel-2 signal over coastal waters (AERONET-OC stations) and theoretical TOA signal simulated in the same conditions, using 6SV;
- Following GUM recommendations for uncertainty propagation

DATA SET

Data: AERONET-Ocean Color

- AERONET-Ocean Color Network: provides total water-leaving radiance at a defined geometry, i.e. in a limited field-of-view;
- Water-leaving radiance is converted into reflectance and injected in 6SV.

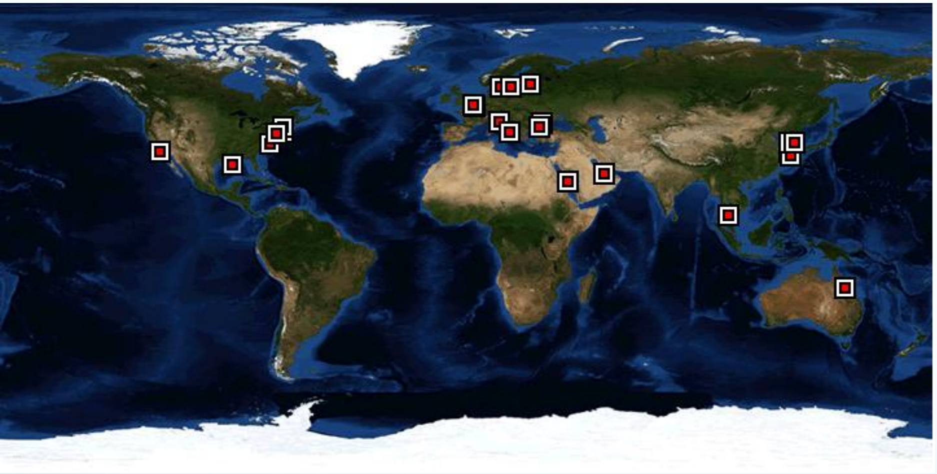
Data: AERONET-Ocean Color

Source: AERONET-Ocean Color Website

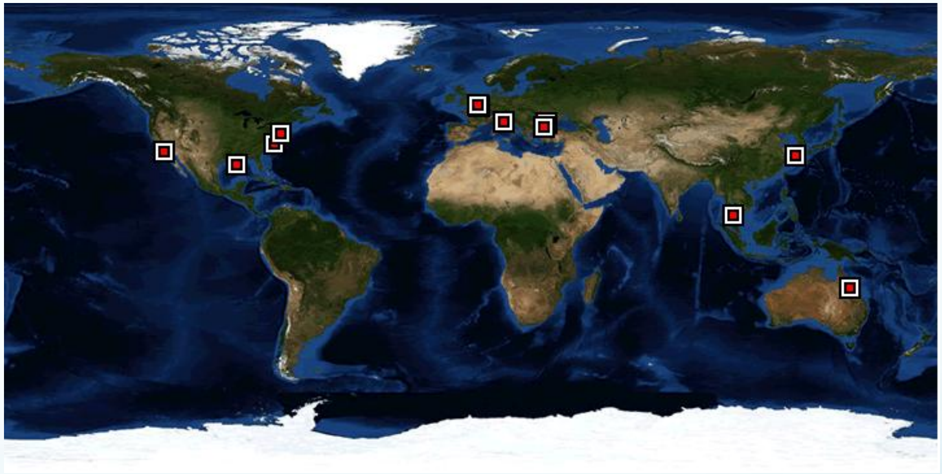
Site names	Lat/Lon
COVE SEAPRISM	36.9° N – 75.1° W
Galata	43.0° N - 28.1° E
Gloria	44.6° N – 29.4° E
GOT Seaprism	9.3° N – 101.4° E
G. Dalen Lighthouse	58.6° N – 17.5° E
Helsinki L. Tower	59.9° N - 24.9° E
LISCO	41° N – 73.3° W
Lucinda	18.5° S – 146.4° E
MVCO	41.3° N – 70.6° W
Palgrunden	58.7° N – 18.2° E
Thornton	51.5° N – 3° E
USC Seaprism	33.6° N – 118.1° W
Venice (AAOT)	45.3° N – 12.5° E
WaveCIS	28.9° N – 90.5° W
Zeebrugge	51.7° N – 3.1° E

Data: AERONET-Ocean Color

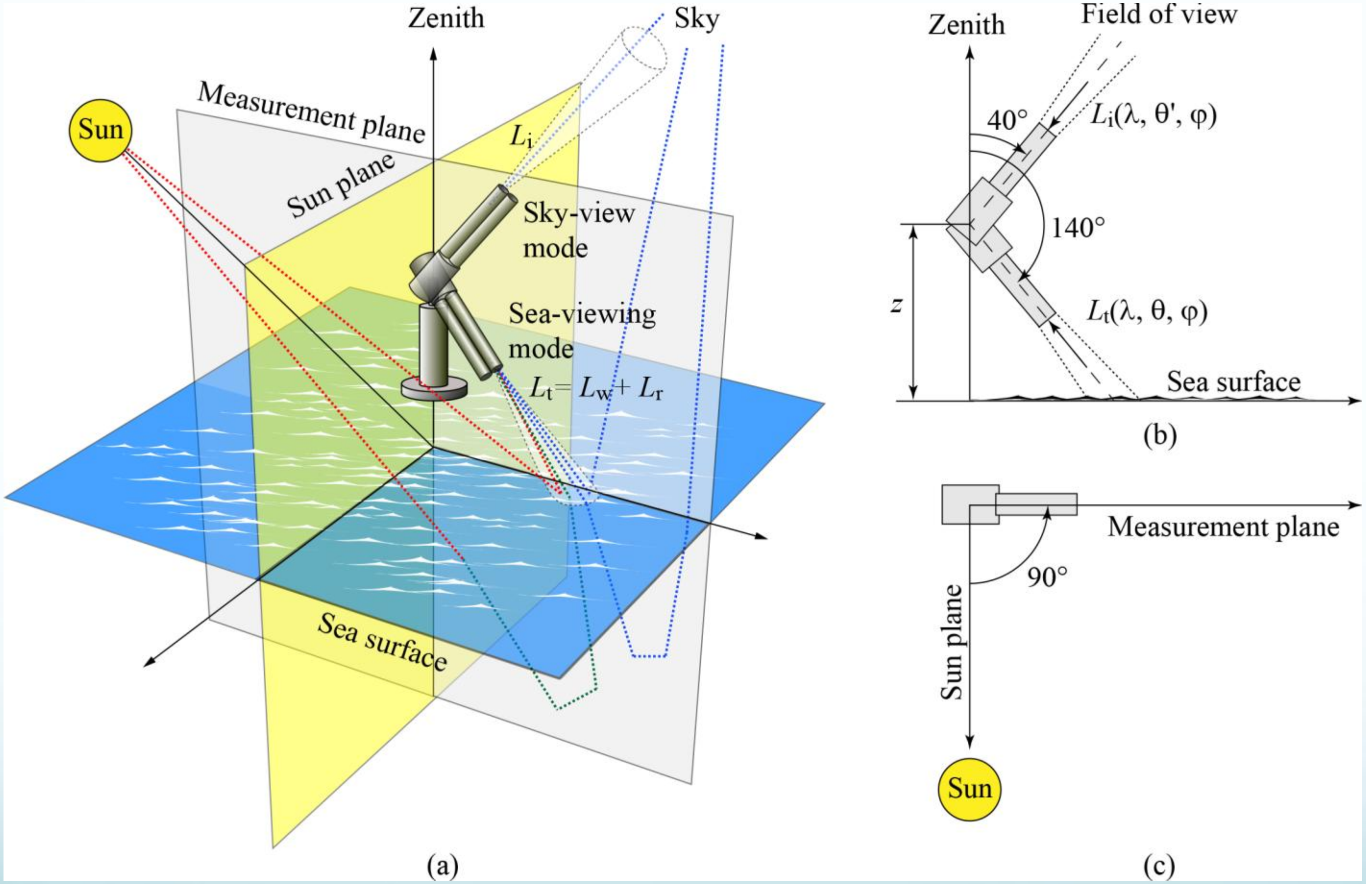
Level 1.5 All stations



Level 1.5 2016



Data: AERONET-Ocean Color



Source: "Effects of light polarization and waves slope statistics on the reflectance factor of the sea surface", D. D'Alimonte, T. Kajiyama

Data: AERONET-Ocean Color

Field	Symbol	Description
Time of acquisition	t'	Date (day/month/year) and Time (hours/minutes/seconds) of the measure
Solar Zenith	$\theta'_s(\lambda_C)$	Solar zenith angle at t' (in degree)
Solar Azimuth	$\varphi'_s(\lambda_C)$	Solar Azimuth angle at t' (in degree)
L_t mean	$L'_T(\lambda_C)$	Above-water total radiance at $\theta_v = 40°$ (in $mW/(cm^2\ sr\ \mu m)$)
AOT	$\tau'_A(\lambda_C)$	Aerosol optical thickness (no units)
OOT	$\tau'_O(\lambda_C)$	Ozone optical thickness (no units)
ROT	$\tau'_R(\lambda_C)$	Rayleigh optical thickness (no units)
Surface pressure	h'_s	Surface pressure (in hPa)
Wind speed	w'_s	Surface wind speed (in m/s)
Chlorophyll-a	Chla	Chlorophyll-a concentration (in mg/m^3)

Source: AERONET-Ocean Color Website

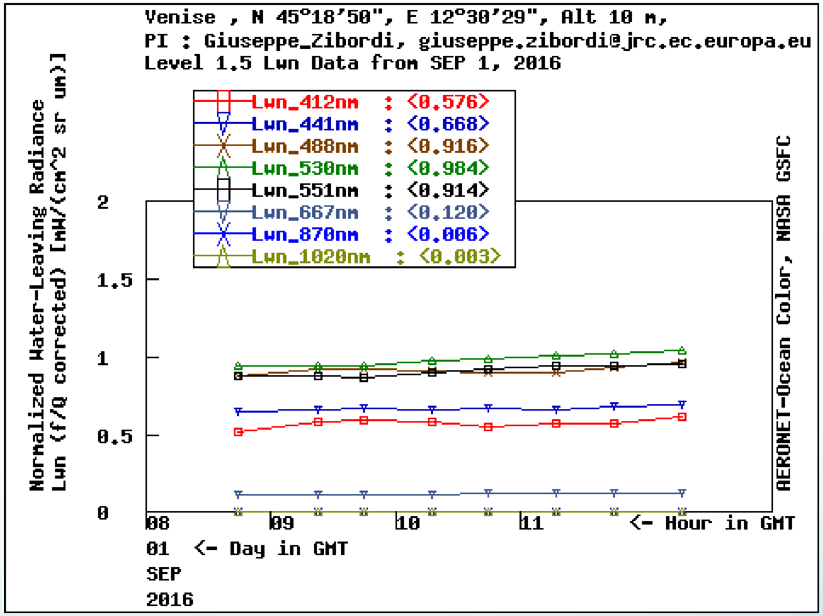
Data: AERONET-Ocean Color

- Accuracy

Field	Symbol	Uncertainty
L_t mean	L'_T	Relative: 2.7% (in 400-1000 nm)
AOT	τ'_A	Absolute: 0.02
Wind speed	w'_s	Relative: 1.1%

Source: "Description and access to AERONET-OC data", Zibordi

- Temporal variation



Temporal variation of the normalized water-leaving radiance L_{wn} over 1 day

Source: AERONET-Ocean Color Website

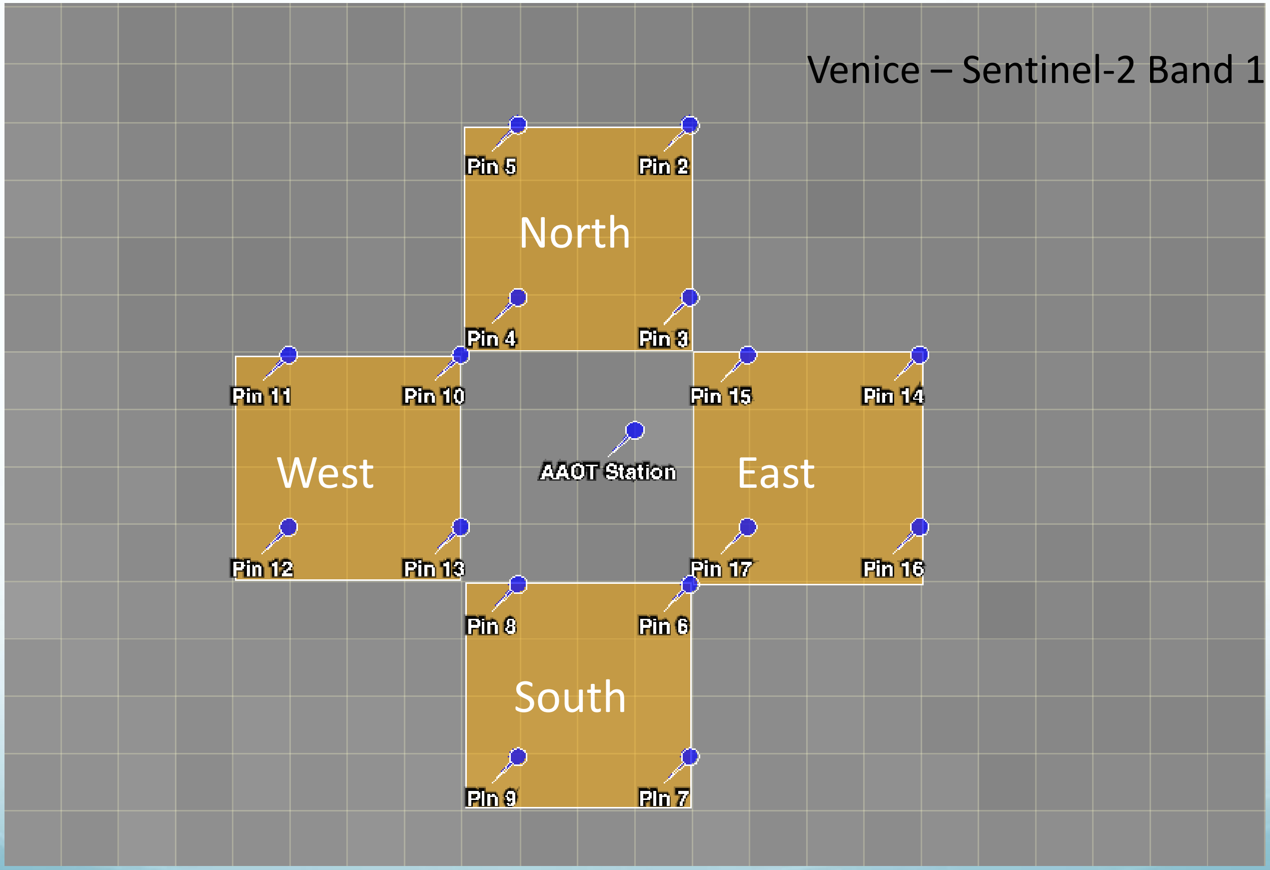
Data: Sentinel-2/MSI

Sentinel-2 L1C data extraction: data type

Field	Symbol	Description
Time of acquisition	t	Day/month/year, Hours/minutes/Seconds
Solar Zenith	θ_s	Solar zenith angle (in degree)
Solar Azimuth	φ_s	Solar Azimuth angle (in degree)
Viewing Zenith	θ_v	Viewing zenith angle (in degree)
Viewing Azimuth	φ_v	Viewing Azimuth angle (in degree)
Lat-Lon		Latitude, Longitude (in degree)
Reflectance	O	L1c TOA BRF for each band (no units)

Data: Sentinel-2/MSI

Sentinel-2 L1C data extraction



Venice – Sentinel-2 Band 1 – 20/01/2016

Data: Sentinel-2/MSI

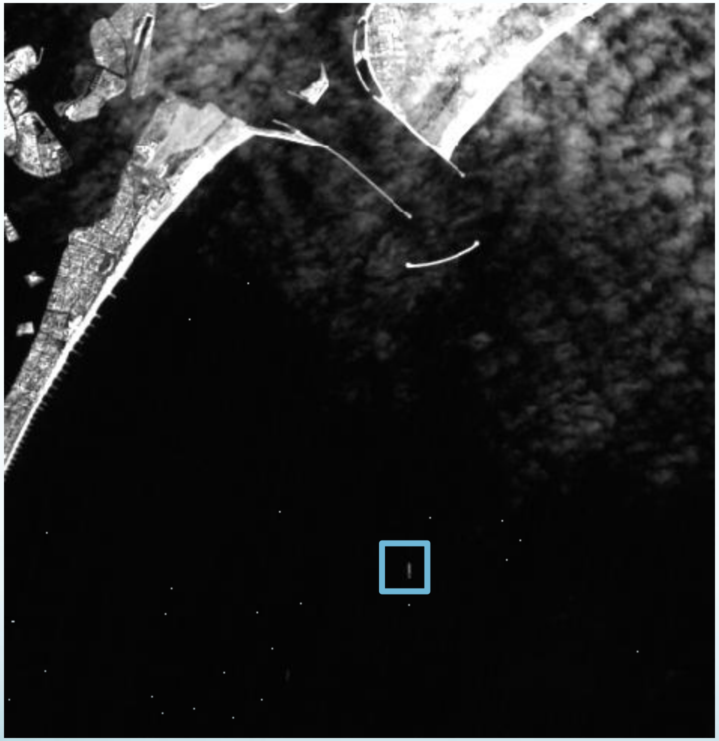
Extraction of 4 areas of 4*4 60-meter resolution pixels around the AERONET-OC platform, which allows us:

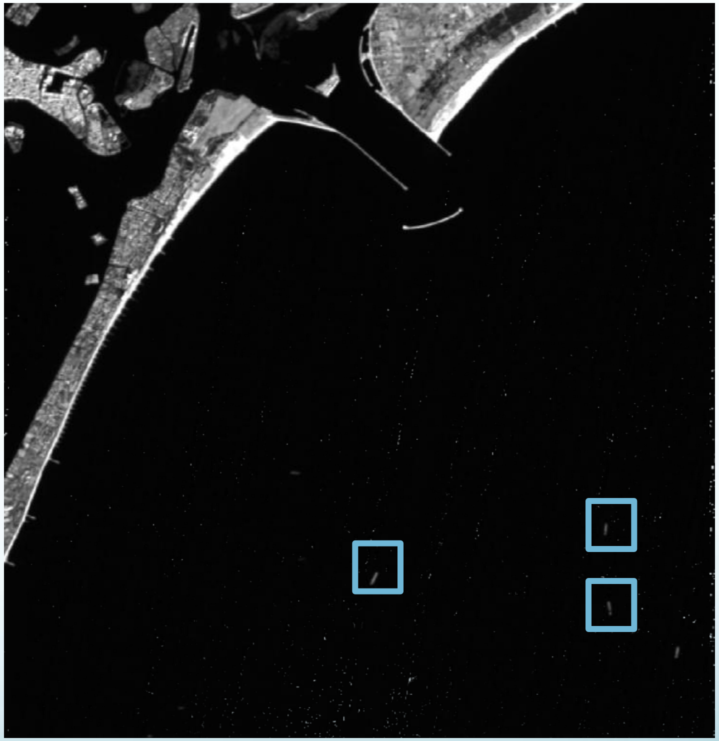
- To avoid the possible contamination of the reflectance by the shadow of the platform
- To determine the observation uncertainties, based on the standard deviation of the pixel reflectance in those 4 areas of interest assuming that all 4x4 pixels are identical

$$\sigma_{MSI}(\lambda_{MSI}) = \sqrt{(\sigma_{MSI}^{north}(\lambda_{MSI}))^2 + (\sigma_{MSI}^{south}(\lambda_{MSI}))^2 + (\sigma_{MSI}^{east}(\lambda_{MSI}))^2 + (\sigma_{MSI}^{west}(\lambda_{MSI}))^2}$$

Data: Sentinel-2/MSI

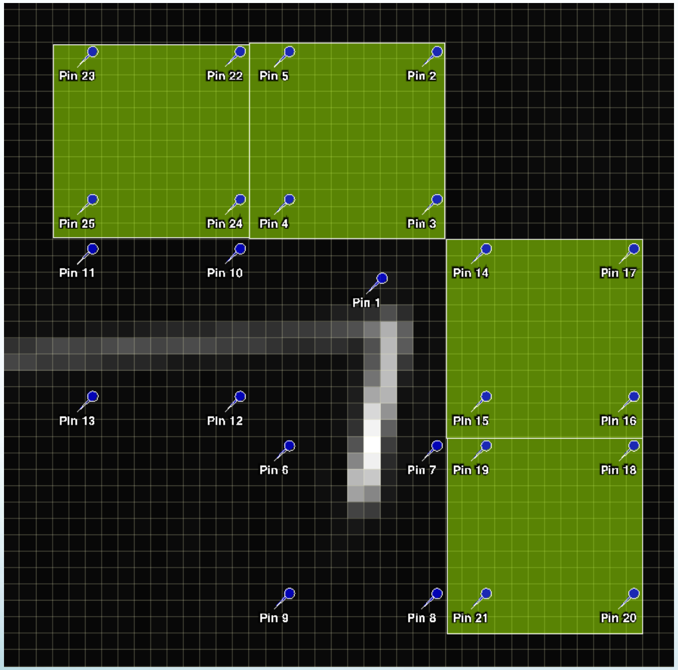
Possible contamination





Venice – B12 – January 2016

Data: Sentinel-2/MSI



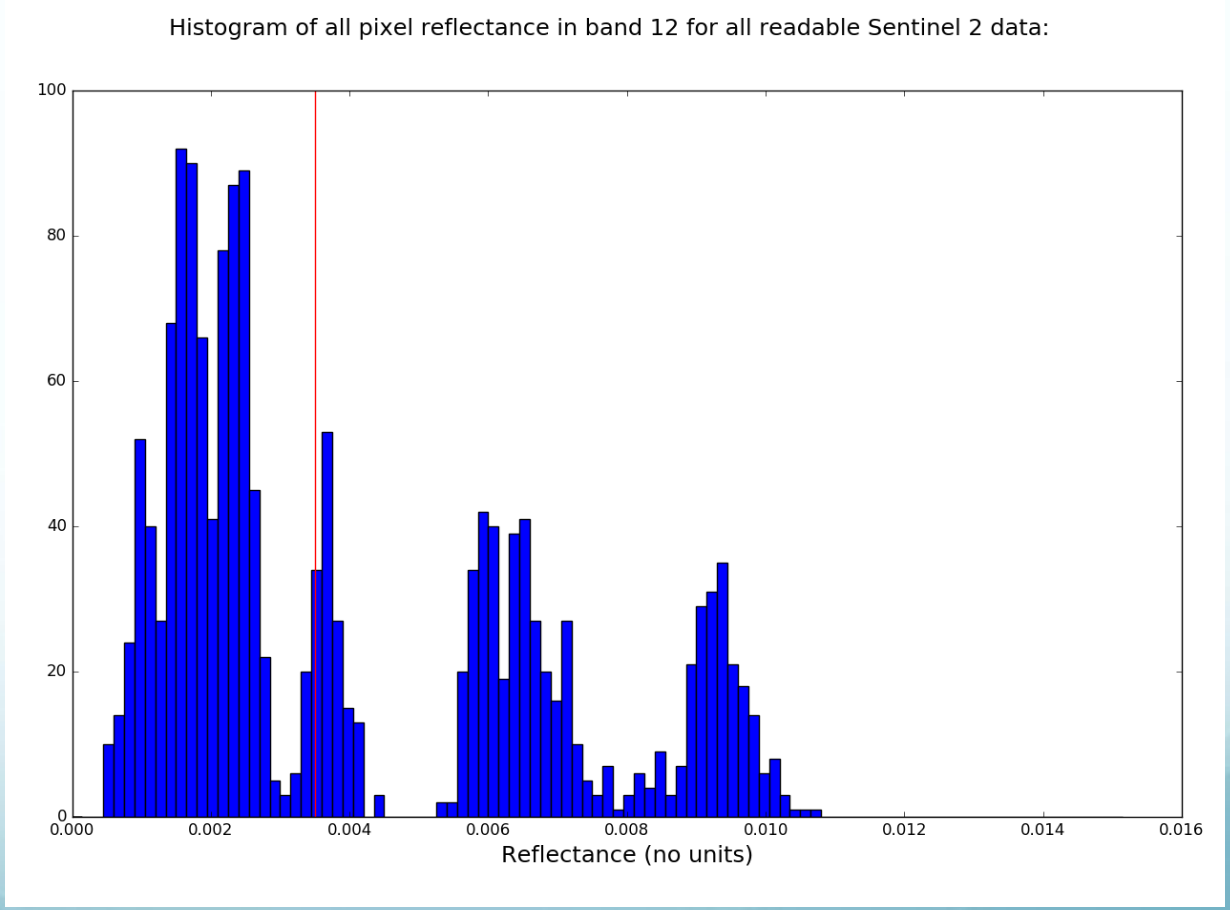
Lucinda – Sentinel-2 Band 12

Source: Google Maps

Data: Sentinel-2/MSI

Sentinel-2 data extraction: filtering

If one pixel is rejected, the entire area is rejected



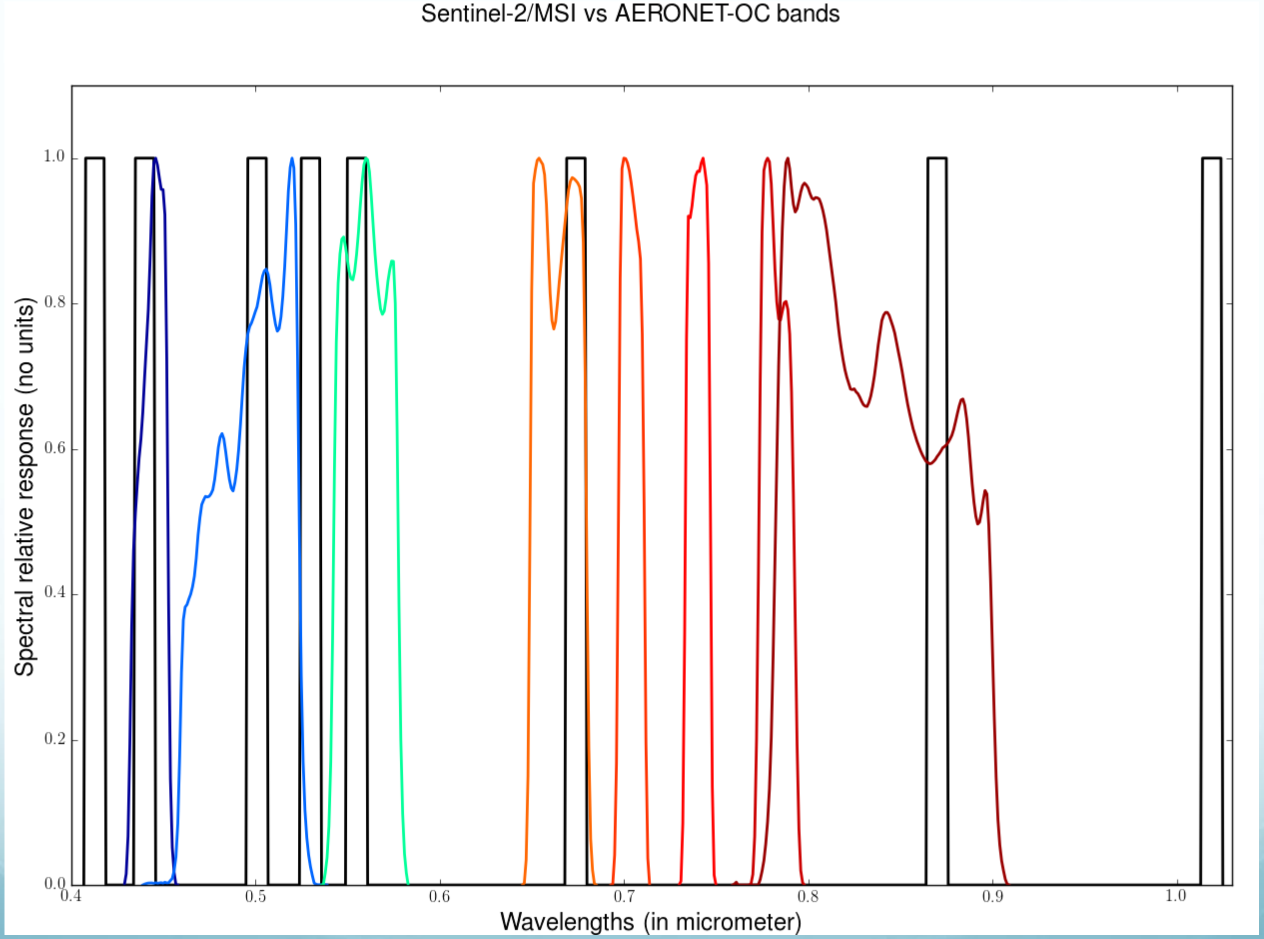
Data: Comparison S2/A-OC

Viewing Angles

Variables	Sentinal-2/MSI	AERONET-Ocean Color
Time of acquisition	Must be within a ±15 minute window	
Solar Zenith	$\theta_s \cong \theta'_s$	
Solar Azimuth	$\varphi_s \in [145°, 165°]$	φ'_s = Daily variation
Viewing Zenith	$\theta_v \in [0°, 10°]$	$\theta'_v = 40°$
Viewing Azimuth	$\varphi_v \in [15°, 210°]$	$\varphi'_v = \varphi'_s - 90°$

Data: Comparison S2/A-OC

Spectral Bands



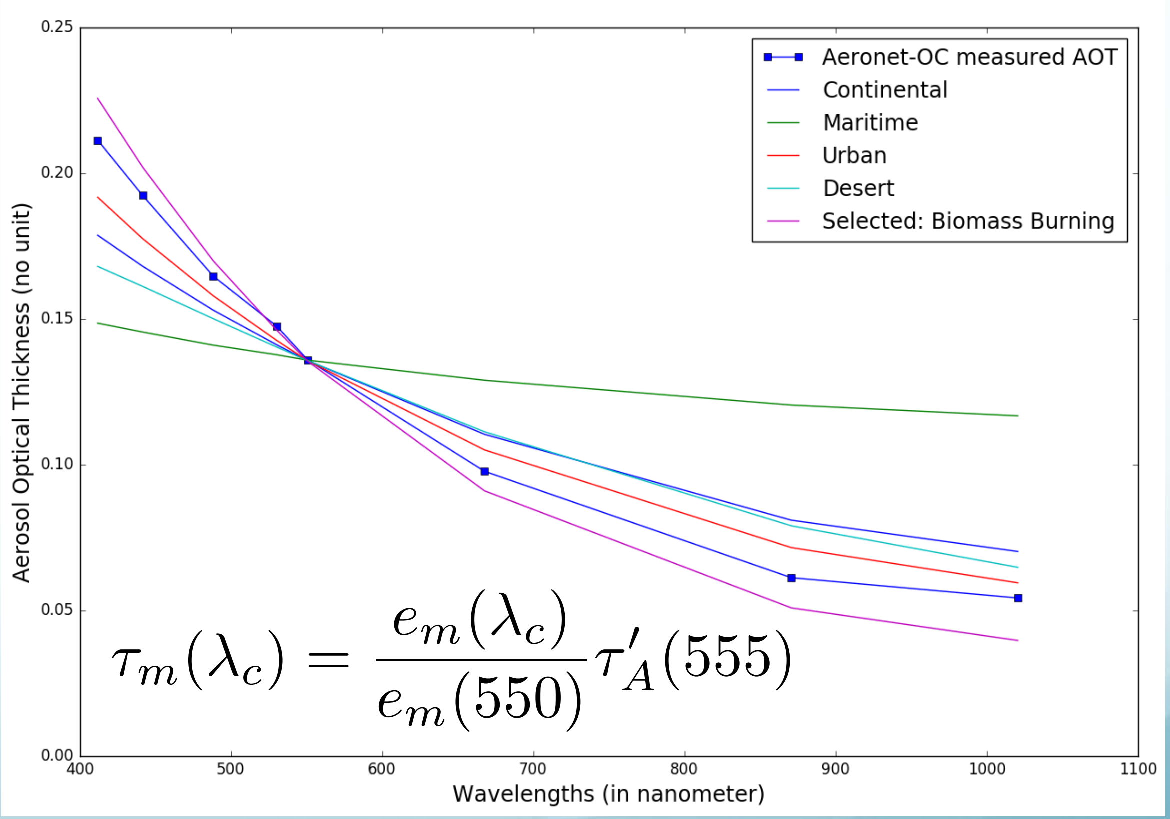
METHOD

Method: Sea Reflectance Model

Determination of the aerosol model

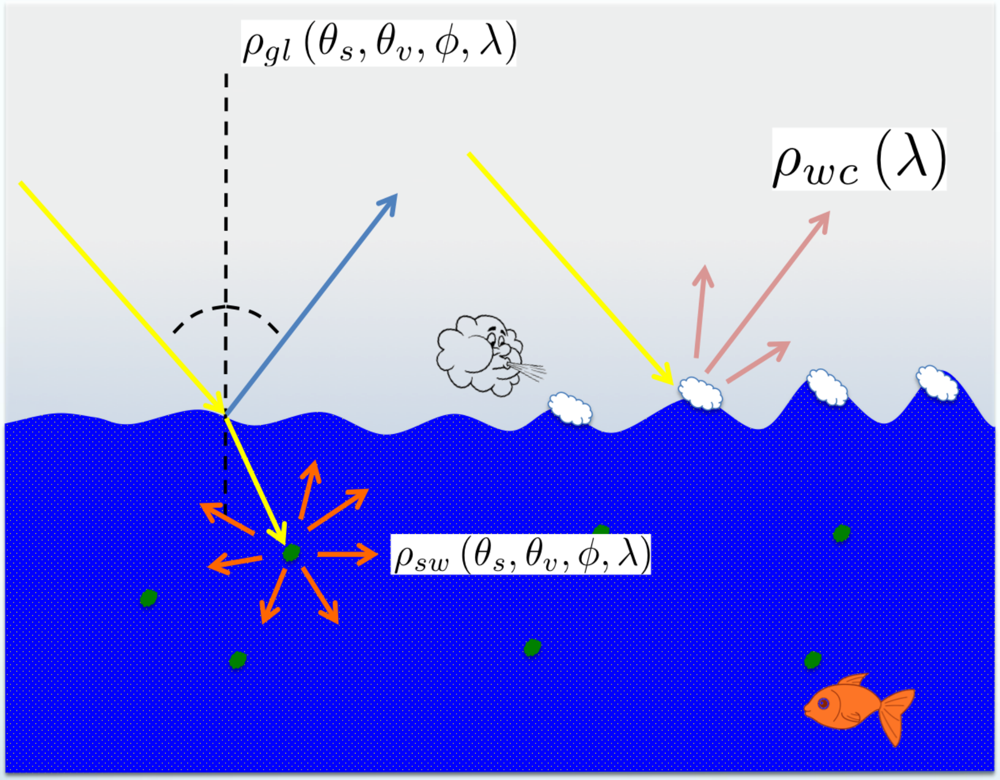
6SV offers 5 build-in aerosol models of interest :

- -Maritime
- -Continental
- -Urban
- -Biomass Burning
- -Desert



$$\tau_m(\lambda_c) = \frac{e_m(\lambda_c)}{e_m(550)} \tau'_A(555)$$

Method: Sea Reflectance Model



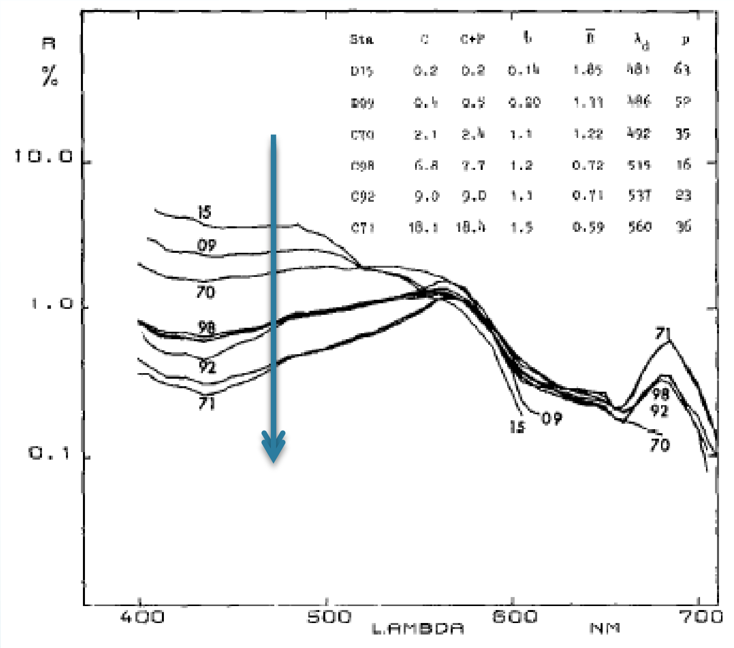
Sum of 3 contributions:

- Reflectance due to whitecaps,
- Sunglint or specular reflectance,
- Scattered reflectance emerging from the sea (only case I waters in 6SV)

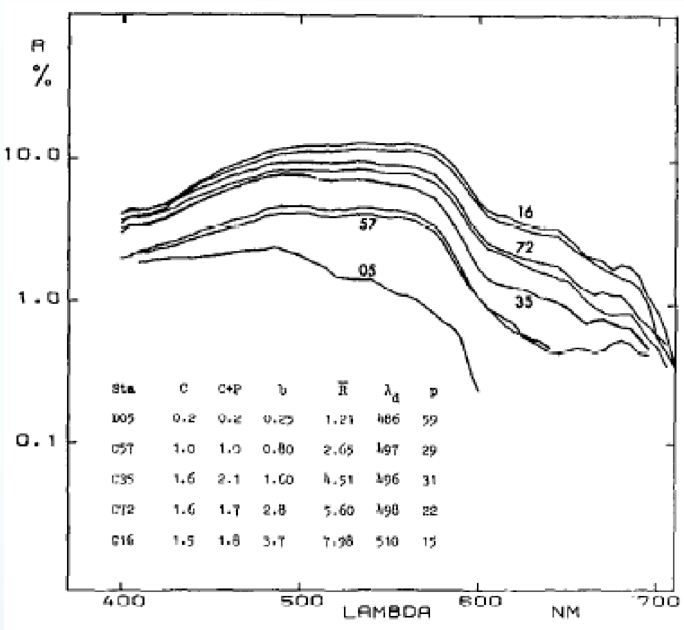
$$\rho_s(\theta_s, \theta_v, \phi, \lambda) = \rho_{wc}(\lambda) + (1 - W)\rho_{gl}(\theta_s, \theta_v, \phi, \lambda) + (1 - \rho_{wc}(\lambda))\rho_{sw}(\theta_s, \theta_v, \phi, \lambda)$$

Method: Sea Reflectance Model

- Case I vs Case II Waters



Chlorophyll-a is dominant in the waters. As its concentration increases, reflectance decreases in the blue/green band.



Inorganic sediments composed the suspended matter. Waters are brighter in the 500-600nm band.

Source: Morel, 1977

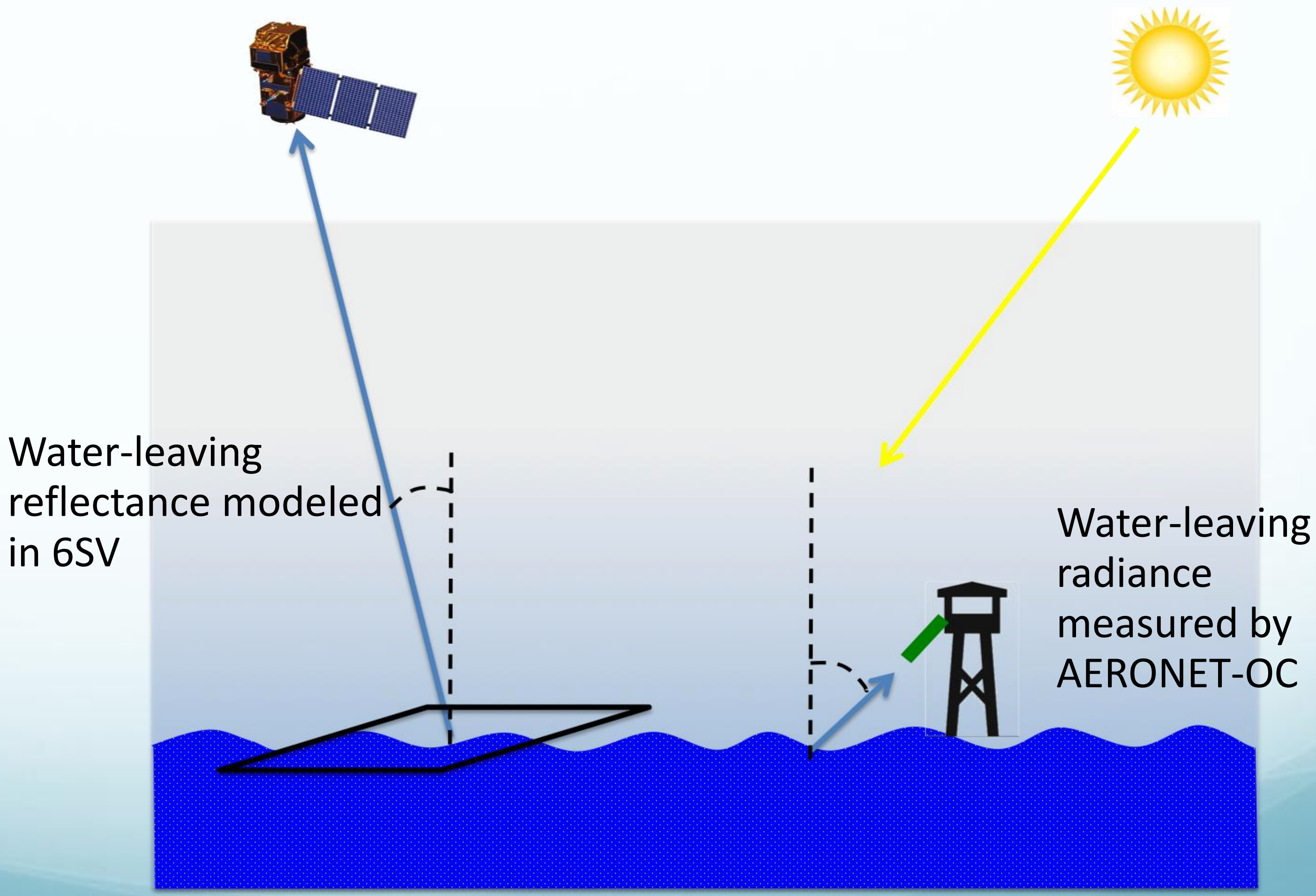
Method: Sea Reflectance Model

Summary

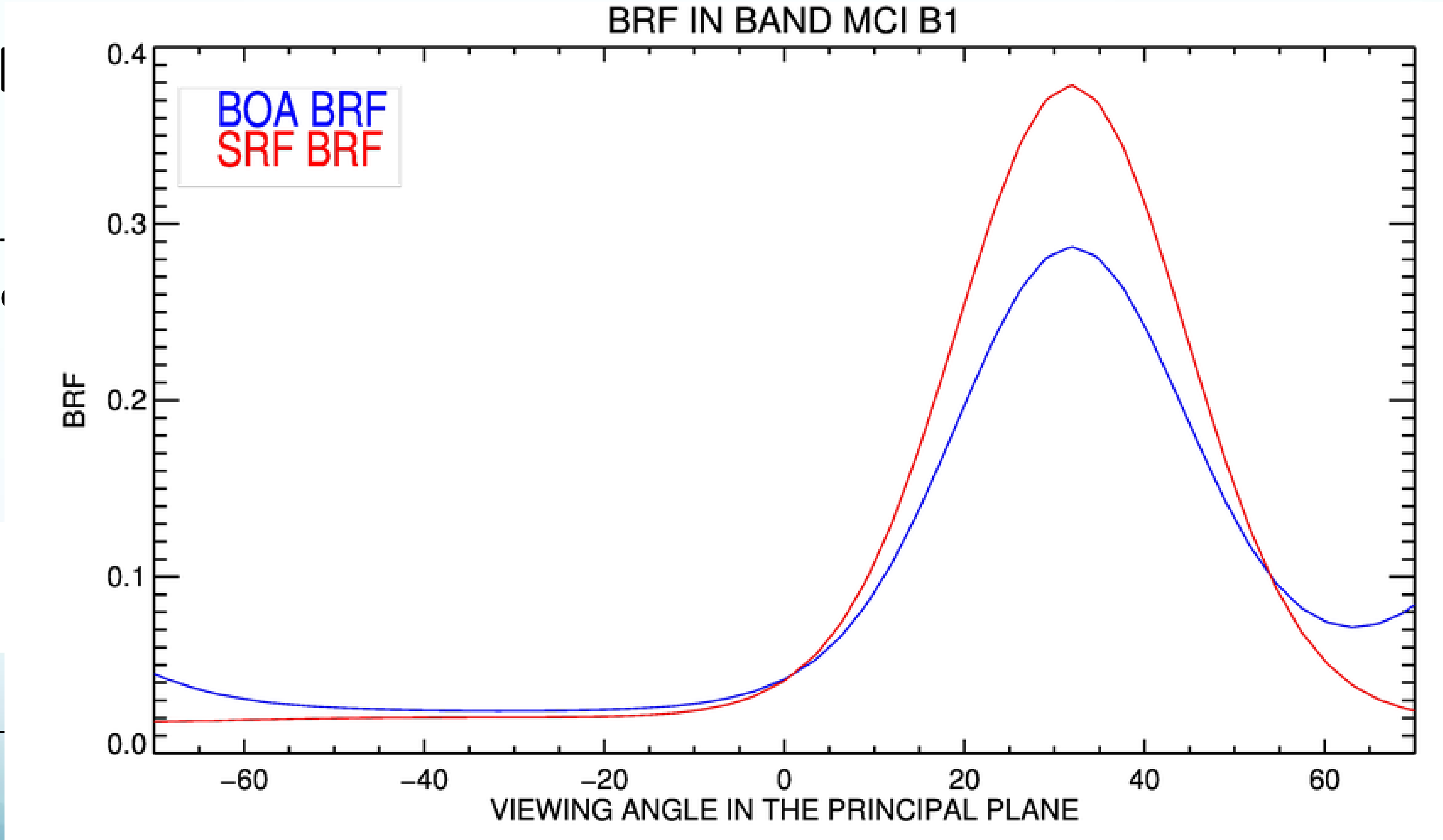
- The sea surface reflectance ρ'_s is expected to be dominated by the scattered reflectance emerging from the sea ρ'_{sw}, since we select measures with:
  - low wind speeds : $\rho'_{wc} \rightarrow 0$
  - geometries avoiding sunglint $\rho'_{gl} \rightarrow 0$

- In 6SV, ρ'_{sw} is computed in the case of homogeneous waters, neglecting:
  - the contribution of (yellowish or reddish) inorganic matter that can absorb or scatter the light entering the surface
  - the reflection of the light on a close ocean floor (case of shallow waters)

Method: Sea Reflectance Model



Method: Sea Reflectance Model

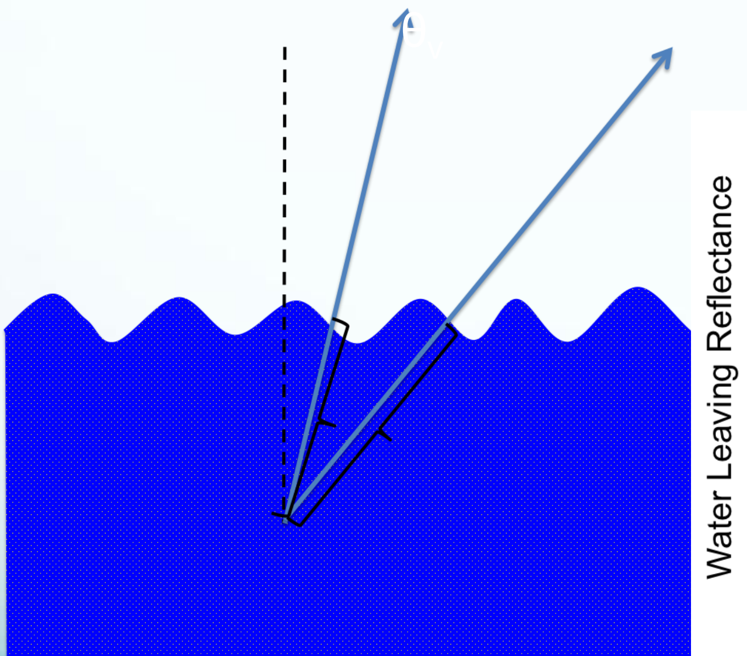


$\bar{\rho}'_s$

Method: Sea Reflectance Model

Estimation of the water-leaving reflectance ρ'_{sw}

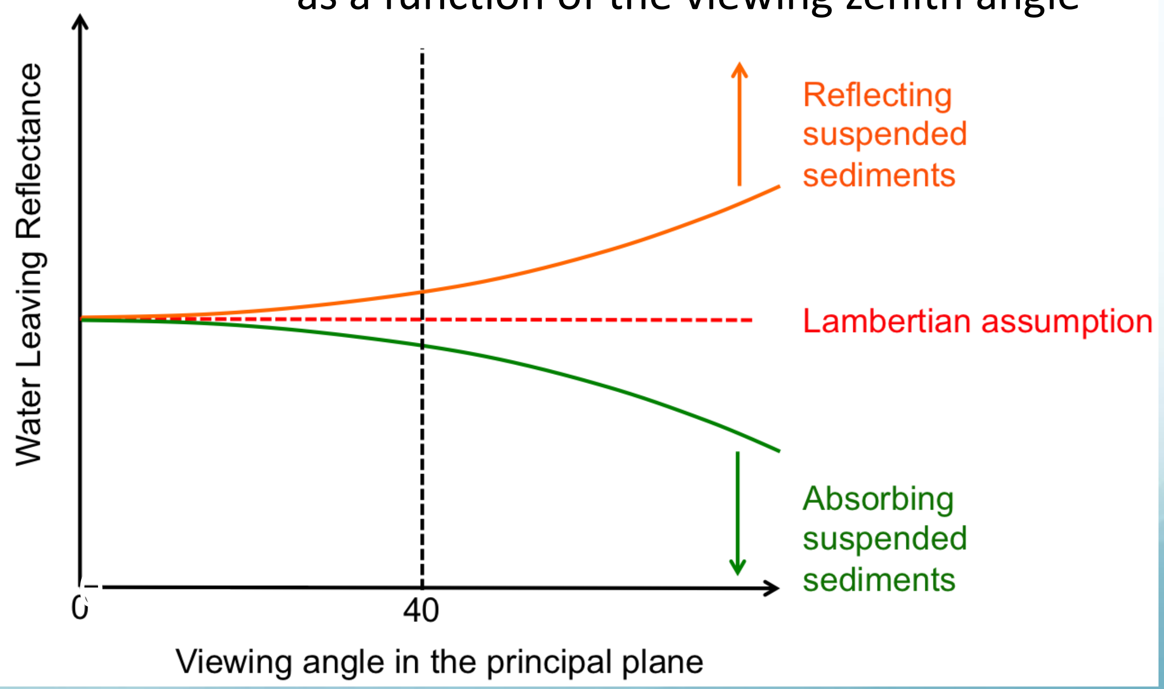
Variations of the optical path with theta_v



Variation of the water-leaving reflectance

$$\rho_{sw}\left(\theta_s, \theta_v, \phi, \lambda\right)$$

as a function of the viewing zenith angle

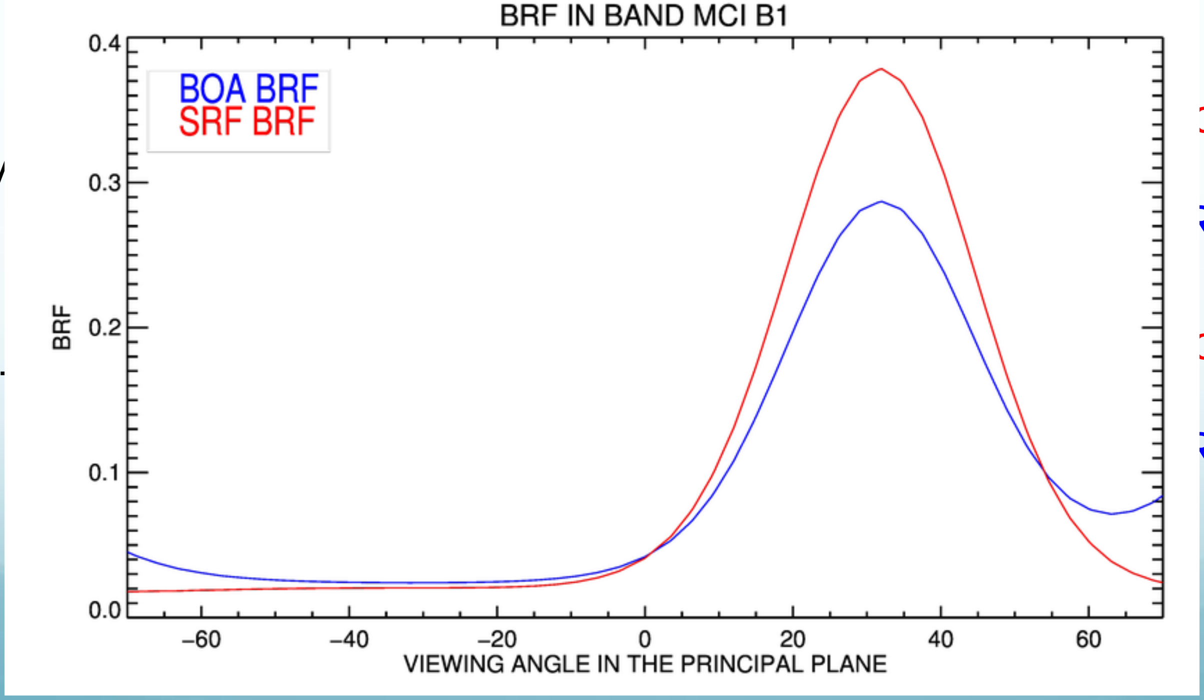


Method: Sea Reflectance Model

It is assumed that the ratio f between the sea surface reflectance (no atmopshere) and the bottom of atmosphere reflectance calculated with 6S or derived from AERONET-OC observations are the same

S2 M

AERONE



osphere srf BRF

RF

osphere srf BRF

RF

Method: Sea Reflectance Model

Estimation of the water-leaving reflectance ρ'_{sw}

$$f' = \frac{\rho'_s(\mu'_s, \mu'_v, \phi')}{\bar{\rho}'_s(\tau; \mu'_s, \mu'_v, \phi')} = \frac{\rho_s(\mu_s, \mu_v, \phi)}{\bar{\rho}_s(\tau; \mu_s, \mu_v, \phi)}$$

By replacing each term, we get:

$$f' = \frac{\rho'_{wc}(\lambda_c) + (1 - W)\rho'_{gl}(\theta'_s, \theta'_v, \phi', \lambda_c) + (1 - \rho'_{wc}(\lambda_c))\rho'_{sw}(\theta'_s, \theta'_v, \phi', \lambda_c)}{\bar{\rho}'_s(\theta'_s, \theta'_v, \phi', \lambda_c)}$$

Hypotheses: the whitecaps contribution is negligible (since the wind speed is low) and the sunglint is correctly modeled by 6SV. Therefore:

$$\rho'_{sw}(\theta'_s, \theta'_v, \phi', \lambda_c) = \frac{\bar{\rho}'_s(\theta'_s, \theta'_v, \phi', \lambda_c)}{f} - \rho_{gl}(\theta'_s, \theta'_v, \phi', \lambda_c)$$

Atmospheric-free water-leaving reflectance

BOA total reflectance

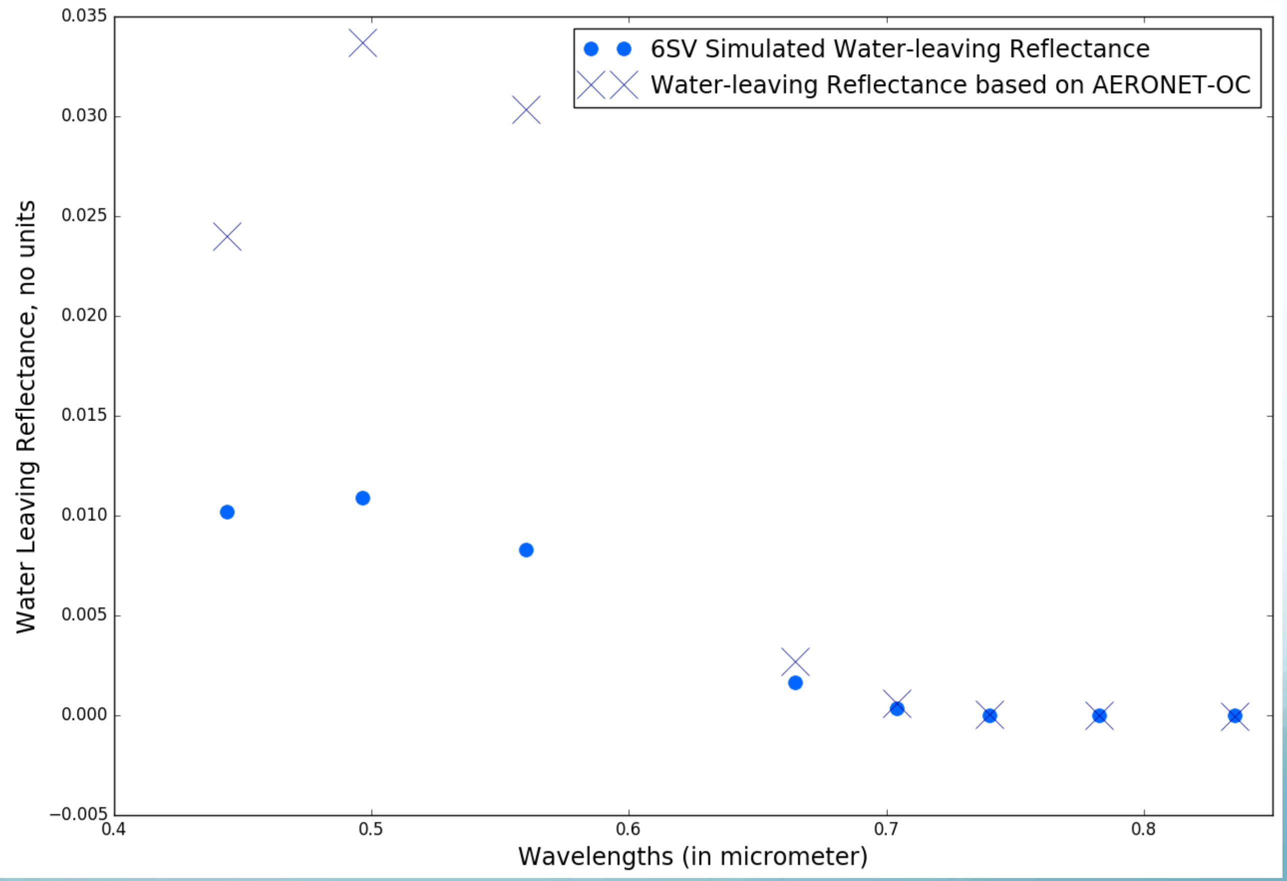
Calculated with 6SV based on AOT

Calculated with 6SV based on wind speed

Method: Sea Reflectance Model

Estimation of the water-leaving reflectance ρ'_{sw}

Example of Venice: Sentinel-2 observation from the 17/01/2016



Simulation uncertainty estimation

For all parameters

$$\sigma_R(t, s, \lambda_{MSI}; p_i) = \sqrt{\sum_{i=1}^{N} \left(\frac{\partial R(t, s, \lambda_{MSI}; p_i)}{\partial p_i} \sigma_{p_i} \right)^2}$$

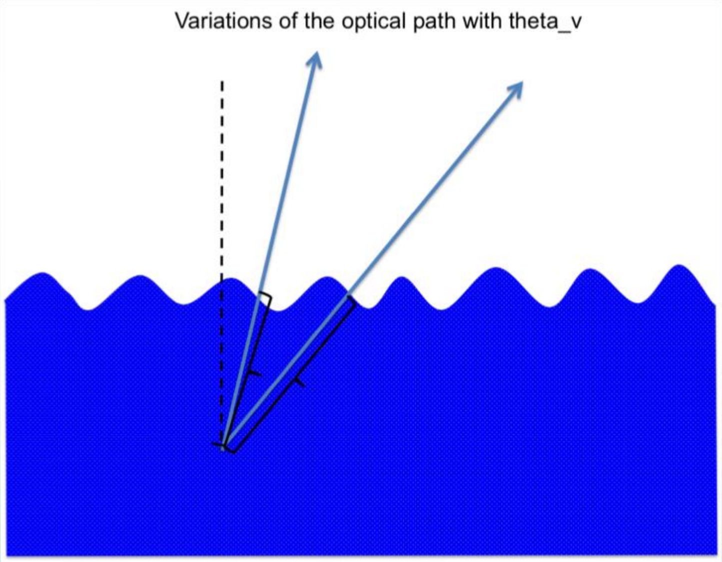
Cross-terms are neglected

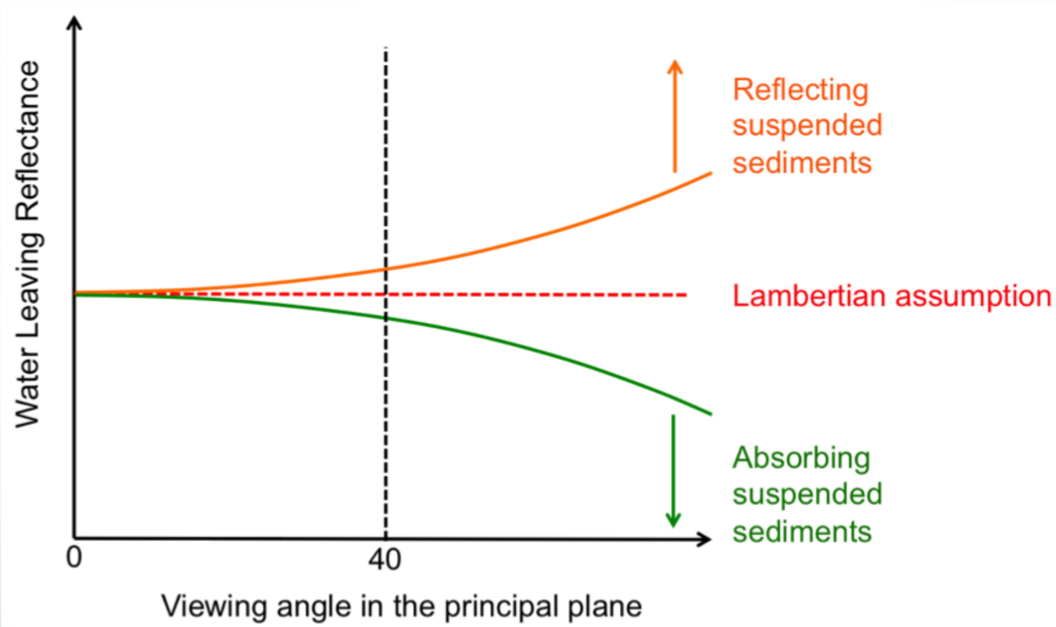
p_i	Units	σ_{pi}	Source
Wind speed	m/s	1.1%	AERONET-OC
Wind direction	degree	45°	-
Water leaving Reflectance	-	Following Equation	AERONET-OC
Surface pressure	hPa	1%	AERONET-OC
AOT at 550nm	-	0.02	AERONET-OC
Aerosol type	-	Second best	AERONET-OC
TCWV	Kg/m^2	10%	AERONET
TCO3	Dobson units	20%	ECMWF reanalysis

Uncertainties

For the water-leaving reflectance

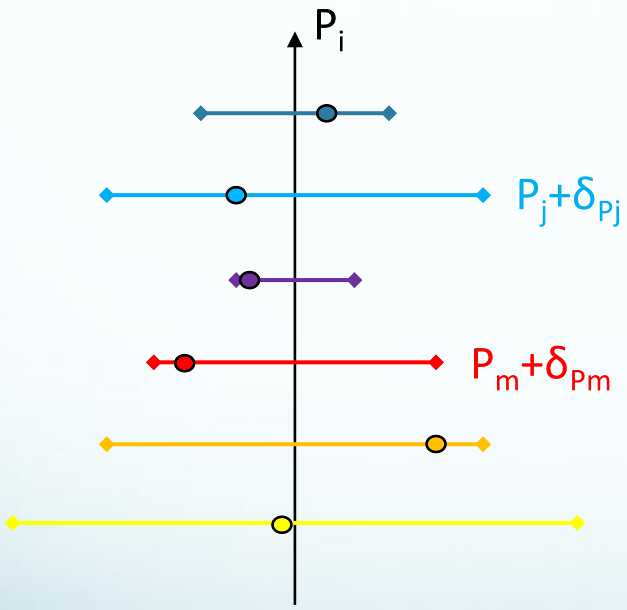
$$\sigma_{\rho_{sw}}(t, s, \lambda_{MSI}; p_i) = \sqrt{\sum_{i=1}^{N}\left(\frac{\partial \rho_{sw}}{\partial p_i}\sigma_{p_i}\right)^2 + \left(\frac{\partial \rho_{sw}}{\partial \theta_s}\Delta\theta_s\right)^2 + \left(\frac{\partial \rho_{sw}}{\partial \theta_v}\Delta\theta_v\right)^2}$$





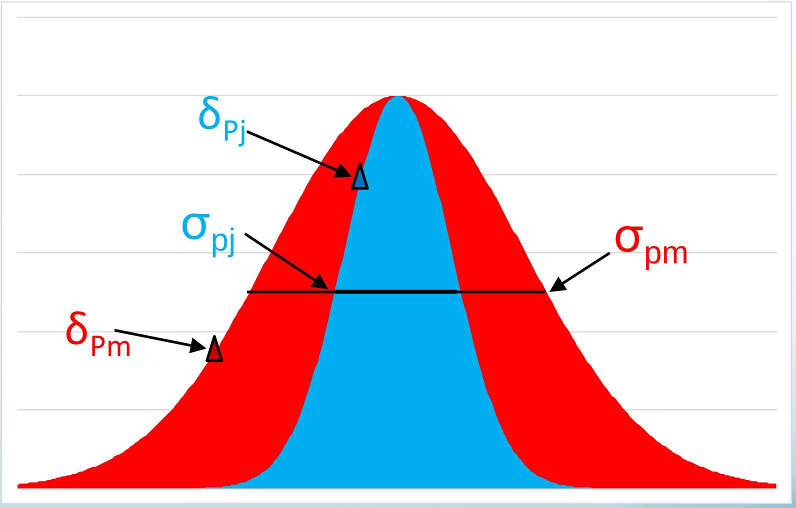
MONTE-CARLO VALIDATION OF UNCERTAINTY ESTIMATION

Method

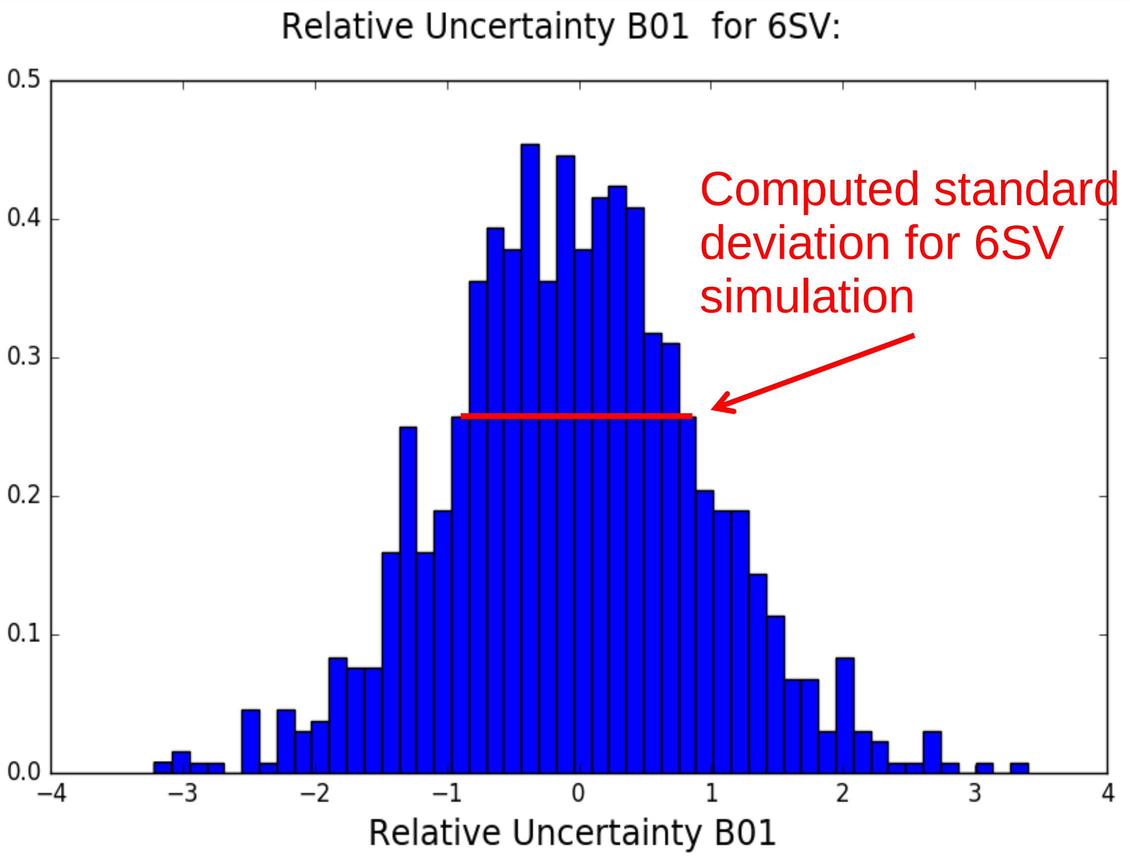


For one Monte-Carlo draw

The perturbed quantity δ_{pi} is randomly chosen inside a Gaussian distribution whose HWHM is the uncertainty associated to σ_{pi} of the parameter p_i.



Monte-Carlo validation



Band	Associated standard deviation	Approximated result from the Monte-Carlo draws
B01	1.99 %	2 %
B02	2.93 %	2 %
B03	5.66 %	5 %
B04	6.61 %	6 %
B05	7.16 %	8 %
B06	8.05 %	9 %
B07	9.36 %	12 %
B08	10.30 %	12 %

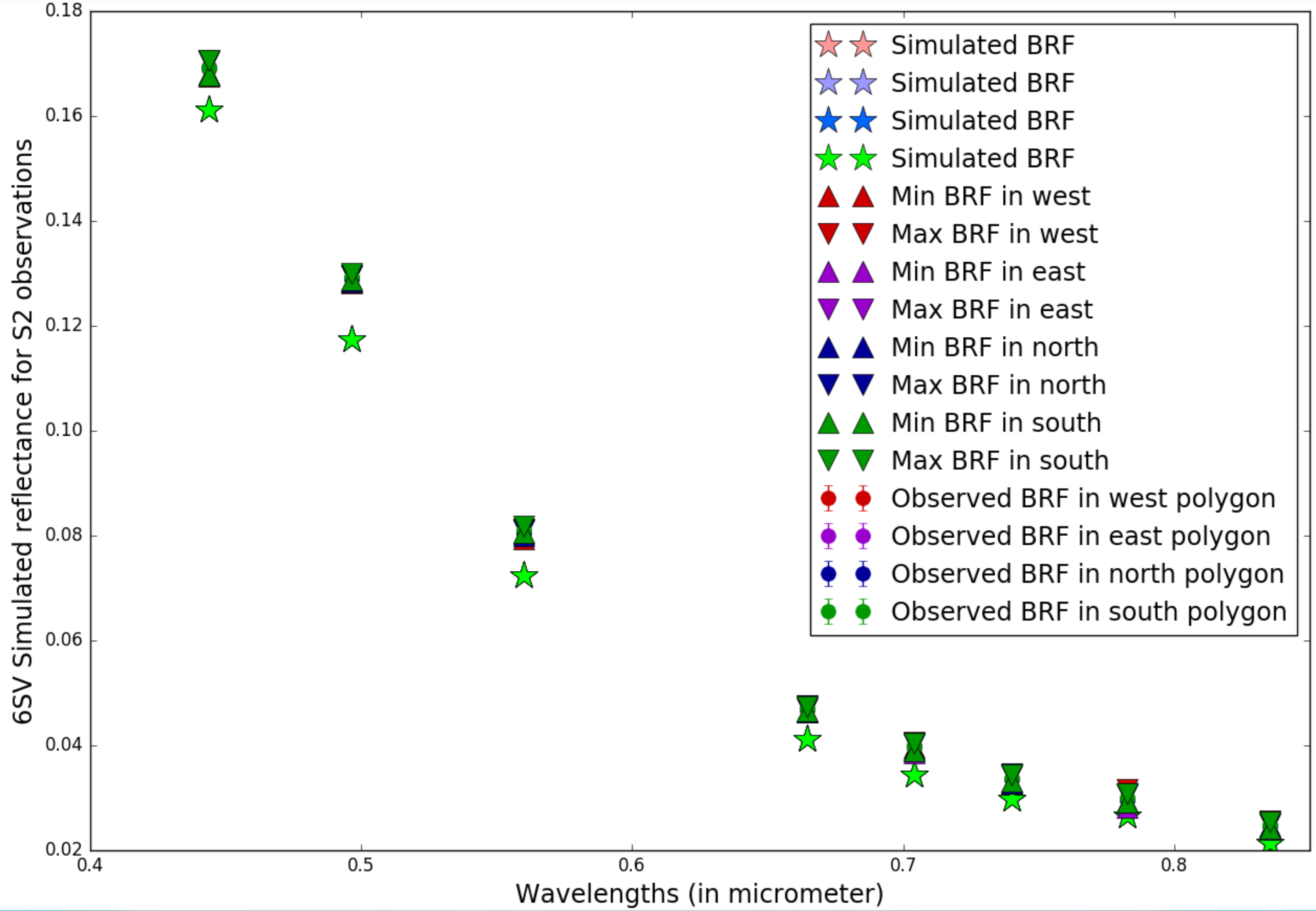
RESULTS

A case study: Venice (20/01/2016)

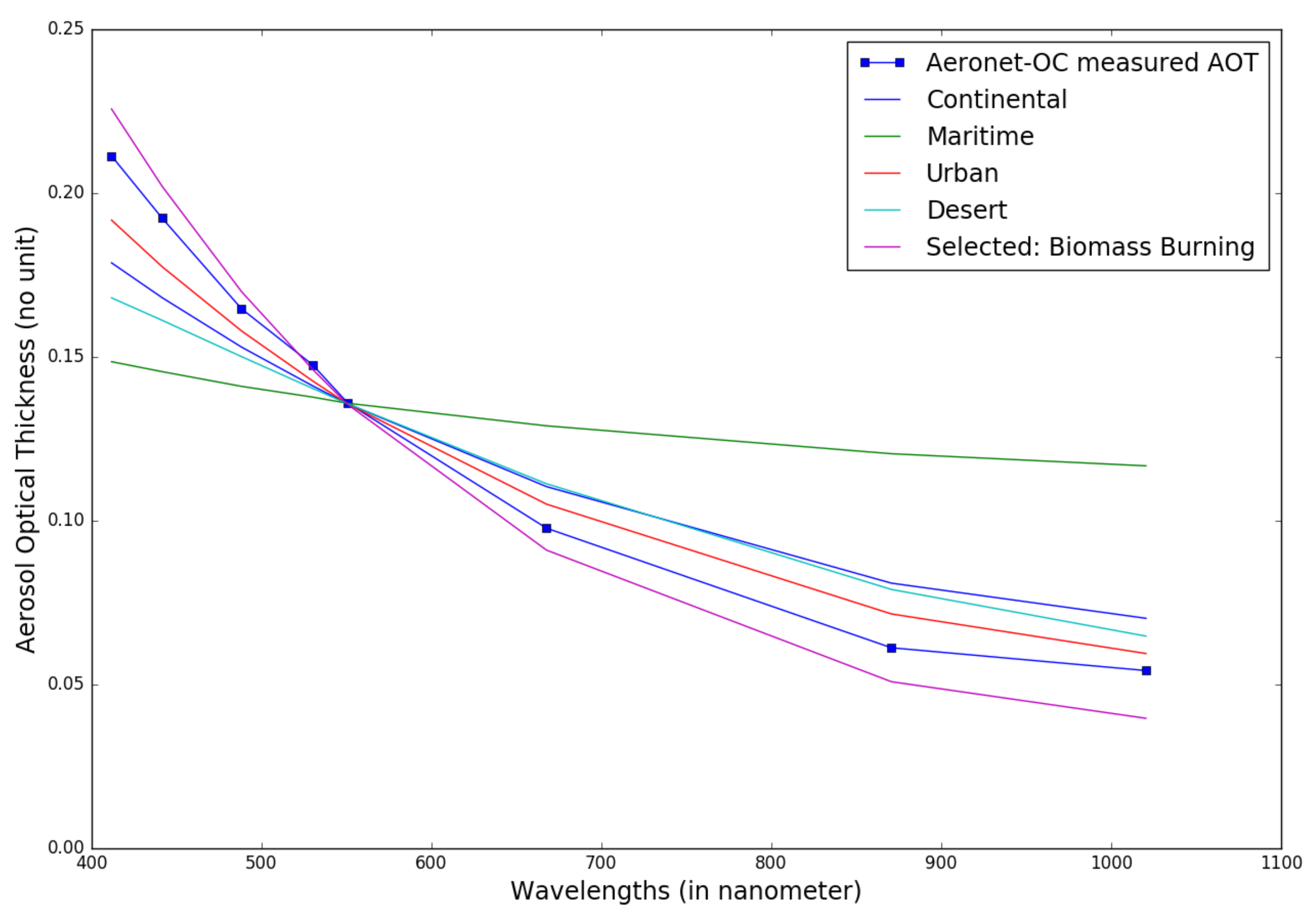
Variables	Sentinal-2/MSI
Time of acquisition	20/01/2016 At 10:27:49
Solar Zenith	$\theta_s = 67.04°$
Solar Azimuth	$\varphi_s = 164.02°$
Viewing Zenith	$\theta_v = 5.28°$
Viewing Azimuth	$\varphi_v = 180.72°$

Variables	AERONET_OC
Time of acquisition	20/01/2016 At 10:32:50
Solar Zenith	$\theta'_s = 66.3°$
Solar Azimuth	$\varphi_s = 168.0°$
Viewing Zenith	$\theta'_v = 40°$
AOT(555)	0.135912
Wind speed	4.37872 m/s

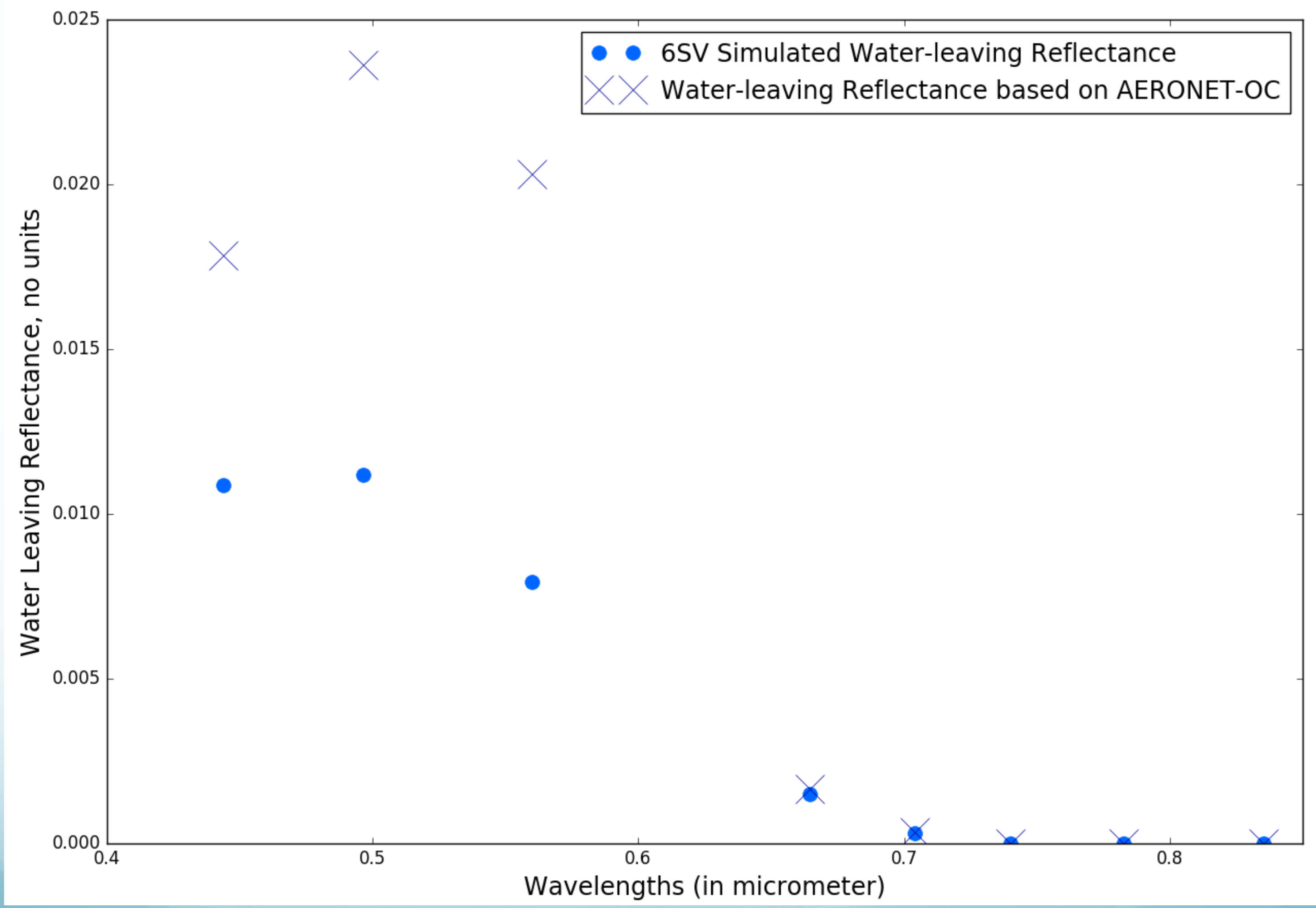
A case study: Venice (20/01/2016)



A case study: Venice (20/01/2016)

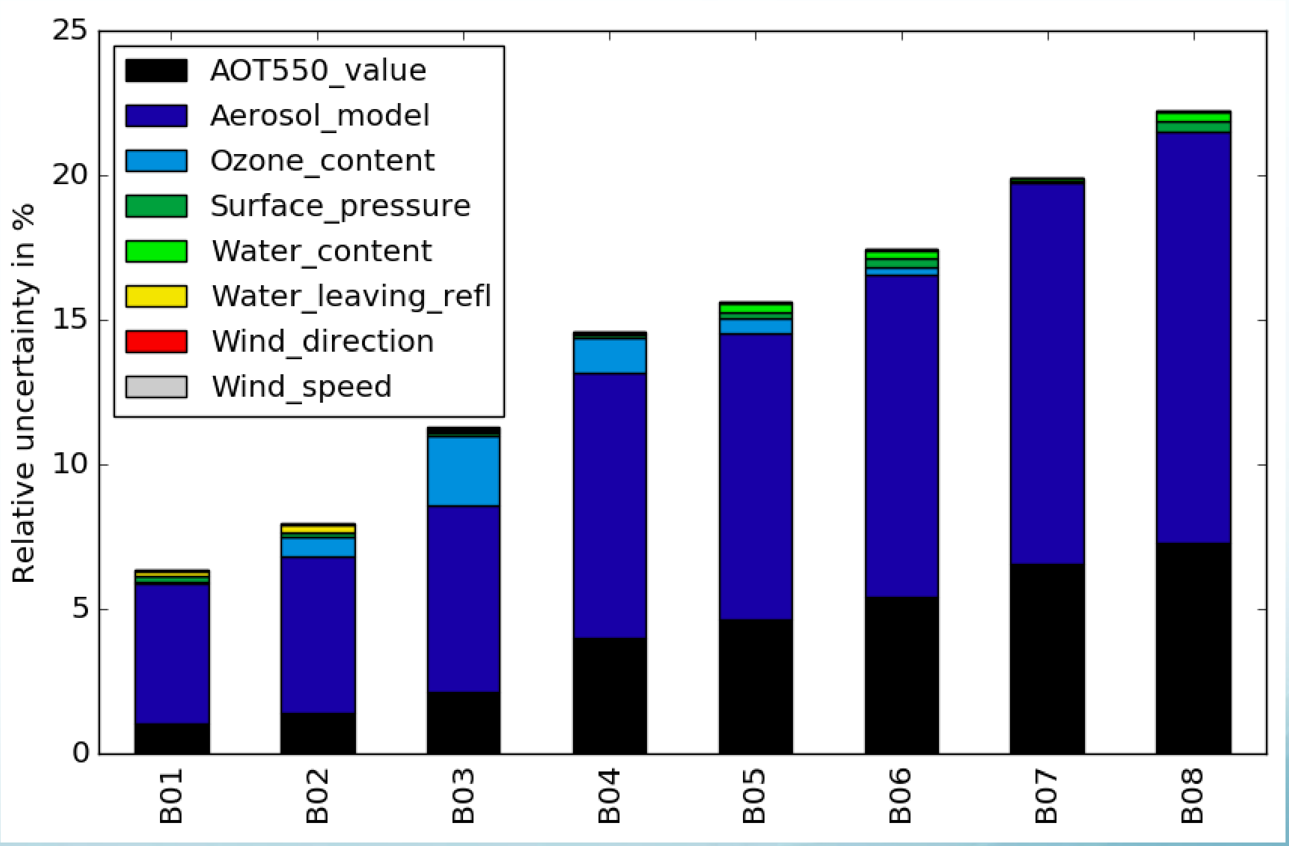


A case study: Venice (20/01/2016)



A case study: Venice (20/01/2016)

Variables	AERONET_ OC/S2
Time of acquisition	20/01/2016 At 10:32:50
Solar Zenith	θ'_s = 67.04°
Solar Azimuth	φ_s= 164.03°
Viewing Zenith	θ'_v = 0.41°
AOT(555)	0.136
Wind speed	4.378 m/s

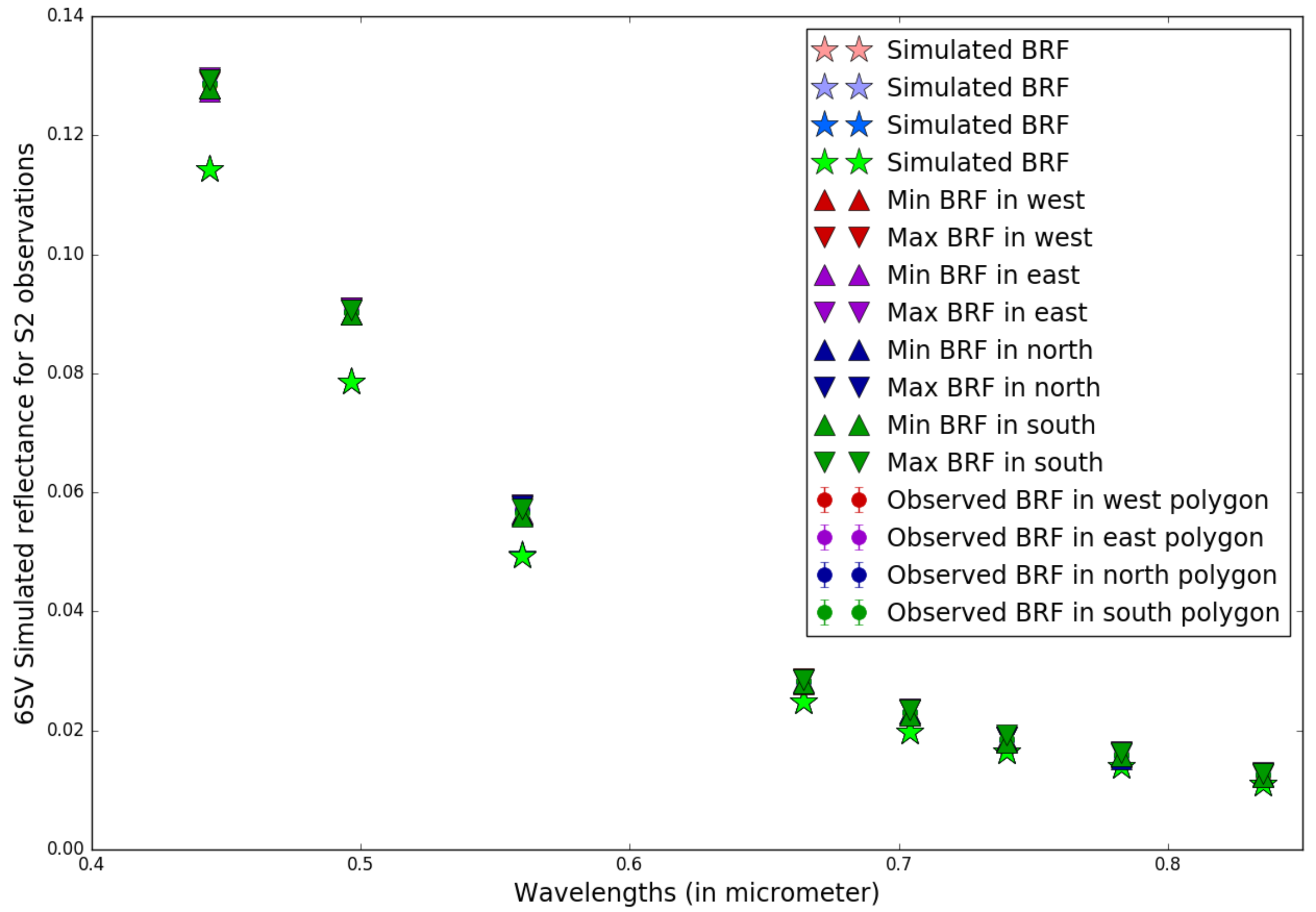


A case study: WaveCIS (24/01/2016)

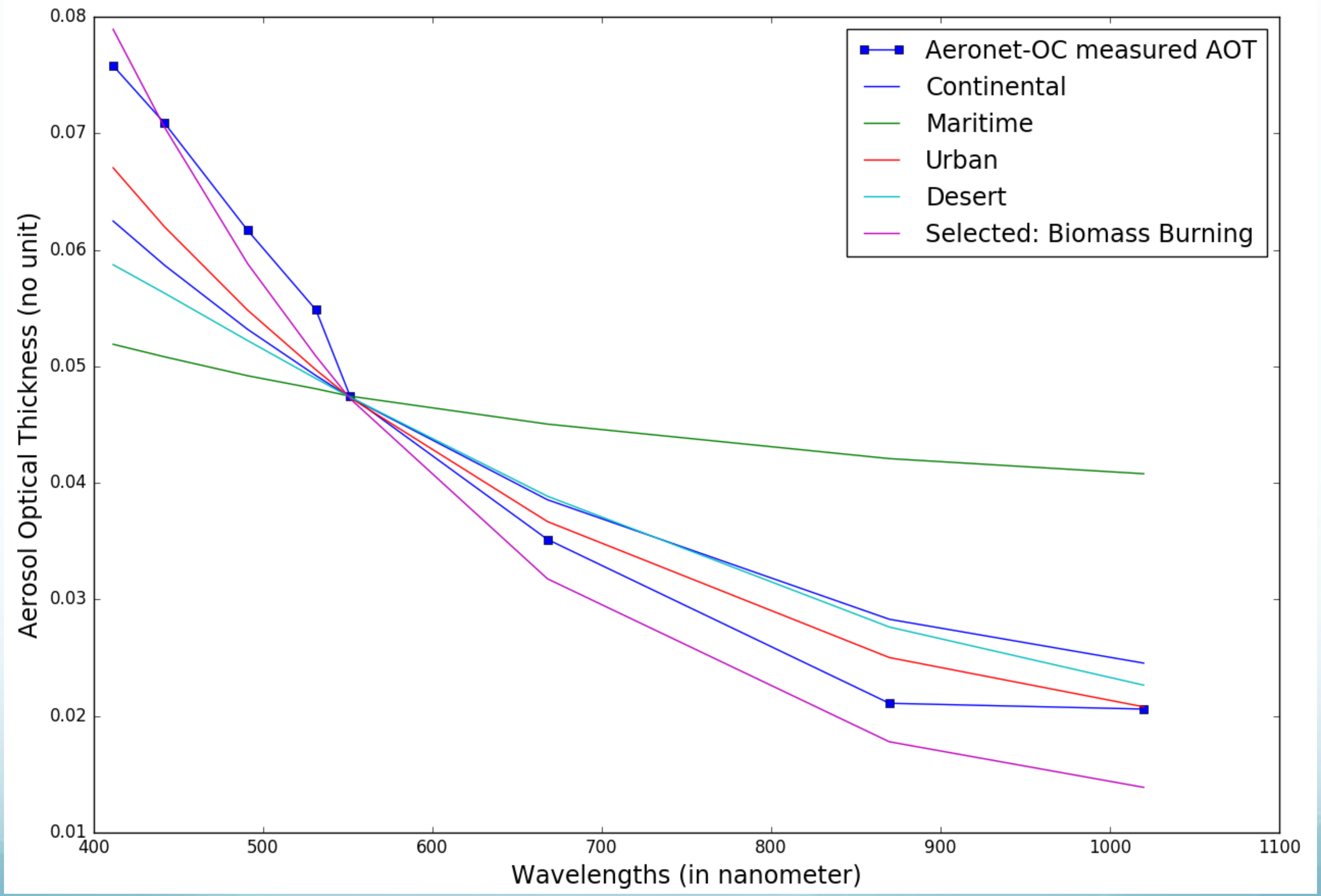
Variables	Sentinal-2/MSI
Time of acquisition	24/01/2016 At 16:49:56
Solar Zenith	θ_s = 52.6 °
Solar Azimuth	φ_s= 153.45°
Viewing Zenith	θ_v = 10.45°
Viewing Azimuth	φ_v= 18.94°

Variables	AERONET_OC
Time of acquisition	24/01/2016 At 16:47:47
Solar Zenith	θ'_s = 52.24°
Solar Azimuth	φ_s= 154.42°
Viewing Zenith	θ'_v = 40°
AOT(555)	0.040813
Wind speed	1.891505 m/s

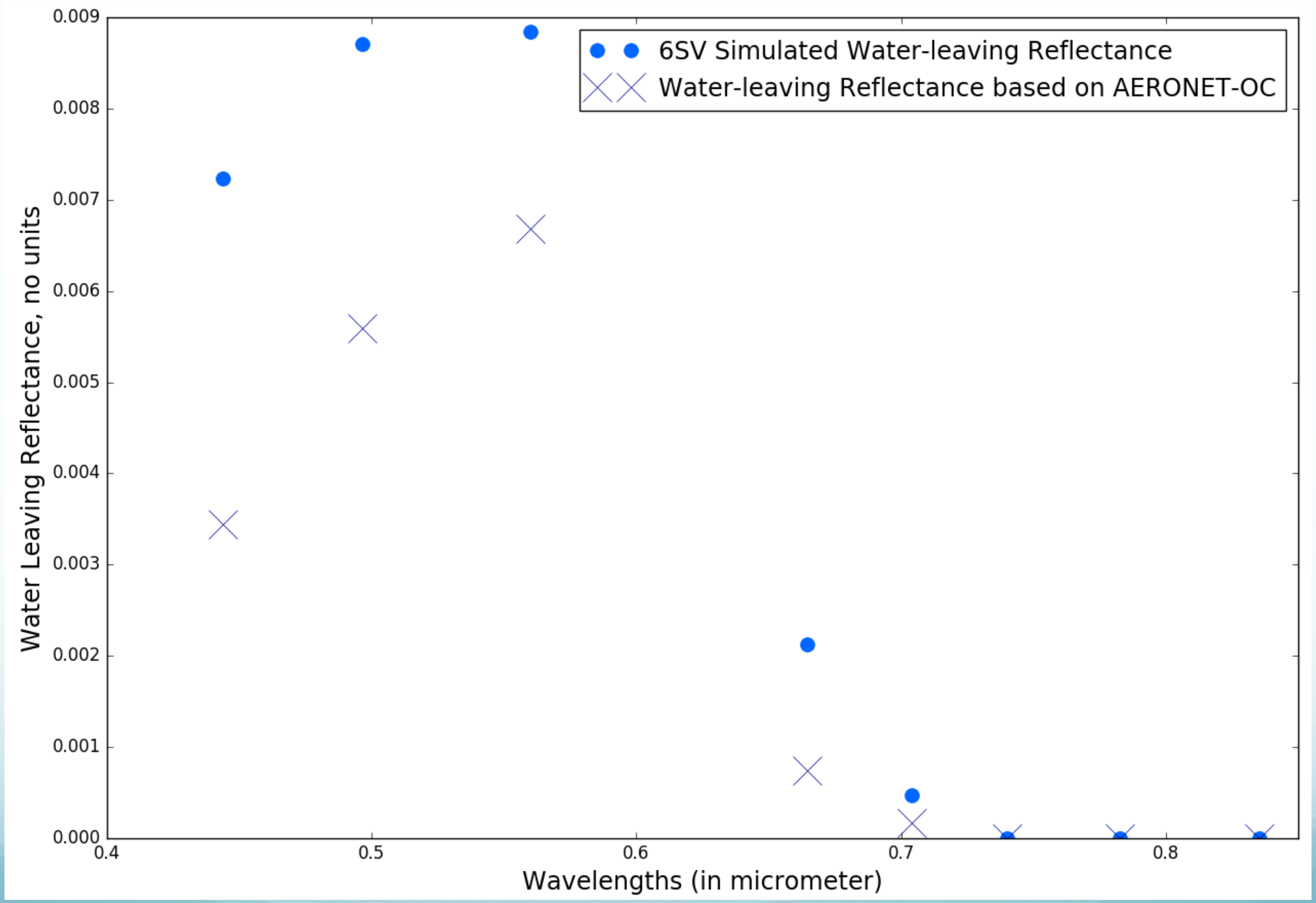
A case study: WaveCIS (24/01/2016)



A case study: WaveCIS

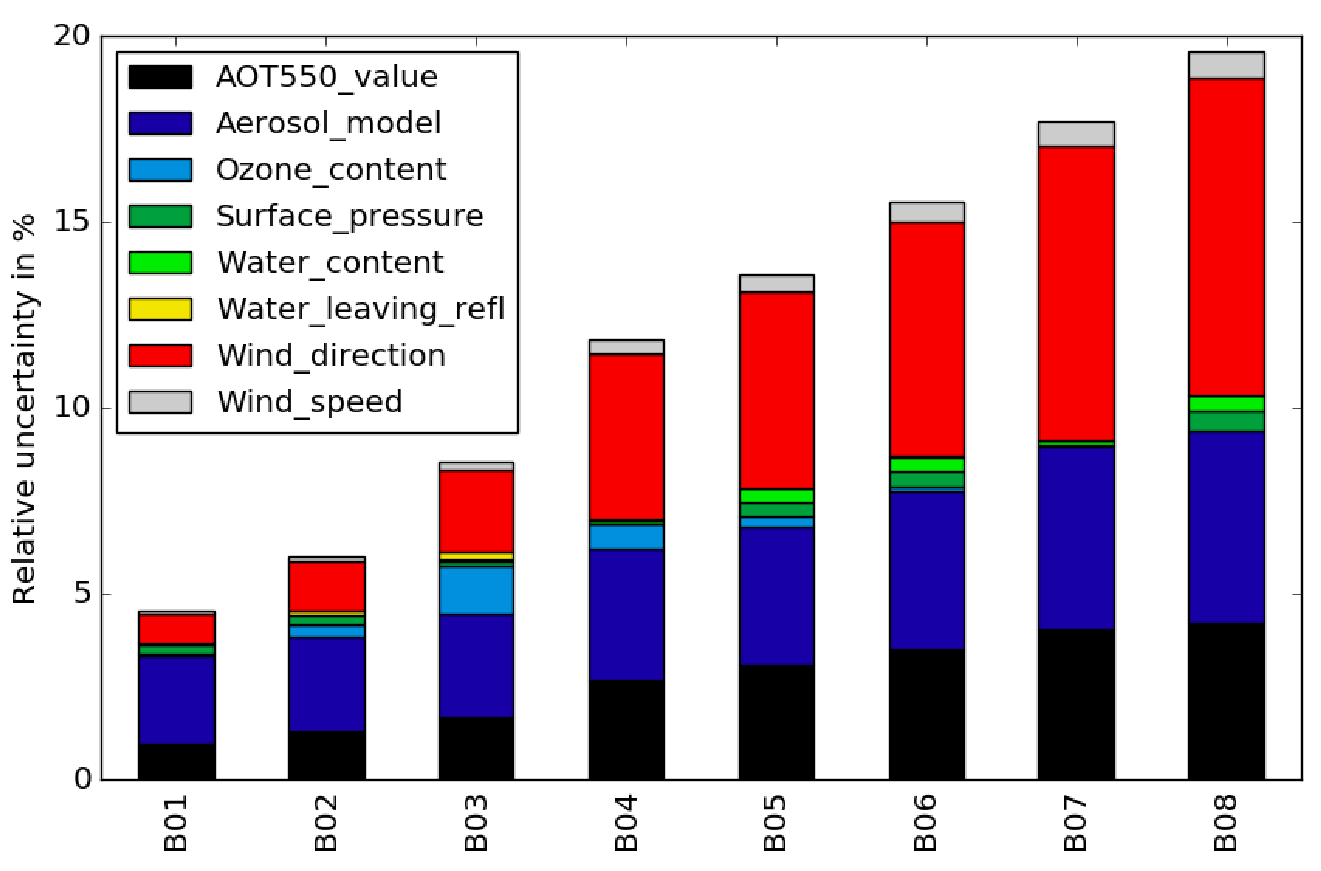


A case study: WaveCIS



A case study: WaveCIS

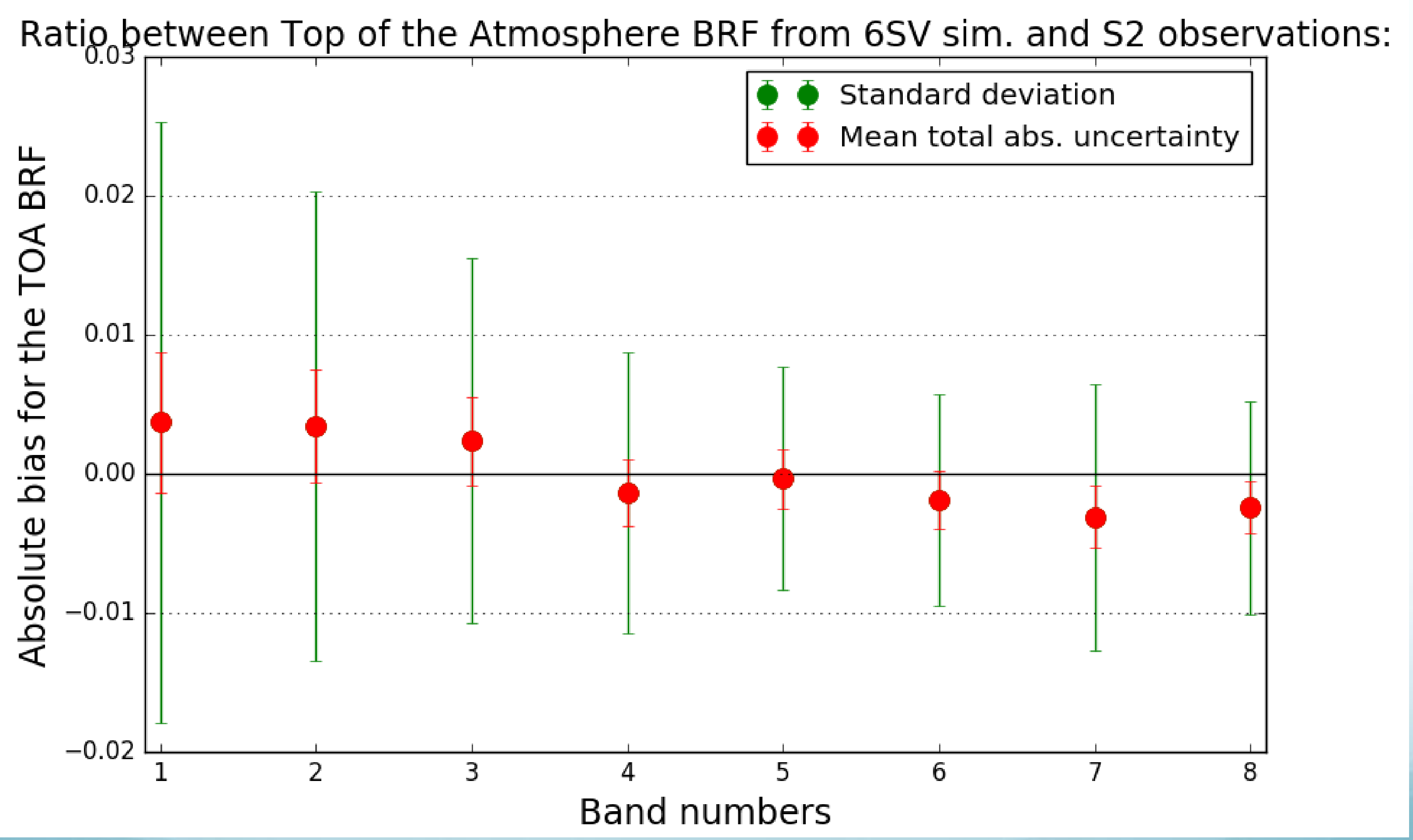
Variables	AERONET_OC/S2
Time of acquisition	24/01/2016 At 16:47:47
Solar Zenith	θ'_s = 52.60°
Solar Azimuth	φ_s= 153.45°
Viewing Zenith	θ'_v = 0.65°
AOT(555)	0.0408
Wind speed	1.891 m/s



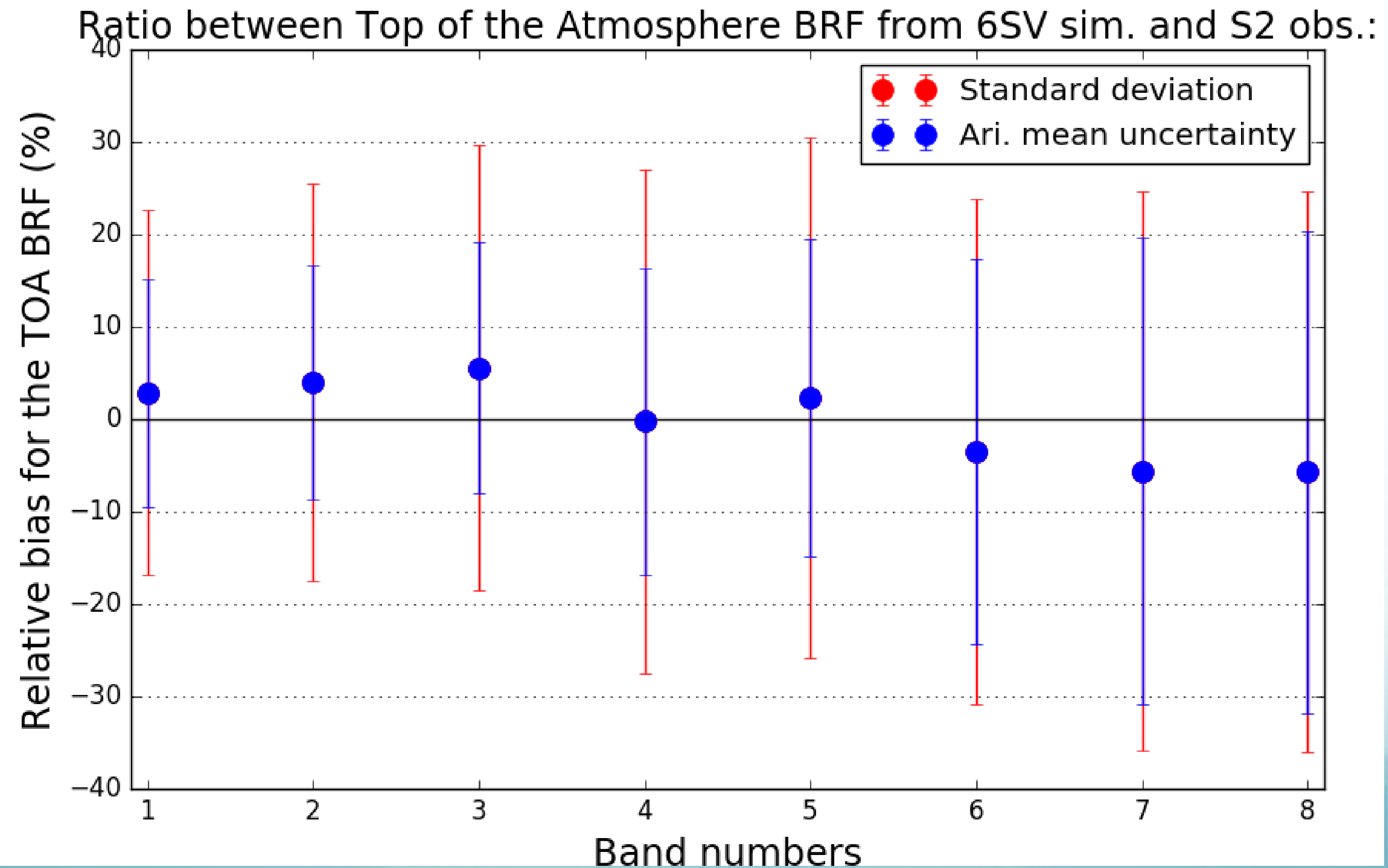
S-2 data: from 7/2015 to 9/2016

Stations	Cove Sea prism	Galata	Gloria	HLT	LISCO	MVCO	Palgrunden	Venice
S-2 measures	24	35	45	43	38	31	44	78
Readable	13	24	31	37	19	18	35	41
Used	2	0	0	3	0	0	4	10

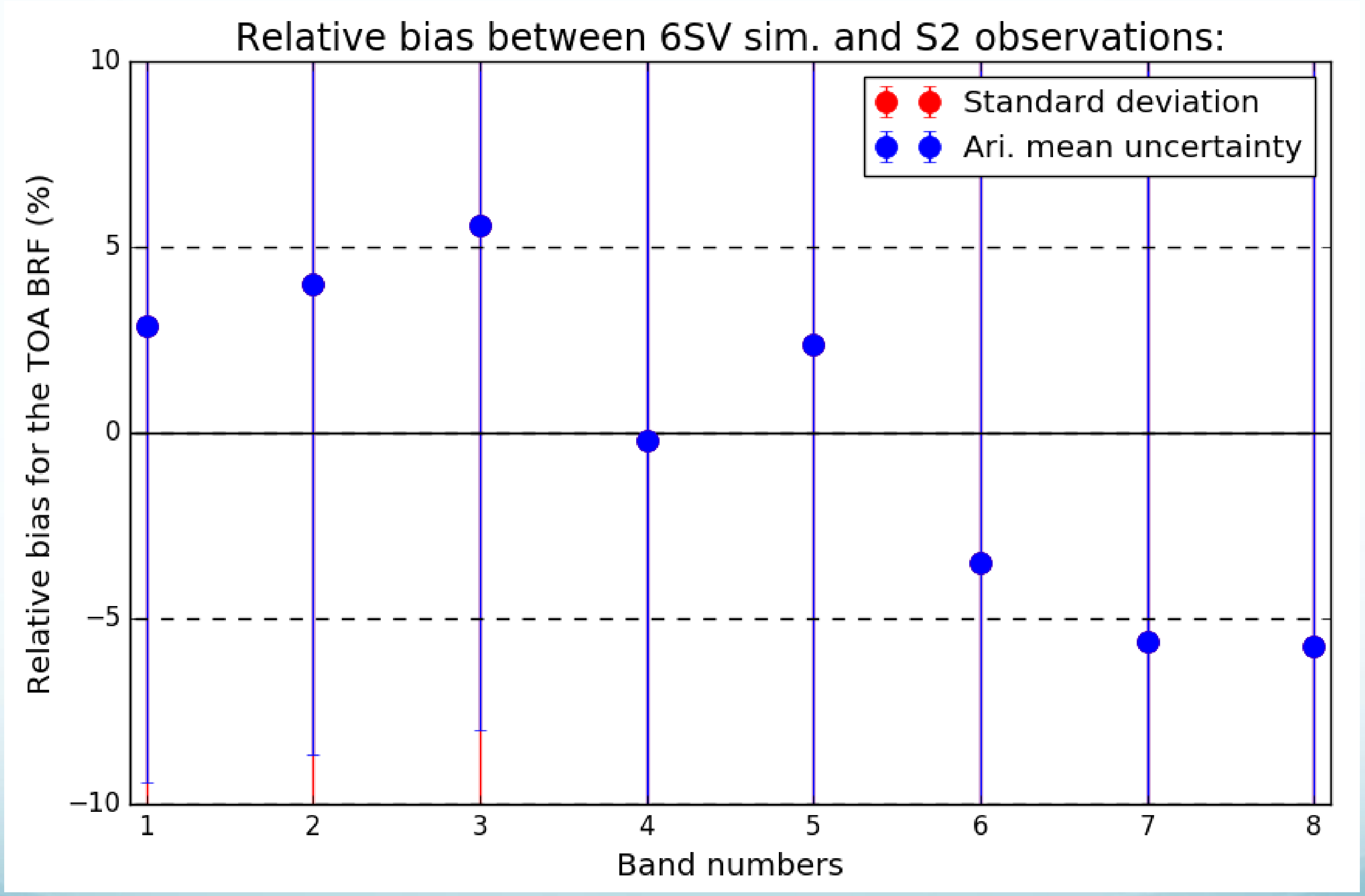
Overall mean absolute bias



Overall mean relative bias



Overall mean relative bias: zoom



Conclusions (1)

- Development of a method for the validation of the S2/MSI low radiance values, based on the use of AERONET-OC and 6SV RTM;
- The water-leaving reflectance is deduced from AERONET-OC total reflected radiance observation and injected in 6S;
- Uncertainty estimation validated against Monte-Carlo simulations.

Conclusions (2)

- The bias between MSI/6SV is within the 5% requirement, knowing that :
  - comparisons of 6SV with LibRadTran show that it is slightly too bright due to missing molecules (O4, NO2);
  - There is room to improve the aerosol type characterization (single scattering albedo and phase function) and spectral interpolation between AERONET-OC and MSI band.

Thanks for your attention