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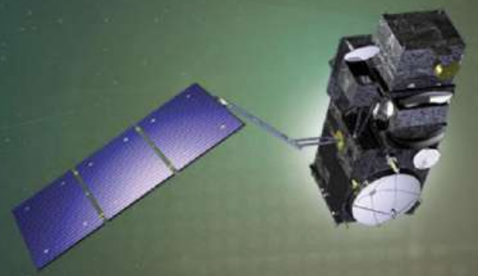

OPT-MPC
Copernicus Sentinel Optical Mission Performance Cluster

7th Sentinel-3 Validation Team Meeting 2022

18-20 October 2022 | ESA-ESRIN | Frascati (Rm), Italy

Analysis of global cloud shadow occurrence in OLCI FR products and estimation of impact on current OLCI FR L2 products

Carsten Brockmann, Jan Wevers, Thomas Storm

Brockmann Consult GmbH, 21029 Hamburg, Germany

Brockmann Consult GmbH

Cloud and Cloud Shadows

Z. Li et al. ISPRS Journal of Photogrammetry and Remote Sensing 188 (2022) 89–108

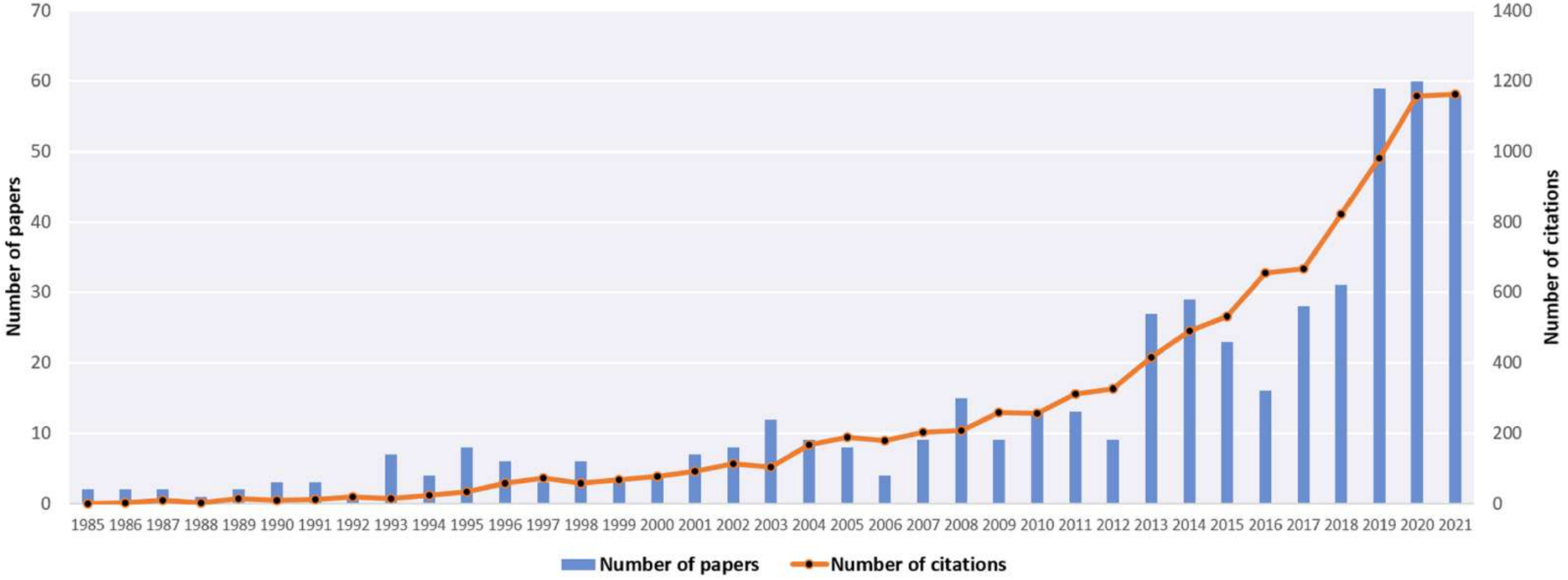

Fig. 2. The number of papers and citations on cloud and cloud shadow detection, 1985–2021.

From: Cloud and cloud shadow detection for optical satellite imagery: Features, algorithms, validation, and prospects. Li et al 2022

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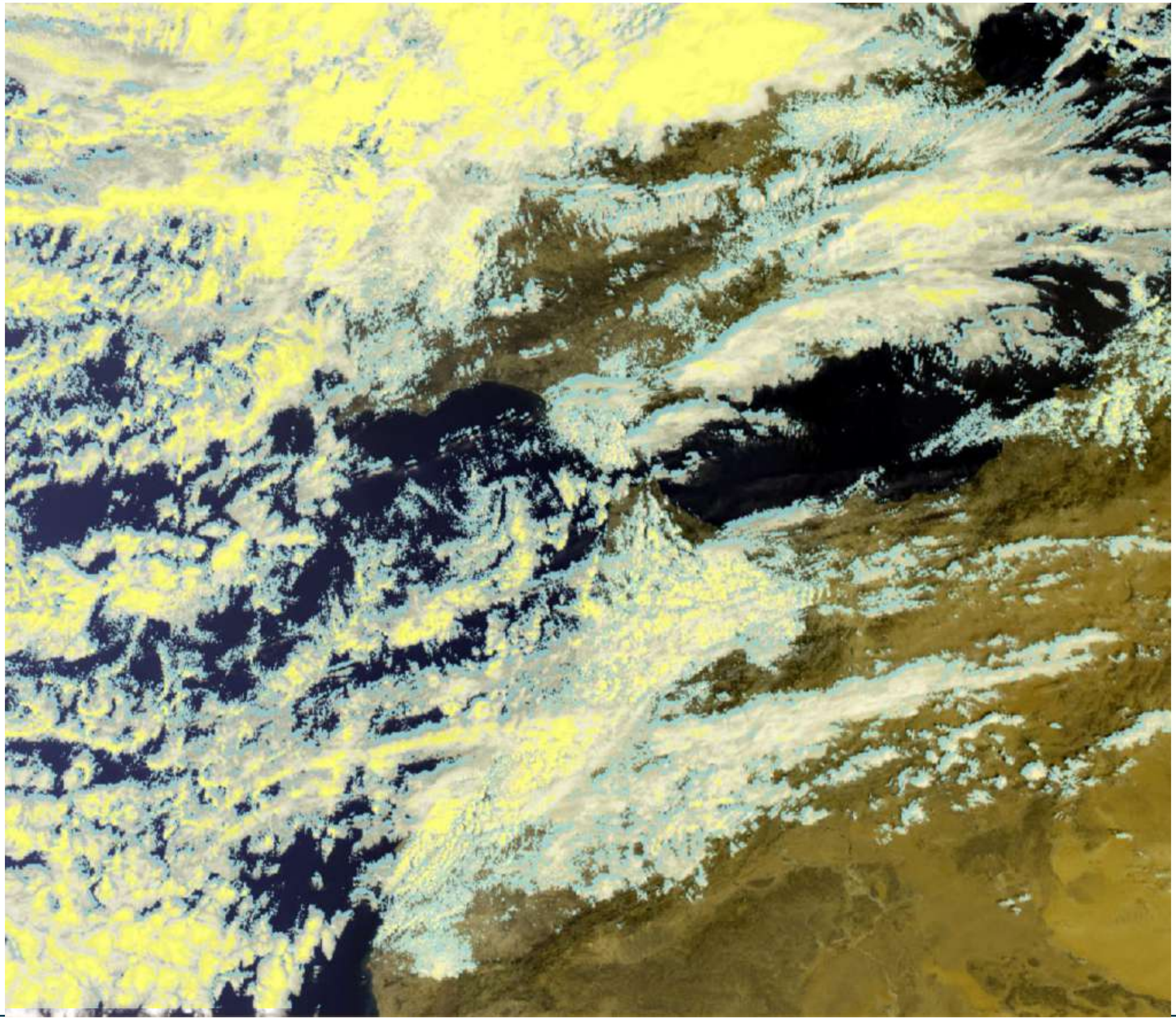
OLCI-A 29.09.2022



Cloud flags
Idepix Cloud Shadow flag

(Shadow flag integration into OLCI L2 processing is ongoing and algorihm transfer to SLSTR started)

Relevance at global scale

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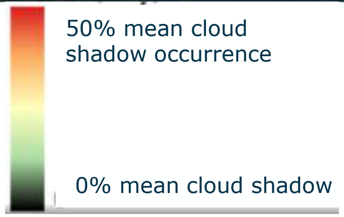
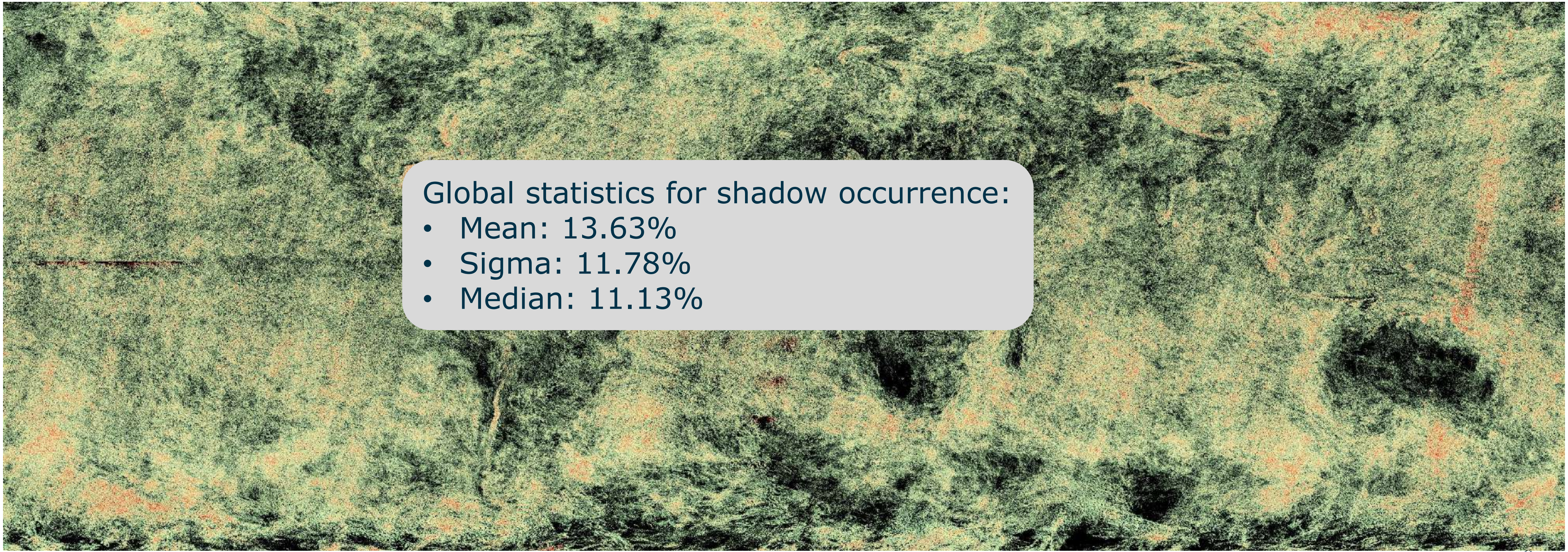
Estimation of global mean annual cloud shadow occurrence for the year 2020

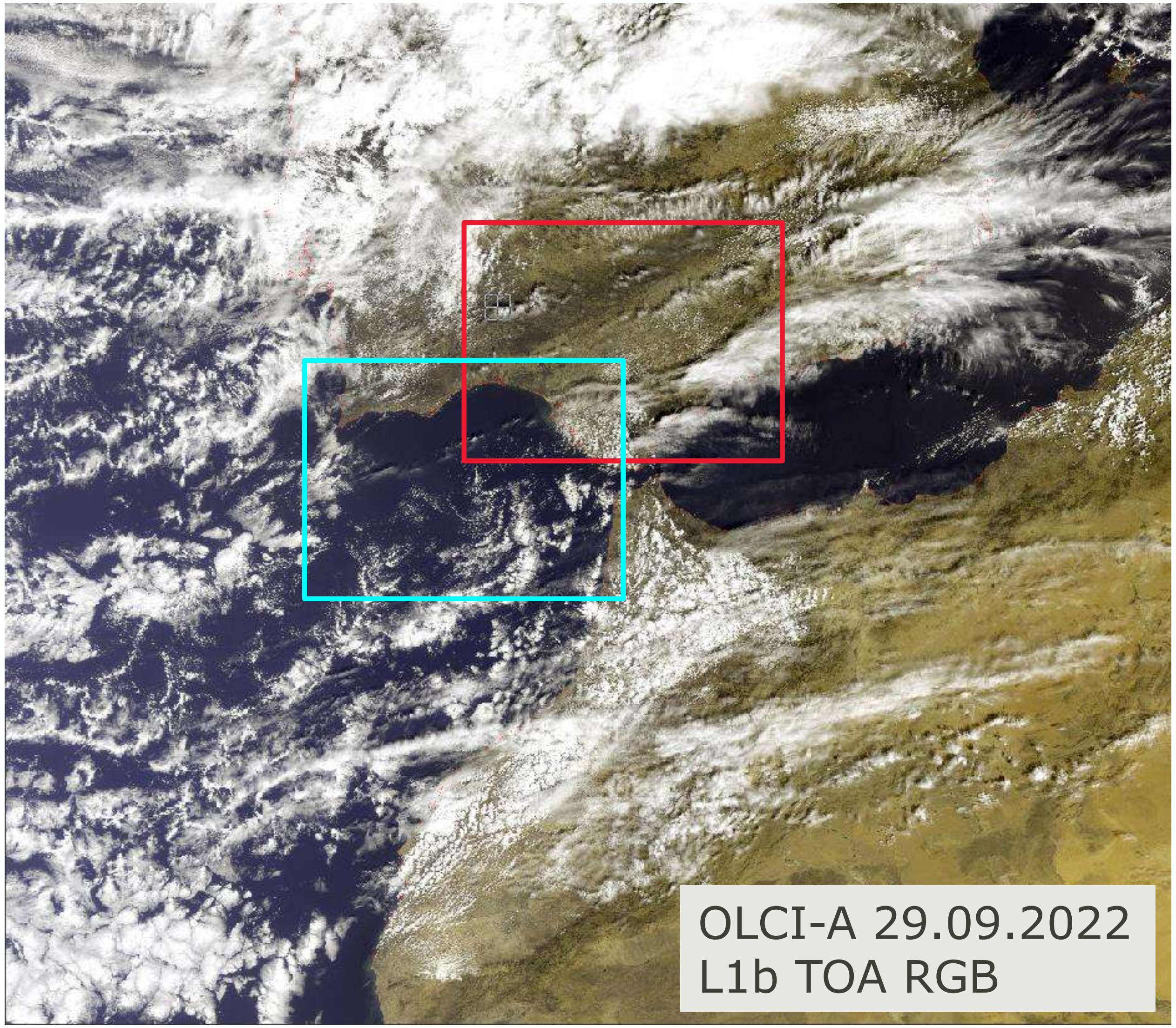


- Based on OLCI IdePix cloud shadow for all products acquired on the 15th of each month of 2020



Global statistics for shadow occurrence:
- Mean: 13.63%
- Sigma: 11.78%
- Median: 11.13%

TOA Radiance



Level 2 Land Products: OLCI and SYN

Surface Reflectance

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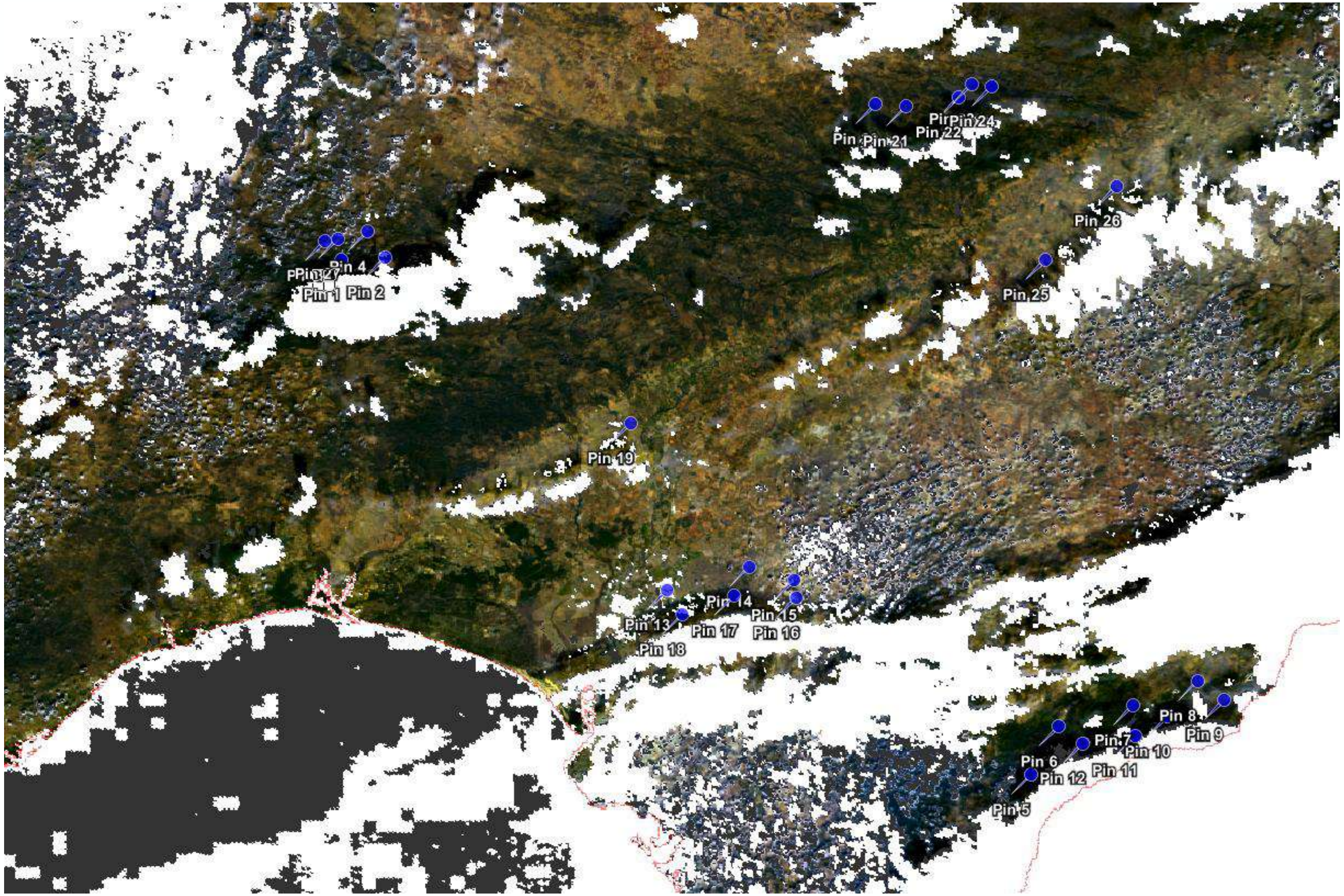

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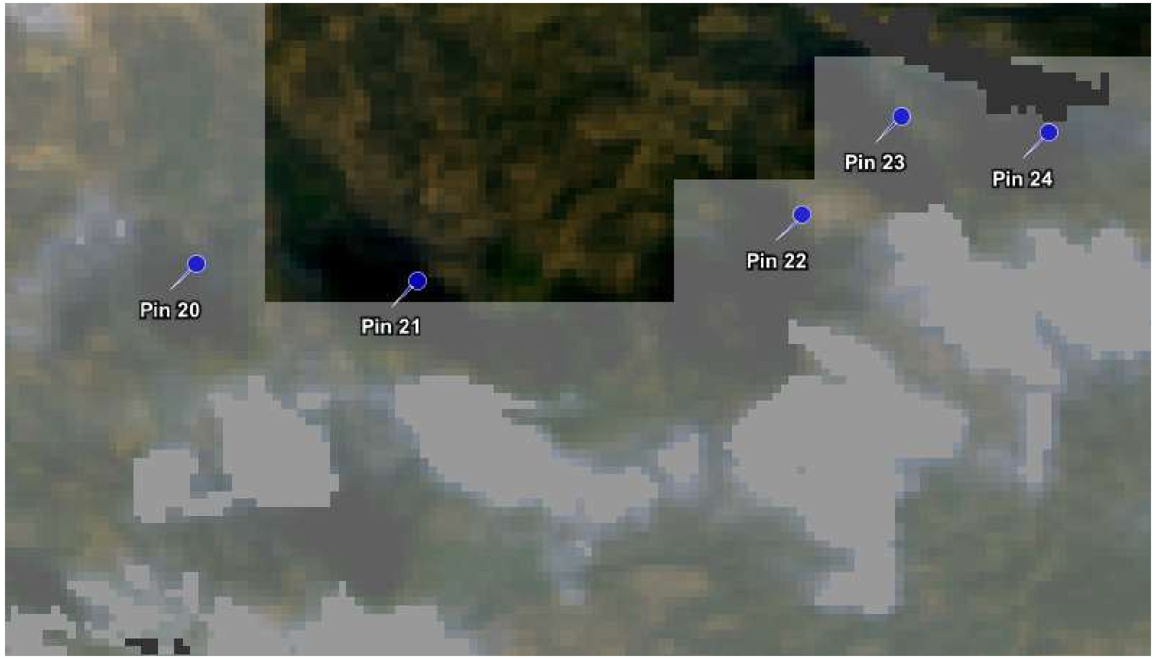
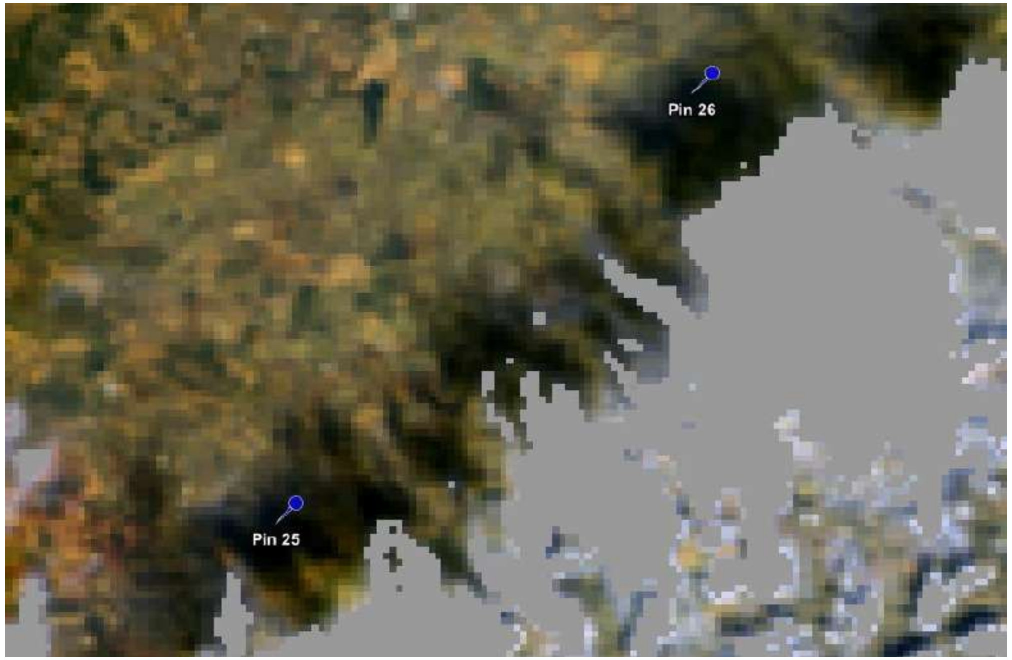
Surface Reflectance

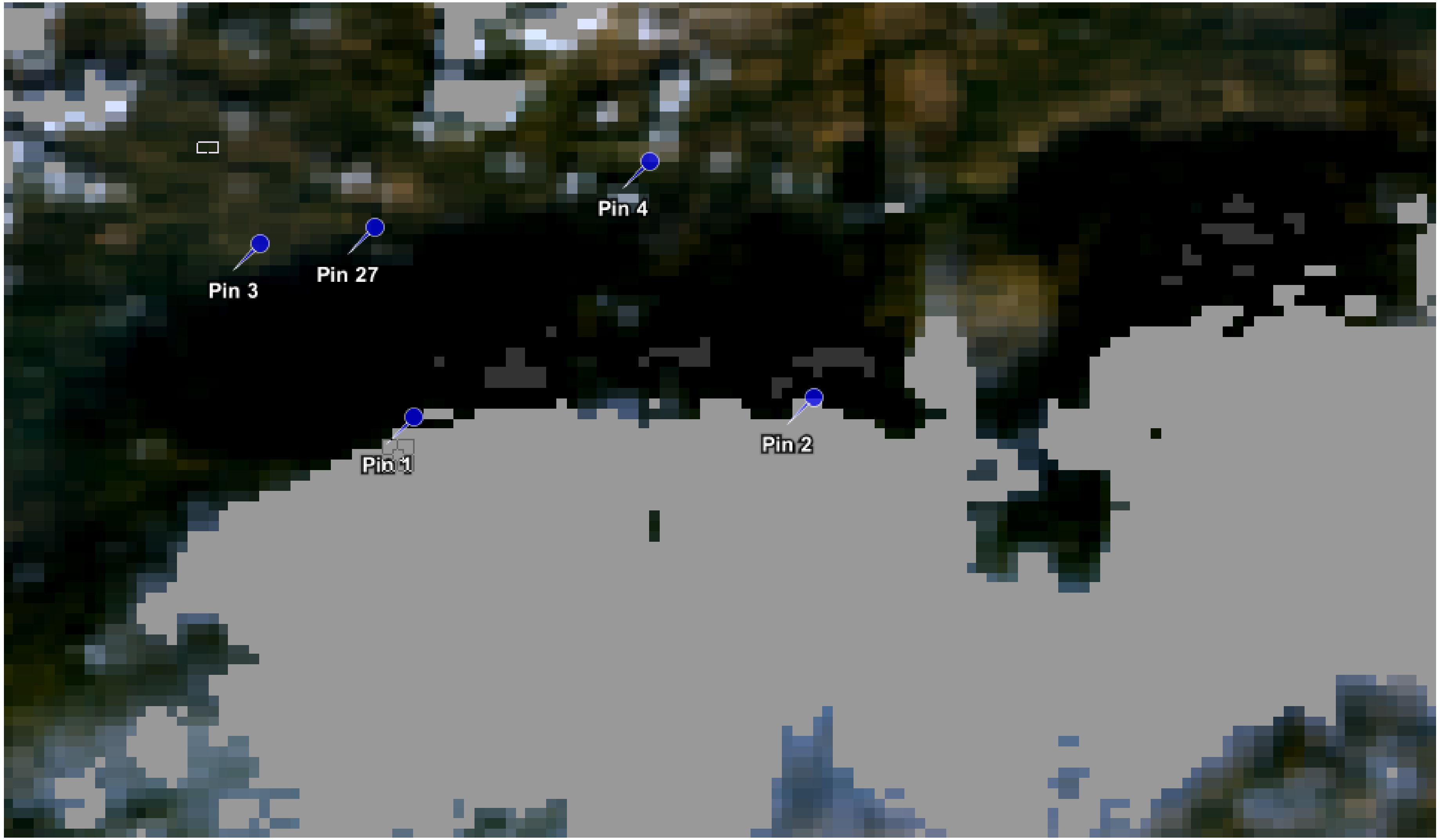




grey mask = SYN cloud

light grey = SYN partly cloudy

Surface Reflectance



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SDR Band02, 412nm

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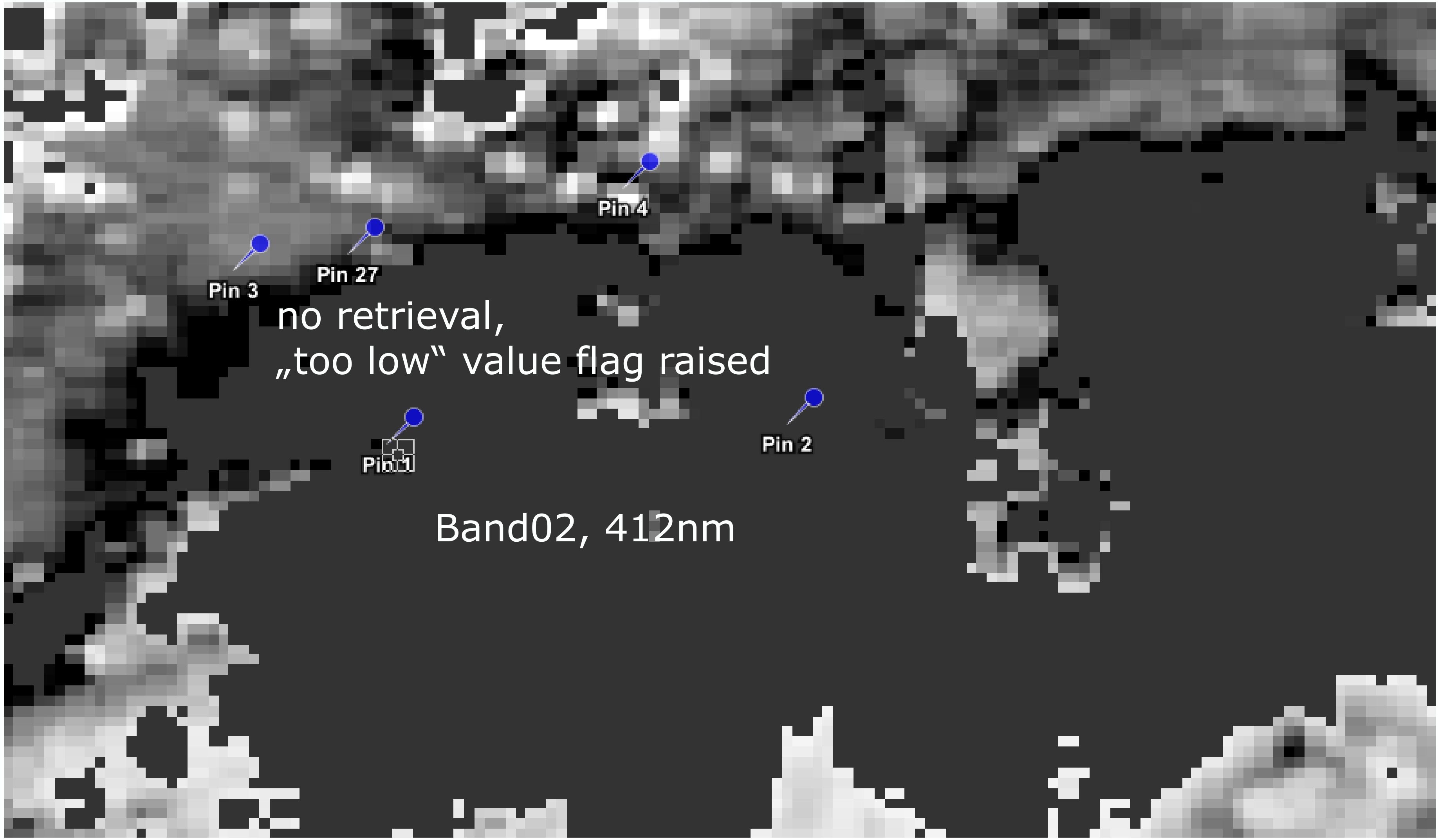

SDR Band08, 665nm

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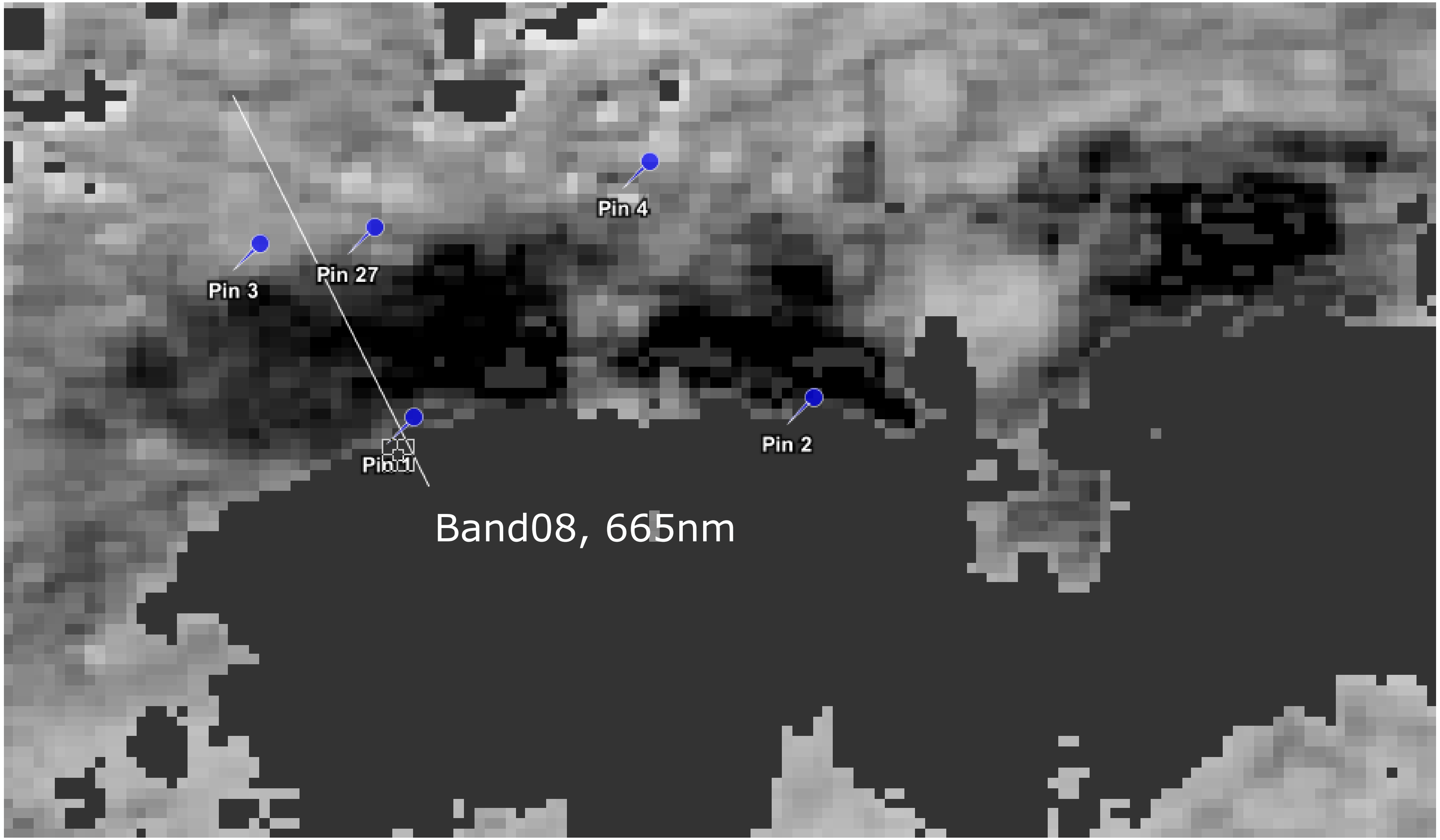

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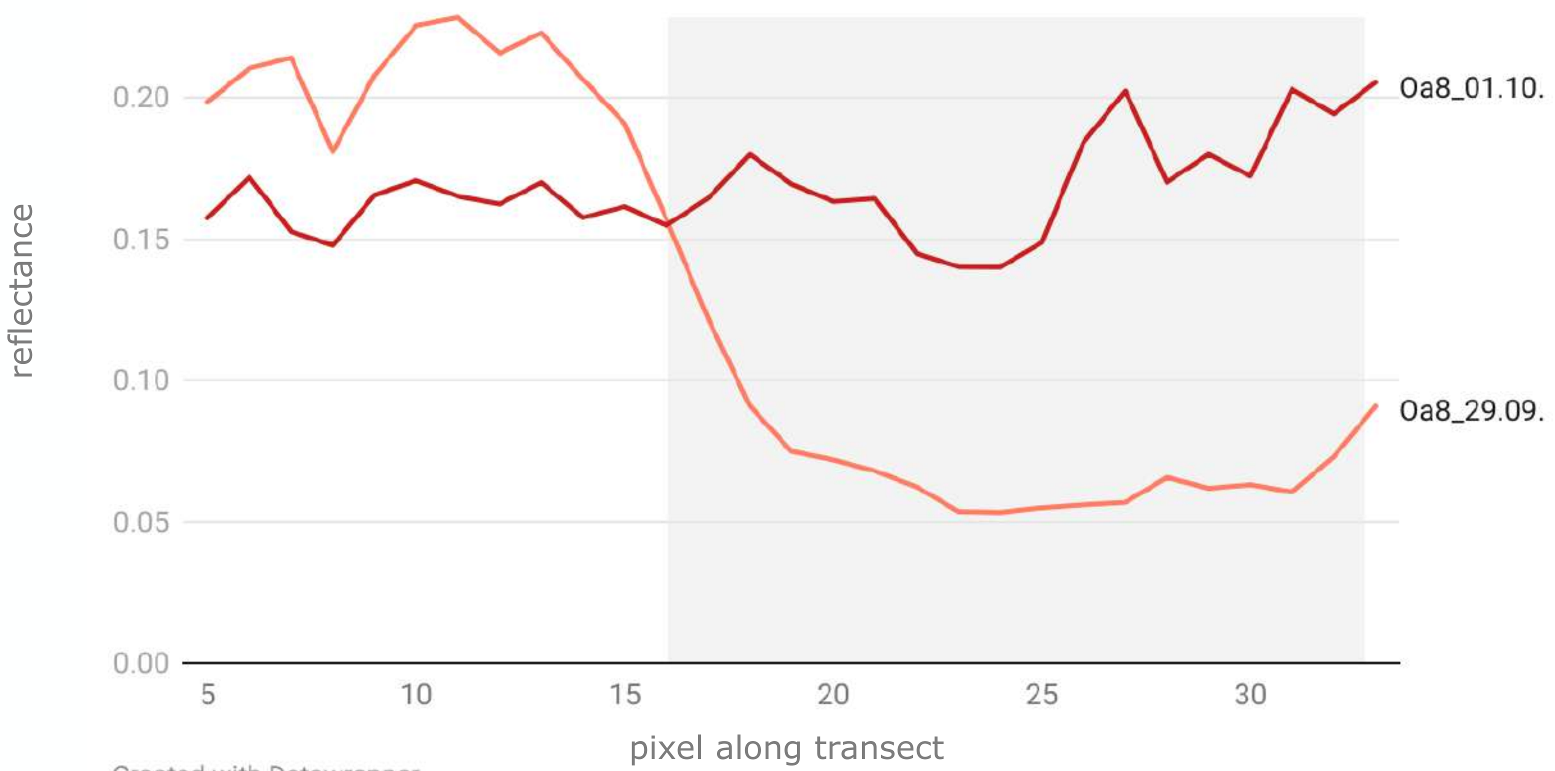
SDR Oa08 @ 665nm

29.09. cloud shadow, 01.10. clear



Created with Datawrapper

SDR Band08 unc, 665nm

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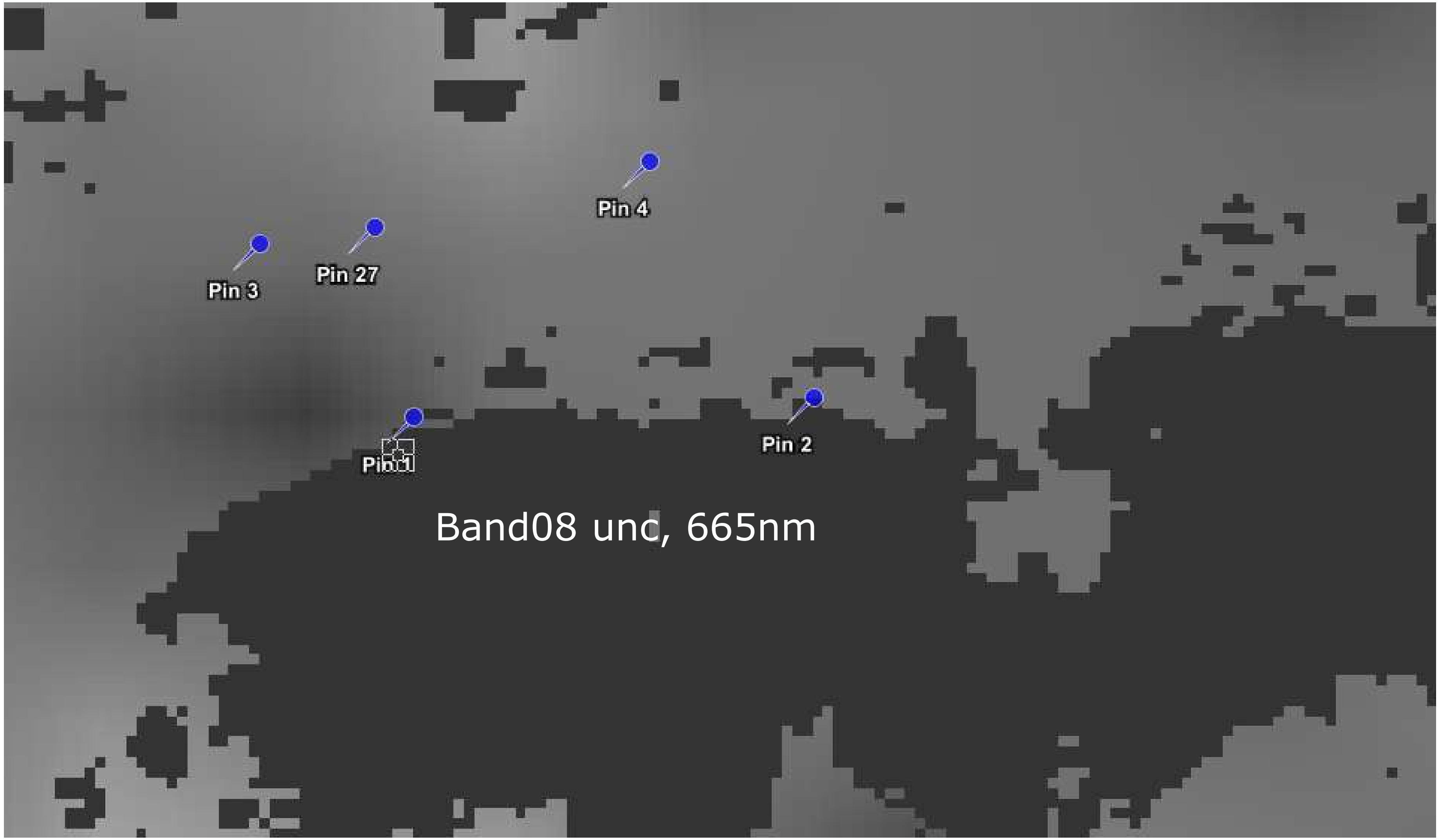

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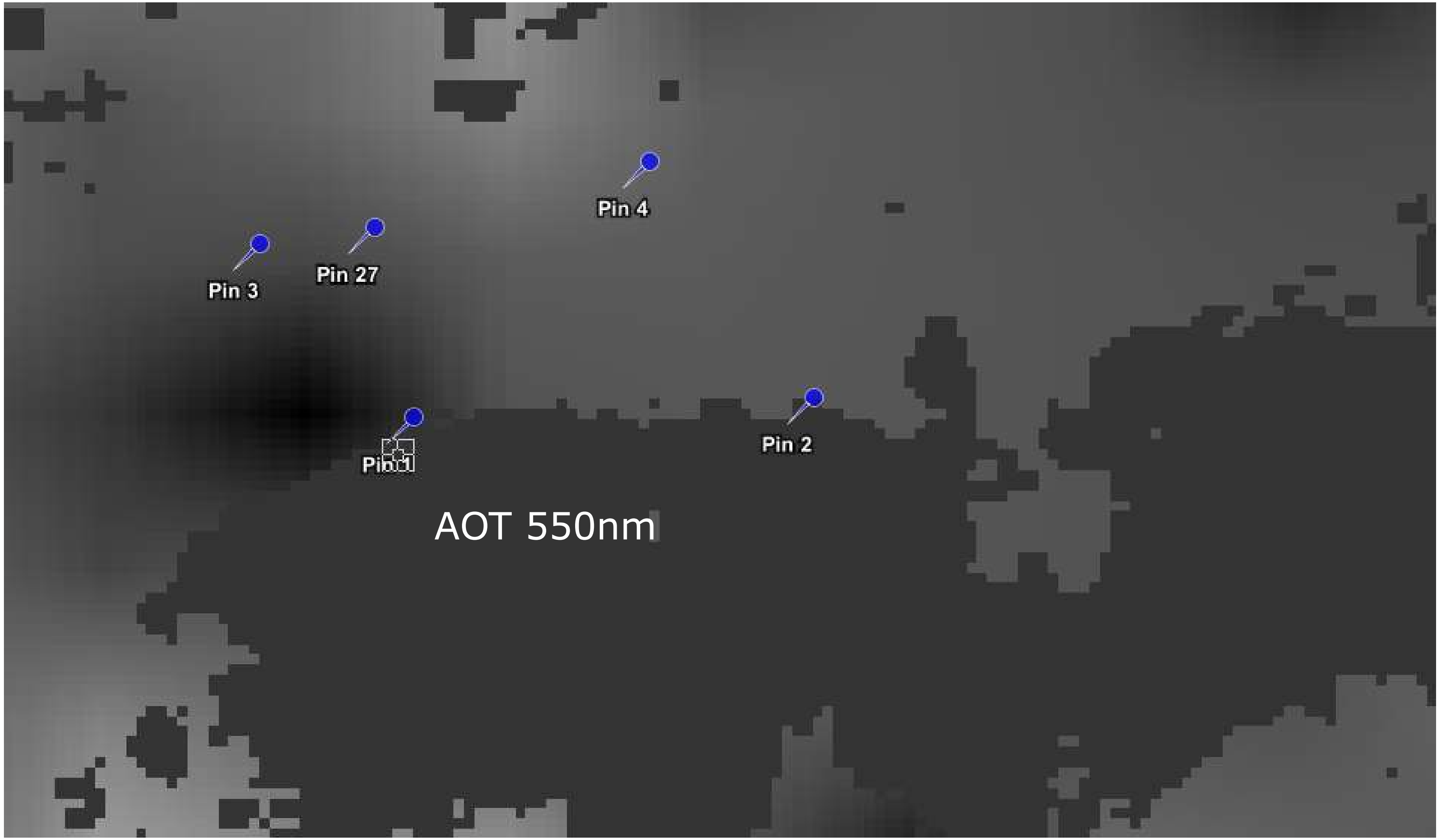
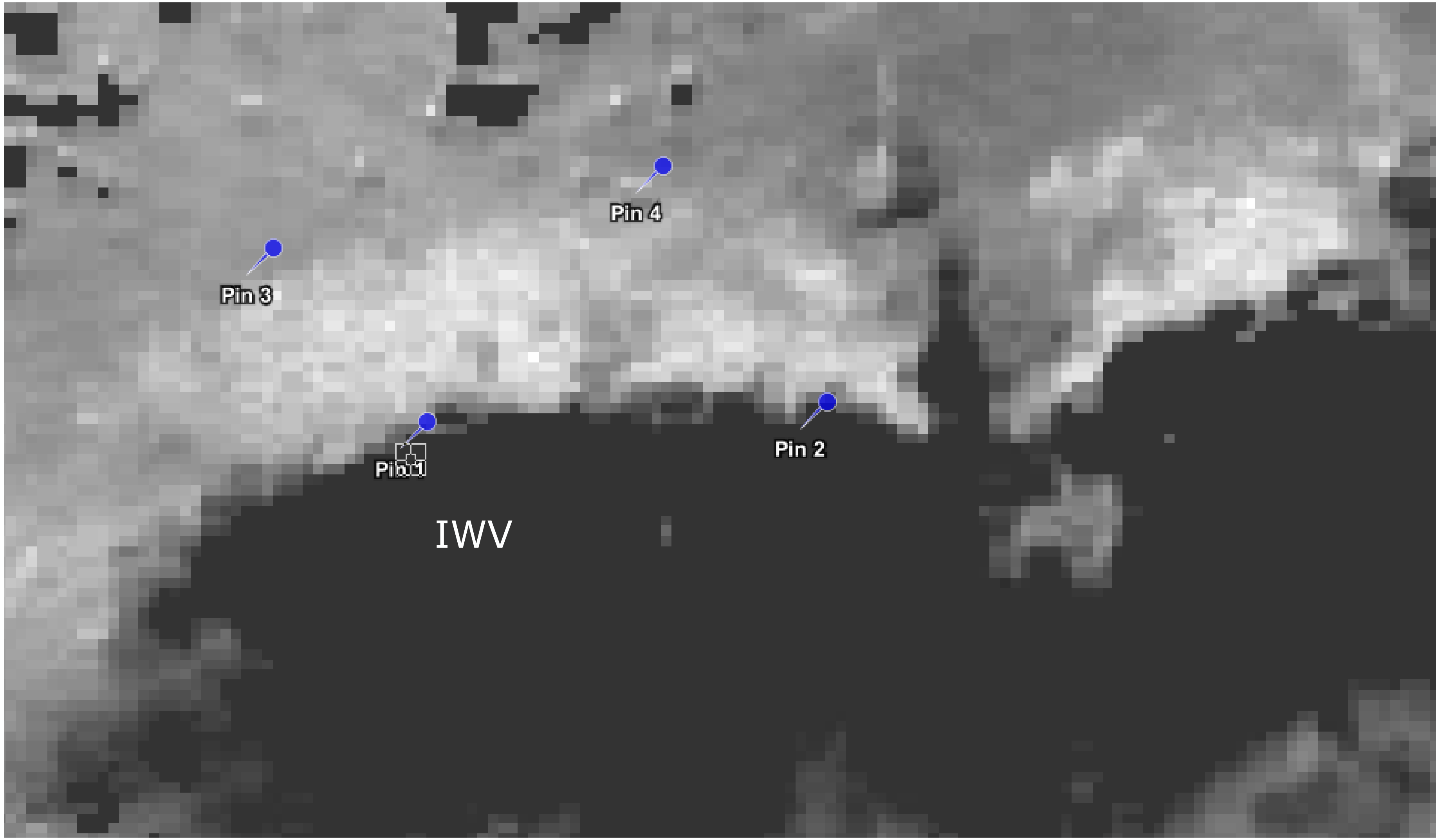
AOT 550nm



Water Vapour



GiFAPAR

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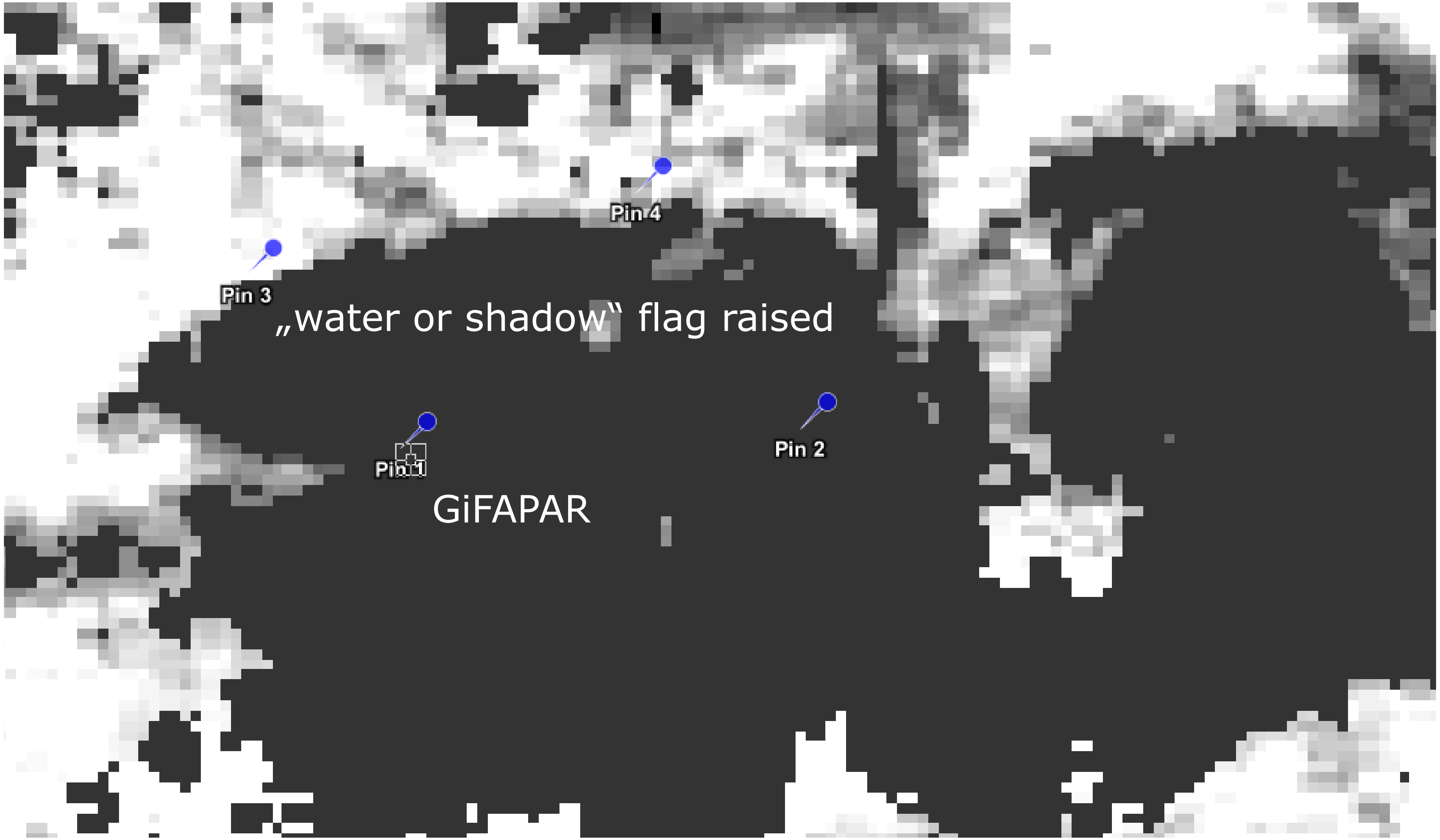

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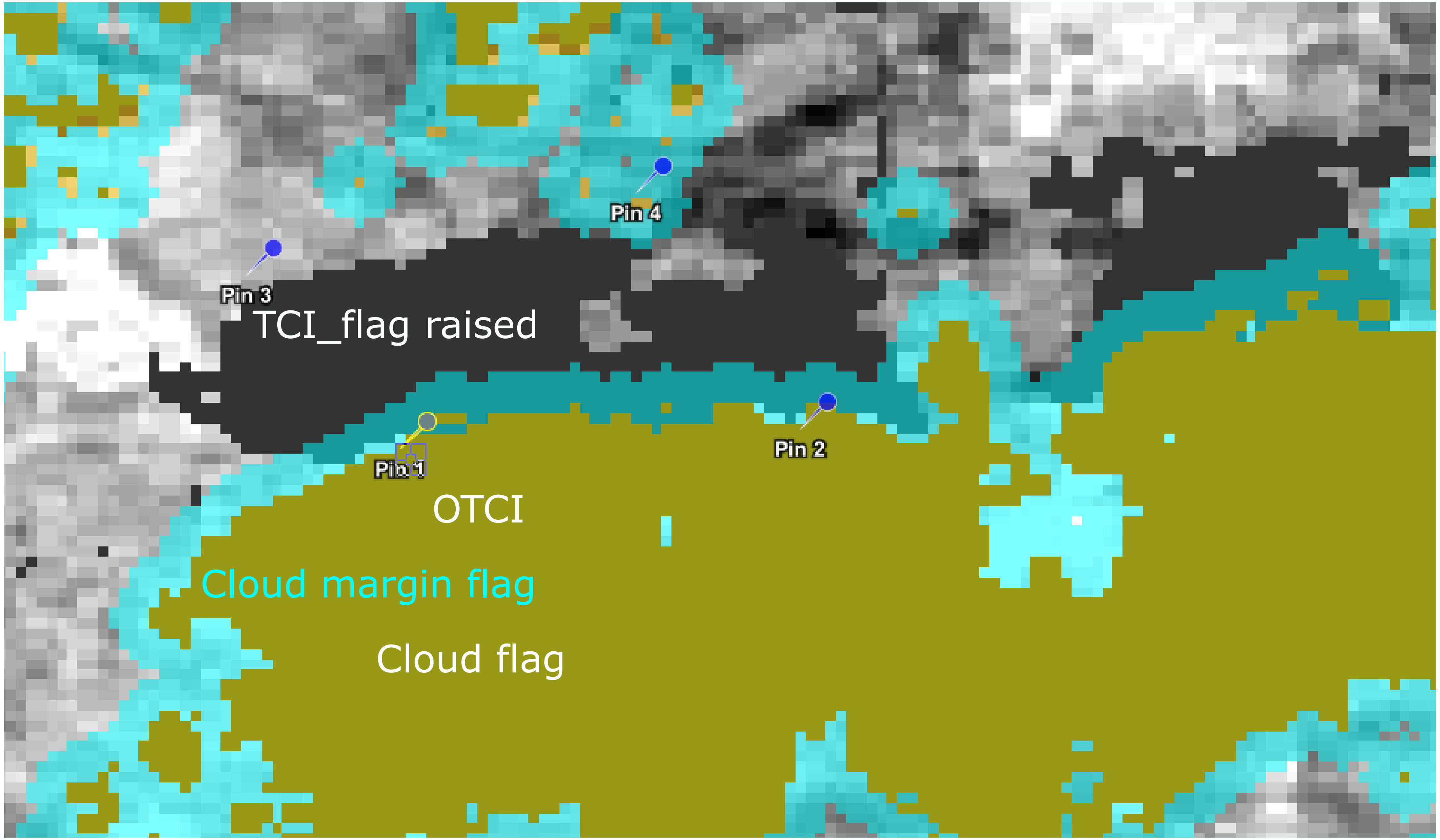
OTCI


Pin 4
Pin 3
TCI_flag raised
Pin 1
Pin 2
OTCI
Cloud margin flag
Cloud flag

Level 2 Water Products

Water Leaving Reflectances

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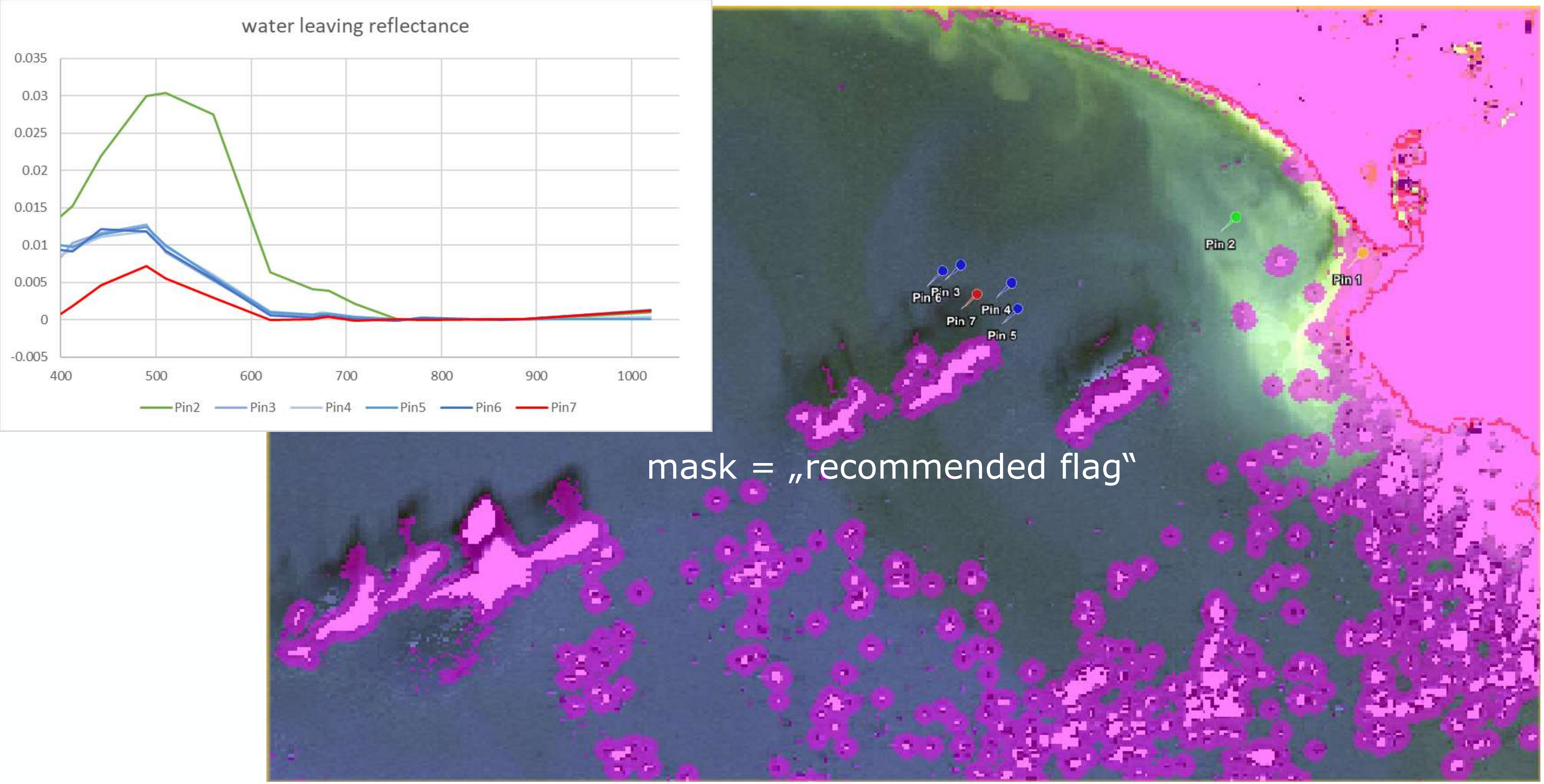

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Water Leaving Reflectances

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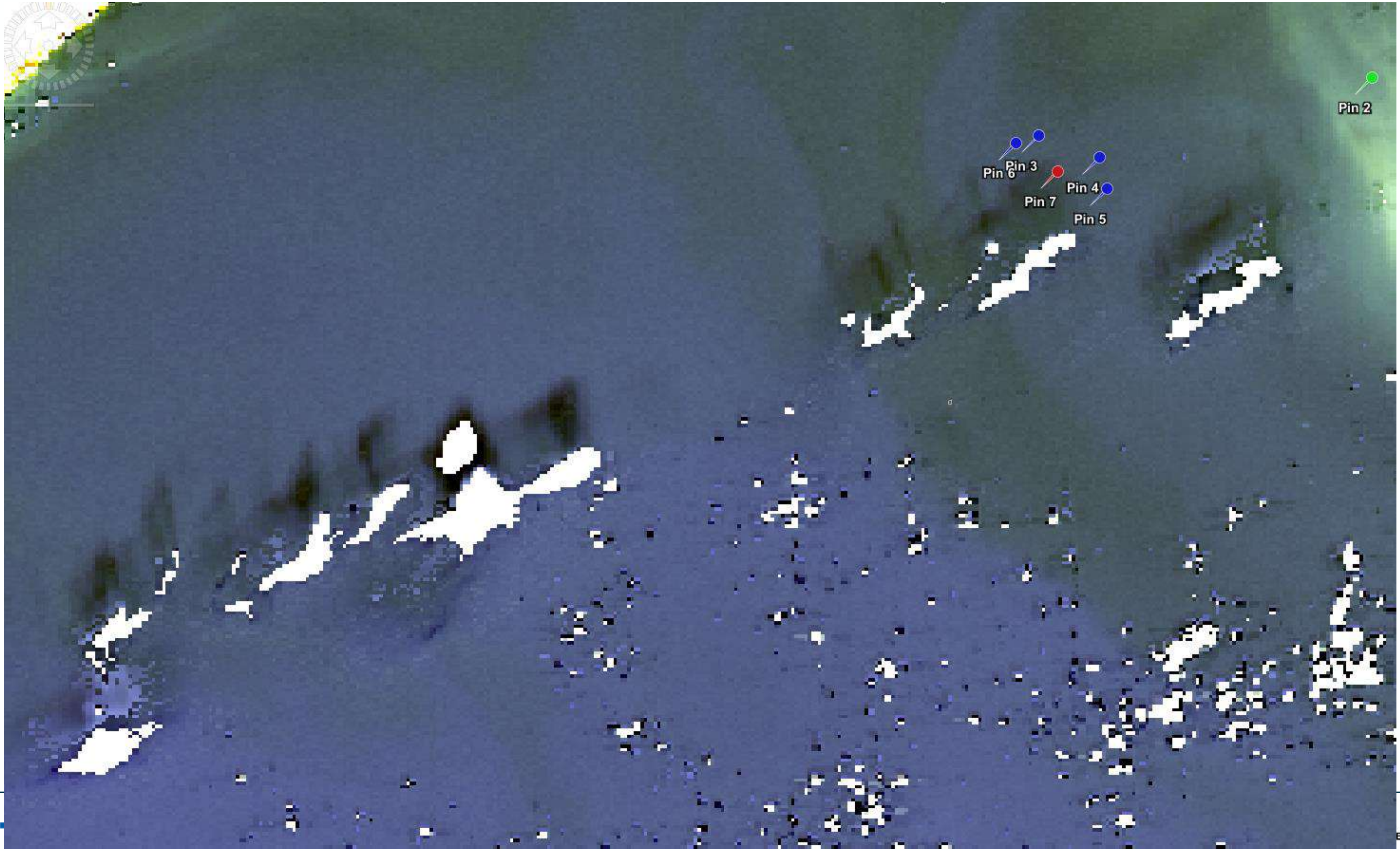
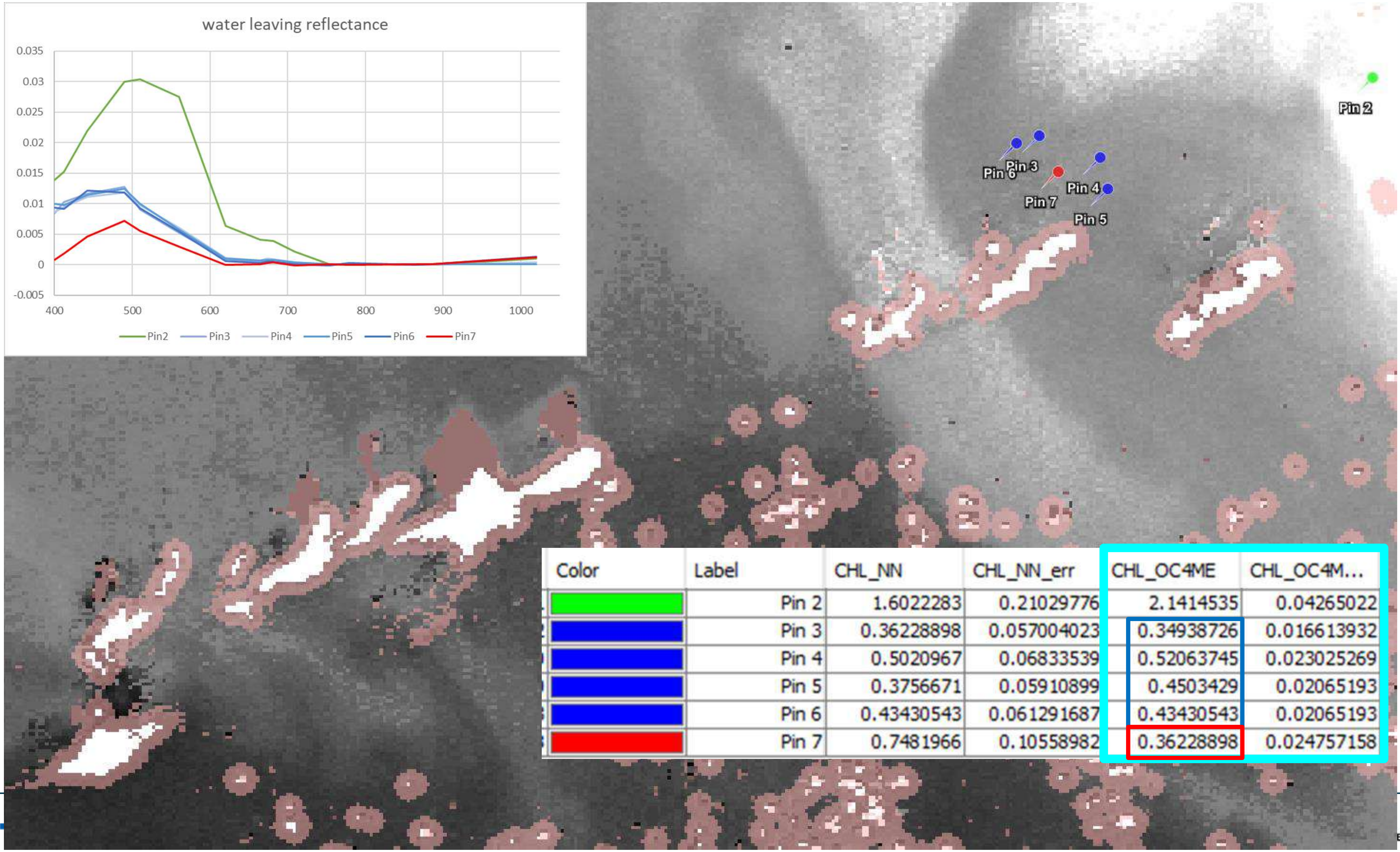


CHL-a Concentration



Color	Label	CHL_NN	CHL_NN_err	CHL_OC4ME	CHL_OC4M...
	Pin 2	1.6022283	0.21029776	2.1414535	0.04265022
	Pin 3	0.36228898	0.057004023	0.34938726	0.016613932
	Pin 4	0.5020967	0.06833539	0.52063745	0.023025269
	Pin 5	0.3756671	0.05910899	0.4503429	0.02065193
	Pin 6	0.43430543	0.061291687	0.43430543	0.02065193
	Pin 7	0.7481966	0.10558982	0.36228898	0.024757158

Summary OLCI & SYN

Parameter	Sensitivity to Cloud Shadow	Captured by L2 specific flag	Comment
Land			
SDR	High	No	Cloud shadow effect has a spectral profile
AOT	Medium	No	
Angstrøm exp.			Not tested
IWV	High	No	
GIFAPAR	Unknown due to flag	Yes	
OTCI	Medium	partly	
Water			
rho_w	High	No	
AOT	High	Partly	
Angstrom			Not tested
IWV	High	No	
CHL_ME	Low	No	
CHL_NN, TSM, YS	High	No	
Kd490	High	Partly	
PAR			Not tested

AC in the Shadow

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- Radiative Transfer background (simplistic):

$$L_{Toa} = \rho_{surf} * \frac{\delta(E_{direct} + E_{diffuse})}{\pi} + L_{path}$$

$$\rho_{surf} = \frac{\pi(L_{Toa} - L_{path})}{\delta(E_{direct} + E_{diffuse})}$$

- In principle, there is no fundamental issue to perform an AC under the assumption $E_{direct} = 0$
- Challenges:
    - E_{direct} contributes most energy to the solar radiation flux at surface, typically 80% or more (Richter 2005)
    - Due to multiple scattering, also other terms in the RT equation change
    - ➔ the TOA radiance becomes significantly lower, maybe reaching detection limit, relative importance of noise, amplification of errors in AC …
    - ➔ the effect has a spectral dependency and is not just an additive term

- De-shadowing approaches have been developed for land applications but not yet for water applications

Cloud Shadow Spectral Shape

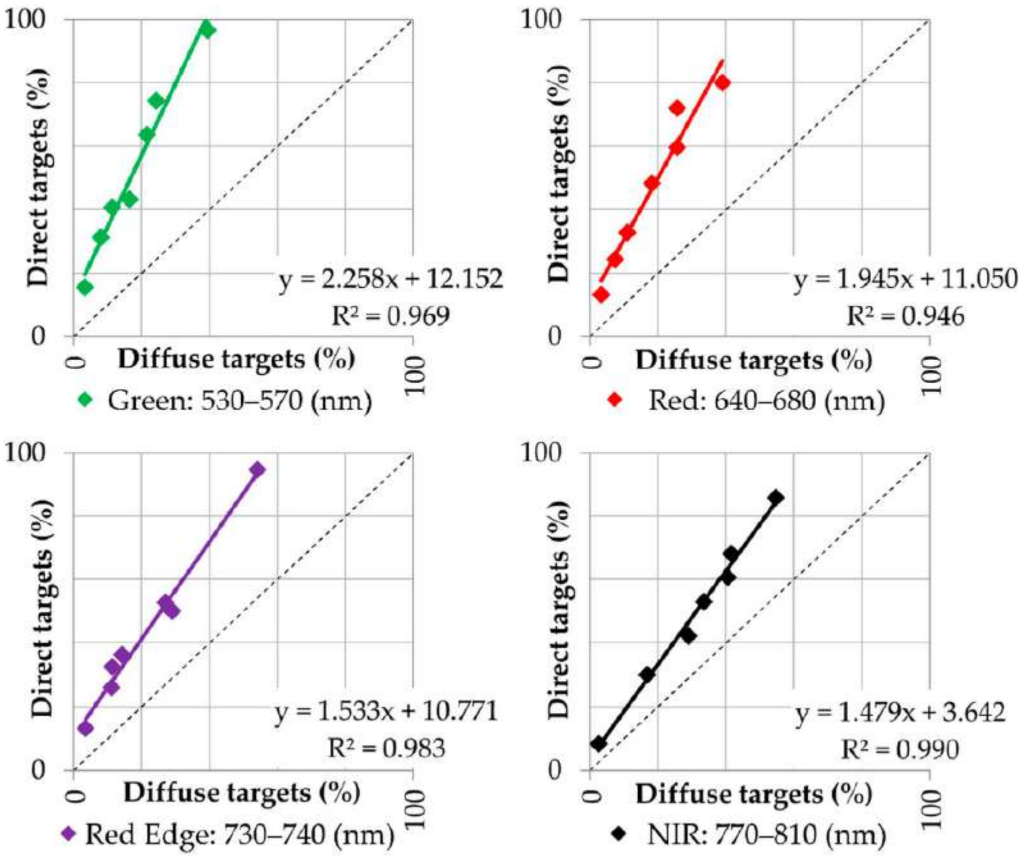
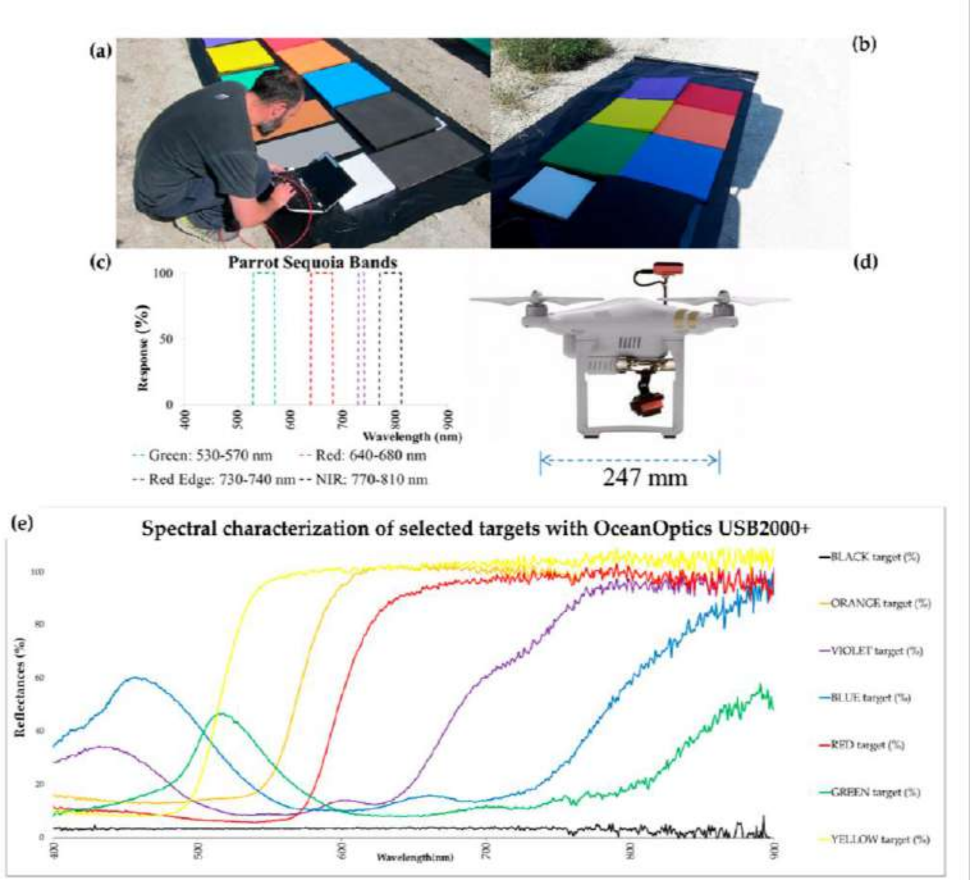


Figure 9. Spectral-dependent linear regression plots for Parrot Sequoia bands, between twin targets (n = 7) located in diffuse illumination conditions and direct illumination conditions. All regressions show an R^2 higher than 0.90 and a p-value < 0.01; additionally, note the reasonably good distribution along the [0, 100] % of reflectance values (also for all spectral bands). These empirical line functions were applied to all the detected shadowed pixels to enhance their radiometry and obtain de-shadowed pixels.



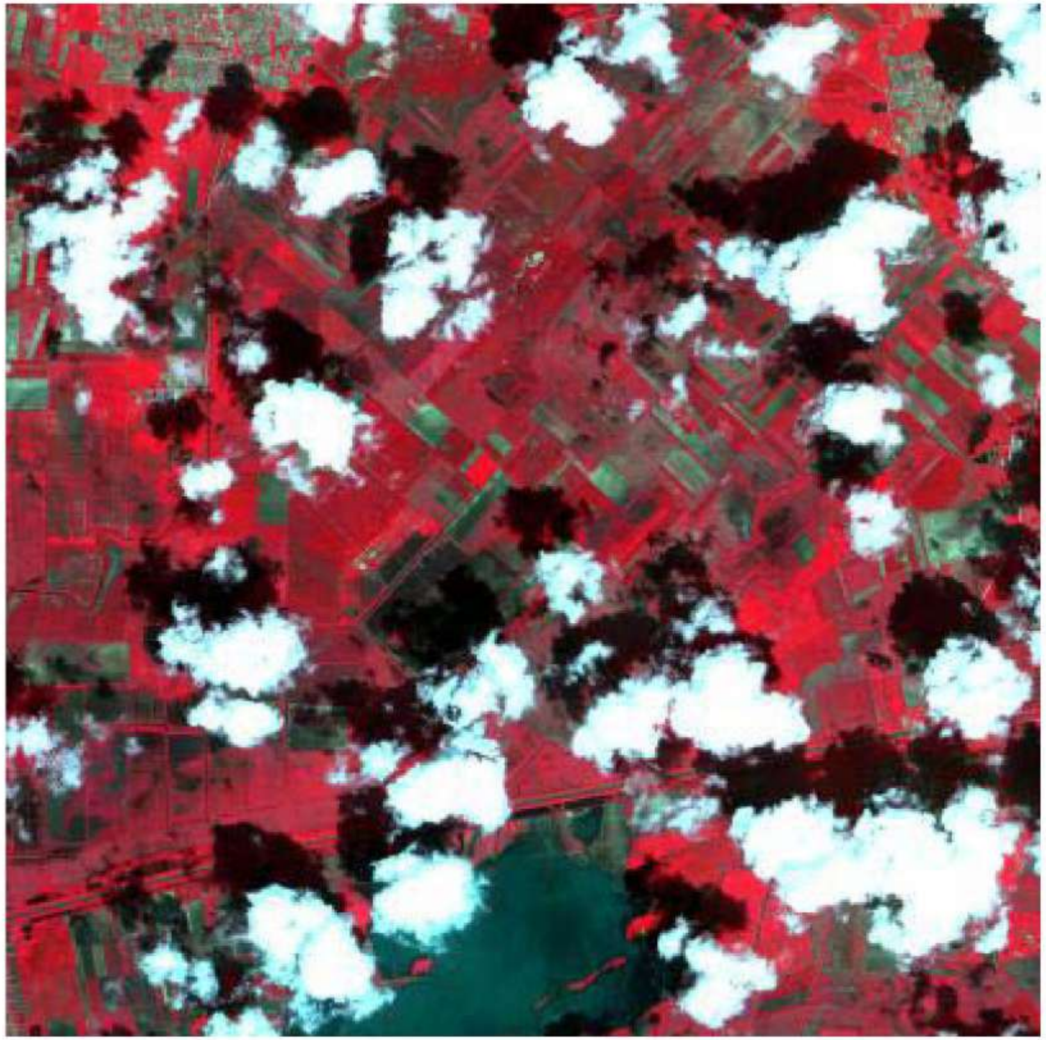
From: Pons and Padro, 2021, An Operational Radiometric Correction Technique for Shadow Reduction in Multispectral UAV Imagery

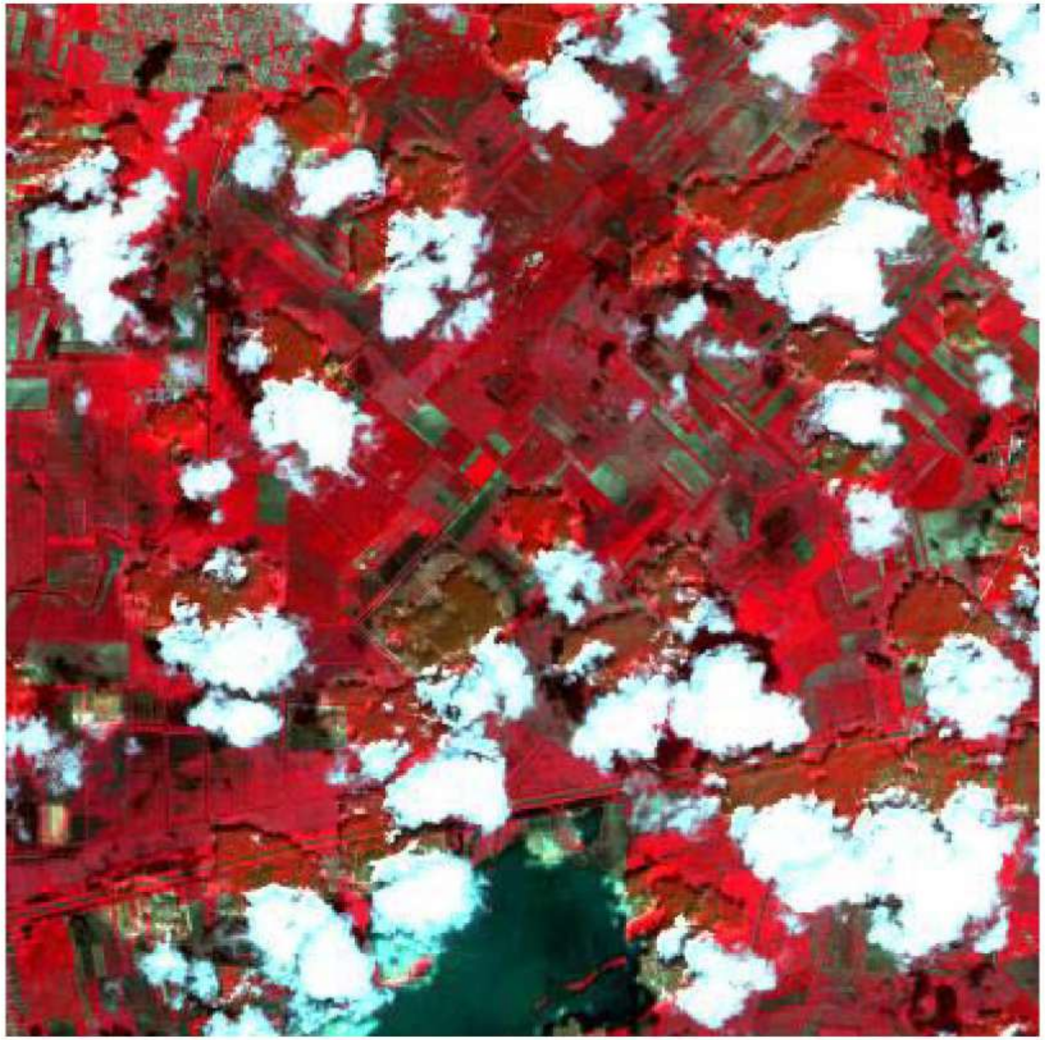
De-Shadowing

- Shahtamassebi et al 2013 „Review of Shadow Detection and De-shadowing Methods in Remote Sensing"
    - Not many papers published since then on this subject

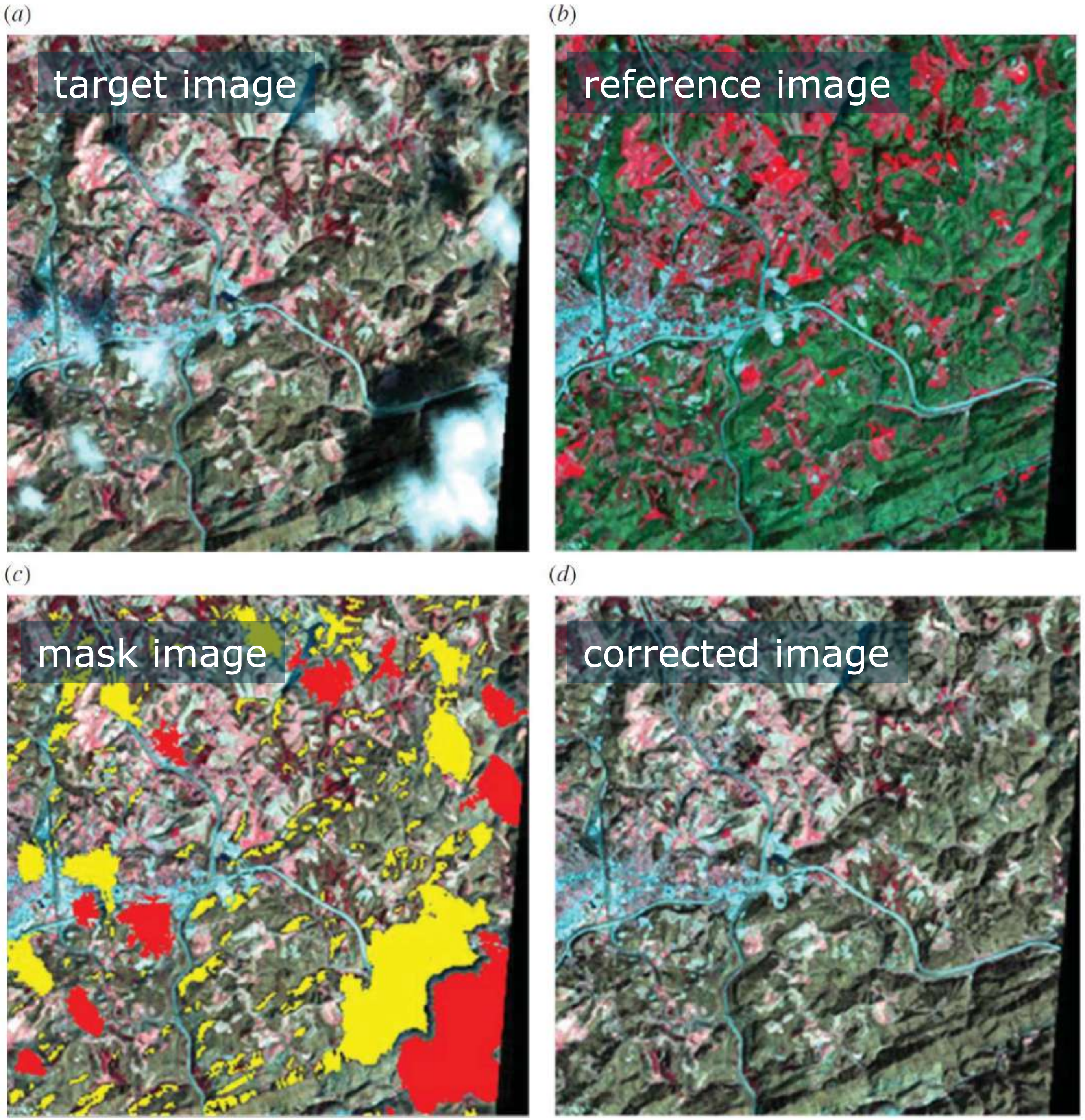
- Generalised (most common) approach, over land:
    1. Cloud detetion
    2. AC for all clear sky pixels <u>under the assumption of fully illuminated pixel</u>
    3. Cloud shadow detection
    4. Corretion of the AC:
        1. Assuming a spectral mixing model: $\rho_{surf,E_{dir}=0} = \rho_{surf} + \rho_{shadow}$
        2. Correcting – different methods published (see below)
        3. Post-processing / corrections (mask expansion, …)
- AC correction:
    - Matched-filter approach (Adler-Golden 2002, Richter 2005) for unmixing
    - Transfer image based spectral clustering (Jin 2013) to replace pixel in shadow in those outside the shadow
    - others

Example: Matched filter method





From: Richter 2005; De-Shadowing of Satellite/Airborne Multispectral and Hyperspectral Imagery



Example: Reference Image and spectral similarity

From: Jin et al, 2012: Automated cloud and shadow detection and filling using two-date Landsat imagery in the USA.

Summary

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1) Cloud shadows pose a significant problem for S3 products (OLCI, SLSTR, SYN)
    - A large portion of the globally acquired, cloud free pixels are measured under cloud shadow conditions
    - Surface reflectances over land and water are not correctly retrieved in current Level 2 Products
    - Uncertainties provided with surface reflectances do not include the effect of cloud shadows
    - Surface reflectance quality masks do not flag affected areas
    - Level 2 products over land and water are differently sensitive to cloud shadow
    - Some (but not all) Level 2 products partly mask cloud shadow areas as part of their algorithms/quality control

2) Future evolution of S3 OLCI processing will include a Cloud Shadow mask
    - Good and necessary first step but not enough

3) De-shading algorithms over land exist in literature
    - Mostly developed for HR and VHR data, but also for MODIS or AVHRR
    - Up to now developed for land applications only

Recommendations

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1) In-depth analysis of the the problem
    - Include SLSTR in all analyses
    - Calculate the statistics of cloud shadow occurrence for a full year
    - Split for land and water
    - Compare with cloud-margin and individual L2 product failure flags
    - Study the robustness of AC and L2 algorithms with more examples and by theoretical considerations
2) Analyse the quality of the cloud shadow mask with respect to L2 product quality
    - How good does the OLCI cloud shadow mask match the areas of decreased L2 product quality?
    - Can we improve the shadow mask?
    - Transfer the OLCI algorithm to SYN and SLSTR
3) De-shading algorithm over land
    - Identify candidate algorithms and compare them
    - Transfer to OLCI, SYN and SLSTR(?)
4) De-shading algorithm over water
    - Perform a feasibility study

SPARE