ISSN 2039-7941
Anno 2018_Numero 392

rapporti tecnici INGV

The environmental characterization of Lake Vättern and the AUV test for the Clean Sea project

392

Istituto Nazionale di
Geofisica e Vulcanologia

REGISTRAZIONE AL TRIBUNALE DI ROMA N.173|2014, 23 LUGLIO

Rappresentante legale: Carlo DOGLIONI
Sede: Via di Vigna Murata, 605 | Roma

ISSN 2039-7941
Anno 2018_Numero 392

rapporti tecnici INGV

THE ENVIRONMENTAL CHARACTERIZATION OF LAKE VÄTTERN AND THE AUV TEST FOR THE CLEAN SEA PROJECT

Marina Locritani[1], Cosmo Carmisciano[1], Federico Bruni[2] and Michele Filippini[2]

[1]**INGV** (Istituto Nazionale di Geofisica e Vulcanologia, Sezione Geomagnetismo, Aeronomia e Geofisica Ambientale)
[2]**EniProgetti SpA**

How to cite: Locritani M. et al., (2018). The environmental characterization of Lake Vättern and the AUV test for the Clean Sea project. Rapp. Tec. INGV, 392: 1-30.

392

Index

Introduction

Clean Sea (Continuous Long-term Environmental and Asset iNtegrity monitoring at SEA) project [Gasparoni et al., 2013a] concerns the use of commercially AUV [Gasparoni et al., 2013b] with a modular interchangeable payload for environmental monitoring and inspection tasks around Eni oil & gas offshore infrastructures. The platform identified for the development of the project was SAAB Seaeye Sabertooth. The project defined peculiar hardware and software architecture, where the payload controller is separate from the AUV controller and able of modifying "in real time" the mission strategy [Buffagni et al., 2014]. The environmental payload chosen for AUV was: Temperature [°C], Salinity [psu], Methane [µmol/l], Colored Dissolved Organic Matter [ppb], Chlorophyll [µg/l], Turbidity [m-1 sr-1], Oxygen [µmol], Oxygen [%], Polycyclic Aromatic Hydrocarbons [µg/l], pH, Oxidation Reduction Potential [mV]. The Lake Vättern (Figure 1), the sixth largest lake in Europe and the second largest lake in Sweden after Lake Vänern, has been chosen as test field for the first AUV ascertainment. In detail, 36 tests have been realized in two different sites (Figure 1), located in the North-East (latitude 58°32'32.27"N, longitude 14°58'9.03"E) and North-West (latitude 58°32'32.27"N, longitude 14°58'9.03"E) side of the Lake, from November, 2012 to July 2013.

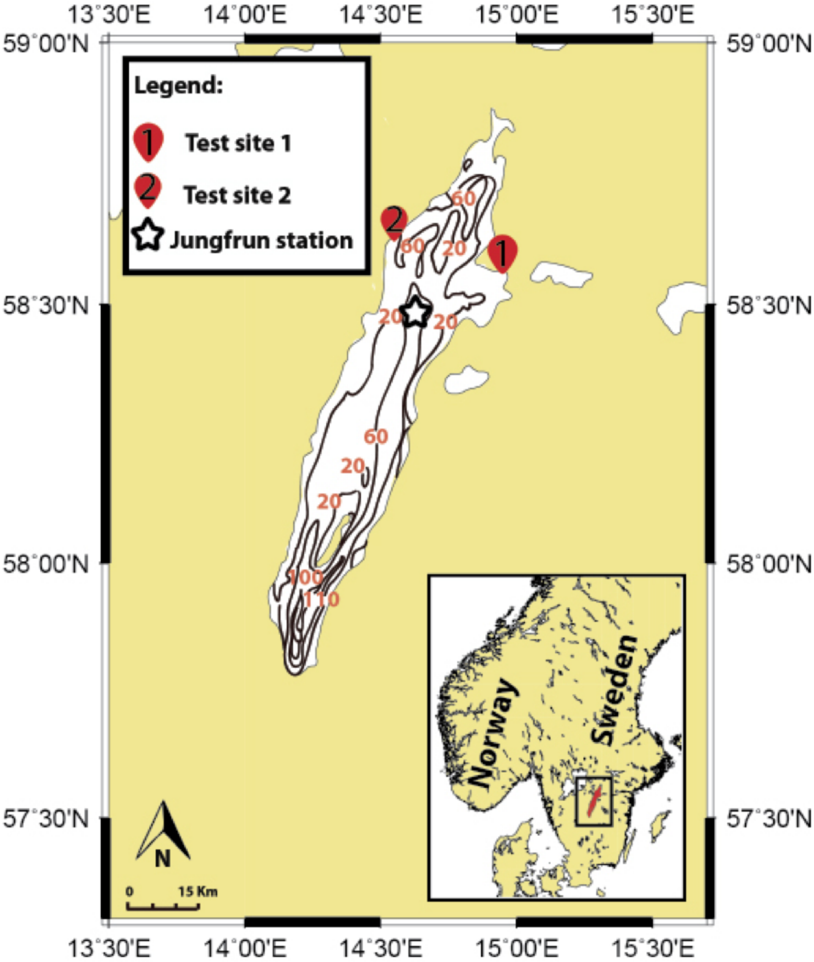

Figure 1. Lake Vättern location and bathymetry. The red numbers indicate the depth along the isobaths [m]. Moreover the two test sites (Test site 1 and Test site 2) and a reference station (Jungfrun) have been indicated in legend.

The aim of this report is the Lake Vättern characterization made by on-line available data, needed to support the AUV mission planned and to evaluate the data acquired during the tests. The most significant tests results are: the spatial and seasonal variation of measured parameters during the tests, and the comparison between the historical data free available on-line and the data acquired during the tests.

1. Lake Vättern characterization

Lake Vättern, a long, finger-shaped body of fresh water in south central Sweden is situated in a very large rift-valley lying in a North North East-South South West direction. Lake Vättern has a water volume of 74 km^3, a surface of 1856 km^2, a shore length development of 460 km [Kvarnäs, 2001]. Lake Vättern consists of three different deep sub-basins separated by submarine thresholds [Kourzeneva, 2012]. The western shore of the lake is more shallow and the bottom-topography (Figure 1) more flat than the eastern one [Liljequist, 1941]. The deeper basin (maximum depth 128 m) is located in the Southern part. The mean depth of the lake is 39.9 m [Kvarnäs, 2001]. The shores are generally steep, especially at the southernmost end of the lake, while the western coastline is not too steep as the eastern. The North part is characterized by bays and inlets, differently from the other coast of the lake. The height of Lake Vättern above sea-level is 88 meters. Lake Vättern has great economical influence for its touristic, commercial, transports uses and for the excellent quality of its transparent water. Lake Vättern is classified as an ultraoligotrophic lake [Willén, 2001a, Willén, 2001b], it holds over 30 fish species with a mixture between arctic and temperate species [Florén, 2008]. The climate of the lake is mild with respect to the other lakes at the same north latitude (57-60 degrees) thanks to the western winds action mitigated by the Gulf Stream. In fact, during the winter, the Lake Vättern rarely freezes completely [Reinart and Reinhold, 2008]. To freeze, Vättern, requires cold and absolutely calm weather. Between 1970 and 1996, the lake, however, froze 10 times in its entirety, which means that in modern times it froze every three years [Dahlén, P., 1996]. The ice cover data from satellite are available from ARC-Lake project from August 1991 to December 2011 for each day. The clime of the region is also conditioning by the daily sunlight hours. In winter approximately the day has 6 hours of sunlight, in Spring 13 hours, in Summer 19 hours and in Autumn 11 hours. Lake water movements are created by various processes as local water inflow, convection, wind interaction and internal seiches [Goran et al., 1990] they may act singly or in combination, and be occasional or with long duration. The tide is negligible. The currents very often attain appreciable strength, due to the fresh wind effect and to the smooth bottom-topography together with the lack of shallow thresholds running across its longitudinal direction [Fankquist, 1979]. In detail, to judge from the well-developed seiches which are generated, the currents generally last some time after the wind has ceased blowing [Liljequist, 1941]. The uninodal surface seiches of Lake Vättern have a periodicity of about 179 minutes and a maximum amplitude of about 12-13 cm [Kvarnäs, 2001], this depends on the shape of the basin and the thermal stratification. Instead, the internal seiches may move upward or downward more than 15 m within a few days and considerable amounts of water are displaced [Bjork and Lundberg, 1990; Goran, 1990]. This phenomenon can cause the rotating wave (Kelvin wave) that turns anticlockwise. These waves are affected by topography and by the bathymetry of the lake. In Lake Vättern the periodicity of the waves has been estimated to be ~ 136 hours and the phase speed ~ 0.05 m/s [Funkquist, 1979]. The area of Lake Vättern is not classified as a site of natural emission of methane from geological seepage [Etiope, 2009]. Production rates for freshwater lakes and marine environments are difficult to convert into emission rates to the atmosphere. One reason for this problem is the simultaneous occurrence of microbial methane oxidation in aero-biotic parts of the sediments and in the water-body above the sediment [Svensson, 1991]. However methane gas has been known to be found in the central part of Östergötland (Eastern of Lake Vättern) for many years [Soderberg and Flode, 1992]. The Swedish Geological Survey has reported over 50 gas seeps from the region but probably many more exist.

2. Data and Methods

2.1. Historical data

A lot of data sets exist which comprise information on location, extent and other basic characteristics of open water bodies and wetland areas on a global scale [Lehner, B. and P. Döll, 2004]. The Lake Vättern characterization has been performed by free on line data from different institutes. In detail:

- Satellite Sea Surface Temperature Advanced Very High Resolution Radiometer (AVHRR) data, from 1981 since 2009, are available by the follow links *ftp://podaac-ftp.jpl.nasa.gov/allData/avhrr/L3/pathfinder_v5/monthly/day/04km/2009/* and *ftp://podaac-ftp.jpl.nasa.gov/allData/avhrr/L3/pathfinder_v5/monthly/night/04km/2009/.* Surface Temperature (4 Km of resolution) from AVHRR satellite data (for 2009) are extracted for the test area (Latitude 58°32’32.30”N and Longitude 14°58’8.78”E) by ad hoc MatLab routines.

- In situ data about biological, chemical and physical water parameters (Temperature, pH, Chlorophyll, and Colored Dissolved Organic Matter) are available thanks to the International Lake Environmental Committee (ILEC) at the following link: http://wldb.ilec.or.jp/Details/LakeDataList/EUR-15 [Kourzeneva, 2012]. Three sampling stations are available for Lake Vättern, but we consider only the station closer to the study area: Jungfrun Station (is 20 km South-West of the study area, latitude 58°30'03,0" and longitude 14°40'42,0", Figure 1). The sites were sampled approximately four times a year. The historical in situ data have been acquired from 1981 to 1985 from April to October from the surface to the bottom and averaged every 10 m of depth. Moreover the historical data about physical parameters (Temperature, pH, Conductivity, Oxygen, Transparency - Disco Secchi) is available by Institutionen för vatten och miljö (*http://info1.ma.slu.se/ma/www_ma.acgi$StationC&ID=StationData&S=579*) from 1978 to 2012.

In this report we present the data about 2009 in comparison with the satellite data. The data have been averaged for each month and for the entire column of water (0,1 - 95 m). The data have been processed by ad hoc MatLab routines.

2.2. AUV data

The tests, with SAAB AUV, have been realized in two different phases. The first one starting on November 2nd, 2012 until November 23rd, 2012 and included 20 tests (see appendix Table 1 and 2) in two different areas (Figure 1), the second one included 16 tests (see appendix Table 3 and 4) performed between May 18th and July 4th, 2013 in the Eastern area (Figure 1) of the Lake Vättern. The AUV missions have been planned with different shapes of trajectories (see appendix Table 2 and 4): the rectangular and the square grid with different dimension, and the linear track. In each case, the AUV floated for some meters at surface and then dipped to the estimated depth toward the starting mission point. For each test the following parameters have been analyzed: Temperature [°C] and Salinity [psu] acquired by SeaBird model SBE-49 FastCAT; Methane [µmol/l] measured by two instruments Franatech model METS G121-E307 (with higher detection limit 100 µmol/l) and Franatech model G93-E385 (10 µmol/l); Colored Dissolved Organic Matter [ppb], Chlorophyll [µg/l] and Turbidity [m-1 sr-1] recorded by WetLabs model ECO Triplet; Oxygen [µmol] and Oxygen [%] measured by AADI model Oxygen Optode 4330F, Polycyclic Aromatic Hydrocarbons [µg/l] acquired by Contros model HydroC/PAH, pH and Oxidation Reduction Potential [mV] recorded by SeaBird model SBE-27; Crude Oil [ppb] and Refined Oil [ppb] acquired by Turner Designs model Cyclops-7 available only for some tests (T48BP7B, T48BP7C, T53BPRE2, T53BB, T53CA, T53CB and T53BD). In tests performed until May 18th, 2013 the Methane sensor mounted in the standard payload (EPOD1) was METS G121-E307, and the Methane sensor mounted in the EPOD2 was METS G121-E307. For the other tests (from May 27th, 2013) the configuration has been inverted. Moreover the standard payload included two cameras able to producing continuous video shooting [Gasparoni et al., 2013a; 2013b]. Raw data acquired by the Payload Control Unit during each test are organized in single files, one for each instrument. Data processing includes readapting raw data in MatLab compatible files. The codes have been computed specifically for each test and allowed to realize the following procedures: statistic analysis and quality check of each parameter for each test; 2D plots (parameter vs. time) to show the eventually presence of spikes; de-spiking where necessary; comparison between the AUV speed variations and the presence of the spikes in the parameters time series; 3D plots to highlight the spatial variations of every parameters; mean value of each parameter for each test to evaluate the temporal and seasonal (from November 8th, 2012 to July 4th, 2013) variations of environmental data; comparison between the available historical data.

3. Results

3.1 Historical data analysis

3.1.1 In situ data

We considered the averaged data from 1981 and 1985 and the more recent data acquired in situ during 2009 (we choose this year because is the most recent year that overlapped with satellite data) to evaluate the water column stratification and seasonality.

From 1981 to 1985 the in situ value of the column of water has been acquired in May, June, July, August, September and October (the measures for winter period are not available) in Jungfrun station. The mean of historical data has been made every 10 m from surface to the bottom and shown in Figure 2. In detail, the minimum mean temperature (Figure 2a) was 2.9°C from 10 and 70 m of depth in May. In this month the column of water was almost homogeneous with the maximum of 5°C (mean value from 1981 to 1985) at 80 m of depth. The maximum recorded mean temperature was 16.7°C in surface in August, and the temperature decreases along the column of water from the surface to the bottom (5°C). In June the mean temperature varied from 9.5°C (surface) to 4.1°C (at 70 m of depth). The temperature of 4°C is an important threshold because it represents the maximum density of water, then the mixing regime of the lake changes. In July increased up to 16.7 and in September decreased with a range from 12.2°C (surface) and 4.7 (bottom), in October decreased against with the maximum in surface of 8.6°C and the minimum to the bottom (6°C). This trend is in agreement with the seasonality of the Lake descripted by Reinart and Reinold [2008]. The pH mean values (Figure 2b) were almost homogeneous and range between 7.3 and 7.8. In July and August have been recorded the major variation, in detail in July the maximum pH mean value was 7.6 at 10 m and the minimum was 7.3 at 80 m of depth, in August the maximum mean value was 7.8 at 120 m and the minimum was 7.4 to the bottom at 70 m of depth. The Chlorophyll mean value (Figure 2c) was homogeneous along the column of water in May (1 µg/l), increased in June with a maximum of 1.8 µg/l at 10 m of depth, decreased in July with a minimum of 0.7 µg/l and in August and September was almost stable around 1 µg/l, while in October decreased with a minimum mean value of 0.6 µg/l. The Colored Dissolved Organic Matter mean values are shown in Figure 2d. The mean Colored Dissolved Organic Matter values didn't vary a lot. The month with larger variability was September, with the range of values from 6.3 mg/l (at 10 m of depth) to 8.4 mg/l (to the bottom, 80 m of depth); and the month with lower variability was May, in which mean Colored Dissolved Organic Matter varied from 6.3 and 6.7 mg/l. The maximum mean value was 8.5 mg/l in June to the bottom (85 m) and the minimum was 6.3 reached in May and in September.

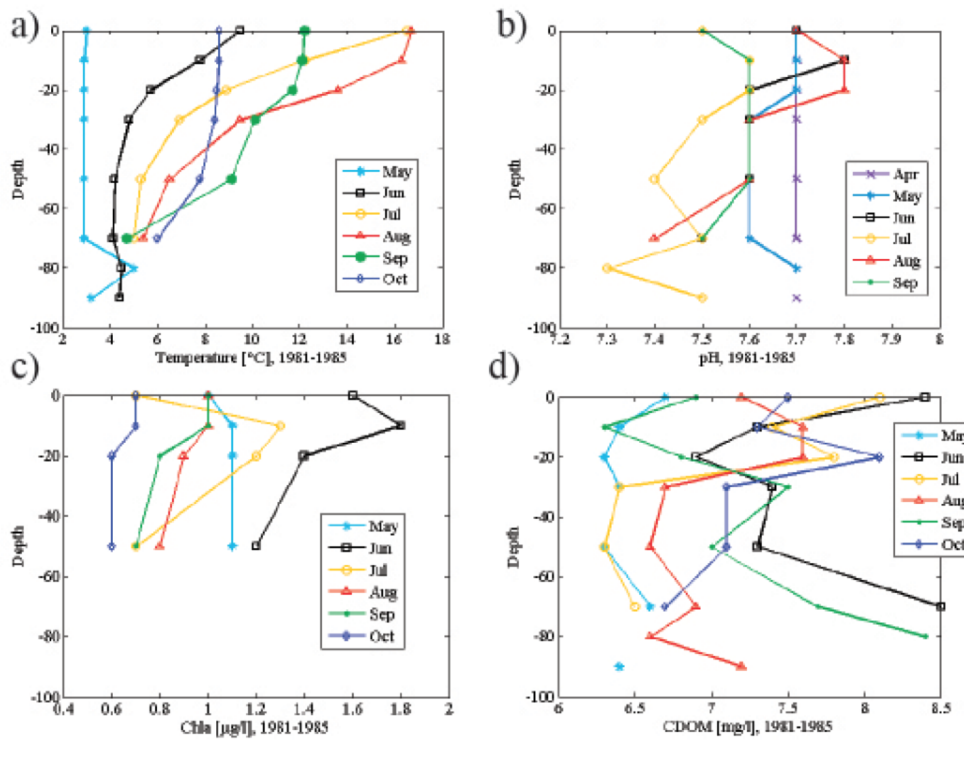

Figure 2. The figure shows the mean values computed by the acquired in situ data from 1981 to 1985 in May, June, July, August, September and October in Jungfrun station. The profiles have been made for Temperature in panel a), pH in panel b), Chlorophyll in panel c) and Colored Dissolved Organic Matter - CDOM in panel d).

More in detail, the in situ data recorded in Jungfrun station in April, May, August and September 2009 (Figure 3), allow to better evaluating the stratification [Heitmann, 1973] and the seasonality of the Lake.

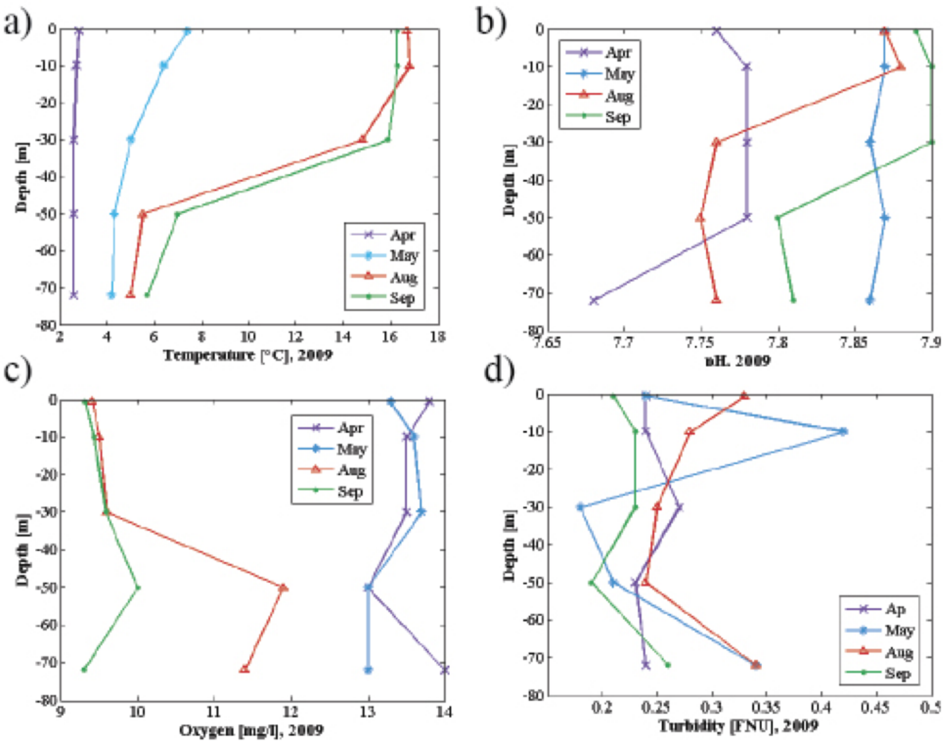

Figure 3. The figure shows the values acquired in situ data in April, May, August and September 2009. The profiles have been made for Temperature a), pH b), Oxygen c) and Turbidity d) in situ data acquired in Jungfrun station during 2009.

The temperature along the column of water, shown in Figure 3a, was almost stable in April and in May, while the profile change pattern in August and September, as just shown previously with mean data acquired between 1981 and 1985. In April the temperature profile is close to the average value (2.6°C), in May the temperature weakly increased both close to the bottom (about 70 m depth) and to the surface (average temperature 5.46°C), in August the temperature increased until 16.8°C at the surface with the average temperature of 11.74°C and in September the average temperature is 12.24°C. In detail in summer the column of water was almost homogeneous (average 16.1°C) from the surface to 30 m of depth, then decreased (7°C) until 50 m and even more toward the bottom (5.7°C). The maximum temperature in 2009 was lower than the maximum computed for historical data showed upward. The Figure 3b illustrates the pH profiles measured in April, May, August and September 2009 in Jungfrun Station. The August and September pH profiles give an idea about the water column stratification (according with previous considered data), while during April and May the column of water was more homogeneous. The maximum value of pH (7.9) was recorded in September between 10 and 30 m of depth. The Figure 3c shows the oxygen concentration profiles measured in April, May, August and September 2009 in Jungfrun Station. Oxygen was higher in spring (April and May) reaching in April 14 mg/l at 70 m of depth, than in August and September with a minimum in September of 9.3 mg/l. In August the oxygen concentration had a large gradient (2.49 mg/l) from surface toward bottom. The Figure 3d shows the Turbidity profiles acquired in April, May, August and September 2009 in Jungfrun Station. The column of water was very limpid during the considered periods in whole column of water.

3.1.2 Satellite data

The form and size of the lake basin play an important role on its temperature together with meteorological conditions. Lake water temperature is one of the most important parameters determining ecological condition in lake water. It influenced, with extraordinary exceptional events, but also with annual cycle, water chemistry as well as biological processes inside of a lake [Horne and Glodman, 1994].

As listed above, a lot of data are available for the Lake Vättern. Considering that the lake has a long residence time (58 years, [Kvarnäs, 2001]) and it is affected by small variations (paragraph 3.1), we decide to examine the more recent data (2009 period) to characterize the test area with satellite data.

The annual cycle for the surface temperature is revealed by satellite AVHRR measures, in detail the Figure

4 shows annual surface temperature oscillations by monthly means data both for day and night. In February and March the satellite sensor measured the lowest temperature in the Lake Vättern (2.48°C), then the surface temperature rises and reaches the maximum in August (17.55°C). The yearly mean temperature is 8.56°C (Table 4). The day and night monthly mean temperatures are mainly similar, but during April, June, August and October had been computed a gradient major then 1°C, respectively of 1.73, 1.2, 1.2 and -2.78°C (Figure 4).

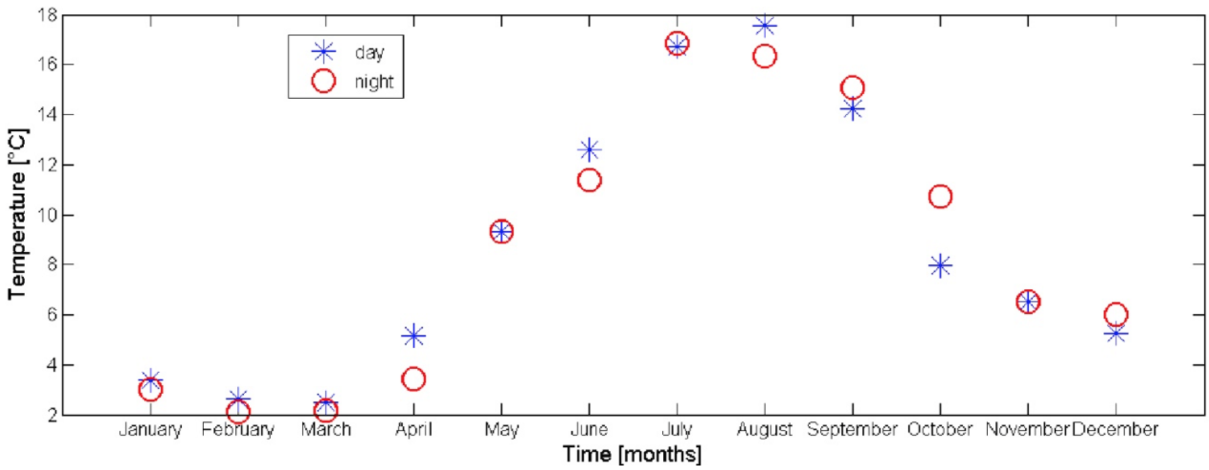

Figure 4. Lake Vättern surface temperature extrapolated by AVHRR satellite data in the study area (latitude 58°32'32.30"N and longitude 14°58'8.78"E) for year 2009. The blue stars indicate the mean daily temperature and the red circles indicate the mean nightly temperature.

3.2 AUV data analysis

3.2.1 AUV missions types

In this report we present the capability and the main uses of SAAB Sabertooth AUV; the most interesting results and the critical issue about the specific used environmental payload during the test performed in Lake Vättern. In detail, we show the different kinds of mission plans (Tables 1 and 2 shown in appendix), the different trajectories types (Figures 3 and 4 shown in appendix) and the most relevant problems revealed during the tests. One of the aims of two test phases of the CleanSea project was to experiment different missions characterized by different trajectories, depth, velocity and time. This approach allows to acquired the specific know how to plan, in the environmental applications of the AUV, the best mission in any kind of scenario of acquisition.

The Tables 1 and 2 (in appendix) listed all missions summarizing the main information: Name, Date, Area (only for Phase 1), CH4 leakage presence (only for Phase 2), Mission time, Mean AUV speed, Max AUV speed, Mode AUV speed, Running distance, Max depth reached, Mode depth reached, number of Level of depth in which the mission has been done and indicate the presence of spikes and/or noise for each parameter. The Area is specified only in the Phase 1 because during the second Phase the site test was only the Area 1. During the first Phase, 14 tests have been made in Area 1 (East side of the lake) and 7 tests have been made in Area 2 (West side of the lake). In the second Phase, in addition with respect to the first Phase, during 11 tests have been simulated the Methane leakage presence in order to test the two Methane sensors capability. The Figure 1 and 2 shown in appendix point out the 2D and 3D graphs of the trajectories performed in the tests, the color bars indicate respectively the AUV speed (2D graphs) and the time line of the mission (3D graphs). 16 different kinds of trajectories have been planned and tested. The trajectories have been developed in one, two or three levels along linear, rectangular or square shape, only in 4 cases the AUV made a vertical track from surface towards the sea bottom (vertical profile). The shape of trajectory included diving, forward, backward, lateral and rotational movement of the AUV that require maneuvers, change of heading and speed, this could have affected the data acquisition.

The mission time varies from 10 minutes (minimum) to 4 hours and 10 minutes (maximum). The Tables 1 and 2 highlights the mean, max and mode of AUV speed, this last statistics data is important to define the cruise speed used during AUV mission. The AUV speed varies from the minimum 0.01 m/s to the maximum of 1.2 m/s. The missions had different trajectories and different running distances, in detail the longer one was 15497 m (realized in more level) and the shorter one was 69 m (similar to a vertical profile). The depth reached changes from -1 m and -36.4 m. It is interesting calculated the mode of the depth to define the main plan in which the mission has been made. The last 14 columns of the Tables (1 and 2) indicated the spikes events and/or noisy find in the acquired data for each parameters (1- Temperature [°C], 2- Salinity [psu], 3- Methane [µmol/l], 4- Colored Dissolved 5- Organic Matter [ppb], 6- Chlorophyll [µg/l], 7- Turbidity [m-1 sr-1], 8- Oxygen [µmol], 9- Oxygen [%], 10- Polycyclic Aromatic Hydrocarbons [µg/l], 11- pH, 12- Oxidation Reduction Potential [mV], 13- Crude Oil [ppb] and 14- Refined Oil [ppb]). The sensors that more frequently produced data with spikes and/or noisy are listed (in order of more frequency of occurrence): Turbidimeter, Fluorimeter, Colored Dissolved Organic Matter, Salinity and Oxygen sensors. In the second Phase of the test, two Methane sensors have been included in the payload to better detect the Methane leakage artificially propagated for the test.

3.2.2 Tests data evaluation

The data analysis revealed in all datasets, acquired by AUV, the small positioning vertical depth error of about 4 cm. The Figure 5 illustrates an example of the error take place during test T53A1 performed in November 23rd, 2012. The reason is the accuracy of the vertical depth positioning sensor of the AUV that has a resolution of 10 cm. The data have been corrected using a mean depth value by using MatLab routine.

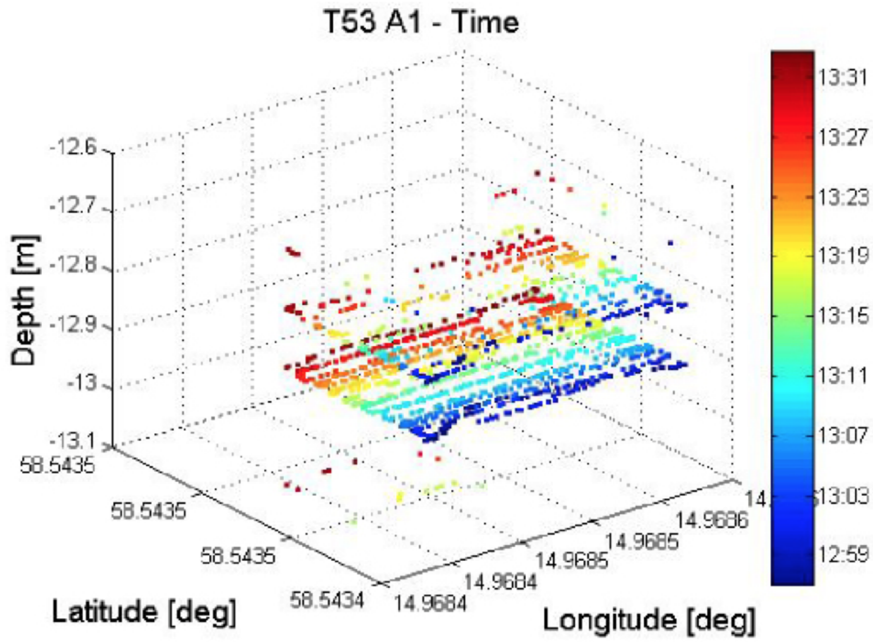

Figure 5. AUV trajectory reached during test T53A1 on 23rd November 2012. The 3D graph shows the small positioning vertical depth error of about 4 cm.

The lake environmental observations consist in time series acquired during the AUV missions. No significant correlation has been finding between environmental time series and AUV navigation data, but some spikes and/or noisy occurred in low velocity, low depth conditions and fast heading variation. In detail, Chlorophyll, Turbidity, Colored Dissolved Organic Matter, Oxidation Reduction Potential and Methane sensors were more sensible, with respect to the other sensors to the AUV speed and trajectories variation. Figure 6 shows the time series of AUV Depth and Speed compared to Chlorophyll, Turbidity, Colored Dissolved Organic Matter and Oxidation Redaction Potential, recorded during test T44A. Some spikes and noisy are present in the environmental time series in correspondence to the Depth and Speed changes. In detail Chlorophyll, Turbidity and Colored Dissolved Organic Matter had higher value in correspondence of low Speed except for a spike in Chlorophyll dataset, while Oxidation Redaction Potential had lower value in correspondence of low Speed. Moreover, Oxidation Redaction Potential values positively drifts during all mission time (value increase, Figure 6f); this trend was present in all surveys and was not correlated with Depth, trajectory or AUV navigation data (heading, pitch, roll).

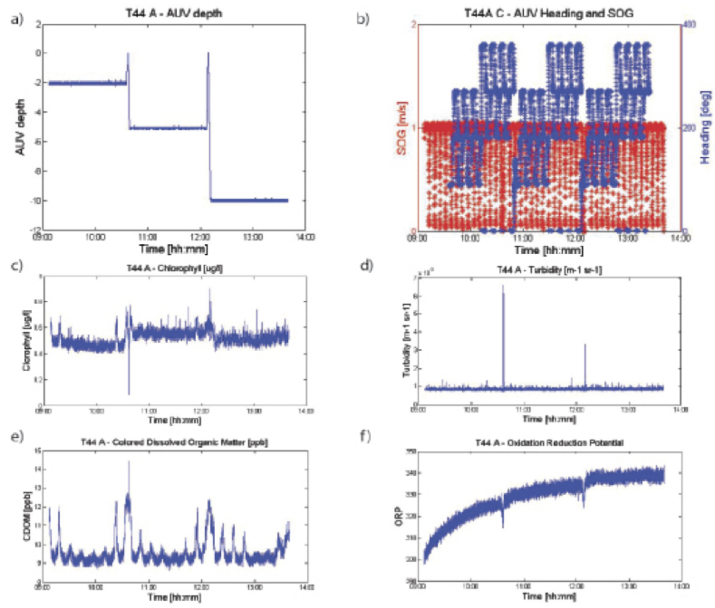

Figure 6. The Figure shows the time series of AUV Depth a), Speed together with Heading b), Chlorophyll c), Turbidity d), Colored Dissolved Organic Matter e) and Oxidation Redaction Potential f), recorded during test T44A.

During the test some Methane leakages have been simulated (Table 2 in appendix). In some tests the AUV mounted two Methane sensors. The leakage was detected, but data acquired by the two Methane sensors showed small differences, for example in test T48BP7B (Figure 7) the sensor G121-E307 measured a maximum value of about 0.2 µmol/l in the centre of the trajectory, and the second sensor in the same place, measured about 1.2 µmol/l. The displacement in Methane data could be due to the different resolution (100 µmol/l and 10 µmol/l) of the two sensors.

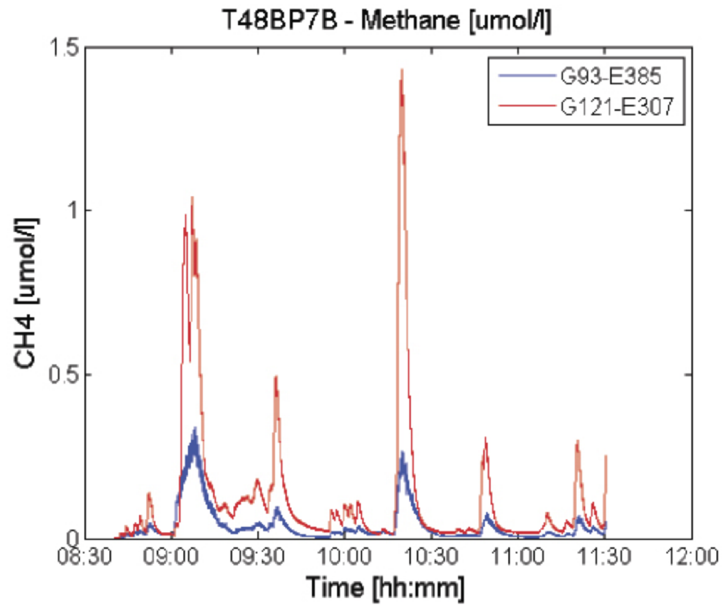

Figure 7. Methane time series acquired during test T48BP7B. The blue values were acquired with G93-E385 sensor and the red ones with G121-E307 sensor in 28th May 2013.

3.2.3 AUV environmental data

The SAAB Sabertooth AUV properly adapted to meet Clean Sea requirements has been able to detect environmental variation also in small space. Test T53CA (Table 2 and Figure 2 in appendix) has been performed during Phase 2 of the project on 7 June 2013. The total mission time for the test was ~ 3 hours and 4 minutes. The test has been made in Site 1 (in the eastern part of Lake Vättern, Figure 1). The trajectory of the test T53CA is shown in the Figure 2 in appendix. The trajectory has been run in three different overlap grids at 2 m of depth. Each grid had a different spatial resolution. First grid was about 22,5 km^2 (a square with side length 150 m), the second grid was about 2,5 km^2 (a square with side length 50 m) and the third grid was about 100 m^2 (a square with side length 10 m). The AUV speed changed from about 0.80, 0.60 and 0.47 m/s in the different grid. For each squares all parameters (Temperature, Salinity, Methane with G93-E385 and G121-E307 sensors, Turbidity, Chlorophyll, Colored Dissolved Organic Matter, Polycyclic Aromatic Hydrocarbons, Oxygen concentration, Oxygen percentage, pH and Oxidation Reduction Potential) have been acquired along AUV trajectory. During this test a Methane leakage has been simulated. Temperature varied from 11 to 13.5°C, Salinity varied from 0.0674 to 0.068 psu. Methane acquired by both two sensors (G93-E385 and G121-E307) well detects the presence of leakage. Figure 8 shows the Methane values acquired by sensor G93-E385 in the three different grids.

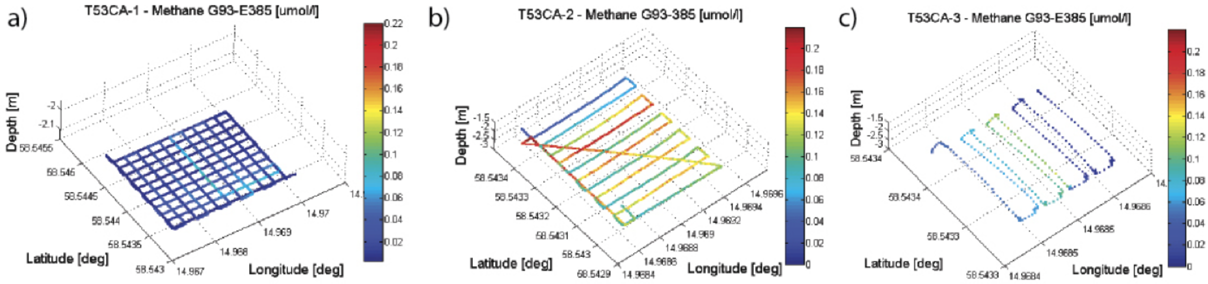

Figure 8. The figure shows the three levels grids of test T53CA1. Methane sensor took over the presence of Methane leakage in the center of the trajectory.

Turbidity was almost constant and varied between 0.5*10-3 and 2 *10-3 m-1sr-1. The spatial variability of Chlorophyll value was almost constant. Colored Dissolved Organic Matter and Polycyclic Aromatic Hydrocarbons didn't show spatial variation. The other parameters (oxygen and pH) were not significantly different. Oxidation Reduction Potential drifts up. This electrochemical parameter is known to have weaknesses and limitations, such as limited depth capability, drift and attendant need for frequent re-calibration, pressure hysteresis, fragility, limited life expectancy, etc. Moreover electrochemical sensors have long and indeterminate stabilization times, for this reason, successive samples may be significantly different. These differences could appear as noise in the time series record, the mean value may also be in error because the signal is never fully equilibrate. Moreover stable ORP requires that a definite oxidizing or reducing condition be present. In pure water, ORP will drift around, responding to levels of dissolved oxygen, traces of contaminants or the last solution in which the sensor was immersed.

3.3 Comparison between AUV and historical data

3.3.1 Spatial variability

The comparison between the AUV surveys performed in the East and West side of the Lake Vättern in 2012 has been made by the sub-group of tests. In detail the tests used to highlights the spatial variation of the environmental parameters for the East sites are: T40BTB, T40BTF, T41A, T41B, T42A, T42B, T42C1, T43D2, T45A3, T42C2, T46A, T44B, T53A1, T53A2. And for the West site are: T41A1,T43A, T43B, T43D1, T43C, T44A, T45A2. The Refined Oil and Crude Oil measures were not performed for each test, the names are: T43D2, T53A1, T53A2 (East site) T43A, T43B, T43D1, T43C (West side). The mean and standard deviation for each parameter is shown in Table 3 in appendix and in Figure 9.

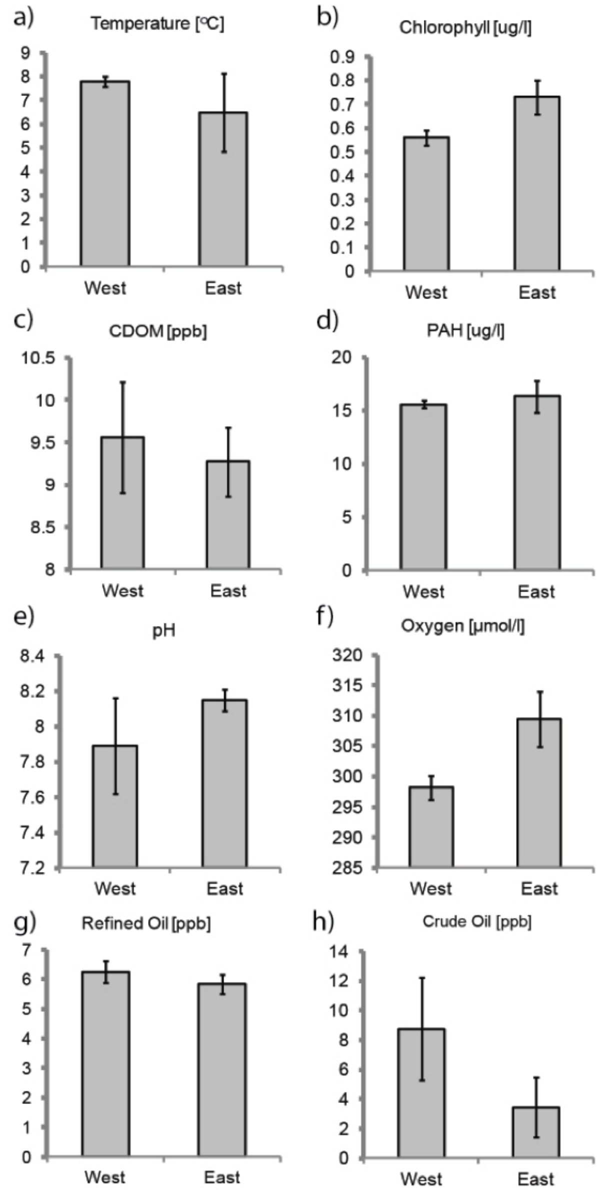

Figure 9. The spatial variation of environmental parameters. The West and East mean values of Temperature a), Chlorophyll b), CDOM c), PAH d), pH e), Oxygen f), Refined Oil g) and Crude Oil h). The averages have been obtained with data acquired by AUV.

The data have been collected in a short time period, about 20 days between 2nd to 23rd November, 2012 and in a more restricted period for the West site, from November 7th to 19th, 2012. The statistic data (mean and standard deviation) for each parameter in each site are shown in Table 3. Reinart and Reinhold [2008] affirm that Lake Vättern warms up in a uniform way and that the small difference was close to the northern coast than the other coasts. In detail, our test area is located in the North coast (Figure 1) but date didn't show any relevant spatial differences: the temperature was higher in the West site with a gradient of 1.3°C with respect to the East site. The salinity mean value was homogeneous in space. Methane was almost constant. Colored Dissolved Organic Matter mean value didn't show high differences between the West and East site. Polycyclic Aromatic Hydrocarbons was higher in the two first tests (T40BTB and T40BTF), no large differences were present between the West and the East site. The concentration of oxygen saturation in water increases with decreasing temperature, so the observed trend of increasing oxygen during the period is normal. The oxygen mean value (both concentration and %) shows a gradient (11.29 µmol/l and 1.25 %) between West and East site. The East site had larger values with respect to the West one. No large differences have been found in the pH mean value distribution in the two sites, but it is worth of note the lower value (0.5) of pH measured during test T43C and T44A in the West site. Oxidation Reduction Potential mean value and refined oil didn't highlight a specific trend. The crude oil appears lower in the East site with respect to the West site, but is not clear if this difference is due to the spatial or the temporal variation. The other parameters result almost homogeneous in both sites.

3.3.2 Seasonal variability

The seasonal variation of environmental parameters has been highlight by data acquired during November 2012 and July 2013. Moreover, the comparison between historical data (available on-line and shown in paragraphs from 3.1.2) and the data collected by the SAAB AUV data has been made (shown in paragraph 3).

The mean values for each parameters acquired by AUV during different tests have been computed and shown in Figure 10. The average of data measured by the AUV in November 2012 has been considered representative of autumn, the mean value for spring has been computed by data acquired in May 2013 and the data recorded from June to July 2013 has been averaged and used to represent summer period.

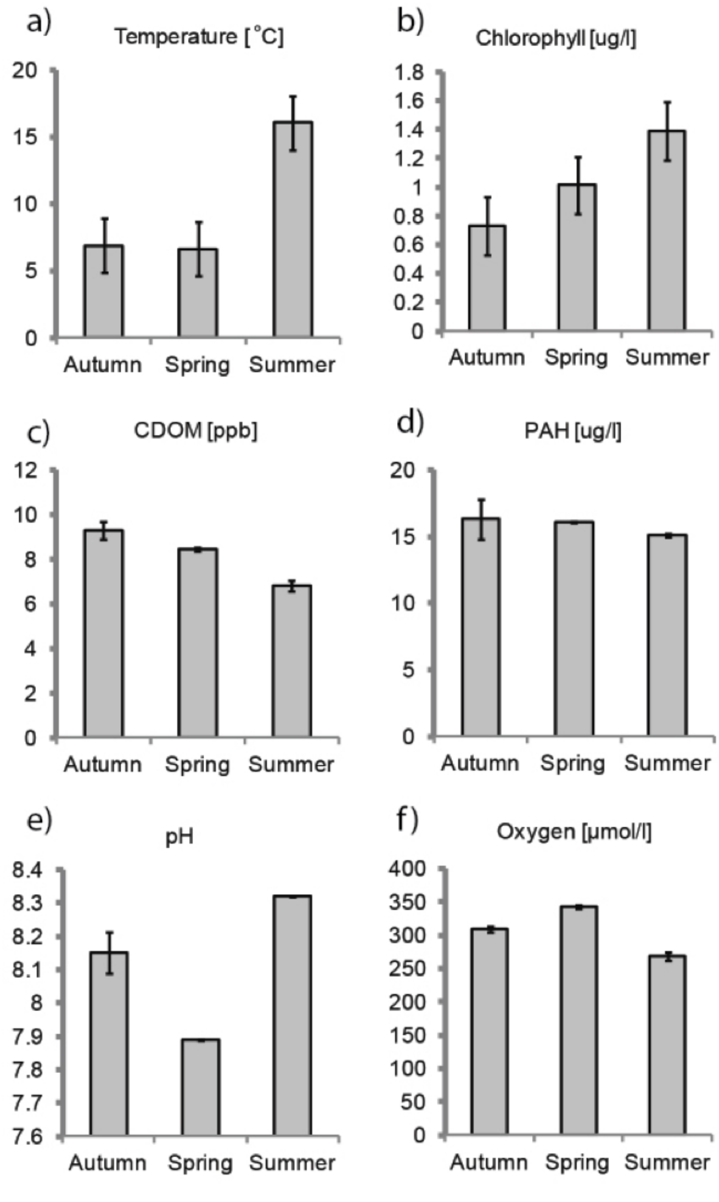

Figure 10. The seasonal variation of Temperature a), Chlorophyll b), CDOM c), PAH d), pH e) and Oxygen f) computed averaging the data acquired by AUV during the tests.

The more stable parameters (not shown) were Salinity (around the value 0.066±0.0 psu), Methane (around the value 0.0048±0.0035 µmol/l) and Turbidity (0.001±0 m^{-1} sr^{-1}). The temperature was almost constant in autumn and spring, while increased of about 10°C in summer (until 16.06±0.95 °C, Figure 10). Chlorophyll increased (see Figure 10) from autumn (0.73±0.07 µg/l) towards summer (1.39±0.12 µg/l), instead Colored Dissolved Organic Matter and Oxidation Reduction Potential decreased from autumn (respectively 9.27±0.41 ppb, shown in

Figure 20; 305.68±13.22, not shown) toward summer (respectively 6.80±0.25 ppb, shown in Figure 20; 226.35±18.87, not shown). PAH and pH were higher in summer (respectively 15.10±0.14 µg/l, 8.32±0.0014), while Oxigen was higher in spring (342.35±2.44 µmol/l and 89.27±0.44 %), as shown in Figure 10.

The comparison between AUV (data acquired during 2012 and 2013, Figure 10), historical data from satellite (2009 monthly mean, Figure 2) and in situ acquisition (mean data acquired between 1981 to 1985, Figure 3) has been made. The AUV data have been acquired in the test area in the first 10 m of the water column. The satellite data, extracted for the test area, measured only the surface layer of temperature [Schluessel et al., 1987], while the historical in situ data have been acquired in Jungfrun station from the surface to the bottom, and has been considered only the surface layer. We compare, the surface historical data, both from satellite and in situ measurements, with the AUV data (averaged for the first 10 m of the column of water). Satellite-derived sea surface temperatures can be compared with the in situ bulk temperatures, which are usually conducted within the first several meters of the water column [Reinart Reinhold, 2008].

The comparison of data shows small variation for autumn and summer, but high differences for spring. In detail, the mean surface temperature computed in autumn (November) was: 6.9°C from AUV data, 6.53°C from satellite data and 8.6°C from historical data (mean value for October - 1981/85). In summer (mean between June and July) was: 16.06°C from AUV data, 14.67°C from satellite data and 13°C from historical data. Temperature for spring (May) was different among the three dataset: 6.62°C from AUV data, 9.3°C from satellite data and 3°C from in situ data, while for in situ data recorded in 2009 was 7.4°C. The trend of temperature in different season is aligned to the results of Reinart Reinhold [2008]. The comparison among Chlorophyll data shows lower value measured by the AUV in 2012 (0.73 ug/l) with respect to the historical data (1 ug/l) in Spring and in Summer (1.01 ug/l for AUV data and 1.15 ug/l for historical data), while were higher for Autumn (1.39 ug/l from AUV and 0.7 in October from historical data). pH was lower by historical data for each seasons: historical data are not available for Autumn, and was 7.7 both for spring and summer; AUV data measure 8.15 in spring and 7.89 in summer.

4. Conclusions

The main objective of this report is to evaluate the critical issue about the specific environmental payload used for the Sabertooth AUV during the missions organized for the test phase of Clean Sea project and to demonstrating their capability to execute the entire reference-monitoring task foreseen by Eni e&p. The complex functionalities of Clean Sea technology has been highlight by the two Phases testing of the project and have been presented and analyzed in this report:

- The main benefits of the Clean Sea technology included reduced ship time, faster response time, increased verification ability, early warning of anomalous events or conditions, work in extreme conditions or in areas affected by incidents (e.g. leaks or oil spills);
- The Sabertooth AUV is a multitasking platform that allows coping different needs, in fact the 36 tests allow simulating the complexity of real scenarios, by 19 different mission types, with diverse grids at different layers of depth.

The evaluation of the performance of the AUV sensors allowed making some observation to improve the capability of the Clean Sea concept:

- The data analysis showed some spikes in dataset, especially in optical measures, in salinity and in oxygen measures. In some cases has been highlighted a possible correspondence between the AUV velocity, the heading and depth changes and the spikes. In detail low AUV velocity and the quickly changes of depth seem to be related to spikes.
- The Oxidation and Reduction Potential sensor drift up: each graph of Oxidation and Reduction Potential shown an increasing trend not correlated to the depth or the position of the point of measure.
- A small positioning vertical depth error (± 4 cm) affected the data. The reason is the accuracy of the vertical depth positioning error sensor of the AUV that has a resolution of 10 cm. The tests have been corrected using a mean depth value.
- Some differences have been highlight in Methane acquisition. The displacement of data can be justified by different resolution (100 µmol/l and 10 µmol/l) of the two sensors used.

Given these practical considerations, it is possible improve the system, with small technical modifies and data corrections, to obtain an optimal result.

The second outcome of the test Phase of Clean Sea project was the preliminary environmental characterization of the Lake Vättern, made by the historical data free available on-line, that has been useful and essential to evaluate data acquired by AUV during the test. Moreover the historical data have been compared with the results of data acquired during the 36 tests performed from November 2nd, 2012 to July 4th, 2013.

In detail, data acquired between November 2nd and 23rd, 2012 allowed evaluating the spatial variability from East to West side of the lake, while the whole data-set analyzed (included data from 18 May to 04 July 2013) given information about seasonal variability. In detail, the data analysis highlights the following small variations: the Temperature was almost constant in autumn and spring, and increased in summer and data show up a spatial variability (higher in West site); the salinity variations were negligible; the Methane value (measured by sensor G93-E385) shown small variation; the water was limpid and the turbidity was spatially and temporally homogeneous; Chlorophyll varies more in time than in space: enlarging from autumn toward summer and was weakly higher in the eastern site; the Colored Dissolved Organic Matter was weakly higher in western site and decreasing from the autumn toward the summer; the Polycyclic Aromatic Hydrocarbons, as methane, was higher in summer and in the eastern site (tests T40BTB and T40BTF) and then was more stable around 15 µg/l. The oxygen mean values showed a decreasing gradient between West and East site and decreased in the summer months (July 2013); the pH showed small variation between 7.9 and 8.4 with higher values in summer, but not shown large differences between the two sites; the Oxidation Reduction Potential mean value was almost constant until May then decreased toward summer period; the crude oil appears lower in the East site with respect to the West site, but is not clear if this difference is due to the spatial or the temporal variation. The other parameters result almost homogeneous in both sites.

The comparison with historical data has been possible only for Temperature, Chlorophyll and pH. The larger difference was recorded for Temperature in spring: the historical data show a mean value of 3°C in May, while the AUV mean data was 6.62°C and satellite value was 9.3°C; on the other hand Chlorophyll data show smaller variation with respect to historical data, different for season: AUV data in spring and summer were lower and in autumn were higher; the pH value acquired by AUV during the test was weakly lower with respect to the historical data set. Overall, the data analysis shows that the data acquired during the tests are coherent with the expected results and the historical data.

Acknowledgements

Clean Sea is a project carried out in the framework of Eni R&D technology plan. Authors wish to thank SAAB team for their highly professional support during the integration and field test.

References

Buffagni M., Gasparoni F., Bergseth N.H., Bjornbom E., Broccia P., (2014). *Development and test of an AUV for environmental monitoring and asset integrity in offshore O&G scenarios: CLEAN SEA project.* In: SPE International Conference on Health, Safety, and Environment. Society of Petroleum Engineers.

Dahlén P., (1996). *Östgötavatten: guidebok för långfärdsskridskoåkare*. Illustrated by Valtonen K. and Carlsson B. Tjåmuhas infomedia, ISBN 9163048450.

Etiope G., (2009). *Natural emissions of methane from geological seepage in Europe*. Atmospheric Environment, 43, 1430-1443.

Fiedler E.K., Martin J.M., Roberts-Jones J., (2014). *An operational analysis of lake surface water temperature.* Tellus A: Dynamic Meteorology and Oceanography, Vol. 66, Iss. 1,2014. doi: 10.3402/tellusa.v66.21247.

Florén K., (2008). *Effects of introduced signal cryfish (pacifastacus leniusculus) on the littoral community in Lake Vättern.* Master thesis at stockholm University, Department of Systems Ecology.

Funkquist L., (1979). *The dynamics of lake Vättern, an introduction*. Swedish Meteorological and Hydrological Institute, No RHO 16, Norrköping. (In Swedish).

Gasparoni F., Favaretto M., Grasso T., Bjornbom E., Broccia P., Buffagni M., (2013b). *Towards automatic,*

continuous and long-term asset integrity and environmental monitoring in offshore scenarios: Clean Sea project. 11th Offshore Mediterranean Conference, Mar 20-22, 2013 (Ravenna, Italy).
Gasparoni F., Bruni F., Chomicz R., Ciccarelli V., Favaretto M., Filippini M., Furlan F., Grasso T., Hveding Bergseth N., Bjornbom E., Broccia P., Buffagni M., (2013a). *Development and Test of an AUV for Asset Integrity and Environmental Monitoring in Offshore Oil & Gas Scenarios.* 23rd International Ocean and Polar Engineering Conference (ISOPE 2013), June 30-July 5 2013 (Anchorage, Alaska, USA).
Goran G., Bjork A. and Lundberg P.A., (1990). *A re-examination of the seiche periods of Lake Vättern.* Tellus, 42A, 615-626.
Heitmann M-L., (1973). *Stability of thermal stratification in a lake.* Publ. Int. Assoc. Hydrol. Sei 109 321-326.
Horne A.J. and Glodman C.R., (1994). *Lake water temperature is one of the most important parameters determining ecological conditions in lake water*. Limnology.: McGraw-Hill, Inc. 575.
Kourzeneva E., Asensio H., Martin E., Faroux S., (2012). *Global gridded dataset of lake coverage and lake depth for use in numerical weather prediction and climate modeling*. Tellus 64., doi: 10.3402.
Kvarnäs H., (2001). *Morphometry and Hydrology of the Four Large Lakes of Sweden*. Ambio, Vol. 30 No. 8.
Lehner B., and Döll P., (2004). *Development and validation of a global database of lakes, reservoirs and wetlands*. Journal of Hydrology 296/1-4: 1-22.
Liljequist G., (1941). *Winter Temperatures and Ice Conditions of Lake Vetter with Special Regard to the Winter 1939/40*. Geografiska Annaler, Vol. 23, pp. 24-52.
Reinart A. and Reinhold M., (2008). *Mapping surface temperature in large lakes with MODIS data*. Remote Sensing of Environment, 122, 603-611.
Schluessel P., Shin H.Y., Emery W.J. and Grassl H., (1987). *Comparison of satellite derived sea surface temperatures with in situ skin measurements.* J. Geophys. Res., Vol. 92, pp. 2859-2874.
Soderberg P. and Floden T., (1992). *Gas seepages, gas eruptions and degassing structures in the seafloor along the Strömma tectonic lineament in the crystalline Stockholm Archipelago, east Sweden.* Continental Shelf Research, 12(10), 1157- 1171.
Svensson B.H., Lantsheer J.C. and Henning R., (1991). *Sources and Sinks of Methane in Sweden*. Ambio, Vol. 20, No. 3/4, 155-160.
Willén E., (2001a). *Four Decades of Research on the Swedish Large Lakes Mälaren, Hjälmaren, Vättern and Vänern: The Significance of Monitoring and Remedial Measures for a Sustainable*. A Journal of the Human Environment, 30(8), 458-466.
Willén E., (2001b). *Phytoplankton and Water Quality Characterization: Experiences from the Swedish Large Lakes Malaren, Hjalmaren, Vättern and Vanern*. A Journal of the Human Environment, 30(8), 529-537.

ISSN 2039-7941
Anno 2018_Numero 392

Appendix

TEST NAME	Date (yyyy/mm/dd)	Area	Mission time (hh mm)	Mean AUV speed (m/s)	Max AUV speed (m/s)	Mode AUV speed (m/s)	Running distance (m)	Max depth reached (m)	Mode depth reached (m)	Number of levels	Mode depth reached (m)	Spikes and noisy (yes/no)													
												1	2	3	4	5	6	7	8	9	10	11	12	13	14
T40BTB	2012/11/02	1	00 37	0.7	1.2	1.0	1307	- 3.1	- 2	2	- 2		y		y		y	y							
T40BTF	2012/11/05	1	00 10	0.07	0.2	0.01	69	- 7.1	- 6.7	2	- 6.7						y								
T41A1	2012/11/07	2	00 50	0.7	1.5	0.8	3482	- 4.5	- 4	2	- 4		y		y		y	y				y			
T41A	2012/11/08	1	00 50	0.8	0.8	0.8	2445	- 4.2	- 4	1	- 4				y		y								
T41B	2012/11/08	1	00 33	1.2	1.2	1.2	2396	- 4.2	- 4	1	- 4				y		y	y							
T42A	2012/11/09	1	00 48	0.8	0.9	0.8	2327	- 4.2	- 4	1	- 4		y				y	y	y	y					
T42B	2012/11/10	1	00 32	1.2	1.3	1.2	2336	- 4.2	- 4	1	- 4		y		y		y	y	y	y					
T42C1	2012/11/10	1	02 31	0.05	1.2	0.01	638	- 9.8	- 9.6	1	- 9.6				y		y	y							
T43A	2012/11/13	2	00 50	0.8	1.0	0.8	2609	- 4.2	- 4	1	- 4				y		y	y							
T43B	2012/11/13	2	00 36	1.2	1.3	1.2	2652	- 4.2	- 4	1	- 4				y		y	y							
T43D1	2012/11/13	2	00 54	0.5	1.1	0.6	1698	-36.4	-35.7	2	-35.7				y		y	y	y	y					
T43C	2012/11/14	2	03 22	0.2	1.1	0.01	3475	-36.1		1			y		y		y	y							
T44A	2012/11/15	2	04 33	0.9	1.1	1.1	15497	- 1	2	3	2		y		y		y	y					y		
T45A2	2012/11/19	2	02 02	0.4	1.0	0.01	2938	-24.2	-18.7	1	-18.7				y		y	y							
T43D2	2012/11/20	1	01 10	0.6	0.7	0.6	2391	-13.7	-10.8	1	-10.8				y		y	y	y	y					
T45A3	2012/11/20	1	03 57	0.4	1.1	0.01	5632	-13.4	- 12	1	- 12				y		y		y	y			y		
T46A	2012/11/21	1	00 38	0.1	1.0	0.1	623	- 6.9	- 5.7	1	- 5.7			y	y		y	y							
T42C2	2012/11/21	1	01 03	0.6	1.1	1.0	2560	-10.6	- 7.6	1	- 7.6						y	y							
T44B	2012/11/22	1	02 59	0.9	1.1	1.0	10087	- 8.2	- 8	3	- 8				y			y							
T53A1	2012/11/23	1	00 25	0.1	0.3	0.2	232	-13.1	-12.9	1	-12.9			y	y		y	y							
T53A2	2012/11/23	1	00 26	0.1	0.3	0.2	229	-12.9	-12.9	1	-12.9			y	y		y	y							

Table 1. The Table summarizes the main characteristic of the mission performed during Phase 1 of Clean Sea tests in Lake Vättern. In detail, it shows: Name, Date, Area, Mission time, Mean AUV speed, Max AUV speed, Mode AUV speed, Running distance, Max depth reached, Mode depth reached, number of Level of depth in which the mission has been done and indicates the presence of spikes and/or noise for each parameter (1 -Temperature [°C], 2- Salinity [psu], 3- Methane [µmol/l], 4- Colored Dissolved 5- Organic Matter [ppb], 6- Chlorophyll [µg/l], 7- Turbidity [m-1 sr-1], 8- Oxygen [µmol], 9- Oxygen [%], 10- Polycyclic Aromatic Hydrocarbons [µg/l], 11- pH, 12- Oxidation Reduction Potential [mV], 13- Crude Oil [ppb] and 14- Refined Oil [ppb]).

TEST NAME	Date (yyyy/mm/dd)	CH4 leakage presence	Mission time (hh mm)	Mean AUV speed (m/s)	Max AUV speed (m/s)	Mode AUV speed (m/s)	Running distance (m)	Max depth reached (m)	Mode depth reached (m)	Number of levels	Spikes and noisy (yes/no)													
											1	2	3	4	5	6	7	8	9	10	11	12	13	14
T48BP2	18/05/13	Yes	**01 00**	**0.7**	**1.0**	**0.9**	**2584**	**- 11.9**	**-11.6**	**1**						**y**	**y**							
T48BP3	18/05/13	Yes	**00 56**	**0.7**	**1.0**	**1.0**	**2585**	**-10.0**	**-9.6**	**1**														
T48BP7B	28/05/2013	Yes	**02 23**	**0.6**	**1.0**	**1.0**	**5259**	**- 11**	**- 6.6**	**2**				**y**			**y**							
T48BP7C	28/05/2013	Yes	**01 43**	**0.4**	**0.6**	**0.5**	**2460**	**- 13.1**	**- 0.5**	**2**				**y**		**y**	**y**						**y**	
T49C	30/05/13	No	**03 46**	**0.3**	**1.0**	**0.01**	**2431**	**- 12.3**	**- 7.5**	**1**							**y**			**y**				
T54AB	31/05/13	No	**04 11**	**0.2**	**1.1**	**0.01**	**3320**	**- 12.3**	**- 12**	**2**	**y**	**y**		**y**		**y**	**y**	**y**	**y**		**y**	**y**		
T53BPRE2	06/06/13	Yes	**00 20**	**0.8**	**1.0**	**0.8**	**1004**	**- 2.1**	**- 0.8**	**1**							**y**							
T53BPRE4	06/06/13	No	**00 34**	**0.4**	**1.0**	**0.4**	**813**	**- 13**	**- 2.0**	**2**				**y**		**y**	**y**							
T53BB	07/06/13	Yes	**00 56**	**0.56**	**1.0**	**0.8**	**1935**	**- 12.8**	**- 2.0**	**2**		**y**											**y**	
T53CA	07/06/13	Yes	**02 41**	**0.5**	**1.0**	**0.8, 0.6, 04**	**5416**	**-2.0**	**- 2.0**	**3**				**y**			**y**							
T53CB	10/06/13	Yes	**01 23**	**0.7**	**0.8**	**0.5, 0.6, 04**	**3611**	**- 2.1**	**2.0**	**3**		**y**				**y**	**y**		**y**					
T50B2	27/06/13	Yes	**00 23**	**0.8**	**1.0**	**1.0**	**1084**	**- 9.8**	**- 6.8**	**2**														
T50B3	27/06/13	Yes	**00 31**	**0.6**	**1.0**	**1.0**	**1119**	**- 10.0**	**- 6.6**	**2**														
T50A1	06/24/2013	No	**00 29**	**0.8**	**1.1**	**1.0**	**1486**	**- 9.6**	**- 6.5**	**2**														
T53BD	03/07/2013	No	**00 11**	**0.8**	**1.1**	**0.8**	**566**	**- 11.6**	**- 2.0**	**2**														
T471	04/07/2013	Yes	**00 32**	**0.9**	**1.1**	**1.0**	**1696**	**- 7.0**	**6.8**	**1**		**y**					**y**							

Table 2. The Table summarizes the main characteristic of the mission performed during Phase 1 of Clean Sea tests in Lake Vättern. In detail, it shows: Name, Date, CH4 leakage presence , Mission time, Mean AUV speed, Max AUV speed, Mode AUV speed, Running distance, Max depth reached, Mode depth reached, number of Level of depth in which the mission has been done and indicates the presence of spikes and/or noise for each parameter (1 -Temperature [°C], 2- Salinity [psu], 3- Methane [µmol/l], 4- Colored Dissolved 5- Organic Matter [ppb], 6- Chlorophyll [µg/l], 7- Turbidity [m-1 sr-1], 8- Oxygen [µmol], 9- Oxygen [%], 10- Polycyclic Aromatic Hydrocarbons [µg/l], 11- pH, 12- Oxidation Reduction Potential [mV], 13- Crude Oil [ppb] and 14- Refined Oil [ppb]).

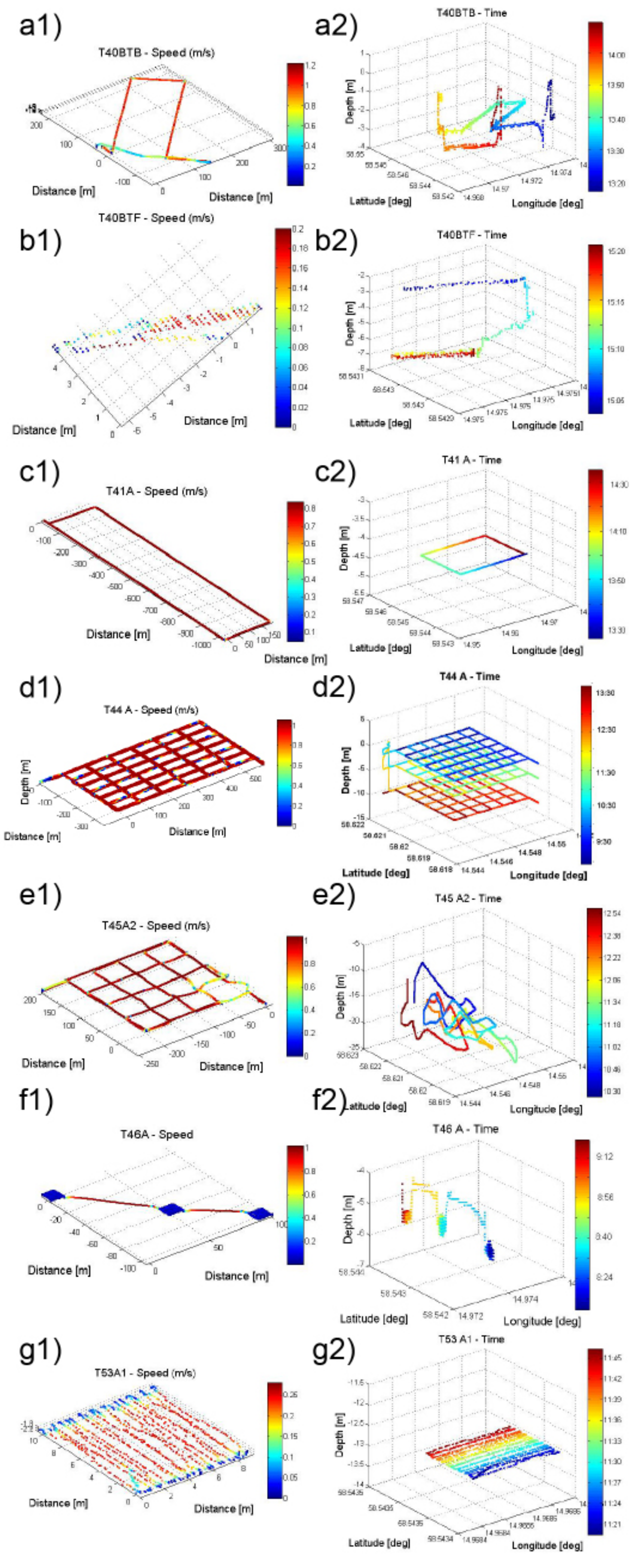

Figure 1. The Figure shows the trajectories running by the AUV during phase 1. The a1) and a2) trajectories (respectively 2D and 3D representation) has been running during test T40BTB; the b1) and b2) trajectory has been done during T40BTF test and partially in T41A1 test; c1) and c2) show T41A, T41B, T42A, T42B, T42C1, T42C2, T43A, T43B, T43C, and T43D2; d1) and d2) show T44A and T44B tests trajectory; e1) and e2) show T45A2 and T45A3 test; f1) and f2) show the trajectory followed during T46C tests and g1) and g2) show T53A1 and T53A2 test trajectory.

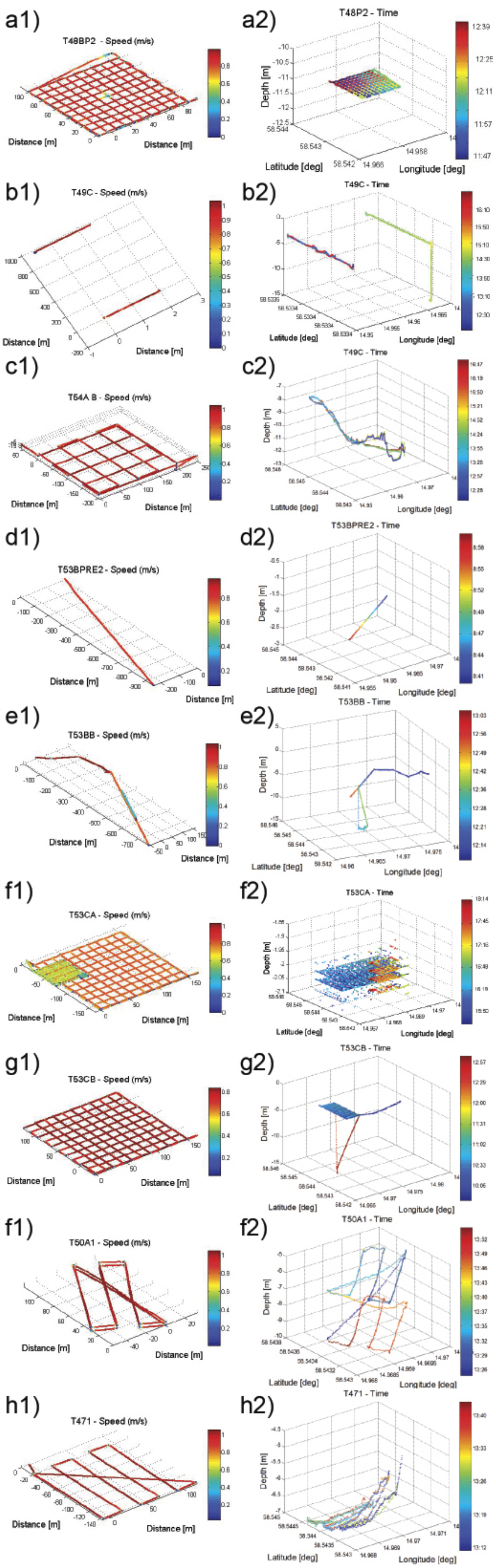

Figure 2. The Figure shows the trajectories running by the AUV during phase 2. The a1) and a2) trajectories (respectively 2D and 3D representation) has been running during test: T48BP2, T48BP3, T48BP7B and T48BP7C; the b1) and b2) trajectory has been done during T49C test; c1) and c2) show T54AB test; d1) and d2) show T53BPRE2 test; e1) and e2) show the trajectory followed during T53BPRE4, T53BB and T53BD tests; f1) and f2) show T53CA test trajectory; g1) and g2) show T53CB test trajectory; h1) and h2) show T50B2, T50B3 and T50A1 and i1) and i2) show T471 test trajectory.

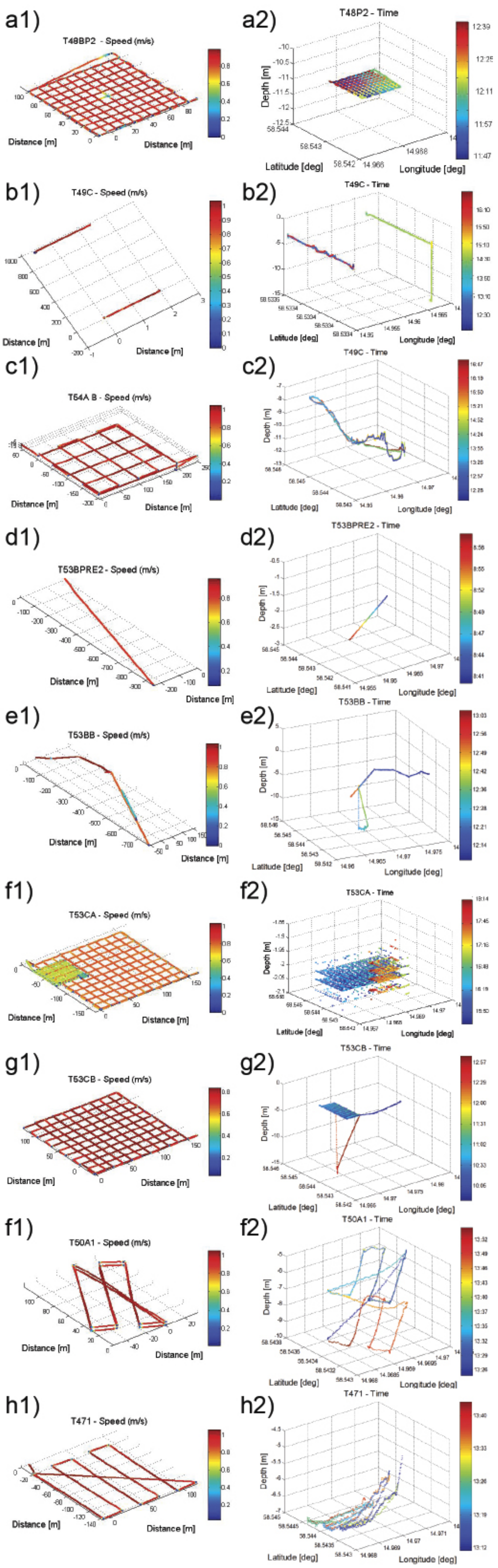

Figure 2. The Figure shows the trajectories running by the AUV during phase 2. The a1) and a2) trajectories (respectively 2D and 3D representation) has been running during test: T48BP2, T48BP3, T48BP7B and T48BP7C; the b1) and b2) trajectory has been done during T49C test; c1) and c2) show T54AB test; d1) and d2) show T53BPRE2 test; e1) and e2) show the trajectory followed during T53BPRE4, T53BB and T53BD tests; f1) and f2) show T53CA test trajectory; g1) and g2) show T53CB test trajectory; h1) and h2) show T50B2, T50B3 and T50A1 and i1) and i2) show T471 test trajectory.

ISSN 1590-2595

Quaderni di Geofisica

http://istituto.ingv.it/it/le-collane-editoriali-ingv/quaderni-di-geofisica.html

I Quaderni di Geofisica coprono tutti i campi disciplinari sviluppati all'interno dell'INGV, dando particolare risalto alla pubblicazione di dati, misure, osservazioni e loro elaborazioni anche preliminari, che per tipologia e dettaglio necessitano di una rapida diffusione nella comunità scientifica nazionale ed internazionale. La pubblicazione on-line fornisce accesso immediato a tutti i possibili utenti. L'Editorial Board multidisciplinare garantisce i requisiti di qualità per la pubblicazione dei contributi.

ISSN 2039-7941

rapporti tecnici INGV

http://istituto.ingv.it/it/le-collane-editoriali-ingv/raporti-tecnici-ingv.html

I Rapporti Tecnici INGV pubblicano contributi, sia in italiano che in inglese, di tipo tecnologico e di rilevante interesse tecnico-scientifico per gli ambiti disciplinari propri dell'INGV. La collana Rapporti Tecnici INGV pubblica esclusivamente on-line per garantire agli autori rapidità di diffusione e agli utenti accesso immediato ai dati pubblicati. L'Editorial Board multidisciplinare garantisce i requisiti di qualità per la pubblicazione dei contributi.

ISSN 2039-6651

miscellanea INGV

http://istituto.ingv.it/it/le-collane-editoriali-ingv/miscellanea-ingv.html

La collana Miscellanea INGV nasce con l'intento di favorire la pubblicazione di contributi scientifici riguardanti le attività svolte dall'INGV (sismologia, vulcanologia, geologia, geomagnetismo, geochimica, aeronomia e innovazione tecnologica). In particolare, la collana Miscellanea INGV raccoglie reports di progetti scientifici, proceedings di convegni, manuali, monografie di rilevante interesse, raccolte di articoli, ecc.

Coordinamento editoriale e impaginazione
Centro Editoriale Nazionale | INGV

Progetto grafico e redazionale
Daniela Riposati | Laboratorio Grafica e Immagini | INGV

Via di Vigna Murata, 605
00143 Roma
Tel. +39 06518601 Fax +39 065041181

http://www.ingv.it

Istituto Nazionale di Geofisica e Vulcanologia