DEVELOPMENT CAMPAIGN REPORT

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ACRONYMS & GLOSSARY

AGL: Above Ground Level
AOP: Apparent Optical Properties
APEX: Airborne Prism EXperiment
BLI: Balaton Limnological Institute
CDOM: Colored Dissolved Organic Matter
Chla: Chlorophyll-a
CORPI KU: Klaipeda University Coastal Research and Planning Institute
CNR: Italian National Research Council
CTD: Conductivity-Temperature-Depth
DLR: German Aerospace Center
DOC: Dissolved Organic Carbon
Eawag: Aquatic Research Institute, Switzerland
EO: Earth Observation
EPFL: École Polytechnique Fédérale de Lausanne
FR: Full Range
HICO: Hyperspectral Imager for the Coastal Ocean
HPLC: High Performance Liquid Chromatography
IOP: Inherent Optical Properties
KDT KTF: Central Transdanubian Inspectorate for Environmental and Natural Protection
KDT VIZIG: Central-Transdanubian Water Directorate
MAAs: mycosporine-like amino acids
MTA OK: Magyar Tudomanyos Akademia Okologiai Kutatokozpont
NASA: National Aeronautics and Space Administration
NERC: UK Natural Environment Research Council
NERC ARSF: UK NERC Airborne Research and Survey Facility
NTU: Nephelometric Turbidity Units
OLI: Operational Land Imager
PAB: particulate absorption
PC: Phycocyanin
POC: Particulate Organic Carbon
SPIM: Suspended Particulate Inorganic Matter
SPOM: Suspended Particulate Organic Matter
TIRS: Thermal Infrared Imager
TOC: Total Organic Carbon
TSM: Total Suspended Matter
USTIR: University of Stirling
VITO: Flemish Institute for Technological Research

EXECUTIVE SUMMARY

This report details the *in situ* IOP, AOP, biogeochemical data with concurrent airborne hyperspectral images and satellite images that were acquired in 2014 during the 3-weeks Development Campaign organized at Lake Balaton and Kis-Balaton in Hungary and additional campaigns at Lakes Mantua (Italy), several UK lakes, the Curonian Lagoon (Lithuania) and Lake Geneva (Switzerland).
The data sets acquired in 2014 are available for the INFORM project partners for algorithm development and validation within the INFORM project.

1. Introduction

The Development Campaign took place from 9 July to 27 July 2014 at Lake Balaton, and Kis-Balaton, a large, hypertrophic shallow water reservoir system, Hungary (46.8333° N, 17.7333° E). The campaign was hosted by the Balaton Limnological Institute (BLI) and involved validation teams from the University of Stirling (USTIR; United Kingdom), Consiglio Nazionale delle Ricerche (CNR; Italy) and the Flemish Institute for Technological Research (VITO; Belgium).

The objectives of the Development Campaign Balaton 2014 were:

- to acquire APEX imagery in support of INFORM atmospheric correction and water quality algorithm development
- to acquire APEX imagery to simulate Sentinel-2, Sentinel-3, EnMAP and PRISMA imagery
- to provide *in situ* data (optical and biogeochemical) in support of the validation of APEX-based products
- to provide *in situ* data (optical and biogeochemical) in support of the validation of Landsat-8 OLI (Operational Land Imager) and HICO (Hyperspectral Imager of the Coastal Ocean)–based products

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3. Lake Balaton & Kis-Balaton

Lake Balaton is Europe's largest shallow lake at 592 km^2 (Figure 1). In spite of its large surface area, it is very shallow with a mean depth of approximately 3.2 m. The lake has historically been subdivided into four basins (west to east): Keszthely, Szigliget, Szemes, and Siófok. The main inflow to the lake is the River Zala in the western Keszthely basin and the only outflow is via a regulated canal in the eastern Siófok basin.

In the 1980-90s the western basins became hyper-eutrophic with Chla maxima above 200 µg/l due to the high external load of nutrients mainly from the River Zala, with eutro-mesotrophic condition (up to 75 µg/l Chla) prevalent in the eastern basins. From the 1990s onwards a number of management measures were undertaken reducing the external P load by approximately 50%. In this post-management period the trophic status of the lake has been reversed. By this time the whole lake became oligo-mesotrophic with slightly higher Chla maxima in the western (up to 20 µg/l) than in the eastern (below 10 µg/l) basins.

The lake also receives humic water from the River Zala and as such DOC concentrations in the western basin can be very high. However, the DOC is rapidly diluted and degraded through the system and thus concentrations are typically low and invariant in the eastern regions of the lake. The extreme shallowness of the lake also promotes the resuspension of bottom sediment and as such the lake typically carries a high TSM load (10-50 mg/l) but this can reach up to 200 mg/l of minerogenic particulate matter during high wind events.

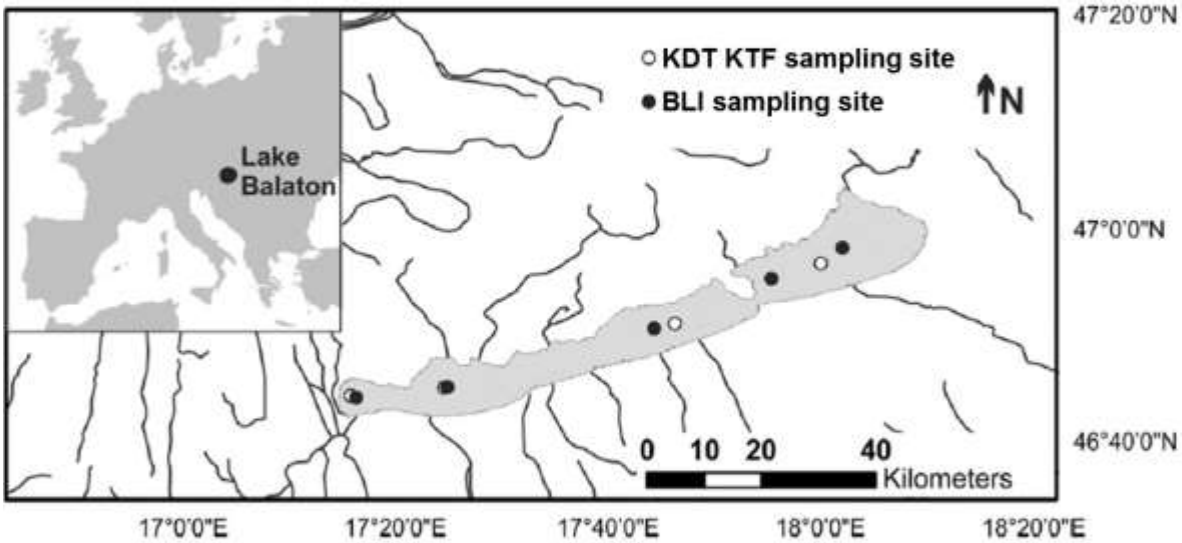

Figure 1. Lake Balaton in Hungary and the approximate locations of the routine sampling stations used by BLI and the Central Transdanubian Inspectorate for Environmental and Natural Protection (KDT KTF) (adapted from Palmer et al., 2014).

Kis-Balaton is a large, hypertrophic shallow water reservoir system constructed to the south west of Lake Balaton. The system extends to about 76 km^2 encompassing open water (some 28 km^2) and wetland habitats. The mean depth of the open water is typically about 1m. The system was constructed to reduce the external loading of nutrients and sediment in Lake Balaton from the River Zala. Kis-Balaton is therefore a highly nutrient enriched system and Chla concentrations are typically in the order of 100-400 µg/l. The phytoplankton community is dominated by cyanobacteria, although the species composition varies through the system due to the steep trophic gradient.

4. Data acquisition

4.1. Satellite image acquisition

Landsat-8 OLI/TIRS data were acquired on the 9th July, 16th July and 25th July. The data from the 9th and 25th July are affected by cloud, although clear areas are present over the eastern part of the lake where the *in situ* sampling for validation was mainly focused. The data collected on 16th July are largely cloud free.

HICO data was acquired on the 2nd July (outside the Development Campaign time window), 09th July, 11th July, 17th July, 18th July and 21st July. The data collected on the 18th and 21st July are largely cloud free. The data from 17th July is largely obscured by cloud and the data collected on 9th and 11th were completely obscured by cloud. There is an additional HICO image collected on 2nd July that is entirely cloud free. There were additional acquisitions planned during the campaign but the data were not collected for operational reasons outwith our control. Quicklooks of the Landsat-8 and HICO data are provided in Annex 1 and Annex 2 respectively.

Table 1. Spectral and spatial characteristics of the acquired satellite data and acquisition date.

Satellite sensor	Number of spectral bands	Spectral range	Spatial resolution	Acquisition date
Landsat-8 OLI	9	0.43-1.38 µm	30 m (15 m PAN)	9 July 2014 16 July 2014 25 July 2014
Landsat-8 TIRS	2	10.60-11.19 µm 11.50-12.51 µm	100 m acquired resampled to 30 m product	9 July 2014 16 July 2014 25 July 2014
HICO	87	0.4-0.9 µm	90 m	2 July 2014 9 July 2014 11 July 2014 17 July 2014 18 July 2014 21 July 2014

4.2. APEX image acquisition

The APEX instrument was developed by a Swiss-Belgian consortium on behalf of ESA as a simulator and a calibration and validation device for spaceborne imagers. APEX records hyperspectral data in approximately 300 spectral bands in the wavelength range between 380 and 2500 nm (Itten *et al.*, 2008). The spatial resolution of the APEX images depends on the flight height.

The APEX sensor was flown on a Dornier 228 aircraft operated by the German Space Agency (DLR) and coordinated by VITO. APEX imagery was acquired on the 19th July and 25th July 2014. The flight plan flown on the 19th July was centered over Kis-Balaton and the westernmost basin (Keszthely) in Lake Balaton. In addition, a flight line running west to east across the full lake was also included. The flight plan flown on the 25th July was centered over the easternmost basin (Siófok). However, again an additional flight line running west to east across the full lake was included.

The flights were undertaken during relatively good weather although some patchy cloud was present at the time of the flight lines on 25th July. There were also strong winds immediately after the flights on 25th July, which resulted in the rapid resuspension of bottom sediment, and probably limits the use of some of the *in situ* data for algorithm development and validation. Maps of the APEX flight lines and concurrent validation stations are provided in Figure 5 and APEX Quicklook mosaics are available in Annex 3.
The flight height was approximately 20.000ft AGL (above ground level) resulting in an APEX image pixel size of approximately 3 m and swath width 3000 m.

Table 2 below provides information on the APEX image acquisition on 19th July 2014:
- the mapping between the quick look naming and the flight line numbering
- the imaging times (local time)
- the flight direction (North –> South / South -> North / East -> West / West -> East)

Table 2. APEX Quicklook name, flight line number, local acquisition time and flight direction for APEX acquisition on 19th July 2014.

Site	Regular image	Time on MissionPrintSheet (LOCAL time)	LineNr Drawing	LineComment
20140719_BalatonBOX				
	M0078_BALAT_140719_a01	09:59 - 10:08	9	N --> S
	M0078_BALAT_140719_a02	10:13 - 10:22	8	S --> N

	M0078_BALAT_140719_a03	10:25 - 10:33	7	N --> S
	M0078_BALAT_140719_a04	10:36 - 10:45	6	S --> N
	M0078_BALAT_140719_a05	10:48 - 10:56	5	N --> S
	M0078_BALAT_140719_a06	11:00 - 11:08	4	S --> N
	M0078_BALAT_140719_a07	11:12 - 11:20	3	N --> S
	M0078_BALAT_140719_a08	11:24 - 11:33	2	S --> N
	M0078_BALAT_140719_a09	11:38 - 11:45	1	N --> S
20140719_BalatonKIS				
	M0079_BALAT_140719_a01	11:52 - 11 :56	12	S --> N
	M0079_BALAT_140719_a02	12:00 - 12:03	11	N --> S
	M0079_BALAT_140719_a03	12:07 - 12:10	10	S --> N
20140719_BalatonEW				
	M0079_BALAT_140719_a04	12:17 - 12:35		W --> E
	M0079_BALAT_140719_a05	12:40 - 12:58		E --> W

Figure 2. BalatonBOX (1-9) and BalatonKIS (10-12) flight lines.

Figure 3. BalatonEW flight line.

Table 3 below provides information on the APEX image acquisition on 25th July 2014:

- the mapping between the quick look naming and the flight line numbering
- the imaging times (local time)
- the flight direction (North –> South / South -> North / East -> West / West -> East)

Table 3. APEX Quicklook name, flight line number, local acquisition time and flight direction for APEX acquisition on 25th July 2014.

Site	Regular image	Time on MissionPrintSheet (LOCAL time)	LineNr Drawing	LineComment
20140725_Balaton				
	M0084_BALAT_140725_a010	10:12-10:17	8	S -> N
	M0084_BALAT_140725_a020	10:23-10:28	9	N -> S
	M0084_BALAT_140725_a030	10:35-10:39	10	SW -> NE
	M0084_BALAT_140725_a040	10:51-11:03	6	E -> W
	M0084_BALAT_140725_a050	11:15-11:22	6	W -> E
	M0084_BALAT_140725_a060	11:41-11:47	6	E -> W

Figure 4. Balaton flight lines.

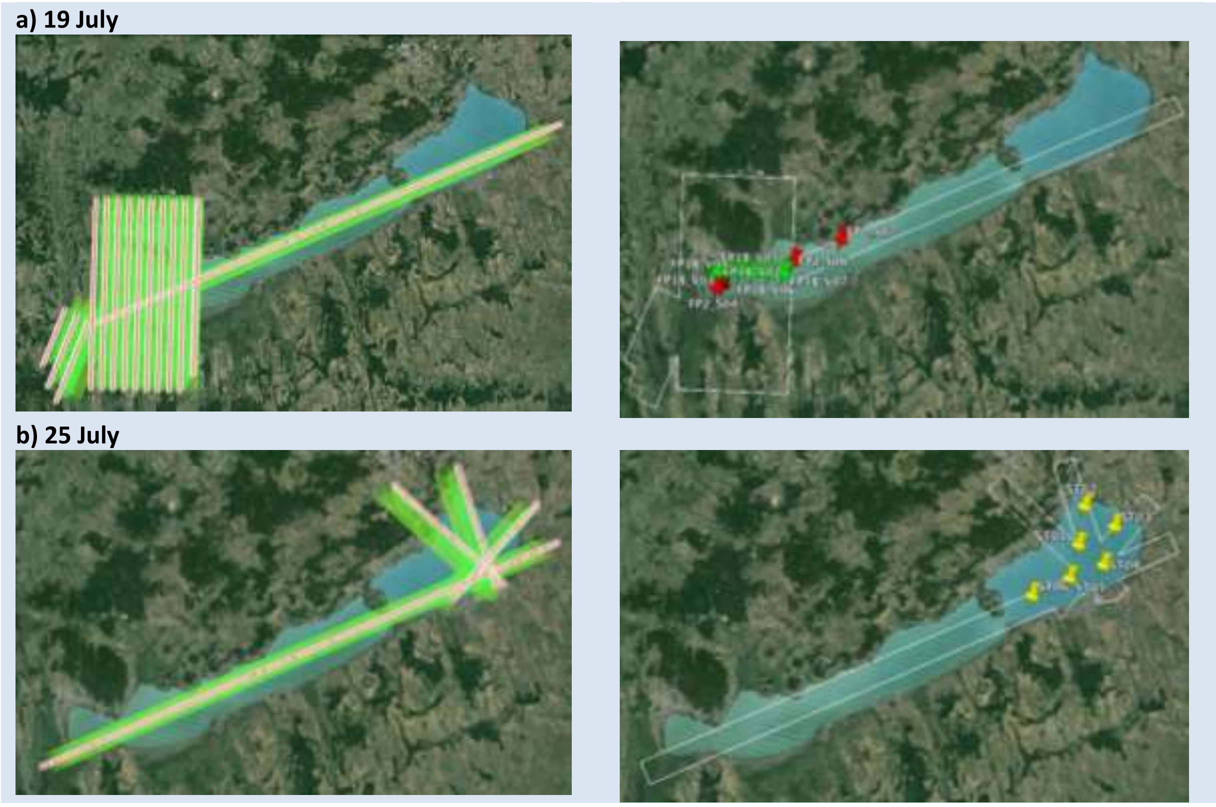

Figure 5. Maps detailing the APEX flight lines and in situ sampling stations over Lake Balaton on the 19th and 25th July 2014.

4.3. *In situ* measurements

4.3.1. Overview

The *in situ* measurement programme was undertaken by teams from USTIR (9th-27th July), CNR (14th-18th July) and VITO (14th-19th July). The USTIR used a BLI R/V for the duration of the Development Campaign; the CNR and VITO teams used R/Vs chartered from KDT VIZIG. *In situ* measurements were made concurrent to the APEX flights and all Landsat-8 and HICO overpasses. In addition, further optical measurements and sampling was undertaken independently on the 14th, 15th and 24th July by USTIR and, on some occasions, also by the CNR and VITO teams. A summary of the *in situ* data collected over the duration of the Development Campaign is provided in Table 4.

Table 4. Summary of the in situ data collected during the Development Campaign at Balaton.

Date	EO Data acquisition			*In situ* sampling stations				Comments
	APEX	Landsat-8	HICO	USTIR	CNR	VITO	ALL	
09/07/2014		X	X	3			3	
14/07/2014				3			3	
15/07/2014				4	4	4	12	Instrument inter-comparison + reference ground targets
16/07/2014		X		4	5 (+3 KB)	4	16	+ 6 Kis-Balaton macrophyte measurements
17/07/2014			X	4	2	2	8	APEX flights aborted
18/07/2014			X	4	4 (+2 KB)		10	+ 3 Kis-Balaton macrophyte measurements + reference ground targets
19/07/2014	X			11			11	Water samples taken at 7 stations. Underway transects with radiometers
21/07/2014			X	5			5	
24/07/2014				5			5	
25/07/2014	X	X		6			6	
TOTAL STATIONS SAMPLED				**46**	**20**	**10**	**76**	

4.3.2. Atmospheric measurements and reference target measurements

Sun photometer measurements for derivation of the aerosol optical thickness (AOT) and column water vapour were made concurrent to the APEX flights and satellite overpasses using a CIMEL CE318. In addition, Microtops II sun photometer measurements were made routinely during the APEX flights and at the time of satellite overpasses.

ASD FieldSpec PRO FR reflectance measurements of 12 land reference targets were performed in support of the atmospheric correction and vicarious calibration of the APEX images.

4.3.3. *In situ* optics

The USTIR team made *in situ* measurements of spectral absorption and attenuation using a WetLabs AC-S (with and without a 0.2 µm filter for removal of particulates) and spectral backscattering using a Wetlabs ECO-BB3. Temperature, depth and salinity were logged using a SeaBird CTD. Size-fractionated (0.2, 2, 20 and 200 µm) measurements of absorption and attenuation were made at selected stations over the course of the Development Campaign. Subsurface radiance reflectance was measured using a trio of Satlantic HyperOCRs. Measurements of downwelling irradiance (E_d), skylight radiance (L_s) and total surface radiance (L_t) for computation of water-leaving reflectance (ρ) were made using a trio of Satlantic HyperSAS radiometers and a trio of TriOS RAMSES radiometers. Spectral absorption measurements were also made in the laboratory using a TriOS OSCAR PSICAM. The PSICAM was originally intended to be used *in situ* but unfortunately it was damaged during shipping and could not mounted on the USTIR optics rig.

The CNR team made *in situ* measurements of spectral absorption and attenuation using a WetLabs AC-9 and a Hobi Labs Hydroscat-6. Subsurface irradiance reflectance and remote-sensing reflectance were measured with an ASD FieldSpec FR (with a fibre optic cable) and a WISP-3 spectroradiometer. Reflectance measurements from different species of macrophyte of Kis-Balaton were taken using an ASD FieldSpec FR, a PR-650 Spectrascan and a WISP-3.

The VITO team measured remote-sensing reflectance using an ASD FieldSpec FR.

4.3.4. Water sample analysis

Water samples were collected from the majority of validation stations for the analysis of bio-optical and biogeochemical parameters in the laboratory. Triplicate large volume water samples (3L) were collected by all validation teams from the surface using a clean opennecked container. The USTIR team filtered the samples immediately onboard the research vessel by passing sample aliquots in triplicate through GF/F filter papers for determination of Chla, PC and HPLC (pigments) and in duplicate for the measurement of particulate absorption. 1 ml of sample was also preserved (100% v/v) with glutaraldehyde for particle counting by flow cytometry. These samples were immediately flash frozen in liquid nitrogen. The remaining water was stored in the dark on ice until they were returned to the BLI laboratory for analysis.

The water samples collected by all three validation teams were processed in the BLI laboratory within 6 hours of sample collection. The samples were filtered in triplicate through 25 mm GF/F filter papers for determination of Chla, PC, HPLC (pigments) and particulate absorption and the filters were immediate frozen for long-term storage. Chla was subsequently determined in the BLI laboratory by spectrophotometry following extraction in hot methanol (Iwamura, *et al*., 1970). PC was determined according to Horvath *et al.* (2013). TSM was determined gravimetrically following filtration in triplicate on to pre-combusted 47 mm GF/F filter papers. The inorganic component was determined after combustion of filter paper.

Samples for CDOM analysis were collected in amber glass bottles by the validation teams and maintained on ice in the dark until they could be processed in the laboratory (always with 12 hours). The samples were subsequently filtered through 0.2 µm membrane filters and CDOM absorption was measured using a dual-beam spectrophotometer against a Milli-Q reference. The DOC and TOC concentration was measured (and the POC was calculated from them) by thermal catalysis at 950 ºC in an Elementar High TOC instrument equipped with platinum cartridge using synthetic air as carrier gas. 100 mL of raw water was fixed with acid Lugol’s (1% v/v) for preservation of samples for phytoplankton cell counts. The samples for HPLC and particulate absorption were shipped to USTIR along with those processed on board the BLI R/V for analysis.

In addition, primary production was measured at selected sampling stations using simulated *in situ* C-14 tracer photosynthesis-irradiance (P-E) curves. Samples were also collected from selected stations for the determination of particle-size distribution (LISST-100X, by CNR) and mycosporine-like amino acids (MAAs by USTIR). Macrophyte samples were collected from Kis-Balaton and the dry weight biomass determined in the BLI laboratory. In addition, subsamples of the macrophytes were retained for pigment and nutrient analyses.

5. Additional campaigns

In 2014 additional measurement campaigns in support of INFORM algorithm development and validation were carried out in Lakes Mantua, several UK lakes, the Curonian Lagoon and Lake Geneva.

5.1. Lakes Mantua

The system of fluvial lakes of Mantua is composed by three small and shallow eutrophic reservoirs located in northern Italy (latitude 45°9' N, longitude 10°47' E) (Figure 6, Table 5). The Superior, Middle and Inferior lakes are semi-artificial lakes created from a meander of the Mincio River that was dammed during the 12th century to protect the town of Mantua from enemy invasions and from Po River floods. The Mantua Lakes have features typical of a shallow lentic environment due to low water velocity and limited depth, and of a wetland hosting dense macrophyte meadows, and therefore can be defined as a fluvial lake system. This system is protected as Natural Regional Park and part of World Heritage by UNESCO and is surrounded by two protected wetlands, "Valli del Mincio" and "Vallazza", which are Site of Community Importance and Natural Reserves (Figure 6).

Table 5. Main features of the Mantua lakes system.

Lake	Lake area (km^2)	Perimeter (km)	Storage volume ($x10^6$ m^3)	Mean depth (m)
Superior	3.67	10	14.5	3.6
Middle	1.09	6	3.27	3.0
Inferior	1.45	6	4.36	3.3

At Vasarone dam (between the Superior and the Middle Lake) the mean annual flow was 20±6 m^3s^{-1} (2000-2006), corresponding to a water residence time in the Superior, Middle and Inferior lakes of about 8.4, 1.9 and 2.5 days, respectively.

The water residence time of the fluvial lake system increased in the last decades due to water discharge decrease for irrigation and industrial purposes, and this was coupled to a progressive deterioration of water quality due to high nutrient loads due to agriculture and animal farming activities and to internal load. The lower hydrodynamism of the system, which favors rapid infilling processes and the increase of pollutant loads, triggers a feedback circuit destabilizing. The progressive deterioration of the water quality has impacts on many activities related to the river and lakes as tourism, fishing, industry and agriculture.

Eutrophic conditions result in dense phytoplankton communities (Chla values up to 100 µg L^{-1}), strongly limiting light availability for benthic macrophytes (water transparency 0.6-1.1 m). The water column hosts phytoplankton communities typical of eutrophic and hypertrophic systems rich in organic matter, including diatoms (e.g. *Synedra* spp., *Aulacoseira* spp.), cyanophytes (e.g. *Oscillatoria* spp.), and chlorophytes (e.g. *Scenedesmus* spp., *Pediastrum simplex*). The shallow areas of the fluvial lake system host annual stands of floating-leaved macrophytes that colonize from late April to September. In the Superior Lake *Nelumbo nucifera* is the main floating-leaved macrophyte which forms two main islands of about 40 and 12 ha. *Trapa natans*, *Nuphar lutea*, *Nymphaea alba* are also present. *Cerathophyllum demersum, Myriophyllum spicatum* and *Potamogetum* spp. are the main submersed macrophytes which colonize the Superior Lake. The Middle Lake hosts a ~12 ha monospecific meadow of *T. natans* and another ~4 ha stand of *T. natans*, *N. lutea* and *N. alba*. The Inferior Lake mainly hosts spread *T. natans* plants.

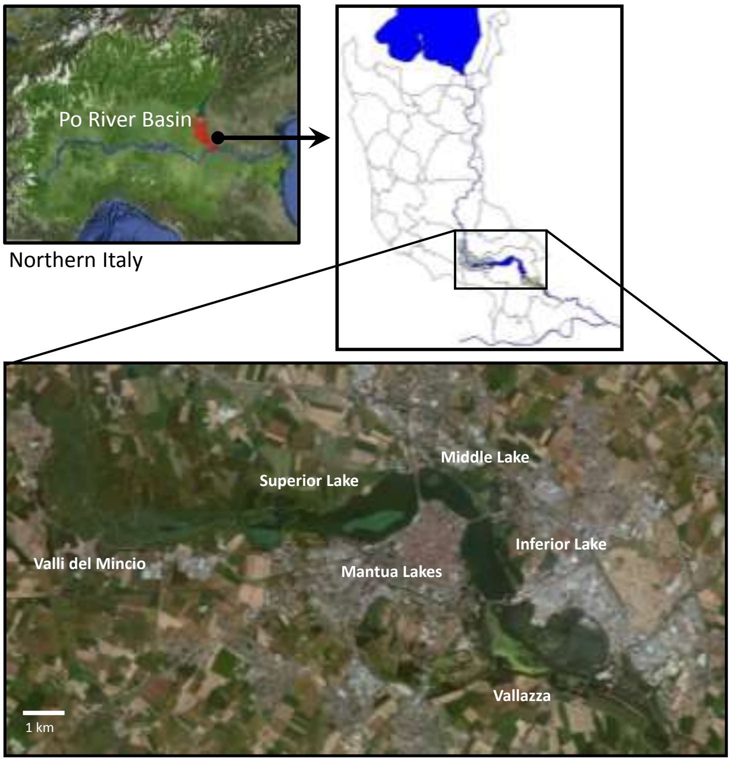

Figure 6. The Mantua Lakes system in the Mincio River watershed, a sub-basin of the Po River (northern Italy).

In 2014, four field campaigns were conducted in the Lakes of Mantua on 26 June, 25 July, 23 September and 27 September 2014; two of those matched a remote sensor overpass: Landsat-8 on 23 September and APEX on 27 September. In particular, the APEX campaign was part of the EUFAR-funded HYPPOS project (HYdrodynamic control of Primary Producers in Optically Shallow fluvial lakes). Table 6 shows the *in situ* observations performed and the number of visited stations. Not included in the table, there is a multi-temporal set of satellite data of 2014 to be processed for investigating the macrophytes. The dataset includes 17 Landsat-8 images in the period January-November and one RapidEye image acquired on 11 July.

Table 6. Summary of the in situ data collected during the campaign at Lake Mantua in 2014. The description of measurements protocol and methods can be found in Giardino et al., 2007; Bresciani et al., 2009; Bresciani et al., 2013 ; Giardino et al., 2014.

			26/06/2014	**25/07/2014**	**23/09/2014**	**27/09/2014**
Water	AOPs (Rrs)	*ASD-FR, SpectraEvolution, WISP-3*	5	4	7	20
	Water constituents	*Chla, SPIM, SPOM, CDOM*	5	6	10	13
	Water quality	*Nutrients + physico-chemical characteristics*	5	10	10	13
	Phytoplankton	*Identification, counts, HPLC, fluorimetric measurements*	5		7	13
		Absorption (filterPAD)	5	6	10	13
	IOPs	*Spectral absorption and beam attenuation (AC-9)*	4			
		Spectral backscattering (HS6)	5		3	10
	SPM characterization	*LISST*	4	2	9	7
Macrophyte	AOPs (Reflectance)	*ASD-FR, SpectraEvolution, WISP-3*	8	3	10	7
	Biomass		5	4	5	2
	Pigments	*Chla and spectral absorption*	6	4	5	
	Atmosphere	*EKO MS-120*			X	X
	Airborne + Satellite data				Landsat-8	APEX

5.2. UK lakes

5.2.1. Loch Leven

Loch Leven is a shallow eutrophic lake in central Scotland (Figure 7). It has a surface area of approximately 13.2 km^2, a mean depth just over 3 m and a maximum depth of 25 m. The lake is very well mixed and non-stratifying. The lake is eutrophic due to high nutrient inputs from the catchment and internally from bottom sediments. The spring phytoplankton bloom on Loch Leven is dominated by diatom species, but cyanobacterial blooms are common in late summer and early autumn. Chla concentrations can reach approximately 50 µg L^{-1} in open water during these bloom events and shoreline scums often form on downwind shorelines.

USTIR undertook a sampling campaign on Loch Leven on 7th August 2014. This campaign included the acquisition of airborne hyperspectral data using the AISA Fenix sensor flown onboard the NERC ARSF Dornier aircraft. LiDAR data and high-resolution images from a wide-format digital camera were also acquired. The Quicklook of the airborne data is provided in Annex 4. The weather conditions were generally good during the flights, but some flighlines were affected by partial cloud. In addition, due to an error by the crew, the aircraft did not fly on the recommended flight plan (i.e., away from the sun) and thus some flight lines are affected by sun glint.

Figure 7. Loch Leven in central Scotland.

In situ optical measurements (IOPs and AOPs) and triplicate water samples were collected at 5 sampling stations on the lake during the airborne campaign. The optical measurement set was the same as that collected by USTIR in Lake Balaton as described in Section 4.3.3. Water samples were filtered in triplicate on GF/F filters for Chla analysis by spectrophotometry using the ISO 10260 method. PC was determined in triplicate according to Horváth *et al.* (2013). CDOM was measured on a Cary-100 dual-beam spectrophotometer according to standard protocols (e.g. NASA, 2003). DOC was measured on a Shimadu TOC analyser. POC was measured on a Carlo-Erba CNO 1108 elemental analyser. Small volume (100 mL) water samples were preserved in acid Lugol's for phytoplankton counts by light microscopy.

This work was partly supported by funding from the UK Natural Environment Research Council GloboLakes projects (www.globolakes.ac.uk).

5.2.2. Loch Lomond

Loch Lomond is the largest lake by surface area in Great Britain covering some 71 km^2 (Figure 8). It is warm, monomictic and thermally stratifies during summer. The lake is comprised of two major ecologically distinct basins: the northern basin is deep (mean depth c. 130 m) and oligotrophic, while the southern basin is much shallower (mean depth c. 10 m) and mesotrophic. Diatoms, desmids and other green algae dominate the phytoplankton flora of the lake, but recently there has been a progressive shift towards taxa more typical of nutrient enriched waters with an increase in the abundance of cyanobacteria species. The lake is also relatively high in CDOM, particularly in the northern basin and near to river inflows.

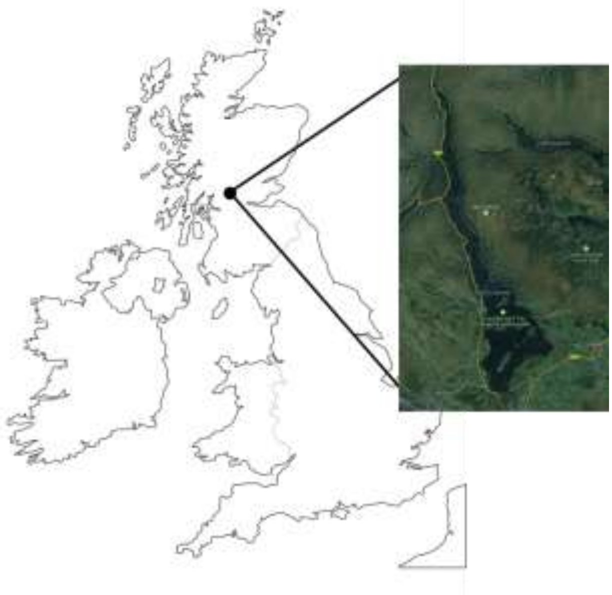

Figure 8. Loch Lomond in central Scotland.

USTIR undertook sampling campaigns on Loch Lomond on 12-14th May 2014 and 8th June 2014. The latter campaign included the acquisiton of airborne hyperspectral data using the AISA Fenix sensor flown onboard the NERC ARSF Dornier aircraft. LiDAR data and high-resolution images from a wide-format digital camera were also acquired. The Quicklook of the airborne data is provided in

Annex 5. The weather conditions were excellent during the flights, but unfortunately the data are badly affected by sun glint due to the flight crew not following the requested flight plan. *In situ* optical measurements (IOPs and AOPs) and water samples were collected at 13 sampling stations on the lake during the campaigns. The dataset is the same as described for Loch Leven above.

This work was partly supported by funding from the UK Natural Environment Research Council GloboLakes projects (www.globolakes.ac.uk).

5.2.3. Loch Ness

Loch Ness is a large, deep oligotrophic lake in northern Scotland (Figure 9). The lake has a mean depth of 132 m and a maximum depth of 225 m. The lake is monomictic and thermally stratifies during the summer. The lake is oligotrophic, with Chla concentrations typically ranging between 0.1 and 5 μg L^{-1}. The lake is also high in DOC compared to other systems in the UK and this has been shown to limit primary production in the lake. The phytoplankton community is dominated by species characteristic of nutrient poor systems, with diatoms often dominated in spring and summer.

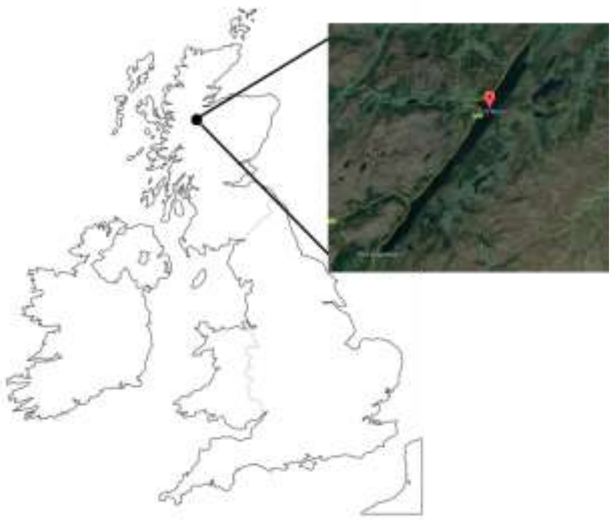

Figure 9. Loch Ness in northern Scotland.

USTIR undertook a sampling campaign on Loch Ness between 23-27th June 2014. *In situ* optical measurements (IOPs and AOPs) and water samples were collected at 7 sampling stations on the lake during the campaign. The dataset is the same as described for Loch Leven above.

This work was partly supported by funding from the UK Natural Environment Research Council GloboLakes projects (www.globolakes.ac.uk).

5.2.4. Cumbrian lakes

The Cumbrian lakes in the north of England are a series of relatively deep, mostly oligo-mesotrophic but occassionally eutrophic lakes formed by glacial processes. USTIR undertook sampling campaigns on five Cumbrian lakes between 18th-22nd August 2014. The five lakes sampled were: Bassenthwaite Lake, Coniston, Derwent Water, Ullswater and Windermere (Figure 10). Coniston and Ullswater are deep, oligotrophic lakes with low Chla concentrations (<5 µg L^{-1}) throughout the year. Derwent Water and Bassenthwaite are more mesotrophic in status and Chla concentrations often reaching 15-20 µg L^{-1} during summer. Windermere is the largest lake in England and has two distinct basins. The northern basin is oligotrophic, while the southern basin is meso-eutrophic. Chla concentrations in the northern basin of Windermere rarely exceed 10 µg L^{-1} but localised blooms of cyanobacteria can occur in the southern basin with Chla concentrations occassionally exceeding 25 µg L^{-1} in the open water and concentrated scums observed in sheltered bays.

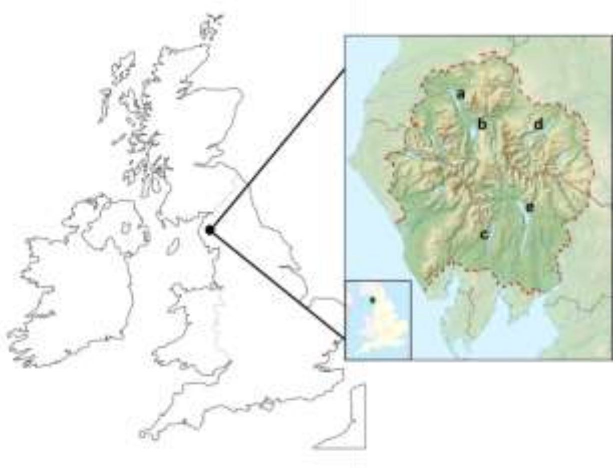

Figure 10. The five lakes sampled in Cumbria, northern England: (a) Bassenthwaite Water; (b) Derwent Water; (c) Coniston Water; (d) Ullswater; and (e) Windermere.

In situ optical measurements (IOPs and AOPs) and water samples were collected at 26 sampling stations on the five lakes during the campaigns. The datasets are as described for Loch Leven above.

5.3. Curonian Lagoon

The Curonian Lagoon is a large, shallow water body (total area 1584 km^2, mean depth 3.8 m) located along the southeastern coast of the Baltic Sea (Figure 11). Geographicaly the lagoon is positioned between Lithuania and the Russian Federation. The mixing of fresh riverine and brackish Baltic Sea water masses creates spatially and temporally unstable gradients with salinity ranging from 0 to 7 PSU. The Nemunas River runoff (22.1 km^3/year) contributes approximately 96% to the total riverine runoff and 77% to the lagoon's water balance. The lagoon is considered as eutrophic or hyper-eutrophic with chlorophyll *a* up to 150 (400) µm/l and enhanced turbidity. In spring constantly occurs spring blooms mainly dominated by diatoms (*Stephanodiscus hantzschii*, *Aulacoseira* spp., *Asterionella* spp., etc.) and summer blooms caused by potentially toxic cyanobacteria (mainly *Aphanizomenon flos-aquae*, *Microcystis* spp., *Planktothrix agardhii*). The Curonian Lagoon receives ~20% of its annual particulate organic matter (POM) inputs from the Nemunas River, phytoplankton contribute ~70% of the annual POM inputs.

Figure 11. *The Curonian Lagoon.*

The *in situ* measurement programme was undertaken by CORPI KU. Field campaigns were organized monthly (during an intensive vegetation – twice per month) from March to October 2014 in the Curonian Lagoon (Table 7).

Table 7. Summary of the in situ data collected during the campaign in the Curonian Lagoon.

Date	EO Data acquisition Landsat 8	Stations	Comments
2014-04-01		3	
2014-04-28	X (27/04/2014)	3	
2014-05-06		8	

2014-05-20		4	
2014-06-04		11	
2014-06-25		4	
2014-07-16	X (16/07/2014)	4	
2014-07-17	X (16/07/2014)	9	
2014-08-04		2	
2014-08-26		3	
2014-08-31		8	Measurements with WISP-3
2014-09-02	X (02/09/2014)	3	Measurements with WISP-3
2014-09-03	X (02/09/2014)	10	Measurements with WISP-3
2014-09-17	X (18/09/2014)	4	
2014-10-15		2	
2014-10-21		3	

Water sample analysis. Surface water samples were collected for the analysis of bio-optical and biogeochemical parameters in the laboratory. Water for Chlorophyll-*a* and pheopigments was filtered through glass fiber GF/F filters with a nominal pore size 0.7 µm and extracted into 90% acetone. Photosynthetic pigments were measured spectrophotometrically. Additionally phycocyanin, phycoerythrin, carotenoids were assessed. CDOM was measured spectrophotometrically after filtration through 0.22 µm membrane filters. The CDOM absorption coefficient at 440 nm (g440) and slope were derived. Absorption by pigments and non-algal particles (after bleaching) were assessed spectrophotometricaly using PAB method. SHIMADZU UV-2600 dual beam spectrophotometer was used for the analysis of chla, CDOM, absorption by pigments and non-algal particle. Concentration of DOC was analysed using SHIMADZU TOC-VHS analyser. Water samples for the analysis of phytoplankton species composition, abundance and biomass were preserved with acid Lugol's solution. Fraction <10 µm of photoautotrophs was analysed with BD Accuri™ C6 Flow Cytometer. In some sampling stations primary production of phytoplankton was measured using oxygen method. TSM, SPIM and SPOM were assessed gravimetrically. Turbidity (in NTU) was measured with turbiditymeter TN-100 (Eutech Instruments).
During field campaigns supplementary environmental parameters (temperature, salinity, pH, O_2), vertical profiles of PAR (with Li-COR 192 and Li-COR 193) and Chlorophyll-a of different phytoplankton groups (with FluoroProbe II, BBE Moldaenke GmbH), water transparency (Secchi disk depth) were measured. Weather (wind speed, direction, cloudiness) and water conditions (wave height and direction, current speed and direction etc.) were described.
***In situ* optics.** During three field campaigns on 31 August, 2 and 3 September 2014 measurements of remote sensing reflectance were performed with a WISP-3 spectroradiometer.

5.4. Lake Geneva

Lake Geneva (Lac Léman) is one of the largest lakes in western Europe with a surface area of approximately 580 km^2 (Figure 12). The lake is extremely deep, with a mean depth of 152 m and a maximum depth of 310 m. The main inflow into the lake is the Rhone River in the east. The lake is divided into 3 basins. The Upper Lake (Haut Lac) in the east receives water from the surrounding Alps via the Rhone river and as such often exhibits relatively high concentrations of mineral particles. The Large Lake (Grand Lac) is the largest and deepest basin, while the Small Lake (Petit Lac) in the south-west is more shallow. Historically the lake has suffered from eutrophication, but reductions in the nutrient load have retruned the lake towards an oligo-mesotrophic state – although phytoplankton blooms can occur on the lake during summer.

Figure 12. Lake Geneva, Switzerland and France.

USTIR in collaboration with École polytechnique fédérale de Lausanne (EPFL) and the Swiss Aquatic Research Institute (Eawag) undertook a sampling campaign on Lake Geneva from 2nd to 6th June 2014. Measurements of remote sensing reflectance were made at 18 stations on the lake using Satlantic HyperSAS, two sets of TriOS RAMSES, an ASD FieldSpec FR and a WISP-3. IOP measurements and water samples for analysis of Chla, PC, TSM and CDOM were collected at approximately 9 stations on the lake as described in Section 4.3.3 for Lake Balaton.

This work was partly supported by funding from the UK Natural Environment Research Council GloboLakes and INCIS-3IVE projects (www.globolakes.ac.uk).

6. Conclusion

In 2014 several measurement campaigns were set up to acquire data sets encompassing *in situ* IOP, AOP and biogeochemical data with concurrent airborne hyperspectral and/or spaceborne images. These data sets bring added value to the INFORM project and will greatly enhance the amount of data available for algorithm development and validation within the INFORM project.

7. References

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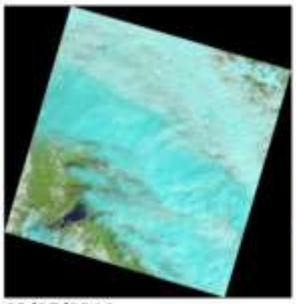
DOI: http://dx.doi.org/10.1016/j.rse.2014.07.024.

Annex 1: Balaton Landsat-8 OLI Quicklooks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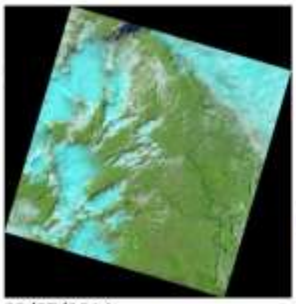
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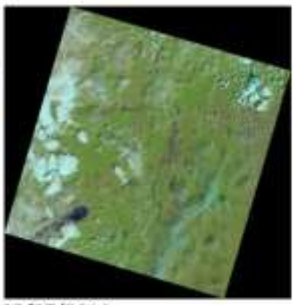
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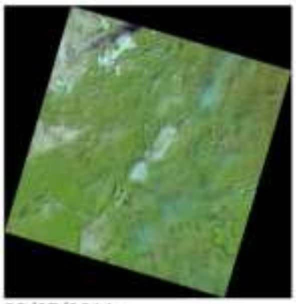
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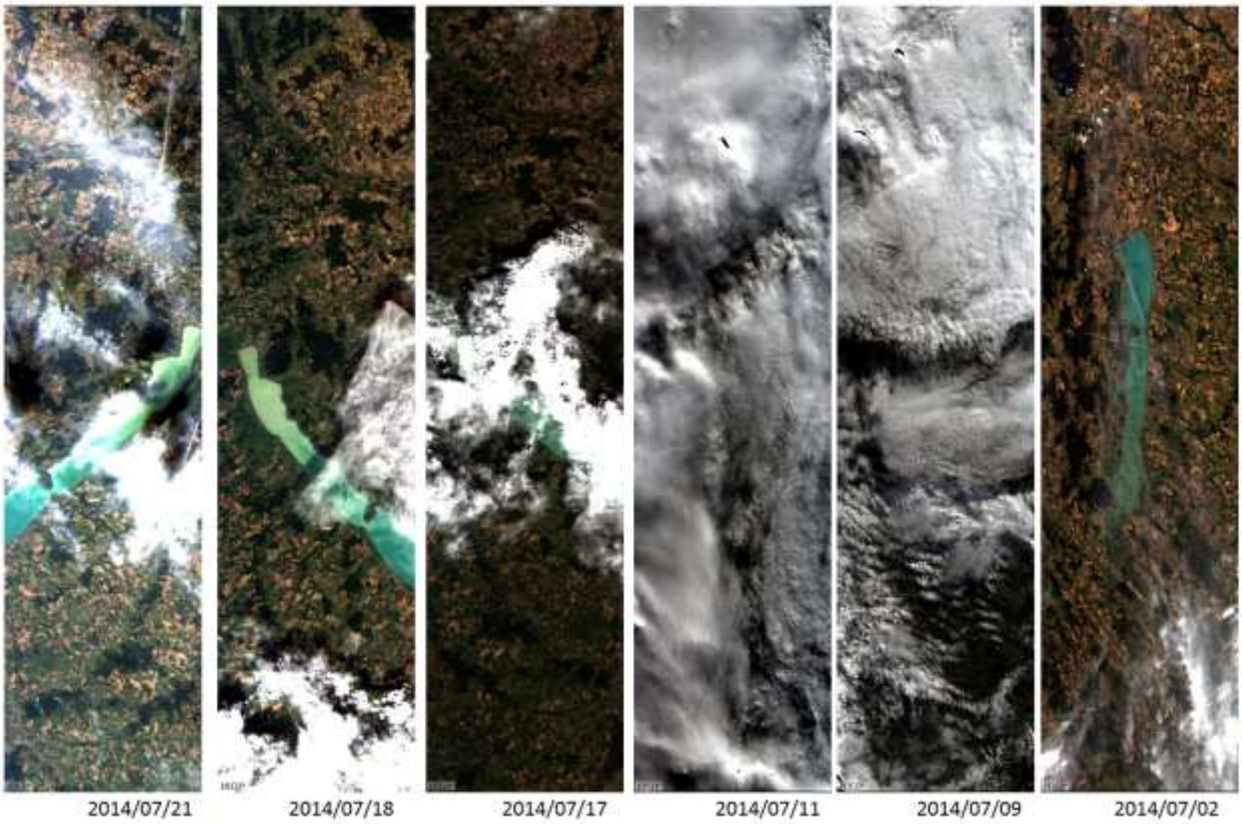
Annex 2: Balaton HICO Quicklooks



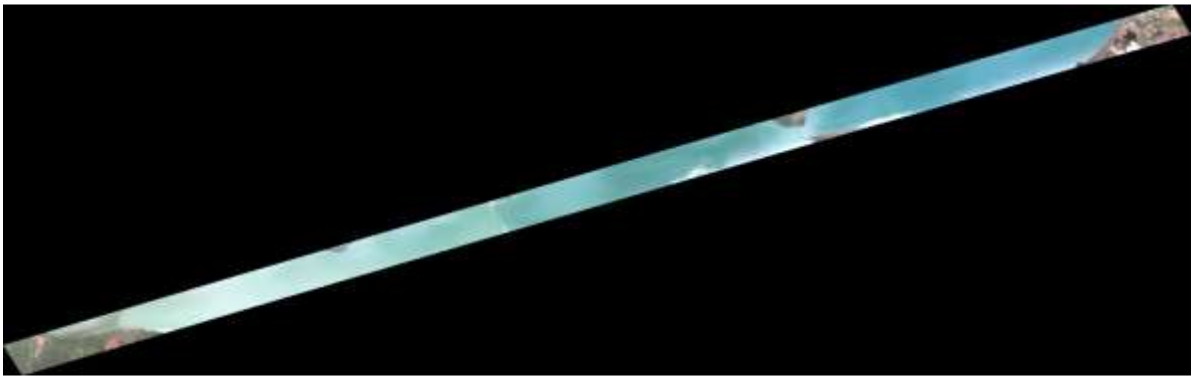
Annex 3: Balaton APEX Quicklooks

19 July 2014

BalatonBOX (flight line 1-9)

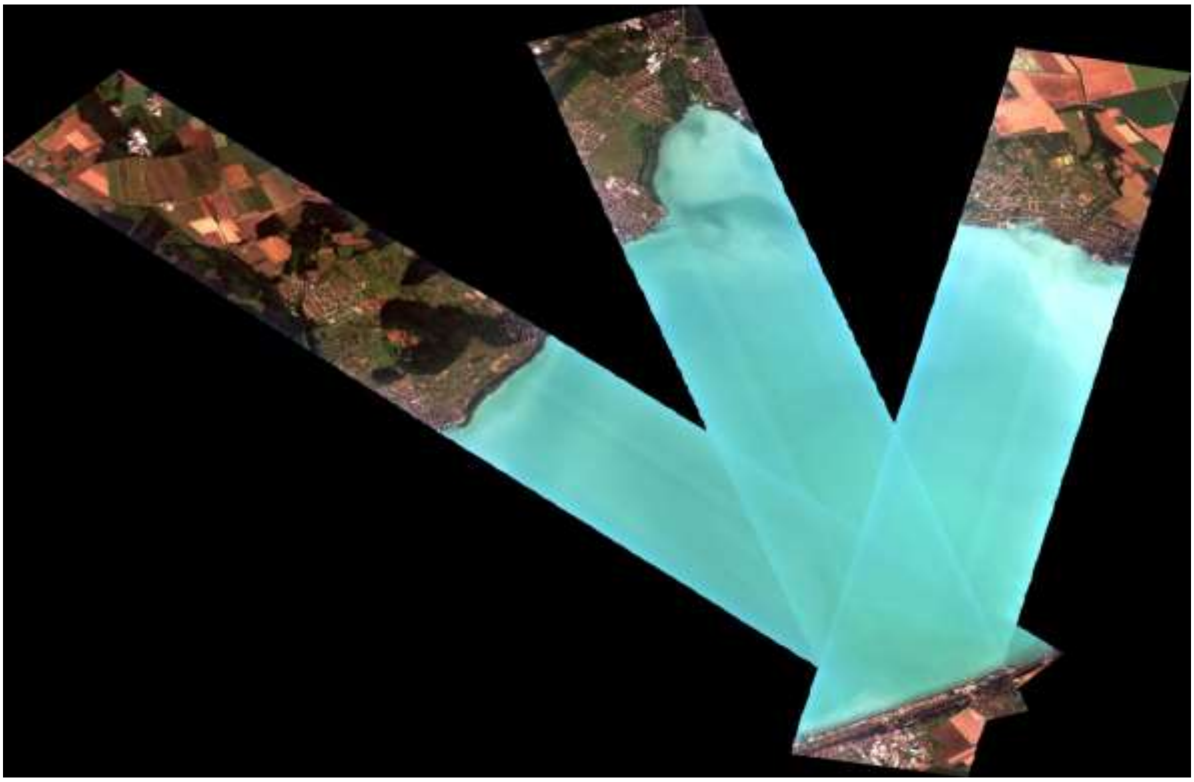
BalatonKIS (flight line 10-12)

BalatonEW

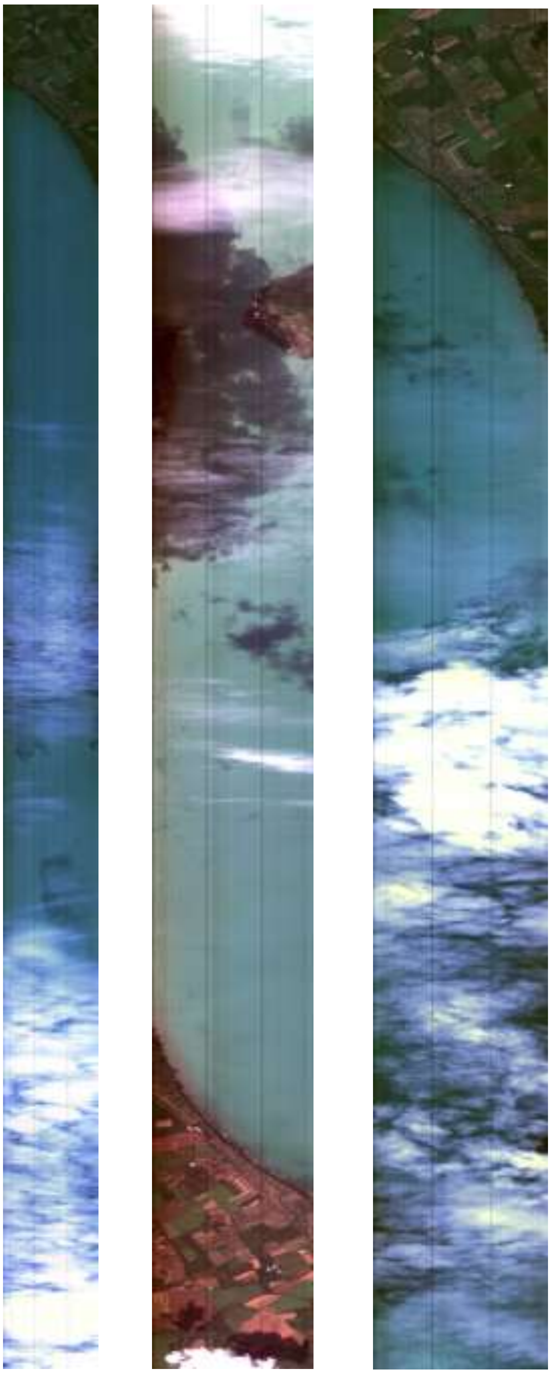


25 July 2014

Balaton (flight lines 8-10)



Balaton (flight line 6 mainly affected by clouds)



Annex 4: Loch Leven AISA Fenix Quicklooks

7 August 2014

Annex 5: Loch Lomond AISA Fenix Quicklooks

8 June 2014