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WQeMS

ΕΥΑΘ Quality in Life!
THESSALONIKI WATER SUPPLY & SEWERAGE Co S.A.

Living Planet Symposium
Bonn, 23-27 May 2022

Fusion of Sentinel-1 and Sentinel-2 data for inundation mapping in service of the water utilities

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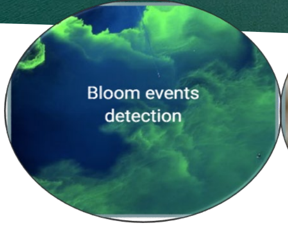
Water we drink…

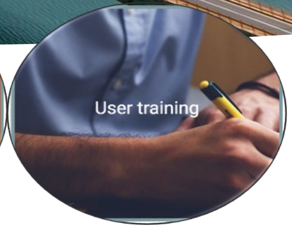
This project has received funding from the European Union's Horizon 2020 Research Innovation Action programme under Grant Agreement No 101004157

Copernicus Assisted Lake Water Quality Emergency Monitoring Service

The overall objective of WQeMS is to provide an open surface Water Quality Emergency Monitoring Service (WQeMS) to the water utilities’ industry leveraging on the Copernicus products and services.

Target is the optimization of the use of resources by gaining access to frequently acquired, wide covering and locally accurate water-status information.





The **land-water transition zone changes detection** service element will perform inundation mapping at areas of interest, detect possible changes that took place between dates or seasons and calculate the inundation regime of the land-water transition zones.

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Objectives

Objectives of this study focus on the adaptation of existing workflows performing inundation mapping for the assessment of open surface water reservoirs used by the water utilities to produce drinking water according to their needs. Specifically, to

- confirm and further expand on the conclusion derived from the application of the S-1 & S-2 fusion approach* regarding the ability of the S-1 per pixel trained classifier to generate credible results for the cloudy days up to and beyond +- 30 days away from validated inundation maps, when using these for training; and

- report about the balance that shall be achieved between the number of S-1 products to incorporate in the production of the hydroperiod vs. the loss in accuracy that these products bring into the hydroperiod estimation.

* I. Manakos, G. Kordelas, K. Marini, Fusion of Sentinel-1 data with Sentinel-2 products to overcome non-favourable atmospheric conditions for the delineation of inundation maps", 2019, European Journal of Remote Sensing, DOI: 10.1080/22797254.2019.1596757

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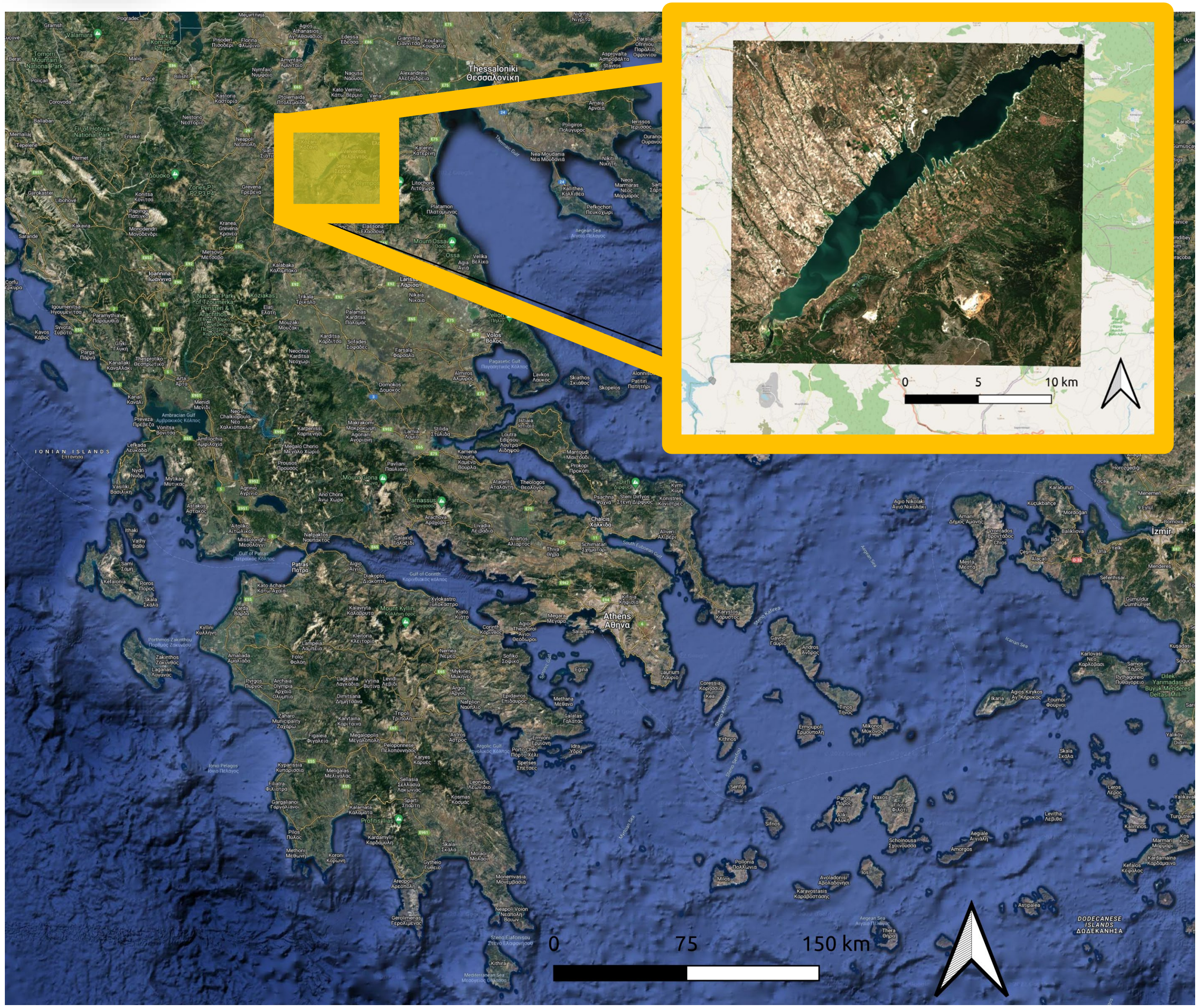
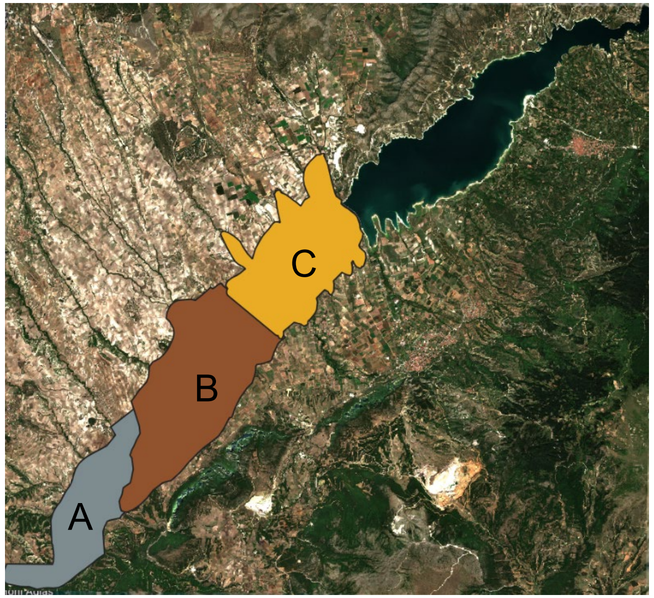
Study and experimentation area: Polyphytos water reservoir



Formed in 1973.
Polyphytos water reservoir belongs to the Aliakmonas River water reservoirs stretching from west, in Pindos, to east, at the Aegean sea.

Covers an area of 74 km^2.

Maximum length: 31 km, Maximum width: 2.5 km.



A: deltaic formation due to inflow from the upper dam

B: part of the main water body I

C: part of the main water body II

Polyphytos acquired from Sentinel-2, 05-09-2020

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Generation of the ground reference layer I

1. Find Google Earth Images that coincide with Sentinel-2 acquisitions for Region A, B for the Greece Pilot Case of WQeMS project.

2. Extract the boundary of land water for each Region through on screen digitizing.

Region A

Region B

3. Compare the boundary with the contours from bathymetric maps and water level measurements of Polyphytos open surface water reservoir.

Official bathymetric isolines of Polyphytos water reservoir, 2011

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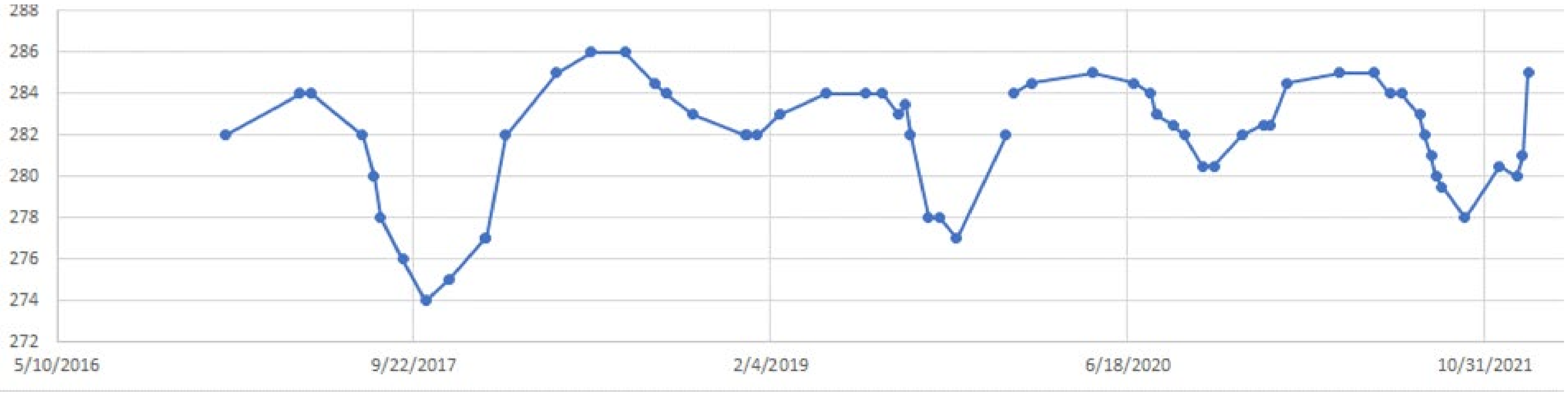
Generation of the ground reference layer, towards ground truth

4. Compare the adopted boundaries with the contours from bathymetric maps and water level measurements of Polyphytos open surface water reservoir, as delineated by the water utility personnel at a coarser time step.



Water Level Measurements, 2017 - 2021 (EYATH)

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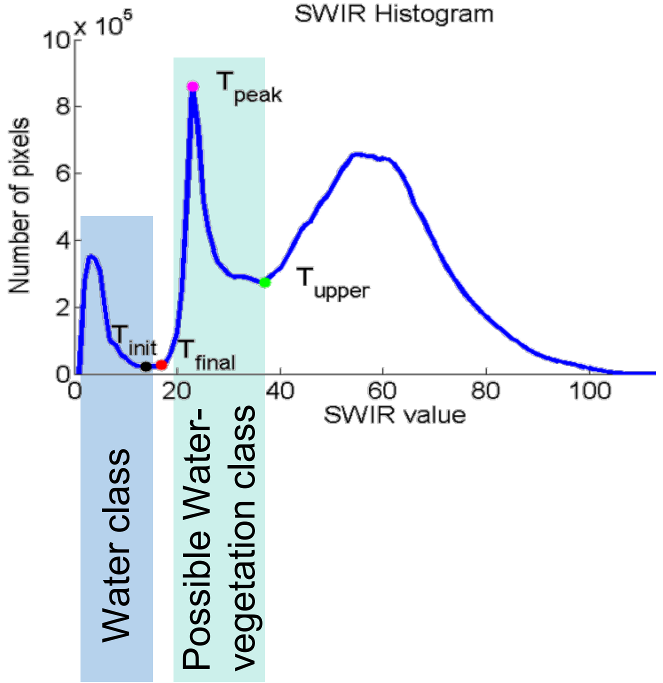
Inundation Mapping based on multispectral data

A **novel automatic local thresholding unsupervised** methodology* detects open-water and water vegetation subclasses, comprising of the water class, by estimating automatically thresholds on the Short-Wave Infrared band (SWIR – Band 11) and on a Modified-Normalized Difference Vegetation Index (MNDVI = (Band 7 – Band 5)/(Band 7 + Band 5))

Main elements of the approach:

- Initial threshold $\mathbf{T_{init}}$, corresponding to the first deep valley of the SWIR histogram, separates coarsely inundated from non-inundated pixels S2 image is segmented into non-overlapping segments.
- Expanding patches are set around segments with high percentage of inundated pixels, and the median of the "splitting" thresholds of all patches is the optimal threshold per segment.
- Final threshold $\mathbf{T_{final}}$, estimated as the median of optimal thresholds, separates the **open-water subclass**.



* Kordelas GA, Manakos I, Aragonés D, Díaz-Delgado R, Bustamante J. Fast and Automatic Data-Driven Thresholding for Inundation Mapping with Sentinel-2 Data. *Remote Sensing*. 2018; 10(6):910. https://doi.org/10.3390/rs10060910

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Alternatives of the approach based on literature insentives and experimentation

The **modified automatic local thresholding unsupervised** methodology*:

1. Detects water class, by estimating automatically a threshold on:
    1. Alt1: SWIR1 – Band 11 (λ = 1610 nm),
    2. Alt2: The product (per pixel multiplication) of Band 12 (λ = 2190 nm, SWIR 2) and Band 8A (λ = 865 nm) (Band 12 * Band 8A),
    3. Alt3: The product of Band 11 (SWIR 1) and Band 8A (Band 11 * Band 8A)

2. For the **estimation of splitting thresholds**, the following approaches were tested:
    1. MCET algorithm,
    2. Otsu’s algorithm,
    3. Average of 1 and 2

* Kordelas GA, Manakos I, Lefebvre G, Poulin B. Automatic Inundation Mapping Using Sentinel-2 Data Applicable to Both Camargue and Doñana Biosphere Reserves. *Remote Sensing*. 2019; 11(19):2251. https://doi.org/10.3390/rs11192251

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Visual comparison of results (example on 31-08-2020)

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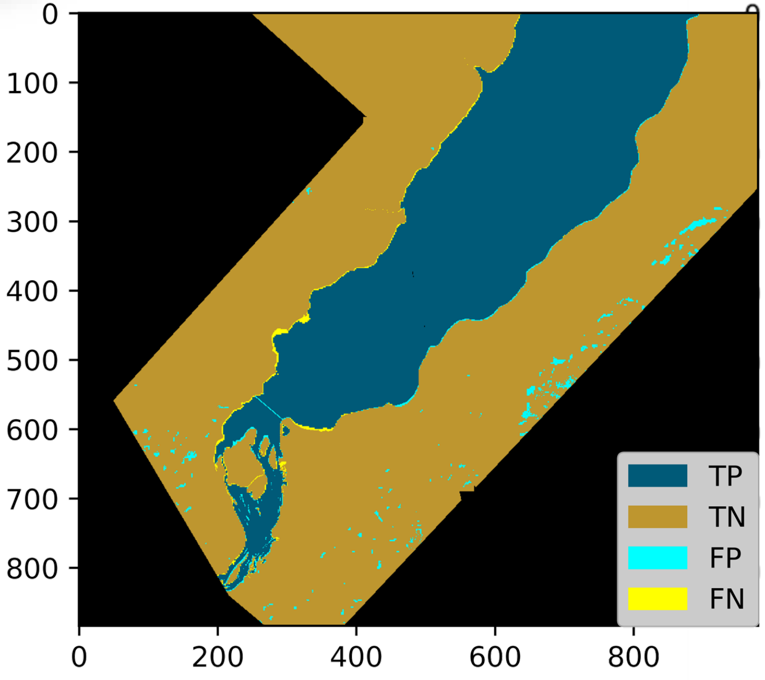
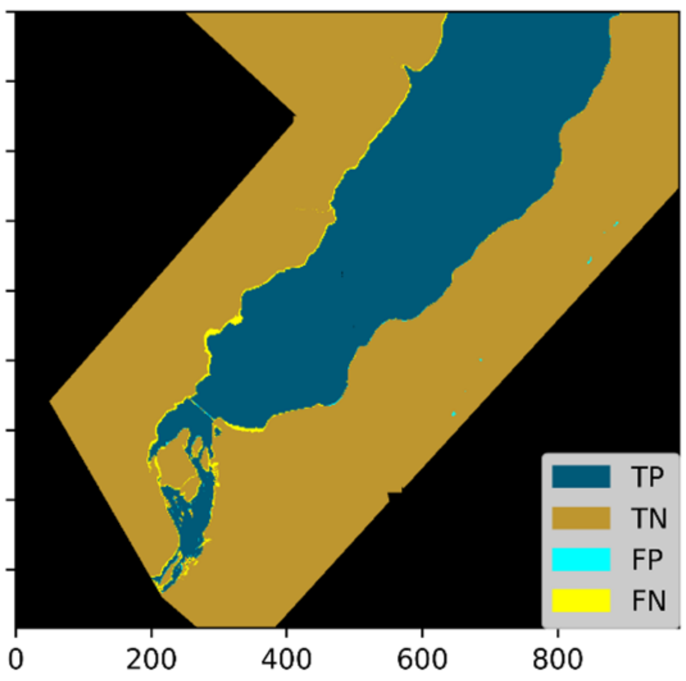
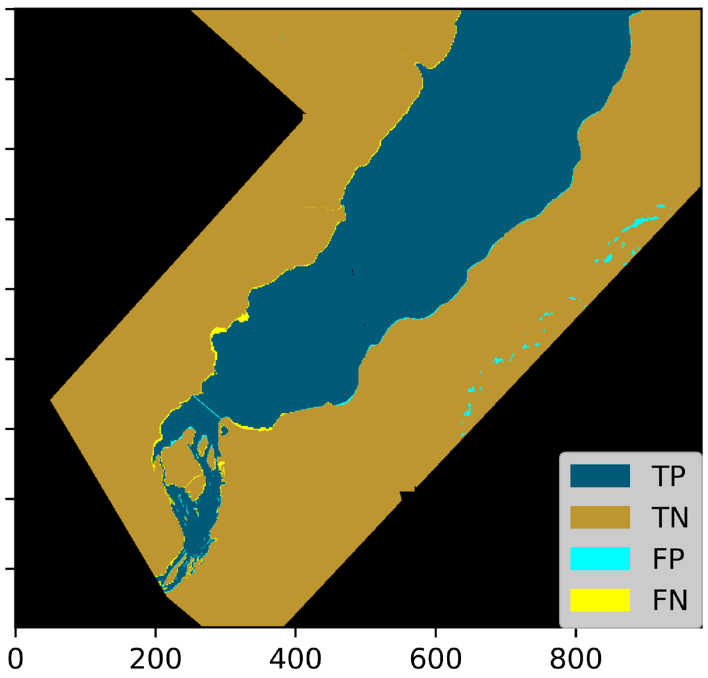


Alt1, Otsu, k: 0.971,
User's Accuracy: 97.4%
Producer's Accuracy: 98.5%



Alt1, MCET, k: 0.978,
User's Accuracy: 99.7%
Producer's Accuracy: 97.2%



Alt3, MCET, k: 0.98,
User's Accuracy: 98.7%
Producer's Accuracy: 98.4%

TP: True Positive
TN: True Negative

FP: False Positive, Inundated in result not inundated in reference

FN: False Negative, not inundated in result, inundated in reference

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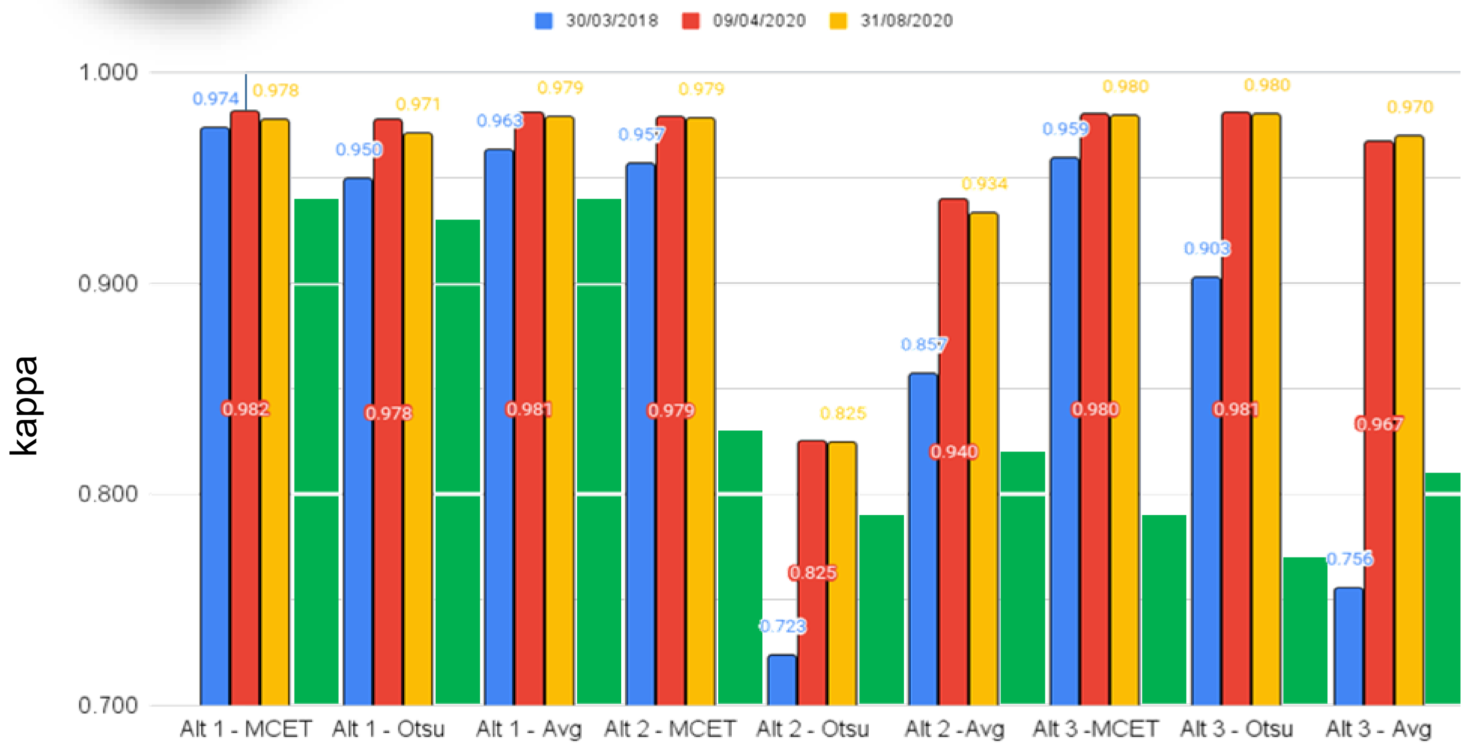
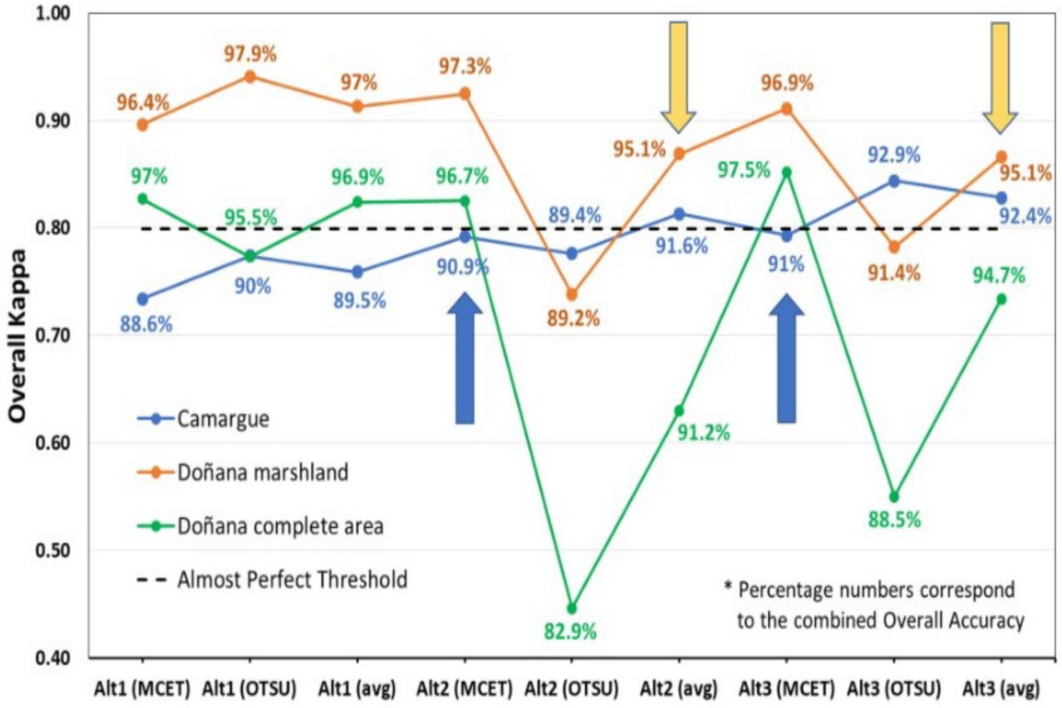
Validation of alternatives based on three dates (green columns are from Kerkini lake in GR)

(Manakos et al., 2021 - doi:10.5220/0010555700480055)





The use of "Alt2" and "Alt3" input alternatives leads to the estimation of **additional inundated areas** compared to "Alt1", but sometimes leads to overestimating the water presence in dry areas.

"OTSU" algorithm identifies the final threshold at a relatively high value leading to a **possible overestimation** of the inundated areas.

The use of "Alt2 and Otsu" shows the **overall lower performance** in most regions.

Kordelas GA, Manakos I, Lefebvre G, Poulin B. Automatic Inundation Mapping Using Sentinel-2 Data Applicable to Both Camargue and Doñana Biosphere Reserves. *Remote Sensing*. 2019; 11(19):2251. https://doi.org/10.3390/rs11192251

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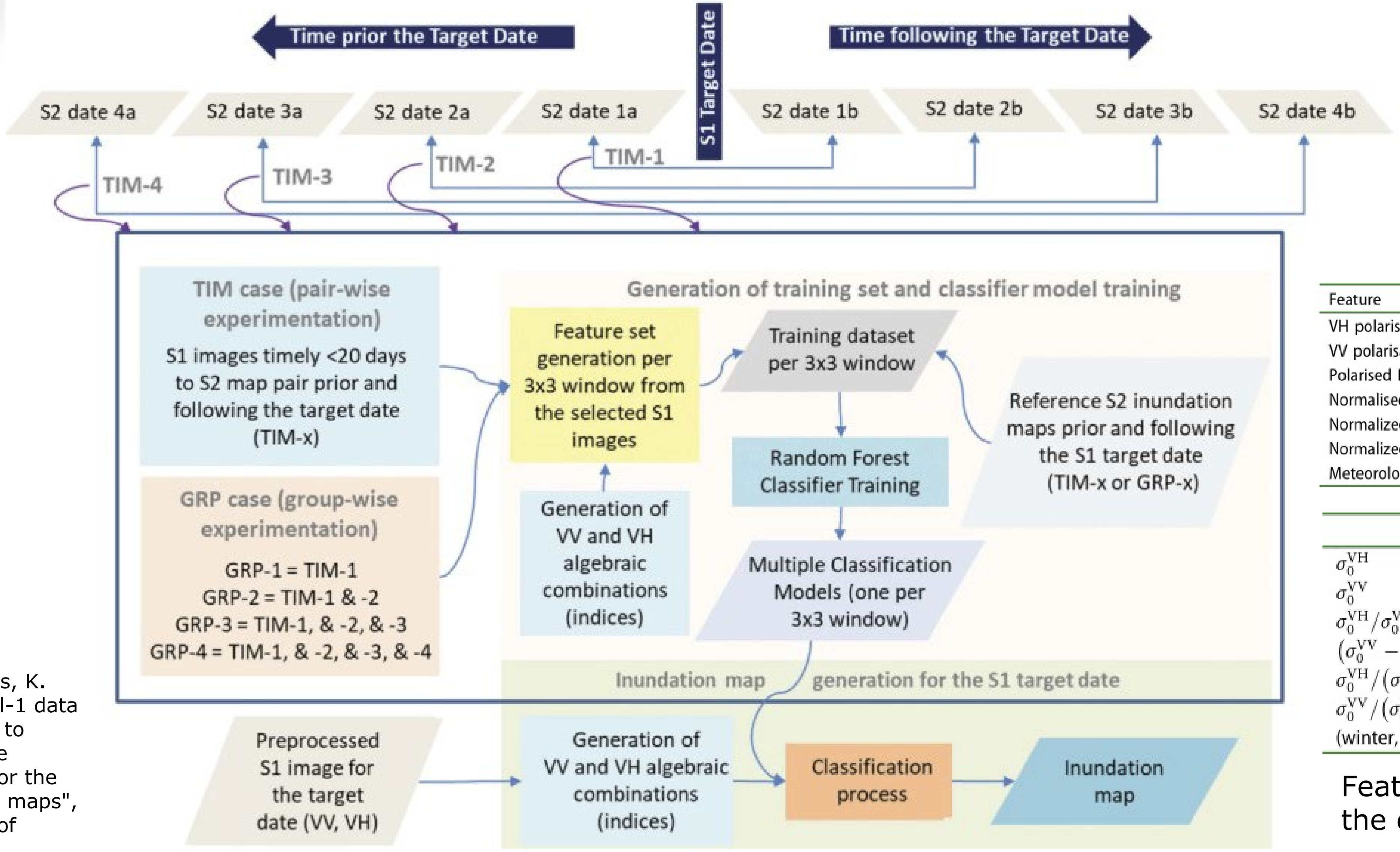
Concept: Fusion of S1 and S2 Inundation Mapping



A pixel centric multi temporal classification approach *, by training per pixel Random Forest Classifiers.

Feature	Equation
VH polarisation	σ_0^{VH}
VV polarisation	σ_0^{VV}
Polarised Ratio Index	$\sigma_0^{VH}/\sigma_0^{VV}$
Normalised Difference Polarised Index (NDPI)	$(\sigma_0^{VV}-\sigma_0^{VH})/(\sigma_0^{VV}+\sigma_0^{VH})$
Normalized VH Index (NDHI)	$\sigma_0^{VH}/(\sigma_0^{VV}+\sigma_0^{VH})$
Normalized VV Index (NVVI)	$\sigma_0^{VV}/(\sigma_0^{VV}+\sigma_0^{VH})$
Meteorological season	(winter, spring, summer, autumn)

Features utilized for the classification

* I. Manakos, G. Kordelas, K. Marini, Fusion of Sentinel-1 data with Sentinel-2 products to overcome non-favourable atmospheric conditions for the delineation of inundation maps", 2019, European Journal of Remote Sensing, DOI: 10.1080/22797254.2019.1596757

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Fusion approach: main steps at Polyphytos reservoir

Apply the approach on Polyphytos water reservoir for **5 target dates**:

- 16-10-2019
- 29-08-2020
- 10-09-2020
- 08-05-2021
- 12-07-2021

- TIM methodology **for 6-7 sequential S2 inundation map pairs**.

- A swarm of S1A and S1B were selected for each case (**~10 images per case** based on day difference criteria).

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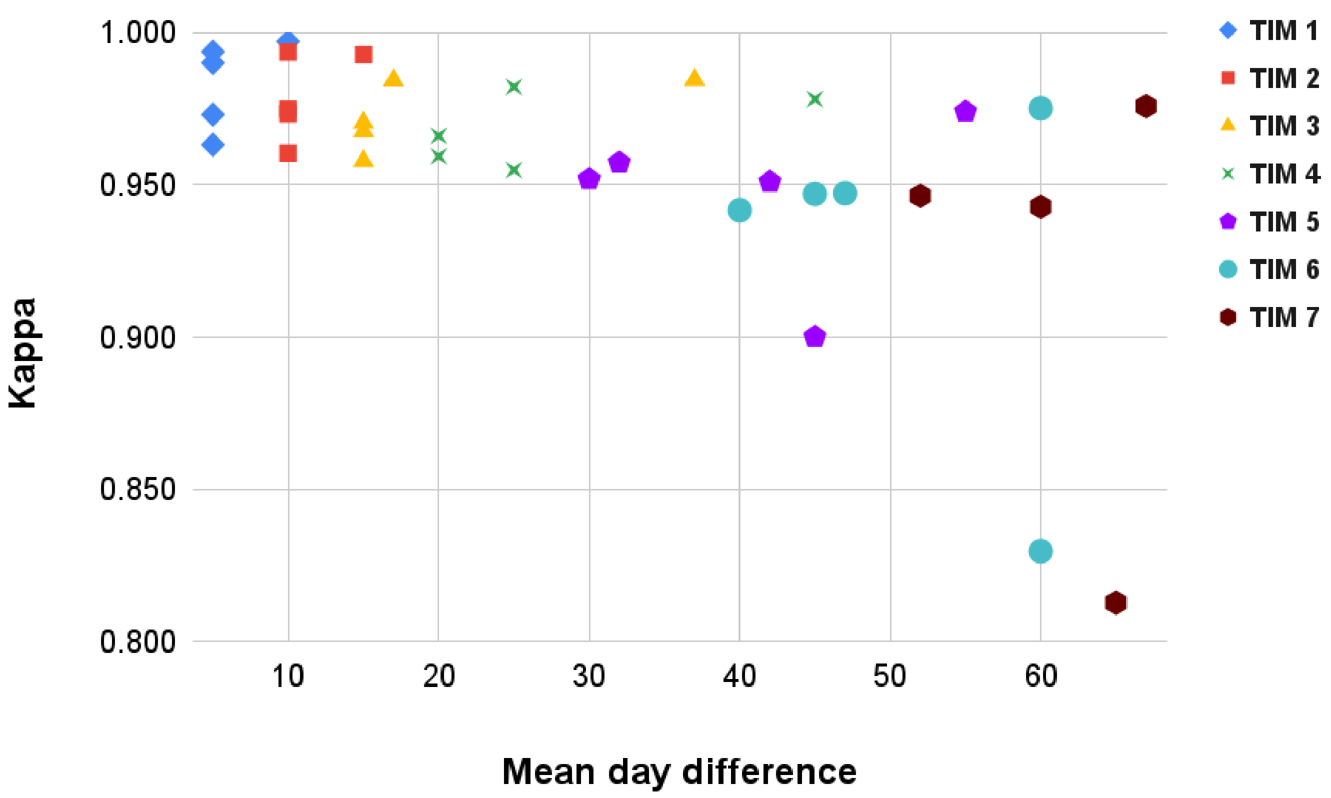
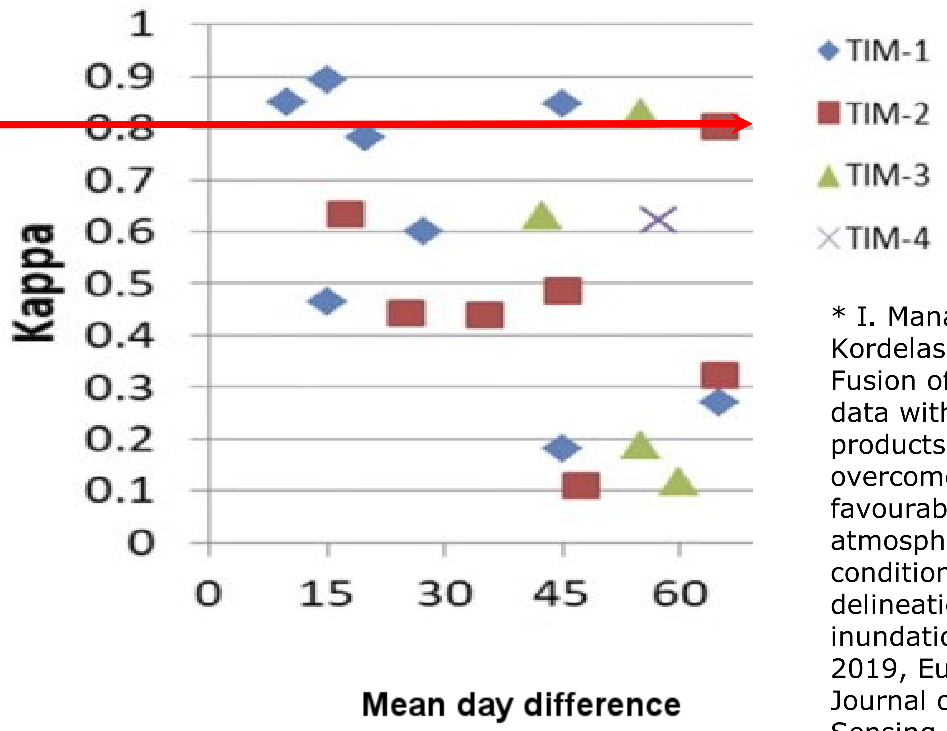
Fusion results: Polyphytos vs. Doñana cases

The case study of Polyphytos



The case study of Doñana



* I. Manakos, G. Kordelas, K. Marini, Fusion of Sentinel-1 data with Sentinel-2 products to overcome non-favourable atmospheric conditions for the delineation of inundation maps", 2019, European Journal of Remote Sensing, DOI: 10.1080/22797254.2019.1596757

The **mean day difference (mdd)** is calculated by the mean difference between the two S2 reference inundation maps and the target date.

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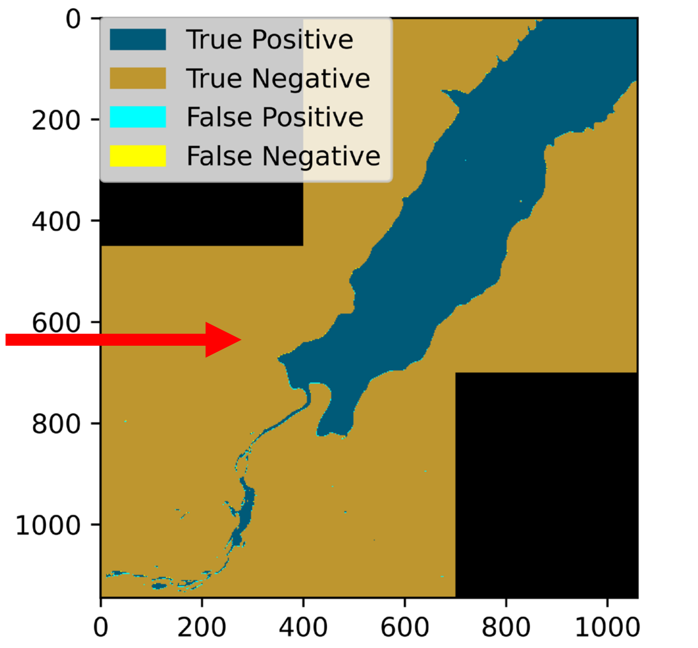
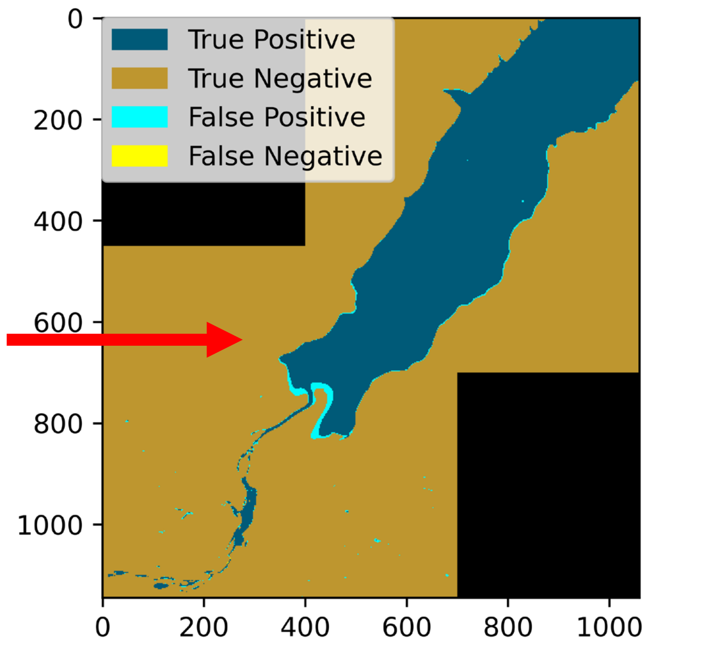
The mdd effect



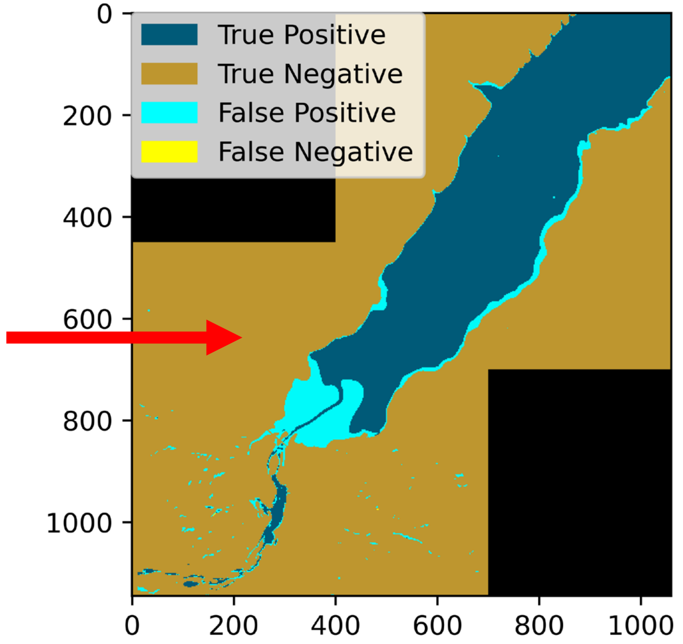
Target date: 16-10-2019
S2 reference maps: 11-09-2019
05-11-2019

mdd: **5**, **k: 0.994**, UA: 99 %



Target date: 16-10-2019
S2 reference maps: 26-09-2019
15-11-2019

mdd: **25, k: 0.982**, UA: 97%



Target date: 16-10-2019
S2 reference maps: 16-09-2019
15-12-2019

mdd: **45, k: 0.9**, UA: 86%

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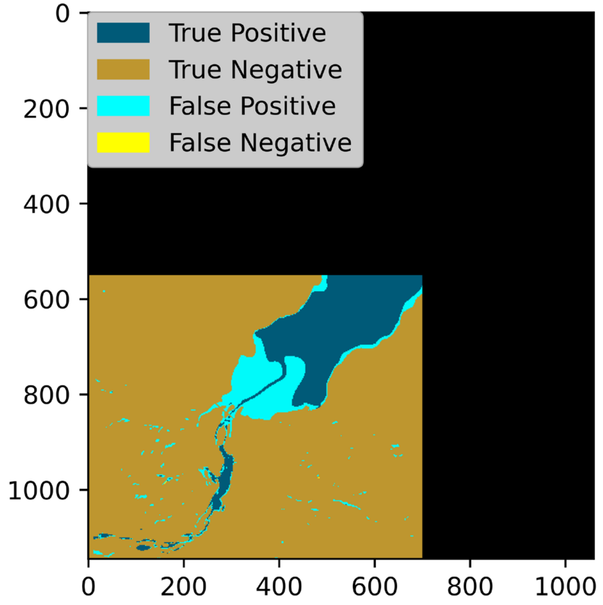
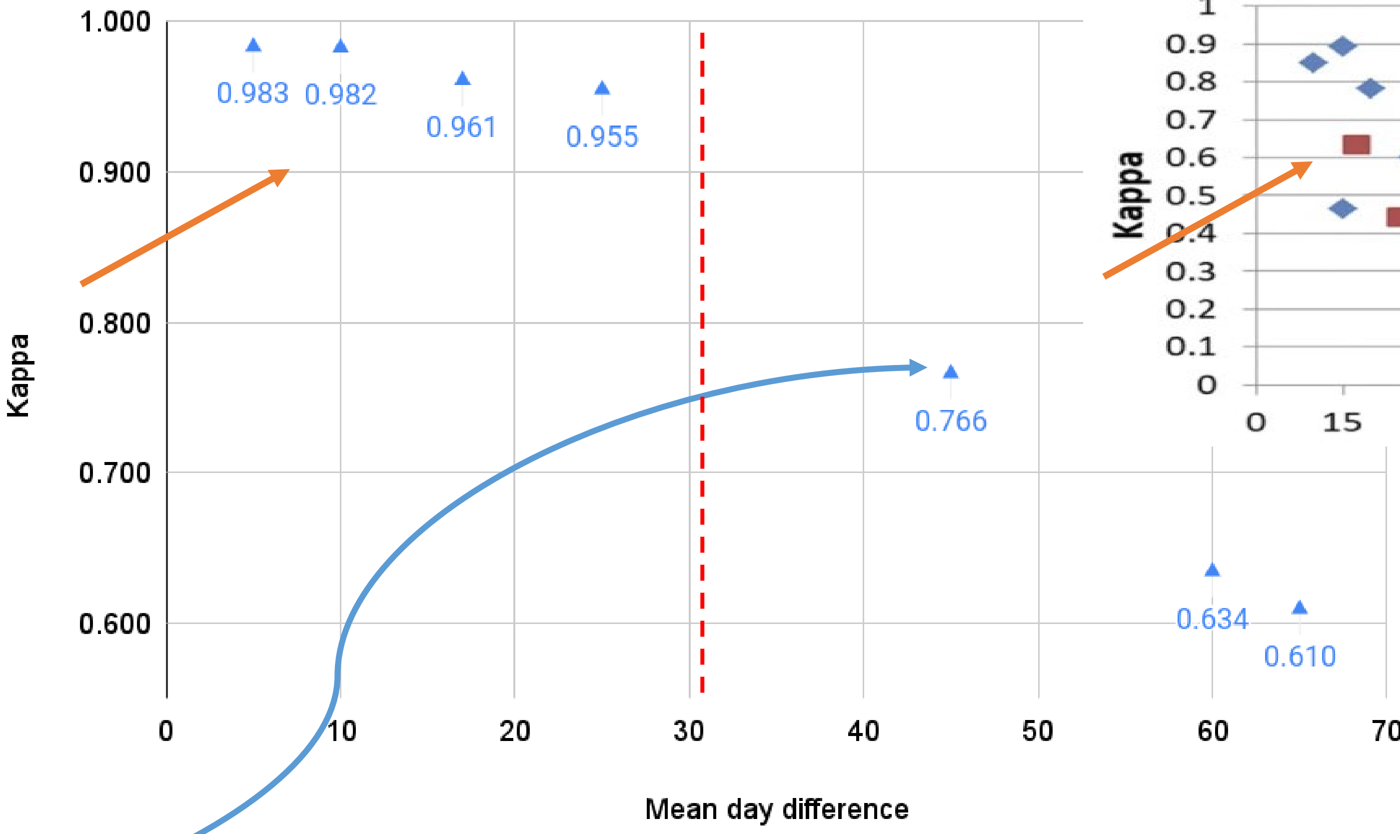
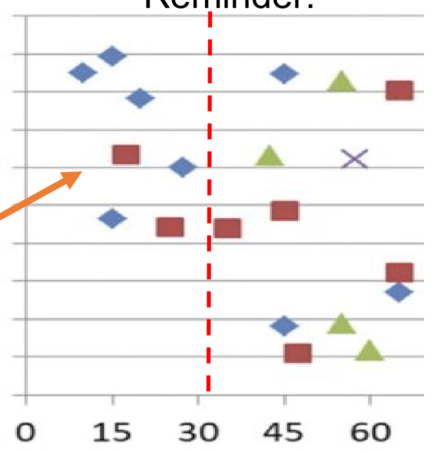
Verification of results



Target date: 16-10-2019
S2 reference maps:
16-09-2019 | 15-12-2019
mdd: 45



Reminder:



… performs better than Donana due to the size of the area and the complexity of the landscape elements; thus, becoming more appropriate for the open water reservoirs used by the water utilities

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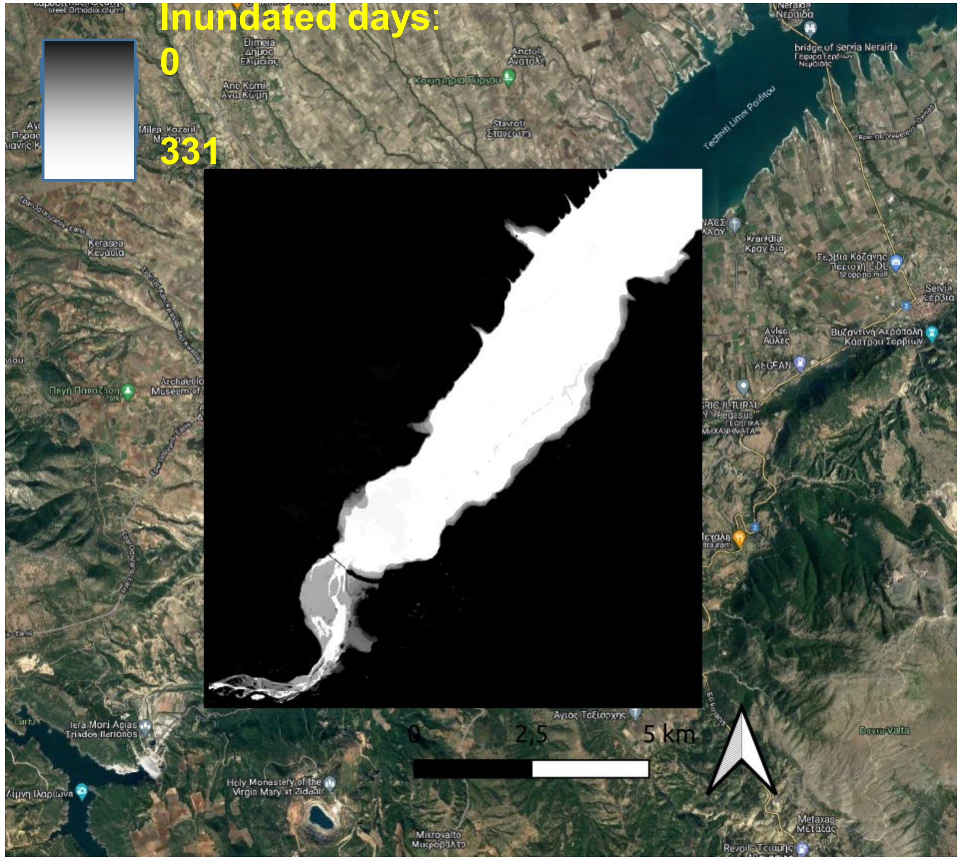
Hydroperiod Estimation

Hydroperiod maps show the **number of days** that a pixel was inundated during the period of interest.



Best Case Scenario: Availability of S2 inundation map every 5 days. Highest value of kappa: 0.98

For the period September 2020 – August 2021, scarcity of S2 maps is encountered in the following time periods:

25-09-2020 to 10-10-2020 (16 days)
10-10-2020 to 09-11-2020 (31 days)
24-11-2020 to 18-01-2021 (56 days)
19-03-2021 to 28-04-2021 (41 days)

The use of Fusion algorithm contributes to a highly accurate hydroperiod estimation while even for the **56 days** case, kappa coefficient is greater than 0.9 (mdd = 28).

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Conclusions

Existing inundation mapping workflows, which assimilate spaceborne EO data, are adequate and may be best adopted for the estimation of the extent of open surface water reservoirs used by the water utilities.

The fusion approach outperforms results from previous works in inland water and wetland environments, providing a tool to estimate the land water transition zone for cloudy conditions beyond +- 30 days mdd.

The loss in accuracy by employing S-1 data in inundation mapping generated minimum impact for the production of a credible hydroperiod, as the drop even for 30mdd remains less than 10% and between 0.95 and 0.75.

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Outlook

Resolution driven — Apply the approach employing VHR data with spatial resolution < 10m to better cope with transition areas.

Feature driven — Study the integration of additional features in the training samples, such as interferometric coherence.

Topography driven — Utilize ancillary information, such as the DEM, to correct erroneous classifications.

Factor driven — Investigate factors that may be taken into consideration to minimize the fluctuation in the performance even in the 30mdd cases

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Thank you for your attention

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