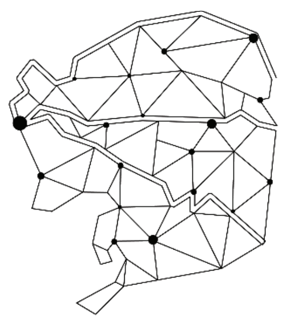
Wetland monitoring using SAR and optical data

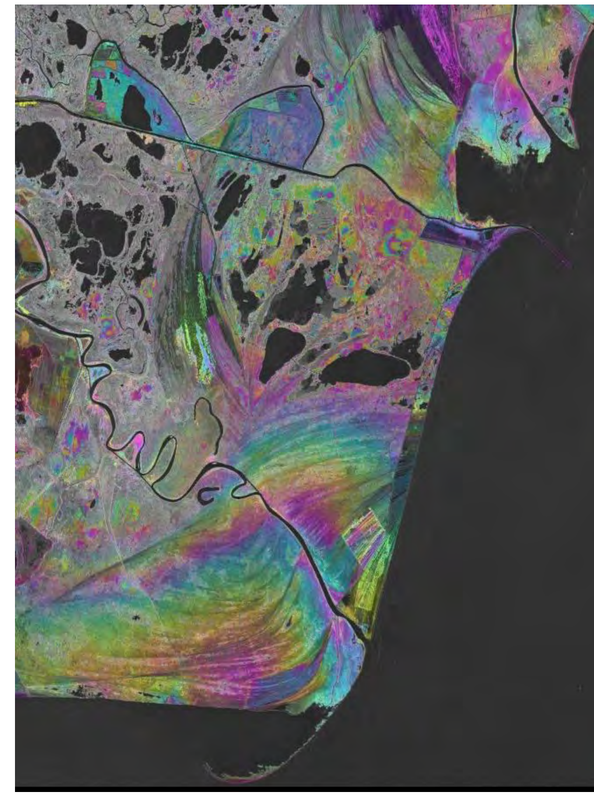
Florin Serban

Delia Teleaga

Sorin Constantin

TERRASIGNA





Overview

Applications of SAR and optical data relevant to wetland monitoring:

- **Water extent maps**
- **Polarimetric processing**
- **Water level changes maps**
- **Flow directions**
- **Change detection analysis (e.g. coastal area, floating reed beds)**

Hydro-SAR

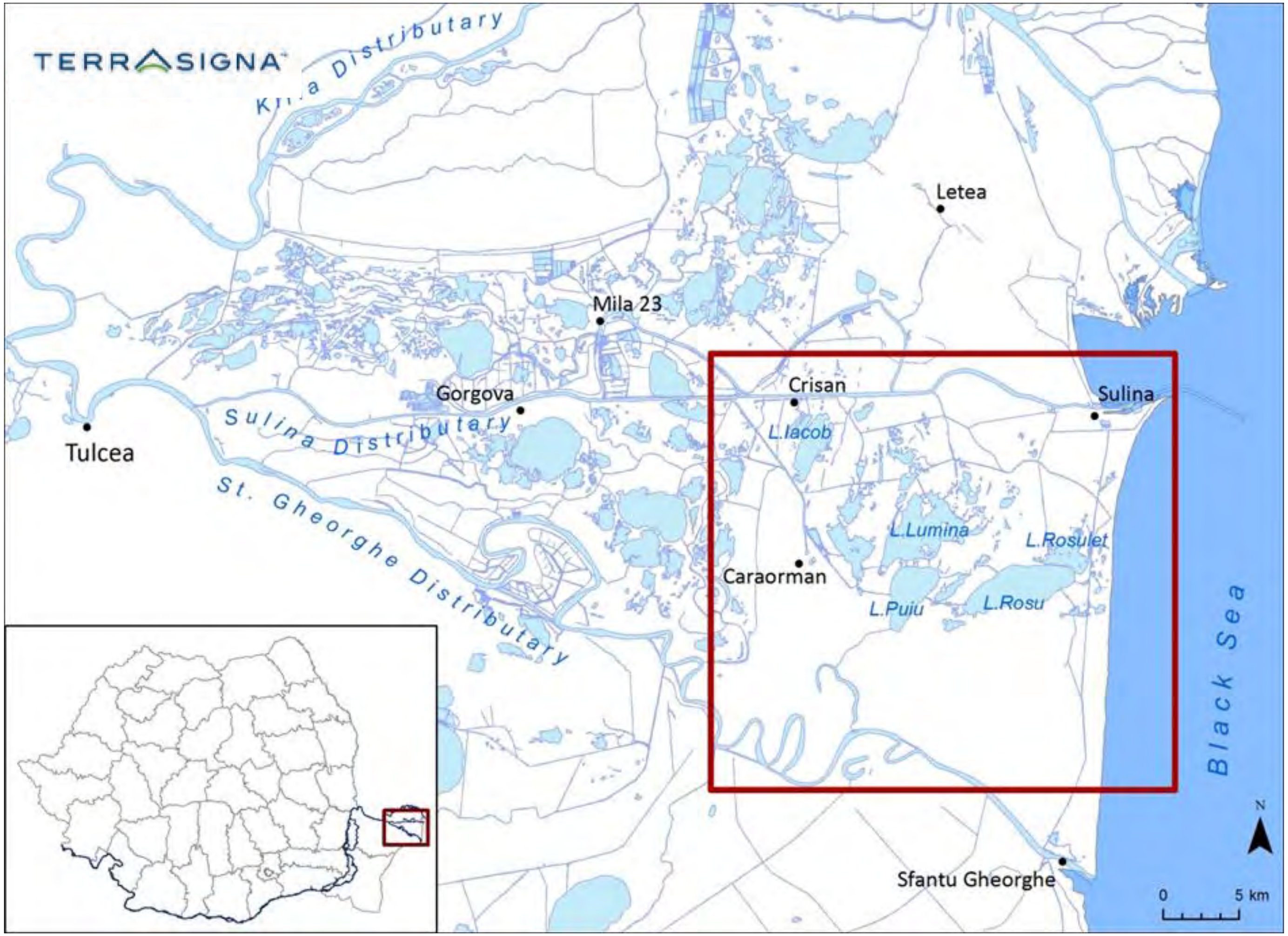
Area of interest

Wetlands -> wetland vegetation and open water distributed in an intricate pattern of marshes, channels, streamlets and lakes

Danube Delta pictures

Test area

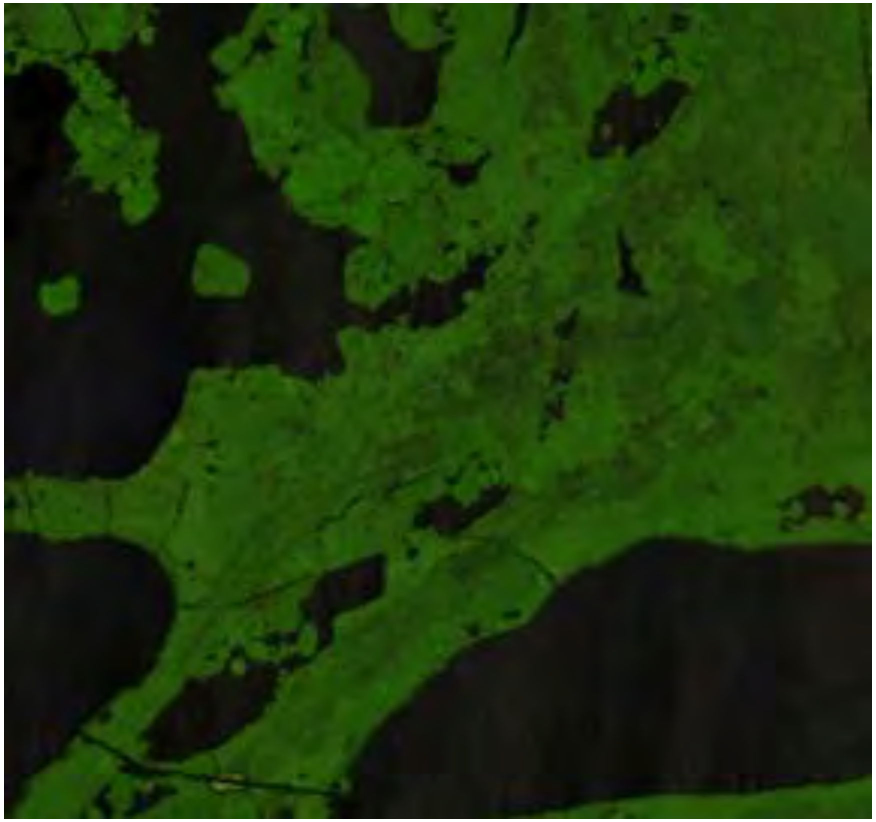
Wetland: Danube Delta, Romania



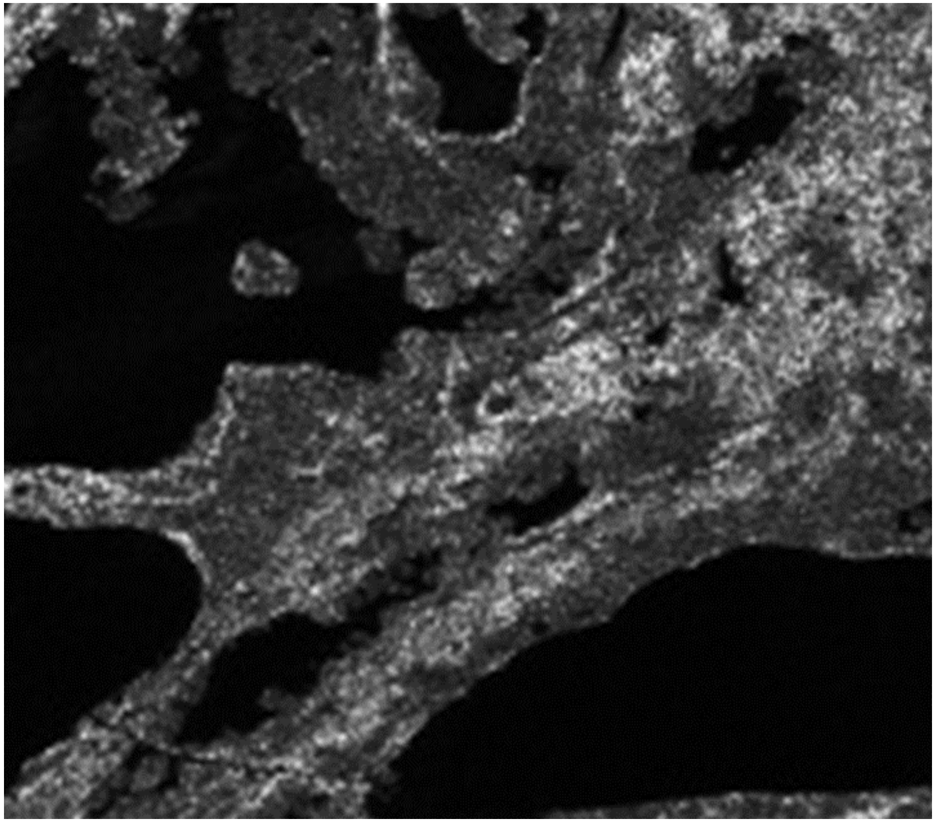
Location map of the Danube Delta, Romania and the study area – the hydrographical unit of Puiu–Rosu

Water extent mapping

Water extent can be mapped from satellite (optical and SAR) imagery:



Landsat image of Danube Delta (detail)



SAR amplitude image of Danube Delta (detail)

Water extent mapping

Water surface extent estimation products:

- ✓ Open surface water extent maps obtained from optical data
- ✓ Open surface water and flooded areas extent (water under vegetation) maps from SAR data

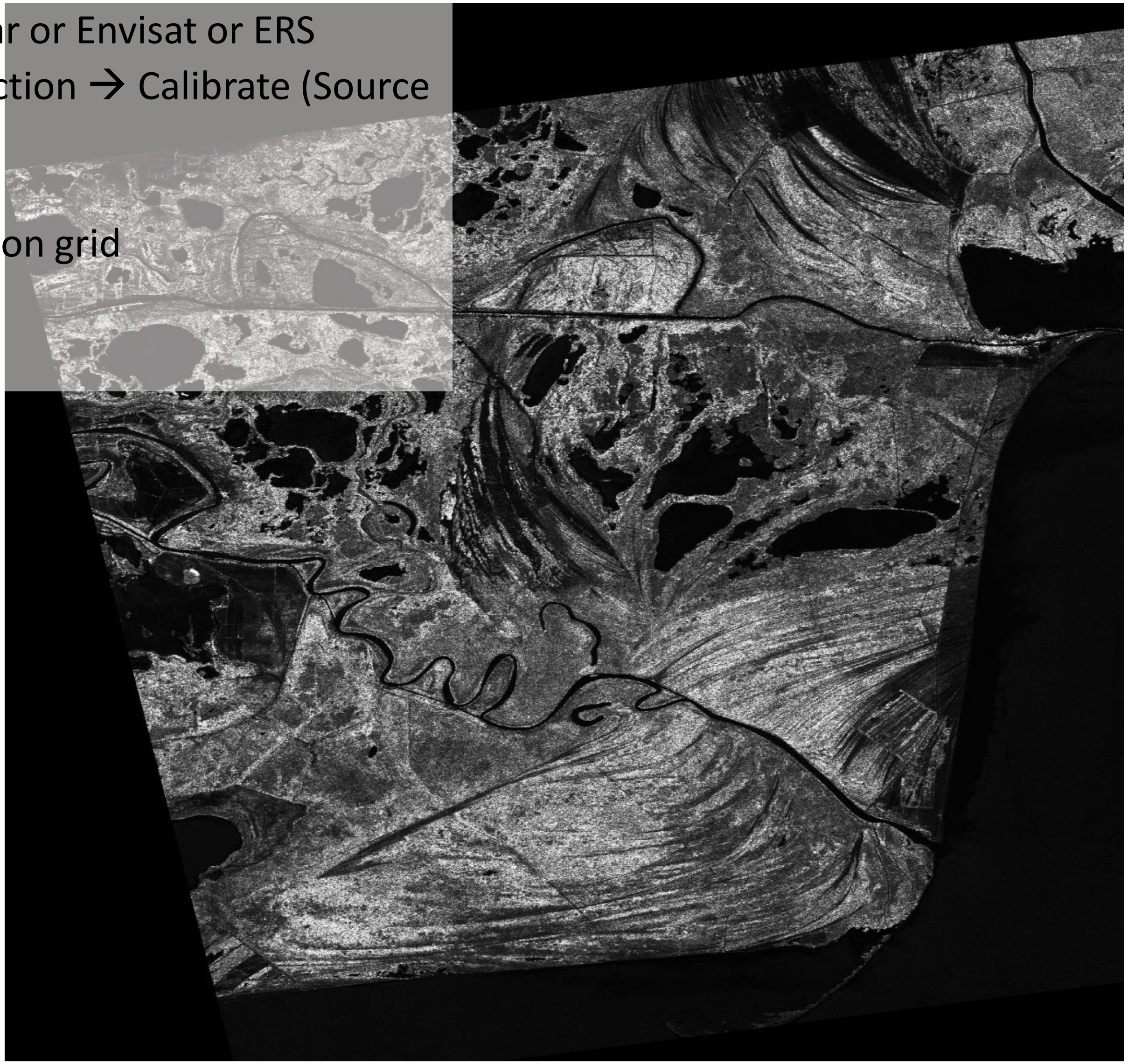
Motivation:

- ➢ Surface water extent in wetlands represents an important ecological parameter that can be analyzed using GIS techniques and remote sensing data;
- ➢ determination of areas that are being prone to frequent flooding is of interest for wetlands management plans;

Water extent: SAR amplitude data

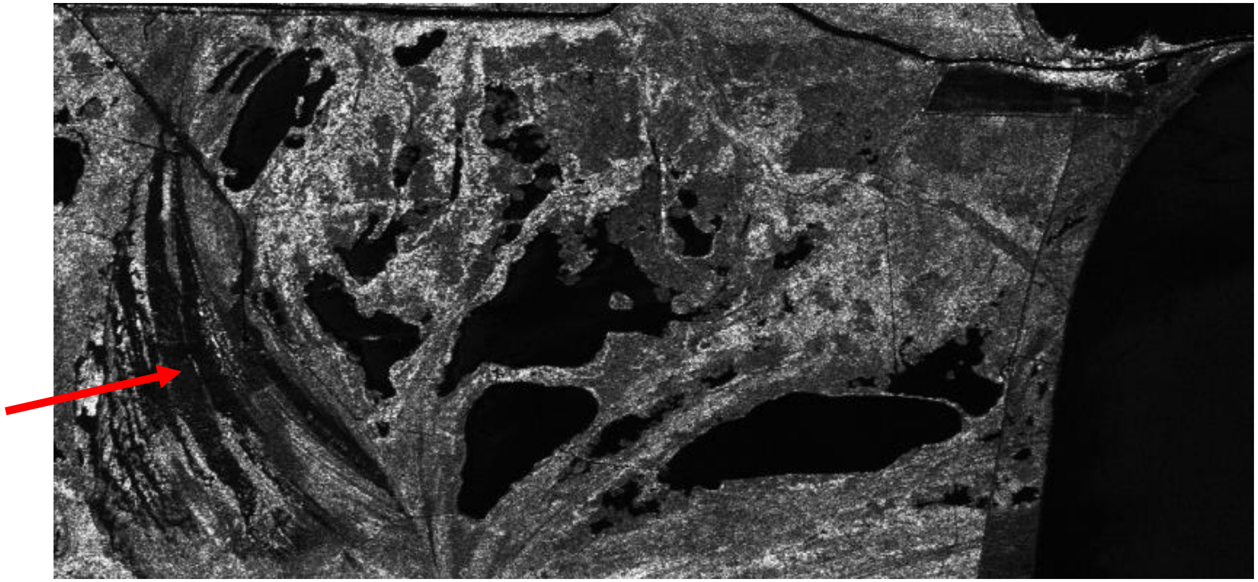
Preprocessing steps (using Nest):

- Import Raster Data → Alos Palsar or Envisat or ERS
- SAR Tools → Radiometric correction → Calibrate (Source bands: Intensity)
- Speckle filtering
- Ellipsoid correction → Geolocation grid
- Export Raster Data → Geotiff



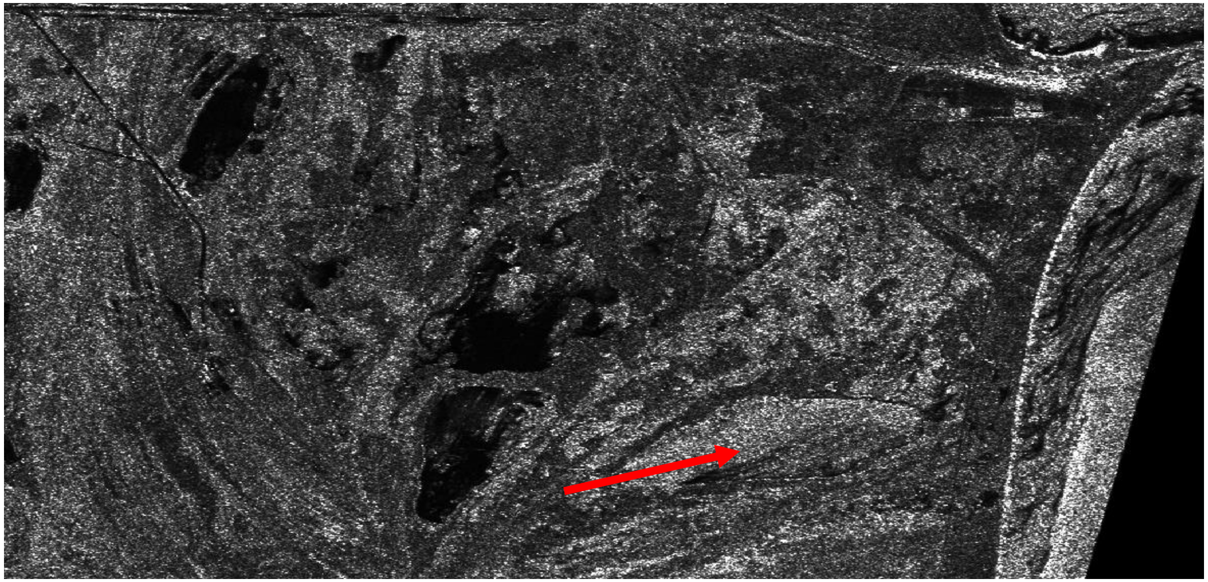
Calibrated SAR amplitude of a Alos PalSAR data

Water extent: SAR amplitude data



Alos Palsar data, HH
10.06.2007

-> problems with sand dunes, misidentified as water

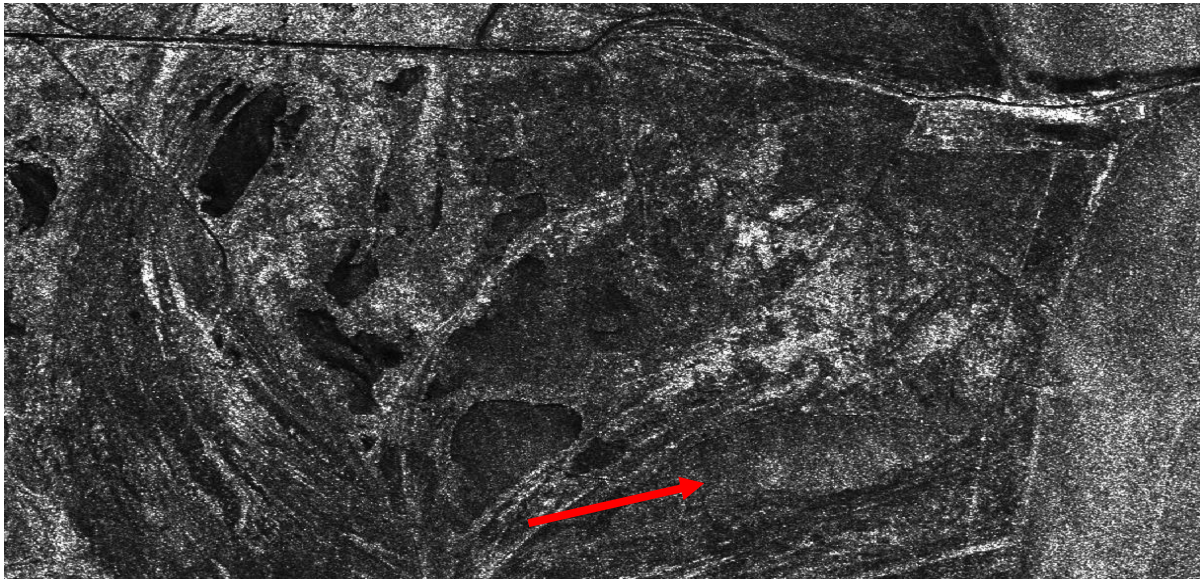


Envisat ASAR data, VV
23.07.2006

-> problems with wavy water identification

Water extent: SAR amplitude data

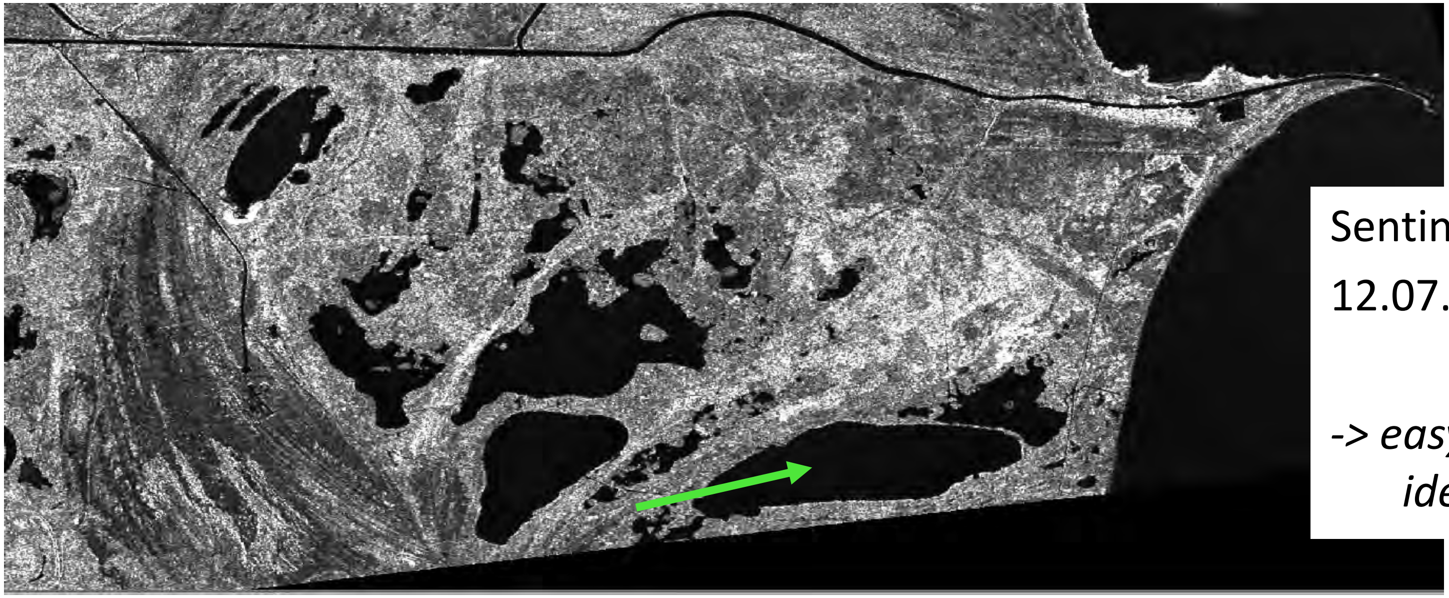
Google Earth imagery
19.08.2006



ERS-1 data, VV
18.07.1992

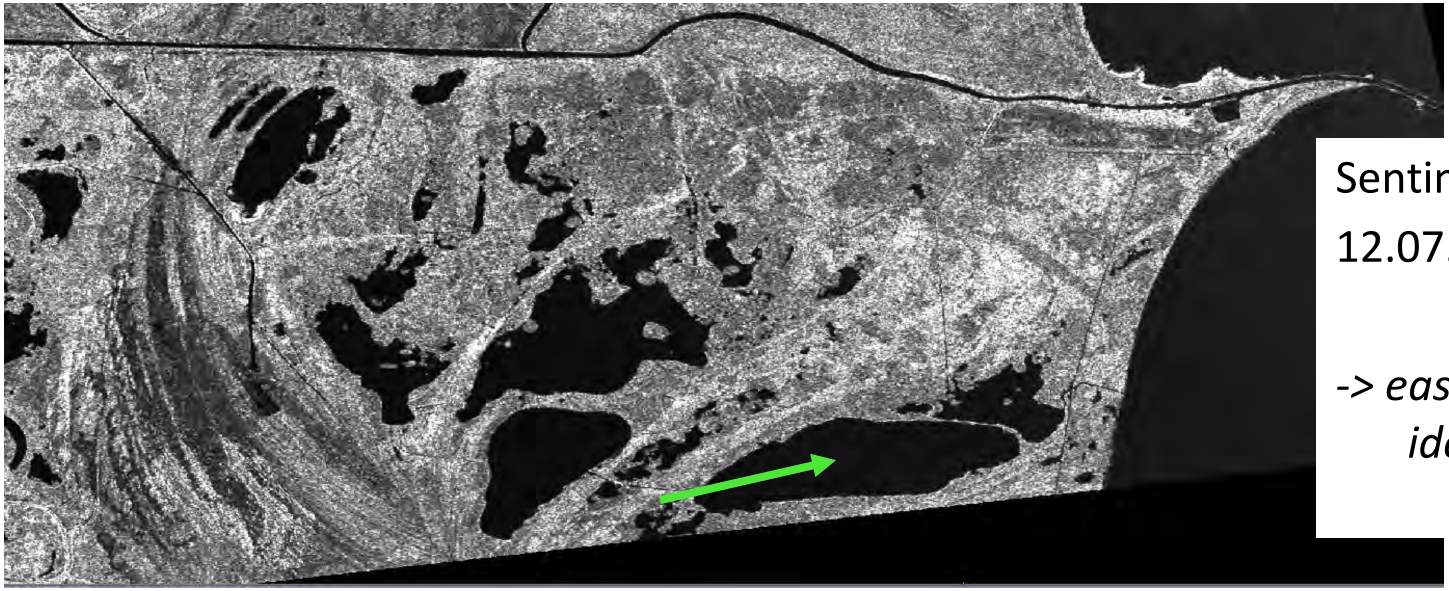
-> problems with wavy water identification

Water extent: SAR amplitude data



Sentinel-1 data, VV
12.07.2014

-> easy open water identification

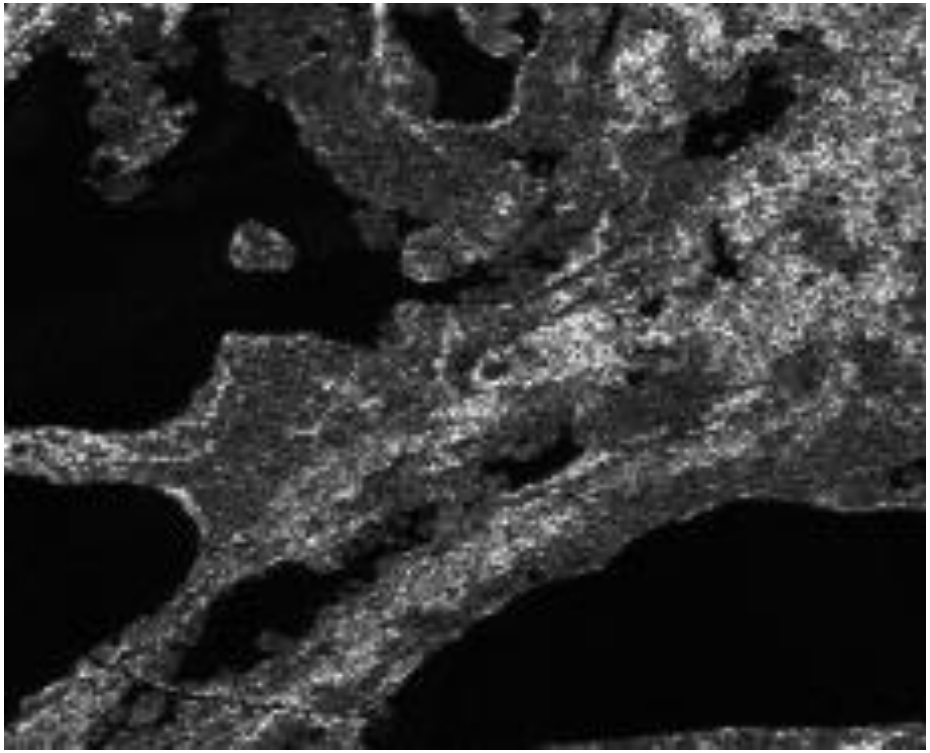


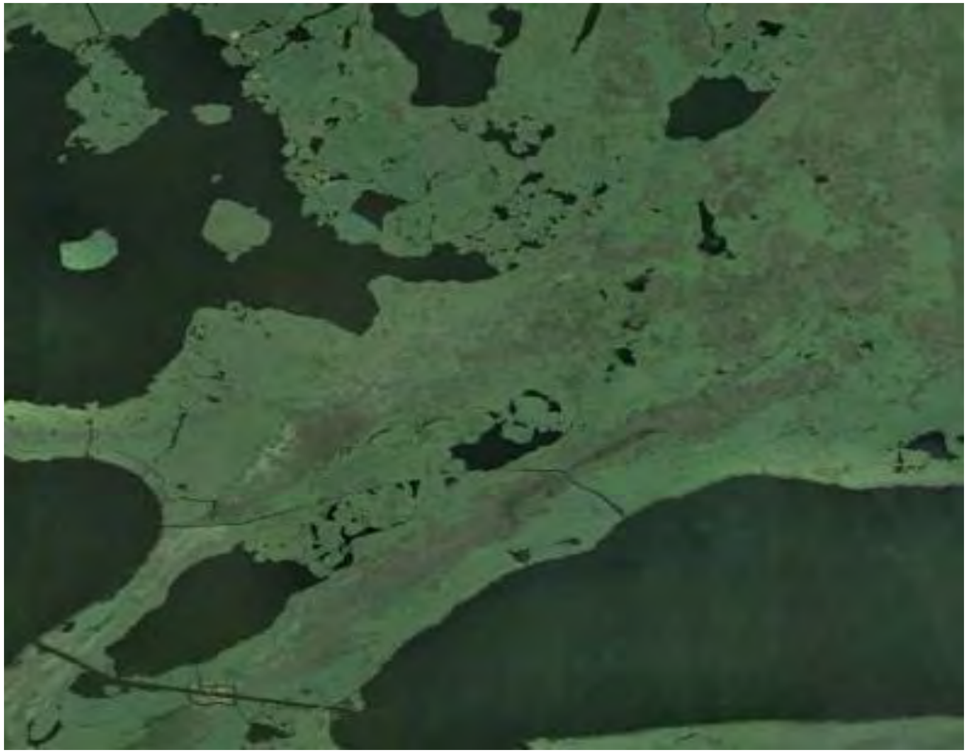
Sentinel-1 data, VH
12.07.2014

-> easy open water identification

Water extent: SAR amplitude data

- We may identify 3 main classes on the SAR image:
  - black : open water / sand dunes;
  - grey: water / dry areas covered by small vegetation / floating reeds;
  - white: vegetation protruding the water surface / forested areas / urban areas (where possible double bounce mechanism is present), or dry land covered by taller vegetation / urban areas (single bounce).





Water extent: SAR amplitude data

- **2 methods were applied to classify the SAR amplitude data in 3 classes:**

  - ✓ **K-means unsupervised classification** (Beam, Nest, Envi)

  - ✓ **Thresholding algorithm** (in-house implemented in Matlab):

    Step 1: Image enhancement

    - bilateral noise filter

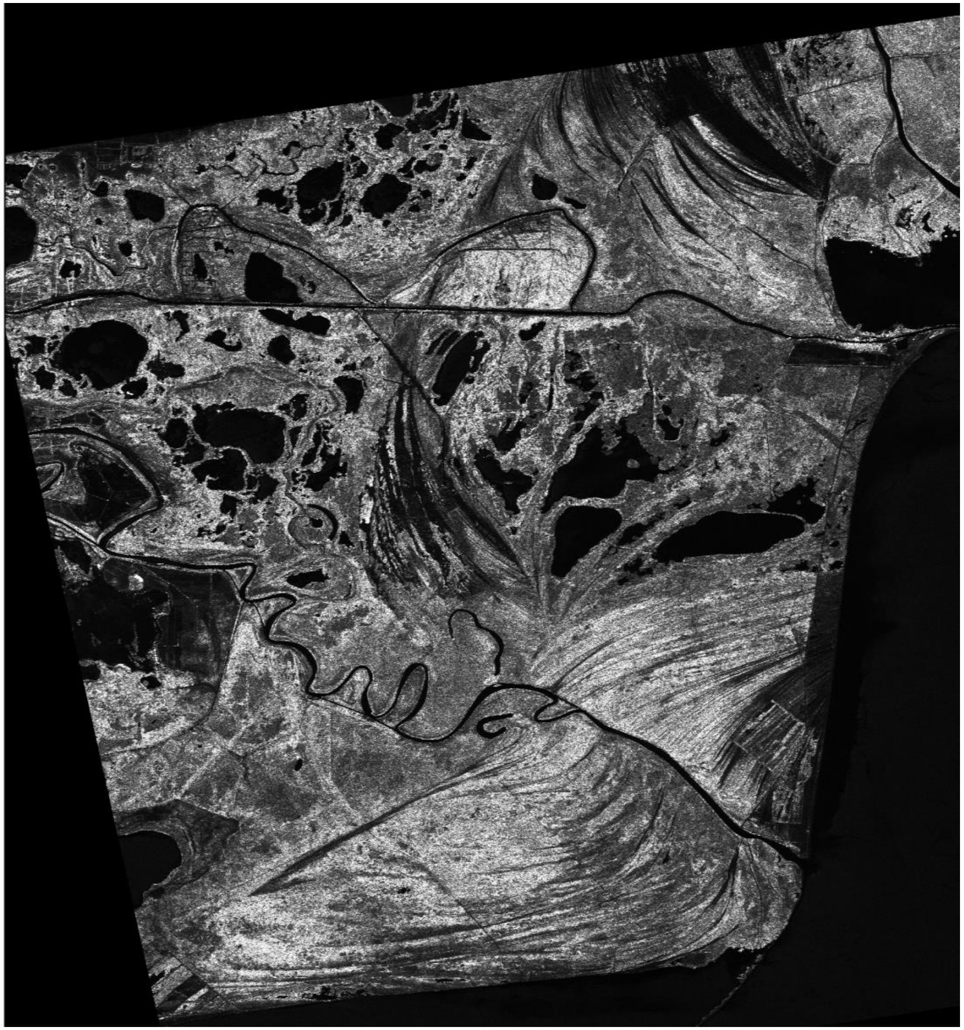
      This filter significantly removes speckle noise while true structures, edges and contour information are well preserved.
    - Histogram equalization

    Step 2: Thresholds choice such that to obtain 3 classes

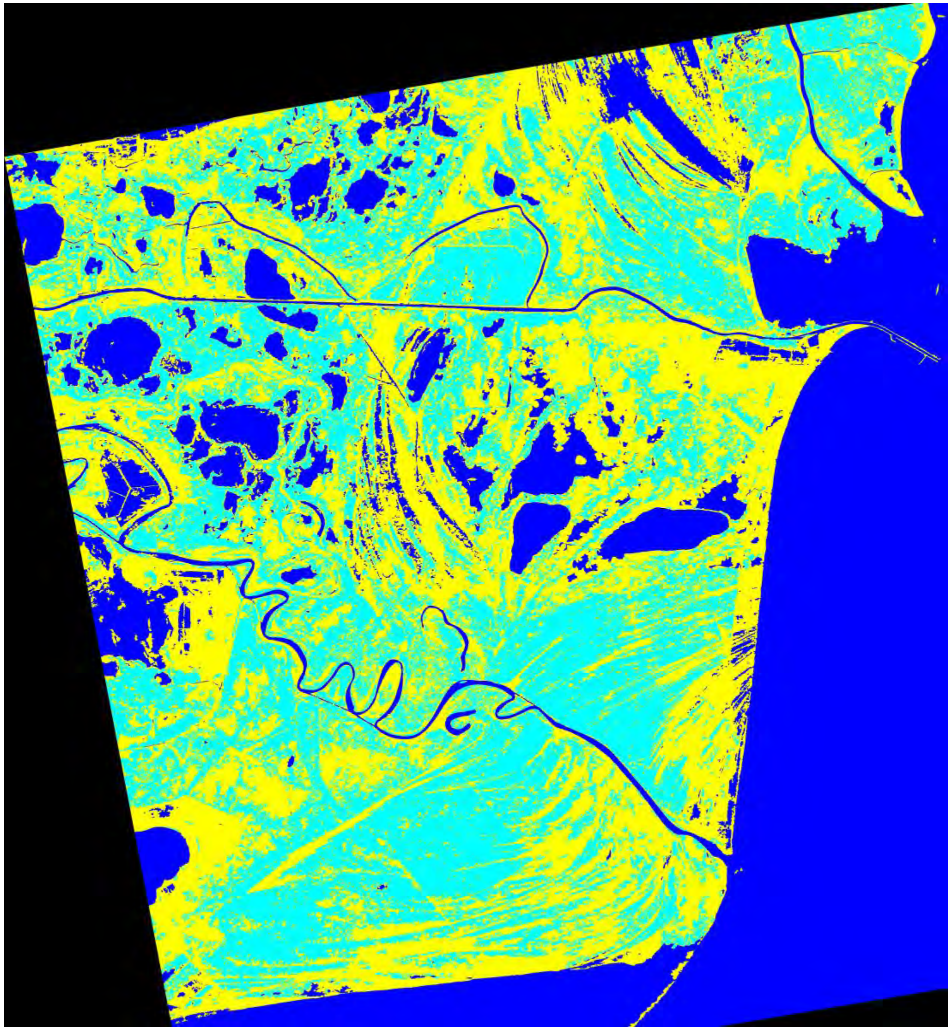
    Uses an exigent, low threshold for the extraction of the water surfaces and a relaxed, higher limit for the wet areas

    Step 3: automatic absorption of small segments, i.e. any area smaller than a certain number of pixels will be assimilated by the bigger neighboring area

Water extent: SAR amplitude data

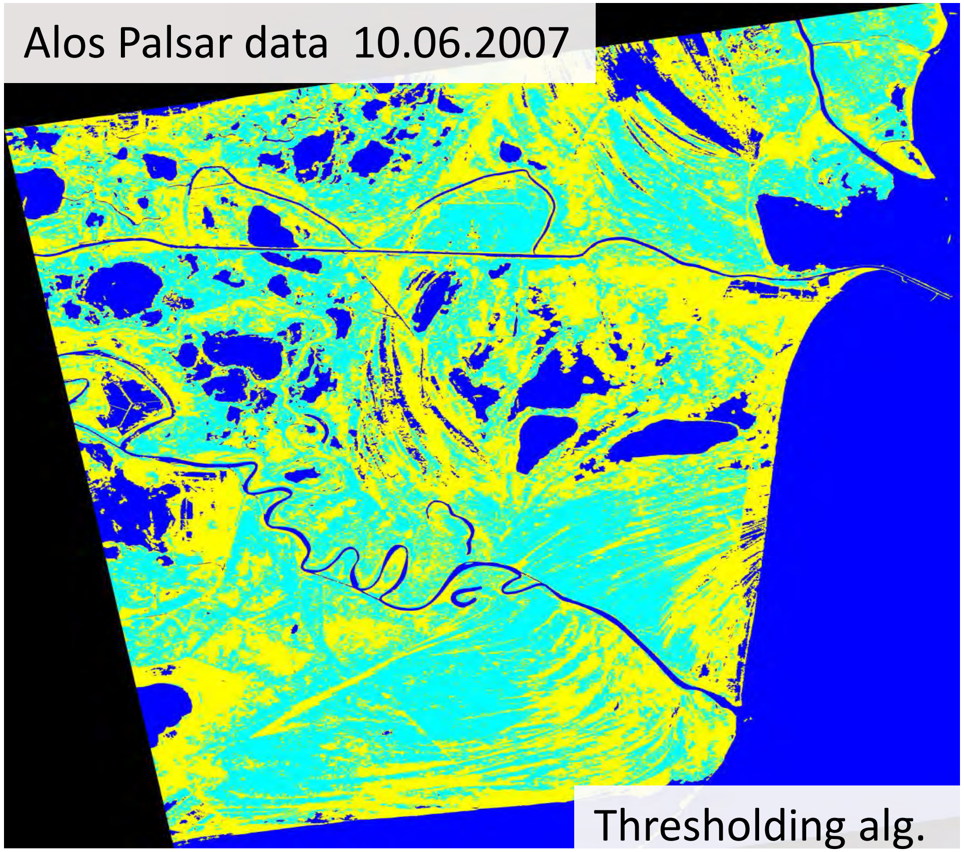


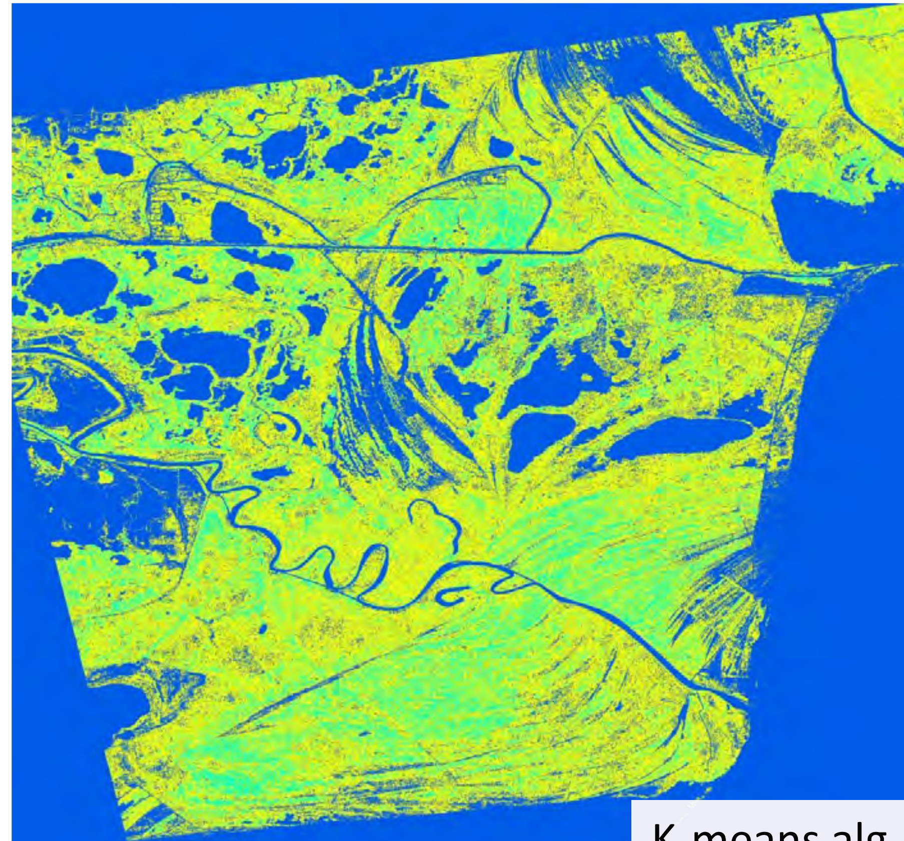
Alos Palsar data, 10.06.2007

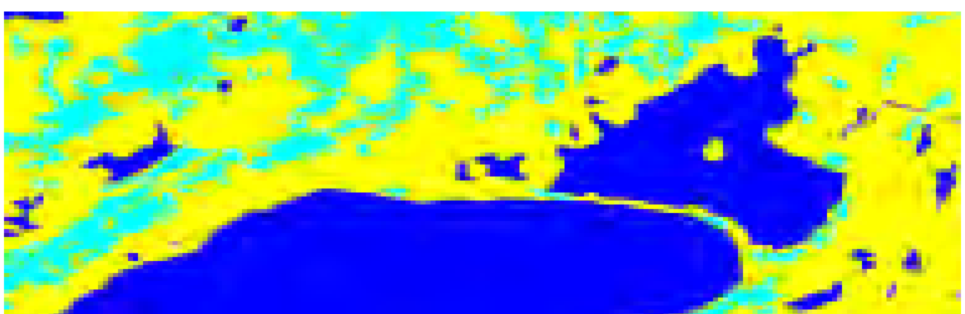


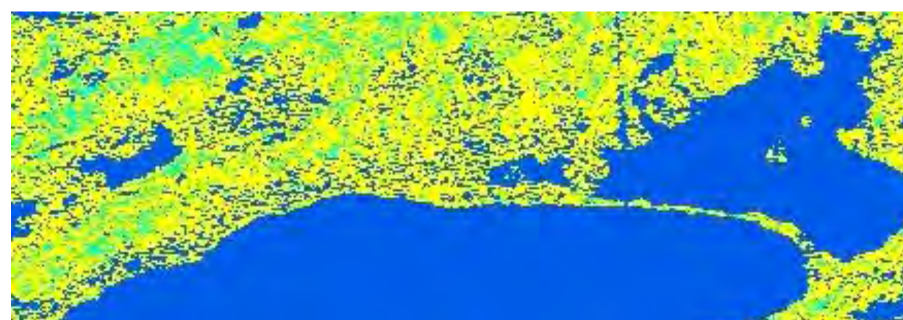
Thresholding alg. classification

Water extent: SAR amplitude data

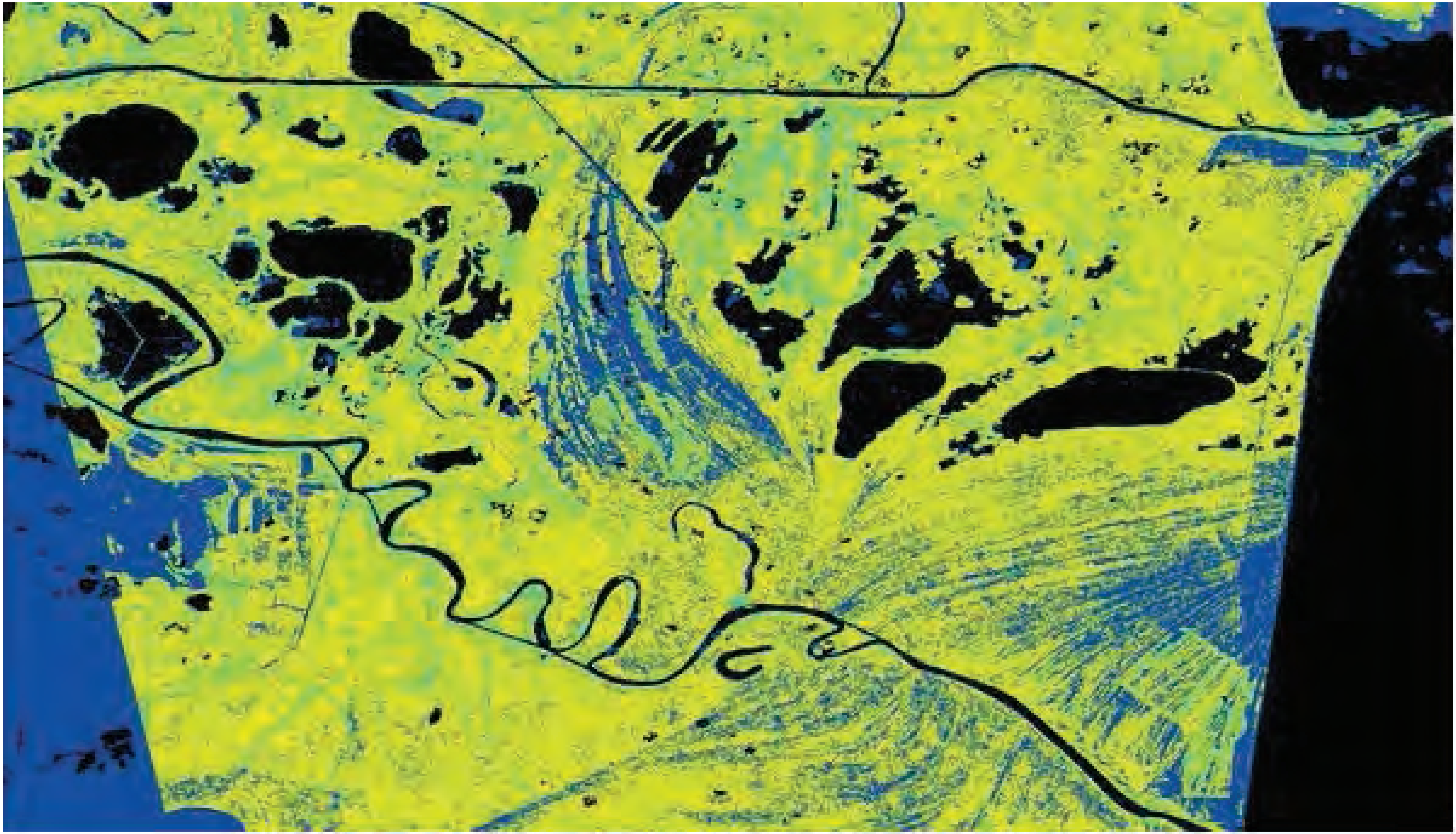






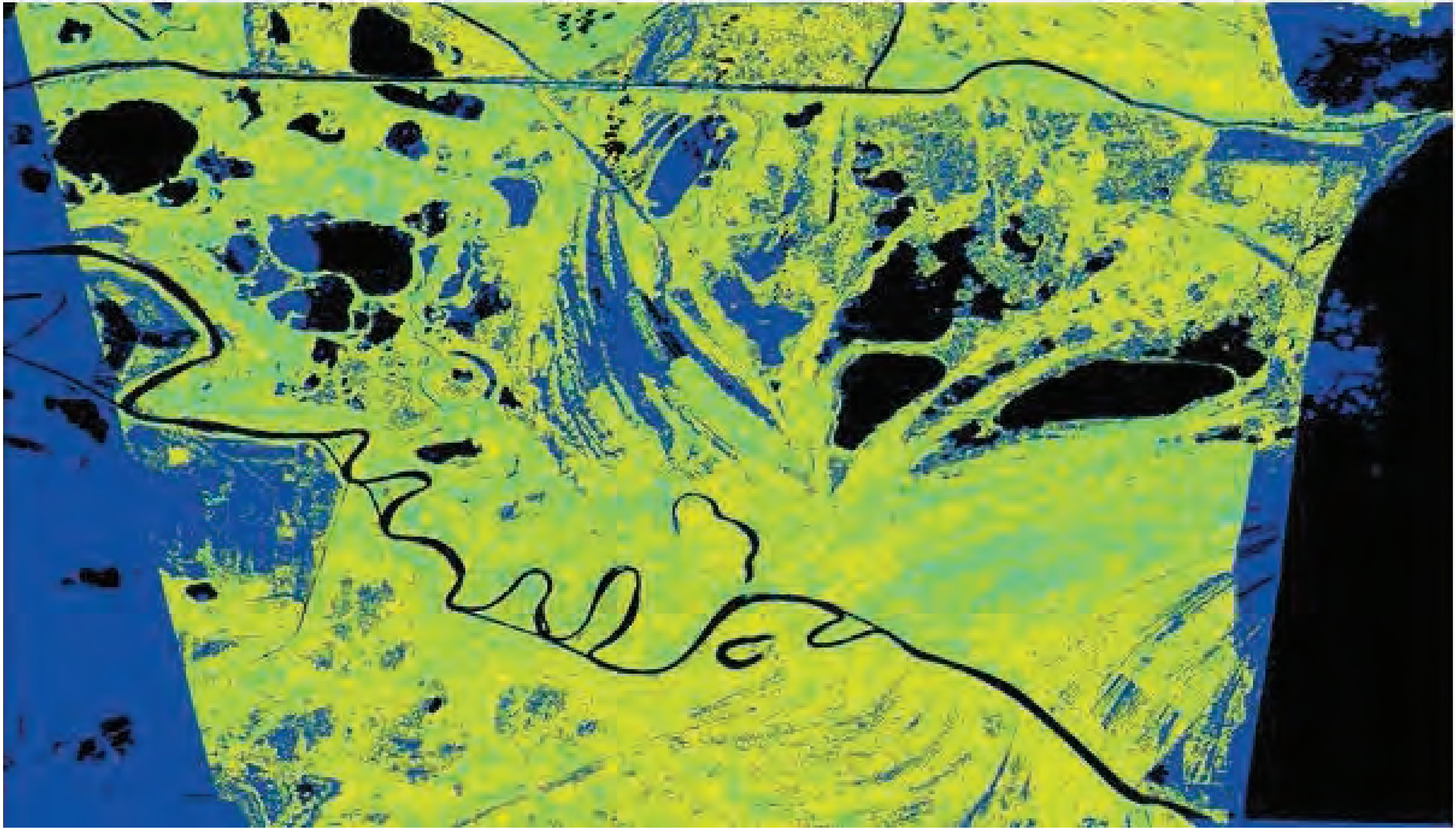


Water extent: SAR amplitude data



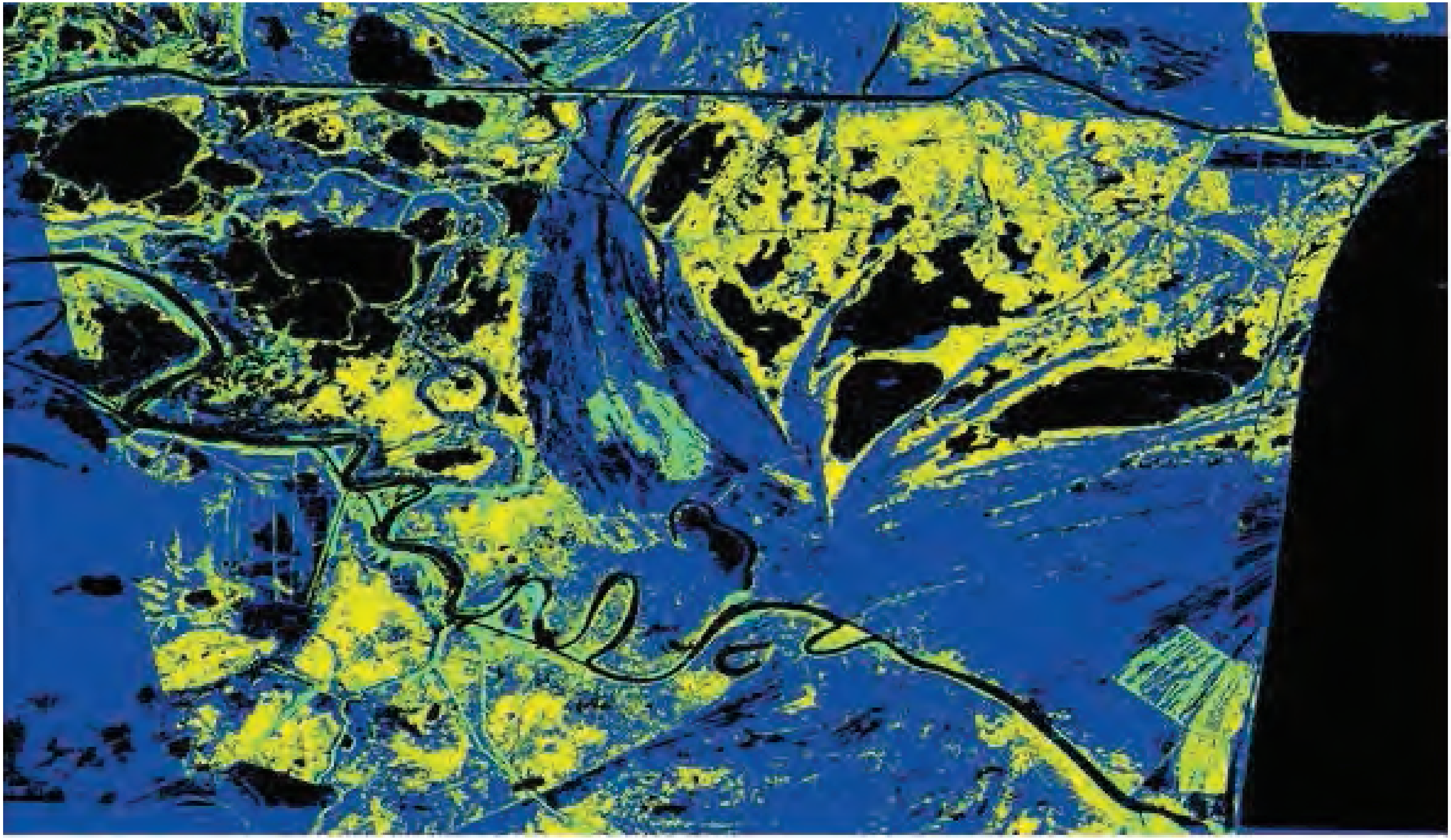
The open water mask (black) from Landsat scene, 07.09.2007, over the K-means result of PalSAR scene, 10.09.2007; 54 cm water level at Tulcea

WP 3 Water extent: SAR amplitude data



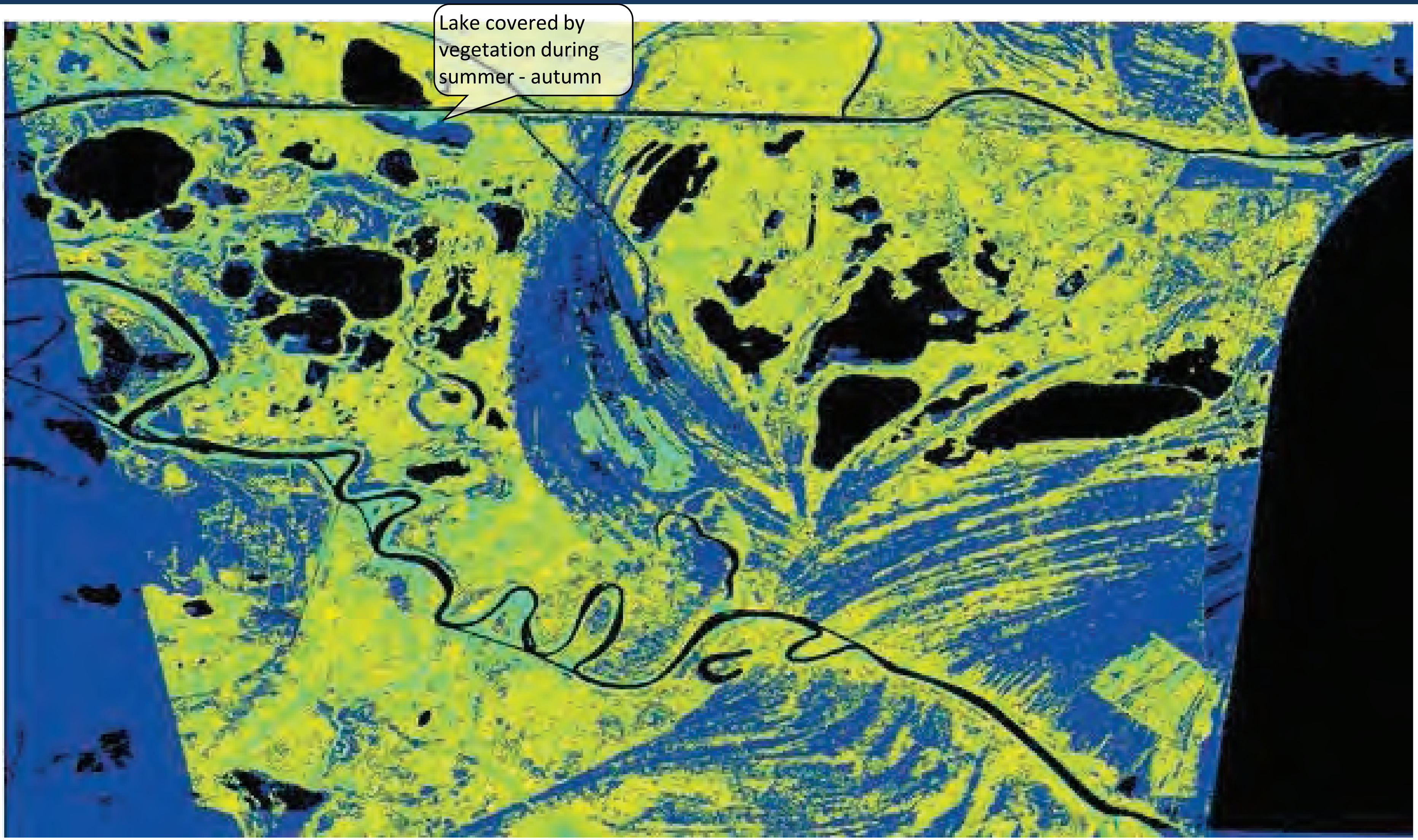
The open water mask (black) from Landsat scene, 15.09.2010, over the K-means result of PalSAR scene, 18.09.2010, 205 cm water level at Tulcea

Water extent: SAR amplitude data



The open water mask (black) from Landsat scene, 07.03.2010, over the K-means result of PalSAR scene, 18.03.2010, 369 cm water level at Tulcea

Water extent: SAR amplitude data

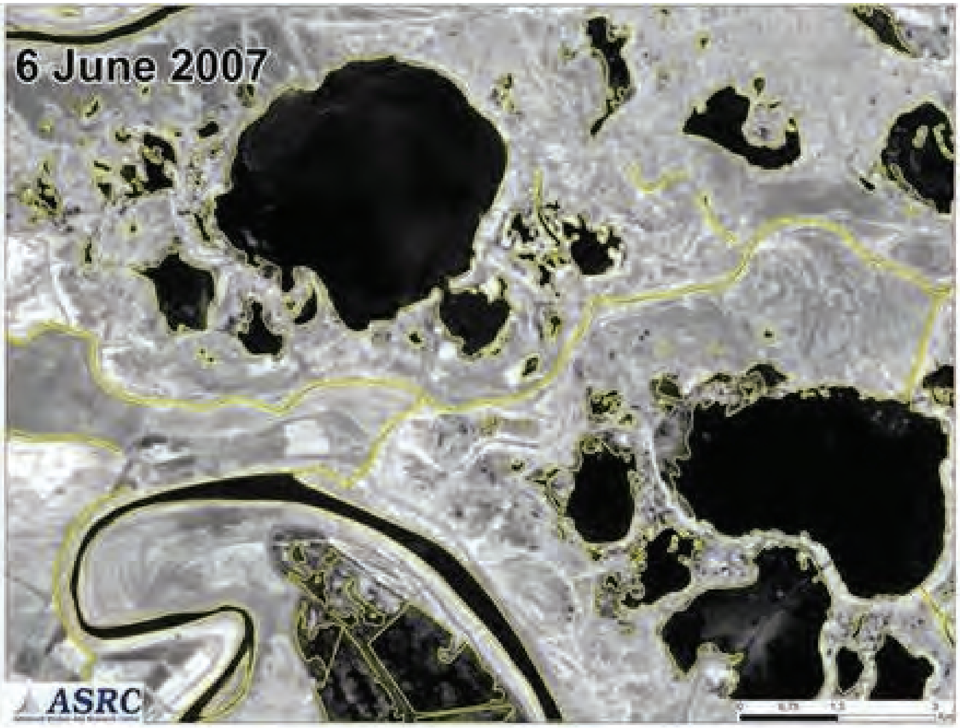


The open water mask (black) from Landsat scene, 11.06.2010, over the K-means result of PalSAR scene, 18.06.2010, 381 cm water level at Tulcea

Water extent: Landsat data

Water extent computation based on:

- NDWI (Normalized Difference Water Index) threshold;
- SWIR (Short-wave Infrared) band density slicing;
- Fu June formula: (GREEN + RED) > (NIR + SWIR);
- K-means unsupervised classification;



Near Infrared band of Landsat scene and manually extracted water bodies (yellow lines)

Water extent: Landsat data

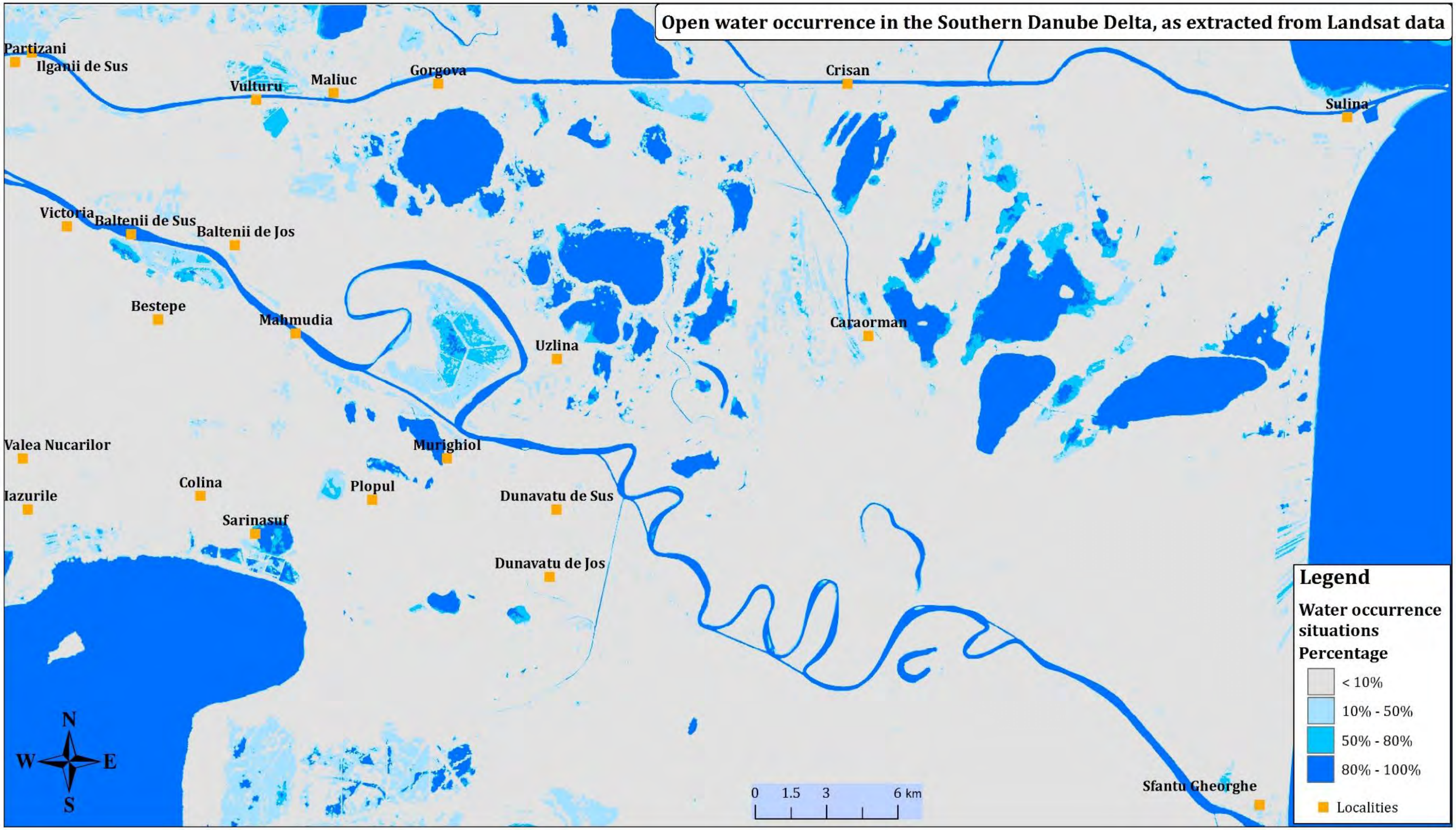
Comparison of different water extent extraction methods

Scene date	Water surface									Overestimated pixels			
	Manual extraction	Unsupervised classification		SWIR band density slicing		NDWI threshold		Fu June's formula		Unsupervised classification	SWIR band density slicing	NDWI threshold	Fu June's formula
	ha	ha	%*	ha	%*	ha	%*	ha	%*				
3-Jun-2007	4847.12	4357.17	89.89	4279.32	88.29	3816.72	78.74	4355.37	89.85	182.34	142.38	46.89	181.08
21-Jul-2007	4737.95	4316.04	91.10	4203.09	88.71	3512.61	74.14	4282.02	90.38	197.46	135.36	39.51	159.75
22-Aug-2007	4865.26	4338.54	89.17	4264.65	87.66	3828.60	78.69	4336.74	89.14	144.81	91.44	26.37	97.92
7-Sep-2007	4730.49	4287.51	90.64	4258.62	90.02	3774.60	79.79	4294.08	90.77	202.77	171.99	49.95	153.99
23-Sep-2007	4964.66	4500.54	90.65	4460.85	89.85	4233.51	85.27	4480.65	90.25	206.28	193.77	54.9	142.56
7-Jul-2008	4850.13	4163.04	85.83	4117.77	84.90	3688.47	76.05	4083.48	84.19	137.88	89.01	36.9	81.99
24-Aug-2008	4444.54	3878.55	87.27	3717.72	83.65	3457.71	77.80	3980.79	89.57	584.19	354.87	37.08	495.81
8-Jun-2009	4813.37	4203.81	87.34	2530.35	52.57	3109.95	64.61	4107.06	85.33	237.6	37.71	23.4	122.13
26-Jul-2009	4653.87	4196.88	90.18	2497.68	53.67	3723.21	80.00	4104.36	88.19	302.76	85.41	36.09	196.29
27-Aug-2009	4594.91	4119.12	89.65	4091.58	89.05	3845.34	83.69	4071.69	88.61	172.08	193.32	46.08	119.79
11-Jun-2010	4491.82	4026.06	89.63	3981.15	88.63	3768.93	83.91	4017.42	89.44	113.85	97.11	33.66	119.52
29-Jul-2010	4531.78	4048.38	89.33	3921.03	86.52	3783.60	83.49	4007.52	88.43	216.99	133.65	38.7	189.36
15-Sep-2010	4107.69	3638.34	88.57	3296.16	80.24	3280.23	79.86	3485.07	84.84	313.74	112.86	117.63	188.28
1-Oct-2010	4787.55	4297.41	89.76	4335.75	90.56	4179.51	87.30	4296.24	89.74	166.41	210.96	85.23	149.4

* Percentages were calculated corresponding to the manual extraction values

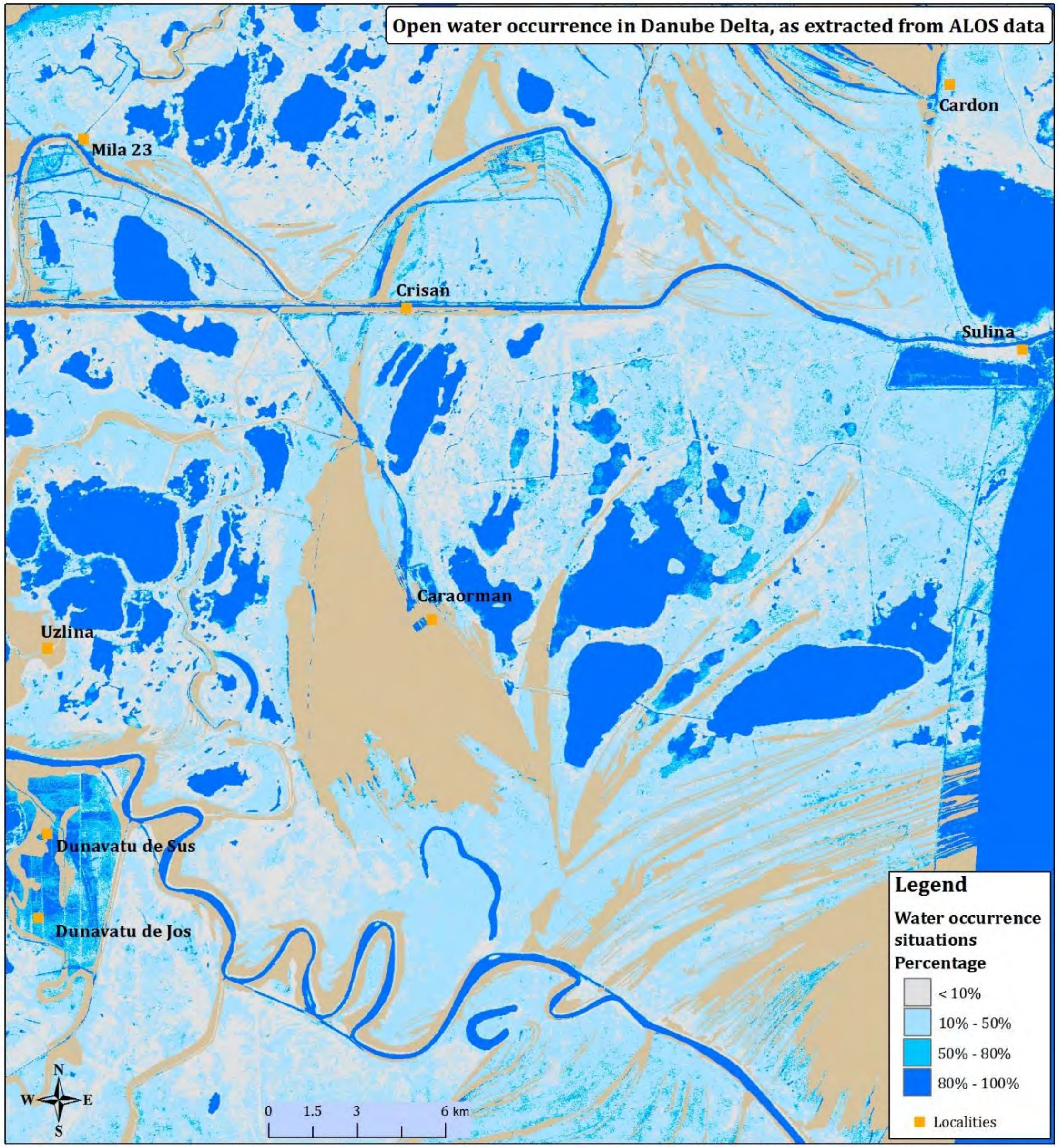
Fu June's formula was chosen to be the most suitable automatic procedure for analyzing an entire set of images

Water extent: obtained results



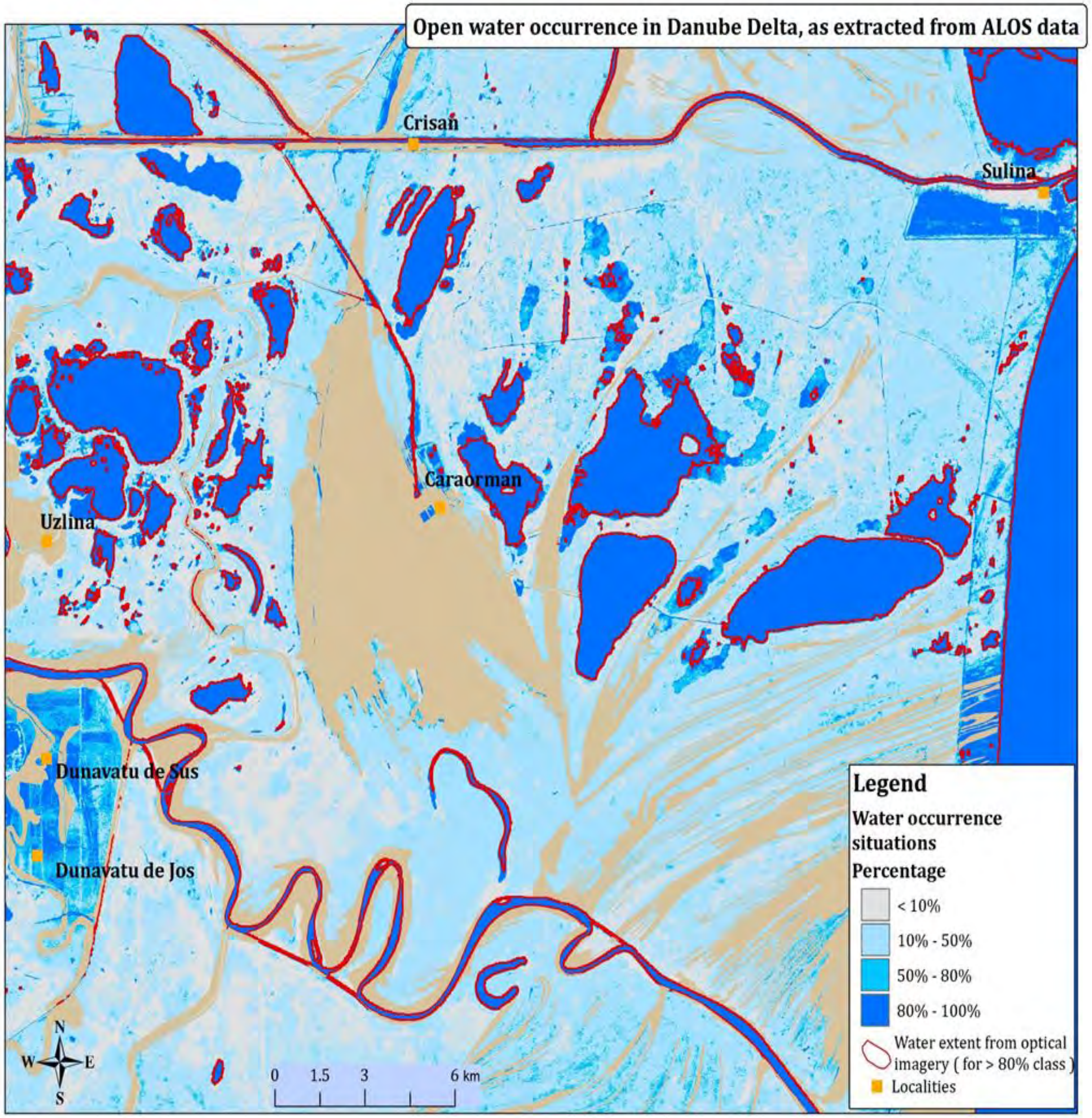
A statistical calculation in order to stress out the areas that are most commonly covered by water and also areas prone to be flooded; computed from a time series of 62 Landsat scenes covering the time period 1984 - 2013, with most of them from after year 2000 (53 out of 62).

Water extent : obtained results



- Statistical representation of the areas covered by water, extracted from 14 PalSAR data acquired during 2007 – 2010, with a layer of sand dunes and grinds overlaid on it

Water extent : obtained results



- Comparison of the water extent obtained from Landsat imagery (the 80 – 100 % class) – red lines - with the water extent probabilities obtained from PalSAR data

Water extent: Conclusions

- Water surface delineation can be done using optical and / or SAR remote sensing data. Both kind of data have their own characteristics which, depending on the targeted feature, can be seen as an advantage or drawback.

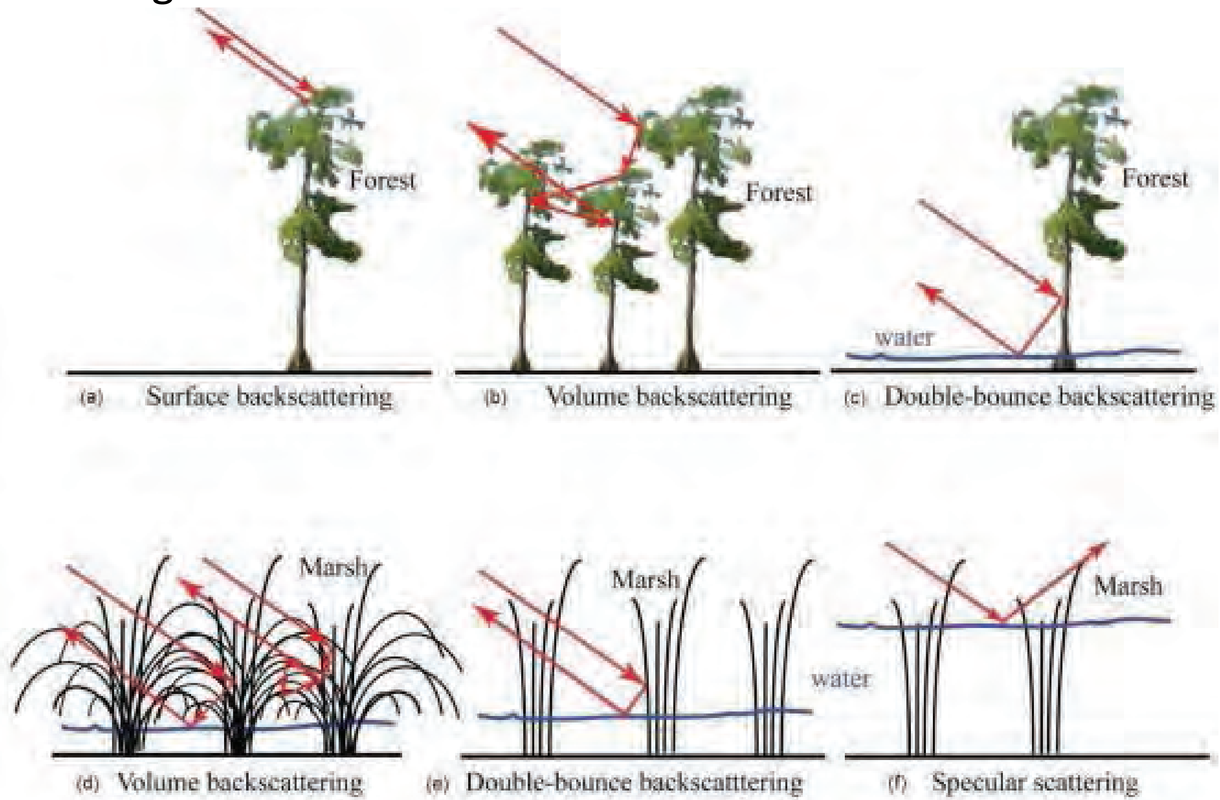
- Disregarding cloud cover, an optical scene can provide very accurate (depending on its resolution) open water extent delineation of water bodies which are uncovered by vegetation.

- On the other hand, radar imagery is not influenced by weather and do not ‘see’ thin layers of vegetation on water bodies, but the radar ‘sees’ as water also very high moisture/water saturated ground, marshy soil or sand dunes.

- The fusion of results from the 2 types of satellite data provides useful complementary information regarding the water surface.

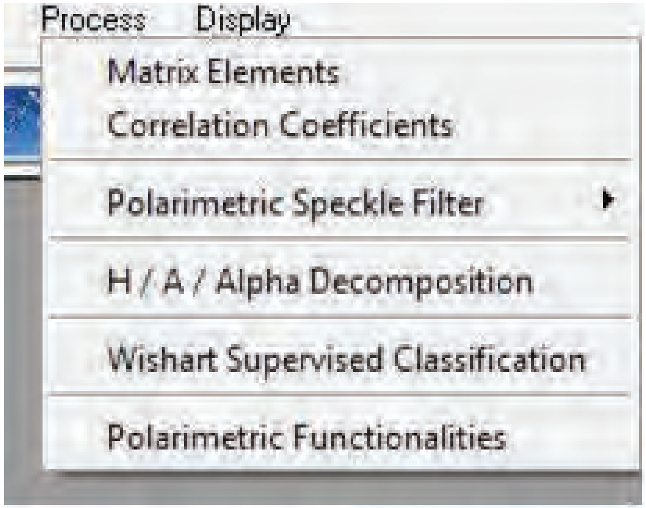
Polarimetric processing

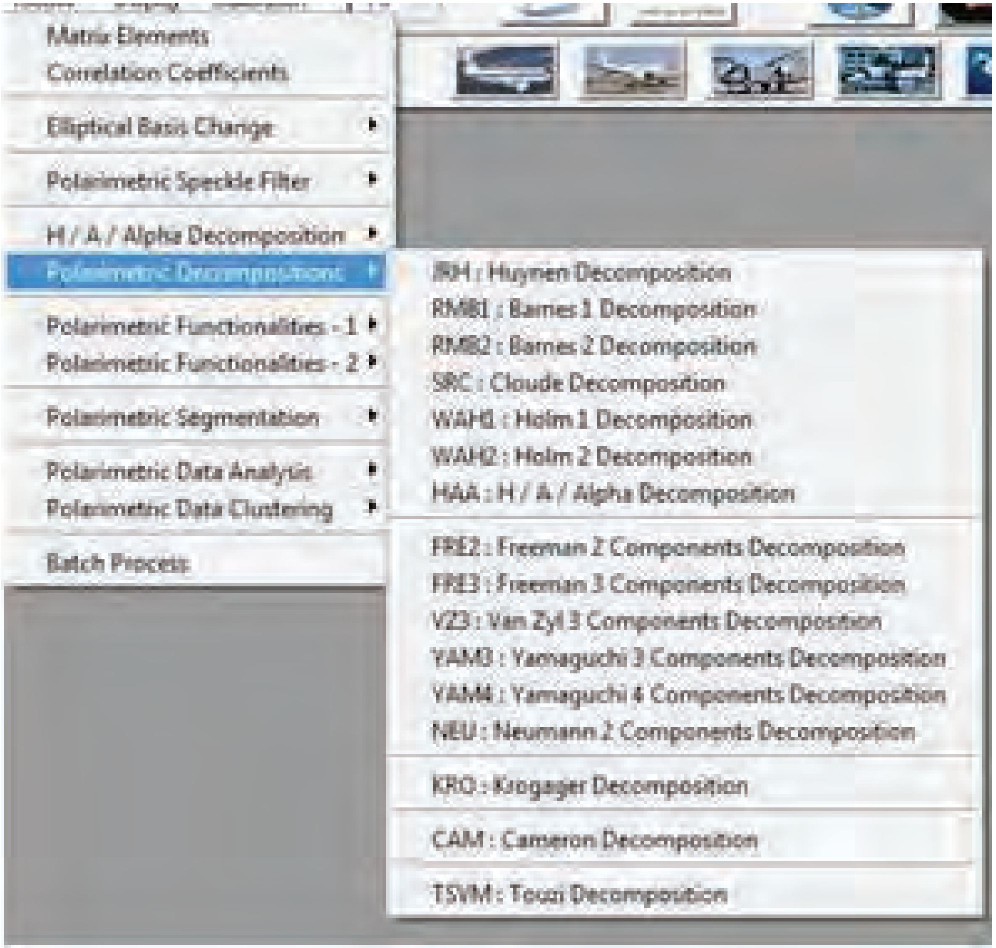
- Polarimetric techniques are designed to analyze the behaviour of the electromagnetic waves polarization and relate it to the ground backscattering mechanisms.
- Ground backscattering mechanisms are furthermore related to specific physical properties of the ground.



The three main groups of backscattering mechanism distinguished with PolSAR

Polarimetric processing



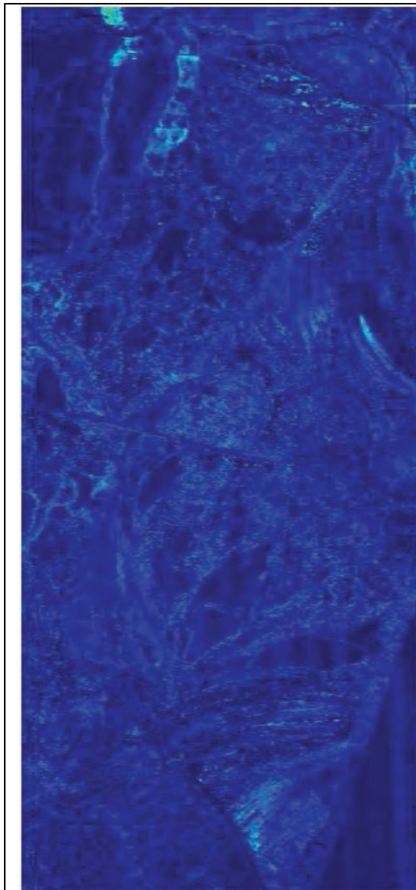


Polarimetric decompositions available in PolSARPro for dual-polarization (left) and for quad-polarization data (right)

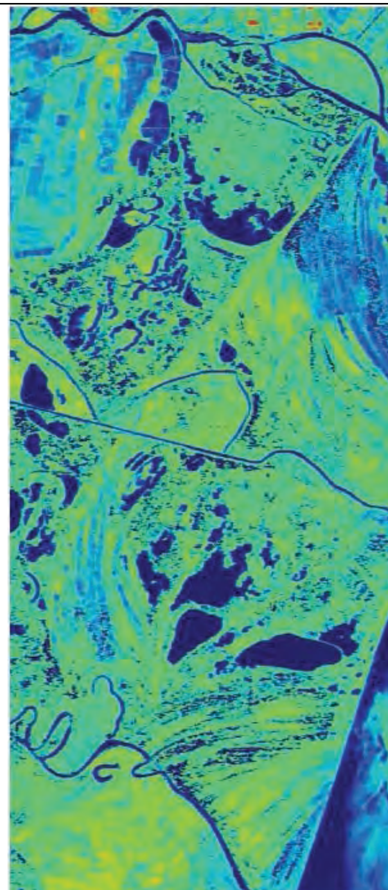
➢ Available data: 14 Alos PalSAR dual-polarized;
1 Alos PalSAR quad-polarized

Polarimetric processing

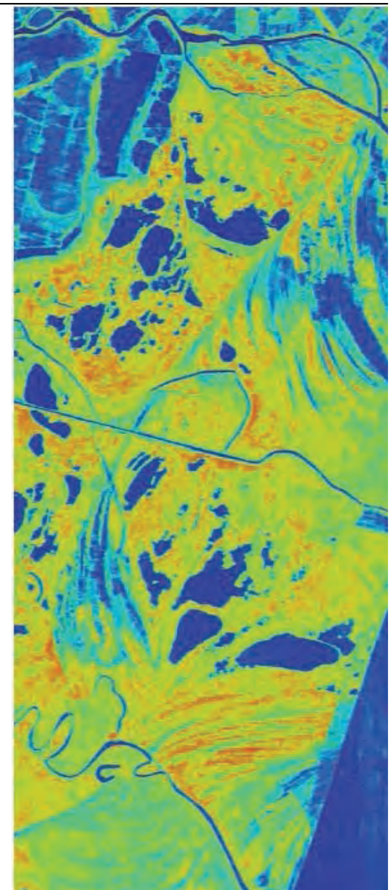
- Color-coded backscattering mechanisms extracted with **Freeman decomposition** (blue - singe bounce, red-double bounce, green-volumetric scattering)
- The amplitude and spatial distribution separately for every backscattering mechanism:



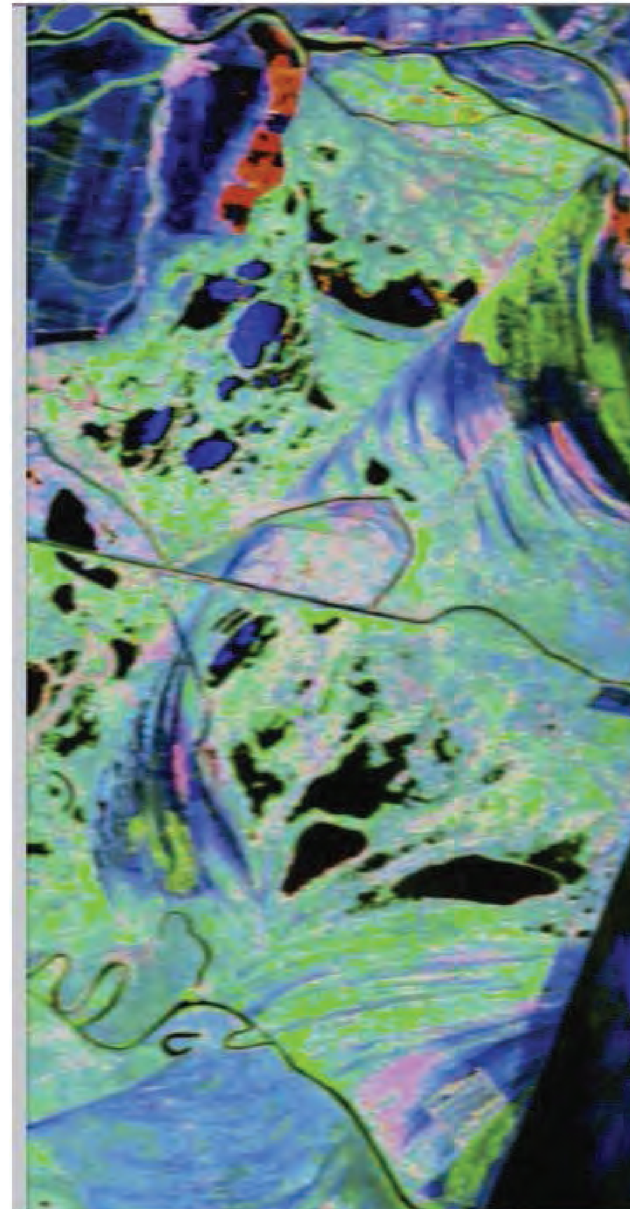
Freeman double (even)-bounce



Freeman single (odd)-bounce

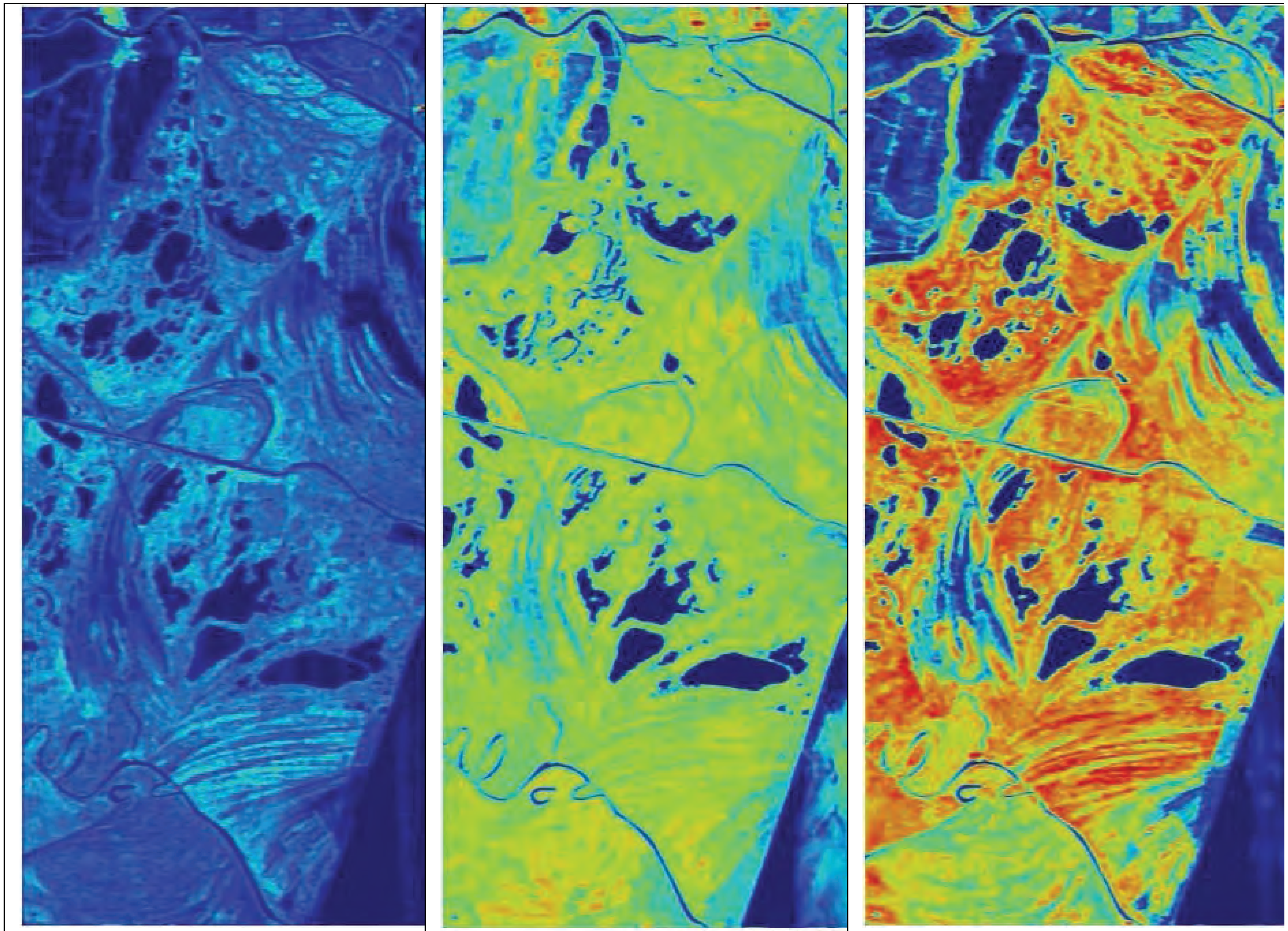


Freeman volumetric



Polarimetric processing

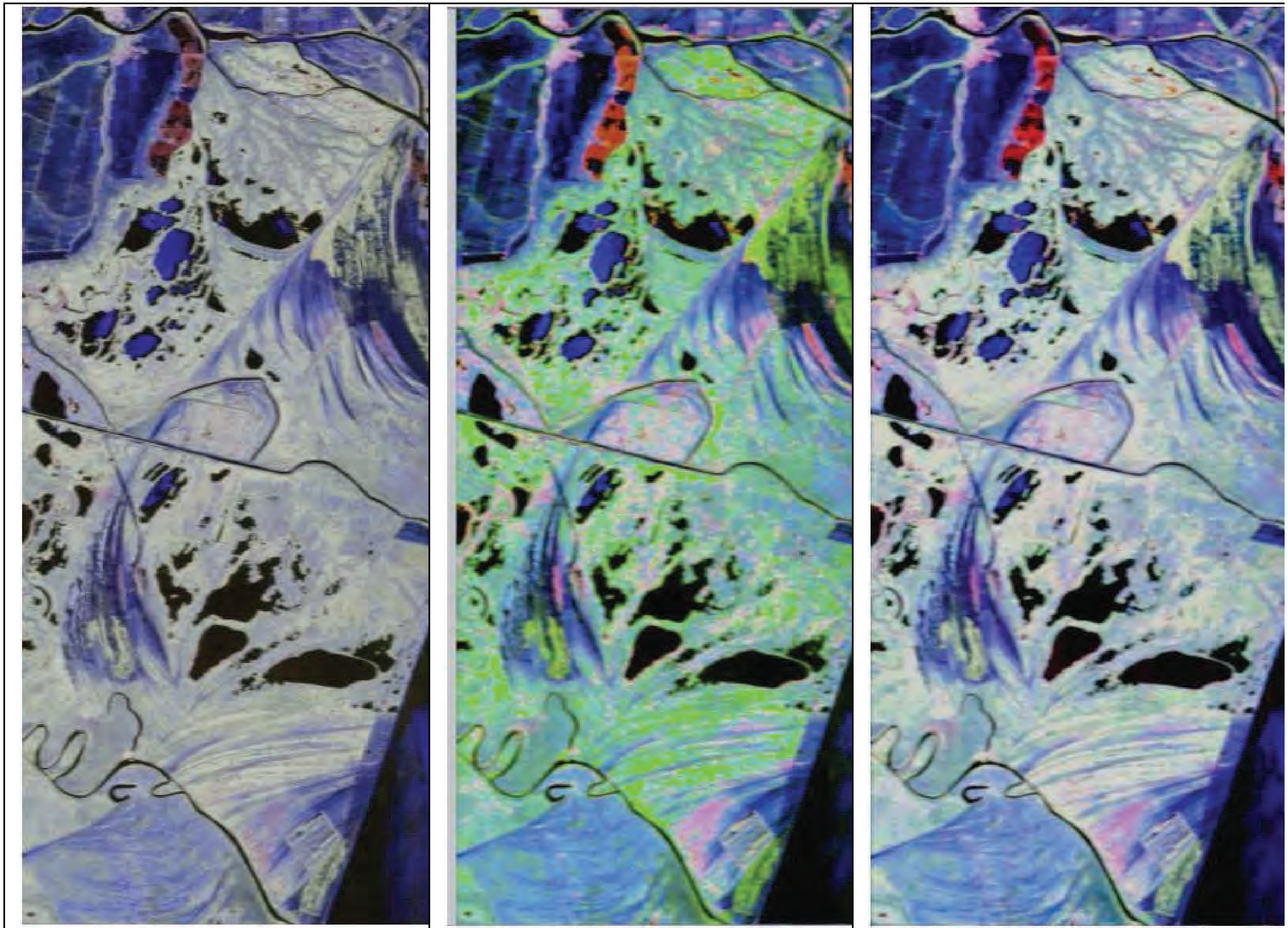
- The amplitude and spatial distribution separately for every backscattering mechanism extracted from the Van-Zyl decomposition:



Van Zyl double-bounce	Van-Zyl single-bounce	Van Zyl volumetric

Polarimetric processing

➢ Comparison between Pauli, Freeman and Van-Zyl polarimetric decompositions:



Pauli	Freeman	Van Zyl

Polarimetric processing

- The polarimetric statistical Wishart classification creates a very complex image of the Danube Delta

Open surface water

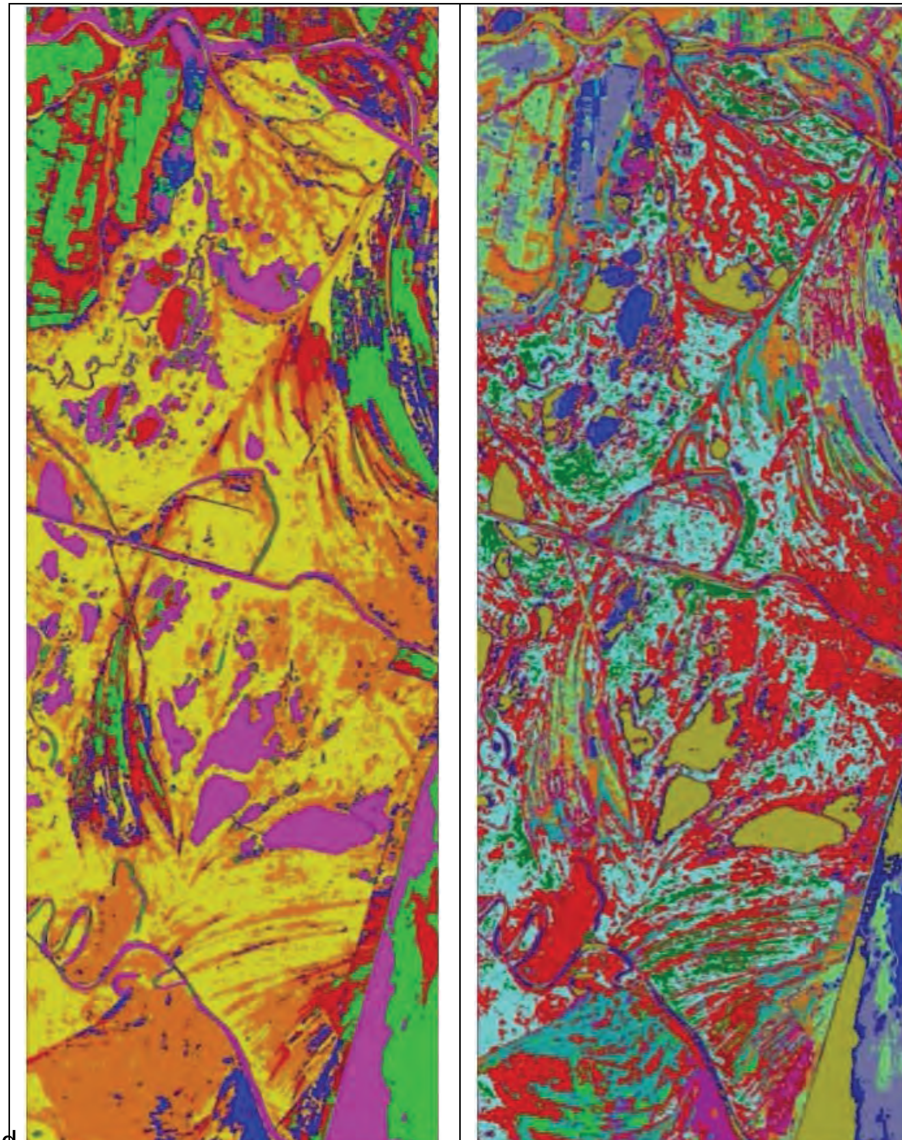
Reed vegetation and bushes on compact plaur

Inland high dune vegetation

Dunes vegetation

Mixed sedges vegetation

Unidentified; at the edge between water and vegetation/land



Wishart H-Alpha 8 classes

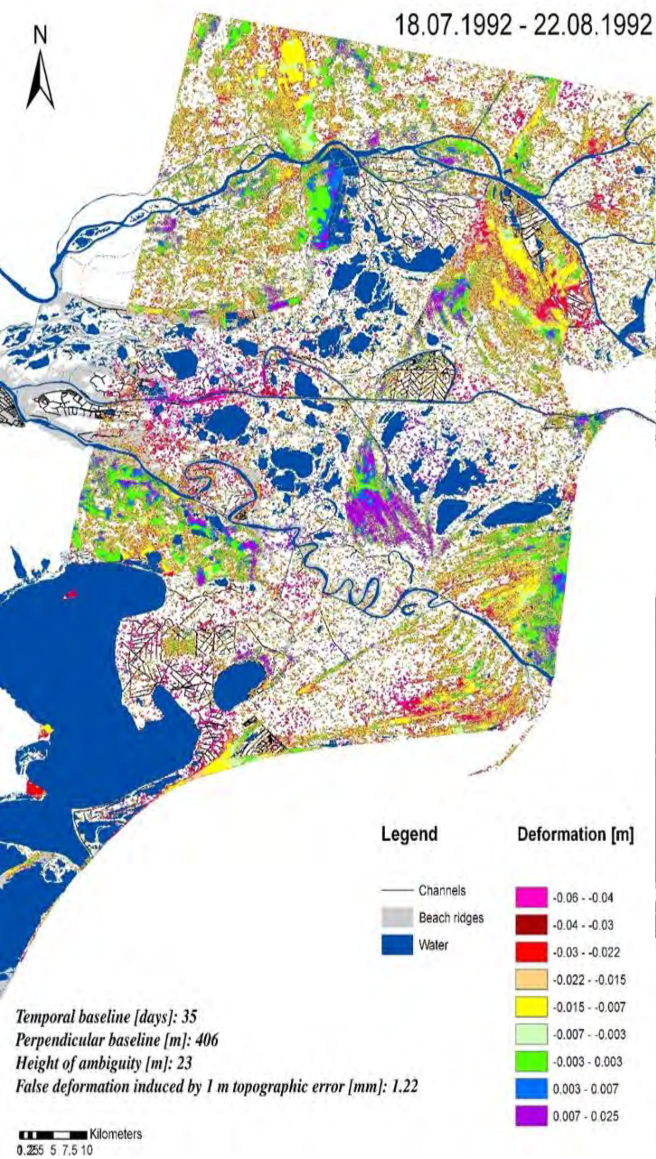
Wishart H-A-Alpha 16 classes

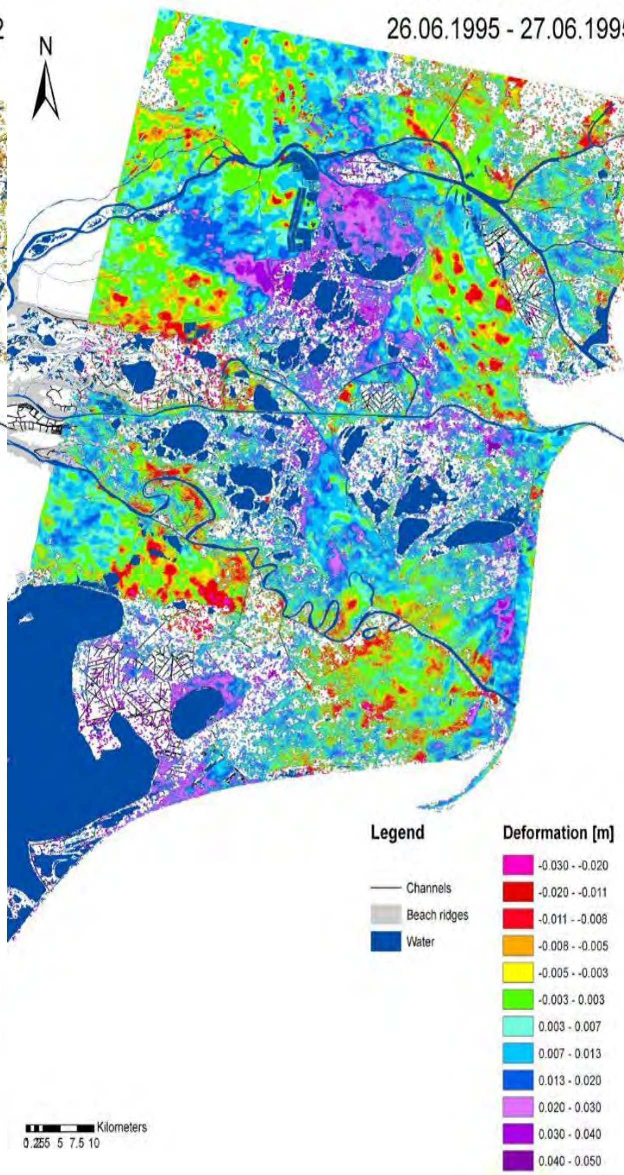
Wetland InSAR

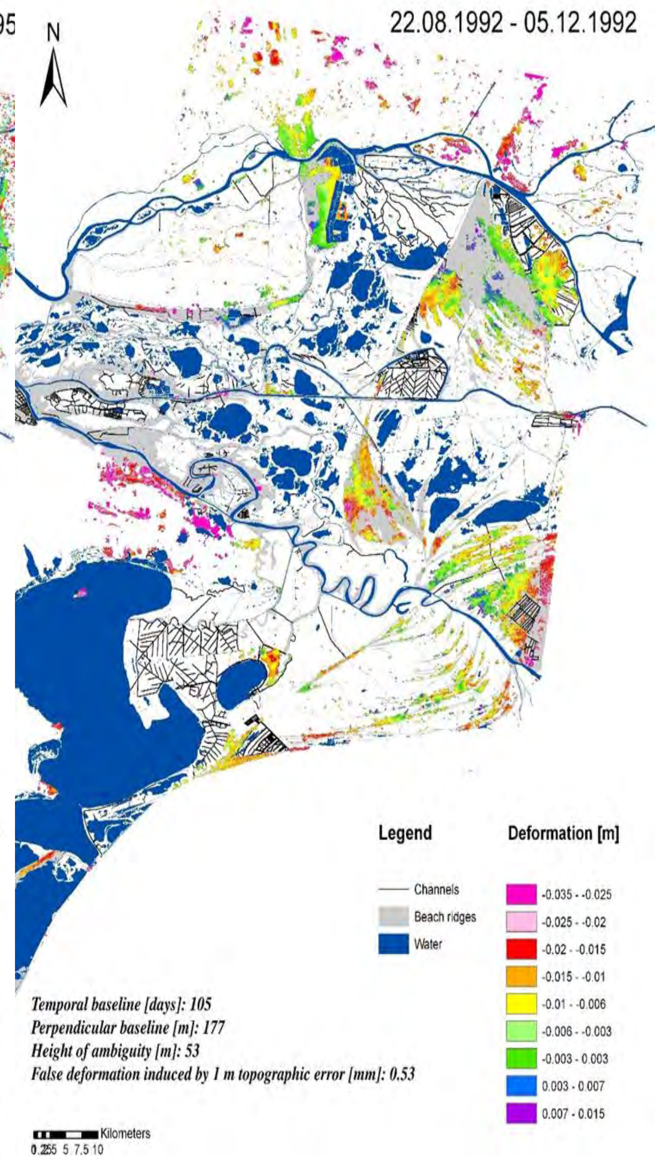
- SAR interferometric phase can be related to water level changes in aquatic environments with emergent vegetation.
- The main idea is the presence of water at the base of the vegetation canopy (double-bounce backscattering), and/or the presence of floating islands of vegetation moving up and down together with the water levels (single bounce reflections). Open surface water is not suitable for the analysis since the specular reflections do not return to the radar.

Double-bounce

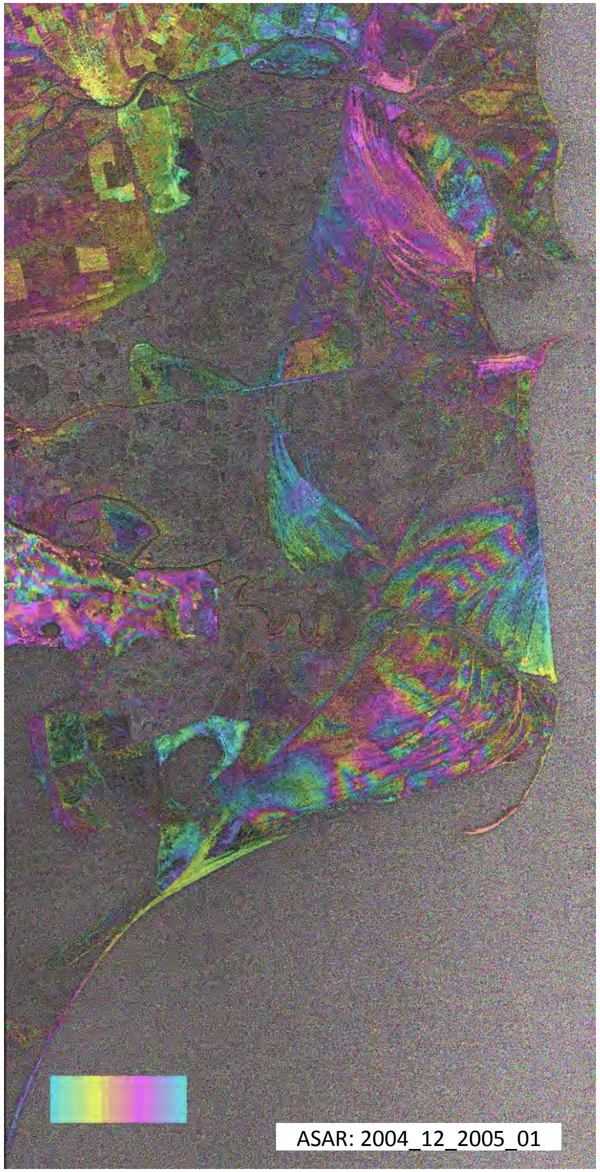
DInSAR analysis: ERS

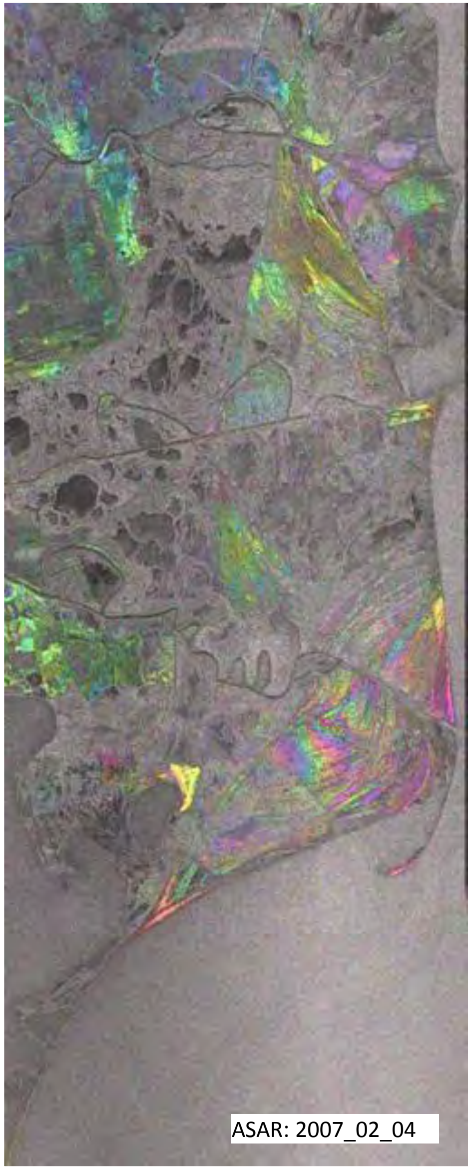


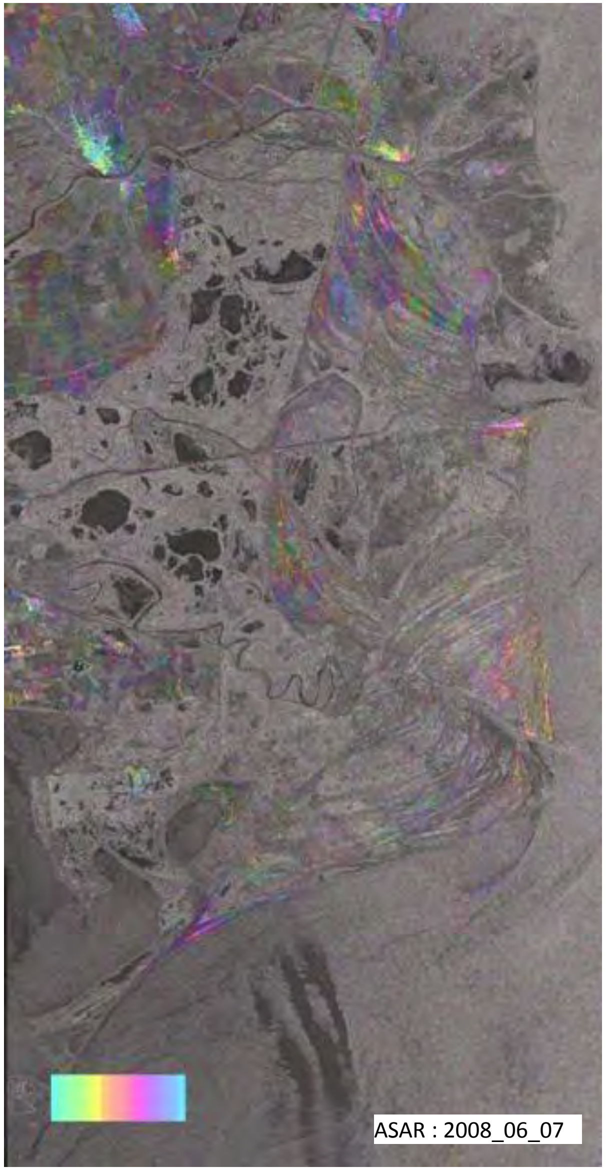




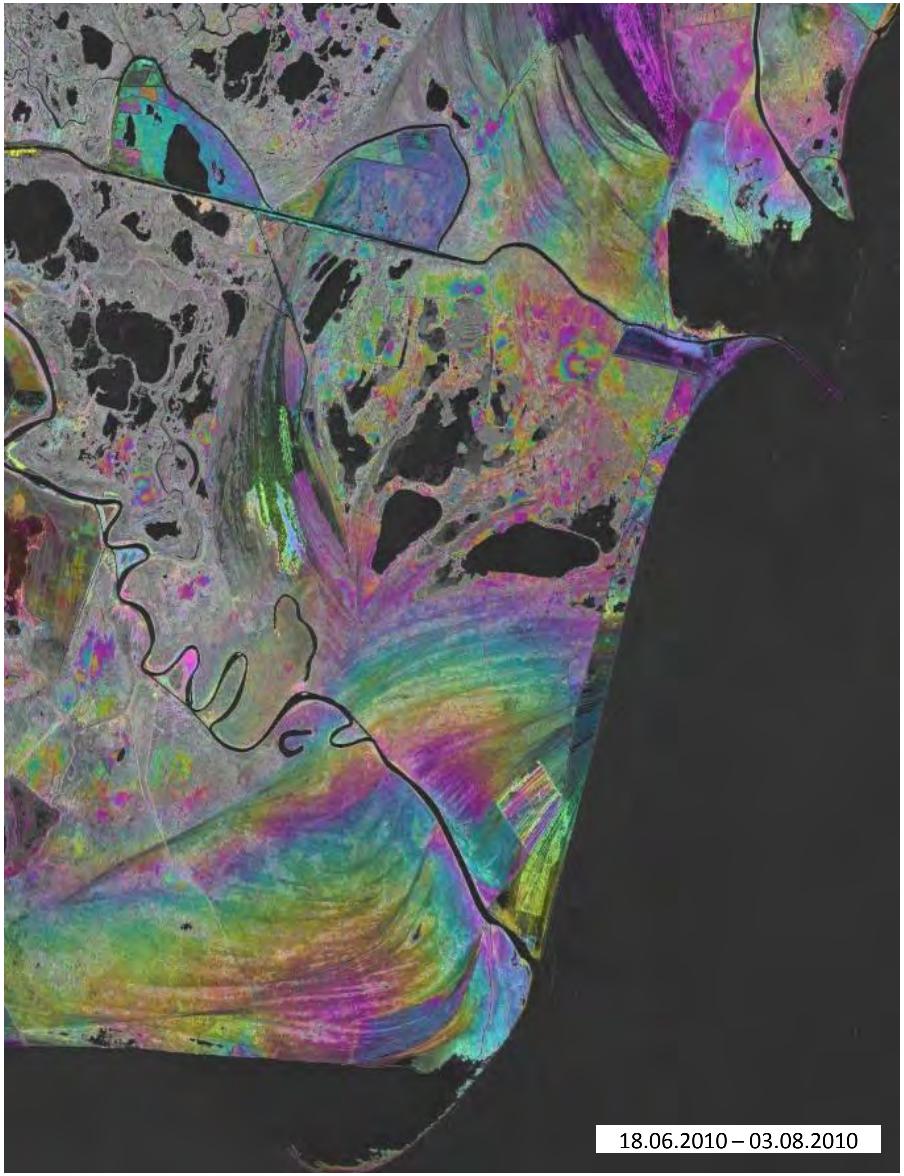
DInSAR analysis: ASAR

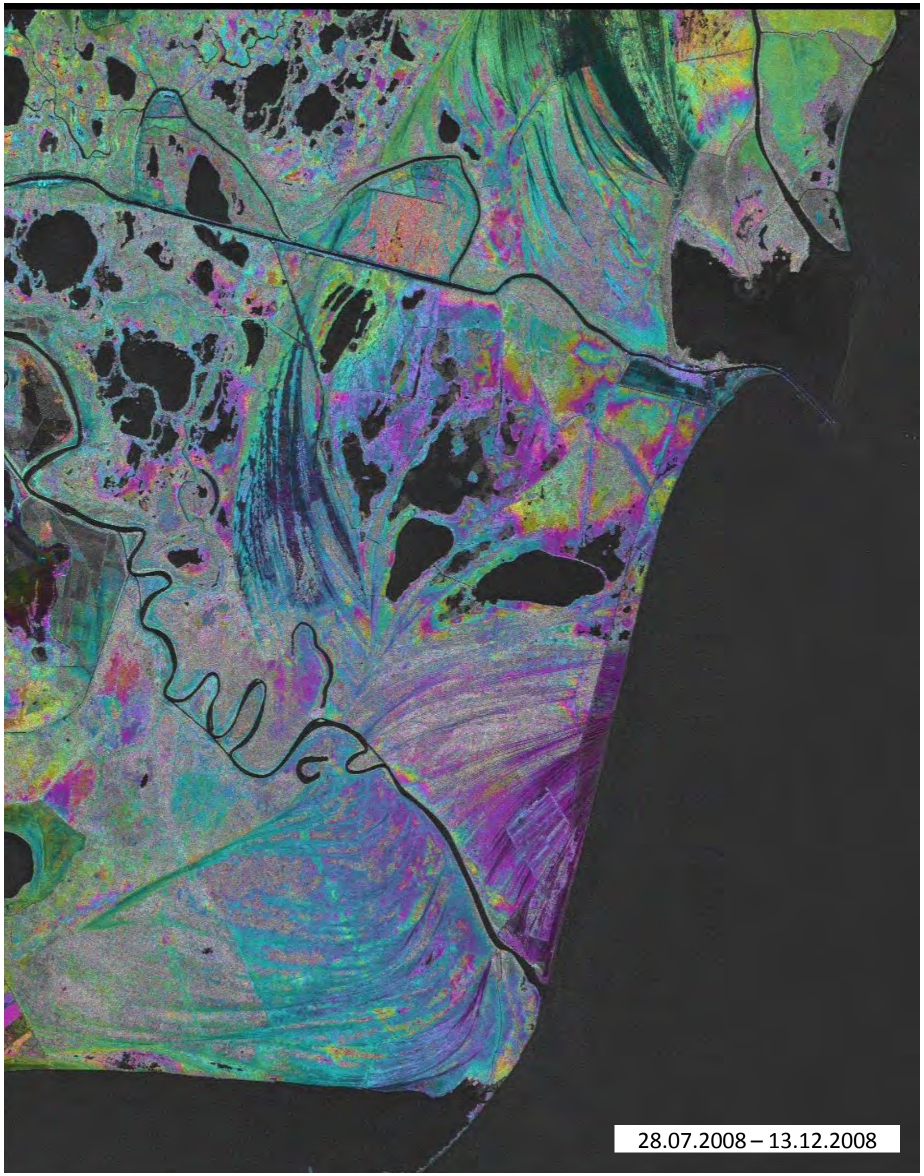




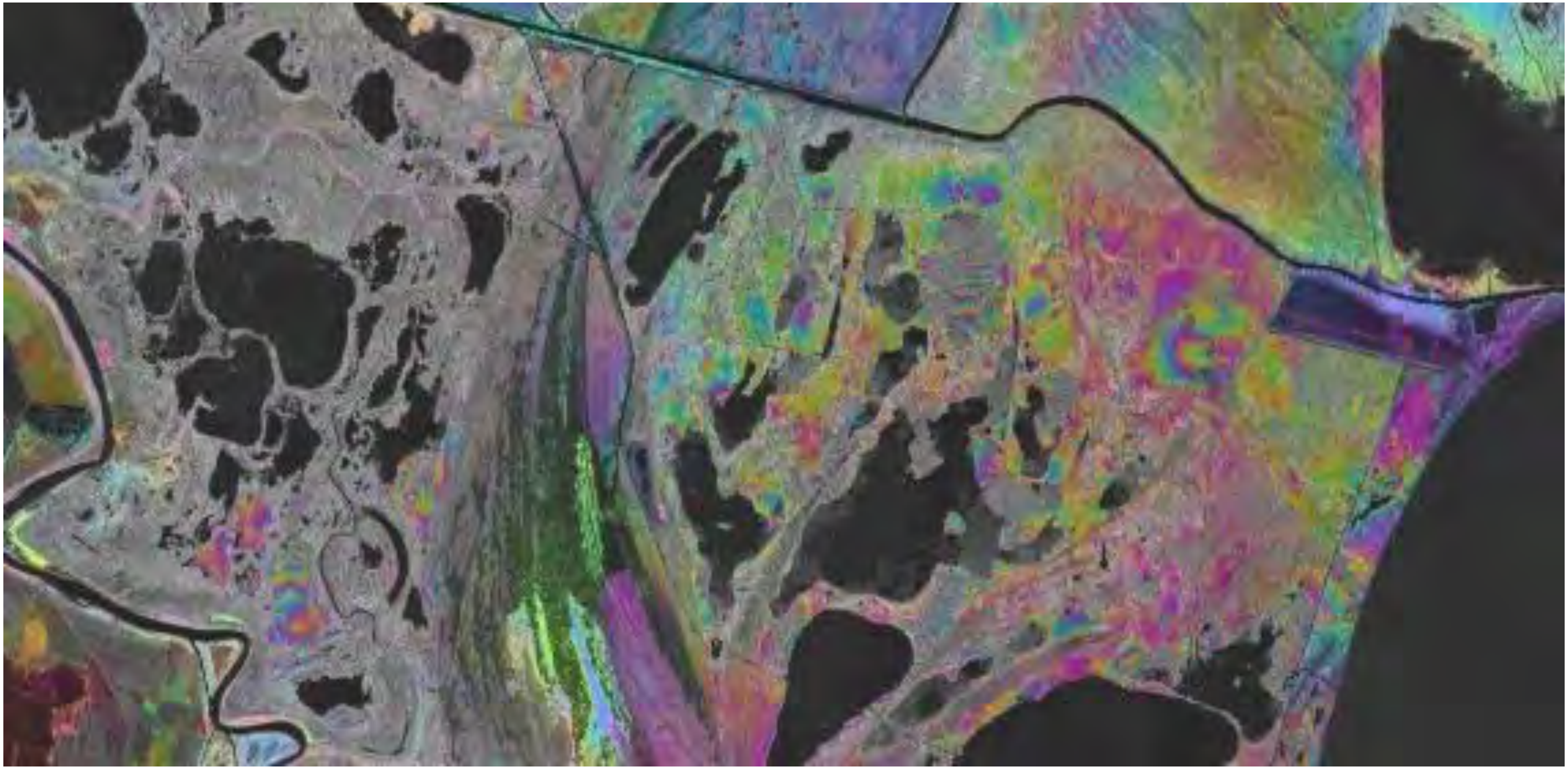


DInSAR analysis: Alos PalSAR



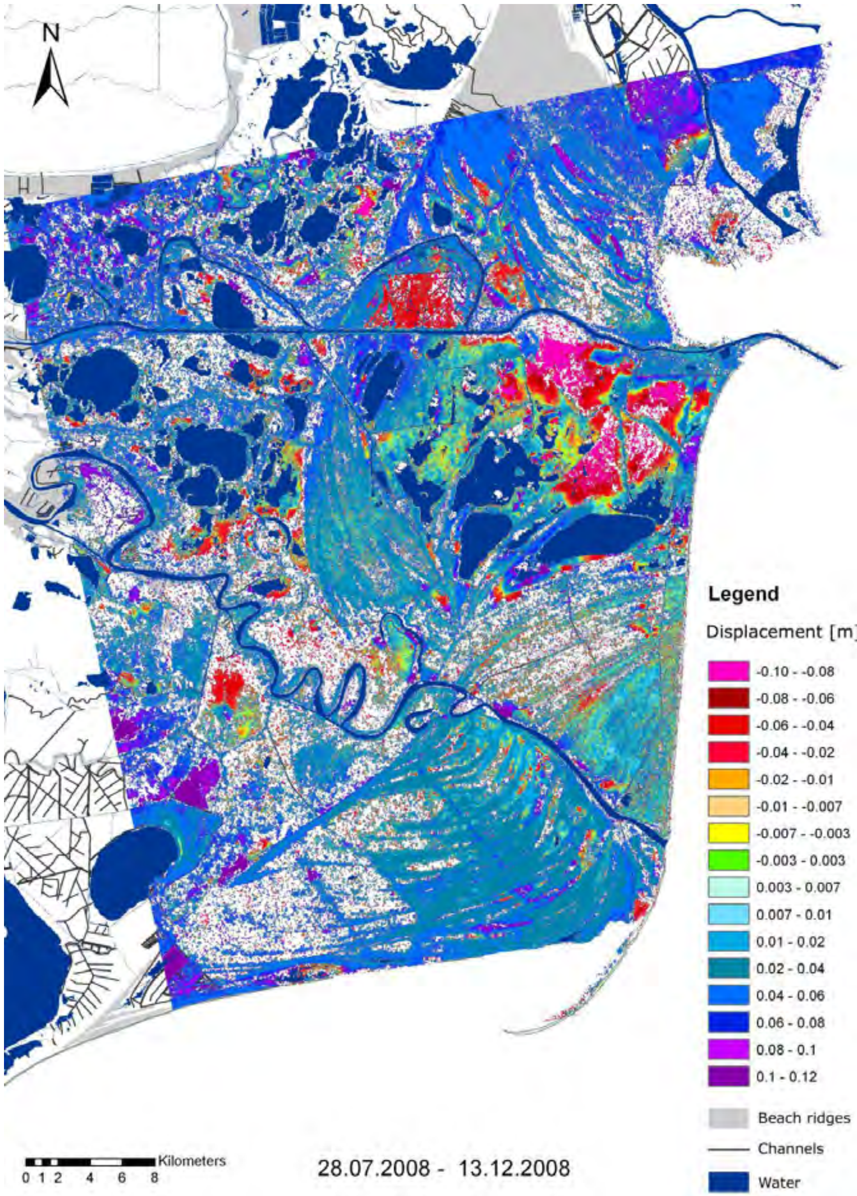


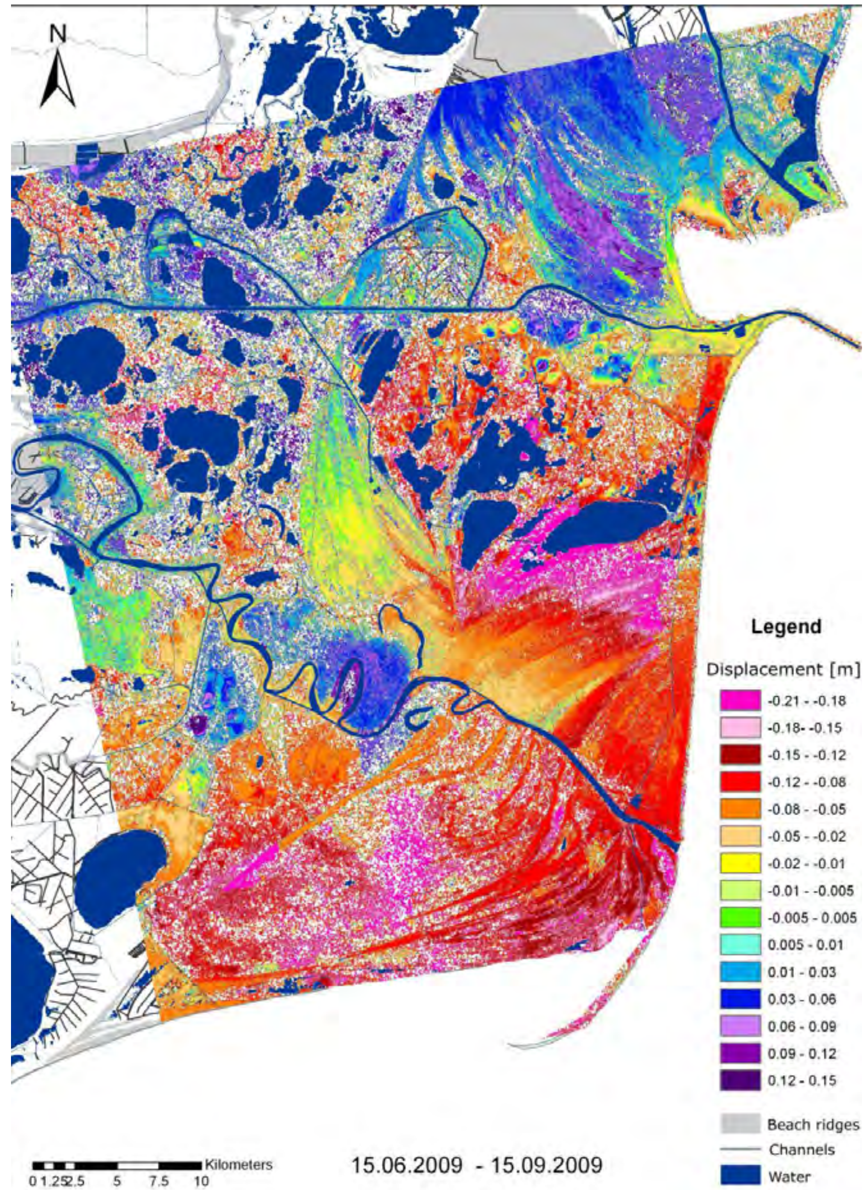
DInSAR analysis: Alos PalSAR



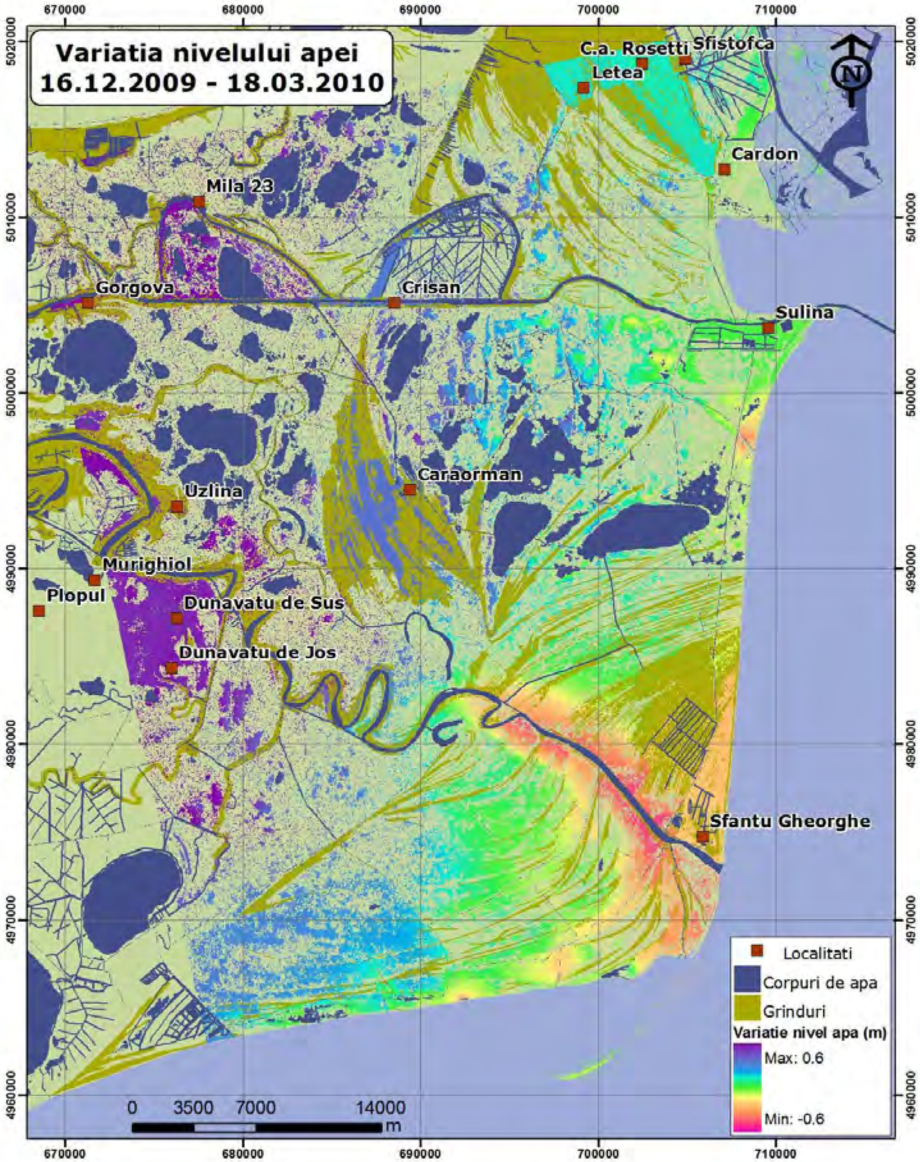
Details from the deformation map obtained from the diff. interferogram 18.06 – 03.08.2010. One color fringe represents 12 cm vertical displacement.

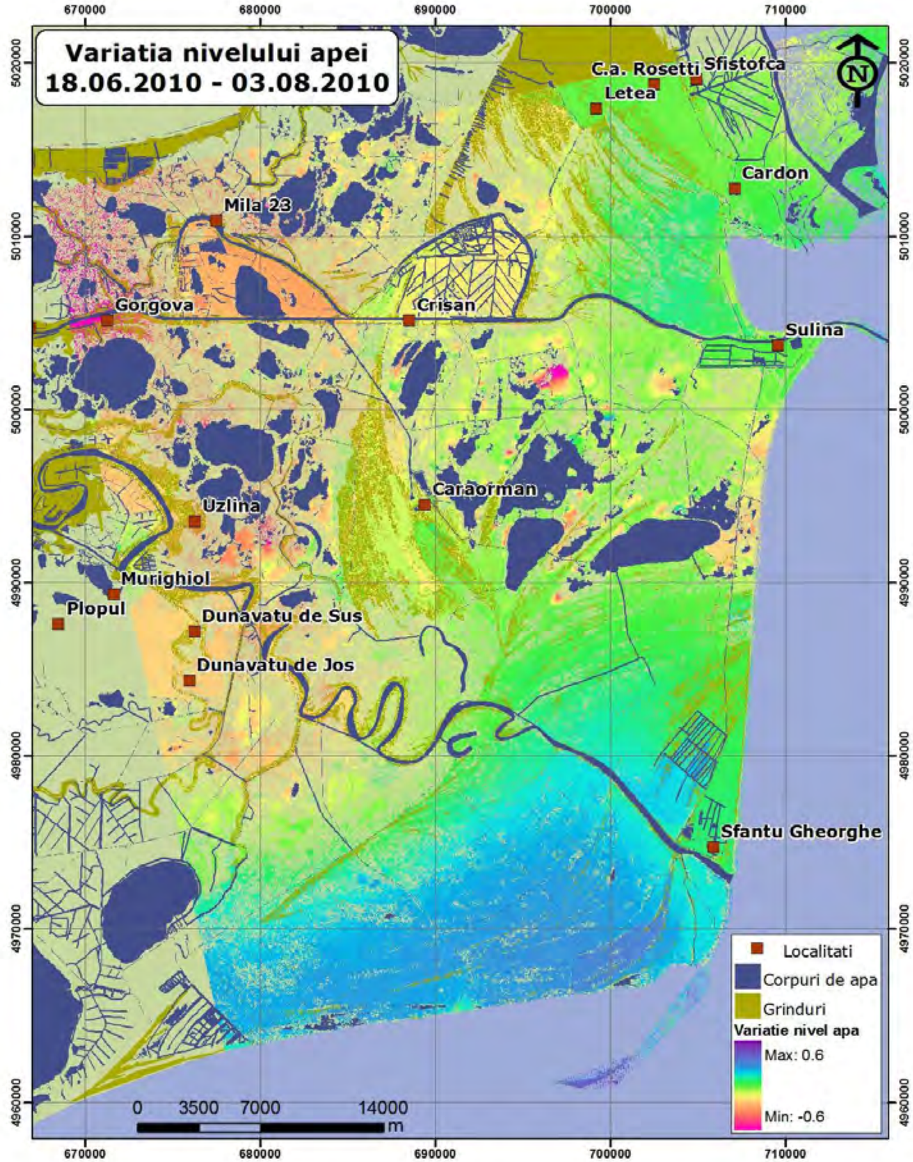
Water level changes maps



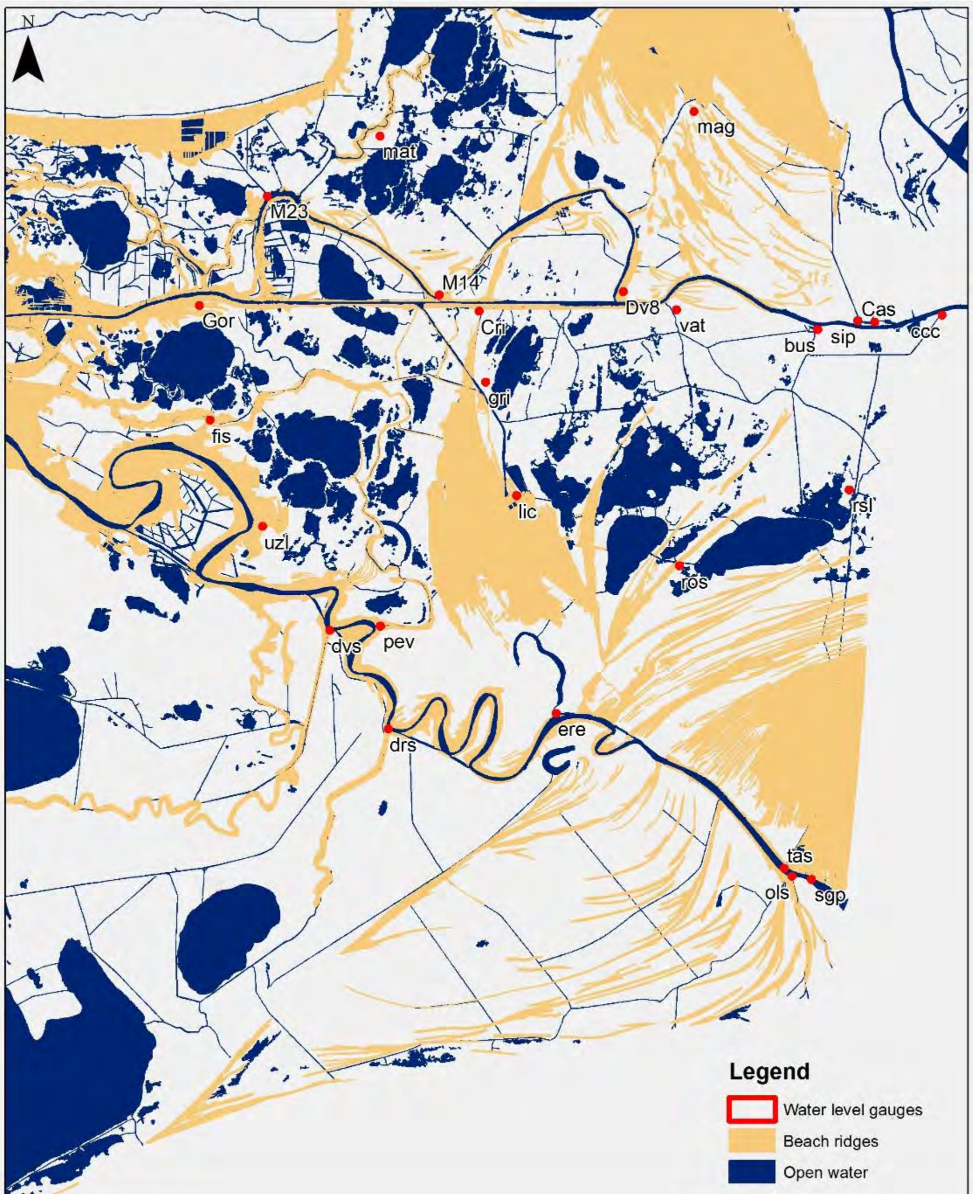


Water level changes maps



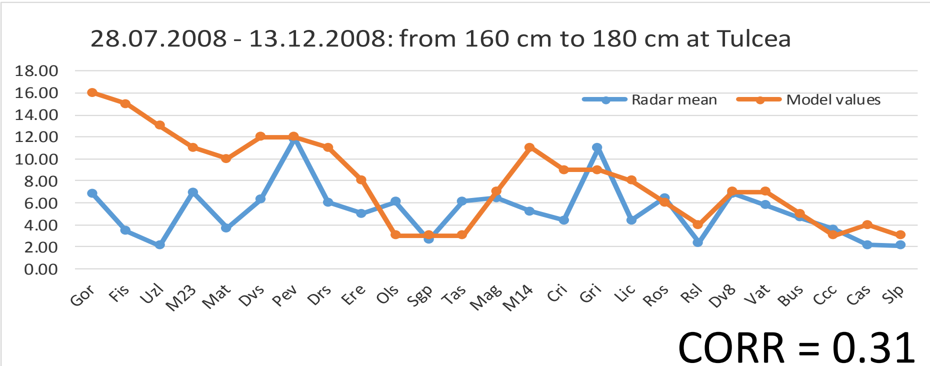


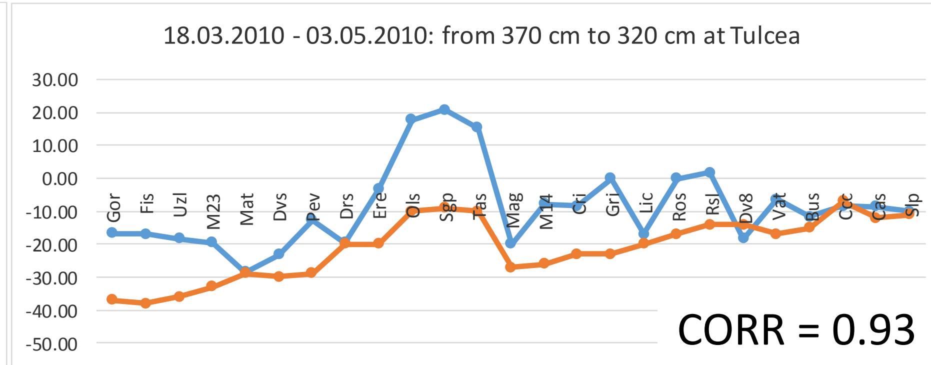
Validation of water level changes

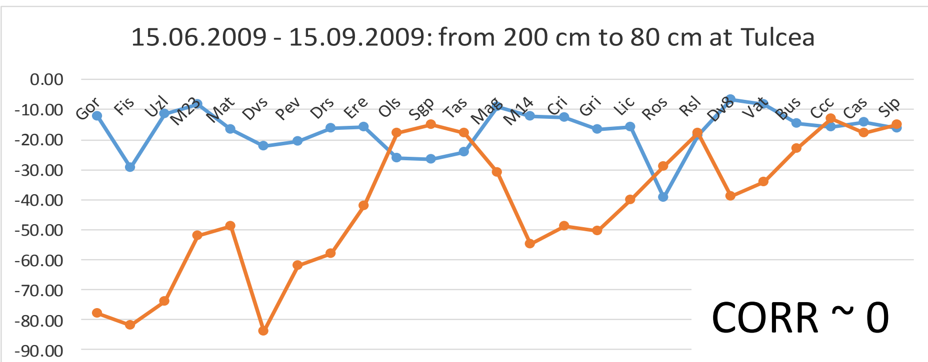


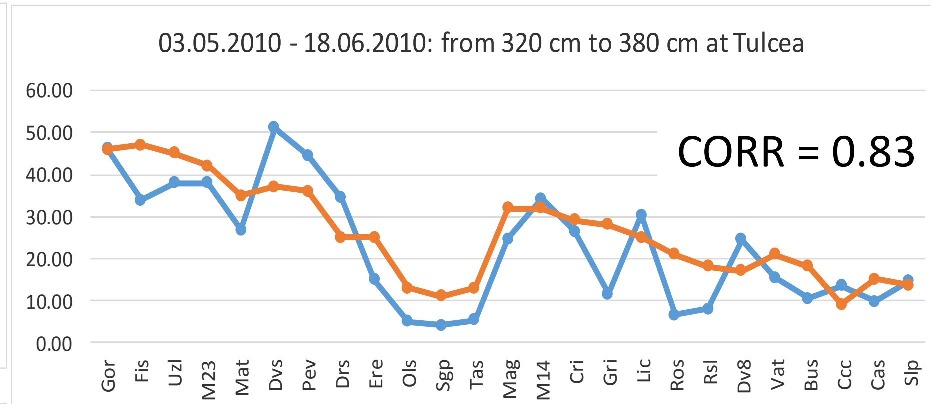
- The water levels measurements are available in points located on the channels, i.e. on open water, and there, exactly on those locations, no radar coherent response is available. Unfortunately there are no water level measurements available in the interior of the inundated vegetation.
- That is why the area surrounding each location was analyzed in order to identify an area formed by ‘water + vegetation’ which is representative for each water level measurement location;
- The identified areas were drawn as polygons in a GIS software and the mean and the standard deviation values were extracted for each polygon and from each of 6 deformation maps;

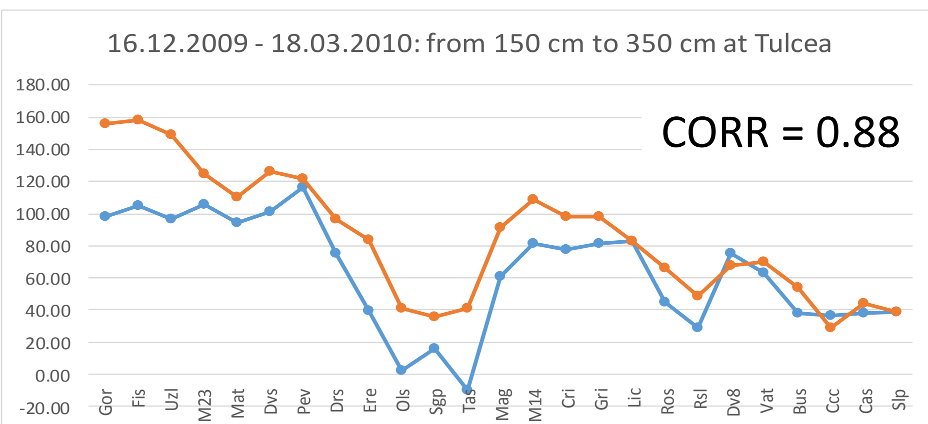
Validation of water level changes

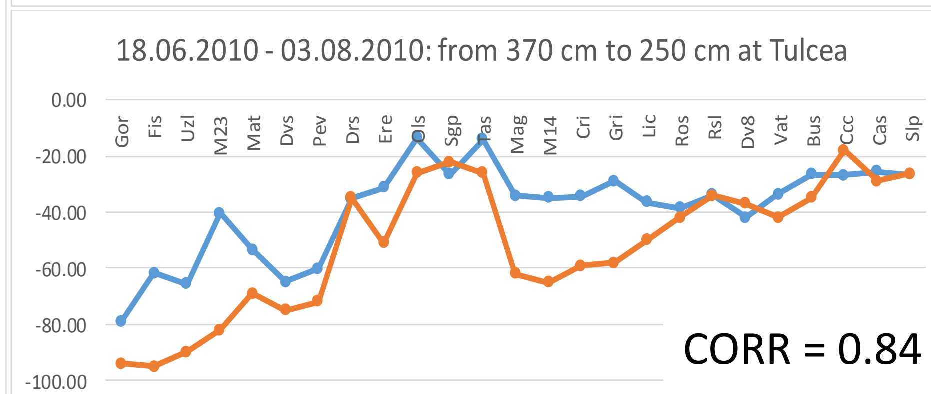












Validation of water level changes

➢ Correlation computed for each location with respect to the time intervals:

Levels variation (cm)	Codes	Intervals	Radar	Model	Measurements
158-180	1. Gor	28.07.2008-03.12.2008	6.85	16	15
196-83		15.06.2009-15.09.2009	-12.33	-78	-77
148-369		16.12.2009-18.03.2010	98.2	156	155
369-317		18.03.2010-03.05.2010	-16.68	-37	-37
317-381		03.05.2010-18.06.2010	46.19	46	46
381-250		18.06.2010-03.08.2010	-79.2	-94	-93
			mas = 1.444 * rad -8.86		r = 0.898
	2. M14	28.07.2008-13.12.2008	5.21	11	11
		15.06.2009-15.09.2009	-12.37	-55	-35
		16.12.2009-18.03.2010	81.33	109	110
		18.03.2010-03.05.2010	-7.85	-26	-26
		03.05.2010-18.06.2010	34.31	32	32
		18.06.2010-03.08.2010	-34.86	-65	-65
			mas = 1.49 * rad - 11.84		r = 0.984
	3. Cri	28.07.2008-13.12.2008	4.37	9	9
		15.06.2009-15.09.2009	-12.5	-49	-49
		16.12.2009-18.03.2010	77.92	98	99
		18.03.2010-03.05.2010	-8.31	-23	-24
		03.05.2010-18.06.2010	26.4	29	29
		18.06.2010-03.08.2010	-34.31	-59	-59
			mas = 1.467 * rad -12.26		r = 0.966

Examinating of the data results from all 25 locations, the following findings are resulting:

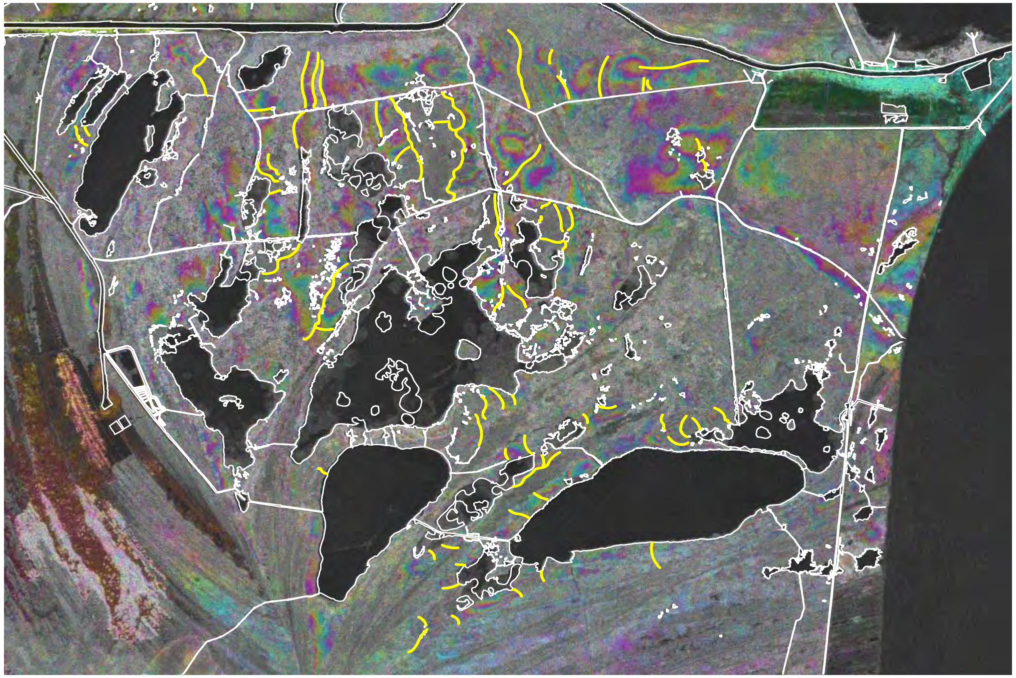
➢ In 20 locations, correlation coefficients were greater than 0.9;

➢ In two locations, correlation coefficients were greater than 0.8;

➢ In three locations near the Black Sea coast, the correlation coefficients were very low.

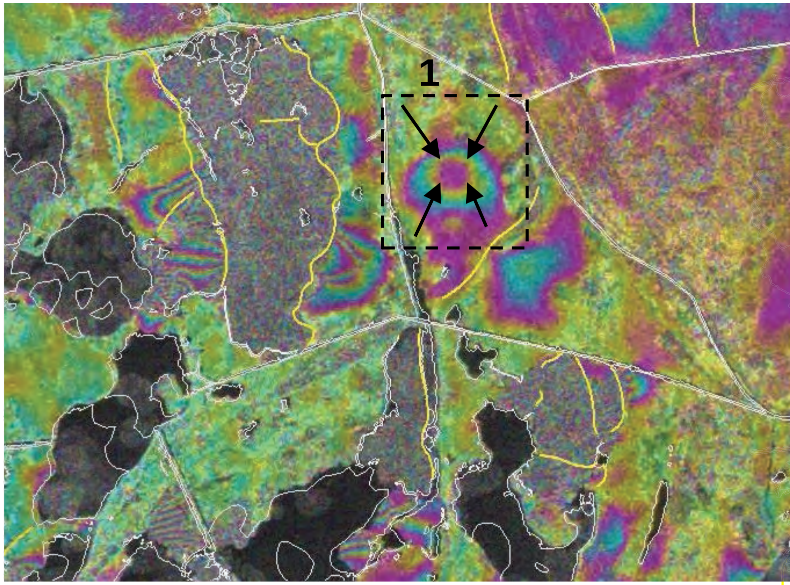
Flow patterns from InSAR

- As water level and water level changes tend to be different across barriers, these differences will be shown in the interferogram as phase discontinuities. Consequently, useful and important observations of flow patterns and flow discontinuities can be derived directly from the raw interferograms, without the need of stage data for calibration;
- Thus areas with different patterns of fringes, starting from wrapped interferograms (in order to avoid unwrapping errors), were identified and delimitated;
- The obtained separation lines between areas with different fringe patterns indicate different water flow direction and/or speed, since the direction of motion is perpendicular on the direction of fringes;

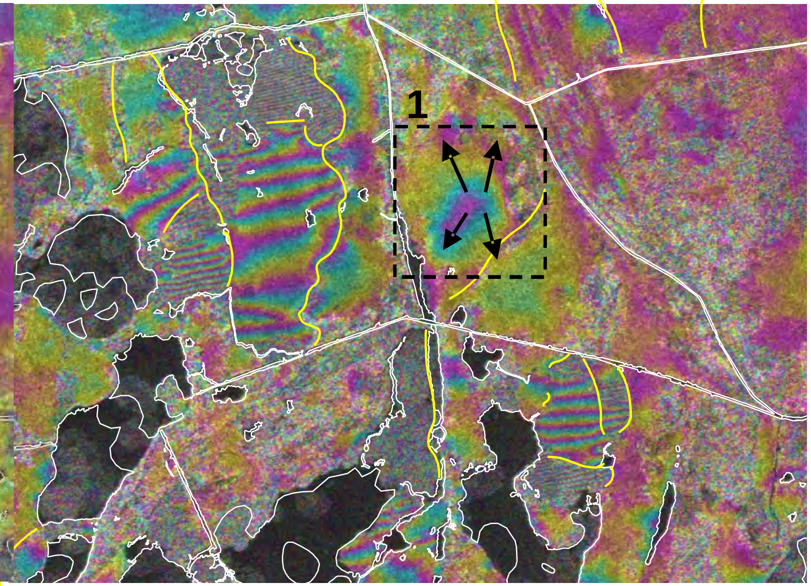


Wrapped interferogram 16.12.2009 – 18.03.2010, overlaid with contours of water bodies and channels (white lines) and semi- or impermeable water divides, deduced from abrupt phase changes (yellow lines)

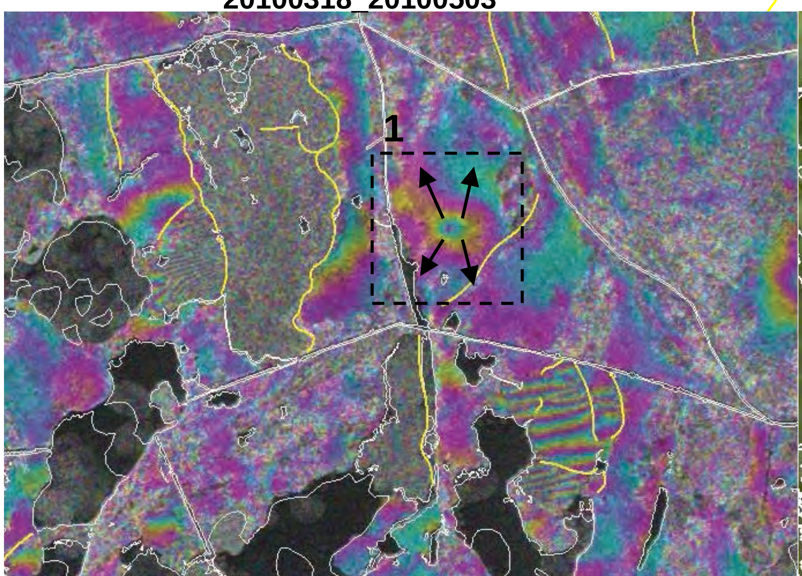
Flow patterns from InSAR



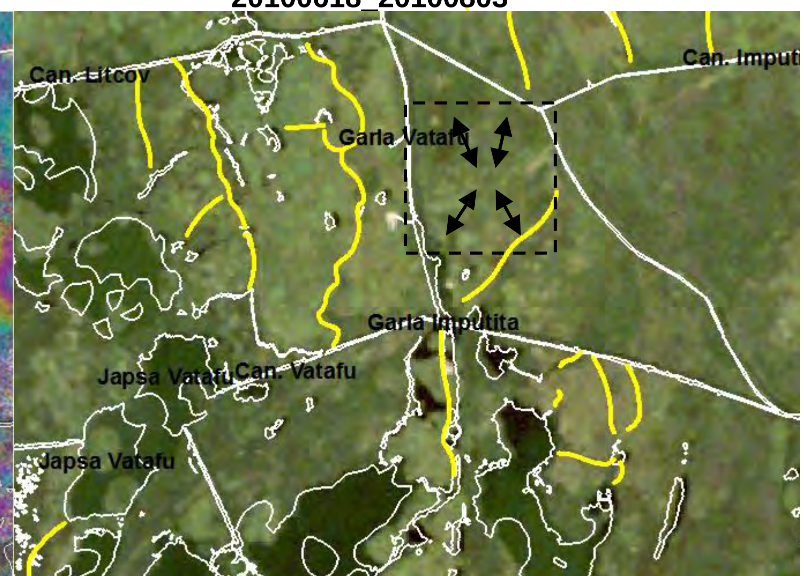
20100318_20100503



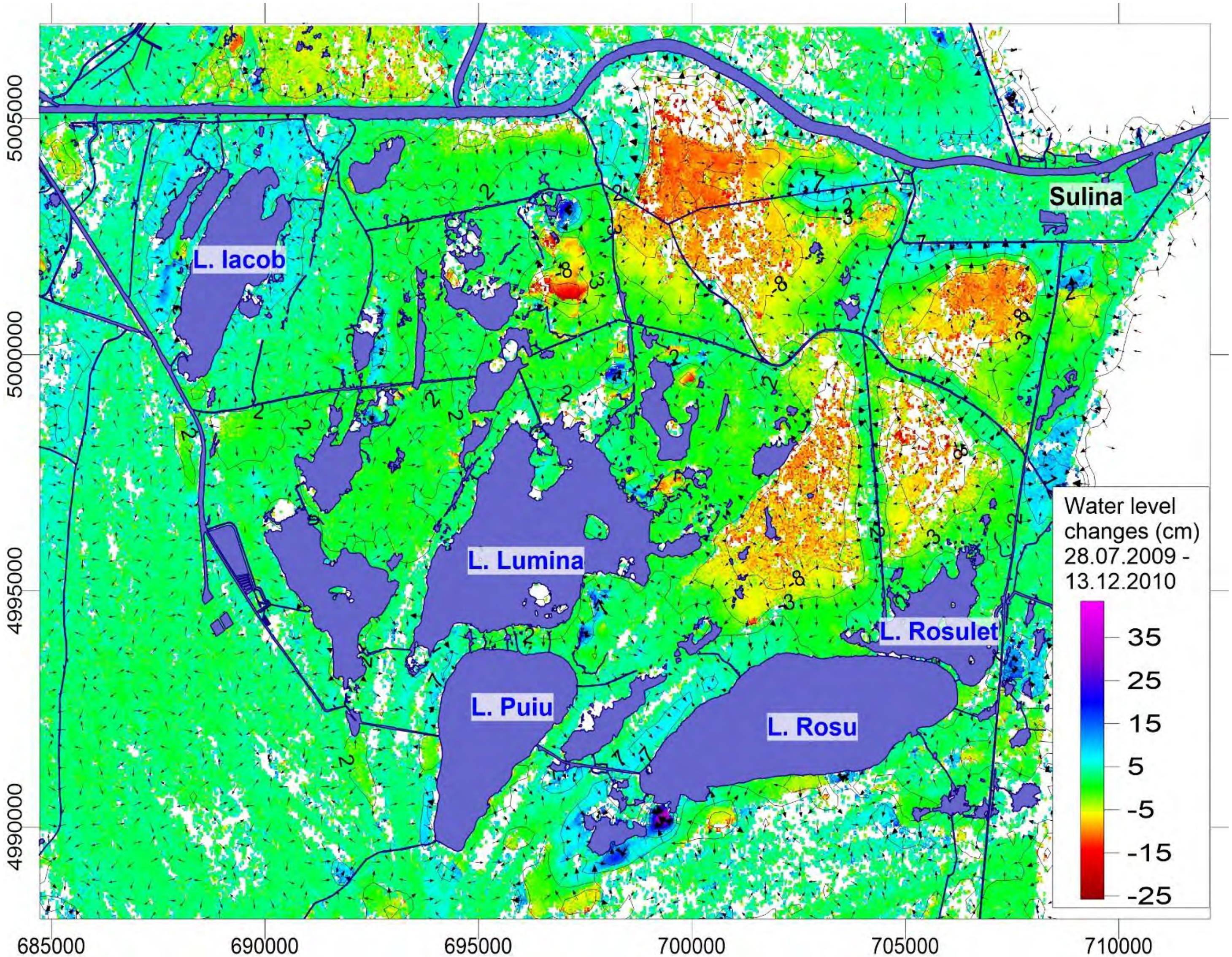
20100618_20100803



20100803_20100918

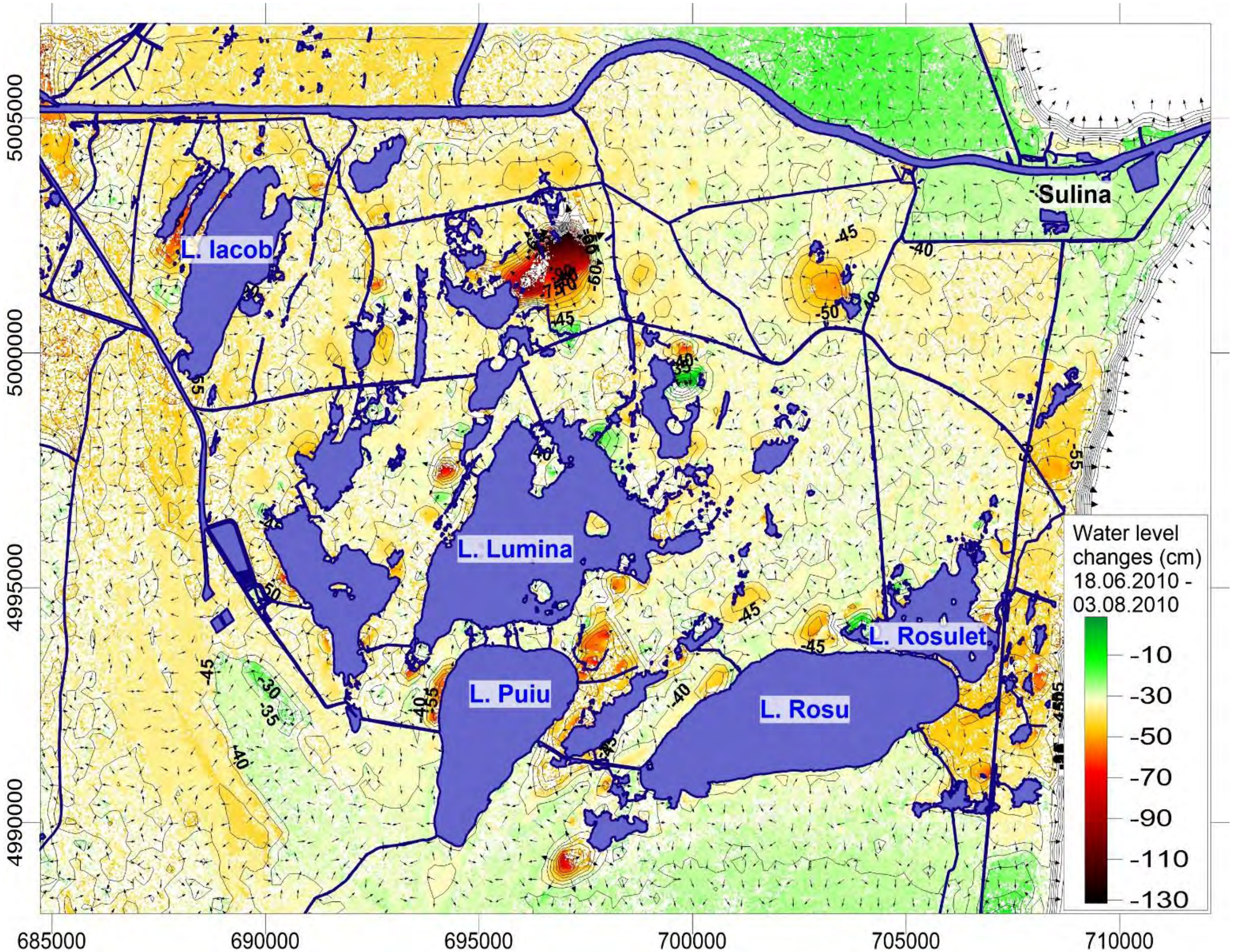


Water flow directions maps



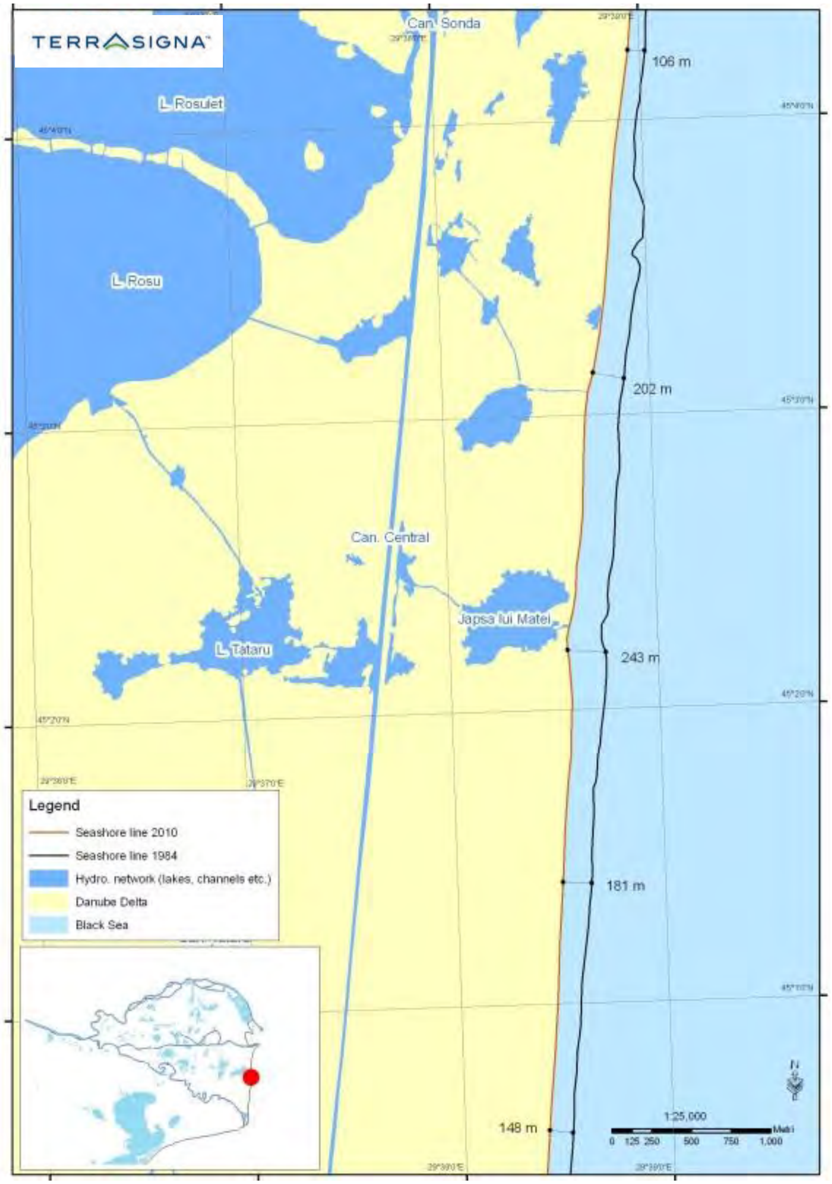
DInSAR water levels change and water flow direction map for 28/07/2008–13/12/2008

Water flow directions maps



DInSAR water levels change and water flow direction map for 18.06-03.08.2010

Change detection applications to wetlands

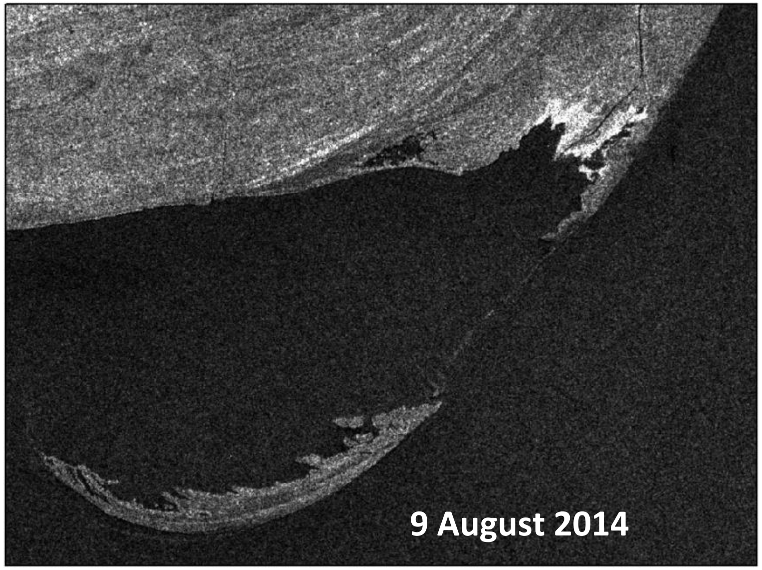


➢ Coastal line evolution between 1984 and 2010 detected from Landsat imagery

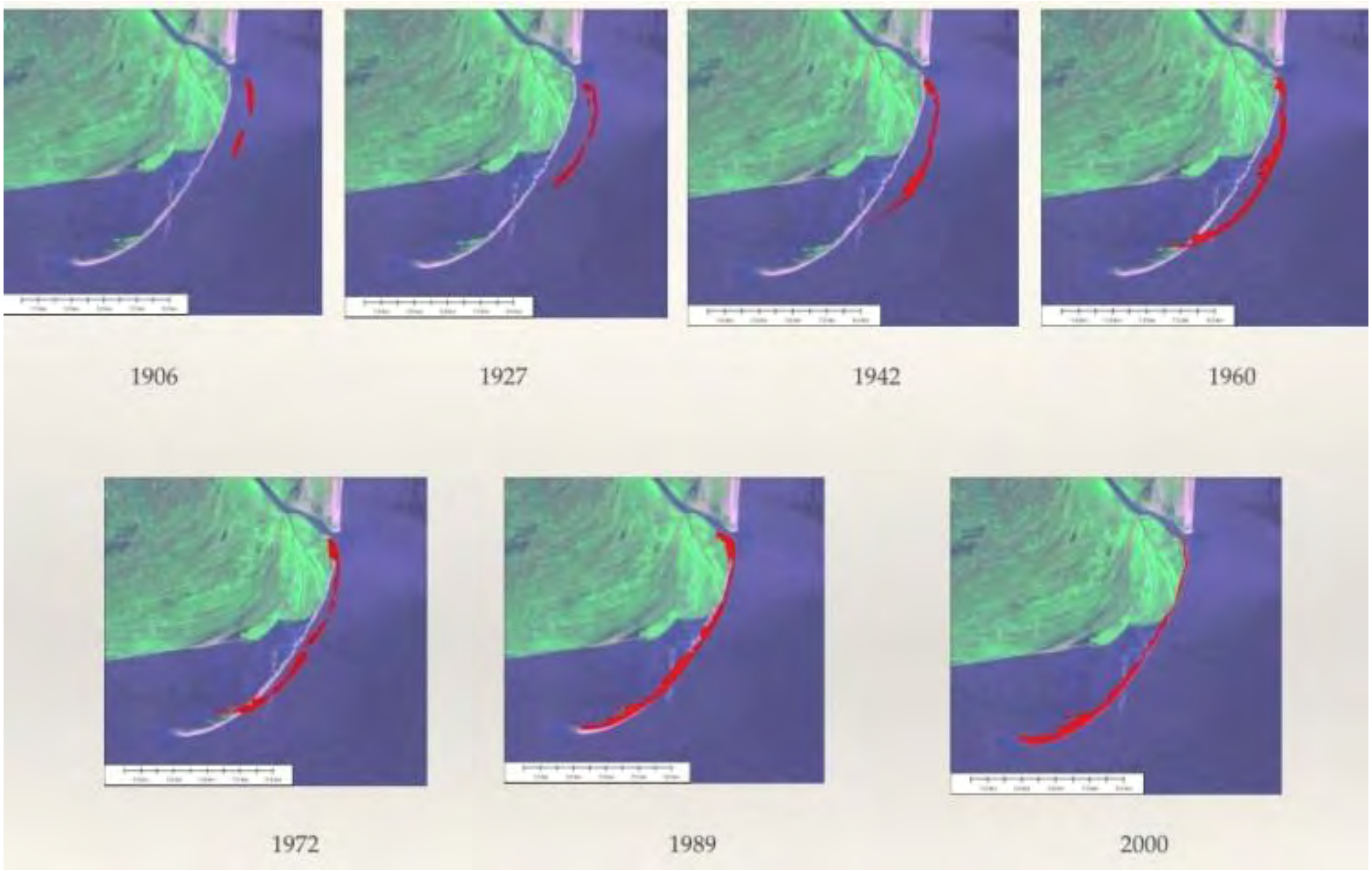
Change detection applications to wetlands

Optic VS Radar observation of Sacalin island:

- S1 data portrays the fully emersed areas;
- Shallow water zones might be classified as land in Landsat data; not the case with radar information;
- Optic data can yield the magnitude of the reconstruction process by making visible the underwater sediment depositions, while radar treats such areas as simply water.
- Radar sensor -> cloud independent !



Change detection applications to wetlands



Sacalin island evolution during the last century; example of using data coming from different sources (satellite and maps)

Change detection applications to wetlands

Methodology:

The amplitude VV from the three S1 products were used to generate a composite RGB image of the Danube Delta.

Red band – 9 August 2014

Green band – 21 August 2014

Blue band – 29 August 2014

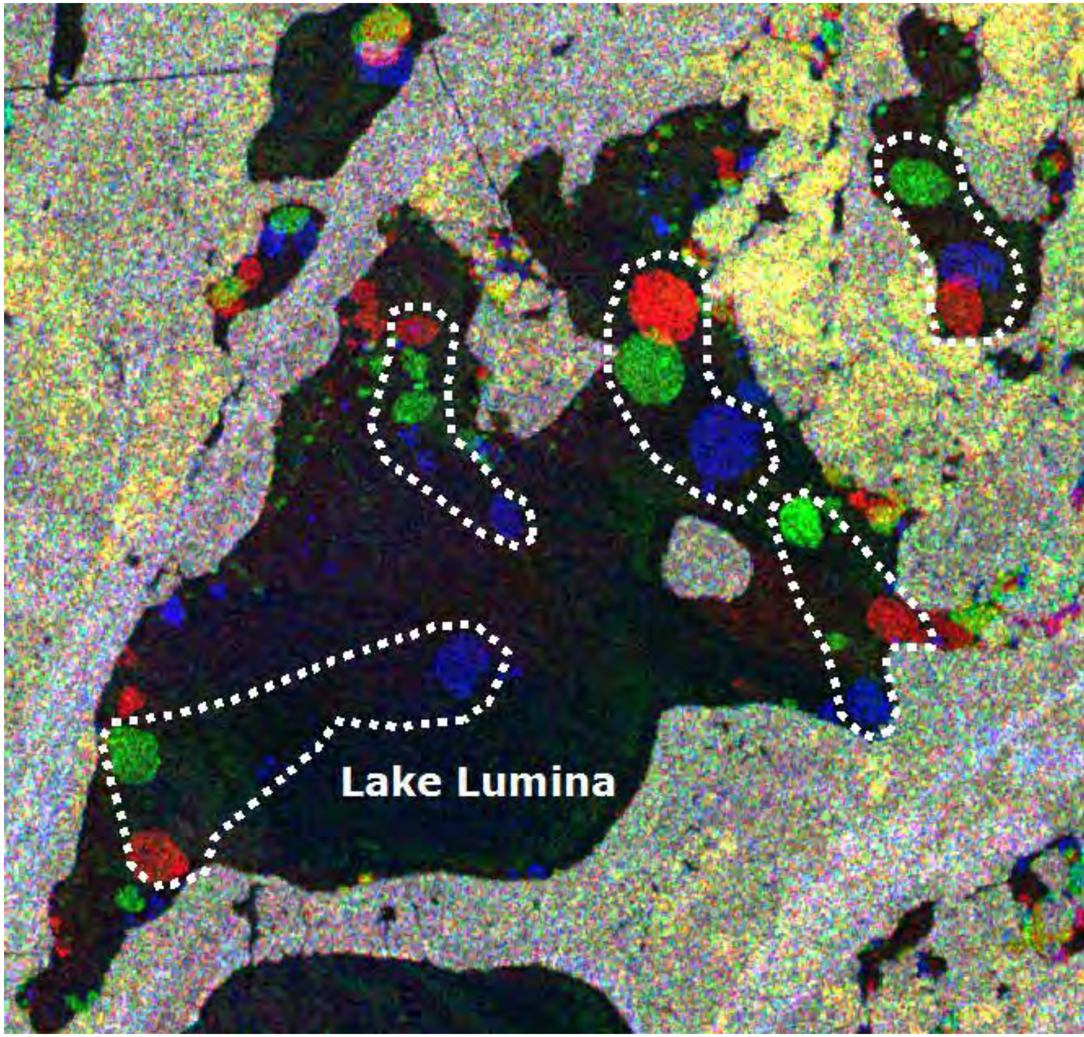
Analyzing the image, important changes of the environment can be depicted.

Change detection applications to wetlands

Monitoring floating reed beds in Lake Lumina

The red, green and blue circles represent the positions on 9, 21 and 29 August of each floating reed beds.

Their trail can be reconstructed for the entire month of August.



Thank you!