Estudos em Ciências Exatas e da Terra

Desafios, Avanços e Possibilidades

Alireza Mohebi Ashtiani
(organizador)

EDITORA ARTEMIS
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Imagem da Capa Abstract Style Landscapes /123RF
Bibliotecário Maurício Amormino Júnior – CRB6/2422

2023

Editora Artemis
Curitiba-PR Brasil
www.editoraartemis.com.br
e-mail:publicar@editoraartemis.com.br

Dados Internacionais de Catalogação na Publicação (CIP)
(eDOC BRASIL, Belo Horizonte/MG)

E82 Estudos em Ciências Exatas e da Terra: Desafios, Avanços e Possibilidades / Organizador Alireza Mohebi Ashtiani. – Curitiba, PR: Artemis, 2023.

Formato: PDF
Requisitos de sistema: Adobe Digital Editions
Modo de acesso: World Wide Web
Inclui bibliografia
Edição bilíngue
ISBN 978-65-87396-74-3
DOI 10.37572/EdArt_240223743

1. Ciências exatas e da terra – Pesquisa – Brasil. I. Ashtiani, Alireza Mohebi.

CDD 509

Elaborado por Maurício Amormino Júnior – CRB6/2422

EDITORA ARTEMIS
2023

Editora Artemis
Curitiba-PR Brasil
www.editoraartemis.com.br
e-mail:publicar@editoraartemis.com.br

APRESENTAÇÃO

As ciências exatas e da terra têm uma importância muito especial e são consideradas a origem e a base principal do progresso de outras áreas de conhecimento, que ganharam destaque com a evolução tecnológica e a complexidade dos desafios humanos.

De modo geral, pode-se dizer que as importantes conquistas dos séculos passados e atuais se devem à atuação e ao avanço do campo das ciências exatas e da terra, que, através de desafios, situações e aplicações, avançaram e cruzaram as fronteiras tradicionais de outras áreas de conhecimento, resolvendo problemas complexos que abrangem diversas áreas: a isto chamamos "interdisciplinaridade".

Diante dessa realidade, o primeiro volume de **"Estudos em Ciências Exatas e da Terra: Desafios, Avanços e Possibilidades"** publicado pela Editora Artemis e apresentado em 10 capítulos, tem por objetivo dar um panorama geral dos desafios, avanços e possibilidades que envolvem essa área de conhecimento, tanto na teoria quanto na prática.

Os trabalhos aqui apresentados, de pesquisadores de diversos países, entre eles Argentina, Brasil, México, Paraguai, Portugal e Rússia, oferecem aos leitores e interessados a oportunidade de ampliar seus conhecimentos e adquirir uma visão mais profunda da área.

Alireza Mohebi Ashtiani

SUMÁRIO

CAPÍTULO 10

HYDROLOGICAL CHARACTERISTICS OF THE SUBMARINE GROUNDWATER DISCHARGES AT OLHOS DE ÁGUA, ALGARVE, PORTUGAL – FREEZE PROJECT

Data de submissão: 15/01/2023
Data de aceite: 03/02/2023

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ABSTRACT: The name of the small village Olhos de Água, in Algarve, is associated with the existence of freshwater springs visible at the beach, during low tide. These springs have also been identified on the continental shelf, just in front of the beach, often observed from shore in days of calm sea. In the frame of the R&D project "FREEZE – Submarine Freshwater DischargEs: characteriZation and Evaluation study on their impact on the Algarve coastal ecosystem", three oceanographic surveys took place in November 2012, April 2013 and November 2013 in the Olhos de Água region, to study the thermohaline characteristics of the Submarine Groundwater Discharges

(SGDs). The analysis of the 196 CTD stations carried out during the surveys, allowed the identification of the SGDs sources, based on low salinities found near the bottom or along the water column.
KEYWORDS: Submarine Groundwater Discharge (SGD). CTD. Olhos de Água. Algarve. Portugal.

CARACTERÍSTICAS HIDROLÓGICAS DAS DESCARGAS DE ÁGUAS SUBTERRÂNEAS NOS OLHOS DE ÁGUA, ALGARVE, PORTUGAL – PROJECTO FREEZE

RESUMO: O nome da pequena vila de Olhos de Água, no Algarve, está associado à existência de nascentes de água doce, visíveis na praia durante a maré vazia. Estas nascentes foram também identificadas na plataforma continental, frente à praia, sendo bem visíveis da costa, particularmente em dias de mar calmo. No âmbito do Projecto de I&D "FREEZE - Submarine Freshwater DischargEs: characteriZation and Evaluation study on their impact on the Algarve coastal ecosystem", realizaram-se 3 campanhas oceanográficas em Novembro 2012, Abril 2013 e Novembro 2013 na região dos Olhos de Água, para estudar as características termohalinas das Descargas de Águas Subterrâneas (DAS). A análise das 196 estações CTD, realizadas durante as 3 campanhas, permitiram identificar as fontes das DAS, baseadas nos baixos valores de salinidade junto ao fundo ou na coluna de água.
PALAVRAS-CHAVE: Descargas de Águas Subterrâneas (DAS). CTD. Olhos de Água. Algarve. Portugal.

1 INTRODUCTION

The existence of inter- and subtidal springs of fresh to brackish water at the Olhos de Água beach (Algarve, southern coast of Portugal) has been known for a long time, being the name of the small fishermen village historically related to these "water eyes" (in Portuguese, *olheiros*) still observed nowadays, at the beach during low tide. These springs have also been identified at sea, just in front of the beach, as they can be observed from shore during days of calm sea (FREEZE, 2014). When the outflows are very strong, they can drift the small boats of the local fishermen. The discharges with high flow have a surface signature characterized by the reduction of roughness due to the sudden change in densities, derived from the sharp salinity contrasts between submarine springs waters and seawater (UNESCO, 2004).

The R&D project "FREEZE – Submarine FREshwater dischargEs: characteriZation and Evaluation study on their impact on the Algarve coastal ecosystem" took place in the period January 2010 – December 2013 and its main objective was the study of the Submarine Groundwater Discharges (SGDs) at sea in the Olhos de Água region.

The southern coast of Portugal is characterized by an important development of the tourism sector, particularly demanding in water supply directly but also indirectly for the irrigation of the numerous hotels, resorts and golf courses flanking the coast. Furthermore, the water abstraction for agricultural purposes, such as the irrigated market gardening, represents a significant need of water. The vegetation is mainly composed of citrus tree used for cultivation and other commercially attractive trees such as olive, almond and cork oak trees. This is the reason why the identification and quantification of groundwater submarine discharges are crucial for water and ecosystem management in the Algarve.

In this study SAR (Synthetic Aperture Radar) imagery was used to identify surface signatures of potential submarine groundwater discharges (SGDs) over the continental shelf off Olhos de Água. This information was very helpful for the station array conducted during the oceanographic campaigns described further ahead.

The objective of this study consisted in the identification of the SGDs over the continental shelf in the region of Olhos de Água and the characterization of the physical properties of the waters coming from the submarine springs. To achieve those objectives, three oceanographic cruises were conducted in November 2012, April 2013 and November 2013.

2. DATA AND METHODS

2.1 SATELLITE IMAGERY

In the frame of FREEZE project, 10 SAR images obtained during particularly rainy winters were processed and analyzed to look for patterns of sea surface roughness that could be associated with the presence of SGDs.

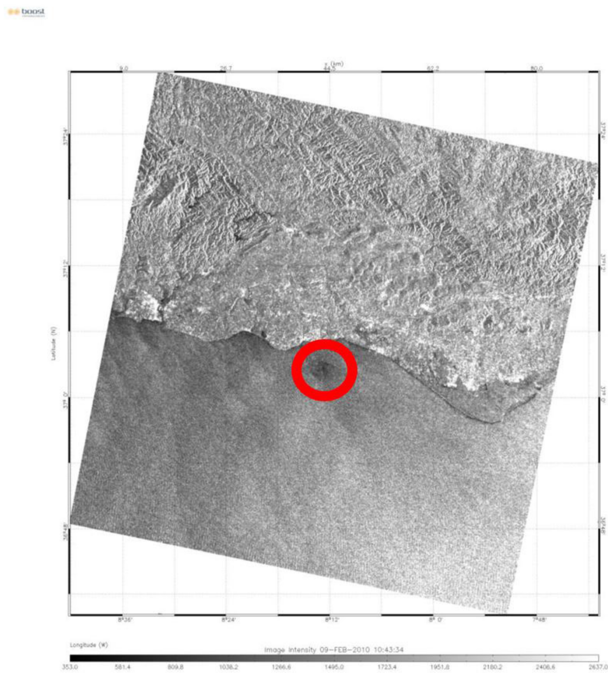
The winter periods were chosen because precipitation is, in general, more abundant and the SGD activity is stronger. Previous studies indicated that SGD fluxes are higher after periods of heavy rain (e.g. Garcia-Solsona *et al.,* 2010; Cave and Henri, 2011).

Those patterns, usually called slicks, identify areas where capillary and small gravity waves are attenuated, and the surface roughness is reduced. The smoothed areas appear darker on SAR imagery compared with the usually wind-roughened surrounding ocean, which appears brighter on those images.

These slicks could represent the surface signature of the SGDs, where less dense water discharging from the submarine springs reach the surface.

One image obtained in 9 February 2010, at 10:43 UT, during a particularly rainy winter, is presented in Fig. 1; this image, with a 75-m ground resolution, shows an excellent example of a slick, just in front of Olhos de Água beach, thus indicating a potential location of SGDs (Sousa *et al.*, 2014). The slick presents an almost circular shape, with a diameter of about 3.5-4.0 km, and is identified by a red circle in the figure. The geographical location of the slick was crucial for the planning of the CTD station array to occupy during the surveys, being essential to cover not only the areas where the SGDs could be found but also the surrounding waters with coastal oceanic thermohaline properties.

Figure 1 - SAR image obtained on 9 February 2010, at 10:43 UT, during a particularly rainy winter. The slick, represented by a dark area in front of Olhos de Água and identified by a red circle, could indicate the potential location of the SGDs.



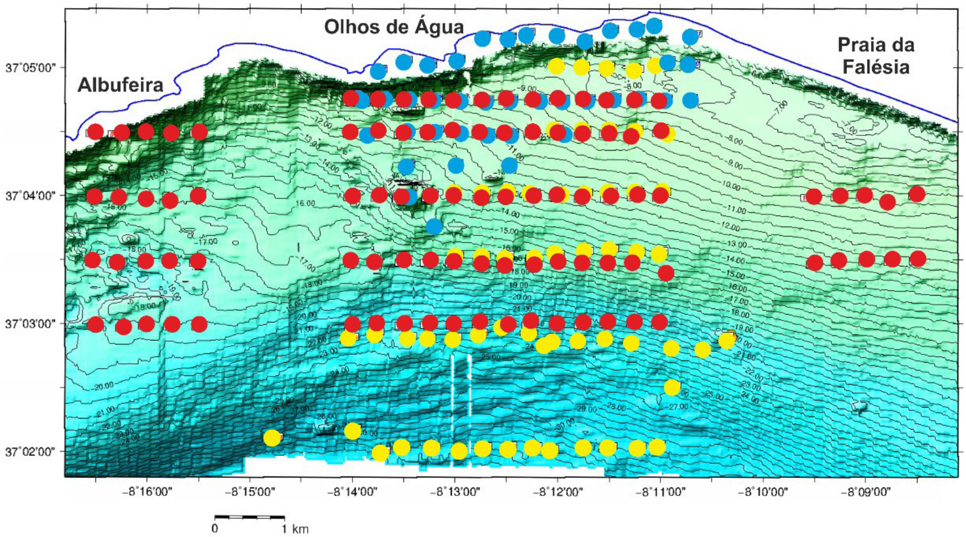
2.2 CTD SURVEYS

Three CTD (Conductivity, Temperature and Depth) surveys were conducted in the Olhos de Água area in the period November 2012-November 2013, on board the "Ecorecursus I" boat belonging to the Centro de Ciências do Mar da Universidade do Algarve (CCMAR/UAlg). The small dimensions of the boat forced to operate inside the limit of 3 n.m. from the coast (≈ 5.6 km).

During the first survey, which took place on 6 November 2012 (Nov/2012 survey), 59 CTD stations were carried out over the continental shelf off Olhos de Água, with depths ranging from 8 to 30 m. These stations are represented by yellow circles in Fig. 2.

The second campaign took place on 9 April 2013 (Apr/2013 survey) and 42 CTD stations were carried out in a very shallow area, with depths ranging between 2 and 14 m – see the stations represented by light blue circles in Fig. 2.

Figure 2 - Location of the 196 CTD stations carried out during the three surveys: Nov/2012 (59 circles in yellow), Apr/2013 (42 circles in blue) and Nov/2013 (20+65+10 circles in red) (from Frazão, 2016).



On 11-12 November 2013, a third oceanographic campaign (Nov/2013 survey) was carried out aiming to repeat the stations where the analysis of the CTD data from the two previous surveys, revealed the presence of salinity minima in the water column. In this last survey, 95 stations were completed: 65 in the Olhos de Água area (the same area covered in the previous two surveys), 20 stations located westwards, just in front of Albufeira and 10 more stations located eastwards, in front of Praia da Falésia. The whole set of 95 stations are represented by red circles on Fig. 2.

The Albufeira and Praia da Falésia areas were chosen as locations where supposedly there were no submarine springs, constituting the "non-SGDs referee places". These non-SGDs areas could help in the identification of waters with a coastal oceanic origin in contrast with the waters influenced by submarine springs over the continental shelf off Olhos de Água.

The CTD data were collected with a relatively high-density station array, with an average distance between stations of about 500 m. During the 3 surveys, and apart from the 30 non-SGDs stations, a total of 166 (59+42+65) CTD stations were carried out in the Olhos de Água area.

The positioning system used during the first survey was a Garmin GPSMAP® 60CSX without differential correction, but in the second and third surveys, a combined GPS positioning system and depth controller (GPSMAP® 421s) was installed on board.

In the three campaigns, temperature, conductivity, and pressure were collected with a NXIC (Non-eXternal Inductive Conductivity) CTD of Falmouth Scientific, Inc.

(FSI, USA). The analysis of the parameters allowed the identification of places on the continental shelf under the influence of waters coming from submarine springs, which present hydrological characteristics different from the ones with coastal oceanic origin.

3 RESULTS AND DISCUSSION

The observations carried out during the three surveys constitute the first CTD database gathered over the continental shelf off Algarve, covering an area very close to the coast with maximum depths of 30 m.

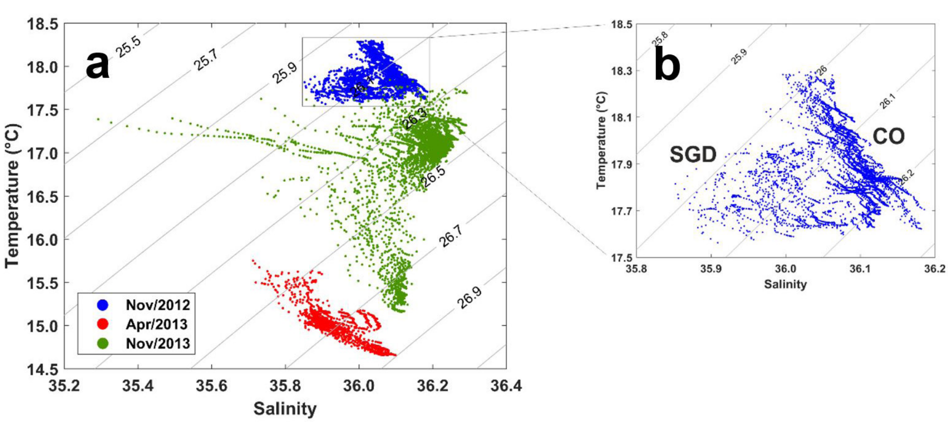
The submarine discharges at sea usually occur in shallow waters on the continental shelf and one way to detect them is mostly through their lower salinity values compared with the ones presented by oceanic coastal waters.

Temperature, salinity and sigma-t (density) profiles, as well as the temperature-salinity (T/S) diagrams, were drawn for each one of the 166 CTD stations carried out in the Olhos de Água area. The number of stations occupied during the surveys Nov/2012, April/2013 and Nov/2013 were 59, 42 and 65, respectively. The scatter T/S diagram with the whole set of 166 CTD stations is presented in Fig. 3a.

Each oceanographic campaign represented in Fig. 3a was characterized by different thermohaline properties thus reflecting not only the time of the year when each survey took place but also if its occurrence was under a dry or wet situation.

The Nov/2012 cruise, represented in blue in Fig. 3a, was conducted during a summer-winter transition situation of a relatively hot and dry year, and presents the highest values of temperature (17.5ºC ≤ T ≤ 18.3°C) reached in the whole period analyzed.

Figure 3 - a) T/S diagram with the 166 CTD stations carried out in the Olhos de Água area: 59 stations in Nov/2012 (blue), 42 stations in April/2013 (red) and 65 stations in Nov/2013 (green); b) Zoom of the 59 T/S diagrams obtained during the Nov/2012 survey showing stations with a coastal oceanic (CO) behavior and stations with influence of SGDs (adapted from Frazão, 2016).



Temperatures between 14.5°C and 16.0°C were obtained during the Apr/2013 survey (represented in red in Fig. 3a), which took place right after a rainy winter, with sea temperatures reaching the lowest values observed. Since all the stations were located very close to the coast in very shallow waters (maximum depth of 14 m), they reflected the lower values reached by the air temperature.

The salinity values obtained during both surveys were very similar ($35.7 < S < 36.2$) presenting only a difference of 0.1 higher observed during the hot and dry Nov/2012 survey.

The last survey (Nov/2013, represented in green in Fig. 3a) took place also in the summer-winter transition but after a relatively rainy year and presented the largest variations in temperature and salinity.

It is interesting to note that the temperature values were much lower (15.0-17.7°C) than the ones obtained exactly in the same month but one year before. Salinity values presented the highest variation, ranging betwwen 35.3 and 36.3.

A more carefully analysis of the T/S diagrams of the stations carried out during the Nov/2012 and Apr/2013 surveys (blue and red, respectively, in Fig. 3a) reveals that the stations are grouped in two different patterns. Fig. 3b shows, as an example, the zoom of the T/S diagrams of the stations carried out in Nov/2012 (in blue in Fig. 3a). The stations with a coastal oceanic behaviour (CO in Fig. 3b) show a gradual increase of density (sigma-t) with depth, due to a small increase in salinity and the correspondant small decrease in temperature.

T/S diagrams of the stations influenced by SGDs (Fig. 3b) present a completely different shape. They reveal instabilities in the water column showing sigma-t inversions, probably due to vertical mixing with waters coming out from the submarine springs. The lowest salinity values reached in these stations could also indicate that they are under the influence of the SGDs waters.

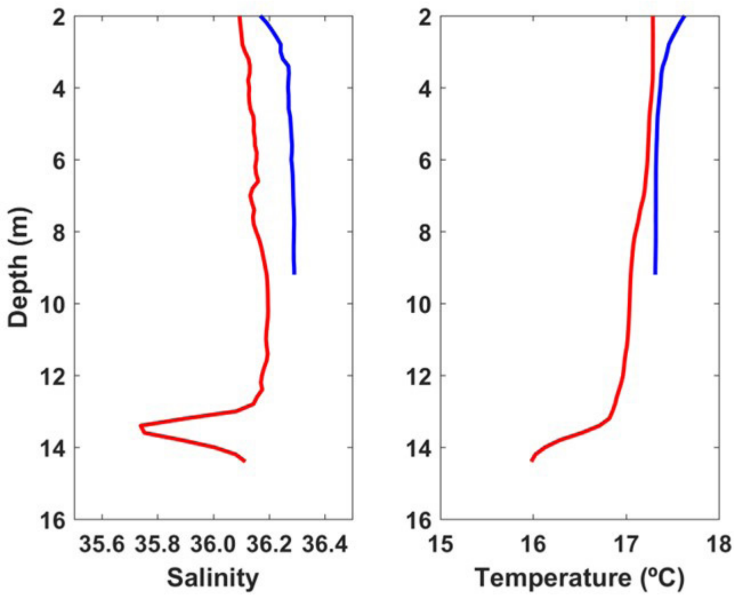
T/S diagrams of the stations carried out during the Nov/2013 survey (in green in Fig. 3a) do not clearly show, the two patterns mentioned above, but only the SGD influenced pattern. As this last survey took place after a particularly rainy year, the large number of submarine springs in the area off Olhos de Água, associated with higher discharges, could be responsible for the predominant SGD pattern in the T/S scatter diagram, thus masking the presence of few stations with a coastal oceanic behaviour.

Examples of salinity and temperature profiles of CO and SGD influenced stations are represented in Fig. 4. The CO station presents a small increase in salinity and a small decrease in temperature with depth (blue profiles). The SGD station presents a salinity minimum ($S \approx 35.7$) at about 13.5 m depth, relatively to the constant value $S \approx 36.2$ registered along the whole water column. This high variation in salinity $\Delta S = -0.50$, is also combined with a relatively high temperature variation of $\Delta T \approx$ -1.0°C. These sudden salinity and temperature decreases are due to waters with other hydrological characteristics corresponding to the presence of the SGD signal afecting the water column of the station.

The location of the SGD signal in the water column allowed the classification of each station. If the SGD signal occurred near the bottom, it could be classified as a SGD source, but if the SGD signal was located in the water column, at any depth, then it indicates that it was under the influence of a SGD.

The (20+10) CTD stations conducted, respectively, in the "non-SGDs referee places" Albufeira and Praia da Falésia (see Fig. 2 for location) showed similar hydrological characteristics to the ones found in the Olhos de Água area. Salinity decreases near the bottom or in the water column were also observed, thus suggesting the presence of SGDs. According to these results, Albufeira and Praia da Falésia were bad choices concerning non-SGDs referee places.

Figure 4 – Examples of salinity and temperature profiles of stations with coastal oceanic influence (in blue) and stations with SGD characteristics (in red).

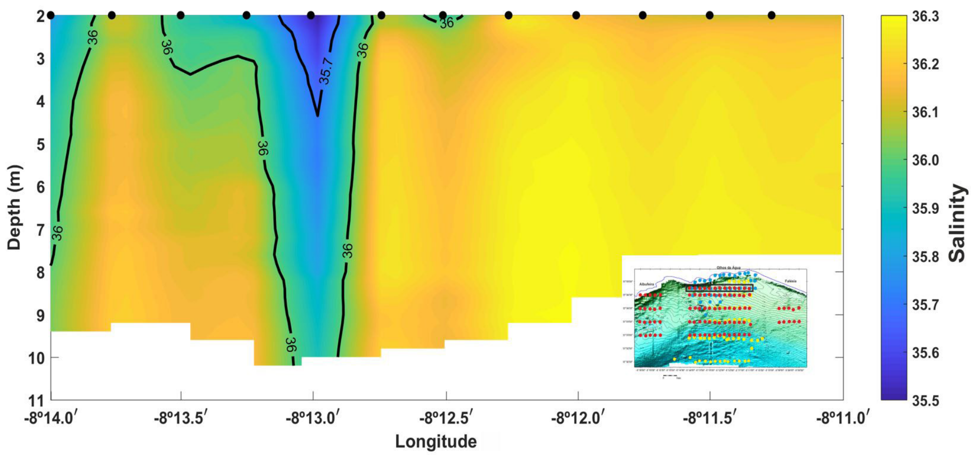


Vertical sections of salinity, temperature and sigma-t, were drawn along lines parallel and perpendicular to the coast, in order to establish a tight net to be able to identify the potential location of the submarine groundwater discharges.

The analysis of the whole hydrological dataset allowed the identification of two major types of SGD sources: ones with a strong signal in the entire water column (see exemple in Fig. 5, where the lower values of salinity are represented in blue tones) and others where the SGD signal occurred near the bottom.

Frequently, the signal of the freshwater discharges was detected, at any depth in the water column and at the surface, possibly indicating that the station was under the influence of an SGD. The waters coming out from the submarine springs are subjected to both local vertical mixing and advection processes. As the submarine discharges occur in shallow waters, they propagate horizontally like plumes which could be affecting partially or totally the water column of the stations located in the direction of the propagation path of the plume.

Figure 5 – Vertical section of salinity at 37º 04.7' N, with ≈ 4.5 km long. Location of the section is in the inset (adapted from Frazão, 2016).



The presence of the SGDs seems to be recurrent as they were detected in the same locations during rainy and dry years, being stronger the signal of the first ones.

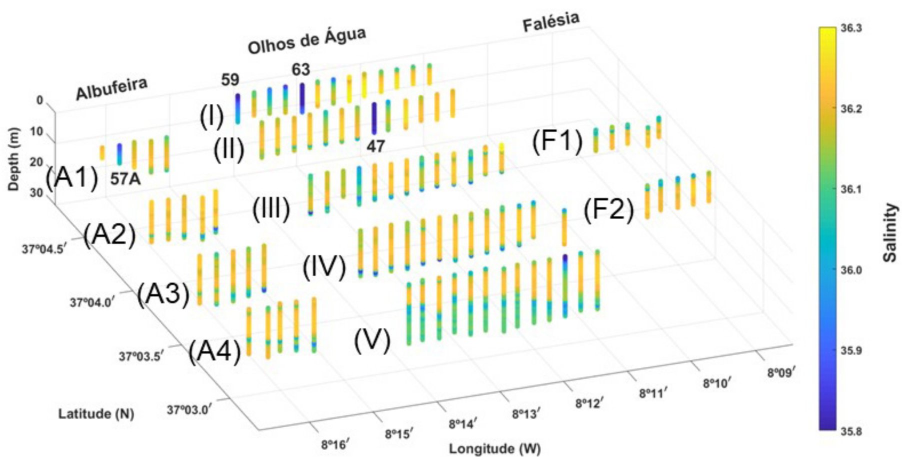
As the Nov/2013 campaign took place in a relatively wet year, a larger number of SGDs were detected as well as SGDs with stronger outflows (FREEZE, 2014).

To have a general idea of the observed salinity field in the whole area occupied during the Nov/2013 campaign, one 3-D representation diagram (Fig. 6) was drawn with all the 95 salinity profiles (20 in front of Albufeira, 65 offshore Olhos de Água and 10 in front of Praia da Falésia).

CTD stations nos. 47, 59 and 63 (this one represented in Fig. 5) located in the Olhos de Água area, and no. 57A in Albufeira, are identified in Fig. 6; all the stations are located near the coast showing strong influence of SGDs, with lower salinities S ≤ 36.0 (blue tones) in the whole water column, and the lowest values being detected at the surface. This could indicate either continuous submarine discharges, or the CTD stations were precisely located over those particular springs.

Fig. 6 shows that the salinity profiles along sections III and IV (Olhos de Água) and along sections A2 and A3, at the same latitudes, in Albufeira, present salinity mínima near the bottom, thus indicating the existence of SGDs.

Figure 6 – Salinity profiles obtained during the Nov/2013 campaign: 20 in front of Albufeira, 65 offshore Olhos de Água and 10 in front of Praia da Falésia. Stations with low salinity values (blue tones) in the whole water column are identified (adapted from Frazão, 2016).



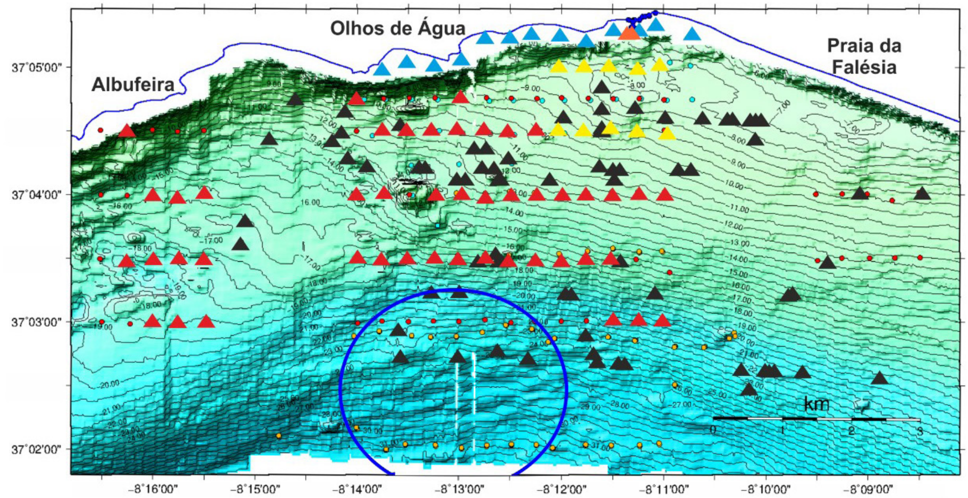
Salinity profiles along sections V (Olhos de Água) and A4, at the same latitude in Albufeira, show low values occurring at different depths in the water column (see Fig. 6); this indicates that the stations could be in the propagation path of a SGD plume.

Along sections F1 and F2 (Falésia), salinity minima occurred at the surface, indicating that the stations could also be in the propagation path of a SGD plume.

The location of the SGDs identified through CTD data is represented in Fig. 7, where the triangles have the same color code as the aforementioned campaigns. In the frame of FREEZE project, two SGDs located at ≈ 120 m from the Olhos de Água beach, were identified through diving, in July 2013 (orange triangles), and several intertidal springs along the coastline were also identified in the period 2010-2012 (small dark blue circles); the schematic representation of the slick observed on the SAR image (Fig. 1) is also represented in Fig. 7.

In the frame of FREEZE project, seismic data was also collected during two campaigns conducted in May 2010 and April 2011. The location of SGDs detected through the analysis of the high-resolution seismic profiles is also represented in Fig. 7 by black triangles.

Figure 7 - Location of the SGDs identified through CTD data collected during the surveys: Nov/2012 (yellow), Apr/2013 (light blue) and Nov/2013 (red). The dark blue circle is the schematic representation of the slick identified on the SAR image (adapted from Frazão, 2016).



SGDs identified through the analysis of CTD data were preferentially found between the bathymetric contours 7 m and 18 m and also near the coast. These results are very similar to the ones obtained with the seismic profiles, since the discharges occurred where paleocoast lines and other geological structures were identified (FREEZE, 2014; Fernandes *at al.*, 2015).

Low salinities near the surface along section V (see Fig. 6) indicate that the slick (Fig. 7) could be a recurrent pattern. The slick is located between the bathymetric contours 20 m and 30 m, also corresponding to paleocoast lines (Fernandes *et al.,* 2015).

4 CONCLUSIONS

In conclusion, CTD data collected during three oceanographic surveys conducted in November 2012, April 2013 and November 2013, allowed the identification of the places where Submarine Groundwater Discharges occur over the continental shelf off Olhos de Água, in Algarve.

The analysis of the thermohaline properties of 196 oceanographic stations (20 in front of Albufeira, 166 offshore Olhos de Água and 10 in front of Praia da Falésia), carried out during dry and wet situations, revealed that the SGDs are permanent, with stronger outflows during the rainy years and reduced flows during dry years.

Concerning the location of the submarine springs, there was a good agreement between the results obtained with CTD and the ones obtained with seismic reflection profiles, even though they were obtained in different years. This reinforces that SGDs are recurrent, with different outflows under unlike meteorological conditions.

The non-SGDs referee places, Albufeira and Falésia, were a bad choice, once SGDs were also identified in Albufeira and waters with influence of SGDs were detected in Falésia.

In future studies in the Olhos de Água region or in another areas with SGDs, a systematic monitoring is fundamental, covering different seasons and different hydrological years.

5 ACKNOWLEDGMENTS

The R&D Project FREEZE (PTDC/MAR/102030/2008) was supported by the Fundação para a Ciência e Tecnologia (FCT) and had the following partners: Instituto Português do Mar e da Atmosfera (IPMA), Laboratório Nacional de Energia e Geologia (LNEG), the former Centro de Oceanografia/Faculdade de Ciências da Universidade de Lisboa (CO/FCUL), Universidade do Algarve (UAlg) and Instituto Superior Técnico (IST), Lisboa.

This study had the support of national funds through Fundação para a Ciência e Tecnologia, I. P (FCT), under the projects UIDB/04292/2020, UIDP/04292/2020, granted to MARE, and LA/P/0069/2020, granted to the Associate Laboratory ARNET.

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ÍNDICE REMISSIVO

A

B

C

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