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Aerial infrared thermography in the surface waters contamination monitoring

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ABSTRACT

The feasibility of the surface water contamination monitoring by IR thermography is based on three different key points: (a) the thermal sensors able to measure the thermal energy radiating from water and land surfaces with high sensitivity and accuracy; (b) the thermal gradient existing between land/water surfaces and within these; (c) the rendering of the IR raw data, that produce images with a visible *augmentation* of the anomalies. Illegal sanitary sewer and storm-drain connections, illicit discharges and other "anomalies" on the surface waters could be easily identified by their thermal infrared signatures. If sources of pollution leak, seep or empty into creeks, streams, rivers, lakes and seas their thermal signatures vary from their surroundings and they can be highlighted accurately; in fact, the plume of liquid joining and flowing downstream with the body of water is visible in the thermal infrared spectrum due to the difference in temperatures of the two liquids. Standards methods of pollution-source detection, including on-the-ground water quality sampling and visual stream surveys, do not provide effective coverage of large surface waters. Moreover, where we have small size sources of pollution and the contamination of a wide area, it is very difficult to detect and to correlate causes and effects. The aerial infrared thermography exceeds the current limits of traditional methods of detection. The effectiveness of infrared thermography could be also increased using aerial platform; in fact, if we change the altitude of thermal-sensor (IR-camera), it increases the FOV (field of view) in the acquired scene and we obtain a direct thermal comparison of the targets with other objects in the scenario. The monitoring of the surface waters contamination using aerial infrared thermography, based on our direct experience in the Campania (Italy), has proven an extremely efficient tool to detect the pollution sources and the path of the contaminated waters. We scanned several miles of the coast and flew on critical zones using different aerial platforms technologies (ULM, UAV LTA, Tethered Balloon) and a digital HD IR-Camera. In the paper it will be introduced a report about the "discovery" of the surface waters contamination with description of technical instruments and the first IR/visible shots.

Keywords: Environmental monitoring; Aerial infrared thermography; Illegal sewer; Storm-drain; Surface waters contamination; IR monitoring; Thermal images; UAV; LTA

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1. Introduction

The thermal imaging displays the amount of infrared energy emitted, transmitted, and reflected by an object.

Incident energy = Emitted energy + Transmitted energy + Reflected energy

Incident Energy is the energy profile when viewed through a thermal imaging device, Emitted Energy is generally what is intended to be measured, Transmitted Energy is the energy that passes through the subject from a remote thermal source, and Reflected Energy is the amount of energy that reflects off the surface of the object from a remote thermal source [8].

For instance, the amount of solar radiation reflected from land and sea surfaces, as well as the amount absorbed, depends partly on that portion of energy from the sun that reaches these surfaces. A thermal sensor detects radiant energy from a surface target, heated through radiation, convection and conduction; because of this, it is quite difficult to get an accurate temperature of an object using only this method but, it is possible, with accuracy, to detect the difference of temperature between two o more object in the same IR thermal image.

The amount of radiation emitted by an object increases with temperature; therefore thermography allows one to see variations in temperature.

Usually, water has very dark to medium tones in day thermal-IR images and moderately light tones in night thermal images, compared with the land; this simply means it is cooler in the day and warmer in the night than most other materials in the scene, permitting a clear localization of wet-areas [2].

Also in the same wet-area we can discover different thermal "regions" and/or "spots" due to the difference in temperatures of the water.

Illegal sanitary sewer and storm-drain connections, illicit discharges and other "anomalies" on the surface waters could be easily identified by their thermal infrared signatures. If sources of pollution leak, seep or empty into creeks, streams, rivers, lakes and seas their thermal signatures vary from their surroundings and they can be highlighted accurately; in fact, the plume of liquid joining and flowing downstream with the body of water is visible in the thermal infrared spectrum due to the difference in temperatures of the two liquids.

Standards methods of pollution-source detection, including on-the-ground water quality sampling and visual stream surveys, do not provide effective coverage of large surface waters. Moreover, where we have small size sources of pollution and the contamination of a wide area, it is very difficult to detect and to correlate causes and effects.

The aerial infrared thermography exceeds the current limits of traditional methods of detection [4].

The effectiveness of infrared thermography could be also augmented using aerial platform; in fact, if we change the altitude of thermal-sensor (IR-camera), it increases the FOV (field of view) in the acquired scene and we obtain a direct thermal comparison of the targets with other objects in the scenario.

2. Instruments and platforms

The integrated system used to perform our missions includes an aerial platform and instruments (*payload*). The payload includes an array of sensors finalized to the measurement of environmental parameters and it was customized to be hosted on board of the aircraft.

2.1. IR camera

The core of our *payload* is an IR Camera; in detail, we use the model P660 manufactured by FLIR Systems (Fig. 1). Main technical specifications of this model are:

- 640 × 480 Infrared Detector
- Thermal Sensitivity: <45 mK
- High accuracy +/− 1%
- Dynamic Details Enhancement (DDE)
- Built-in GPS
- WLAN remote control and display
- 3.2 Megapixel visible light camera (this feature permit a *data-fusion* between IR and Visible)

2.2. Aerial platforms

The choice of the aerial platform has been done by verifying the particular correspondence of it to the requisites of the mission and, at the same time, appraising the same one like efficient "amplifier" of what is measurable from the sensors positioned on the ground in *pure* configuration (Fig. 2).

Fig. 1. Infrared Camera FLIR-P660.

Fig. 2. ULM – Tethered Balloon – Blimp UAV – Hybrid LTA UAV.

The selected aerial platforms to perform the specific missions were a ULM (Ultra Light Machine), a Tethered Balloon and two type of UAV: a conventional shape mini blimp and a Hybrid LTA (Lighter than Air) type, that will allow the exploration of three-dimensional spaces without altering the measurement parameters, returning geo-referenced data, guaranteeing minimal invasion and maximal safety for the operational context [1,3].

3. Things to consider before starting the monitoring missions

During last years the thermography was a technique generally used to find a problem with only a qualitative approach and this limit derives by the technologies of sensors used (e.g. films with a special sensitivity to IR or electronic sensors, micro-bolometers, but with an analog output) and, for this reason, at the end of the research we had only images/pictures to examine but no data, no numbers.

In this research we used one of first High Definition IR Digital Camera in the world that give us a digital output (radiometric file); in particular, for each scenario target we grab a numerical matrix with the measurements of singular spot/pixel and, successively, a software converts the energy measured to temperatures and to false colors images.

In simple terms, one can think of thermography as "how hot" an object is, whereas radiometry is "how much energy" the object is giving off. Although these two concepts are related, they are not the same thing. IR cameras inherently measure irradiance not temperature, but thermography does stem from radiance. When you thermogragraphically calibrate an IR system you are calibrating/measuring based on effective blackbody radiance [6].

When we illustrate an IR image of this paper we show only the end of a complex data analysis and this output is a quantitative output: we have in the image showed a real graph of energy radiated and, with the help of specific software, it is possible a post-processing of grabbed data.

Surely if you examine the IR pictures included in this paper your first feel is to see a standard picture but with the colors changed, it is incredible but they are graphs! They are the representation of each numeric matrix grabbed on the field.

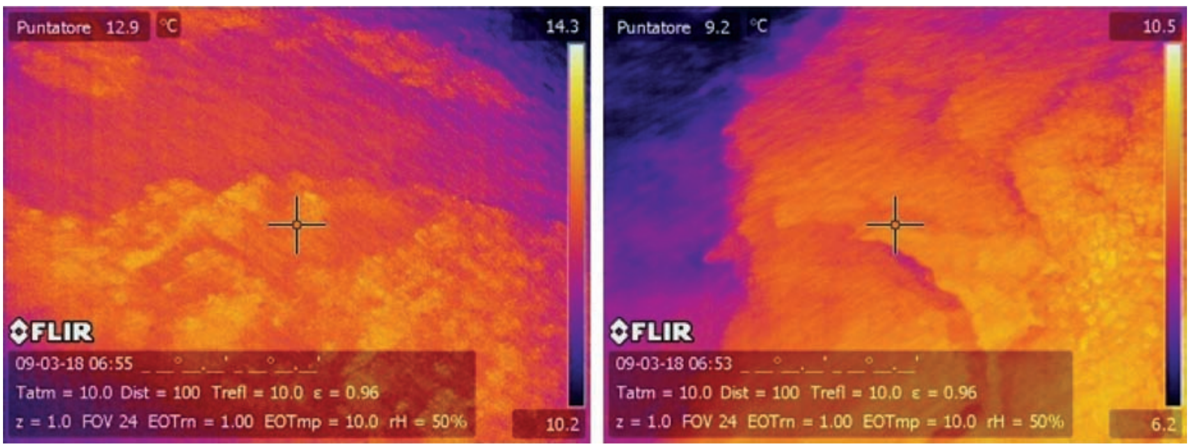


Fig. 3. Examples of thermal pattern of liquid fluxes: cooler surface sea current and plume of liquid joining and flowing downstream.

This result derives by the mix procedure and technologies: high performances of sensor, the particular point of view, the choice of the time of the day and the complex software post-processing.

The main steps of this process are illustrated in Figs. 3 and 4.

3.1. Thermal pattern of liquid fluxes

Analyzing different shots of same typology of phenomena we could discover a composite of traits or features characteristic with the same geometric perceptual structure; if the examined pictures are the rendering of IR data

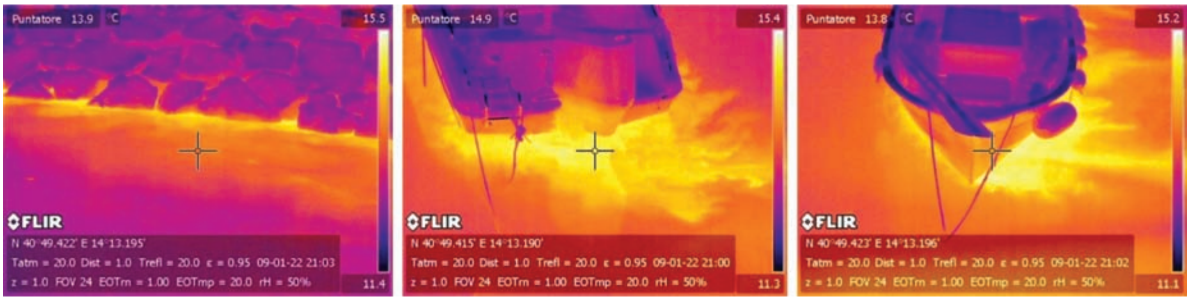


Fig. 4. Examples of thermal tracking in the water (frames grabbed after sunset): black rocks, resin motorboat, wood boat in the sea.

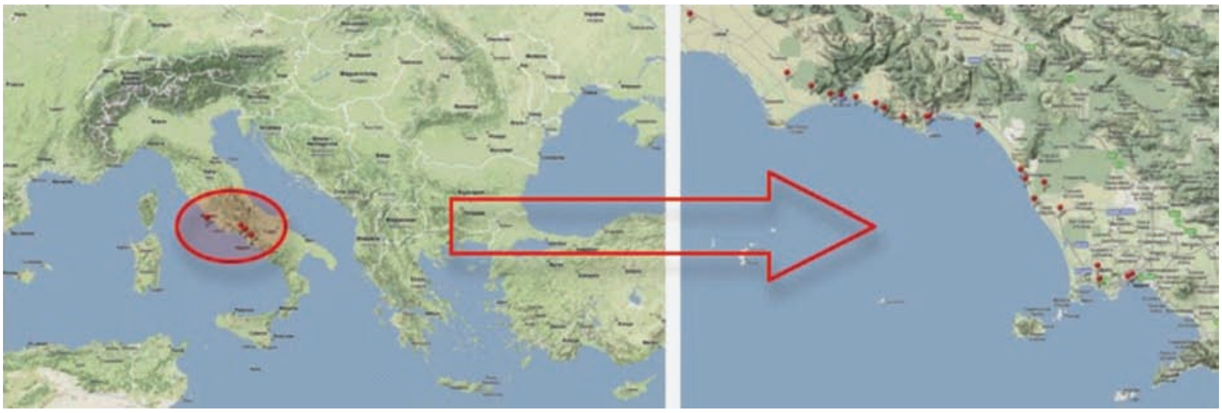


Fig. 5. Illustration of the two-dimensional experimental set up.

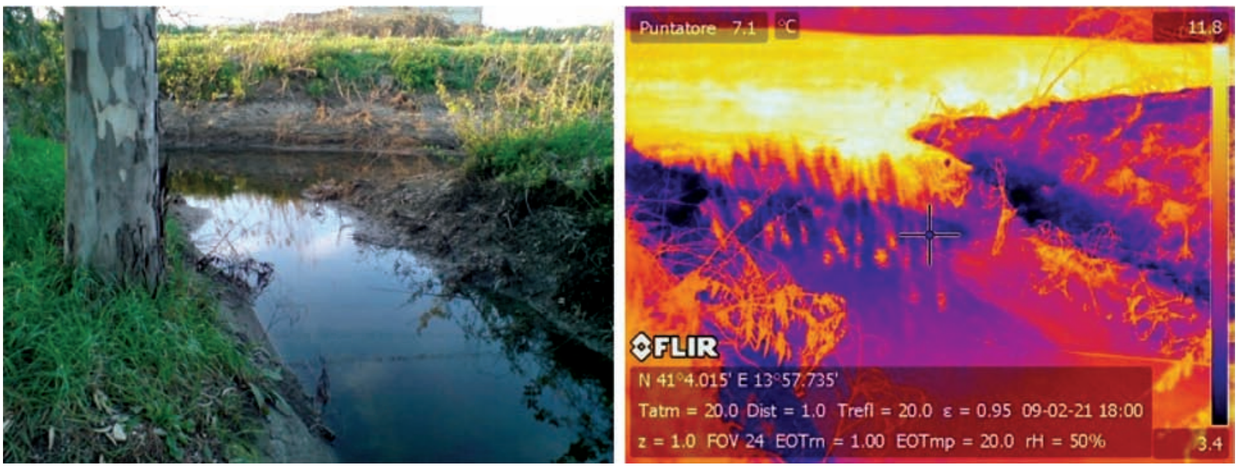


Fig. 6. Connection between two small streams and contamination with sanitary water.

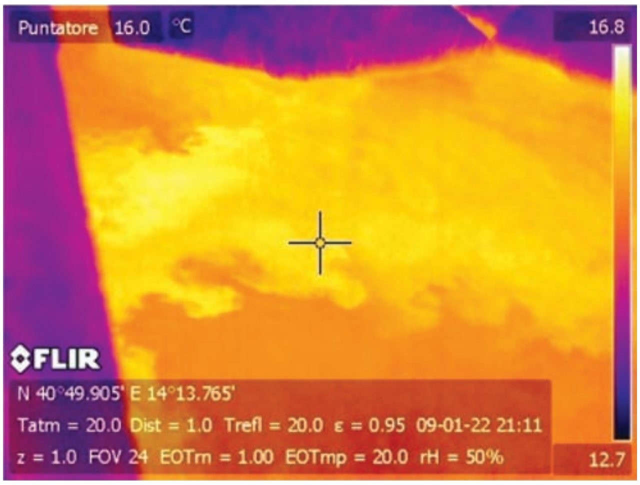


Fig. 7. Illegal sanitary sewer that stream in the sea.

(grabbed with a IR camera) we can define a new concept: *thermal pattern*.

In order to detect a problem in a complex scenario it is important to define several standard *thermal pattern* of liquid fluxes related to known phenomenologies; this approach will permit to build a "visual" data-base.

Fig. 3 shows some shots of the thermal pattern of liquid fluxes grabbed in the sea; it is clear to understand the *border zone* between different surface streams.

3.2. Thermal tracking

As we said before a thermal sensor detects radiant energy from a surface target, heated through radiation, convection and conduction. Usually, water has very dark to medium tones in day thermal-IR images and moderately light tones in night thermal images, compared

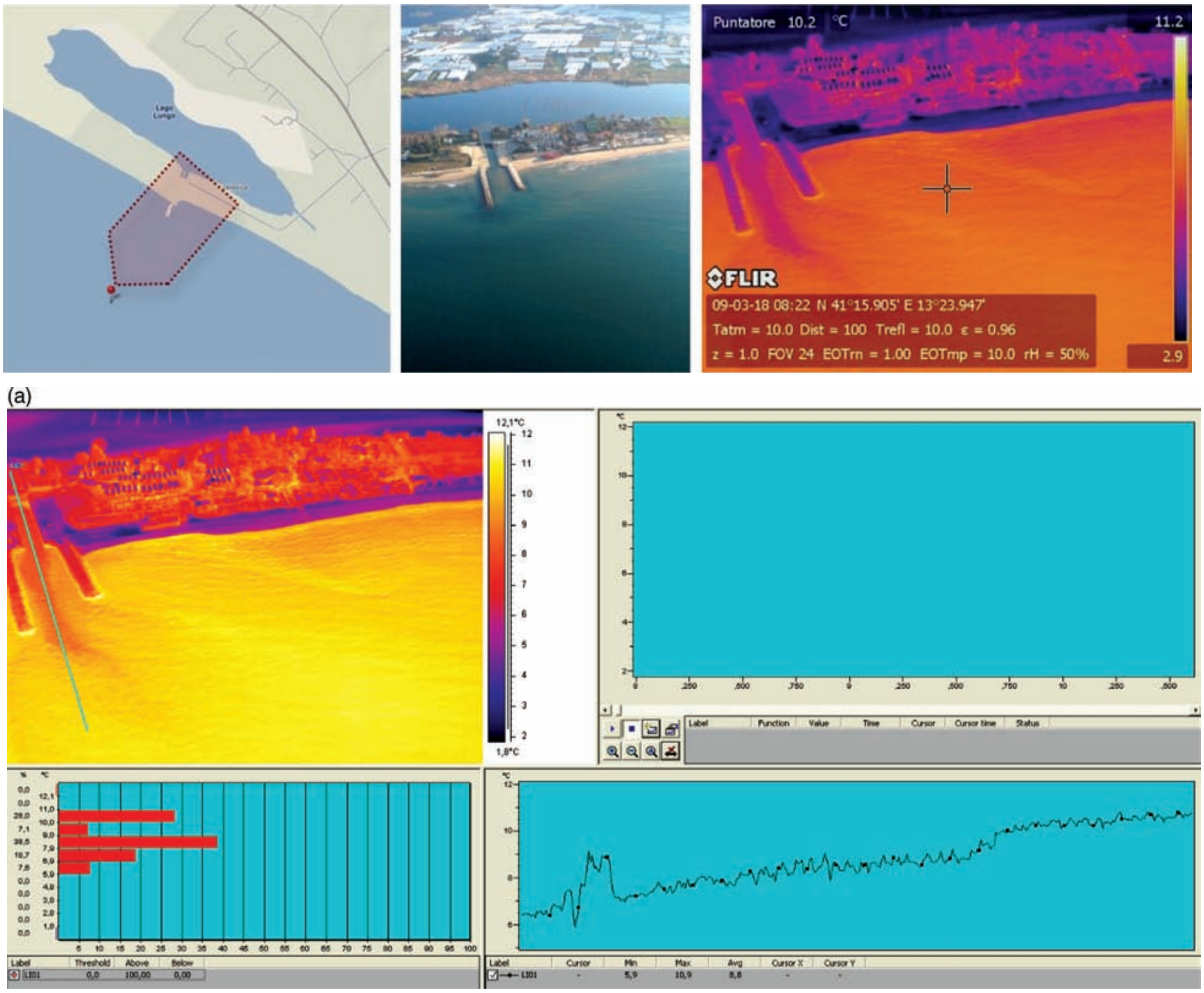
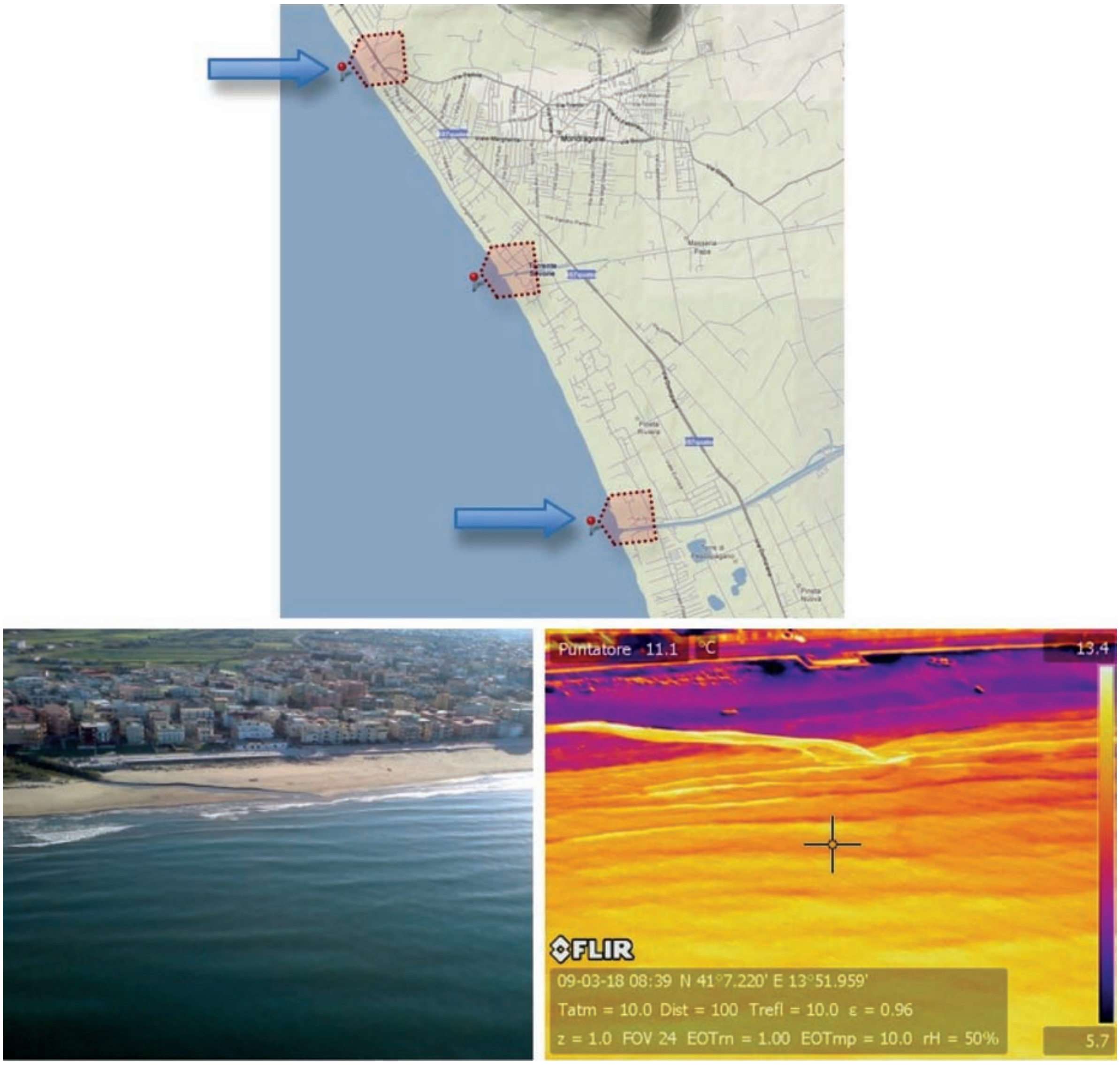


Fig. 8. Connection between a coastal lake and the sea; (a) post-processing of data acquired in Fig. 8.



(a)

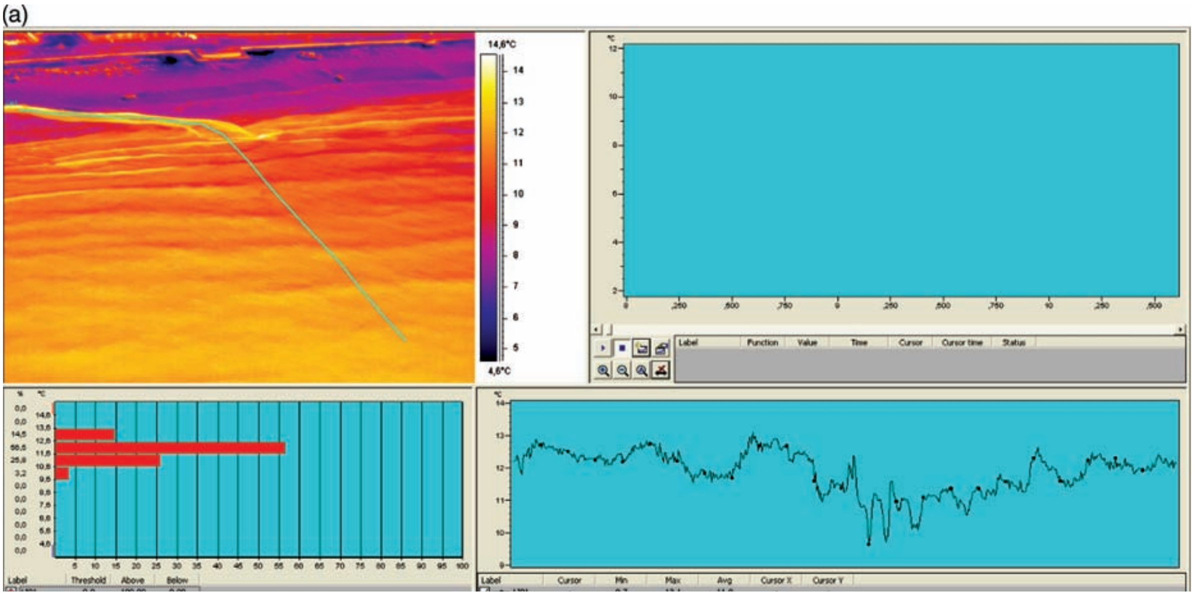


Fig. 9. Storm-drain connection between the centre of a touristic city and the sea; (a) post-processing of data acquired in Fig. 9.

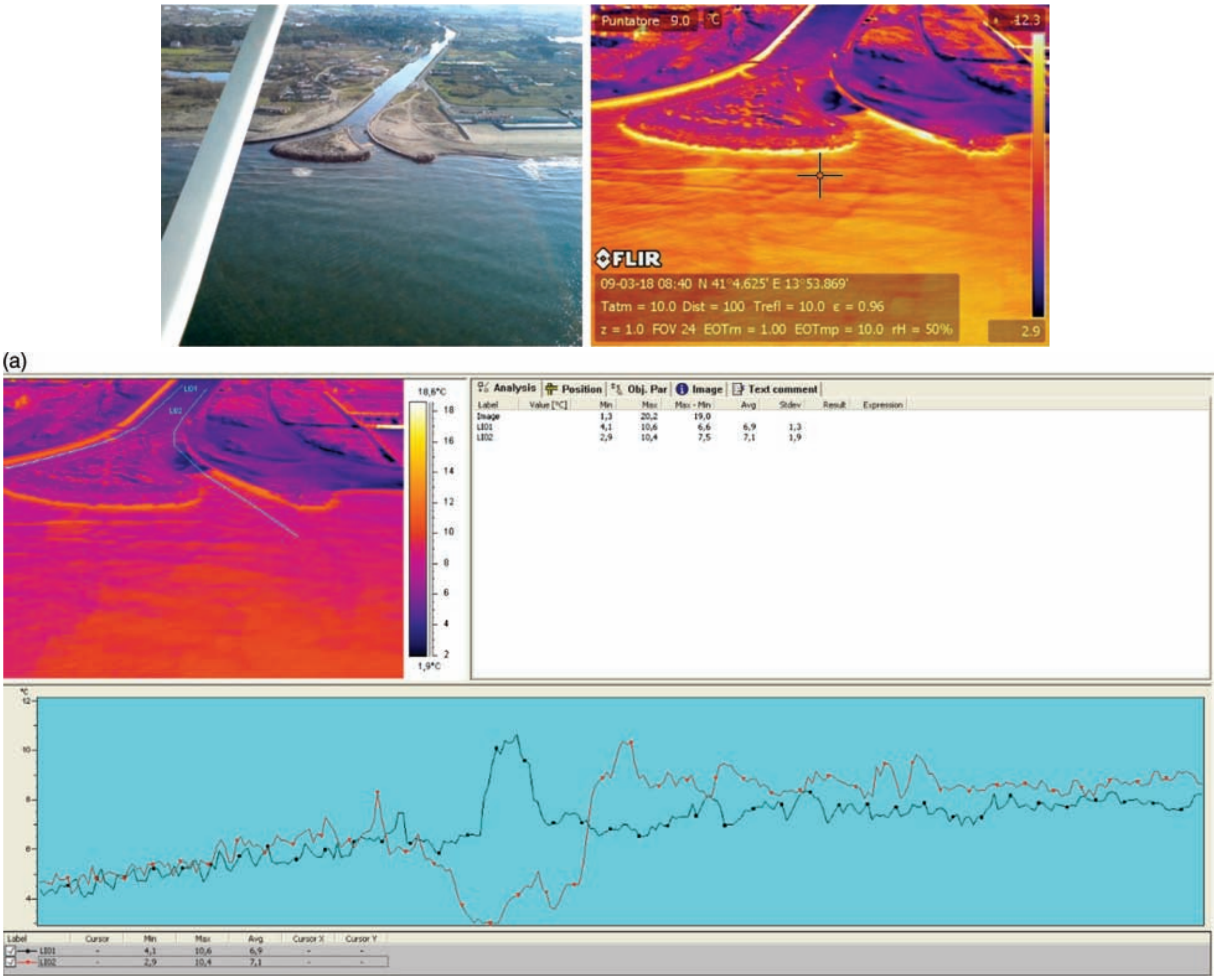


Fig. 10. River delta with a connection closed by the sand; (a) post-processing of data acquired in Fig. 10.

with the land; this simply means it is cooler in the day and warmer in the night than most other materials in the scene. But also in the same wet-area we can discover different thermal "regions" and/or "spots" due to the difference in temperatures of the water; this response is due in part to a different thermal inertia of the bodies. If we introduce in the water surface target a warmer or cooler body, following the signature of the temperature "smoothing", we could trace the flux using thermal signature; we could define this method "thermal tracking".

It is important to highlight that several objects already present in scene to grab, permit a "natural" thermal tracking (see Fig. 3).

4. Missions

The monitoring of the surface waters contamination using aerial infrared thermography, based on our direct experience in the Campania-Italy, has proven an extremely efficient tool to detect the pollution sources and the path of the contaminated waters. It is important to highlight that it was the first case history report using this method/technologies in Italy and Europe and, probably in the world.

We scanned several miles of the coast and flew on critical zones using different platforms technologies ("on the ground", ULM, UAV LTA, Tethered Balloon) and a digital HD IR-Camera (Fig. 5).

4.1. Scan on the ground

The cases considered in this paragraph have been studied experimentally, positioning the IR Camera on the ground, closest the examined area.

The Fig. 6 illustrates the connection between two small streams; the first one is near a road (and probably near houses and illegal discharges) and the second has origin in the agricultural cultivations. In the IR shot it is clearly visible the difference of temperature: the stream near the road has an higher temperature derived by the contamination with sanitary water.

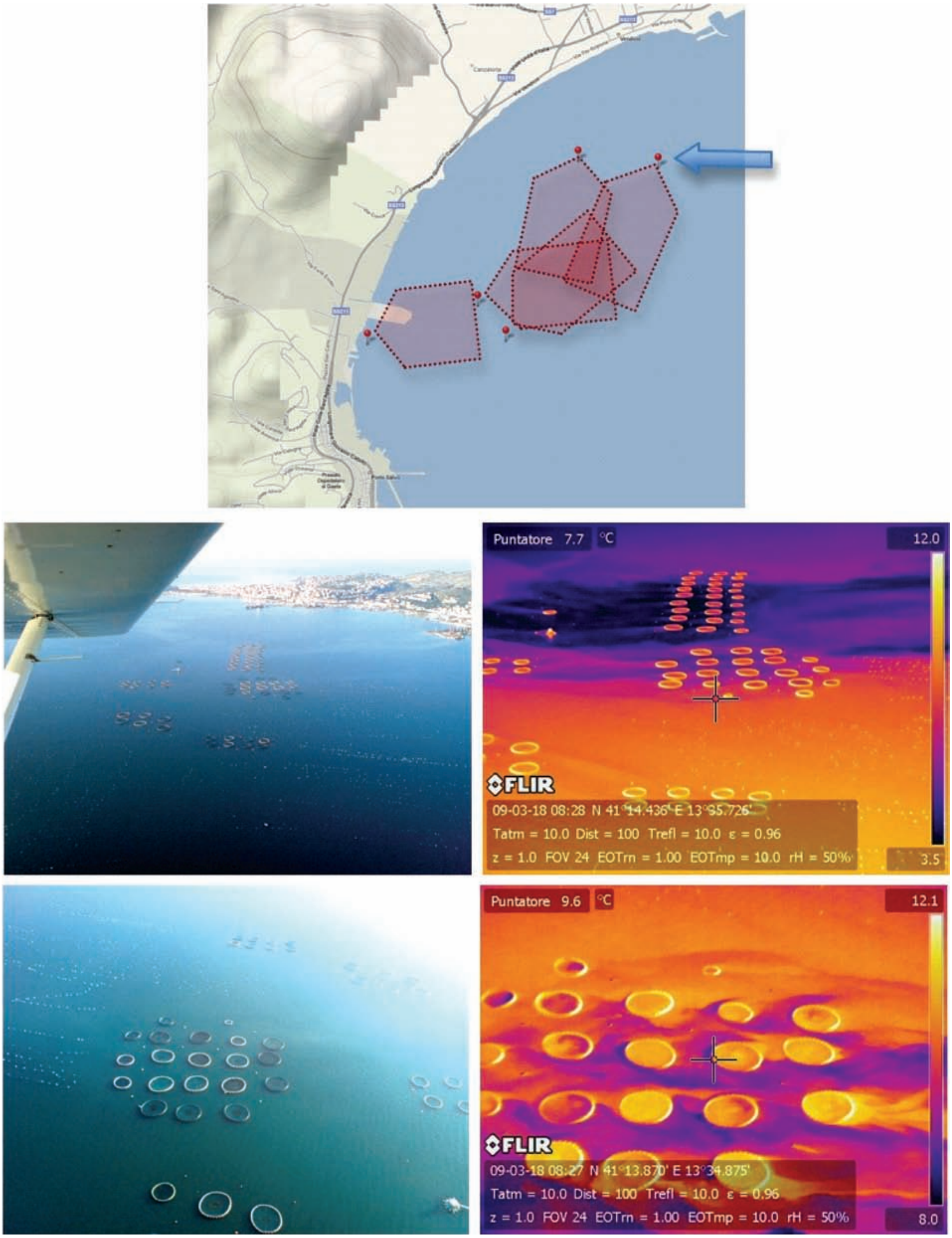


Fig. 11. Surface marine currents cross a fish-farm in the sea (mariculture); (a) post-processing of data acquired in Fig. 11.

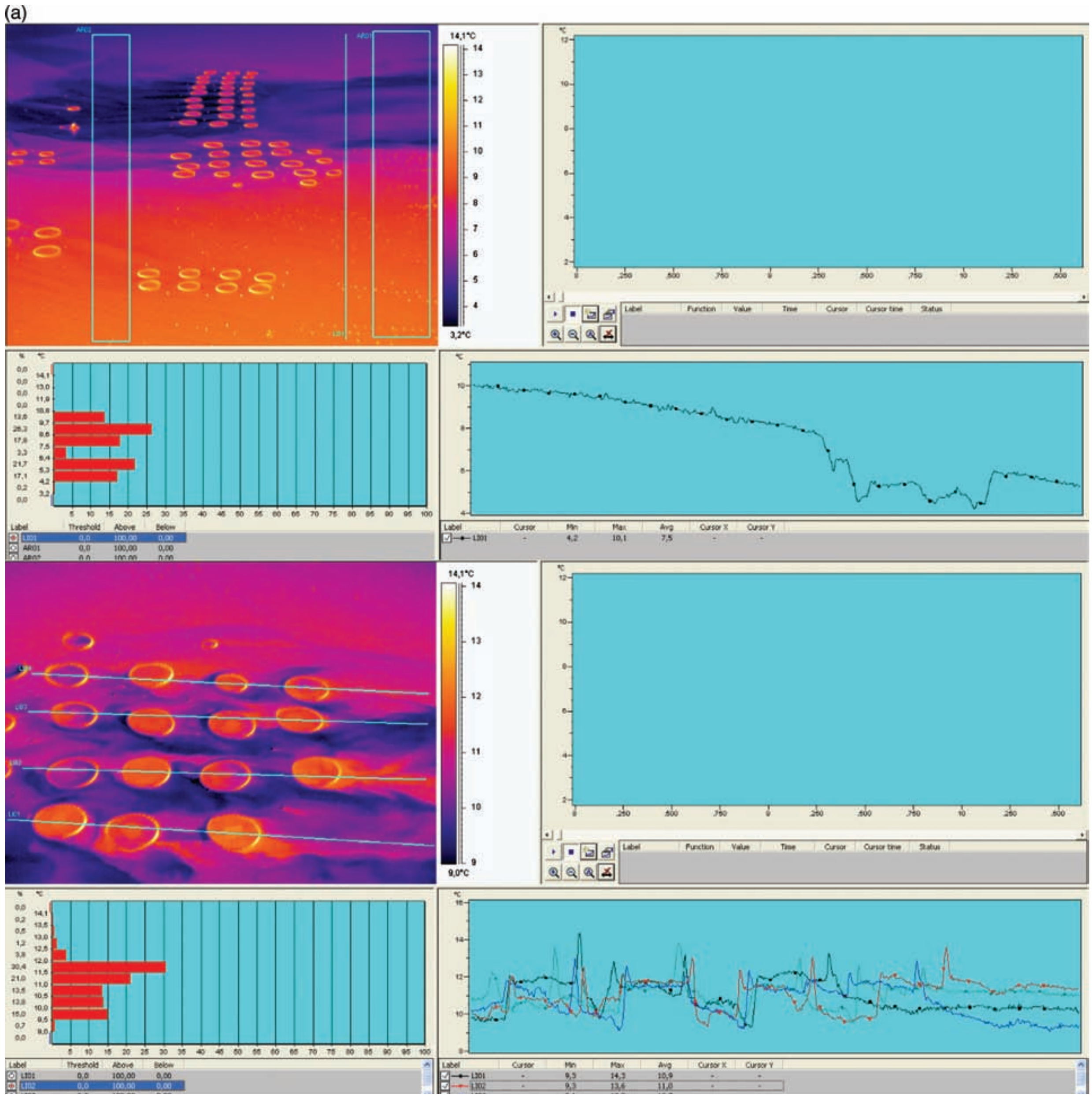


Fig. 11. (*continued*).

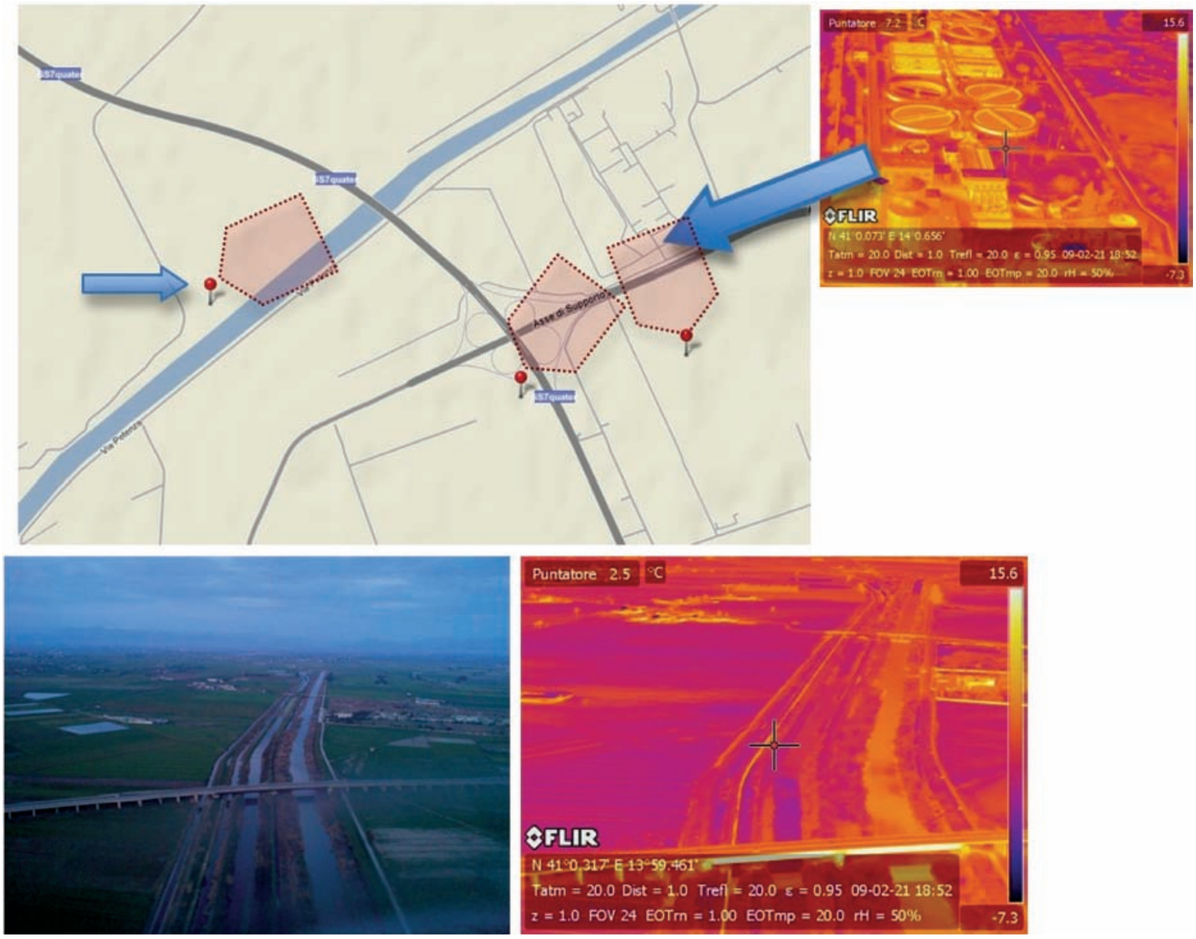
The Fig. 7 illustrates an Illegal sanitary sewer that fills the sea near some rocks: you can see the standard thermal pattern of liquid fluxes related to known phenomenology (as seen in the Fig. 3, rx picture). We grabbed these IR and Visible pictures during the first hours of the night, 09:11 p.m. (we don't show the paired Visible shot since it was too dark and not understandable).

4.2. Scan by aerial platform

The cases considered in this paragraph have been studied experimentally, positioning the IR Camera on several aerial platforms. Moreover, to define with accuracy POV (Point of View) and FOV we used special tools (hw and sw) carried onboard the vehicles and, then, we produced illustrations with POV (red pin-point) and FOV (red view-angle) positioned on a calibrated map.

Fig. 8 illustrate the connection between a lake (coastal lake) and the sea; it is easily understandable the cold flux, originated in the lake, flowing toward the sea.

Figs. 9 and 10 illustrate several "anomalies" along the coast of Campania (Italy) near a tourist city (Mondragone). The blue-arrows point to the selected cases showed in the Figs. 9–10. Fig. 9 shows a storm-drain



(a)

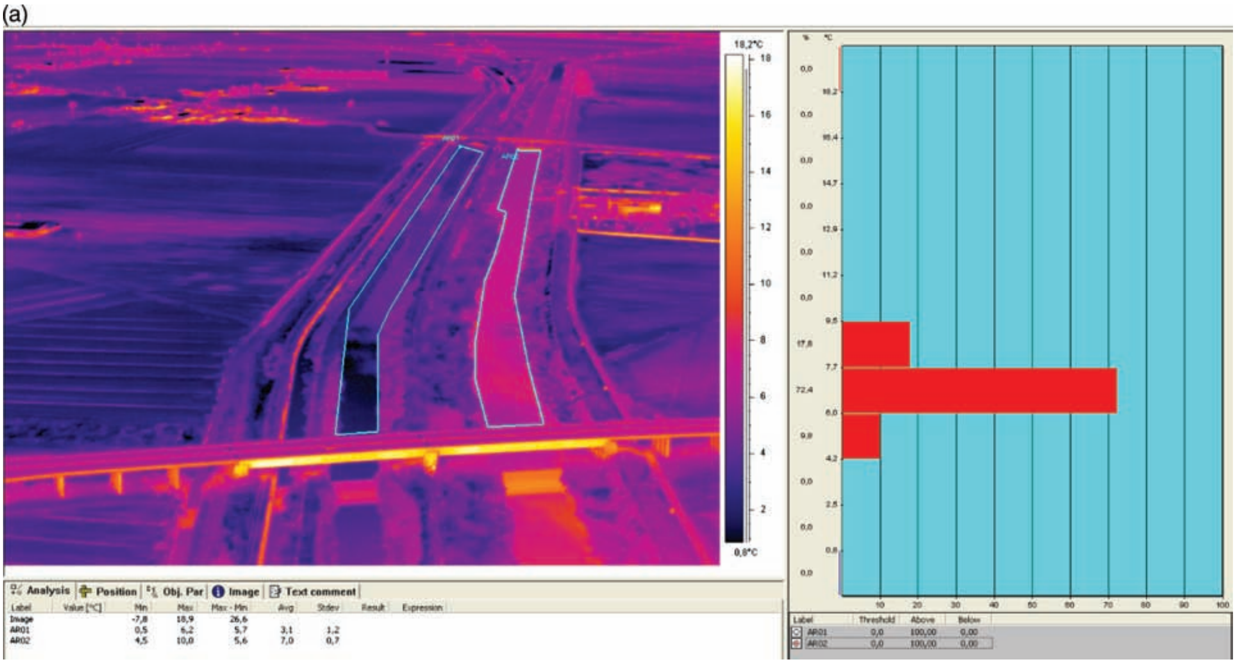


Fig. 12. Wastewater plant fills a dual bed stream connected to the sea; (a) post-processing of data acquired in Fig. 12.

connection between the centre of the city and the sea; too much warm and with a high flow of water for an "only" storm-drain during a week without rain!

Fig. 10 shows a river delta with a connection to the sea closed by the sand. Usually where delta formation is river-dominated and less subject to tidal or wave action, more deposition occurs and a delta may take on a multi-lobed shape which resembles a *bird's foot*. In this case you can follow cold flow of the river (blue color) stopped on right stream, in the other side you can see a continuous changing of colors between river and sea (fluxes mixing).

Fig. 11 shows surface marine currents cross a fish-farm in the sea (mariculture). Several water quality models were developed to simulate the sediment-water-pollutant interaction to address the response of benthic layer to mariculture pollution discharges but, standards methods of pollution-source detection do not provide an effective direct monitoring of the interaction between fish-farm and water matrix. In these pictures you can see an "invisible" cold stream in the middle of the gulf of Gaeta (Italy) and a detail of this flow in the "impact" with the fish-farm. This condition permits a "natural" thermal tracking of the currents along the plant, defining the *flushing time* - the average lifetime of a particle in the given volume of water body - and characterizes the effectiveness of removing the pollutants to clean surrounding water [7].

Fig. 12 shows a dual bed stream where a wastewater plant has the connection; in detail, you can see the difference between the *pass trough* bed (cold stream on the left of IR picture) and *joined* bed (warm stream on the left of IR picture).

5. Results

The cases studied for the purposes of this contribution validated aerial infrared thermography as optimal tool to support the surface waters contamination monitoring.

By using infrared thermography, specialized aerial platforms and advanced techniques of data analysis and visualization we can discover several environmental problems: locating pollution point sources and finding right *path* between sources and targets.

As outlined above, there are many effectiveness uses for aerial infrared thermography in the field of environmental monitoring; it is very easy, compared with standards methods of pollution-source detection, to discover Illegal sanitary sewer and storm-drain connections, illicit discharges and other "anomalies" on the surface waters.

The aerial infrared thermography also exceeds the current limits of traditional methods of detection where we have small size sources of pollution and the contamination of a wide area.

The choice of a specific platform that float in the "air" matrix, permit the data grabbing from a privileged point of view for phenomena in action in the other matrices, increasing the FOV in the acquired scene and with a direct thermal comparison of the targets with other objects in the scenario.

A specific aerial platform (Hybrid LTA), developed in cooperation with Italian Aerospace Research Center, will increase the performance of the standard aerial system to support this advanced monitoring system; moreover, this type of platform will allow the exploration of three-dimensional spaces without altering the measurement parameters, returning geo-referenced data, guaranteeing minimal invasion and maximal safety for the operational context.

Acknowledgments

We wish to thank CIRA (Italian Aerospace Research Center) for their contribution in the development of a specific UAV (Hybrid LTA) to perform the missions.

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