Vizes élőhelyek megkeresése műholdas távérzékeléssel

Observation of local Wetland areas from Satellite Imaging

An European Space Agency project

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1 Project goals

Wetlands are areas where water is available for plants as an unlimited resource during most of the year, but is shallow enough to allow emergent growth. They play an important role in the local environment and associated plant and animal life, being hotspots of biodiversity due to their wide variety of microhabitats and intensive biomass production. Meanwhile, wetlands represent a blank spot of European conservation policy as they are not in focus of the Habitats Directive (hardly any common wetland types are recognized as Natura 2000 habitats), nor the Water Framework Directive (which deals with quality of the water body itself). Using imagery from Earth-observing satellites to map the location and pattern of wetlands, the birth of new wetland sites and changes in wetlands, the project promotes their sustainable use. While large extensive wetlands, such as those on lake shores are in focus of monitoring and conservation, small patches of wetland vegetation in the mosaic of the landscape receive far less attention: in many cases their extent and location are not known precisely as they are smaller than the typical scale of regional vegetation mapping. Meanwhile, these small backcountry wetlands are especially important[1] as they are often the last undisturbed habitats in landscapes extensively modified by agriculture and urbanization, and as such provide sanctuaries and stepping stones for wildlife sensitive to human presence. They also play an important role in regulating water quality and quantity through pollution absorption, groundwater recharge and flood retention. Therefore, backcountry wetlands are essential elements of green infrastructures. Moreover, Hungary in the Carpathian basin has a special river and

[1] Russell, Kevin R., David C. Guynn Jr, and Hugh G. Hanlin: "Importance of small isolated wetlands for herpetofaunal diversity in managed, young growth forests in the Coastal Plain of South Carolina." Forest Ecology and Management 163.1 (2002): 43-59.

wetland structure, where we have remaining wetland habitat patches reduced from large continuous areas of the last centuries or maybe from ancient time when the whole basin was a great wetland area. The remaining great habitats function as natural reserve areas (Natura 2000 habitats), but the tracing and tracking of the small habitats should be the next important step in the protection of biodiversity in Hungary. Small wetland patches are prone to rapid change depending on local water and management conditions, therefore up to date information is necessary for their assessment and protection. The small patches of wetland areas give an important contribution to the co-habitation inside agricultural, urban and traffic areas. At the same time, agricultural land acts as a buffer zone around wetlands, protecting them from developing industrial zones and urban areas.

In this project we address a new and very important issue: the observation of small backcountry wetland areas surrounded by different areas, hosting important species and delivering essential ecosystem services and biodiversity. Although these patches are small one by one, but together they can contribute to the wetland cover area with a very high rate their protection and mapping is a need. These small ecosystems act a main role in the Hungarian biodiversity these many small patches may give an important contribution to the ecosystem in the Carpathian basin.

To obtain the above referred goals, the project work will need to concern several key tasks and problems as follows:

- Selecting the image sources multispectral channels in satellite imaging sensors for which backcountry wetlands can be best discriminated from the local neighbourhood;
- Classifying the sample areas of known natural reserves in order to create ground truth samples based on annotated satellite image data. Semi-automatic annotation will be performed by local clustering of living patches based on biological investigation;
- Defining the best Remote Sensing (RS) features which indicate backcountry wetland areas and contribute to their efficient monitoring process.

The results will have immediate impact both in the science of landscape ecology, and in the application of wetland monitoring for landscape planning and conservation. Finally, our results will be of profound interest to the Remote Sensing science community, as we will develop a new way for region-wide exploitation of low spectral and high temporal resolution images through classification-based fusion. We are confident that our results will be applicable for other study regions and also other classification targets.

Basically, two main approaches were developed during the project. First, a Fusion Markov Random Field (FMRF) process was introduced, which was improved in many aspects to increase the wetland segmentation performance. Second, Deep Learning (DL)-based models, based on the U-Net architecture were trained on a novel, wetland training database. This database was collected by using the ground truth data set of the project, including approximately 33000 image patches. Main improvements of the proposed image analysis methods:

1. The effect of clouds in the satellite imagery and how to eliminate them: state-of-the-art techniques for cloud elimination were tested with respect to their effect on the segmentation performance.
2. FMRF training with global data, instead of local: we tested how different training areas influence the segmentation results.
3. FMRF-based segmentation on different classification levels: segmentation performance was evaluated not only on Level 1, but on Level 2 and 3, including wetland subclasses as input clusters.
4. Deep Learning (DL)-based segmentation with extended training data: the Lake Balaton wetland training dataset was regenerated and extended based on the extended ground truth data, the performance of the retrained networks was tested.
5. DL and FMRF-based methods were fused, the effect of DL prediction map as an input layer for FMRF was investigated.

2 Technology

Any kind of disturbance on the real spectral appearance of satellite images makes segmentation more difficult. A common cause of altering effect on the quality of images are the presence of clouds and their shadows. Fusing multitemporal image dataset could eliminate the strong effect of cloud and shadow pixels on the classification processes. The Fusion Markov Random Field (FMRF, [4]) image segmentation algorithm enables to fuse numerous images taken at different time. Although FMRF is powerful of filtering temporal alteration of images, massive amount of cloud and their shadows could affect the statistical parameters of the classes during the learning process thus segmentation will not be as accurate as segmentation performed with uncorrupted images. The need for cloud and shadow filtering algorithm was important because even if a single image has some cloud and shadow, there are still a large amount of useful information which would be wasteful to drop. Moreover, collecting only perfect images are impossible, so one need an algorithm capable to process cloudy images. Figure 1 shows Sentinel-2 satellite images taken at different dates in year 2017 of the eastern part of the lake Balaton. There are images with no and small amount of clouds, as well as images that are covered largely by cloudy and shadow areas.

Since the FMRF image segmentation algorithm needs data at every single pixel point, one need to estimate the pixel values that are hidden by clouds or shadows. Many methods were tested to recover cloudy and shadow areas. FMRF based image impainting seemed to be promising thanks to the multilayer dataset, but the recovered areas became too homogeneous which resulted in a wrong segmentation. More studies of the FMRF based impainting should be performed to tune up pixel recovery algorithm. The same effect (and even worse) was observed when using OpenCV impainting algorithm. The simplest and apparently most effective method was to copy the value of uncorrupted pixels from other layers to the pixels covered by cloud and shadow. Figure 2 presents the algorithm applied in the FMRF segmentation algorithm.

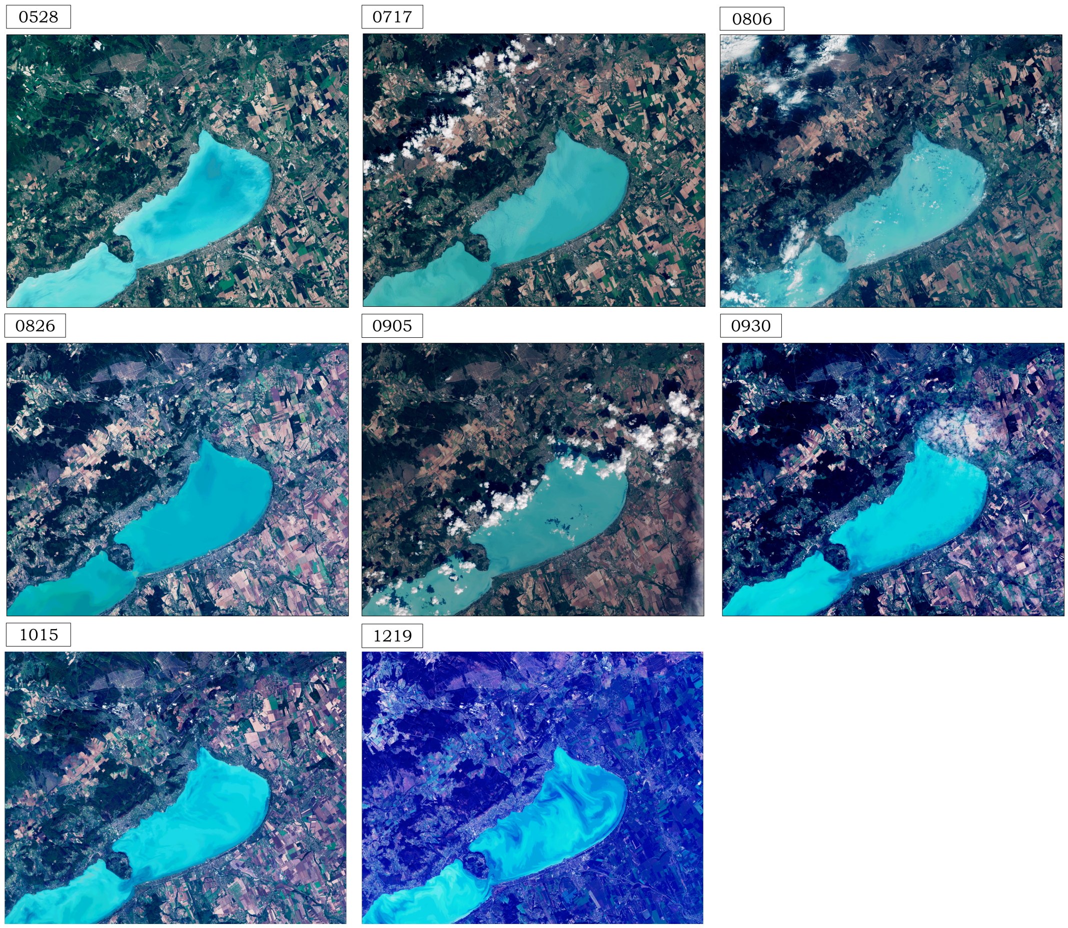

Fig. 1. Color Sentinel-2 satellite images captured at different dates in year 2017.

The algorithm has two parts: shadow and cloud segmentation. The shadow filtering algorithm is detailed in the [1] and [2]. As a first step, RGB composite image is built, then converted to YCbCr color space and finally a ratio image is calculated. From the ratio image, using thresholding, a binary image is generated, which shows shadow as white. Wrongly detected shadow pixels are also generated, that have to be filtered. The cloud segmentation algorithm requires all the 13 bands of Sentinel-2 image to generate a cloud possibility map which is then thresholded to get the cloud mask [3]. The binary cloud mask is used to filter the shadow artifacts with the assumptions that shadows are close to cloud, and any other pixel segmented as shadow located far from clouds are deleted. After merging shadow and cloud binary masks, all satellite images are filtered, and hidden pixels are recovered.

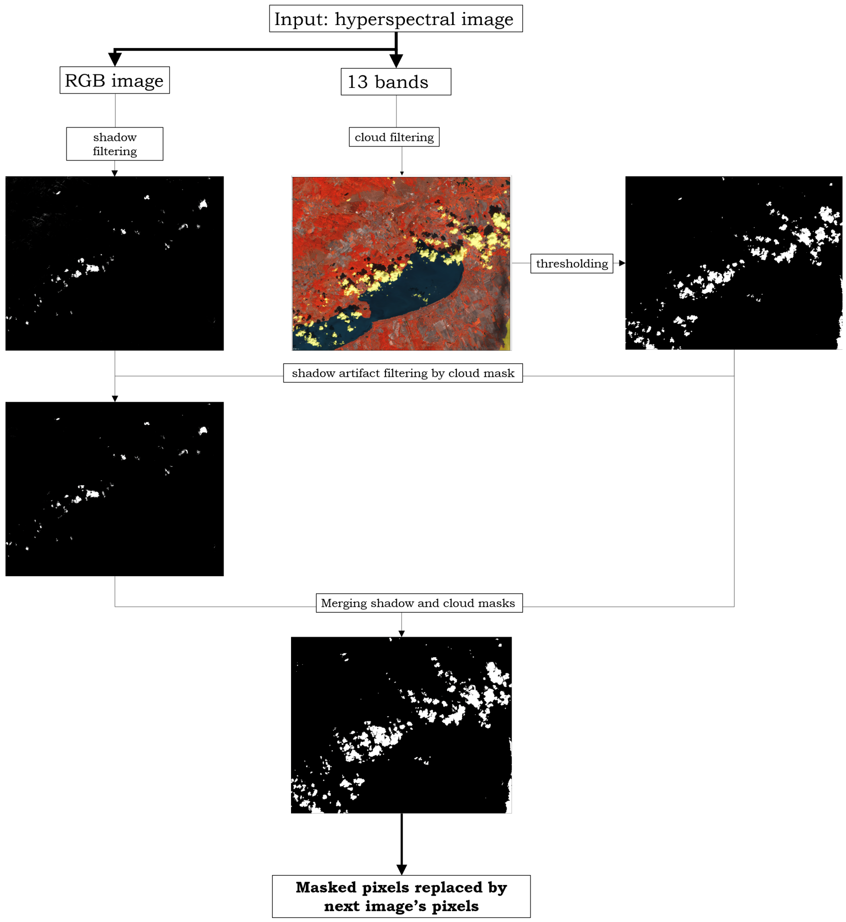

Fig. 2. Shadow and cloud segmentation algorithm.

Figure 3 shows the effect of image number and filtering on the segmentation quality of the FMRF image segmentation algorithm. Figure 3 (1)) shows the segmentation output in the case of four images fusion (28th may, 26th August, 15th October and 19th December, while (2)) is performed by the fusion of all the images shown by Figure 1 and (3)) is also with the whole dataset but with the application of cloud and shadow filtering given by Figure 2. It is seen that four image fusion already gave a good segmentation result (see previous report), but it has the limitation of using only perfectly clean images. Fusing more images (containing cloudy and shadow areas) could result in false segmentation, thus undetected wetland areas (blue color). Light bluish transparent color indicates ground truth data created by an Expert. When cloud and shadow masking and pixel recovery are applied, one can achieve good segmentation for wetlands. In the following, segmentation is always performed by the maximum number of images with cloud and shadow filtering.

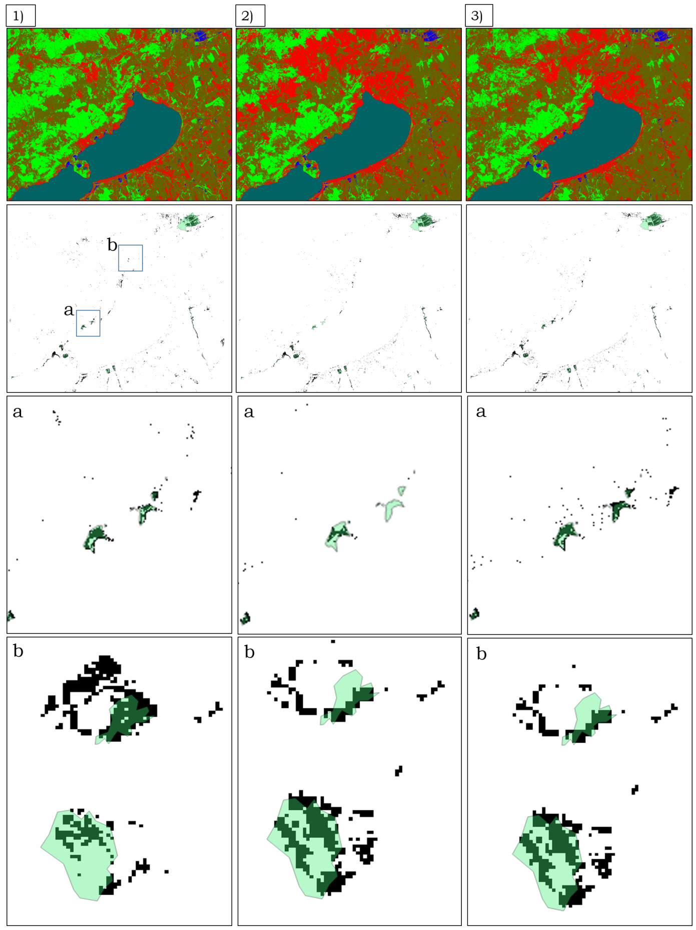

Fig. 3. FMRF segmentation results with different input images.

3 Biological validation

Wetland masks from the years 2016 and 2017 were received together with a monthly mask from the vegetation season of 2016. After initial qualitative evaluation it was found that the monthly masks contain too many random errors for good comparison with ecological processes, but the annual masks were suitable. Documentation on the annual water balance of Lake Balaton is available and contains a record of rainfall and evaporation conditions for each year. This revealed that while 2016 was a particularly wet year with precipitation well above the long-term mean, while 2017 was a relatively dry year in general. The water levels of Lake Balaton were lower in 2017. Nevertheless, most of the wetlands in the region show growth between 2016 and 2017. This may be due to dynamic processes such as the overgrowing of open water locations with reed as part of normal succession, or the encroachment of wetland vegetation after abandonment of mowing of meadows. Finally, it could also be a result of a time lag between the rainfall in one year and its effect on the habitat during the next year. Wetland locations were visualized in ArcGIS and changes compared between years at an approximate scale of 1 : 50000. Observations are listed below according to individual locations:

Nádasdladány Change detection results are shown in Figure 4 (left image). The wetland patch called Csitéri forest appears to be a wetland in 2016, not a wetland in 2017. This is probably an artifact of shrubs being classified as wetland in 2016. Nádasdladány peatland wetland was a lot larger in 2017, with the SW (south-west, directions are marked with abbreviations further on) edge extending wider. This wetland area appears to be unmown and unmanaged, and therefore the growth can be interpreted as natural. In one location along the Sárvízi malomcsatorna canal, wetlands persist in both years, while another old meander was not identified as wetland in 2016 but was dominated by wetlands in 2017. The small ponds NW of Nádasdladány have shore wetland vegetation belts that did not change.

Small parts of the grassland NW of Hajmáskér were incorrectly mapped as wetlands during 2016 but not during 2017. The small Miklád wetland north of Veszprém did not change at all.

Nagyvázsony lake practically unchanged, small wetland N of Kő-hegy has some wetlands in 2017 but not during 2016 (seems realistic, small pond that could be ephemerally a wetland).

Pécsely-Vászoly neighbourhood Many small-scale wetlands in the region were clearly flooded during 2017 and dry during 2016. While field visits in both years showed prevalent wetland vegetation in these locations, the wetness and growth of these vegetation patches can apparently better be followed with remote sensing data (Fig. 4 right image).

Balatonszőlős Balatonszőlős lake is dominated reed, but the perennially flooded part of the lake seems to be along a canal running SW-NE. Both 2017 and 2016 data identify this vegetation perfectly as wetland but omit the rest (Fig. 5 left image, northern region with red circle).

Aszófő Several small wetland pockets recognized by the 2017 data appear to be noise, but a large contiguous patch NW of the road 7303 has a hint. Field visits show this area to be a grassland with shrubs on a relatively dry slope, but according to OpenStreetMap the (probably historic) name of the field is

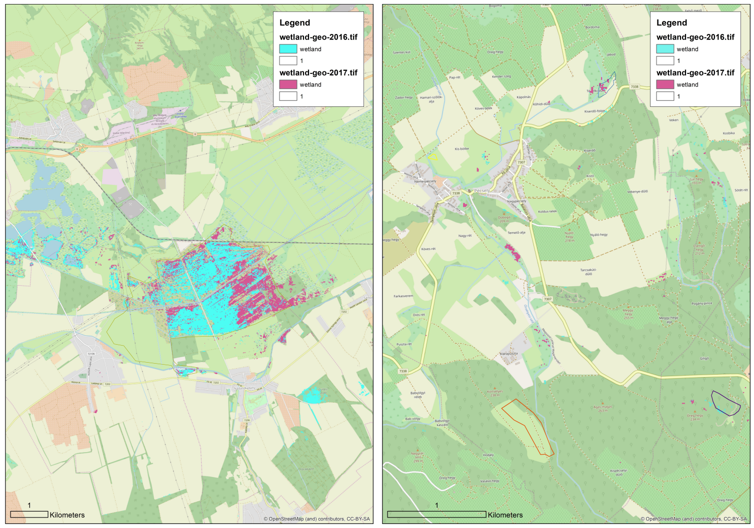

Fig. 4. Analysis of change detection in Nádasdladány area (left) and Pécsely-Vászoly neighbourhood (right).

"Gyékényes" which means "place dominated by *Typha*". This suggests that in a wet year like 2017, wetland vegetation may dominate the site. Also, small pixels marked as wetland along the railway actually belong to the ditch of the embankment which is overgrown by wetland vegetation in many places, as found in the field (Fig. 5 left image, southern region).

Balatonfüred Increase of wetland area between Tihany and the Balatonfüred Shipyard (Hajógyár) on the landward side of the road Nr. 71 is correctly identified and also comfirmed by repeated field visits (Fig. 5 right image). The same applies to the wetland patch N of the railway and W of the Aszófői-séd river. The (re)appearance of a wetland areas directly N of the shipyard and S of the railway and S of the city center of Balatonfüred are also plausible in a wet year like 2017 and confirmed by field visits (south red circle). At these sites, shrubs, dry meadow grasses and tall wetland macrophytes are in intense competition and the local vegetation cover depends strongly on the water regime of each year.

As summary, 2017 was a significantly wetter year than 2016 and the increasing extent of the wetlands was identified correctly in many cases. We also suspect and in some cases have confirmed that wetland-grassland-shrubland mosaics were dominated by wetland vegetation in 2017 and this was well recognized in the data. The 2016 mask seems to be slightly affected by coniferous shrubs misclassified as wetlands.

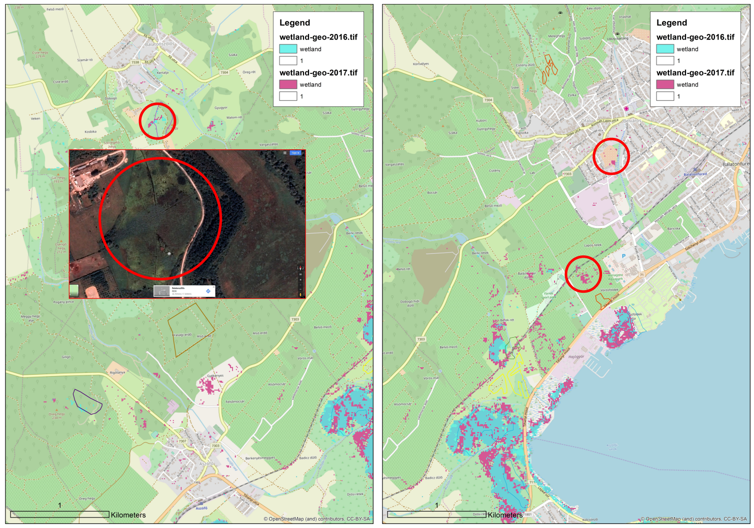

Fig. 5. Analysis of change detection in Balatonszőlős and Aszófő areas (left) and Balatonfüred (right).

Acknowledgements

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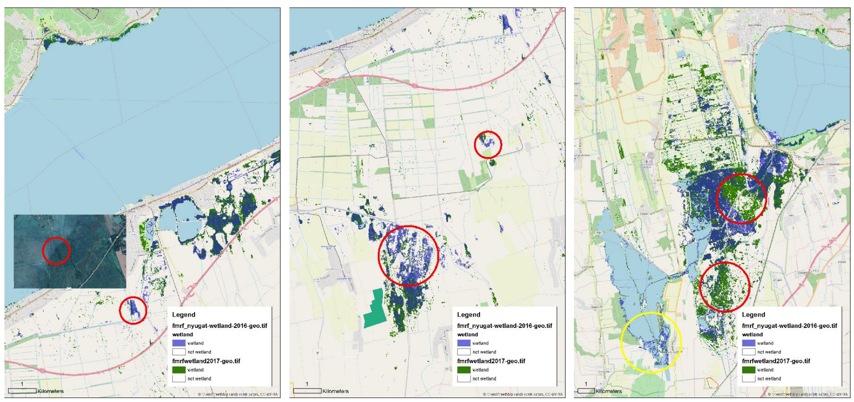

Fig. 6. Analysis of change detection in Fonyód (left), Somogyszentpál (centre) and Kis-Balaton (right).