UNIVERSIDADE TÉCNICA DO ATLÂNTICO
INSTITUTO DE ENGENHARIA E CIÊNCIAS DO MAR

WEST AFRICAN SCIENCE SERVICE CENTRE ON CLIMATE CHANGE AND ADAPTED LAND USE

Master Thesis

Analysis of distribution and migration of mesopelagic organisms based on 38 Khz backscatter around Cabo Verde

Mahaman Harouna

Master Research Program on Climate Change and Marine Sciences

São Vicente
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Master's thesis presented to obtain the master's degree in Climate Change and Marine Sciences, by the Institute of Engineering and Marine Sciences, Atlantic Technical University in the framework of the West African Science Service Centre on Climate Change and Adapted Land Use

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Panel defense

President

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Examiner 1

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Examiner 2

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WASCAL
West African
Science Service Centre on
Climate Change
and Adapted Land Use

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Dedication

To God be the glory! I dedicate this thesis to my parents, Reverend Mahaman CHEKARAOU and HABSOU, who have consistently supported me. My wife Salamatou Pauline and my son Frank waited for me for two (2) years to achieve this success. To Reverend BAGGOTT Frank family for all their support.

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Resumo

O arquipélago de Cabo Verde está localizado no Atlântico Norte tropical oriental entre as águas oceânicas abertas oligotróficas e o afloramento costeiro produtivo do Sistema de Correntes Canárias. Caracteristicamente a região de Cabo Verde tem produtividade primária relativamente baixa, embora existem modelos que indicam maior biomassa de micronekton mesopelágico nessa região em relação ao Atlântico Norte tropical e subtropical, em geral. No entanto, estas ocorrências são extremamente fragmentadas e relacionadas com os turbilhões, filamentos e afloramentos induzidos pelas ilhas ou montes submarinos. A forma como estes fenómenos afetam a distribuição de níveis tróficos mais elevados não é atualmente bem compreendida. Neste estudo, a distribuição e a migração vertical diária dos organismos mesopelágicos foram analisadas em relação a características que potencialmente afetam a sua biomassa, utilizando duas "saildrones", uma equipada com um ADCP e outra com um ecosonda Simrad EK80 incluindo um combi-transdutor de dupla frequência (38 Khz e 200 Khz), durante a missão ALT2MED em Outubro - Dezembro de 2019. O padrão geral de migração vertical foi confirmado e relacionado com a radiação solar a partir da superfície, atingindo maior profundidade durante o dia e menor profundidade à noite. A distribuição vertical e a migração mostraram que a posição dos organismos ao longo de um dia é dinâmica. Os organismos mesopelágicos mudam e adaptam a sua posição durante o dia em resposta à intensidade da luz detectada. A refletância acústica a 38kHz foi maior tanto junto ao redemoinho estudado como perto da ilha do Sal, mas não junto ao banco de Nova Holanda. O redemoinho afetou a distribuição e a abundância de organismos mesopelágicos a redor de Cabo Verde, criando condições que aumentaram a produtividade, o que também era visível em termos de clorofila a. No redemoinho, a distribuição nocturna estava também confinada a uma camada mais rasa em comparação com o exterior do redemoinho. Este estudo poderia ser benéfico para outras ilhas e áreas que têm condições ambientais semelhantes. Poderia também ser aplicado para fins socioeconômicos através do desenvolvimento da atividade pesqueira.

Palavras-chave: "Saildrone", vórtices de mesoescala, efeito de ilha, hidroacústica, migração vertical diária

Abstract

The Cabo Verde archipelago is located in the Eastern Tropical North Atlantic between oligotrophic open ocean waters and the productive coastal upwelling of the Canary Current System. The Cape Verde region features were relatively low primary productivity although models showed the highest biomass of mesopelagic micronekton in the tropical and subtropical North Atlantic. of mesopelagic micronekton in the tropical and subtropical North Atlantic. However, these occurrences are extremely patchy and related to eddies, filaments and island- or seamount-induced upwelling. How this impacts the distribution of higher trophic levels is currently not well understood. In this study, distribution and diel vertical migration of mesopelagic organisms were analysed in regard to features that potentially enhance their biomass using two saildrones equipped with an ADCP and a Simrad EK80 echosounder operated with a dual-frequency combi-transducers (38 Khz and 200 Khz), respectively, during the ALT2MED mission in October - December 2019. The general vertical migration pattern was confirmed and was related to surface irradiation Organisms move from shallow waters to deep waters during the day migrate into shallower water in the nighttime. The vertical distribution and migration showed that the daytime depth is dynamic. Mesopelagic organisms change and adapt their position during the daytime as a response to the intensity of light they could detect. Acoustic backscatter at 38kHz was enhanced both in the eddy and close to the island of Sal, but not near Senghor Seamount. The eddy impacted the distribution and the abundance of mesopelagic organisms around Cabo Verde by creating conditions that increased productivity, which was also visible in chlorophyll-a. In the eddy, the nighttime distribution was also confined to a shallower layer compared to outside of the eddy. This study could be of benefit to other islands and areas that have similar environmental conditions. It could be used also for socio economic purposes through developing fisheries activity

Key-words: Saildrone, mesoscale eddies, island mass effect, hydroacoustics, diel vertical migration.

Abbreviations and acronyms

DSL	Deep Scattering layer
DVM	Diel Vertical migration / diurnal vertical migration
ETNA	Eastern Tropical North Atlantic
PAR	Photosynthetically Active Radiation
UTC	Universal Time Coord
TVG	Time Varied Gain
IME	Island Mass Effect
CC	Canary Current
NEC	North Equatorial Current
LCZ	Light Comfort Zone
POC	Particulate Organic Carbon
SLA	Sea Level anomaly
SST	Sea surrface Temperature
SSS	Sea Surface Salinity
ACME	Anticyclonic Mode Water Eddies

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1. Introduction

1.1 Background and Context

The mesopelagic zone is the transition zone between the epipelagic zone and the deep waters covering 200 m to 1000 m depth. Parameters such as temperature, oxygen and light decrease while density and pressure increase with depth. It is also called the twilight zone due to its difficulties to be penetrated by sunlight for photosynthesis (García-Seoane et al., 2020). Various organisms, such as fish, zooplankton, squid, shrimp, and jellyfish are living in this zone (Bennett, 2017). Given that market prices for fishmeal are continuously increasing, mesopelagic organisms have the potential to become an economically relevant marine living resource in the future. Given the existence of a wide-open market for fish and fish products, there is indeed a real potential need for these organisms for the nutritional and pharmaceutical industries and economy considering the ecological aspects (Paoletti, 2021). However, their global biomass, distribution, growth, reproduction as well as their role in the biological carbon pump are not yet well understood (Honjo et al., 2014; Priou et al., 2021). In this wider context, it is important to understand how mesopelagic organisms are distributed in the ocean, and how they are impacted by locally or temporally constrained.

One way to observe midwater organisms in large-scale surveys is the use of hydro acoustics. Acoustic instruments by emitting or receiving sound waves can localize fish and objects that could not be seen by eyes and this technology has highly impacted marine research and fishery activity (MacLennan & Simmonds, 1992). Since vessel-based acoustic data collection is quite expensive, autonomous platforms such as saildrones are attractive alternative platforms (with zero emissions during operation).

Living organisms - generally squids, crustaceans and schools of fish - congregate at depths below the surface and form a horizontal zone called deep scattering layer (DSL), which can be detected by echosounders (Knutsen et al., 2017). The discovery of the deep scattering layers dates to the second world war following the use of sonar which made them appear as a line, in mesopelagic zone, often confused with the seafloor, hence their name of false bottom (Bennett, 2017).

Mesopelagic scattering layers are ubiquitous features in open oceans around the whole world, also distributed in eddy zones (Salvanes & Kristoffersen, 2001). The modelled distribution using the SEAPODYM model (Lehodey et al., 2016) suggests that the Cabo Verde region features the highest biomass of mesopelagic micronekton in the tropical and subtropical North Atlantic (Fig. 1).

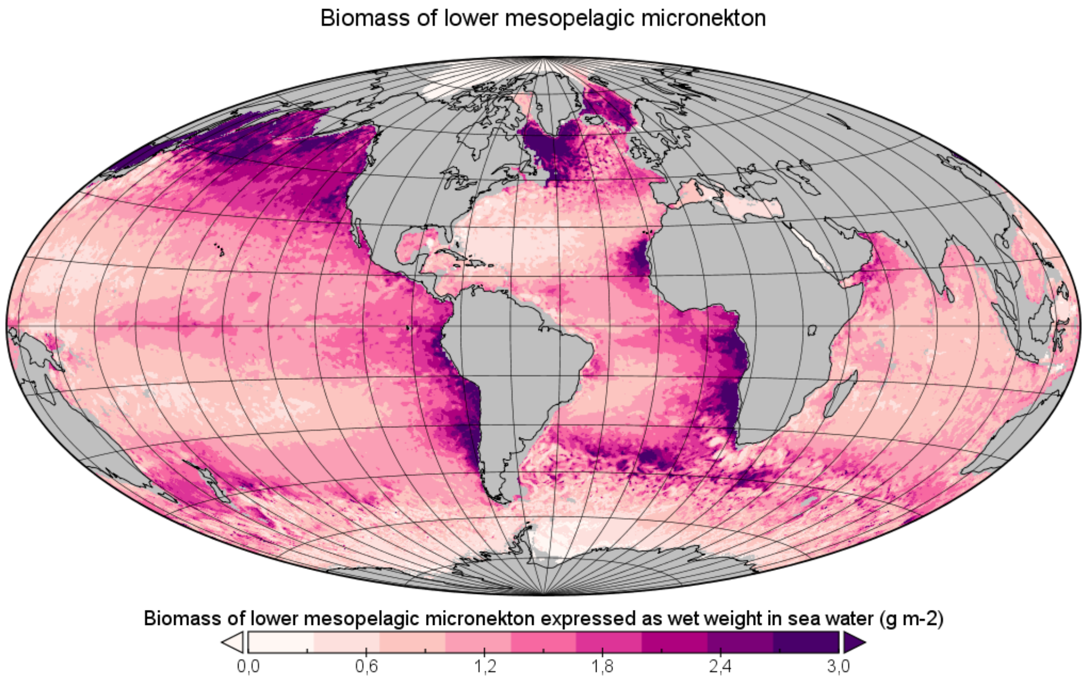

Figure 1 - Modelled global biomass distribution of mesopelagic micronekton (SEAPODYM, Lehodey et al., 2016).

Some mesopelagic organisms carry out an upward and downward movement daily, the diel vertical migration (DVM). This movement of organisms from shallow waters at night to deep waters during the day is an important process for exchange of organic matter from the surface to the deep ocean. They migrate into shallower water at dusk to feed on plankton during the day and return to the dark cold oxygen deficient waters of the mesopelagic zone to be safe from predators. Vertical migrations are made by virtually all taxonomic components of the deep diffusion layers, but not by all the species that make up these layers. There are migrants and non-migrants (residents) in these layers, but both include a wide range of species.

The purpose of this study is to provide an analysis of the distribution and migration of mesopelagic organisms around Cabo Verde islands in Sal, Senghor seamount and eddy zone (Eddy1) using hydroacoustic data collection methods with a commercial saildrone.

1.2 Problem Statement

The Cabo Verde archipelago is in the internal margin of the Eastern Tropical North Atlantic zone which is characterized by oligotrophic waters, far west of the coastal upwelling of the Canary Current System (Fisher et al., 2016). Such oligotrophic waters are prone to receive eddies generated in upwelling regions characterized by nutrient-rich waters, which enhance biological productivity under favorable conditions (Cardoso et al., 2020). These eddies have various sources such as topography (Pattiaratchi et al., 1987; Heywood et al., 1990), ocean-atmosphere interaction (Alpers et al., 2013; Wilson, 2016; Xu et al., 2016 and Ioannou et al., 2017), currents (Perret et al., 2011) or even other eddies (Sangrà et al., 2009).

Some of these eddies are of great importance for the survival of mesopelagic fish and their vertical migration and contribute to enrich the oligotrophic water around Cabo Verde by generating upwelling which enhance the biological productivity in the region (Löscher et al., 2015; Romero et al., 2016).

It is also known that physical turbulent motions are strongly enhanced in the vicinity of coasts or above steep, rough topography and already Doty and Oguri, (1956) proposed the term “island-mass effect” (IME) for the increase in plankton biomass around oceanic islands, which since then has gained importance in studying productive processes around islands.

Like islands, seamounts constitute natural barriers to the current circulation that produce geophysical and biological effects like in open ocean areas (Heywood et al.,1990). Topography interactions of ocean currents result in upwelling of nutrient-rich deep water which is a source of higher primary production. (Abecasis et al., 2009).

Nevertheless, particularly at Senghor Seamount, it has been understood that mesopelagic organism’s distribution patterns show no significant differences to open ocean areas (Denda and Christiansen, 2014). Likewise, the effect of seamounts on the trophic structure of mesopelagic communities weakens. (Denda et al., 2017a). This is due to the fact that stocks of mesopelagic organisms have short residence times on seamounts. (Mendonça et al., 2012).

The aim is to investigate the distribution of mesopelagic organisms around the Cabo Verde archipelago, using the hydroacoustic data collected with commercial sailrones, to analyze the diel vertical migration of mesopelagic and the role of features such eddies, seamounts and island proximity in this distribution and the abundance.

1.3 Research Questions

To analyze the distribution and migration of mesopelagic organisms around Cabo Verde islands, below are listed the main questions that summarize the aim of the present study goals:

- How are mesopelagic organisms distributed in the Eastern Tropical North Atlantic around the Cabo Verde archipelago?
- How do features such as eddies, seamounts and island proximity impact mesopelagic organisms in the Cabo Verde region?
- What are the differences in diel vertical migration inside and outside eddies and on the top of Senghor Seamount and close to the island of Sal?

1.4 Relevance and Importance of the Research

The aim of this study was to investigate eddies activity and try to relate hydroacoustic data collected by saildrones to see the relevant difference of mesopelagic organisms density between inside and outside eddies around Cabo Verde archipelago and Senghor Seamount.

1.5 Objectives of the work

The major objective of this study is to analyze, using hydroacoustic data (38 kHz) from Saildrone Mission Atl2Med, the distribution of mesopelagic organisms in the eastern tropical North Atlantic.

The specific objective was:

To use hydroacoustic data collected by the Saildrone to investigate the distribution of mesopelagic organisms in the survey area around the Cabo Verde Islands.

1.6 Structure of the work

This thesis is organized as follows: The introduction is presented in section one; the literature review in section two; materials and methodology used are presented in section three; the results in section four are described; the discussion in section five. The conclusion and future work recommendations are shown in section six..

2. Literature review

2.1 Mesopelagic environment and organisms

Environmental characteristics are factors known to play a key role in the distributions of pelagic species in the water column (Bonanno et al., 2017 and Giannoulaki et al., 2013). Brierley, (2014) supported that light controlled the vertical migratory movement of organisms through diel vertical migration depending on the intensity of radiation and depth. The photosynthesis ensures growth and reproduction of phytoplankton residing in the area where the sunlight could reach. However, the depth that organisms could reach was also determined by factors such as temperature and density (Brierley, 2014)

Previous work by Irigoien et al., (2014) had supported that there was a large global biomass of mesopelagic organisms in all the world's oceans. They can be determined by their characteristics, their importance and their habitats. In the open ocean mesopelagic organisms are characterized by their number, the diversity and the migratory behavior. They are the major component of the world's marine biomass.

The existing body of research on mesopelagic organisms by Gjøsæter & Kawaguchi, (1980); Lam & Pauly, (2005) suggested that their abundance and their ecological importance remains uncertain. Thus, the net sampling technique of the 1980s, estimated the global mass of mesopelagic fish at one gigatons (10^9 t), which was just an approximation. Mesopelagic organisms are therefore not easily captured by sampling gears and the estimation is subject to ongoing debate (Davison et al., 2015). Although mesopelagic fishes are not suitable for direct human consumption, they represent a source for protein and lipids (in particular omega-3 fatty acids) that is very valuable e.g. for the production of aquaculture feeds, and commercial exploitation seems possible in the near future since global fishmeal market prices are steadily increasing.

Siegelman-Charbit & Planque, (2016) previously observed that many mesopelagic organisms depend on vertical migration as one of their characteristics is called diel vertical distribution (DVM). DVM is the largest motion of animal biomass in the ocean. During the day, organisms in deeper waters move upward to avoid predators, while at night they feed in the upper waters under cover of darkness (Hays., 2003). Underwood et al., (2021) studied the behavior of mesopelagic organisms using artificial light consisting of emitting different colors of light in the water. The result showed that mesopelagic organisms reacted to the artificial light by avoiding vertically and horizontally the light.

Mesopelagic organisms play an important role in the biological pump through DVM by exporting organic carbon from the euphotic layer to the twilight zone of the ocean (Steinberg & Landry, 2017). However, the importance of DVM for the biological pump is that it first allows the species to feed at night at the surface. Subsequently, through respiration, excretion and rejection of organic matter, the mesopelagic organisms are able to transport enough carbon, nitrogen and phosphorus to the depths. (Longhurst et al., 1990., 2002; Hannides et al., 2009)

Although general migratory behaviors are well known, it remains a challenge in biological oceanography to well quantify the relative and absolute importance of the different components of the biological carbon pump (see Claustre et al., 2021 and references therein). In a study by Hernandez-Leon et al., 2019, the active flux by zooplankton and nekton in the Cabo Verde region ranged between 15% and 75% of the passive sinking POC flux (particulate organic carbon), but point measurements tend to vary widely (Kiko et al., 2020).

Discovered during World War II according to Aksnes et al. (2017), deep scattering layers are layers which disperse sounding echoes in the oceans. They can be found in the mesopelagic zone and harbor a huge amount of faunal biomass. Initiated by ambient light levels, many organisms contributing to the DSL migrate toward the surface at night and downward in daytime according to a specific optical depth layer called light comfort zone, (LCZ).

2.2 Eddies

Mesoscale eddies are circular currents with a diameter on the order of 100km (depending on their latitude and generation process) that densely populated the ocean. In the eastern tropical North Atlantic, a quarter of the ocean surface is located in eddies at any time (Chaignaeu et al. 2009). They are often generated in meanders of boundary currents, for example at the capes of West Africa. They exist for several months at a time and travel through the ocean, often containing environmental conditions that are different from outside (Cushman-Roisin, 1994; Chelton et al., 2011). In fact, two types of eddies are observed in the oceans, the cyclonic (rotating counterclockwise in the northern hemisphere) and the anticyclonic (rotating clockwise in the southern hemisphere). They are present in all oceans and ensure the regulation of the general oceanic circulation and climate. In general, they are the result of instabilities created by persistent currents and they also play the role of limiting the forces of opposing currents (Mcwilliams, 2007). In the eastern tropical Atlantic, mesoscale eddies extend in the vertical dimension down to approximately 600-1000m, thus comprising the twilight zone (mesopelagic) and sometimes interacting with the seafloor.

According to (Cheng et al., 2014), eddies are energy sources, thus having more capacity to produce kinetic energy than the global motion of the oceans. Although cyclonic eddies are more numerous than anticyclonic eddies, which have a longer life span and greater propagation distances. His study showed that on average a third of the eddies have a depth of 1000 m and 18 weeks of survival but in some cases, others can remain for years. Both Cyclonic and anticyclonic mode water eddies had a cold core and were very productive, while "regular" anticyclones had a warm core and a downward displacement of isopycnals, resulting in lower productivity than the surrounding areas. Eddies can be identified and tracked using remote sensing, as they are characterized by a positive (anticyclones) or negative (cyclones) sea level anomaly (SLA), with amplitudes between 5 and 25 cm (Chelton et al. 2007). Other satellite-derived surface variables (sea surface temperature and chlorophyll-a) can help to characterize them and to discern e.g. anticyclonic mode water eddies from "normal" anticyclones (see Figure 2, Schütte et al., 2016a).

Therefore, some eddies act as stimulators of biological production in the ocean, providing a food-rich habitat for higher trophic level marine life. These eddies are places of unequal distribution of the biomass of the oceans. They are nutrient rich places for higher trophic level marine fauna because they create habitats comparable to desert oasis for marine environment (Godø et al., 2012). In their studies, Karstensen et al., (2015) showed that in the Tropical North Atlantic Ocean the eddies move westward from the African coast toward the Atlantic. The West African upwelling system is powered by trade wind and eddies. These eddies can be characterized as warm, less salty, unproductive anticyclones (see right panels in Fig. 2), or productive and cold cyclones or anticyclonic mode water eddies, elevated sea levels and higher surface temperatures (see left and middle panels in Fig. 2, respectively, Schütte et al., 2016a). The two productive types are also known to result in low oxygen in their cores (Karstensen et al., 2015, Schütte et al., 2016b), with marked impacts on the distribution of marine life (Löscher et al., 2015, Hauss et al., 2016)., which has led to the term "dead zone eddies", although it was later found that they are not really dead, but inhabited by very different organisms such as the pelagic polychaete Poeobius (Christiansen et al., 2018). Migrant micronekton, however, tended to avoid the low oxygen core (Hauss et al., 2016).

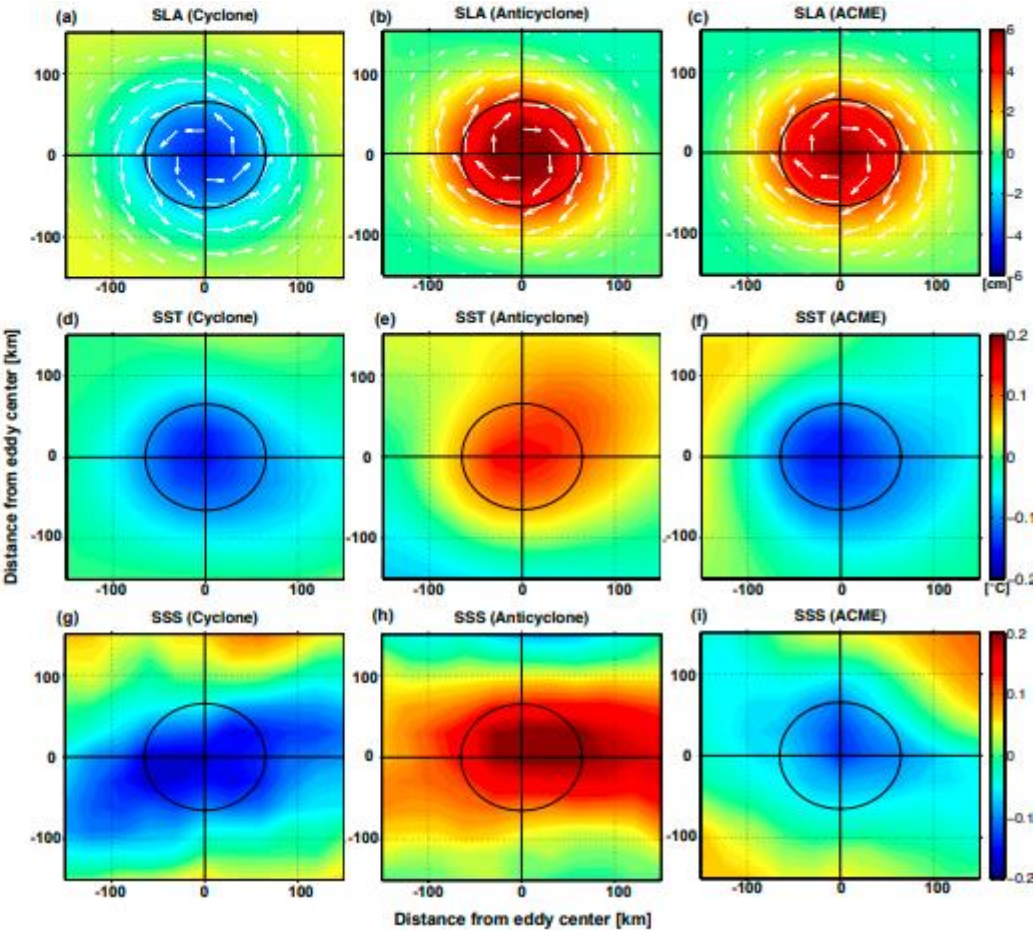

Figure 2 - Mean anomalies of sea level (SLA, upper row), sea surface temperature (SST, middle row) and sea surface salinity (SSS, lower row) in cyclonic (left column), anticyclonic (middle column) and anticyclonic mode water eddies (right column) in the Eastern Tropical North Atlantic. From Schütte et al., 2016b.

Cardoso et al., (2020) showed that eddies in Cabo Verde are eddies formed primarily by currents and winds blocked by the mass of the islands and secondly are locally formed eddies after separating from the bottom. Many of them are areas of high productivity due to chlorophyll concentrations while crossing the region. Condie & Condie, (2016) explained that they create favorable conditions for bioactivities such as the production of fish larvae.

2.3 Seamounts

Seamounts are mountainous formations under the ocean, found in all ocean basins (Wessel et al., 2010). As marine geological structures, they play a key role for marine organisms' life in the ocean system by increasing their productivity and providing habitat (Rogers, 1994). Interaction between seamounts and ambient flow create upwelling where nutrients from the bottom ascend to the surface that feeds species, thus generating abundant productivity (Coelho & Santos, 2003). Pakhorukov, (2008) also supported that seamounts are recognized as habitat and feeding grounds for marine organisms such as fish in the regions of the temperate North-East Atlantic. Therefore, Cabo Verde, Senghor Seamount is known as a productive area with important biodiversity supporting the fishery of the region (De Almeida, 2004).

ADCP (Acoustic Duppler Current Profiler) surveys and remote sensing were conducted by Mohn et al., (2021) at the Senghor Seamount and had found it as a low-effect oceanic zone due to its weak current. This aspect made it a stable flow area, except the top where weak currents were most remarkable. Due to this Senghor seamount was exposed to the influence of the passing edies ensuring a considerable faunal biodiversity. Indeed, it has been shown that there was a mesopelagic faunal layer at depths of more than 400 meters, which was associated with diel vertical migration because of the aggregated micronekton localized in the flanks.

2.4 Islands

As a piece of land that is completely surrounded by water, islands can drive various physical mechanisms acting in the ocean. Doty and Oguri (1956) proposed the term Island Mass Effect (IME) for the increase in plankton biomass around oceanic islands. Variations in IME strength are governed by geomorphic type, bathymetric slope, reef area and local human impacts like human-derived nutrient input (Gove et al., 2016). As an example, eddies can be formed in the wake of islands (Pattiaratchi et al., 1987 and Heywood et al., 1990). A downstream extension of the island can be created followed by eddies generation (Heywood et al., 1990; Barton, 2001; Caldeira et al., 2005 and Hasegawa et al., 2009).

Islands with hills generate disturbance in the atmosphere, creating von Kaman vortex streets and swirls in the clouds (Chopra & Hubert, 1964) called wind wake that follows prevailing wind direction. Cabo Verde is characterized by two chains of islands, the windward northern chain islands and the southern leeward islands (Ramalho 2011).

In the Cabo Verde area, regular eddies have been spotted near the leeward side of the high islands. In terms of productivity, many anticyclonic eddies brought high chlorophyll-a waters towards Cabo Verde increasing its surrounding concentration. This is the case of Fogo where a remarkable concentration in chlorophyll-a was generated by local processes (Cardoso et al., 2020).

3. Materials and Methods

3.1 Description of the survey

3.1.1 The mission Atl2Med

Atlantic to Mediterranean (Atl2Med) 2019-2020 was a research mission with several public and private partners involving commercial saildrone and 12 other institutions and universities from seven different countries. It was a two-phase mission, the first part was about a survey on eddies around Cabo Verde led by the Helmholtz Center for Ocean Research (GEOMAR) based in Kiel, Germany. The second part was led by the Integrated Carbon Observation System, Ocean Thematic Center (ICOS OTC) based in Bergen, Norway, with the task to do cross-calibration of CO_2 measurements.

Saildrone[1] (Fig.3) is a commercial robot used in oceanography as an unmanned surface vehicle (USV), which does not use fuel. Instead, it uses wind energy for propulsion and solar panels to power its payload. It only uses 3 watts of power and it can sail around for months at the time. Compared to research vessels, saildrones are slow with an average speed of 2 to 3 knots. They are about 15 feet high, 23 feet long and 7 feet deep and can be equipped by different sensors depending on the research goals.

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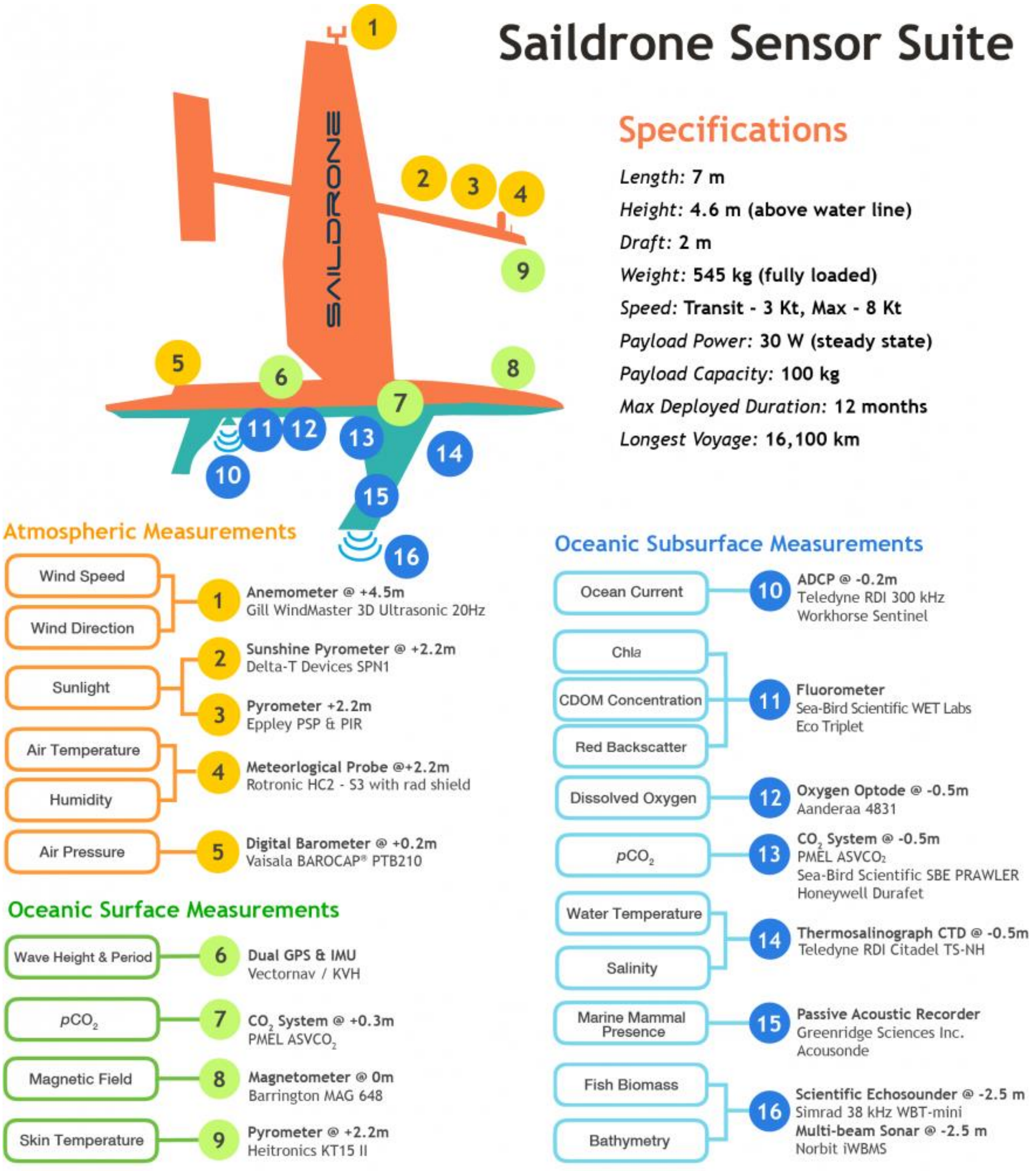
[1] https://www.saildrone.com



Saildrone Sensor Suite

Specifications

Length: **7 m**
Height: **4.6 m (above water line)**
Draft: **2 m**
Weight: **545 kg (fully loaded)**
Speed: **Transit - 3 Kt, Max - 8 Kt**
Payload Power: **30 W (steady state)**
Payload Capacity: **100 kg**
Max Deployed Duration: **12 months**
Longest Voyage: **16,100 km**

Atmospheric Measurements

Wind Speed Wind Direction	1	**Anemometer @ +4.5m** Gill WindMaster 3D Ultrasonic 20Hz
Sunlight	2	**Sunshine Pyrometer @ +2.2m** Delta-T Devices SPN1
	3	**Pyrometer +2.2m** Eppley PSP & PIR
Air Temperature Humidity	4	**Meteorlogical Probe @+2.2m** Rotronic HC2 - S3 with rad shield
Air Pressure	5	**Digital Barometer @ +0.2m** Vaisala BAROCAP® PTB210

Oceanic Surface Measurements

Wave Height & Period	6	**Dual GPS & IMU** Vectornav / KVH
pCO_2	7	**CO_2 System @ +0.3m** PMEL ASVCO$_2$
Magnetic Field	8	**Magnetometer @ 0m** Barrington MAG 648
Skin Temperature	9	**Pyrometer @ +2.2m** Heitronics KT15 II

Oceanic Subsurface Measurements

Ocean Current	10	**ADCP @ -0.2m** Teledyne RDI 300 kHz Workhorse Sentinel
Chla CDOM Concentration Red Backscatter	11	**Fluorometer** Sea-Bird Scientific WET Labs Eco Triplet
Dissolved Oxygen	12	**Oxygen Optode @ -0.5m** Aanderaa 4831
pCO_2	13	**CO_2 System @ -0.5m** PMEL ASVCO$_2$ Sea-Bird Scientific SBE PRAWLER Honeywell Durafet
Water Temperature Salinity	14	**Thermosalinograph CTD @ -0.5m** Teledyne RDI Citadel TS-NH
Marine Mammal Presence	15	**Passive Acoustic Recorder** Greenridge Sciences Inc. Acousonde
Fish Biomass Bathymetry	16	**Scientific Echosounder @ -2.5 m** Simrad 38 kHz WBT-mini **Multi-beam Sonar @ -2.5 m** Norbit iWBMS

Figure 3 - Saildrone system for several measurements, including acoustic data collection, (Source: Alaska Ocean Observing System 2021).

The data that were used for the analysis were collected during the leg of the Saildrone mission that started in October 2019 from Cabo Verde, following the west African coast, crossing the Mediterranean to end in Trieste, Italy. Two saildrones (SD1030 and SD1053) were used for this purpose.

Both the SD1030 with the ADCP and the SD1053 with the EK80 echosounder sailed in parallel. However, SD1053 had to skip part of the survey (the southern portion of the Cabo Verde region) due to a technical service in Mindelo. Their survey had several objectives. One was to cover a large-scale survey from the subtropics to the Mediterranean and back to Trieste passing through the different oceanographic observatories such as Cabo Verde Oceanographic Observatory (CVOO), ESTOC station, MontZE station. Then try to harmonize the in-situ data with the observatories data and with shipboard data which uses CTD, water sampling and comparing them.

During this 9,260-kilometer mission, the UAVs SD1030 with the ADCP and the SD1053 with the EK80 echosounder collected biogeochemical (pCO2, pH, dissolved oxygen, Chlorophyll-a), ecological (biomass/hydroacoustic), and physical measurements, and performed cross-calibrations.

3.1.2 Sampling Process and Data

Based on satellite altimetry, temperature signature and chlorophyll it has been observed and distinguished two types of productive eddies in the region of Cabo Verde. The goal of the Cabo Verde area survey was to look at eddies' activity in the region. It was to resolve the distribution of pelagic organisms (zooplankton and nekton) impacted by eddies in the eastern tropical north Atlantic as well as their importance on biogeochemistry flux in the region.

For the sampling process, acoustic data were recorded at site between 14^o N and 19^o N and between 20^o W and 26^o W from October 18th to December 15th (Fig.4). The track included around Sal Island, Senghor Seamount and Eddy1 region. Data were recorded using a dual-frequency scientific echosounder system with two transducers mounted to commercial saildrone at upper limit of the recording was 8 m below the surface and the lower limit 800 m depth. The echosounders operated at 38Khz and 200 Khz frequency.

The two drones were equipped differently according to their goals. The first one (1030) had an acoustic Doppler current profiler (ADCP RDI at 300Khz), the second saildrone was not equipped with an ADCP but had a SIMRAD EK80 WBT mini echosounder. The echosounder used is based on a SIMRAD EK80 but is referred to as " SIMRAD EK80 WBT Mini", operated with one dual-frequency combi-transducers. The transducers were calibrated according to pulse duration at 1.024 milliseconds, power at 500 watts. Sound speed (1482.41 m.s^{-1}) and pings (1 ping per 2 second). Environmental parameters (temperature, salinity, chlorophyll-a, and light) were recorded by sensors at the saildrone 1030.

Table 1 - List of sensors used

Sensor Type	Manufacturer	Model	Install Height (m)
1.SD1030			
Fluorometer	WET Labs	FLS	-0.5
CTD/ODO/Chl-A	RBR	Saildrone^3	-0.5
Conductivity/Temp/ODO	Sea-Bird Scientific	SBE37-SMP-ODO Microcat	-0.5
ADCP	Teledyne	Workhorse WHM300-I-UG1	-1.9
PAR	LI-COR	LI-192SA	2.6
2. SD1053			
Fluorometer	WET Labs	FLS	-0.5
PAR	LI-COR	LI-192SA	2.6
CTD/ODO/Chl-A	RBR	Saildrone^3	-0.5
Conductivity/Temp/ODO	Sea-Bird Scientific	SBE37-SMP-ODO Microcat	-0.5
Echo Sounder Transducer	Simrad	ES38-18/200-18C	-1.9

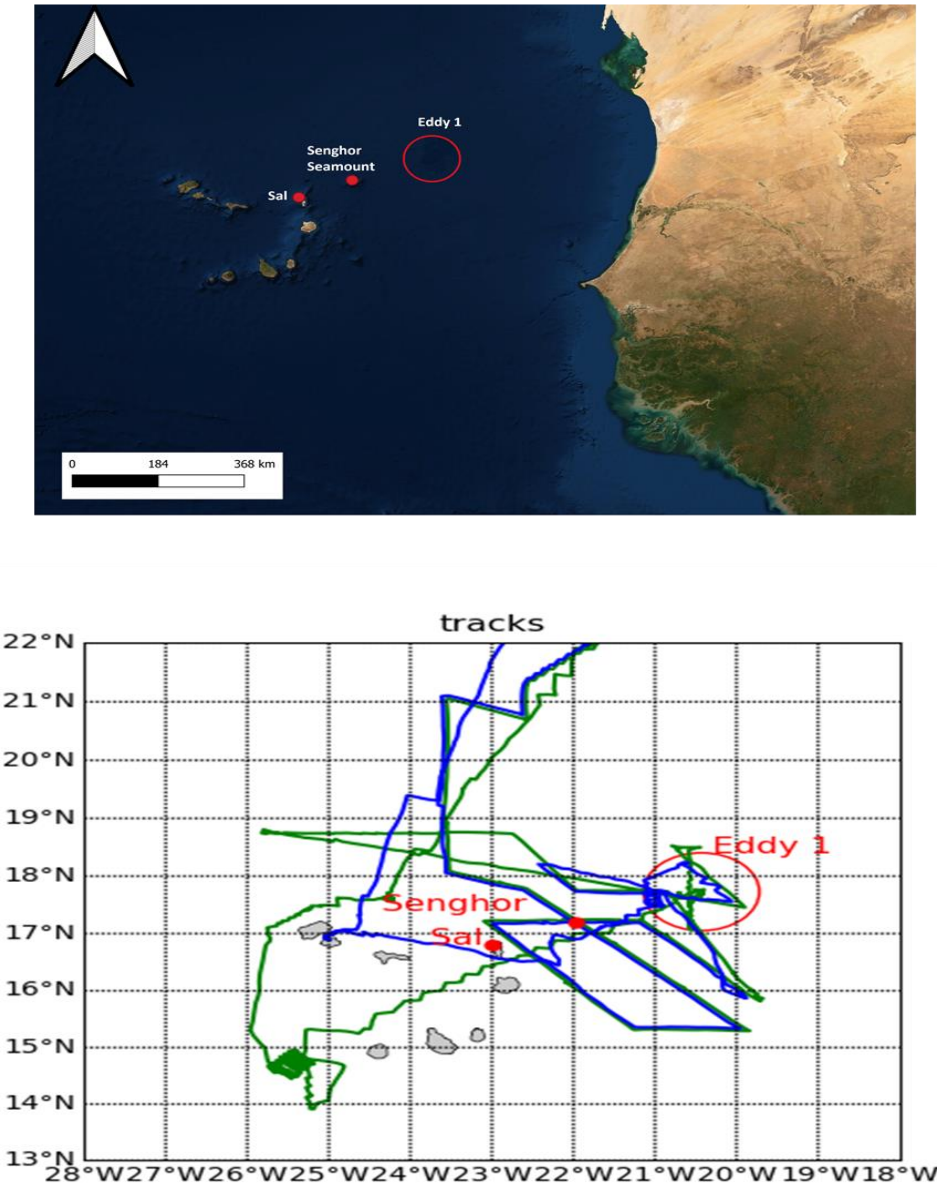


Figure 4 - **Area of interest and the main focus**. Upper part is the map of Cabo Verde from the earth explorer, the lower part is the map study area. Red dots indicate the location of Sal Island and Senghor Seamount, red circle denotes approximate location of Eddy1 (radius = 75 km), green line denotes the track of saidrone EK80 1030 with ADCP, blue line denotes the tack of Saildrone EK80 1053.

3.1.3 Post-processing of hydroacoustic data

The post-processing was done with the Echoview® version 12 (Echoview Software Pty Ltd, 2021). Due to the size of the combined acoustic data files, separated filesets were created for each of the three months data (October, November and December). To these filesets of acoustic raw data, filesets of raw data and GPS were added. The reason was the raw data did not have the GPS signal and were collected separately. For November because of the width of the data, two files had been used. One from the first to the 15th and the second from the 16th to the 30th. Time offsets between acoustic and GPS data observed during some phases of the mission were corrected in Echoview using corresponding time property changes. After loading the data, the next step was to set the echogram variables properties. For the grid, the distance between the grid line was set to 1 nautical mile and the depth line at 50 m of separation. The variable analysis was set on StartIntegration to exclude above and StopIntegration to exclude below, the upper integration threshold line was fixed at 8 m and the lower limit at 800 m for the 38KHz transducer and 200 m for the 200KHz one. In areas shallower than 800m, the bottom was manually annotated in order to exclude bottom echoes from the analysis. The bad data was marked with band tools. It was required also to graph the ping and synchronize it, then showed the Sv TVG curve and adjusted the value of the curve at -140 which was the best approximation. The background noise was removed using the background noise removal algorithm (table 2). To do this, raw data from the dataflow were used by entering a new variable and applying a background noise removal operator then determining the settings upper line and lower line, entering the maximum noise threshold at -140. The transient noise has been removed with the transient noise removal operator using the echogram obtained from background noise removal (table 3). The setting was also made by applying StartIntegration for the upper limit and StopIntegration for the lower limit with the threshold settled at -140 for the exclusion property. For the rest of the setting, to the property smoothing it had been applied vertical window units in meters, vertical window size at 5 m, to the context window it was applied horizontal size at 25 pings, vertical size at 5 samples, calculations per sample at 125, percentile at 50. To the sample, the threshold was fixed at 12db, noise sample replacement on percentile and percentile at 50. Hydroacoustic data reports were exported at a cell size of 15 minutes (horizontal) and 5 meters (vertical) and an integration threshold of -70dB.

Table 2: Background Noise Removal parameters settings:: For the cleaning of the data, it has been needed to read off the background noise from the echogram. To do this there were some manipulations needed. From the raw data manually, a new variable has been entered from which the operator background noise removal has been settled as algorithm background removal. After that, the settings had been determined from background removal operators such as starting with an upper line and stopping with a lower line, ping numbers, vertical extended maximum noise threshold.

Exclusion	**Analysis-settings**	**Bottom-settings**	**Vegetation-settings**
Exclude above: Upper	Apply bad data region	Bottom line: None	Vegetation line: None
Exclude below: StopIntegration	Include the volume of no-data samples	Bottom echo threshold at 1m (dB): -125	Bottom line: None
Exclude below threshold (dB at 1m): -140	Background noise at 1m (dB): -999	Depth normalization reference depth(m): 50	Time/ping interval: time
			Time between intervals (minutes): 0.10

Table 3: Transient Noise Removal parameters settings: For this, it was needed to use the clean background echogram that has been created so far to read off Transient noise. Then a new variable has been created to implement the transient noise removal algorithm. Here also settings had been determined.

Exclusion	**Smoothing**	**Context Window**	**Sample**
Exclude above: Upper	Vertical windows units: meters	Horizontal size (pings): 25	Threshold **(dB)**:12
Excludebelow: StopIntegration	Vertical windows size (m): 5	Vertical size (samples): 5	Noise sample replacement value: Percentile
Exclude below threshold (dB at 1m): -140		Calculation per sample: 125	Percentile: 50
		Percentile:50	

3.2 Data Analysis

Since datasets (environmental, ADCP, echosounder reports) were obtained in different formats (NetCDF as well as tabular data such as CSV), and with the goal in mind to relate data by e.g. timestamp and/or location, all data were written to a relational database (SQL) using PostgreSQL and the package psycopg2 in python. In the process, some new or derived variables were added: approximate solar time for each sampling location was estimated as Solar Time (YYYYMMDD hh:mm: ss) = UTC Timestamp (YYYYMMDD hh:mm: ss) + Longitude (°)/15/24

The distance of each observation location to the two eddies as well as Senghor Seamount and the southern tip of Sal was calculated using Vincenty's formula on the WGS-84 World Geodetic System (package pyproj). These databases could then be queried and joined.

For the data processing the following python packages were used: psycopg2 and sqlalchemy for PostgreSQL database handling and queries; xarray to read NetCDF data and perform calculations on variables; NumPy and pandas for dataframe operations; matplotlib and basemap for plotting. For specific calculations, additional packages such as datetime (date/time unit conversions), math (mathematical operators) and pyproj (geodetic distance calculation) were used. All scripts used are in the Appendix of this thesis.

3.2.1 Environmental characterization

To analyze the environmental parameters, data were collected with the corresponding sensors fitted on saildrone 1030 equipped with an ADCP (300 kHz). The goal was to determine the features of salinity, temperature, chlorophyll-a, light intensity and wind direction with sensors suite fitted on SD1030. Outputs indicating the area where the parameters had significant features were done with python. And also, the average values of these parameters were calculated.

3.2.2 Vertical distribution and migration

To analyze the mean vertical distribution of backscattering organisms, hourly (solar time) mean nautical area scattering coefficient (NASC in m^2 n mi^{-2}) was estimated for each depth bin over the entire dataset and compared to the mean PAR irradiance level. To evaluate the impact of geographical features on the vertical distribution, data were grouped in “in " and “out” by distance (see details on the chosen regions in 4.2). Then, either hourly means for each depth bin were plotted to evaluate the migration pattern over daytime, or the overall mean and standard deviation of all observations during the day- and nighttime (08:00-18:00 and 20:00-06:30, respectively) were calculated and plotted again depth as mean day- and night distribution.

3.2.3 Spatial distribution

The nautical area scattering coefficient (NASC in m^2 n mi^{-2}), measured by square nautical mile of water surface sampled of the acoustic backscatter per unit volume (MacLennan et al. 2002), was integrated over the depth of the data from the surface to 800 m. Because of migration effects (e.g. migration to the bathypelagic beyond the echosounder range during the day), the spatial distribution of integrated NASC backscatter was visualized for the upper 50m at night time only (between 20:00 and 6:30 solar time).

Table 4: List of software of the main goal and the packages used in python.

Software Used and the main purpose		
Echoview Software Pty Ltd (2021). Echoview® version 12	Python (Spyder Interface)	PostgreSQL
Background noise removing	Ek80 distance to core	PgAmin
Transient noise removing	Ek80 plot mean diel vertical migration (DVM)	Data base
Import/Export into CSV	Ek80_queries_v2	
	Saildrone ADCP	
	saildrone ADCP integrated backscatter currents	
	Saildrone chloropyll_acurrents	
	Saildrone environment	
	Saildrone GPS from netCDF4.Dataset minute	
	Saildrone 1030 all data to sql	
	Saildrone ADCP section	
	Saildrone ADCP plots	
	Study area	
The packages used in python	psycopg2, pandas.io.sql, matplotlib. pyplot, pl_toolkits. basemap, pandas, numpy, os, datetime, matplotlib, netCDF4, xarray, Basemap, sqlalchemy, math, pathlib, pyproj.	

4 Results

4.1 Environmental characterization

Environmental variables (chlorophyll-a, salinity and temperature) along the track were shown in figure 5 (temperature on top; salinity on bottom) and figure 6. Indeed, in Sal island, and Eddy1 results showed some variation of values, but the summit of Senghor Seamount did not. Eddy1 area had the highest values of salinity than Sal and Senghor Seamount but it had a lower temperature than them. Also, chlorophyll-a was more concentrated in Eddy1 than in other areas.

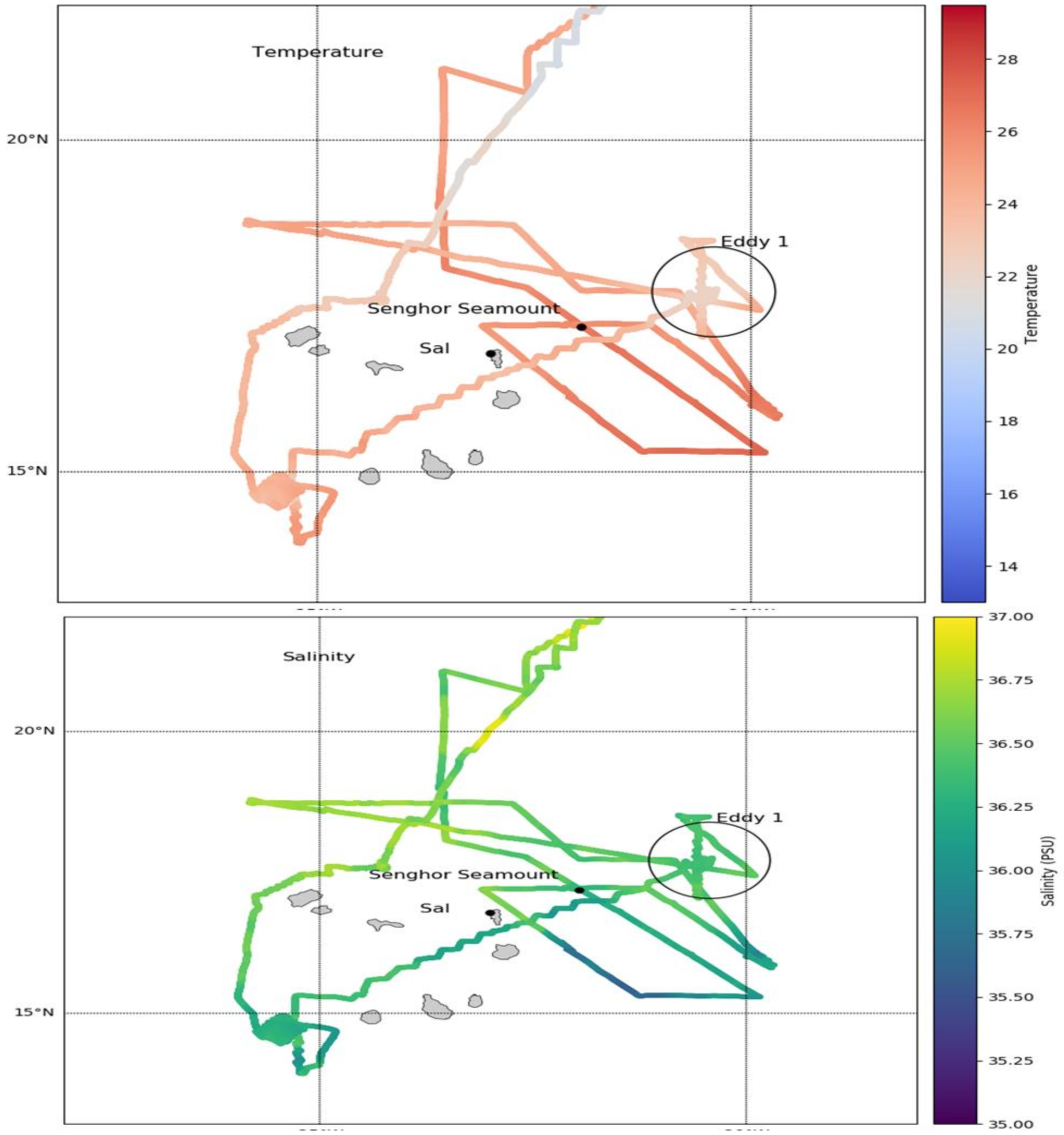


Figure 5- **Environment parameters along the study area.** Temperature (top), salinity (bottom). Black dots indicate the location of Sal and Senghor Seamount, black circle denotes approximate location of Eddy1 (radius = 75 km).

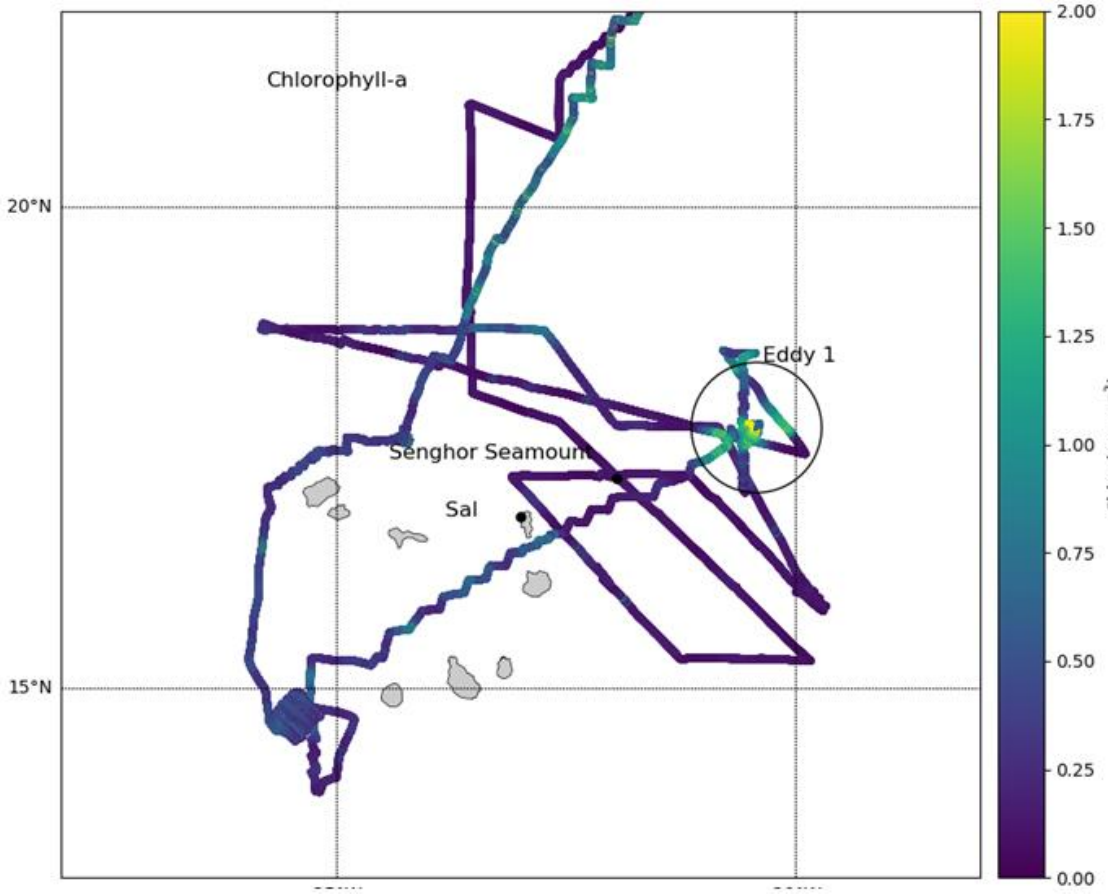


Figure 6 - **Environmental parameters along the study area**. Chlorophyll-a, black dots indicate the location of Sal and Senghor Seamount, black circle denotes approximate location of Eddy1 (radius = 75 km).

Statistics descriptive parameters of environmental variables of sea surface (table 5) gave an idea about different changes. Indeed, chlorophyll-a had higher variability of mean values around Eddy1 than Sal island, Senghor Seamount and the track. This denoted that the Eddy1 region seemed to have higher productivity. The tendency of mean values in salinity looked the same for Sal, Senghor Seamount and Eddy1 but only the truck had high mean values.

While the average surface temperatures varied between about 23 and 24 °C along the track as well as at Eddy 1 and around the Sal island, there was a tendency to be higher around Senghor Seamount (25.45 °C). This area was also noticeable with the lowest values on chlorophyll-a compared to the others. Therefore, the average salinity did not show a remarkable difference between the three zones. Although the track and Eddy1 had the same average values while the Sal island and Senghor Seamount also presented identical mean values

Table 5 - Changes in environmental parameters: temperature, salinity, chlorophyll-a and light in the track, eddy1, Sal and Senghor Seamount. A: average, Max: maximum, Min; minimum.

	Temperature (^{0}C)			Salinity (PSU)			Chlorophyll-a (mg m^{-3})		
	A	Max	Min	A	Max	Min	A	Max	Min
Track	23.99	27.31	20.37	36.45	37.20	35.59	0.60	4.09	0.05
Eddy1	23.06	25.63	22.03	36.42	36.58	36.34	0.75	2.26	0.00
Sal	23.74	25.41	23.40	36.22	36.56	36.15	0.56	1.03	0.12
Senghor	25.45	26.76	24.05	36.24	36.49	36.06	0.14	0.84	0.00

The distribution of currents (direction and velocity) and chlorophyll-a in the same track were shown in Fig.7. Thus, within the Eddy1 area and Sal were observed high concentrations in chlorophyll-a (2 mg.m^{-3}). The outside of the eddy had low concentration of chlorophyll-a. The Senghor Seamount area showed no particular increase in chlorophyll-a. It could also be seen that the interior of Eddy1 and the region of Sal where chlorophyll-a was higher, the current velocity was low. On the other hand, in places where chlorophyll-a was lower such as the Senghor Seamount, higher current velocity was observed. Therefore, when the current velocity was high, the concentration in chlorophyll-a was low.

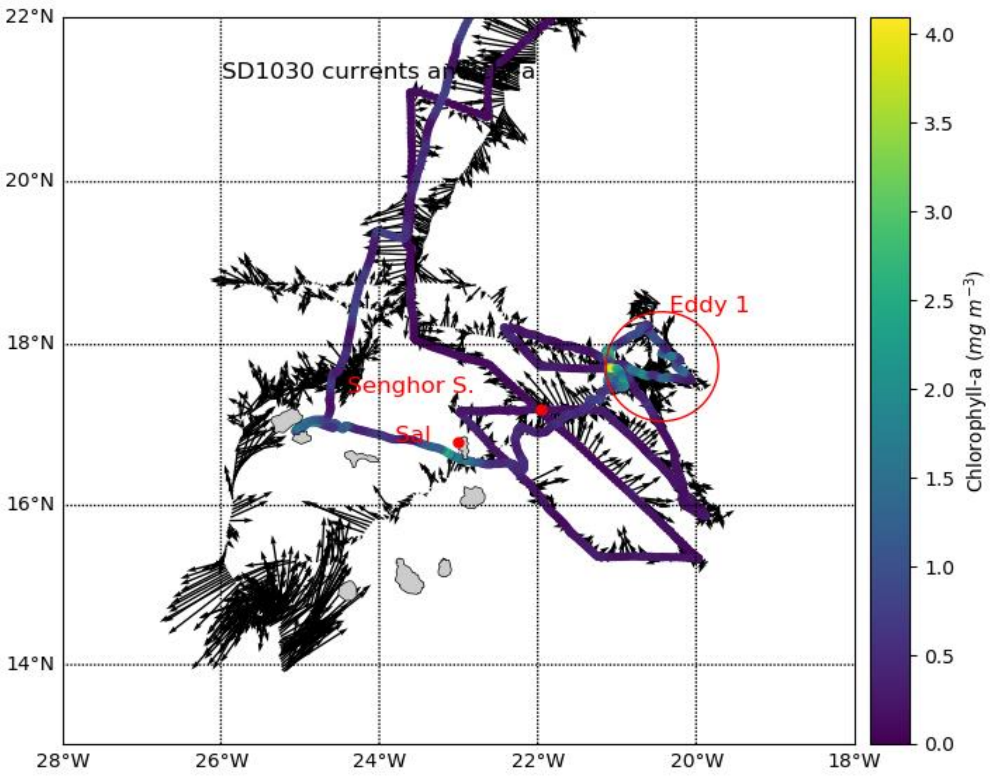


Figure 7 - **Current velocity and chlorophyll-a concentration.** Track of Saildrone 1030 with ADCP in the Cape Verde region. Arrows denote mean current velocity and direction in the upper 200 m, color denotes surface chlorophyll-a concentration (mg.m^{-3}). Red dots indicate the location of Sal and Senghor Seamount, red circle denotes approximate location of Eddy1 (radius = 75 km).

4.2 Vertical distribution and migration

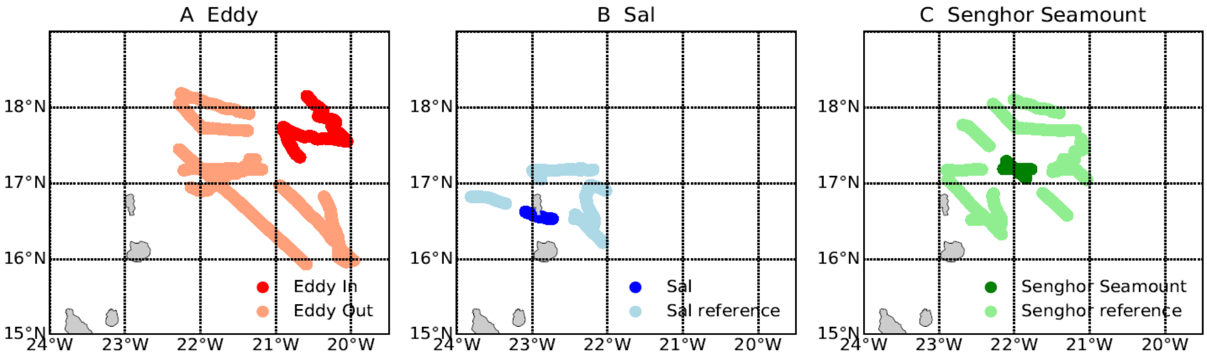


Figure 8- Data selection for the vertical distribution comparison. Left: locations depicted in red were defined as “Eddy in” (within 50 km from core), in light red were defined as “eddy out (100-200km from core). Middle: locations depicted in blue were defined as “close to Sal” (within 20 km), in light blue as reference (50-100 km from southern tip of Sal); right:locations depicted in green were defined as “close to Senghor Seamount (within 20 km to summit), in light green as reference (50-100 km from summit).

To compare the mean vertical distribution in the eddy, near the island of Sal and close to Senghor Seamount relative to the mean distribution in the region, data that were close to the respective feature as well as away from it (but still in the same region) were classified as depicted in Figure 8.

The mean DVM pattern at the South of 18° N (Fig. 9) was related to the light intensity (PAR). The daytime scattering layer was deepest at noon (12:00), while the radiation at the surface was highest. The curve downward and upward migration times were approximately one hour around 06:00 and 18:00 solar time, respectively

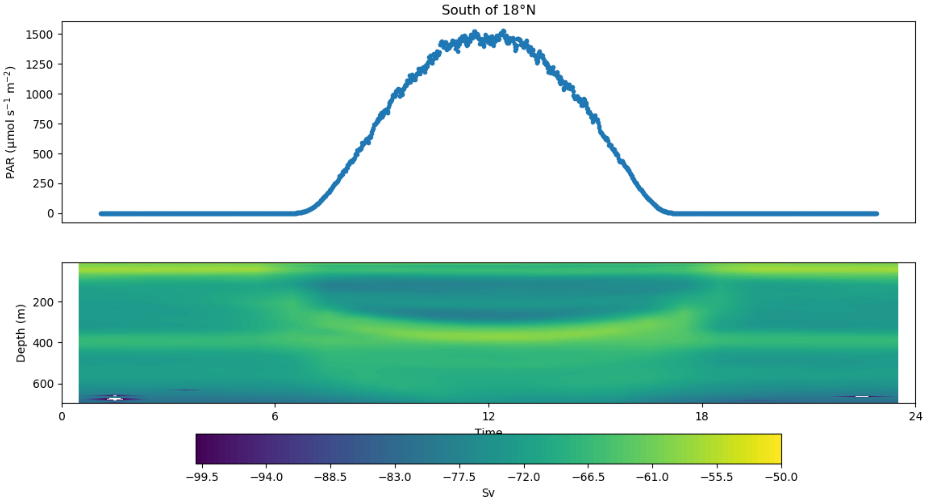


Figure 9 - **Diel vertical migration.** Mean diurnal vertical migration and light (PAR) at the South of 18^0 N. The curve on top showed the pattern of the light during day and night times. Vertical axis is light PAR (µmol $s^{-1}m^{-2}$) The lower part shows the vertical movement of scattering layers. x-axis night to day time backscattering covering 24 hour periods.

Observations inside and outside the Eddy1 showed a surface scattering layer at night, reaching up to ~50 m depth and a downwelling scattering during the day reaching ~750 m (in Fig.10). So, during the day from dawn (6 am) to dusk (6 pm), the migrating fraction of the deep scattering layers descended to depths of up to 750 m. Thus, there was a stationary layer at around 400 m as well as (a weak) around 600 m plus increased backscatter in the surface. A migrating layer showed clear upward and downward movement (diurnal vertical migration) and increased backscatter levels in the surface layer (at night) and in the stationary layer around 400m (during daytime). Also, it was noted that, inside as outside of the Eddy1, the diffusion was denser at the surface with even more abundance for the interior of the eddy.

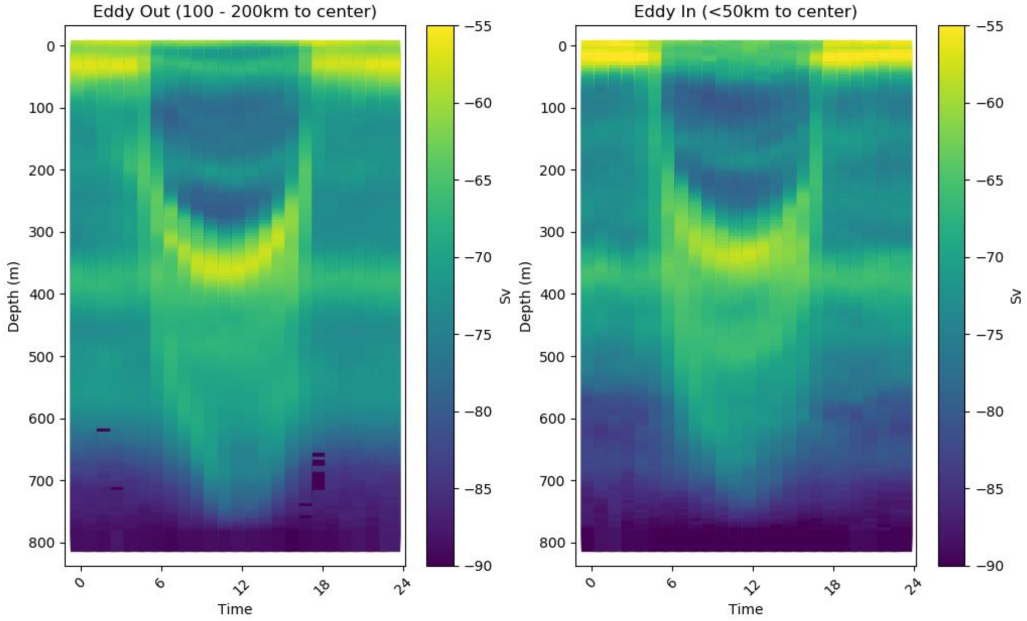


Figure 10 - **Diel vertical migration in the eddy.** Mean diurnal vertical migration from the eddy area. Left out of the eddy at 100 to 200 km to the center, on the right within the eddy less than 50 km to the center. Vertical axis is depth in meters, x-axis night to day time backscattering covering 24 hour periods.

The profile of the vertical distribution acoustic backscatter from the area 100 to 200 km out of the eddy centre and within the eddy at 50 km to the centre (Fig. 11), indicated day and night changes in the backscattering. During night acoustic backscatter levels were higher around 50 m depths in both regions (outside and in the eddy). Then during the day, high backscatter occurred above 400 m depth. However daytime backscatter was less large than nighttime backscatter at a given depth of 50 m. Indeed, the interior of the eddy denoted a higher value of backscattering, particularly at night compared to the out.

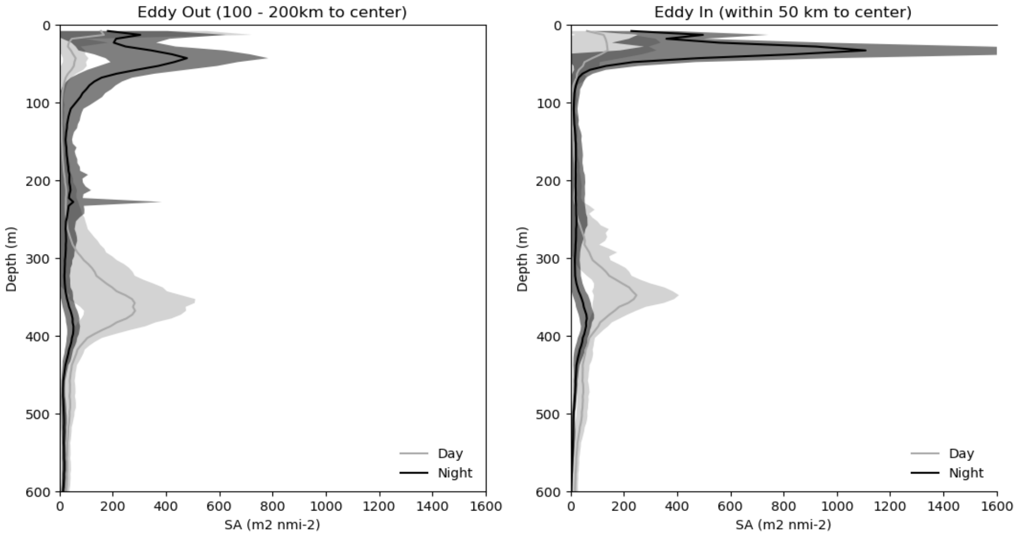


Figure 11- **Vertical distributions of backscatter**. Mean (+- standard deviation) backscatter from Saildrone Ek80_38Khz of eddy out 100 to 300 km to the center on the left and eddy within 50 km to the center on the right during the day (grey) and night (black). Vertical axis is depth in meters, x-axis is Nautical area scattering coefficient SA in m^2 nmi^{-2}.

At Senghor Seamount (Fig.12), particular high backscattering was not observed. However, at Sal island (Fig.13) the echo intensity seemed to be relatively higher than the Senghor Seamount area. There might be small epipelagic fish schools contributing to the signal as well, but given the pronounced migratory pattern and the large daytime peak, it might be possible that a large part of the recorded backscattering. Was mesopelagic micronekton.

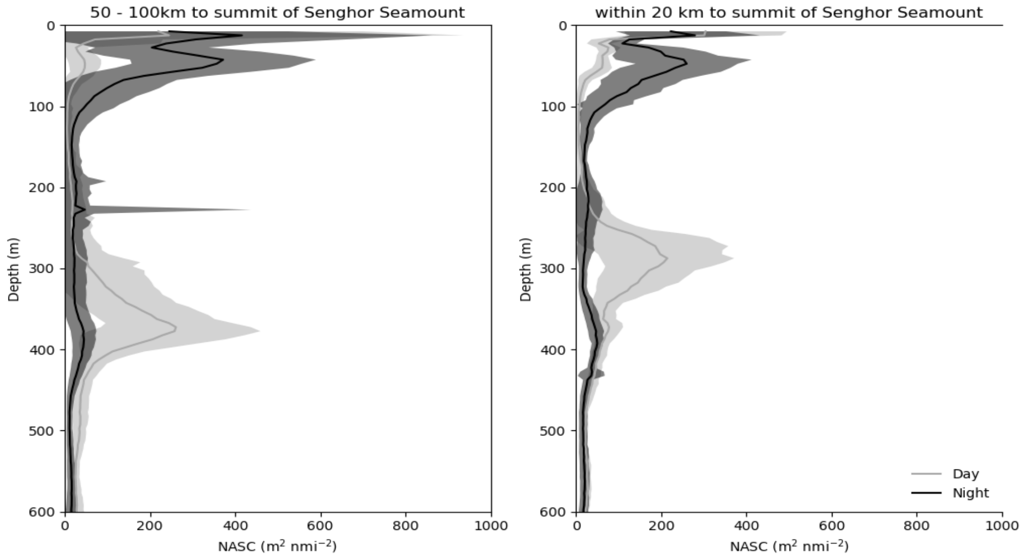


Figure 12 - **Vertical distributions of backscatter.** Backscatter from Saildrone Ek80_38Khz of Senghor seamount 50 to 100 km to the summit on the left and within 20 km to the summit on the right during the day (grey) and night (black). Vertical axis is depth in meters, x-axis is Nautical area scattering coefficient SA in

m^2 nmi^{-2}.

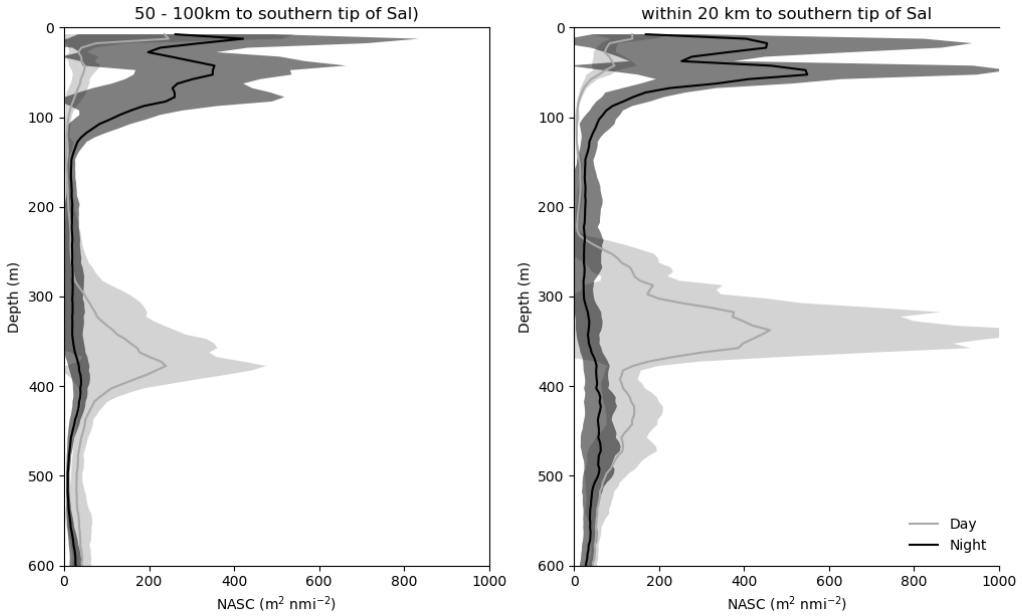


Figure 13 - **Vertical distributions of backscatter.** Backscatter from Saildrone Ek80_38Khz of Southern tip of Sal 50 to 100 km on the left and within 20 km to the Southern tip of Sal on the right during the day (grey) and night (black). Vertical axis is depth in meters, x-axis is Nautical area scattering coefficient NASC in m^2 nmi^{-2}.

4.3 Spatial distribution

The output from distribution analysis of NASC upper 50 m at nighttime over a radius less than 500 km from the center of the eddy (Fig.14) indicated that the eddy area presented a wide distribution of NASC with a high value between 600 to 800 m around the eddy area and Sal. While outside the eddy the distribution was quite lower except between 15oN and 16oN at 100 m depth where some high values were observed denoting occurring bioactivities which were probably due to the fish school moving in the surrounding area. Although in the Senghor seamount area the backscatter has a lower concentration of NASC than Eddy1 and Sal areas. (Fig.14).

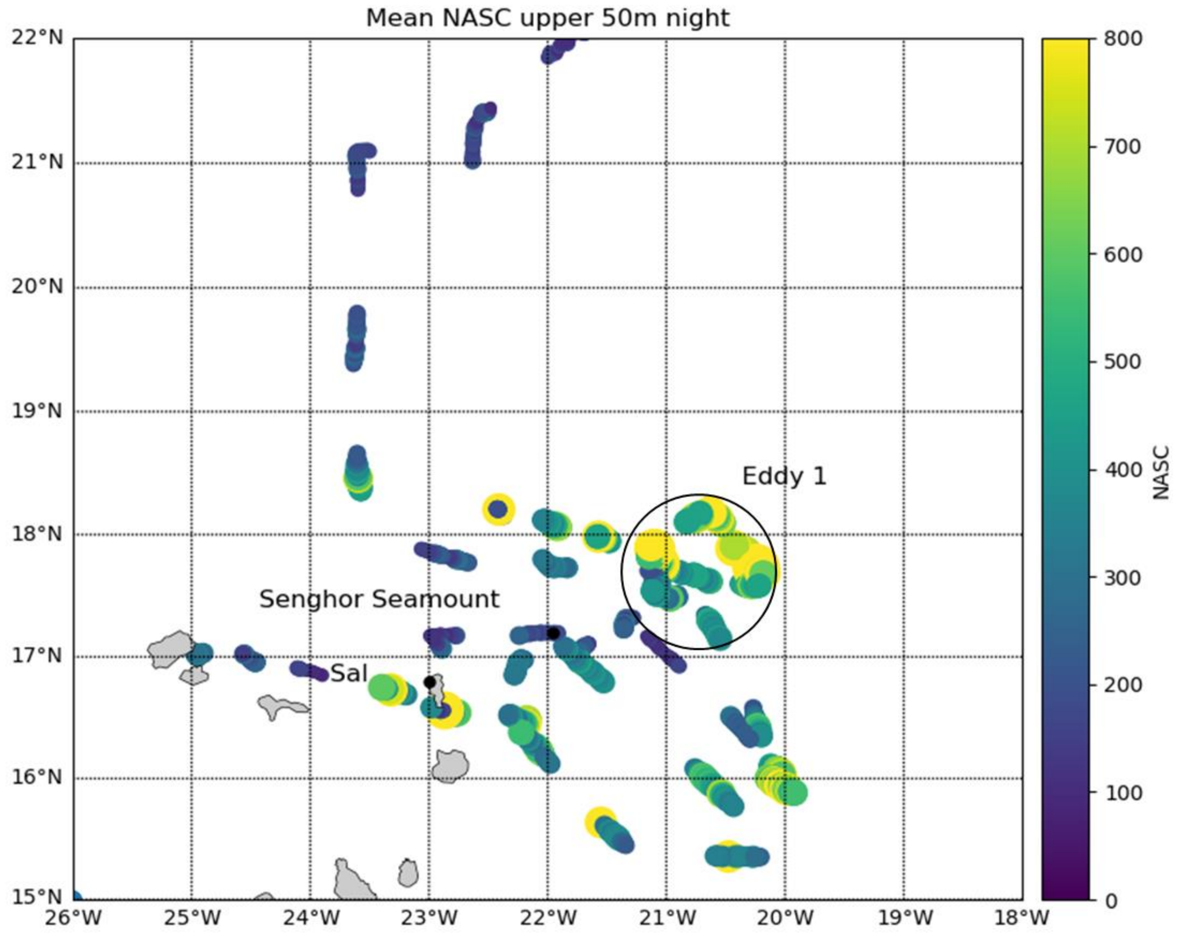


Figure 14- **Spatial distribution of mesopelagic organisms.** Mean NASC backscatter upper 50m at night time between '20:00:00' (8 Pm) and '04:00:00' (4 Am) distance to the core of the Eddy1 <500 km from Saildrone Ek80 38khz. The circle denotes the approximate location of Eddy1 (radius = 75 km).

5 Discussion

Distribution of mesopelagic organisms in the Eastern Tropical North Atlantic around the Cabo Verde archipelago

Results showed an ubiquitous occurrence of mesopelagic organisms in different depth layers throughout the survey area. However, differences in densities (and presumably abundance) were identified in different regions of the survey area. However, the further North-West, the lower the abundance of mesopelagic organisms was becoming. In fact, specifically, the Eddy1 area indicated a higher backscattering followed by Sal island. In contrast, Senghor Seamount and its surrounding areas indicated a low backscattering (Fig.14). These results were similarly reported by Denda et al. (2014) who found already that in the subtropical and tropical North-Eastern Atlantic, the biomass of zooplankton increased from the South-West to the North-East enhancing with the highest concentrations in the subsurface layer of the chlorophyll. In both studies, it is clear that productivity was decreasing towards the open ocean. Chlorophyll and current velocity were indicators of the distribution of mesopelagic organisms in ETNA. From the result in figure 7, it can be seen that current velocity and chlorophyll concentration seemed to be linked so that in areas where the current was weak there was a higher concentration of chlorophyll such as the eddy1 area and in the proximity of Sal island. As mesopelagic organisms were well adapted to the open ocean desert, island proximity did not have a large impact, since the abundance of potential predators was also higher there. However, factors like ocean currents bring food over the island they could produce localized upwelling of water in the island proximity then, nutrients essential for organism growth occur and organisms can feed for miles.

Backscatter of mesopelagic organisms inside and outside of eddies was in fact observed and showed a similar productive pattern (Fig. 10). This similarity in terms of backscattering may be due to the larger of the eddy than expected by the measurements. These findings corroborated with Schutte et al. (2016) work when they identified productive eddies in the region based on satellite altimetry temperature signature, chlorophyll and salinity. In their characteristics, they were passing eddies moving westward and were two types, the anticyclonic mode water eddies (ACME) which were clockwise and cyclonic eddies counterclockwise. Their importance was to create a kind of oasis in the region where local upwelling provided nutrients that contributed to enhancing productivity. These eddies might be one of the reasons for the high productivity in an otherwise oligotrophic area. Previous studies suggested that eddies enhance the upwelling of nutrients toward the euphotic zone via eddy pumping theory and induce strong biological productivity of the oligotrophic regions of the oceans (McGillicuddy Jr. et al., 1998, 2007; Oschlies and Garcon, 1998; Levy et al., 2001).

Cardoso et al. (2020) explained that eddies generation in Cabo Verde might have links with current activities which were controlled by climatic factors, especially seasonal winds. There were winds that operated in relation to seasonal variability. In this context, Cabo Verde was affected by different current interactions. The Canary Current carried cold water from the north to the south of the west coast of Africa. From Cape Blanc, the Canary Curren turned into the North Equatorial Current (Mittelstaedt, 1983, 1991; Stramma et al.,2005). The North Equatorial Current strengthened in summer and reached the peak, then weakened in winter (Arnault, 1987; Mittelstaedt, 1991) and was pushed back by the NECC. This one strengthened in summer when ITCZ dominated the southern position (Lázaro et al., 2005). During this period the NECC influenced the Cabo Verde (Fernandes et al., 2005) favoring the meeting of the different surrounding water masses which formed a large frontal zone This frontal area became a favorable bio productivity zone for the aggregation of migratory pelagic organisms.

Seamounts and islands impact on mesopelagic distribution of organisms around Cabo Verde.

Results showed that Senghor Seamount had low concentrations of biomass (Fig.14). Chlorophyll-a concentration in Sal was high but very low in Senghor Seamount (Fig.7). These results corroborated with the findings of Annasawmy et al. (2019) and Haury et al. (2000), supporting that in the Pacific, there were time-series gaps of biomass abundance in the seamounts, and they suggested that for the Senghor Seamount, the reason might be due to its location in the Equatorward area. The Equatorward zone was a critical latitude zone for seamount as an energetic eddy corridor. This case can also be explained by the data collection period (October, November and December), which corresponded to summer and autumn (from July through December), the time that NECC and ITCZ were moving northernmost. It was in that period that the NECC extended over almost the entire Tropical Atlantic influencing the Cabo Verde area and causing the suppression of the upwelling (Mittelstaedt, 1991; Cardoso et al., 2020). This northward shift of the NECC and ITCZ could be one of the reasons for the rise in mean temperatures as shown in Table 5.

Differences in diel vertical migration inside and outside eddies and on the top of Senghor Seamount and close to the island of Sal

. In this section, there were strong indications of light triggering the DVM observed in figure 9. Similarly, Bagøien et al. (2001) found that species migrated deep down the water column during the day following the intensity of the light, then ascended toward the surface at night. Staby et al. (2011) hypothesised that the behaviour of changing position in-depth at day and night by species was for them to adjust and maintain the intensity of light for the adaptation. However, the DVM ensured exchanges between the surface and the deep ocean. The DVM determined the characteristics and the distribution of mesopelagic DSLs. The variations in DSLs shown in the results (Fig.10) corroborated with a regional scale study by Ariza et al. (2016) in the Canary Islands. They identified that the mesopelagic zone was subdivided into four acoustic scattering layers of migrant and non-migrant organisms. At a depth of 400-500 m, they identified a layer of gas-bearing migrants with swimbladders. At 500-600 m depth, they found a denser layer of migrant and non-migrant species. Between 600-800 m, a weak migrant layer followed a non-migrant layer below 800 m. Therefore at the global level, the mesopelagic zone, according to Proud et al. (2017), comprises two DSL zones. The denser DSL at around 525 m was considered the principal one, and the secondary DSL at about 825 m. The interactions between the surface and the deep ocean were the patterns of the DVM during which organisms feed between dusk and dawn at the surface. The DVM as behaviour enhanced the thickness of the DSLs and developed the trophic interaction between the shallow and deep ocean. In both cases, the regional and global mesopelagic zone was characterized by migrant and non-migrant organisms and is controlled by DVM.

The result in figure 10 showed the patern of deep scattering layers of outside and inside of the eddy1 and the behavior of diel vertical migration. The patern was upward and downward of organisns. Previous studies found that the migration pattern of mesopelagic organisms was first an upward migration by organisms at night for feeding (Hays, 2003). The difference between outside and inside the eddy depicted in figure 11 showded a little higher backscatter inside near the surface to night. The reaison for that might be proximity. So, far from the core the lower, the mesopelagic abondance was becoming. These results were consistent with the results presented by Penna (2020) suggesting that the centers of eddies were areas of intense mesopelagic acoustic backscattering. People thought of the migration pattern to be a stationary phase of organisms at the surface as a pause period for prey (O’Brien et al., 1990). To others, it was the downward movement from which organisms sink in-depth to hide from predators (D’Elia et al., 2016). Some also thought about a stationary phase at daytime depth for nonvisual or mechanosensory for prey detection (Ryer & Olla, 1999). Therefore, the results from figure

9 nicely showed that the daytime depth is dynamic, for that organisms adjust their position during the daytime hours, likely as a reaction to a specific intensity of light level that they could detect.

When focusing on Eddy1, Senghor Seamount and Sal island areas, looking at the backscattering in the first 200 m of the water column in figures 11,12 and 13 as determined by hydroacoustic, it could be seen that there was an unequal distribution of backscattering. It can also be noted that the backscattering was higher during the night record at the surface and lower in the daytime record. This pattern that could be seen at Eddy1, Senghor seamount and Sal island was diel vertical migration. The reason for that was the deep scattering layers in these regions. It was also noted that Sal island and its proximity had high backscattering than Eddy1 and Senghor Seamount. At Senghor Seamount this difference might be due to the seamount effect on the DVM behaviour of Deep scattering layers. It could be related to the topography of the seamount that blocked the movement of migrating organisms where they can suffer from predation. For that reason, they avoided seamount summit (Pusch et al., 2004; Cascão et al., 2010). In the eddy1 area, the difference could be caused by turbidity during eddy diffusion. The strong diffusion of eddy tonight might affect actively the migration of organisms and switch to a negative geotaxis reaction of these organisms that possibly kept them stationary at the surface for food (Butman, 1987; Richards et al.,1996). The highest backscattering observed closer to Sal island (Fig.13) might be due to the feature of the area such as slopes of hills, where scattering layers can search great depths. Reid et al., (1991) and Benoit-Bird, (2004) found differences in mesopelagic organisms distribution in the Hawaiian Islands proximity. Where slopes of the island meet the oceanic mesopelagic zone, the scattering layers migrated deeper around 700 m during the day then came shallow at 10 m tonight along with the band of the island. These deep scattering layers were seen between 350 m and 500 m as depicted in figure 10. These layers migrated upwards in the night between photic and twilight zones. However, at Sal (Fig.13) the backscattering seemed to be relatively higher than the Senghor Seamount area within 300 to 400 m. This difference could probably be related to environmental factors that affected the backscattering distribution in deep layers. Light would be the key factor for the vertical migration of the deep scattering layers. The difference in the eddy area and other regions might be due to the turbidity condition generated from current flows influencing the light regime.

In comparison with other part in world, Annaswamy et al.(2019) conducted a study in the south-western Indian Ocean at La Pérouse and MAD-Ridge Seamounts, using acoustic data. Their findings indicated that seamounts influence the DVM, vertical distribution and community composition of micronekton and seamount associated species. Likewise in Cabo Verde it was also located in an oligotrophic zone of the Indian Ocean but associated to an eddy corridor area crossed by many mesoscale eddies, Coming from South East of Madagascar Current (Pollard and Read, 2015; Vianello et al., 2020) these eddies generated favourable conditions for upwelling affecting the DVM and aggregation of mesopelagic organisms.

6. Conclusions and Recommendations

6.1 Conclusion

The results showed that mesopelagic organisms were distributed from South-East to North-West along the track; however, as moving northwestward, the lower the backscattering of mesopelagic organisms was becoming.

The analysis of the eddy area showed that there was difference in deep scattering layers and DVM between inside and outside the eddy.

Abiotic factors such as light, current velocity and chlorophyll were mean drivers of mesopelagic organisms' distribution.

The light was the key condition of diel vertical movement of species through which they adjust their diurnal position, probably in response to a specific light level they can detect.

Further findings of spatial distribution analysis showed that the mean NASC was larger in the eddies at night between '20:00:00' (8 Pm) and '04:00:00' (4 Am) than Sal Senghor Seamount. Then makes the eddy regions high productivity areas.

In terms of backscattering, Sal island seemed to have a relatively higher concentration than the Senghor Seamount and eddy area.

There is no significant difference in patterns between inside and outside the eddies.

Besides Cabo Verde is located in the oligotrophic zone of the Eastern North Tropical Atlantic, results showed a high distribution of mesopelagic organisms which might have a relation with eddies and island proximity.

6.2 Recommendations

This study explored many important features of eddies' activity islands and seamounts in Cabo Verde, integrating environmental aspects, deep scattering layers, DVM and spatial distribution of mesopelagic organisms.

To better understand the implications of these results, future studies should be continued and extended in other parts of the country via the use of saildrone.

As the Cabo Verde region had the highest biomass of mesopelagic micronekton in the tropical and subtropical, the use of saildrone might be a suitable tool for data collection in association with other methods such as net sampling or cameras.

This study could be of benefit to other islands and areas that have similar environmental conditions. It could be used also by decision-makers to develop their policies for the implementation of socio-economic sustainable strategies such as fishery development.

7. References

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Appendix

Scripts

```
#All data are read, formatted and transferred to sql
#####read in EK80 Echoview report (.csv) data and write to SQL database######
from pathlib import Path
import pandas as pd
import datetime as dt
from sqlalchemy import create_engine
import math
import xarray as xr
from pyproj import Geod

###

engine = create_engine('postgresql://postgres:1234@localhost:5432/local_use')# change the postgres:1234 part to your own user/password, e.g. postgres:password

wgs84_geod = Geod(ellps='WGS84') #Distance will be measured on this ellipsoid - more accurate than a spherical method

#Get distance between pairs of lat-lon points
def Distance(lat1,lon1,lat2,lon2):
az12,az21,dist = wgs84_geod.inv(lon1,lat1,lon2,lat2) #Yes, this order is correct return dist

##############################

######load environmental data

 = xr.open_dataset('D:/Master_Data/saildrone/sensor_data/saildrone-gen_5-atlantic_to_med_2019_to_2020-sd1053-20191018T110000-20200717T134559-1_minutes-v1.1595634214633.nc')
print(list(ds.keys()))

#create simpler dataset and retain only relevant variables (can be changed) and rename them

ds = ds.drop(list(filter(lambda dv: dv not in ["TEMP_SBE37_MEAN", "SAL_SBE37_MEAN", "O2_CONC_SBE37_MEAN", "CHLOR_WETLABS_MEAN", "PAR_AIR_MEAN" ], ds.data_vars.keys())))
ds = ds.rename({"TEMP_SBE37_MEAN": "temperature"})# to rename the selected column temperature

ds = ds.rename({"SAL_SBE37_MEAN": "salinity"}) # to rename the selected column salinity
ds = ds.rename({"O2_CONC_SBE37_MEAN": "oxygen"})# to rename the selected column oxygen
ds = ds.rename({"CHLOR_WETLABS_MEAN": "chla"}) # to rename the selected column chla
ds = ds.rename({"PAR_AIR_MEAN": "par"})# to rename the selected column par
ds.attrs = {} # to attribute the name
#array to dataframe
df = ds.to_dataframe()# to drop the element without affecting the other rows.
df = df[~df['longitude'].isnull()]## to detect the missing value in longitude
df['solar_time'] = df['time'] + (df['longitude']/15/24).map(dt.timedelta)# to convert the time to days, hours, minutes.

#write into SQL table

df.to_sql('sd1053_env', engine, if_exists='replace') ##change to append/replace !!!!!
quit()

######load EK80 data 38hHz
```

```
#dateparse = lambda x: dt.strptime(x, '%Y-%m-%d %H:%M:%S')
##path to 38hz data
files = Path("D:/Master_Data/saildrone/EK80/15Min5M_Resolution/38kHz/").rglob("*.csv")

##read in all the csv files and parse the date and time column to datetime format
all_csvs = [pd.read_csv(file, parse_dates={'datetime_utc':['Date_M', 'Time_M']}) for file in files]
##lump into one table
df_38khz = pd.concat(all_csvs)
#Create eddy positions (could also be dynamic over time)

df_38khz['lat_eddy1'] = 17.73 # coordinate latitude for the location of the eddy1
df_38khz['lon_eddy1'] = -20.43 # coordinate longitude for the location of the eddy1
df_38khz['distance_to_eddy1']# to print the name of the
areaDistance(df_38khz['Lat_M'].tolist(),df_38khz['Lon_M'].tolist(),df_38khz['lat_eddy1'].tolist(),df_38khz['lon_
eddy1'].tolist())# to convert the longitude of eddy1 into a list.
df_38khz['distance_to_eddy1'] = df_38khz['distance_to_eddy1']/1000 # dataframe for the position of edy1
df_38khz['lat_eddy2'] = 14.5 # latitude for the position of eddy2
df_38khz['lon_eddy2'] = -25.03 # longitude for the position of eddy2
df_38khz['distance_to_eddy2']# for the distance to eddy2 location
Distance(df_38khz['Lat_M'].tolist(),df_38khz['Lon_M'].tolist(),df_38khz['lat_eddy2'].tolist(),df_38khz['lon_edd
y2'].tolist())# to convert the longitude into distance to create eddy2 position
df_38khz['distance_to_eddy2'] = df_38khz['distance_to_eddy2']/1000# for the position of eddy2
df_38khz['lat_senghor'] = 17.205 # coordinate latitude for the location of the Senghor
df_38khz['lon_senghor'] = -21.962 # coordinate longitude for the location of the Senghor
df_38khz['distance_to_senghor']# for the name of the area Senghor.
Distance(df_38khz['Lat_M'].tolist(),df_38khz['Lon_M'].tolist(),df_38khz['lat_senghor'].tolist(),df_38khz['lon_se
nghor'].tolist())# to convert the longitude into distance to create senghor positon
df_38khz['distance_to_senghor'] = df_38khz['distance_to_senghor']/1000
df_38khz['lat_sal'] = 16.6
df_38khz['lon_sal'] = -22.9
df_38khz['distance_to_sal'] =
Distance(df_38khz['Lat_M'].tolist(),df_38khz['Lon_M'].tolist(),df_38khz['lat_sal'].tolist(),df_38khz['lon_sal'].tol
ist())
df_38khz['distance_to_sal'] = df_38khz['distance_to_sal']/1000 #
#select columns you want to keep
df_38khz = df_38khz[["Layer", "Sv_mean","NASC",
"Layer_depth_min","Layer_depth_max","datetime_utc","Lat_M","Lon_M", "distance_to_eddy1",
"distance_to_eddy2", "distance_to_senghor", "distance_to_sal"]]
#rename to easier column names
df_38khz.columns = ['layer', 'sv_mean', 'nasc', 'layer_depth_min', 'layer_depth_max','datetime_utc','lat','lon',
'distance_to_eddy1', 'distance_to_eddy2', 'distance_to_senghor', 'distance_to_sal']

#add a mid depth bin column
df_38khz['layer_depth_mid'] = (df_38khz['layer_depth_min']+ df_38khz['layer_depth_max'])/2
#calculate local solar time for migration classification
df_38khz['solar_time'] = df_38khz['datetime_utc']+(df_38khz['lon']/15/24).map(dt.timedelta)
print(df_38khz)
print(df_38khz.dtypes)

#write into SQL table
df_38khz.to_sql('saildrone_ek80_38khz', engine, if_exists='replace') ##change to append/replace !!!!!
##path to 200kHz data
files = Path("D:/Master_Data/saildrone/EK80/15Min5M_Resolution/200kHz/").rglob("*.csv") # to add directory
##read in all the csv files and parse the date and time column to datetime format
all_csvs = [pd.read_csv(file, parse_dates={'datetime_utc':['Date_M', 'Time_M']}) for file in files]
##lump into one table
df_200khz = pd.concat(all_csvs)
#Create eddy positions (could also be dynamic over time)
df_200khz['lat_eddy1'] = 17.73 # to set the latitude of eddy1 from the transducer 200 khz
```

```
df_200khz['lon_eddy1'] = -20.43 # to set the longitude of  eddy1
df_200khz['distance_to_eddy1']# to set the distance of eddy1 from 200 khz
Distance(df_200khz['Lat_M'].tolist(),df_200khz['Lon_M'].tolist(),df_200khz['lat_eddy1'].tolist(),df_200khz['lon
_eddy1'].tolist()) # to calculate distance between latitude and longitude of eddy1 and convert into a list
df_200khz['distance_to_eddy1'] = df_200khz['distance_to_eddy1']/1000
df_200khz['lat_eddy2'] = 14.5 # to get latitude of eddy2
df_200khz['lon_eddy2'] = -25.03# to get longitude of eddy2
df_200khz['distance_to_eddy2'] =
Distance(df_200khz['Lat_M'].tolist(),df_200khz['Lon_M'].tolist(),df_200khz['lat_eddy2'].tolist(),df_200khz['lon
_eddy2'].tolist()) # to get distance between coordinates of  eddy2 and convert into a list
df_200khz['distance_to_eddy2'] = df_200khz['distance_to_eddy2']/1000
df_200khz['lat_senghor'] = 17.205
df_200khz['lon_senghor'] = -21.962
df_200khz['distance_to_senghor']=
Distance(df_200khz['Lat_M'].tolist(),df_200khz['Lon_M'].tolist(),df_200khz['lat_senghor'].tolist(),df_200khz['lo
n_senghor'].tolist())# to get distance between coordinates of  Senghor Seamount and convert into a list
df_200khz['distance_to_senghor'] = df_200khz['distance_to_senghor']/1000
df_200khz['lat_sal'] = 16.6
df_200khz['lon_sal'] = -22.9
df_200khz['distance_to_sal'] =
Distance(df_200khz['Lat_M'].tolist(),df_200khz['Lon_M'].tolist(),df_200khz['lat_sal'].tolist(),df_200khz['lon_sal
'].tolist())
df_200khz['distance_to_sal'] = df_200khz['distance_to_sal']/1000
#select columns you want to keep
df_200khz = df_200khz[["Layer", "Sv_mean","NASC",
"Layer_depth_min","Layer_depth_max","datetime_utc","Lat_M","Lon_M", "distance_to_eddy1",
"distance_to_eddy2", "distance_to_senghor", "distance_to_sal"]]
#rename to easier column names
df_200khz.columns = ['layer', 'sv_mean', 'nasc', 'layer_depth_min', 'layer_depth_max','datetime_utc','lat','lon',
'distance_to_eddy1', 'distance_to_eddy2', 'distance_to_senghor', 'distance_to_sal']
#add a mid depth bin column
df_200khz['layer_depth_mid'] = (df_200khz['layer_depth_min']+ df_200khz['layer_depth_max'])/2
#calculate local solar time for migration classification
df_200khz['solar_time'] = df_200khz['datetime_utc']+(df_200khz['lon']/15/24).map(dt.timedelta)
print(df_200khz)
print(df_200khz.dtypes)
#write into SQL table
df_200khz.to_sql('saildrone_ek80_200khz', engine, if_exists='replace') ##change to append/replace !!!!!
quit()
```

```
##plot tracks from both saildrones in the Cabo Verde region and indicate location of ##eddy, Sal and Senghor

import
os os.environ['PROJ_LIB']=r'C:\\Users\\username\\AppData\\Local\\Continuum\\anaconda2\\pkgs\\proj4-4.9.2-
vc10_0\\Library\\shar'
import psycopg2 as pgsql
import pandas.io.sql as sql

import numpy as np
import matplotlib.pyplot as plt
from mpl_toolkits.basemap import Basemap

##connect database
mydb = pgsql.connect(database="local_use", user="postgres", password="1234")
##define region boundaries
latmin = 13
latmax = 22
lonmin = -28
lonmax = -18
```

```
##load position data from both saildrones from SQL
sd1030 = sql.read_sql("""SELECT DISTINCT time, latitude as lat, longitude as lon
                        FROM sd1030_env
                        ORDER BY time
                        """, mydb)
sd1053 = sql.read_sql("""SELECT DISTINCT time, latitude as lat, longitude as lon
                        FROM sd1053_env
                        ORDER BY time
                        """, mydb)
##set up figure
fig, ax =plt.subplots()
m = Basemap(projection='merc', lat_0 = 12, lon_0 = -20,
            resolution = 'i', llcrnrlon = lonmin,  urcrnrlon = lonmax, llcrnrlat = latmin, urcrnrlat = latmax)
sd1030_lons = sd1030.lon.values  # needs .values here
sd1030_lats = sd1030.lat.values   # same as above
sd1030_x, sd1030_y = m(sd1030_lons, sd1030_lats) #transform position data
sd1053_lons = sd1053.lon.values  # needs .values here
sd1053_lats = sd1053.lat.values   # same as above
sd1053_x, sd1053_y = m(sd1053_lons, sd1053_lats) #transform position data
m.plot(sd1030_x,sd1030_y, c='green')# to show the figure in green
m.plot(sd1053_x,sd1053_y, c='blue')# to show the figure in blue
plt.title("tracks", color="black", fontsize = 12)
m.drawcoastlines(linewidth=1, zorder=1);
m.fillcontinents(zorder=2);
m.drawmeridians(np.arange(-30,20, 1), labels=[0,0,0,1], fontsize=10)
m.drawparallels(np.arange(0, 50, 1), labels=[1,0,0,0], fontsize=10)
#Eddy circle
x,y=m(-20.43,17.73) ## centre of Eddy1
x2,y2=m(-20.43, 17.73+0.675) ## same as 75 km radius
circle1=plt.Circle((x,y), y2-y, color='red', fill=False)
ax.add_patch(circle1)
#label Eddy, Sal and Senghor
plt.text(x2, y2, 'Eddy 1',c='red', fontsize=12);
x, y = m(-23, 16.8)
x1, y1 = m(-23.9, 16.8)
plt.plot(x, y, 'ok', c='red', markersize=5)
plt.text(x1, y1, ' Sal', c='red',fontsize=12);
x, y = m(-21.962, 17.205)
x1, y1 = m(-24.5, 17.4)
plt.plot(x, y, 'ok', c='red', markersize=5)
plt.text(x1, y1, ' Senghor',c='red', fontsize=12);
plt.show()

#################################################################################

#Environmental characterization
import os
os.environ['PROJ_LIB']=r'C:\\Users\\username\\AppData\\Local\\Continuum\\anaconda2\\pkgs\\proj4-4.9.2-
vc10_0\\Library\\shar'
import netCDF4
import numpy as np
import pandas as pd
import matplotlib.pyplot as plt
import datetime
from mpl_toolkits.basemap import Basemap
ncfile='E:/Master_Data/saildrone/sensor_data/saildrone-gen_5-atlantic_to_med_2019_to_2020-sd1030-
20191018T101200-20200717T134559-1_minutes-v1.1595626086288.nc'
sd = netCDF4.Dataset(ncfile, mode='r')
#read variables
lons = sd.variables['longitude'][:]
```

```
lats = sd.variables['latitude'][:]
chl = sd.variables['CHLOR_WETLABS_MEAN'][:]
temp = sd.variables['TEMP_SBE37_MEAN'][:]
#print(temp)
#maximum = max(temp)
#print(maximum)
#minimum=min(temp)
#print(minimum)
#max(temp)
sal = sd.variables['SAL_SBE37_MEAN'][:]
par = sd.variables['PAR_AIR_MEAN'][:]
time_var = sd.variables['time']
datetime = netCDF4.num2date(time_var[:],time_var.units, only_use_cftime_datetimes=False)
#datetime = datetime.to_datetime()
#datetime  = pd.Timestamp(datetime)
chl.min()
chl.max()
chl.mean()
#define boundaries of plotted maps
#cape verde
#latmin = 13
#latmax = 25
#lonmin = -28
#lonmax = -18
#whole mission
#latmin = 13
#latmax = 45
#lonmin = -28
#lonmax = 20
#whole mission
latmin = 13
latmax = 22
lonmin = -28
lonmax = -18
#plot four-panel figure
fig = plt.figure(1, figsize=(12, 12)) # to show figure size
ax1 = fig.add_subplot(2,2,1)# to show axis position in the plot
plt.subplots_adjust(left=0.1, bottom=0.1, wspace=0, hspace=None)
m = Basemap(projection='merc', lat_0 = 12, lon_0 = -20,
            resolution = 'i', llcrnrlon = lonmin,  urcrnrlon = lonmax, llcrnrlat = latmin, urcrnrlat = latmax)
x1,y1=m(lons,lats)
m.scatter(x1,y1,s=50, c=chl,marker=".", vmin=0,vmax=0.5) # to mark the variable chlorophyll
cb = m.colorbar() # to show the colorbar
cb.set_label('Chl-a ($mg\ m^{-3}$)')
plt.title("Chlorophyll-a", x=0.3, y=0.9, color="black", fontsize = 12) # to plot the title
m.drawcoastlines(linewidth=1, zorder=1);3 to grow the coast lines
m.fillcontinents(zorder=2); # to show the continent
m.drawmeridians(np.arange(-30,10, 5), labels=[0,0,0,1], fontsize=10)
m.drawparallels(np.arange(0, 50, 5), labels=[1,0,0,0], fontsize=10)
ax2 = fig.add_subplot(2,2,2)
plt.subplots_adjust(left=0.1, bottom=0.1, wspace=0, hspace=None)
m = Basemap(projection='merc', lat_0 = 12, lon_0 = -20,
            resolution = 'i', llcrnrlon = lonmin,  urcrnrlon = lonmax, llcrnrlat = latmin, urcrnrlat = latmax)
x1,y1=m(lons,lats)
m.scatter(x1,y1,s=50, c=sal,marker=".", vmin=35,vmax=37)
cb = m.colorbar()
cb.set_label('Salinity (PSU)')
plt.title("Salinity", x=0.3, y=0.9, color="black", fontsize = 12)
m.drawcoastlines(linewidth=1, zorder=1);
m.fillcontinents(zorder=2);
```

```
m.drawmeridians(np.arange(-30,10, 5), labels=[0,0,0,1], fontsize=10)
m.drawparallels(np.arange(0, 50, 5), labels=[1,0,0,0], fontsize=10)
ax3 = fig.add_subplot(2,2,3)
plt.subplots_adjust(left=0.1, bottom=0.1, wspace=0, hspace=None)
m = Basemap(projection='merc', lat_0 = 12, lon_0 = -20,
            resolution = 'i', llcrnrlon = lonmin,  urcrnrlon = lonmax, llcrnrlat = latmin, urcrnrlat = latmax)
x1,y1=m(lons,lats)
m.scatter(x1,y1,s=50, c=temp,marker=".", cmap='coolwarm', vmin=15,vmax=28)
cb = m.colorbar()
cb.set_label('Temperature')
plt.title("Temperature", x=0.3, y=0.9, color="black", fontsize = 12)
m.drawcoastlines(linewidth=1, zorder=1);
m.fillcontinents(zorder=2);
m.drawmeridians(np.arange(-30,10, 5), labels=[0,0,0,1], fontsize=10)
m.drawparallels(np.arange(0, 50, 5), labels=[1,0,0,0], fontsize=10)
ax4 = fig.add_subplot(2,2,4)
plt.subplots_adjust(left=0.1, bottom=0.1, wspace=0, hspace=None)

m = Basemap(projection='merc', lat_0 = 12, lon_0 = -20,
            resolution = 'i', llcrnrlon = lonmin,  urcrnrlon = lonmax, llcrnrlat = latmin, urcrnrlat = latmax)
x1,y1=m(lons,lats)
m.scatter(x1,y1,s=50, c=par,marker=".", cmap='binary',vmin=500,vmax=3000)
cb = m.colorbar()
cb.set_label('PAR')
plt.title("PAR", x=0.3, y=0.9, color="black", fontsize = 12)
m.drawcoastlines(linewidth=1, zorder=1);
m.fillcontinents(zorder=2);
m.drawmeridians(np.arange(-30,10, 5), labels=[0,0,0,1], fontsize=10)
m.drawparallels(np.arange(0, 50, 5), labels=[1,0,0,0], fontsize=10)
plt.tight_layout()
plt.show()
#Light
fig = plt.figure(5, figsize=(12, 12))
ax4 = fig.add_subplot(1,1,1)
plt.subplots_adjust(left=0.1, bottom=0.1, wspace=0, hspace=None)
m = Basemap(projection='merc', lat_0 = 12, lon_0 = -20,
            resolution = 'i', llcrnrlon = lonmin,  urcrnrlon = lonmax, llcrnrlat = latmin, urcrnrlat = latmax)
x1,y1=m(lons,lats)
m.scatter(x1,y1,s=50, c=par,marker=".", cmap='Reds',vmin=500,vmax=3000)
#m.scatter(x1,y1,s=50, c=par,marker=".", cmap='binary',vmin=500,vmax=3000)
cb = m.colorbar()
cb.set_label('PAR')
plt.title("PAR", x=0.3, y=0.9, color="black", fontsize = 12)
m.drawcoastlines(linewidth=1, zorder=1);
m.fillcontinents(zorder=2);
m.drawmeridians(np.arange(-30,10, 5), labels=[0,0,0,1], fontsize=10)
m.drawparallels(np.arange(0, 50, 5), labels=[1,0,0,0], fontsize=10)
#Eddy circle
x,y=m(-20.43,17.73) ## centre of Eddy1
x2,y2=m(-20.43, 17.73+0.675) ## same as 75 km radius
circle1=plt.Circle((x,y), y2-y, color='black', fill=False)
ax4.add_patch(circle1)
plt.text(x2, y2, ' Eddy 1',c='black', fontsize=12);
# Label
x, y = m(-23, 16.8) # Sal
x1, y1 = m(-23.9, 16.8) # S
plt.plot(x, y, 'ok', c='black', markersize=5)
plt.text(x1, y1, ' Sal', c='black',fontsize=12);
#x1, y1 = m(-24, 17) # S
#plt.plot(x, y, 'ok', markersize=5)
```

```
#plt.text(x1, y1, ' Sal', fontsize=12);
x, y = m(-21.962, 17.205) # Sengho sea mount
x1, y1 = m(-24.5, 17.4) # S
plt.plot(x, y, 'ok', c='black', markersize=5)
plt.text(x1, y1, ' Senghor Seamount',c='black', fontsize=12);
plt.tight_layout()
plt.show()
#Salinity
fig = plt.figure(6, figsize=(12, 12))
ax2 = fig.add_subplot(1,1,1)
plt.subplots_adjust(left=0.1, bottom=0.1, wspace=0, hspace=None)
m = Basemap(projection='merc', lat_0 = 12, lon_0 = -20,
        resolution = 'i', llcrnrlon = lonmin,  urcrnrlon = lonmax, llcrnrlat = latmin, urcrnrlat = latmax)
x1,y1=m(lons,lats)
m.scatter(x1,y1,s=50, c=sal,marker=".", vmin=35,vmax=37)
cb = m.colorbar()
cb.set_label('Salinity (PSU)')
plt.title("Salinity", x=0.3, y=0.9, color="black", fontsize = 12)
m.drawcoastlines(linewidth=1, zorder=1);
m.fillcontinents(zorder=2);
m.drawmeridians(np.arange(-30,10, 5), labels=[0,0,0,1], fontsize=10)
m.drawparallels(np.arange(0, 50, 5), labels=[1,0,0,0], fontsize=10)
#Eddy circle
x,y=m(-20.43,17.73) ## centre of Eddy1
x2,y2=m(-20.43, 17.73+0.675) ## same as 75 km radius
circle1=plt.Circle((x,y), y2-y, color='black', fill=False)
ax2.add_patch(circle1)
plt.text(x2, y2, ' Eddy 1',c='black', fontsize=12);
# Label
x, y = m(-23, 16.8) # Sal
x1, y1 = m(-23.9, 16.8) # S
plt.plot(x, y, 'ok', c='black', markersize=5)
plt.text(x1, y1, ' Sal', c='black',fontsize=12);
#x1, y1 = m(-24, 17) # S
#plt.plot(x, y, 'ok', markersize=5)
#plt.text(x1, y1, ' Sal', fontsize=12);
x, y = m(-21.962, 17.205) # Sengho sea mount
x1, y1 = m(-24.5, 17.4) # S
plt.plot(x, y, 'ok', c='black', markersize=5)
plt.text(x1, y1, ' Senghor Seamount',c='black', fontsize=12);
plt.tight_layout()
plt.show()
#Temperature
fig = plt.figure(7, figsize=(12, 12))
ax3 = fig.add_subplot(1,1,1)
plt.subplots_adjust(left=0.1, bottom=0.1, wspace=0, hspace=None)
m = Basemap(projection='merc', lat_0 = 12, lon_0 = -20,
        resolution = 'i', llcrnrlon = lonmin,  urcrnrlon = lonmax, llcrnrlat = latmin, urcrnrlat = latmax)
x1,y1=m(lons,lats)
m.scatter(x1,y1,s=50, c=temp,marker=".", cmap='coolwarm', vmin=13,vmax=29.5)
cb = m.colorbar()
cb.set_label('Temperature')
plt.title("Temperature", x=0.3, y=0.9, color="black", fontsize = 12)
m.drawcoastlines(linewidth=1, zorder=1);
m.fillcontinents(zorder=2);
m.drawmeridians(np.arange(-30,10, 5), labels=[0,0,0,1], fontsize=10)
m.drawparallels(np.arange(0, 50, 5), labels=[1,0,0,0], fontsize=10)
#Eddy circle
x,y=m(-20.43,17.73) ## centre of Eddy1
x2,y2=m(-20.43, 17.73+0.675) ## same as 75 km radius
```

```
circle1=plt.Circle((x,y), y2-y, color='black', fill=False) # the circle as eddy
ax3.add_patch(circle1)
plt.text(x2, y2, ' Eddy 1',c='black', fontsize=12);
# Label
x, y = m(-23, 16.8) # Sal
x1, y1 = m(-23.9, 16.8) # S
plt.plot(x, y, 'ok', c='black', markersize=5)
plt.text(x1, y1, ' Sal', c='black',fontsize=12);
#x1, y1 = m(-24, 17) # S
#plt.plot(x, y, 'ok', markersize=5)
#plt.text(x1, y1, ' Sal', fontsize=12);
x, y = m(-21.962, 17.205) # Sengho sea mount
x1, y1 = m(-24.5, 17.4) # S
plt.plot(x, y, 'ok', c='black', markersize=5)
plt.text(x1, y1, ' Senghor Seamount',c='black', fontsize=12); # to write the text of Senghor seamount
plt.tight_layout()
plt.show()
#Light
fig = plt.figure(5, figsize=(12, 12))
ax4 = fig.add_subplot(1,1,1)
plt.subplots_adjust(left=0.1, bottom=0.1, wspace=0, hspace=None)
m = Basemap(projection='merc', lat_0 = 12, lon_0 = -20,
            resolution = 'i', llcrnrlon = lonmin,  urcrnrlon = lonmax, llcrnrlat = latmin, urcrnrlat = latmax)
x1,y1=m(lons,lats)
m.scatter(x1,y1,s=50, c=par,marker=".", cmap='Reds',vmin=500,vmax=3000)
#m.scatter(x1,y1,s=50, c=par,marker=".", cmap='binary',vmin=500,vmax=3000)
cb = m.colorbar()
cb.set_label('PAR')
plt.title("PAR", x=0.3, y=0.9, color="black", fontsize = 12)
m.drawcoastlines(linewidth=1, zorder=1);
m.fillcontinents(zorder=2);
m.drawmeridians(np.arange(-30,10, 5), labels=[0,0,0,1], fontsize=10)
m.drawparallels(np.arange(0, 50, 5), labels=[1,0,0,0], fontsize=10)
#Eddy circle
x,y=m(-20.43,17.73) ## centre of Eddy1
x2,y2=m(-20.43, 17.73+0.675) ## same as 75 km radius
circle1=plt.Circle((x,y), y2-y, color='black', fill=False)
ax4.add_patch(circle1)
plt.text(x2, y2, ' Eddy 1',c='black', fontsize=12);
# Label
x, y = m(-23, 16.8) # Sal
x1, y1 = m(-23.9, 16.8) # S
plt.plot(x, y, 'ok', c='black', markersize=5)
plt.text(x1, y1, ' Sal', c='black',fontsize=12);
#x1, y1 = m(-24, 17) # S
#plt.plot(x, y, 'ok', markersize=5)
#plt.text(x1, y1, ' Sal', fontsize=12);
x, y = m(-21.962, 17.205) # Sengho sea mount
x1, y1 = m(-24.5, 17.4) # S
plt.plot(x, y, 'ok', c='black', markersize=5)
plt.text(x1, y1, ' Senghor Seamount',c='black', fontsize=12);

plt.tight_layout()
plt.show()
#Salinity
fig = plt.figure(6, figsize=(12, 12))
ax2 = fig.add_subplot(1,1,1)
plt.subplots_adjust(left=0.1, bottom=0.1, wspace=0, hspace=None)
m = Basemap(projection='merc', lat_0 = 12, lon_0 = -20,
            resolution = 'i', llcrnrlon = lonmin,  urcrnrlon = lonmax, llcrnrlat = latmin, urcrnrlat = latmax)
```

```
x1,y1=m(lons,lats)
m.scatter(x1,y1,s=50, c=sal,marker=".", vmin=35,vmax=37)
cb = m.colorbar()
cb.set_label('Salinity (PSU)')
plt.title("Salinity", x=0.3, y=0.9, color="black", fontsize = 12)
m.drawcoastlines(linewidth=1, zorder=1);
m.fillcontinents(zorder=2);
m.drawmeridians(np.arange(-30,10, 5), labels=[0,0,0,1], fontsize=10)
m.drawparallels(np.arange(0, 50, 5), labels=[1,0,0,0], fontsize=10)
#Eddy circle
x,y=m(-20.43,17.73) ## centre of Eddy1
x2,y2=m(-20.43, 17.73+0.675) ## same as 75 km radius
circle1=plt.Circle((x,y), y2-y, color='black', fill=False)
ax2.add_patch(circle1)
plt.text(x2, y2, ' Eddy 1',c='black', fontsize=12);
# Label
x, y = m(-23, 16.8) # Sal
x1, y1 = m(-23.9, 16.8) # S
plt.plot(x, y, 'ok', c='black', markersize=5)
plt.text(x1, y1, ' Sal', c='black',fontsize=12);
#x1, y1 = m(-24, 17) # S
#plt.plot(x, y, 'ok', markersize=5)
#plt.text(x1, y1, ' Sal', fontsize=12);
x, y = m(-21.962, 17.205) # Sengho sea mount
x1, y1 = m(-24.5, 17.4) # S
plt.plot(x, y, 'ok', c='black', markersize=5)
plt.text(x1, y1, ' Senghor Seamount',c='black', fontsize=12);

plt.tight_layout()
plt.show()
#Temperature
fig = plt.figure(7, figsize=(12, 12))
ax3 = fig.add_subplot(1,1,1)
plt.subplots_adjust(left=0.1, bottom=0.1, wspace=0, hspace=None)
m = Basemap(projection='merc', lat_0 = 12, lon_0 = -20,
            resolution = 'i', llcrnrlon = lonmin,  urcrnrlon = lonmax, llcrnrlat = latmin, urcrnrlat = latmax)
x1,y1=m(lons,lats)
m.scatter(x1,y1,s=50, c=temp,marker=".", cmap='coolwarm', vmin=13,vmax=29.5)
cb = m.colorbar()
cb.set_label('Temperature')
plt.title("Temperature", x=0.3, y=0.9, color="black", fontsize = 12)
m.drawcoastlines(linewidth=1, zorder=1);
m.fillcontinents(zorder=2);
m.drawmeridians(np.arange(-30,10, 5), labels=[0,0,0,1], fontsize=10)
m.drawparallels(np.arange(0, 50, 5), labels=[1,0,0,0], fontsize=10)
#Eddy circle
x,y=m(-20.43,17.73) ## centre of Eddy1
x2,y2=m(-20.43, 17.73+0.675) ## same as 75 km radius
circle1=plt.Circle((x,y), y2-y, color='black', fill=False)
ax3.add_patch(circle1)
plt.text(x2, y2, ' Eddy 1',c='black', fontsize=12);
# Label
x, y = m(-23, 16.8) # Sal
x1, y1 = m(-23.9, 16.8) # S
plt.plot(x, y, 'ok', c='black', markersize=5)
plt.text(x1, y1, ' Sal', c='black',fontsize=12);
#x1, y1 = m(-24, 17) # S
#plt.plot(x, y, 'ok', markersize=5)
#plt.text(x1, y1, ' Sal', fontsize=12);
x, y = m(-21.962, 17.205) # Sengho sea mount
```

```
x1, y1 = m(-24.5, 17.4) # S
plt.plot(x, y, 'ok', c='black', markersize=5)
plt.text(x1, y1, ' Senghor Seamount',c='black', fontsize=12);
plt.tight_layout()
plt.show()
#############################################################
#Current velocity and chlorophyll
import os
os.environ['PROJ_LIB']=r'C:\\Users\\username\\AppData\\Local\\Continuum\\anaconda2\\pkgs\\proj4-4.9.2-
vc10_0\\Library\\share'
import numpy as np
import matplotlib.pyplot as plt
import psycopg2 as pgsql
import pandas.io.sql as sql
from mpl_toolkits.basemap import Basemap
mydb = pgsql.connect(database="local_use", user="postgres", password="1234")
#plot cape verde currents from SD1030 and chlorophyll distribution from both saildrones
#latmin = 13
#latmax = 22
#lonmin = -28
#lonmax = -18
#plot cape verde currents from SD1030 and chlorophyll distribution from both saildrones ( only study area)
latmin = 16
latmax = 19
lonmin = -25
lonmax = -19
#whole mission
#latmin = 25
#latmax = 45
#lonmin = -20
#lonmax = 20
sd1030 = sql.read_sql("""SELECT date_trunc('hour', time) as time, avg(latitude) as lat, avg(longitude) as lon,
avg(chla) AS chla
                    FROM sd1030_env
                    GROUP BY date_trunc('hour', time)
                ORDER BY time
                                        """, mydb)
sd1053 = sql.read_sql("""SELECT date_trunc('hour', time) as time, avg(latitude) as lat, avg(longitude) as lon,
avg(chla) AS chla
                    FROM sd1053_env
                    GROUP BY date_trunc('hour', time)
                ORDER BY time
                                        """, mydb)
#select hourly bins
adcp_integ = sql.read_sql("""SELECT date_trunc('hour', time) as time, avg(latitude) as lat, avg(longitude) as lon,
avg(echo) AS echo, avg(vel_east) AS u, avg(vel_north) AS v
                                        FROM saildrone_adcp_data
                                        GROUP BY date_trunc('hour', time)
                                    ORDER BY time
                                                            """, mydb)
print(adcp_integ)
#path = "E:\\saildrone\\"
#filename= path + "integrated_capeverde.txt"
#outfile= open(filename, 'w')
#adcp_integ.to_csv(filename, sep="\t", index = False)
fig, ax =plt.subplots()
m = Basemap(projection='merc', lat_0 = 12, lon_0 = -20,
        resolution = 'i', llcrnrlon = lonmin,  urcrnrlon = lonmax, llcrnrlat = latmin, urcrnrlat = latmax)
lons = adcp_integ.lon.values  # needs .values here
lats = adcp_integ.lat.values   # same as above
```

```
x_direct = adcp_integ.u.values
y_direct = adcp_integ.v.values
x, y = m(lons, lats)
sd1030_lons = sd1030.lon.values  # needs .values here
sd1030_lats = sd1030.lat.values   # same as above
sd1030_x, sd1030_y = m(sd1030_lons, sd1030_lats)
sd1053_lons = sd1053.lon.values  # needs .values here
sd1053_lats = sd1053.lat.values   # same as above
sd1053_x, sd1053_y = m(sd1053_lons, sd1053_lats)
m.quiver(x,y,x_direct,y_direct, scale=5)
m.scatter(sd1030_x,sd1030_y,s=50, c=sd1030.chla,marker=".", vmin=0,vmax=2)
m.scatter(sd1053_x,sd1053_y,s=50, c=sd1053.chla,marker=".", vmin=0,vmax=2)
cb = m.colorbar()
cb.set_label('Chlorophyll-a (mg $m^{-3}$)')
plt.title("SD1030 currents and chl-a", color="black", fontsize = 12)
m.drawcoastlines(linewidth=1, zorder=1);
m.fillcontinents(zorder=2);
m.drawmeridians(np.arange(-30,20, 1), labels=[0,0,0,1], fontsize=10)
m.drawparallels(np.arange(0, 50, 1), labels=[1,0,0,0], fontsize=10)
#Eddy circle
x,y=m(-20.43,17.73) ## centre of Eddy1
x2,y2=m(-20.43, 17.73+0.675) ## same as 75 km radius
circle1=plt.Circle((x,y), y2-y, color='red', fill=False)
ax.add_patch(circle1)
plt.text(x2, y2, ' Eddy 1',c='red', fontsize=12);
# Label
x, y = m(-23, 16.8) # Sal
x1, y1 = m(-23.9, 16.8) # Sal
plt.plot(x, y, 'ok', c='red', markersize=5)
plt.text(x1, y1, ' Sal', c='red',fontsize=12);
#x1, y1 = m(-24, 17) # S
#plt.plot(x, y, 'ok', markersize=5)
#plt.text(x1, y1, ' Sal', fontsize=12);
x, y = m(-21.962, 17.205) # Sengho sea mount
x1, y1 = m(-24.5, 17.4) # S
plt.plot(x, y, 'ok', c='red', markersize=5)
plt.text(x1, y1, ' Senghor Seamount',c='red', fontsize=12);
plt.show()

################################################################################

#Diel vertical migration (PAR)

import psycopg2 as pgsql
import pandas.io.sql as sql
import matplotlib.pyplot as plt
import pandas as pd

from datetime import time

import numpy as np
##try to connect to the local_use database you created
mydb = pgsql.connect(database="local_use", user="postgres", password="1234")
#select average PAR (light) for each minute interval during the day (solar time)
df_par = sql.read_sql("""SELECT DISTINCT CAST(e.time as time) as time, AVG(e.par) as par
                    FROM(
                   SELECT date_trunc('minute', solar_time + interval '30 second') AS time, par
                    FROM sd1053_env
                    WHERE latitude <18) as e
                    GROUP BY CAST(time as time)
```

```
                                                  """, mydb)
#select layers as well as mean depth and sv for the hourly bins for solar time
#need to constrain region, otherwise becomes blurry (here I am filtering for just south of 18°N -- you could also do ust the eddy, or eddy in and out...

df = sql.read_sql("""SELECT layer, CAST(s.time as time) as time, avg(s.layer_depth_mid) as depth, avg(s.sv_mean) as sv
                 FROM (
            SELECT date_trunc('hour', solar_time + interval '30 minute') AS time, layer, layer_depth_mid, sv_mean
FROM saildrone_ek80_38khz
            WHERE layer_depth_mid <700
            AND lat <18) as s
            GROUP BY time, layer
            ORDER BY time, layer
                                                  """, mydb)

#format df for contourplot
df['time'] = df['time'].apply(lambda x: x.hour)+0.5
Z = df.pivot_table(index='time', columns='depth', values='sv').T.values
X_unique = np.sort(df.time.unique())
Y_unique = np.sort(df.depth.unique())
X, Y = np.meshgrid(X_unique, Y_unique)
pd.DataFrame(Z).round(3)
#need to reformat time to float
df_par['time'] = df_par['time'].apply(lambda x: x.hour) + (df_par['time'].apply(lambda x: x.minute))/60
###plot two-panel figure
fig = plt.figure(1, figsize=(5, 10))
ax1 = fig.add_subplot(2,1,1)
ax1.scatter(df_par.time,df_par.par, marker ='.')
plt.title('South of 18°N')
plt.yticks()
plt.xticks([],[])
plt.ylabel('PAR (µmol s$^{-1}$ m$^{-2}$)')
#backscatter contourplot
levels = np.linspace(-100, -50, 101)
ax2 = fig.add_subplot(2,1,2)
plt.gca().invert_yaxis()
plt.contourf(X,Y, Z, levels=levels)
plt.xticks([0,6,12,18,24])
plt.yticks()
plt.ylabel('Depth (m)')
plt.xlabel('Time')
plt.colorbar(orientation='horizontal', label = 'Sv')
plt.show()
##############################################################################

#Diel vertical migration in the eddy

import psycopg2 as pgsql
import pandas.io.sql as sql
import matplotlib
import matplotlib.pyplot as plt
import pandas as pd
import datetime
import numpy as np
import matplotlib.dates as mdates
##try to connect to the local_use database you created
mydb = pgsql.connect(database="local_use", user="postgres", password="1234")
#select layer, date_part('hour', solar time) as time
```

```
#select layers as well as mean depth and sv for the hourly bins for solar time
df_out = sql.read_sql("""SELECT date_part('hour', solar_time) as time, layer_depth_mid as depth, avg(sv_mean)
as sv
                    FROM saildrone_ek80_38khz
                 WHERE layer_depth_mid <800
                 AND distance_to_eddy1 BETWEEN 100 AND 200
                 GROUP BY time, depth
                 ORDER BY time, depth
                                                            """, mydb)
df_in = sql.read_sql("""SELECT date_part('hour', solar_time) as time, layer_depth_mid as
depth, avg(sv_mean) as sv
           FROM saildrone_ek80_38khz
                 WHERE layer_depth_mid <800
                 AND distance_to_eddy1 <50
                 GROUP BY time, depth
                 ORDER BY time, depth
                                                            """, mydb)

#simple backscatter vs depth and time plot
#simple mean backscatter vs depth scatter plot
fig = plt.figure(1, figsize=(12, 12))

#######Eddy Out
ax1 = fig.add_subplot(1,2,1)
#Z = df.pivot_table(index='time', columns='depth', values='sv').T.values
ax1.set_title("Eddy Out (100 - 200km to center)")
plt.scatter(df_out.time,df_out.depth, marker ='s', s = 200, c=df_out.sv, vmin=-90, vmax=-55)
plt.colorbar(orientation='vertical', label='Sv')
plt.gca().invert_yaxis()
plt.xticks(rotation=45)
ax1.set_xticks([0,6,12,18,24])
plt.ylabel('Depth (m)')
plt.xlabel('Time')

#######Eddy IN
ax2 = fig.add_subplot(1,2,2)
#Z = df.pivot_table(index='time', columns='depth', values='sv').T.values
ax2.set_title("Eddy In (<50km to center)")
plt.scatter(df_in.time,df_in.depth, marker ='s', s = 200, c=df_in.sv, vmin=-90, vmax=-55)
plt.gca().invert_yaxis()
plt.xticks(rotation=45)
ax2.set_xticks([0,6,12,18,24])
plt.ylabel('Depth (m)')
plt.xlabel('Time')
plt.colorbar(orientation='vertical', label='Sv')
plt.show()
##############################################################################

#Vertical distributions of backscatter

import psycopg2 as pgsql
import pandas.io.sql as sql
import matplotlib.pyplot as plt
import pandas as pd
import datetime
import pandas as pd
import numpy as np
##try to connect to the local_use database you created
mydb = pgsql.connect(database="local_use", user="postgres", password="1234")
```

```
eddy_in_day = sql.read_sql("""SELECT layer, layer_depth_mid as depth, AVG(sv_mean) as sv_mean, STDDEV(sv_mean) as sv_sd
                            FROM saildrone_ek80_38khz
                        WHERE distance_to_eddy1 <50
                        AND CAST(solar_time as time) between '08:00:00' AND '18:00:00'
                        GROUP BY layer, layer_depth_mid
                        ORDER BY layer_depth_mid
                                                                            """, mydb)
eddy_in_night = sql.read_sql("""SELECT layer, layer_depth_mid as depth, AVG(sv_mean) as sv_mean, STDDEV(sv_mean) as sv_sd
                           FROM saildrone_ek80_38khz
                        WHERE distance_to_eddy1 <50
                        AND CAST(solar_time as time) not between '06:30:00' AND '20:00:00'
                        GROUP BY layer, layer_depth_mid
                        ORDER BY layer_depth_mid
                                                                            """, mydb)
eddy_out_day = sql.read_sql("""SELECT layer, layer_depth_mid as depth, AVG(sv_mean) as sv_mean, STDDEV(sv_mean) as sv_sd
                                    FROM saildrone_ek80_38khz
                      WHERE distance_to_eddy1 BETWEEN 50 AND 300
                        AND CAST(solar_time as time) between '08:00:00' AND '18:00:00'
                        GROUP BY layer, layer_depth_mid
                        ORDER BY layer_depth_mid
                                                                            """, mydb)
eddy_out_night = sql.read_sql("""SELECT layer, layer_depth_mid as depth, AVG(sv_mean) as sv_mean, STDDEV(sv_mean) as sv_sd
                        FROM saildrone_ek80_38khz
                        WHERE distance_to_eddy1 BETWEEN 50 AND 300
                        AND CAST(solar_time as time) not between '06:30:00' AND '20:00:00'
                        GROUP BY layer, layer_depth_mid
                        ORDER BY layer_depth_mid
                                                                            """, mydb)
#simple mean backscatter vs depth scatter plot
fig = plt.figure(1, figsize=(12, 12))

#######Eddy Out

ax1 = fig.add_subplot(1,2,1)
ax1.set_title("Eddy Out (50 - 300km to center)")
ax1.set_ylim(600, 0)
ax1.set_xlim(-85, -50)
ax1.set_ylabel('Depth (m)')
ax1.fill_betweenx(eddy_out_day.depth, eddy_out_day.sv_mean-eddy_out_day.sv_sd, eddy_out_day.sv_mean+eddy_out_day.sv_sd, facecolor='darkgrey', alpha=0.5)
ax1.plot(eddy_out_day.sv_mean, eddy_out_day.depth, c='darkgrey', label = 'Day')
ax1.fill_betweenx(eddy_out_night.depth, eddy_out_night.sv_mean-eddy_out_night.sv_sd, eddy_out_night.sv_mean+eddy_out_night.sv_sd, facecolor='black', alpha=0.5)
ax1.plot(eddy_out_night.sv_mean, eddy_out_night.depth, c='black', label = 'Night')
ax1.set_xlabel('Sv (dB)')

#plt.legend(loc='lower right', frameon=False)

# Calcul de bornes

Svmean = eddy_out_day.sv_mean
print(Svmean)
minimal = min(Svmean)
print(minimal)
maximal = max(Svmean)
print(maximal)
```

```
#######Eddy in

ax2 = fig.add_subplot(1,2,2)
ax2.set_title("eddy In (within 50 km to center)")
ax2.set_ylim(600, 0)
ax2.set_xlim(-85, -50)
ax2.set_ylabel('Depth (m)')
ax2.fill_betweenx(eddy_in_day.depth, eddy_in_day.sv_mean-eddy_in_day.sv_sd,
eddy_in_day.sv_mean+eddy_in_day.sv_sd, facecolor='darkgrey', alpha=0.5)
ax2.plot(eddy_in_day.sv_mean, eddy_in_day.depth, c='darkgrey', label = 'Day')
ax2.fill_betweenx(eddy_in_night.depth, eddy_in_night.sv_mean-eddy_in_night.sv_sd,
eddy_in_night.sv_mean+eddy_in_night.sv_sd, facecolor='black', alpha=0.5)
ax2.plot(eddy_in_night.sv_mean, eddy_in_night.depth, c='black', label = 'Night')
ax2.set_xlabel('Sv (dB)')
ax2.spines['right'].set_visible(False)
plt.legend(loc='lower right', frameon=False)
#plt.savefig('Fig_1_eddy_in_out.png')
plt.show()
mydb.commit()
mydb.close()
# Calcul de bornes
Svmean = eddy_in_day.sv_mean
print(Svmean)
minimal = min(Svmean)
print(minimal)
maximal = max(Svmean)
print(maximal)
####### Senghor
mydb = pgsql.connect(database="local_use", user="postgres", password="1234")
senghor_in_day = sql.read_sql("""SELECT layer, layer_depth_mid as depth, AVG(sv_mean) as sv_mean,
STDDEV(sv_mean) as sv_sd
                                        FROM saildrone_ek80_38khz
            WHERE distance_to_senghor <20
            AND CAST(solar_time as time) between '08:00:00' AND '18:00:00'
            GROUP BY layer, layer_depth_mid
            ORDER BY layer_depth_mid
                                        """, mydb)
senghor_in_night = sql.read_sql("""SELECT layer, layer_depth_mid as depth, AVG(sv_mean) as sv_mean,
STDDEV(sv_mean) as sv_sd
                                        FROM saildrone_ek80_38khz
            WHERE distance_to_senghor <20
            AND CAST(solar_time as time) not between '06:30:00' AND '20:00:00'
            GROUP BY layer, layer_depth_mid
            ORDER BY layer_depth_mid
                                        """, mydb)

senghor_out_day = sql.read_sql("""SELECT layer, layer_depth_mid as depth, AVG(sv_mean) as sv_mean,
STDDEV(sv_mean) as sv_sd
                                        FROM saildrone_ek80_38khz
            WHERE distance_to_senghor BETWEEN 20 AND 300
            AND CAST(solar_time as time) between '08:00:00' AND '18:00:00'
            GROUP BY layer, layer_depth_mid
            ORDER BY layer_depth_mid
                                        """, mydb)



senghor_out_night = sql.read_sql("""SELECT layer, layer_depth_mid as depth, AVG(sv_mean) as sv_mean,
STDDEV(sv_mean) as sv_sd
                                        FROM saildrone_ek80_38khz
```

```
                    WHERE distance_to_senghor BETWEEN 20 AND 300
                  AND CAST(solar_time as time) not between '06:30:00' AND '20:00:00'
                    GROUP BY layer, layer_depth_mid
                    ORDER BY layer_depth_mid
                                                                        """, mydb)
#simple mean backscatter vs depth scatter plot
fig = plt.figure(1, figsize=(12, 12))

#######Senghor Out

ax1 = fig.add_subplot(1,2,1)
ax1.set_title("senghor Out (20 - 300km to center)")
ax1.set_ylim(600, 0)
ax1.set_xlim(-85, -50)
ax1.set_ylabel('Depth (m)')
ax1.fill_betweenx(senghor_out_day.depth,                              senghor_out_day.sv_mean-senghor_out_day.sv_sd,
senghor_out_day.sv_mean+senghor_out_day.sv_sd, facecolor='darkgrey', alpha=0.5)
ax1.plot(senghor_out_day.sv_mean, senghor_out_day.depth, c='darkgrey', label = 'Day')
ax1.fill_betweenx(senghor_out_night.depth,                        senghor_out_night.sv_mean-senghor_out_night.sv_sd,
senghor_out_night.sv_mean+senghor_out_night.sv_sd, facecolor='black', alpha=0.5)
ax1.plot(senghor_out_night.sv_mean, senghor_out_night.depth, c='black', label = 'Night')
ax1.set_xlabel('NASC (dB)')
#plt.legend(loc='lower right', frameon=False)

# calcul de bornes

Svmean = senghor_out_day.sv_mean
print(Svmean)
minimal = min(Svmean)
print(minimal)
maximal = max(Svmean)
print(maximal)

#######Senghor in

ax2 = fig.add_subplot(1,2,2)
ax2.set_title("senghor In (within 20 km to center)")
ax2.set_ylim(600, 0)
ax2.set_xlim(-85, -50)
ax2.set_ylabel('Depth (m)')
ax2.fill_betweenx(senghor_in_day.depth,                                  senghor_in_day.sv_mean-senghor_in_day.sv_sd,
senghor_in_day.sv_mean+senghor_in_day.sv_sd, facecolor='darkgrey', alpha=0.5)
ax2.plot(senghor_in_day.sv_mean, senghor_in_day.depth, c='darkgrey', label = 'Day')
ax2.fill_betweenx(senghor_in_night.depth,                              senghor_in_night.sv_mean-senghor_in_night.sv_sd,
senghor_in_night.sv_mean+senghor_in_night.sv_sd, facecolor='black', alpha=0.5)
ax2.plot(senghor_in_night.sv_mean, senghor_in_night.depth, c='black', label = 'Night')
ax2.set_xlabel('NASC (dB)')
ax2.spines['right'].set_visible(False)
plt.legend(loc='lower right', frameon=False)
#plt.savefig('Fig_1_eddy_in_out.png')
plt.show()

# Calcul de bornes
Svmean = senghor_in_day.sv_mean
print(Svmean)
minimal = min(Svmean)
print(minimal)
maximal = max(Svmean)
print(maximal)
###### Sal
```

```
mydb = pgsql.connect(database="local_use", user="postgres", password="1234")


sal_in_day = sql.read_sql("""SELECT layer, layer_depth_mid as depth, AVG(sv_mean) as sv_mean, 
STDDEV(sv_mean) as sv_sd
                  FROM saildrone_ek80_38khz
                WHERE distance_to_sal <20
                AND CAST(solar_time as time) between '08:00:00' AND '18:00:00'
                GROUP BY layer, layer_depth_mid
                ORDER BY layer_depth_mid
                                                        """, mydb)


sal_in_night = sql.read_sql("""SELECT layer, layer_depth_mid as depth, AVG(sv_mean) as sv_mean, 
STDDEV(sv_mean) as sv_sd
                                                        FROM saildrone_ek80_38khz
                WHERE distance_to_sal <20
 AND CAST(solar_time as time) not between '06:30:00' AND '20:00:00'
                GROUP BY layer, layer_depth_mid
                ORDER BY layer_depth_mid
                                                        """, mydb)

sal_out_day = sql.read_sql("""SELECT layer, layer_depth_mid as depth, AVG(sv_mean) as sv_mean, 
STDDEV(sv_mean) as sv_sd
                                                        FROM saildrone_ek80_38khz
                WHERE distance_to_sal BETWEEN 20 AND 300
                AND CAST(solar_time as time) between '08:00:00' AND '18:00:00'
                GROUP BY layer, layer_depth_mid
                ORDER BY layer_depth_mid
                                                        """, mydb)
sal_out_night = sql.read_sql("""SELECT layer, layer_depth_mid as depth, AVG(sv_mean) as sv_mean, 
STDDEV(sv_mean) as sv_sd
                                                        FROM saildrone_ek80_38khz
                WHERE distance_to_sal BETWEEN 20 AND 300
                AND CAST(solar_time as time) not between '06:30:00' AND '20:00:00'
                GROUP BY layer, layer_depth_mid
                ORDER BY layer_depth_mid
                                                        """, mydb)
#simple mean backscatter vs depth scatter plot
fig = plt.figure(1, figsize=(12, 12))

#######Sal Out

ax1 = fig.add_subplot(1,2,1)
ax1.set_title("sal Out (20 - 300km to center)")
ax1.set_ylim(600, 0)
ax1.set_xlim(-85, -50)
ax1.set_ylabel('Depth (m)')
ax1.fill_betweenx(sal_out_day.depth, sal_out_day.sv_mean-sal_out_day.sv_sd, 
sal_out_day.sv_mean+sal_out_day.sv_sd, facecolor='darkgrey', alpha=0.5)
ax1.plot(sal_out_day.sv_mean, sal_out_day.depth, c='darkgrey', label = 'Day')
ax1.fill_betweenx(sal_out_night.depth, sal_out_night.sv_mean-sal_out_night.sv_sd, 
sal_out_night.sv_mean+sal_out_night.sv_sd, facecolor='black', alpha=0.5)
ax1.plot(sal_out_night.sv_mean, sal_out_night.depth, c='black', label = 'Night')
ax1.set_xlabel('NASC (dB)')
#plt.legend(loc='lower right', frameon=False)
# Calcul de bornes
Svmean = sal_out_day.sv_mean
print(Svmean)
minimal = min(Svmean)
```

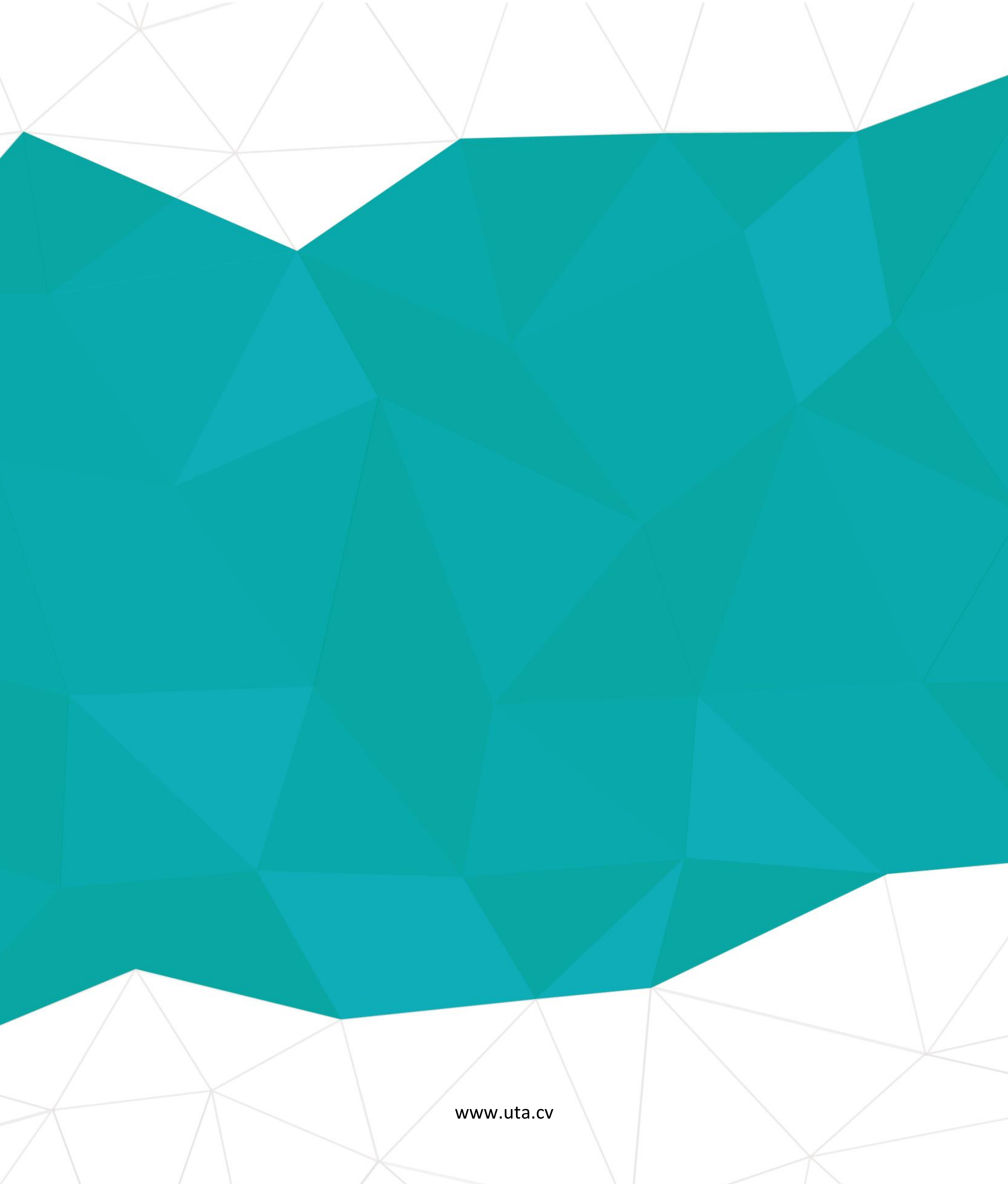
```
print(minimal)

maximal = max(Svmean)
print(maximal)
#######Sal in
ax2 = fig.add_subplot(1,2,2)
ax2.set_title("sal In (within 20 km to center)")
ax2.set_ylim(600, 0)
ax2.set_xlim(-85, -50)
ax2.set_ylabel('Depth (m)')
ax2.fill_betweenx(sal_in_day.depth, sal_in_day.sv_mean-sal_in_day.sv_sd,
sal_in_day.sv_mean+sal_in_day.sv_sd, facecolor='darkgrey', alpha=0.5)
ax2.plot(sal_in_day.sv_mean, sal_in_day.depth, c='darkgrey', label = 'Day')
ax2.fill_betweenx(sal_in_night.depth, sal_in_night.sv_mean-sal_in_night.sv_sd,
sal_in_night.sv_mean+sal_in_night.sv_sd, facecolor='black', alpha=0.5)
ax2.plot(sal_in_night.sv_mean, sal_in_night.depth, c='black', label = 'Night')
ax2.set_xlabel('NASC (dB)')
ax2.spines['right'].set_visible(False)
plt.legend(loc='lower right', frameon=False)
#plt.savefig('Fig_1_eddy_in_out.png')
plt.show()

# Calcul de bornes

Svmean = sal_in_day.sv_mean
print(Svmean)
minimal = min(Svmean)
print(minimal)
maximal = max(Svmean)
print(maximal)
a=-86.07
b=-58.26
N=1000
x = np.linspace(a, b, N)
f= -86.07
np.sum(f)*(b-a)/N

#integrate(f, a, b, N)
def integrate(f, a, b, N):
 x = np.linspace(a, b, N)
   fx = f(x)
 area = np.sum(f)*(b-a)/N
return area
   print(fx)

##########################################################################
```

Spatial distribution of mesopelagic organisms

```
import os
os.environ['PROJ_LIB']=r'C:\\Users\\username\\AppData\\Local\\Continuum\\anaconda2\\pkgs\\proj4-4.9.2-
vc10_0\\Library\\share'
import psycopg2 as pgsql
import pandas.io.sql as sql
import matplotlib.pyplot as plt
from mpl_toolkits.basemap import Basemap
import pandas as pd
import numpy as np

##try to connect to the local_use database you created
mydb = pgsql.connect(database="local_use", user="postgres", password="1234")
```

```
latmin = 15
latmax = 22
lonmin = -26
lonmax = -18
df = sql.read_sql("""SELECT distinct ROUND(distance_to_eddy1) as distance, lat, lon, AVG(nasc) AS nasc
                        FROM saildrone_ek80_38khz
                        WHERE distance_to_eddy1 <500
                        AND CAST(solar_time as time) not between '04:00:00' AND '20:00:00'
                        AND layer_depth_mid BETWEEN 5 and 50
                        GROUP BY distance, lat, lon
                        ORDER BY distance
                                                              """, mydb)
print(df)

fig = plt.figure(1, figsize=(8, 8)) # To give size to the figure.
m = Basemap(projection='merc', lat_0 = 12, lon_0 = -20,
          resolution = 'i', llcrnrlon = lonmin,  urcrnrlon = lonmax, llcrnrlat = latmin, urcrnrlat = latmax)# to showt
land map of cntinent
lons = df.lon.values  # needs .values here
lats = df.lat.values   # same as above
x, y = m(lons, lats)
m.scatter(x,y,s=df.nasc, c=df.nasc, marker=".", vmin=0,vmax=800)
cb = m.colorbar()
cb.set_label('NASC')
plt.title("Mean NASC upper 50m night", color="black", fontsize = 12) # to plot the figure of NASC
m.drawcoastlines(linewidth=1, zorder=1); # to show the coast line
m.fillcontinents(zorder=2); # to show the continent
m.drawmeridians(np.arange(-30,20, 1), labels=[0,0,0,1], fontsize=10) # to show labels along the meridian
m.drawparallels(np.arange(0, 50, 1), labels=[1,0,0,0], fontsize=10)# labels along parallels
plt.show()
#simple mean backscatter vs depth scatter plot
fig = plt.figure(1, figsize=(12, 12))
plt.scatter(df.distance, df.nasc)
#plt.xlabel('Distance to Eddy core (km)') # to wite label along x axis
#plt.ylabel('NASC')

#Eddy circle

x,y=m(-20.43,17.73) ## centre of Eddy1
x2,y2=m(-20.43, 17.73+0.675) ## same as 75 km radius
circle1=plt.Circle((x,y), y2-y, color='black', fill=False)
#plt.add_patch(circle1)
plt.text(x2, y2, ' Eddy 1',c='black', fontsize=12);

# Label

x, y = m(-23, 16.8) # Sal
x1, y1 = m(-23.9, 16.8) # S
plt.plot(x, y, 'ok', c='black', markersize=5)
plt.text(x1, y1, ' Sal', c='black',fontsize=12);
#x1, y1 = m(-24, 17) # S
#plt.plot(x, y, 'ok', markersize=5)
#plt.text(x1, y1, ' Sal', fontsize=12);
x, y = m(-21.962, 17.205) # Sengho sea mount
x1, y1 = m(-24.5, 17.4) # S
plt.plot(x, y, 'ok', c='black', markersize=5)
plt.text(x1, y1, ' Senghor Seamount',c='black', fontsize=12);
plt.tight_layout()
plt.show()
# Senghor seamount
```

```
##try to connect to the local_use database you created
mydb = pgsql.connect(database="local_use", user="postgres", password="1234"

latmin = 15
latmax = 22
lonmin = -26
lonmax = -18
df = sql.read_sql("""SELECT distinct ROUND(distance_to_senghor) as distance, lat, lon, AVG(nasc) AS nasc
                    FROM saildrone_ek80_38khz
                    WHERE distance_to_senghor <500
                    AND CAST(solar_time as time) not between '04:00:00' AND '20:00:00'
                    AND layer_depth_mid BETWEEN 5 and 50
                    GROUP BY distance, lat, lon
                    ORDER BY distance
                                                                                """, mydb)
print(df)
fig = plt.figure(1, figsize=(8, 8))
m = Basemap(projection='merc', lat_0 = 12, lon_0 = -20,
          resolution = 'i', llcrnrlon = lonmin,  urcrnrlon = lonmax, llcrnrlat = latmin, urcrnrlat = latmax)
lons = df.lon.values  # needs .values here
lats = df.lat.values   # same as above
x, y = m(lons, lats)
m.scatter(x,y,s=df.nasc, c=df.nasc, marker=".", vmin=0,vmax=800)
cb = m.colorbar()
cb.set_label('NASC')
plt.title("Mean NASC upper 50m night", color="black", fontsize = 12)
m.drawcoastlines(linewidth=1, zorder=1);
m.fillcontinents(zorder=2);
m.drawmeridians(np.arange(-30,20, 1), labels=[0,0,0,1], fontsize=10)
m.drawparallels(np.arange(0, 50, 1), labels=[1,0,0,0], fontsize=10)
plt.show()
```



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