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Climatological analysis of the Pelagos sanctuary surrounding and possible correlation to anomalies in fin whale distribution in the sanctuary

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Abstract

The Pelagos sanctuary is a pelagic marine protected area located in the northwestern Mediterranean Sea. This sanctuary’s main goal is to protect the marine mammals' foraging and breeding grounds in the Ligurian sea. One of the commonly sighted marine mammals in the sanctuary are the fin whales. In general, fin whale presence records in the summer seasons in this area. The summer aggregation of fin whales can be associated with some environmental parameters such as sea surface temperature and phytoplankton spring bloom. The winter rainfall from the Pelagos sanctuary surrounding region is an important factor for the phytoplankton spring bloom. The input river discharge from the surrounding land to the Pelagos sanctuary area makes nutrient availability for the spring primary production. Therefore, the rainfall in the winter season has a crucial importance for the phytoplankton bloom development.

This work developed as a first approach to investigate the winter seasonal characteristics and the fin whale distribution in the Pelagos sanctuary. The first part of the work assesses the comparison between the seasonal average of rainfall and temperature with the climatological average. The dataset used for the climatological analysis was the E-OBS dataset, the rainfall and temperature data set retrieved from the Italian Civil Protection Department Network. The winter seasonal analysis result shows an increasing trend of hot and dry periods in recent decade. The second part assesses the daily rainfall distribution in the winter season to obtain the dry/wet days to evaluate the rainfall distribution along each considered season. Nowadays, the seasonal rainfall amount not homogeneously distributed along the season with often falling all in a few days with droughts in the middle, this is more frequent in ongoing climate change. The daily rainfall distribution results show some of the years have these scenarios. The third part investigates the possible relation between winter season characteristics and fin whale distribution in the Pelagos sanctuary. The fin whale encounter rate (ER) with frequency of survey data derived from a past thesis. The ER>0 in shallow water recorded in the 2007, 2019 and 2020. The highest anomalous years were in 2019 and 2020, while in 2007 whale presence was less anomalous because, despite the sightings in shallow water, their presence was mainly observed in usual habitats (2000 m). Furthermore,

2006/07 rainfall results show above the climatological value, and it shows an evident difference from other anomalous years. The daily rainfall distribution in winter 2018/19 and 2019/20 shows more dry days in between winter season. These dry days might affect the phytoplankton bloom and fin whale distribution in the Pelagos sanctuary.

Overall, from the first assessment presented in this thesis it seems that in recent years the fin whale presence in shallow water is becoming more frequent (2007, 2019, 2020, most probably 2022). Such behaviour from this first approach seems to be probably related to dry winter conditions. Furthermore, future works will be devoted to clustering the dry/rainy days using climatological indices and clustering the phytoplankton bloom type, as an example in terms of initiation day, duration, and intensity to identify how it changes as a consequence of the different winter conditions. Afterwards, the bloom will be used as a proxy of fin whale distribution.

Acknowledgements

I'm grateful to the people who helped me to achieve this goal, it was an amazing journey of the learning experience. I would like to thank God for giving me the opportunities, to giving me the strength to keep going. I would like to thank my parents for giving me the support to chase what I love to do in life.

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Introduction

Climatology is the scientific study of the earth's climate, typically defined as the weather conditions averaged over a period of at least 30 years. The climatology scope is to describe the nature of the atmosphere from location to location over many different time scales to explain why particular attributes occur and change over time. Modern climatology also assesses the potential impacts of climate changes on natural and social systems. According to Rohli and Vega (2018) climatology has various subfields regarding the different aspects of climate study and each of the subfields correspond to different analysis scales. For example, the microscale processes study involving interactions between the lower atmosphere and the local surface have the scope in Boundary layer climatology, while Paleoclimatology aim to reconstruct and understand past climates by examining records such as ice cores, tree rings and fossils and Applied climatology is primarily concerned with the climate effects on natural and social phenomena for example which helps to understand the impact of urban landscapes on the natural human environment. Other examples for the sub fields are hydro climatology, dynamic climatology, physical climatology, regional climatology etc. The study of contemporary climates incorporates meteorological data collected over many years such as rainfall, temperature, and atmospheric composition records. The Knowledge of atmosphere and its complex dynamics is also embodied in models, either statistical or mathematical, which help by integrating different observations and testing how they fit together. Modelling is used to understand past, present, and potential future climate changes. The climate analysis studies are routinely carried out using different data from many sources including in situ observations, satellite instruments, measurements in field campaigns and outputs from numerical models. There are three climate data properties that can be considered in the climate analysis, and they are Normals, Extremes and Frequencies. Normals refers to average weather conditions, they are typically calculated for 30 years periods and give a view of the type of expected weather conditions for a location through the course of a year. Climatic extremes are used to describe the maximum and minimum measurements of atmospheric variables that can be expected to occur at a certain place and time, based on a long period of observations. Climatic frequencies refer to the rate of incidence of a particular phenomenon at a particular place over a long period of time. frequency data are often important for risk assessment, engineering, or agriculture applications (Rohli and Vega ,2018).

Today climate change is affecting all over the world, it includes both global warming and its impacts on earth's weather patterns. In recent decades, changes in climate have caused impacts on natural and human systems on all continents and across the oceans. Climate change threatens people with food and water scarcity, increased flooding, extreme heat, more disease, and economic loss. Human migration and conflict can be a result of climate change. The world health organization names climate change as the greatest threat to global health in the 21st century. Many terrestrials, fresh water, and marine species have shifted their geographic ranges, seasonal activities, migration patterns, abundances, and species interactions in response to ongoing climate change (IPCC 2014). There have been many climate change episodes in the past, but the current changes are distinctly more rapid and not due to natural causes; instead, they are caused by the emission of greenhouse gasses (GHG), mostly carbon dioxide (CO2) and methane (IPCC 2018). Extreme greenhouse gasses emission can cause earth's atmosphere to trap more heat, and this will cause the earth warming rising up. The ocean also absorbs a lot of excess carbon dioxide in the air, which causes ocean acidification. Ocean acidification could be harmful to many ocean creatures, such as shellfish and coral. Anthropogenic GHG emissions are mainly driven by population size, economic activity, lifestyle, energy use, land-use patterns, technology, and climate policy. The Representative Concentration Pathways (RCPs) are used to make projections based on these factors which describe four different 21st century pathways of GHG emissions and atmospheric concentrations, air pollutant emissions and land use. The RCP includes a stringent mitigation scenario (RCP2.6), two intermediate scenarios (RCP4.5 and RCP6.0) and one scenario with very high GHG emissions (RCP8.5). RCP2.6 is representative of a scenario that aims to keep global warming likely below 2° Celsius above pre-industrial temperatures (IPCC 2014).

Recent analysis of the temperature shows mean global temperature on earth has increased by at least 1.1 ° Celsius since the end of the 19th century. Most of the warming has occurred since 1975, at a rate of roughly 0.15 to 0.20 ° Celsius per decade (Hansen et al.,2010). The increased atmospheric moisture content associated with global warming might be expected to lead to increased global mean precipitation. According to IPCC (2007), global annual mean precipitation showed a small, but uncertain upward trend over the 20th century of approximately 1.1 mm per decade. However, the record is characterized by large interdecadal variability and global annual land mean precipitation shows a non-significant decrease since 1950(IPCC 2007). Since the 1950s, droughts and heat waves have appeared simultaneously with increasing frequency (Kopp et al,2017). Until the end of the twentieth century, heat waves were predominantly seen as a recurrent meteorological fact with major attention to drought, being almost independent from human activities and unpredictable. However, since 1950, distinct changes in extreme climate and weather events have been increasingly observed. Meanwhile, climate change studies show these changes are clearly linked to the human influence on the content of greenhouse gasses in the earth's atmosphere. Climate-related extremes, such as heat waves, droughts, floods, cyclones, and wildfires reveal significant vulnerability to climate change as a result of global warming (Marx et al.,2021).

The Mediterranean is one of the most vulnerable and prominent climate change 'hotspots' (Giorgi 2006). In fact, the Mediterranean climate, and its impacts on land processes and on human activities are also deeply connected with the circulation of water masses and the ecological process of the Mediterranean Sea. Because of its relatively small size, geographical location and semi landlocked nature, this marine basin is very sensitive and responds quickly to atmospheric forcings and anthropogenic influences (Lionello 2012). Due to anthropogenic emissions of greenhouse gasses, climate is changing in the Mediterranean basin, historically and projected by climate models, faster than global trends. According to first Mediterranean assessment report (MedECC,2020) annual mean temperature on land and sea across the Mediterranean basin are 1.5°C higher than during pre-industrial times and they are projected to rise until 2100 by an additional 3.8 ° Celsius to 6.5 ° Celsius for a high greenhouse gas concentration scenario (RCP8.5) and 0.5 to 2.0 ° Celsius for a scenario compatible with the long-term goal of the UNFCCC Paris agreement to keep the global temperature well below +2° C above the pre-industrial level(RCP 2.6). Heat waves also intensified in this region and research shows in future it will affect more in the land and the sea (MedECC,2020). In the Mediterranean region climate change is also vulnerable to the terrestrial and marine environment which tends to alter the biodiversity.

Climate change also influences marine life and mammals, which is a growing concern. Some of the global warming effects are currently unknown due to their unpredictability but others are becoming increasingly evident today. Some effects are directly influencing marine life such as loss of habitat, temperature stress and higher exposure to severe weather. Whereas other effects are indirect such as changes in host pathogens associations, changes in body conditions because of predator-prey interaction, changes in exposure to toxins and CO2 emissions and increased human interactions (Burek et al., 2008).

These climate change effects are also evident in the Pelagos sanctuary, which is the only pelagic marine protected area in North-western Mediterranean Sea. Pelagos sanctuary is the key area for the Mediterranean marine mammals because it contains essential habitats for the diverse complement of species regularly sighted in the western Mediterranean and supports large resident populations of several genetically distinct stocks (Sciara G et al.,2008). One of the commonly sighted cetaceans in the sanctuary are fin whales and a lot of studies are considering their distribution in the sanctuary, especially during the summer period. In general, the summer aggregation of fin whale in the western mediterranean basin is associated to the environmental parameters such as Sea surface temperature, phytoplankton biomass and bathymetry, which are usually sight in greater distances from the coast side (Druon JN et al.,2012). Some special cases of fin whale distribution were recorded in the 2007 summer which showed their presence also in the inshore waters and even in the ports. The abnormal presence of the species in coastal waters was also correlated to high mortality, especially in the case of juveniles. These unusual anomalies of the fin whales point to the climatic conditions especially to the increased water temperature, and to the earlier and poorer phytoplankton bloom in the basin. The fin whale summer distribution anomalies might point to the effects of global warming in top predator distribution in the northwestern mediterranean basin (Tepsich et al.,2008). According to the international panel on climate change (IPCC 2007) and the

European environmental agency (EEA 2008) global warming can affect many ecological factors, including changes in phytoplankton composition, blooms timing and northward boundary shifts of warm water species. This might particularly affect the distribution of the main fin whale prey, meganyctiphanes norvegica, which is located at the southern limits of its ecological tolerance in the western Mediterranean basin (Tarling et al.,2010;IPCC 2007;EEA 2008) also from several decades western mediterranean sea has been subjected to an increase in human activities with climate changes which makes probable impacts on nutrient concentrations for the primary production (Béthoux and Gentili, 1999; Béthoux et al., 2002). Climate change might influence the normal food habitats and the movements of fin whales in the western mediterranean basin, and which can cause their existence. Consequently, present, and future climate scenarios are important for this particular species conservation.

The thesis aim is the climatological analysis of rainfall and temperature variables in the Pelagos sanctuary surrounding region and investigate the potential impacts of climate change on the fin whale presence in the sanctuary. In this work we are analyzing the observed temperature and rainfall seasonal average with respect to climatological data and analyzing the daily rainfall of winter seasons to assess the distribution of raining days during the season.

The Thesis is divided into 4 chapters

Chapter 1, about the Mediterranean climate general features and trend, Pelagos sanctuary and the fin whale distribution in the sanctuary.

Chapter 2, the description of the data set used for the analysis

Chapter 3, the results of the climatological analysis and fin whale distribution in the sanctuary.

Chapter 4, the conclusions, and future assumptions of the study.

Chapter one

General features of Mediterranean climate, Pelagos sanctuary, and fin whale distribution in the sanctuary

1.1) The Mediterranean climate: general features and trends

The Mediterranean climate is characterized by mild wet winters and warm, dry summers. Mediterranean climate zones are typically located along the west side of continents between about 30° and 40° latitude. This region is characterized by complex orography and by the presence of distinct basins and gulfs, islands, and peninsulas of various sizes (Figure 1.1.1). High mountain ridges surround the Mediterranean Sea on almost every side and tend to produce much sharper climatic features than expected without their existence (Lionello et al., 2006).

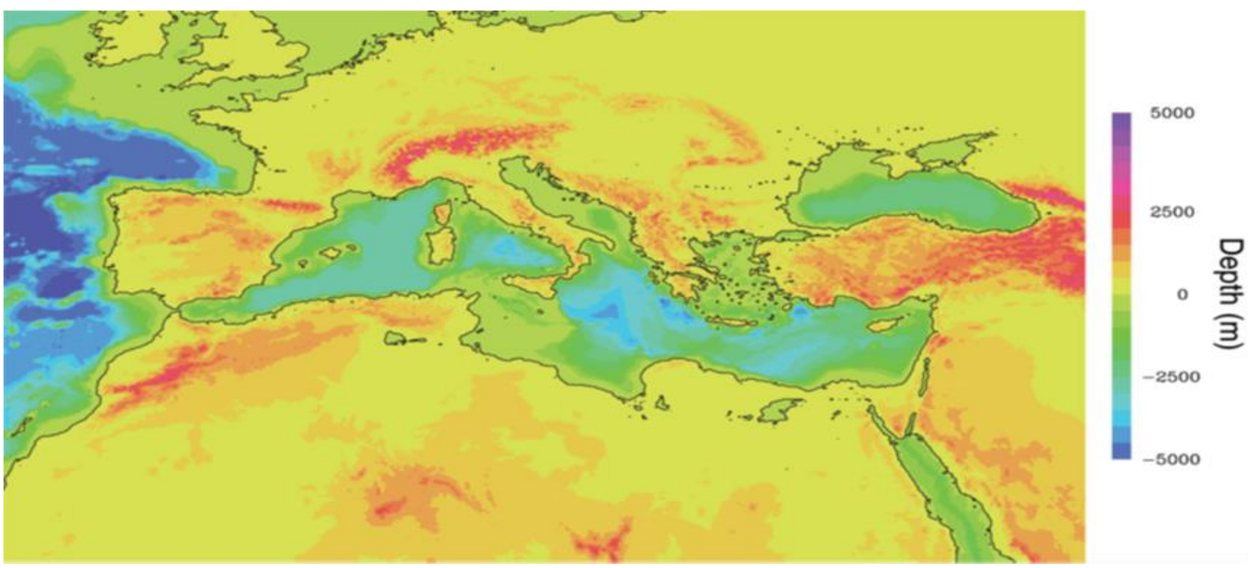


Figure 1.1.1: Altitude and bathymetry of the Mediterranean region (Courtesy of Lionello et al.,2006)

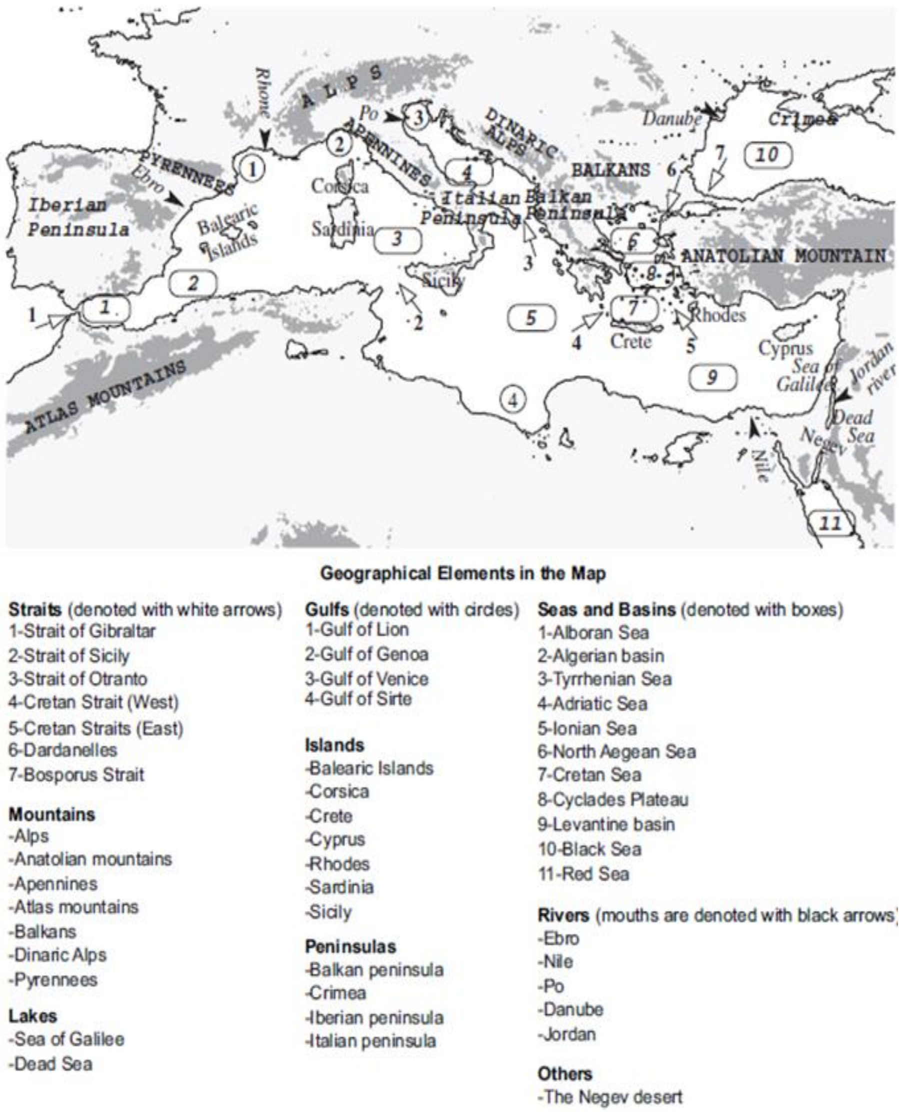


Figure 1.1.2: Map of the Mediterranean region: numbers represent the geographical features (Courtesy of Lionello et al., 2006)

Figure 1.1.2 shows the detailed map of the geographical features in the Mediterranean region, and it includes the straits, mountains, lakes, gulfs, islands, peninsulas, seas and basins, rivers etc. In general, the Mediterranean Sea is divided into three basins (Fig 1.1.3), the western basin extends from the Iberian Peninsula at the west to the Apennine Mountain chain at the east and from southern France to the northern African coast in the north-south direction. The central basin includes the watershed of the Adriatic Sea from the Apennines to the Balkans and at the south includes the ionic sea from the east coast of the Tunisia south of Sicily across the Libyan gulf to an imaginary line extending north south from the Balkan peninsula to the Libyan coast. The eastern (or Levantine) basin extends west from this imaginary line to the Israeli and Lebanon coasts and includes Aegean and black seas. The Iberian Peninsula separates the central Atlantic from the Mediterranean. Its high plateau and mountain ranges, together with the Apennines and the Balkans act as orographic barriers to the east-west displacement of weather systems. The Pyrenees, the Alps and the Balkans in Europe, the atlas in northern Africa, and the Taurus and high Anatolian peninsula in Asia minor (Turkey) also act as topographical barriers to the weather systems in north-south movement. The Mediterranean basin, therefore, acts as a physical interface between the frontal weather systems to the north, the Sahara and inter tropical fronts (ITF) to the south and the Asian monsoon system to the east (Millan et al.,2002).

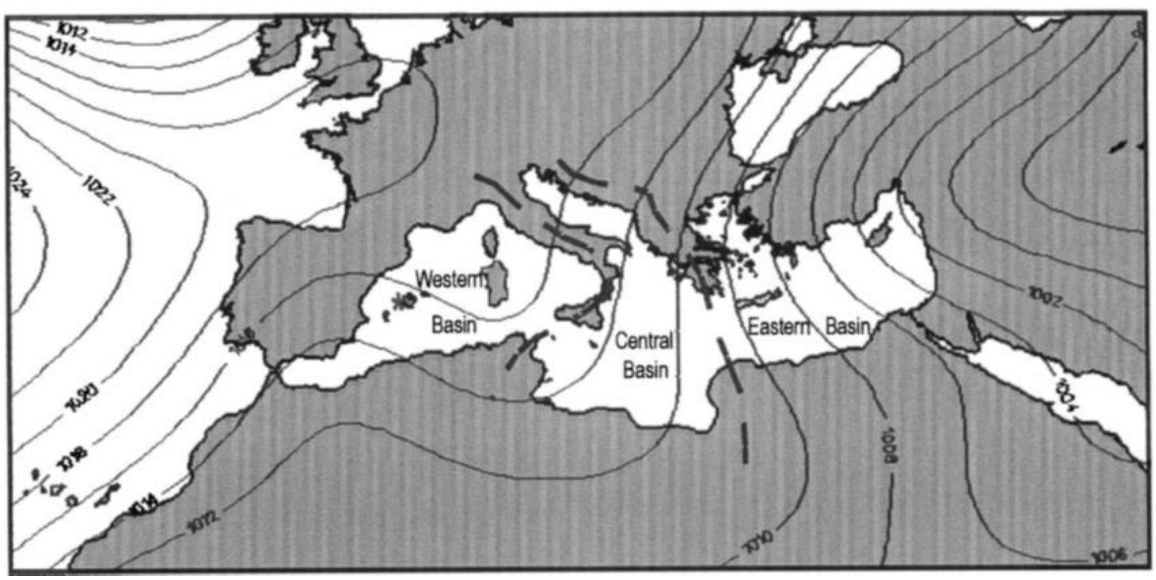


Figure 1.1.3: The three Mediterranean sub-basins and the average sea surface pressure for Europe in July (Courtesy of Millan et al., 1997

In general, Mediterranean Sea circulation can divide into three different water masses, in which the modified Atlantic water (MAW) is located between the surface and 100 m entering from the strait of Gibraltar. Due to the intermediate convection process MAW transformed into Levantine intermediate water (LIW) which is located between 200 and 300m. LIW is produced in the Levantine basin during the winter and its circulation goes from east to south. Third one is the Mediterranean deep water (MDW), which is the deep-water mass, separated in two reservoirs from the strait of Sicily. The western part

(WMDW) was produced during winter in the gulf of lions, the eastern part (EMDW) in the Adriatic Sea and Aegean Sea also in winter (Pinardi et al., 2013). These two vertical cells are driven by deep convective events leading to the formation of dense water masses and spread in the deepest layers, with subsequent upwelling and return flow at the intermediate layer into the convection region. The importance of these localized convection processes is determined by air-sea interaction and long-term preconditioning. In the western basin deep water convection process is also important for the primary production because when the upwelling occurs, the water that rises to the surface is colder and rich in nutrients. The nutrient-rich upwelled water means that these waters have high biological productivity and in these waters phytoplankton and zooplankton are present in such a large amount that they can support the main populations of cetaceans in the Mediterranean Sea (Macias D et al.,2018).

Atmospheric circulations across the Mediterranean basin in summer are dominated by two large, semi-permanent weather systems located at each end of the basin, the Azores high at the west and the Asian monsoon system at the east. As a result, pressure differences of up to almost 30-40 hPa can develop between the Atlantic coast of Portugal and the Arabian Peninsula (meteorological office, 1962). The surface properties and the mountains surrounding the basin trigger the development of strong sea breezes, up-slope winds, or combinations of the two, depending on the mountain/coast orientation. Extensive and deep convective cells, enhanced by the steep orography, can lead to orographically aided convection and mesoscale thermal lows also develop over the major landmasses such as peninsulas and islands during the day and decay during the night. Thus, subordinate to the major weather structures other large mesoscale circulations develop with marked diurnal cycles, i.e., the Iberian, Italian and Anatolian thermal lows. These together with their compensatory subsidence over the seas, strongly influence the evolution of the regional flows during the day. During late autumn and winter seasons the Mediterranean Sea acts as a large source of energy. Warm core anticyclones migrate to and stagnate over central Europe and can promote the development of episodic conditions over extensive areas (Millan et al.,2002). During these seasons atmospheric circulation over the Mediterranean Sea is characterized by the southern position of the polar front, the baroclinic instability of the long waves in the upper atmosphere and the associated depression activity. The depressions are formed mainly along the northern Mediterranean coasts due to the local orography and the strong baroclinicity (Trigo et al., 2002) and move over the warm sea surface (averagely warmer than the air above it), being deepened by the convection associated with the intense upward sensible and latent heat fluxes. The main areas of cyclogenesis along the northern Mediterranean coasts are the lee of the alps and to a lesser extent, the lee of Pyrenees (Lolis et al.,2008). Usually, mediterranean cyclones are frequently associated with severe weather such as heavy precipitation and strong winds. It is difficult to detect such depressions in their early stages due to their relatively small-scale structure (Buzzi A, 2010).

According to Koppen climate classification (1936), the northern part of the Mediterranean region refers to a maritime west coastal climate while the southern part is characterized by a subtropical desert climate. This classification is mainly due to the latitude of the Mediterranean Sea where this area is located in a transitional zone location, and mid latitude and tropical variability are crucial factors to determine the climate here.

The Mediterranean region is also prone to the effects of the North Atlantic oscillation (NAO) which is a large-scale climatic pattern associated with air masses displacement between the Arctic and the subtropical Atlantic (Brandimarte et al.,2010). NAO has a strong influence on winter weather and climate patterns in Europe and North America and can extend further into northern Asia if the phases are prolonged. Recent studies have identified the NAO as one of the dominant atmospheric patterns on the temporal evolution of winter precipitation in the Mediterranean area. NAO has a large and robust signal on winter precipitation, and it is anti-correlated over most of the western Mediterranean region (Hurrell 1995; Dai et al.,1997; Rodo et al.,1997; Xoplaki,2002; Trigo et al.,2004). On the contrary, NAO shows weaker signals in the eastern Mediterranean region (Yakir et a.,1996). The NAO influence on the winter temperature is smaller than that on precipitation. Above the North-western Mediterranean region, the spatial distribution of correlation with temperature has a positive feature which is weaker than the negative one of the correlations with precipitation (Pozo-Vazquez et al.,2001). Studies show variability of monthly mean winter temperature over the western part of the Mediterranean basin is mainly controlled by the variability of the East Atlantic (EA) pattern (Saenz et al.,2001; Frias et al.,2005).

Precipitation and temperature in the Mediterranean during the 20th century show significant trends. Giorgi (2002a) found negative winter precipitation trends over the larger Mediterranean land area for the 20th century. However, sub-regional variability is high and trends in many regions are not statistically significant in view of the large variability (e.g., Xoplaki, 2002). Giorgi (2002a) also analyzed the surface air temperature variability and trends over the larger Mediterranean land area for the 20th century based on gridded data of New et al., (2000). He found a significant warming trend of 0.75 °C in one-hundred years, mostly from contributions in the early and late decades of the century. Since 1950 large areas across Europe have experienced many intense and long heatwaves producing notable impacts on human mortality, regional economies, and natural ecosystems (Meehl and Tebaldi 2004; schar et al.,2004; Garcia-Herrera et al.,2010). Increase of the heat waves is perceived to be a major problem especially after the 2003 episode that hit Central Europe. It heavily affects north-western Mediterranean countries such as Spain, France, and Italy. The average summer temperature in Europe exceeded, very likely, the average temperature of any previous summer over the last 500 years (Lautenbacher et al., 2004). Béthoux et al. (1998) found that temperature and salinity of Mediterranean deep waters have been increasing, based on observations extending back to 1959 and which will affect the Mediterranean Sea general circulation. Béthoux et al., (1998) also observed, over a period of 1940-1995, the corresponding changes in heat and water budgets across the sea surface which have been estimated to be 1.74 Wm_{-2} for the greenhouse effect change and found the increase of mean air and sea surface temperature with respect to 0.5 ° and 0.4 ° Celsius.

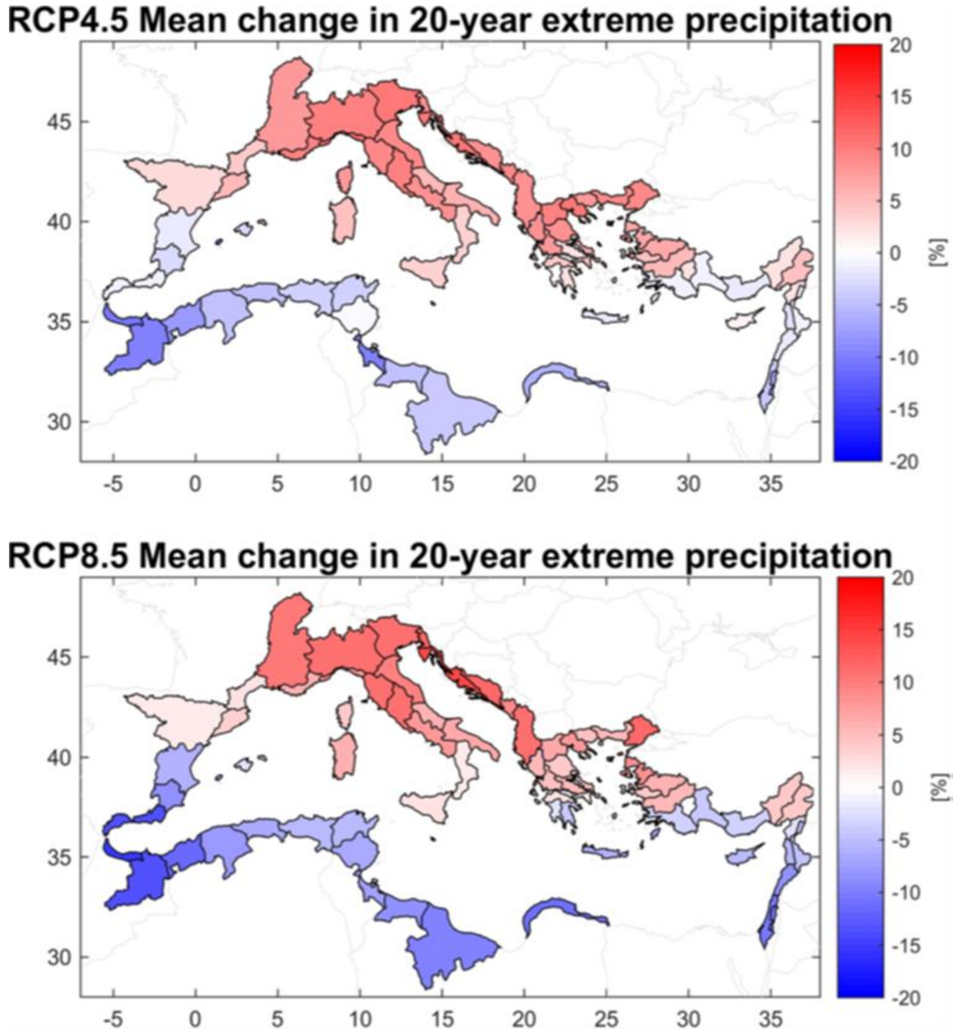


Figure 1.1.4: Mean relative changes towards the year 2100 in the 20-year return period of extreme precipitation for each of the 102 Mediterranean basins under scenario RCP4.5 and RCP8.5 (Courtesy of Tramblay and Somot, 2018)

According to Tramblay and Somot (2018) Mediterranean basins can be impacted by severe floods caused by extreme rainfall, and there is a growing concern about the possible increase in these heavy rainfall events due to climate change. Tramblay and somot investigated extreme daily precipitation in 102 catchments using nonstationary extreme value model applied to annual maximum precipitation in an ensemble of high-resolution regional climate model simulations from the Euro-CORDEX experiment. Figure 1.1.4 shows the relative changes in extreme precipitation for the 20 years quantified for RCP 4.5 and RCP 8.5. The relative mean changes between the different RCM's are spanning between -20 % and +20% on average, depending on the locations.

Increasing trends are observed in north-Spain, south France, northern Italy, Greece, and the Adriatic Sea whereas decreasing trends are found in north-African basins.

According to Kjellström et al (2018) Europe will warm in all the seasons in the future, temperature increase shows highly consistent and the temperature changes in Europe were mostly larger than the global mean warming. They used an ensemble of EURO-CORDEX high resolution regional climate model (RCM) simulations undertaken at a computational grid of 12.5 km horizontal resolution covering Europe. The ensemble consists of a range of RCMs that have been used for downscaling different GCMs under the RCP8.5 forcing scenario. They investigated periods for which the global mean near surface temperature is 1.5 or 2° Celsius above pre-industrial conditions which are referred to as SWL1.5 and SWL2, where SWL stands for specific warming level. They found the warming is strongest in northern and north-eastern Europe in winter and in southernmost and northernmost Europe in summer. In these areas future temperature changes with respect to 1971-2000 are larger than respectively +1.5 and 2 ° Celsius at SWL1.5 and SWL2, which corresponds to a warming of almost +2 or +2.5°Celsius compared to pre-industrial (1861-1890) conditions. They found the wind speed future changes are highly uncertain and also observed the changes in the mean sea level pressure (MSLP) which can make an impact on regional wind changes. Changes in MSLP not only influence wind speed but also modify the climate change signal in temperature and precipitation.

Long run heat waves that are unusual in the current climate will become more common along with rising global mean temperatures and could occur in any country in Europe. The anthropogenic increase in greenhouse gas concentrations implies an increased probability of extreme heat waves in Europe in the next two decades (2021-2040) (Russo et al.,2015). In the mediterranean basin there is also evidence for the marine heat wave (MHW) impact, MHW is usually defined as the coherent area of extreme warm sea surface temperature (SST) that persists for days to months. According to Darmaraki et al (2019), due to increasing greenhouse gas emissions the MHW events become stronger and more intense under RCP4.5 and RCP8.5 than RCP2.6. They used a dedicated ensemble of fully coupled regional climate system models from the Med-CORDEX initiative and a multi scenario approach. They observed, by 2100, under RCP8.5, the simulations showed at least one long lasting MHW every year, up to three months longer, mainly expected to occur in June-October months in the entire basin. The evolution of MHW mainly occurs due to an increase in the mean SST and increased daily SST variability also plays a noticeable role. By the end of the century the annual mean SST in the Mediterranean basin is expected to increase from + 1.5 °C to + 3 °C relative to present-day levels, depending on the greenhouse gas (GHG) emission scenario (Somot et al. 2006; Mariotti et al. 2015; Adloff et al. 2015). In fact, this significant rise in SST is expected to accelerate future MHW occurrence. The marine heat wave can alter the eco systems in the Mediterranean basin. The MHW and SST changes predicted for the 21st century will clearly impact the Mediterranean Sea's Biodiversity. MHWs exert a strong influence not only on marine ecosystems but also on marine-dependent economies and hence society.

According to Reale et al (2021), at the end of the twenty-first century Mediterranean cyclones show a decrease in the number and their observation shows an overall weakening of cyclones moving across the Mediterranean region. Their analysis of future projections of cyclone activity in the Mediterranean region at the end of the twenty-first century was based on an ensemble of fully coupled Regional Climate System Models (RCMs) from the Med-CORDEX initiative under the RCP8.5. They observed a decrease in the number and intensity of cyclones mainly crossing the central part of Italy, Tyrrhenian Sea, part of the Anatolian Peninsula, Balkan area, and part of Northern Africa. They also found a robust increase in the cyclone-related precipitation and wind intensity in the central part of the Mediterranean region.

1.2) Pelagos Sanctuary for Mediterranean marine mammals

The Sanctuary for Mediterranean Marine Mammals - Pelagos, is a marine protected area instituted for the conservation of marine mammals. It covers an area of approximately 87500km^2 including the waters between Toulon (French riviera), Capo Falcone (western Sardinia), Capo Ferro (eastern Sardinia) and Fosso Chiarone (Tuscany).

The Pelagos sanctuary was established in 2002 with an agreement between France, Italy and Monaco and it contributes to the conservation of the Mediterranean Sea at two scales: (i) locally, by protecting important marine mammals foraging and breeding grounds in the Ligurian Sea, and by providing ‘umbrella’ protection to other marine predators in this area; and (ii) regionally, by empowering other conservation measures, such as the Specially Protected Areas Protocol of the Barcelona Convention and the wider goals of the Agreement on the Conservation of Cetaceans of the Black and Mediterranean Seas (ACCOBAMS). The sanctuary includes the Ligurian sea and parts of the Corsican and Tyrrhenian seas which is composed of the internal maritime (15% of its extent) and territorial water (32%) of France, Monaco, and Italy as well as the adjacent high seas (53%). The continental shelf (200 m isobath) is wide within the sanctuary only where it abuts limited coastal plains; it is mostly narrow and dissected by steep, deeply cut submarine canyons. The figure 1.2.1 shows the Pelagos sanctuary’s bathymetry, in which the western offshore portion of the sanctuary consists of a uniform abyssal plain of 2500-2700 m deep offshore of the continental slope while east of the Corsica the seafloor is shallower (1600-1700 m) and uneven with a series of islets and a deep-water channel bisecting the continental shelf (Sciara G et al., 2008).

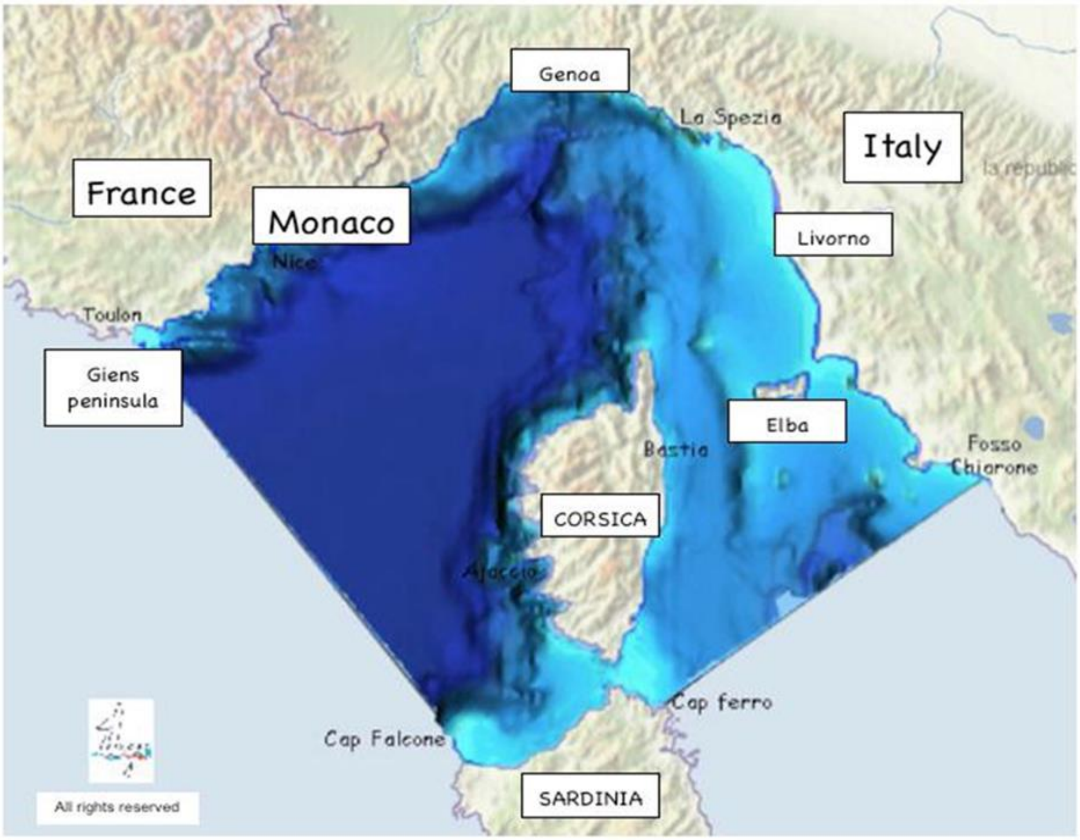


Figure 1.2.1: Pelagos sanctuary bathymetry (Courtesy: https://www.sanctuaire-pelagos.org/images/cartes/CartePelagos2b_en.jpg)

The dominant circulation near the sanctuary is modulated by intense mesoscale activity characterized by cyclonic and anticyclonic fronts (Druon et al., 2012). Specifically, the Liguria province is an area of cyclonic currents between Corsica and the mainland (Laran and Gannier 2008) which continues south of the Channel of Ibiza where has been renamed “Northern Current”. In summer this current is shallow, wide and displays a reduced mesoscale variability; in winter it becomes thicker and narrower and tends to flow close to the slope. From winter to spring, an intense and barotropic mesoscale propagates and induces seasonal variability (Millot 1999). The “Northern Current” flows along the continental slope, but there is another current that is associated with the North Balearic front (Cottè et al., 2012).

In winter the dominant wind is “mistral”, instead, during summer, the wind regime is much changeable, but still capable to strongly affect the upwelling, pumping deep nutrients and other organic substances contributed by rivers into the eutrophic zone (Azzelino et al., 2012; Agostini et al., 2002). Floods events are characteristic of most Mediterranean river systems and in addition, Rhone and Ebro rivers dominate the discharge on the north of the Mediterranean Sea (Arnau et al., 2004).

Casella et al., (2014) observed the ecosystem dynamics in the Liguro-provençal basin to obtain the role of eddies in biological production. They studied numerically the role of mesoscale structures in the Ligurian sea (NW mediterranean sea) as a possible factor affecting the chlorophyll spring bloom's spatial distribution. They used the regional ocean modeling system (ROMS) configured for the NW mediterranean sea also satellite derived altimetric, sea surface temperature, and chlorophyll concentration data for years 2009 and 2010. They observed a significantly high number of eddies which were found during the chlorophyll rich year 2010. These high numbers of eddies generate spatially and temporally localized fluxes of nutrients into the eutrophic zone and it will contribute to the ligurian sea's fertilization. So that, eddies in the Ligurian rim current can have a crucial importance on the location of development of the main patch of chlorophyll spring bloom and on local ecosystem dynamics.

1.3) Fin whale distribution in the Pelagos sanctuary

The fin whales are not homogeneously distributed in the Mediterranean basin. Dividing the Mediterranean Sea into sub-regions, moving from north to south it is possible to highlight: Western Basin, Ligurian-Corsican-Provençal Basin, and Gulf of Lions, where the species is regularly present; Tyrrhenian Sea where the species is present, Aegean Basin where the species is rare or absent, Levantine Basin where we don't have information (Figure 1.3.1).

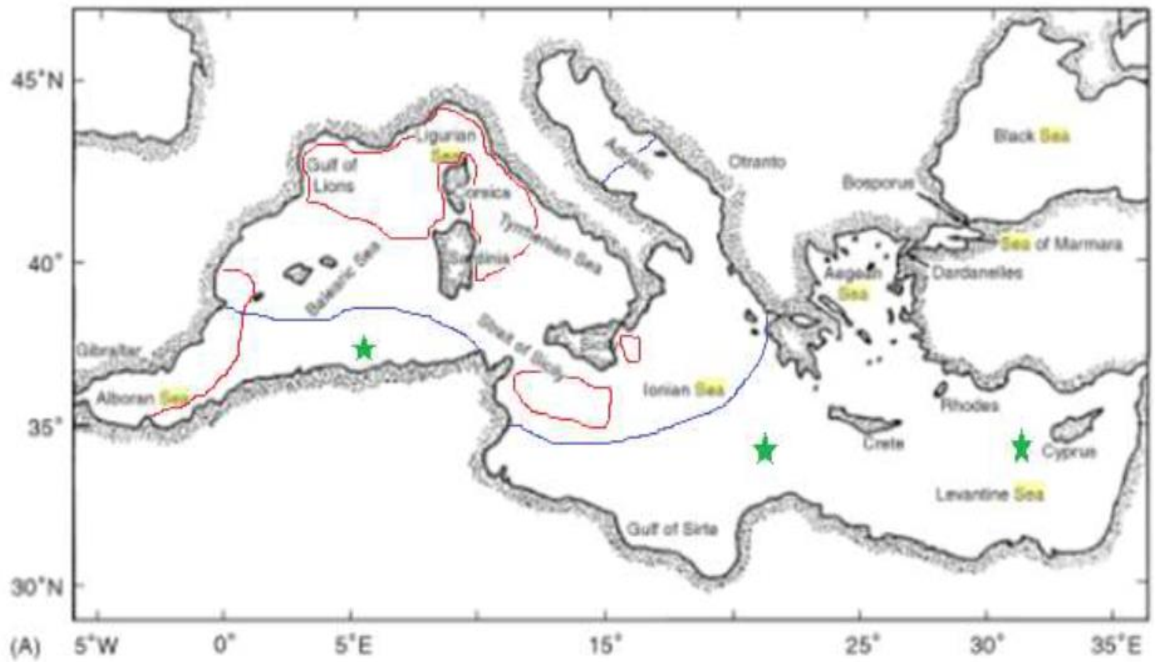


Figure 1.3.1: Map of the Mediterranean Sea, showing currently known geographical ranges of fin whale populations: red = Mediterranean sub-population regular, blue = Mediterranean sub-population present, white = Rare or absent, green = Missing information

One of the main forcing factors to establish the Pelagos sanctuary institution in 2002, was the relevant presence of the only mysticete species regularly sighted in the Mediterranean Sea, the fin whale *Balaenoptera physalus* (Sciara G et al.,2008). Generally, fin whales aggregate in the north-western Mediterranean Sea from spring to the end of summer (Sciara G et al.,2003). However, their destination during other seasons is still a matter of debate.

Fin whale distribution in the NW Mediterranean Sea is mainly linked to prey availability, which is in turn determined by primary production. Fin whales feed in most season zooplanktonic shrimps and small pelagic fish, although it appears that in the mediterranean sea, this large cetacean mainly forages during the summer on small euphausiid species (e.g., *Meganyctiphanes norvegica, Nyctiphanes couchi*) (Martins AM et al.,22006; BentalebI et al.,2011). While little information is available on for the distribution of these species, it has been demonstrated that parameters such as sea surface chlorophyll concentration, sea surface altimetry or sea surface temperature can be efficiently used as proxies for food availability (Arcangeli A et al.,2014; Panigada S et al.,2008; Cotté C et al.,2009).

Fin whales are found mostly in deep, offshore waters (400 to 2500 m) of the western and central portion of the Mediterranean basin, but their presence also shows in slope and even shelf waters, depending on the distribution of their prey (Azzellino A et al.,2008; Moulins A et al.,2008; Laran S et al.,2008). In general, the fin whale presence and distribution can be directly correlated with coupled physical/biological dynamic oceanographic processes (e.g., species biomass, primary production, eddy signatures, currents, frontal structures, Laran S et al.,2008; Panigada S et al., 2008). These processes occur at different spatial and temporal scales which can modulate the whale pattern depending on their prey patches.

The almost complete separation of the fin whales from the Mediterranean and from the Atlantic coastal waters of Canada, Greenland, Iceland, and Spain are confirmed by genetic and ecological differences (Bérubé et al., 1998). Recent studies show that rising risks from local human activities, especially the marine traffic has raised concerns about the conservation status of the species within Mediterranean limits. As a result, the Mediterranean fin whales have been listed as vulnerable species according to the red list criteria of the international union for conservation of nature (IUCN) (Panigada S et al.,2012). The species is also facing ship strikes, marine litter, chemical pollution, and noise (Tepsich P et al.,2020). The coastal zone of the Pelagos sanctuary consists of a lot of tourist destinations, and which might be the potential threats to the fin whale especially in the summer period because of whale watching tours, ferry traffic and coastal runoff (Sciara G et al.,2008).

According to Tepsich et al (2020) summer presence of Fin whales in the Western Mediterranean area shows a strong interannual variability (Figure 1.3.2). They used the Generalized additive model (GAM) to describe density trends over a 11-year period (2008-2018) in four different sub areas which are western Pelagos sub area, Pelagos sanctuary sub area, south-eastern Pelagos sub area and Adriatic sub area. Their analysis shows western Pelagos sanctuary has the highest density of fin whales and the lowest density value characterized in the south-eastern Pelagos sub area. Overall, the western Mediterranean basin shows high density (rich) years as 2012, 2013, 2015 and specifically low-density years are 2009, 2014 as for 2008 it showed lower research effort which likely contributes to low density. They assumed also that small and large groups of fin whales were sighted only during rich years, confirming the favorable feeding condition influencing species presence (Tepsich et al.,2020).

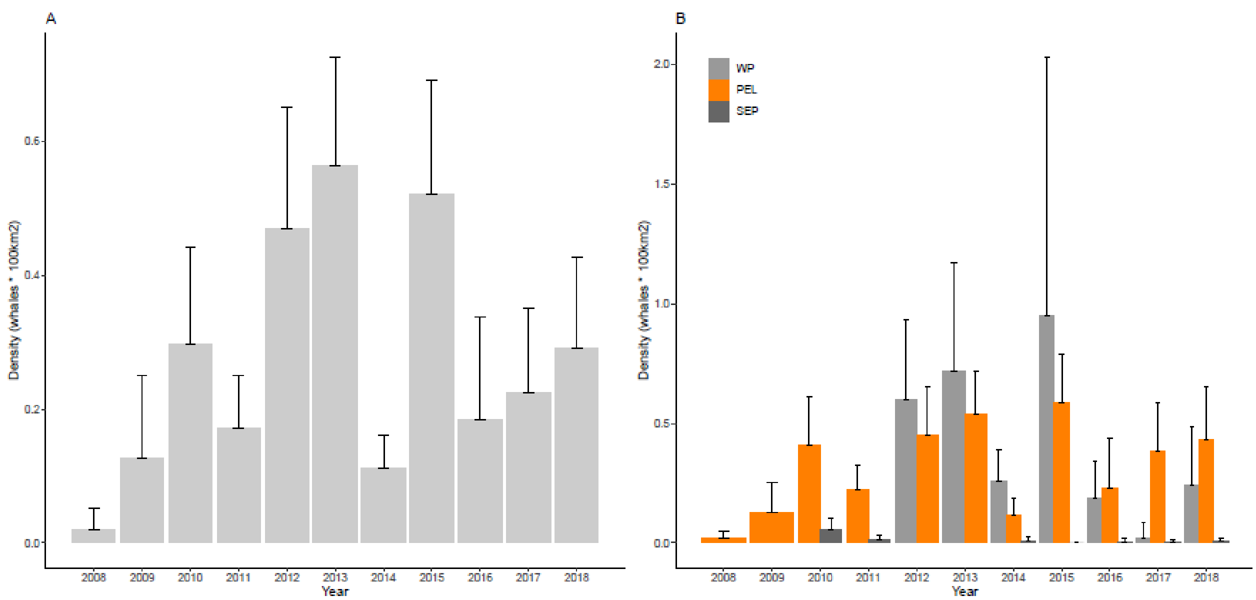


Figure 1.3.2: Density of fin whales in the western Mediterranean Sea with the sub areas. A) mean density of the fin whales per year in the western mediterranean basin (B) Mean density of fin whales per year in the western Pelagos (WP), Pelagos sanctuary (PEL) and southeastern Pelagos (SEP) sub areas (Tepsich et al.,2020)

During summer 2007 fin whale distribution in the north-western Mediterranean Sea showed many anomalies. Tepsich et al., (2008) observed these anomalies, their first observation was about the individuals which sighted in the near coastal areas. They analyzed the general distribution of the fin whale in the Ligurian sea with whale watching cruises and compared the results with past years (Fig 1.3.3). In 2007, at least 20 sightings of fin whales in the Mediterranean Sea were found at less than a mile off the coastline and among them 6 were juveniles. The juvenile fin whales showed a high mortality rate. Overall, this year sighted comparatively low number of fin whale. Tepsich et al., (2008) also observed the sea surface temperature and the chlorophyll concentration. They found the anomalies in SST values especially during May and SST was about 16-19 °C, it was higher than 5-6 °C higher than the average values. Also, during 2007 chlorophyll concentration showed low values in the month of march, which significance the early and poorer spring phytoplankton bloom. Therefore, fin whale distribution anomalies in 2007 might affected due to these factors, especially the early and poorer phytoplankton blooming which could have affected fin whale's prey availability.

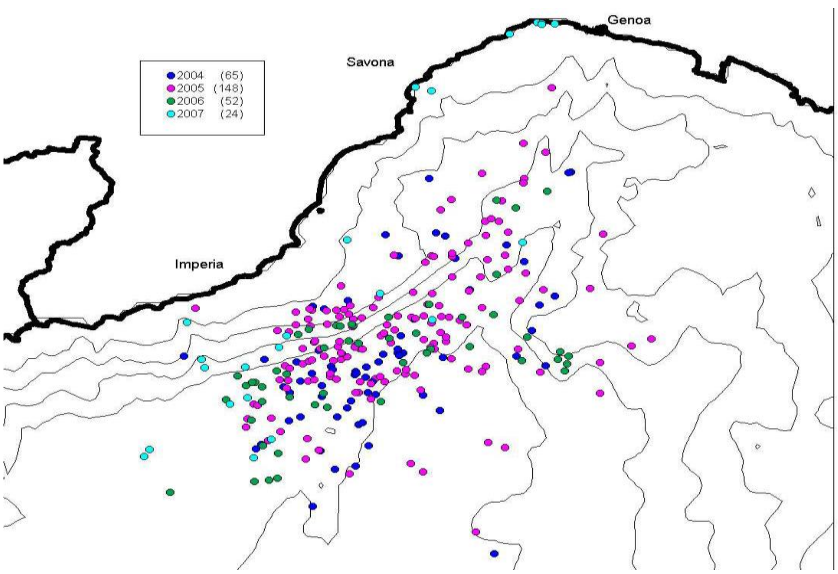


Figure 1.3.3: fin whale distribution in Ligurian sea from 2004 to 2007 (Tepsich et al.,2008)

Generally, the Mediterranean Sea is considered as oligotrophic, therefore any supply of nutrients is extremely important for the primary production in this region. The Western Mediterranean productivity is notoriously spatially heterogeneous, and influenced by the effects of currents, the freshwater river runoff input, and the mixing by localized winds steered by topographic features (Estrada, 1996; Salat, 1996; Agostini and Bakun, 2002; Arnau et al., 2004). Among them our rainfall and temperature analysis mainly related to the river discharge into the Pelagos sanctuary area.

Chapter two

Data details

2.1) Study area

For the climatological analysis we have chosen an area surrounding the Pelagos sanctuary which includes three of the Italian regions: Liguria, Tuscany, and the northern side of the Sardinia region. The study area extends from Latitude of 40.5N to 44.5N and longitudes of 7.5E to 10.7E (Figure 2.2.1). The rainfall in the considered study area probably discharges into the Ligurian and Tyrrhenian Sea. For better work, the study area has to be constructed along the basins discharging into the sea. However, this would have led to a very irregular domain, so as a first approach in the thesis we tried to cut the domain a proper way that could be a good proxy of the rainfall insisting on those basins discharging in the interested area but using a regular domain. The Liguria region includes all of its provinces which are Imperia, Savona, Genova, and La Spezia. The region is crossed east to west by the Ligurian Alps and the Ligurian Apennines that form an interrupted chain, but discontinuous in its morphology. The continental shelf of Liguria is very narrow and so steep it descends almost immediately to considerable depths along its 350-kilometer coastline. Orographic forcing is a key element that generates intense precipitation over this region, it is due to the presence of the Alps and Apennines close to the coast. Ligurian Alps are drained by the Tanaro river along with other tributaries of the Po River on the Piedmontese side and by several smaller rivers flowing directly to the Mediterranean Sea on the Ligurian and French side. There are totally 20 rivers in the Liguria region, mainly discharging into the Ligurian sea. This region is well known for the cyclone events especially the Genoa type depressions which are mainly occurring in this region. The depressions bear rain, often intense, on the Ligurian coast and hills of Tuscany, due to orographic lift which affects the southern side of the Apennines. During the winter season the precipitation in this area is mainly correlated to the North Atlantic Oscillation. The NAO has crucial importance in marine ecosystems in the western mediterranean basin, it can make an impact on the hydrodynamics of the water column and currents are felt in the dynamics of populations from plankton to fishes in both pelagic and benthic environments.

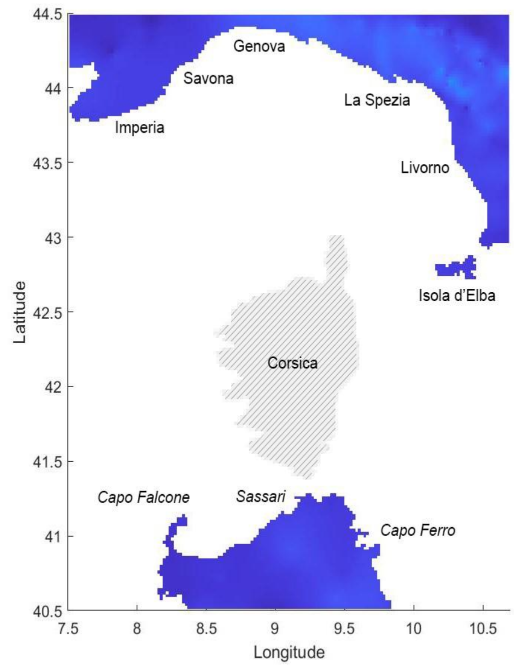


Figure 2.2.1: Study area for the climatological analysis of Pelagos sanctuary surrounding region

The provinces of Tuscany which are Massa carrara, Lucca, Pisa, Livorno included in the study area, these are near coast provinces of the Tuscany region. Tuscany has a western coastline of Ligurian sea and Tyrrenhian sea, among which is the Tuscan Archipelago, of which the largest island is Elba. Apuane mountain ranges located in the northern Tuscany which includes the valleys of Serchio and Magra rivers both discharge into the Tyrrhenian Sea near to the Pelagos sanctuary area. Another important river in this region is Arno, which is also an important river in central Italy, and it discharges into the Tyrrhenian Sea. Sardinia is the second largest island in the Mediterranean Sea and for this study area we have chosen the northern part of the region. Sardinia region consists of west as Capo Falcone and east as Capo Ferro and which are the border for Pelagos sanctuary on the south side.

2.2) Observational data sets used in this thesis

2.2.1) E-OBS climatological data set

Concerning the climatological dataset used in this work, the E-OBS dataset (version 23.1e) of daily average of temperature and daily rainfall over 30 years. This dataset is at 0.1degree (11 km) grid spacing resolution and the data spans from 1979 to 2008.

The E-OBS is a land-only gridded daily observational dataset for precipitation, temperature, sea level pressure, global radiation, wind speed and relative humidity in Europe. This dataset is based on observations from meteorological stations across Europe which are provided by the National Meteorological and Hydrological Services (NMHSs) and other data holding institutes. The E-OBS Dataset is provided with regular latitude-longitude grids, with spatial resolutions of 0.1° and 0.25°, and has a daily resolution. The E-OBS coverage spans much of the European continent, from northern Scandinavia to southern Spain and north Africa, and from Iceland into the Russian Federation at 40°E, but the coverage changes through time as the station coverage expands and decreases in time. The station data are provided by 79 participants and the ECA&D dataset contains over 20000 meteorological stations. The series Metadata, including the source and metadata of the meteorological stations are provided through the ECA&D website. For a considerable number of countries, the stations number used is the complete national network and therefore much denser than the station network that is routinely shared among NMHSs which is the basis of other gridded datasets. Figure 2.2.1 shows the stations map that are used in the E-OBS dataset. This figure shows the stations high density stations in many parts of Europe, but it also shows the observations inhomogeneity spatial coverage, with generally a less dense coverage in Europe's southeast and northern Africa. The stations density gradually increases through collaborations with NMHSs within European research contracts. Figure 2.2.2 shows the steep increase in the number of stations in the 1950s, leveling-off in the early 1960s for temperature and reaching a maximum in the 1980s-1990s for precipitation. The decline in the most recent part of the record mostly relates to slow and infrequent updates of data by the NMHSs that do not provide updates on a regular basis

Initially, E-OBS gridded dataset was developed to provide a validation dataset for the suite of Europe-wide climate model simulations produced as part of the EU ENSEMBLES project. While E-OBS remains an important data set for model validation, it is also used more generally to monitor the climate across Europe, particularly with a focus on the daily extremes magnitude and frequency assessment. E-OBS and the underlying station dataset are the backbone of the climate data node for WMO RA VI regional climate center. The dataset will be updated twice a year with provisional monthly updates. Figure 2.2.3 shows the user groups pie chart of ECA&D and E-OBS based on a survey from 2013, which shows that the use of E-OBS has spread beyond the climate community.

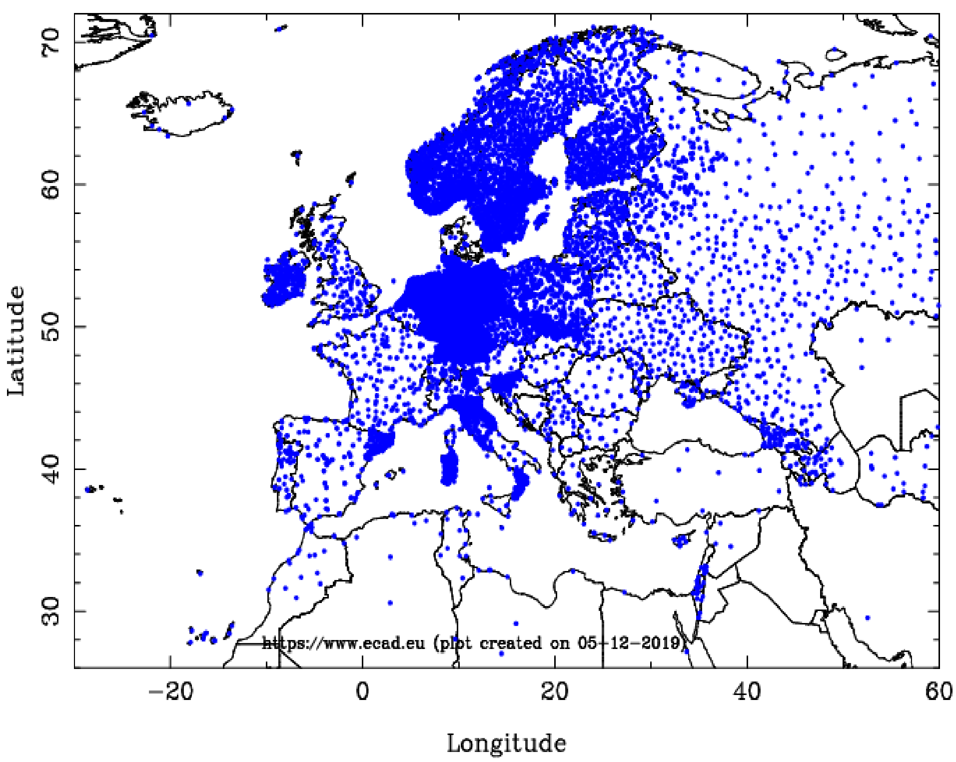


Figure 2.2.1: i) Map with the station coverage in ECA&D which is the basis for the E-OBS precipitation dataset v20.0e (v20e released in October 2019)

(Courtesy:https://cds.climate.copernicus.eu/cdsapp#!/dataset/insitu-gridded-observations-europe?tab=doc, E-OBS product user guide)

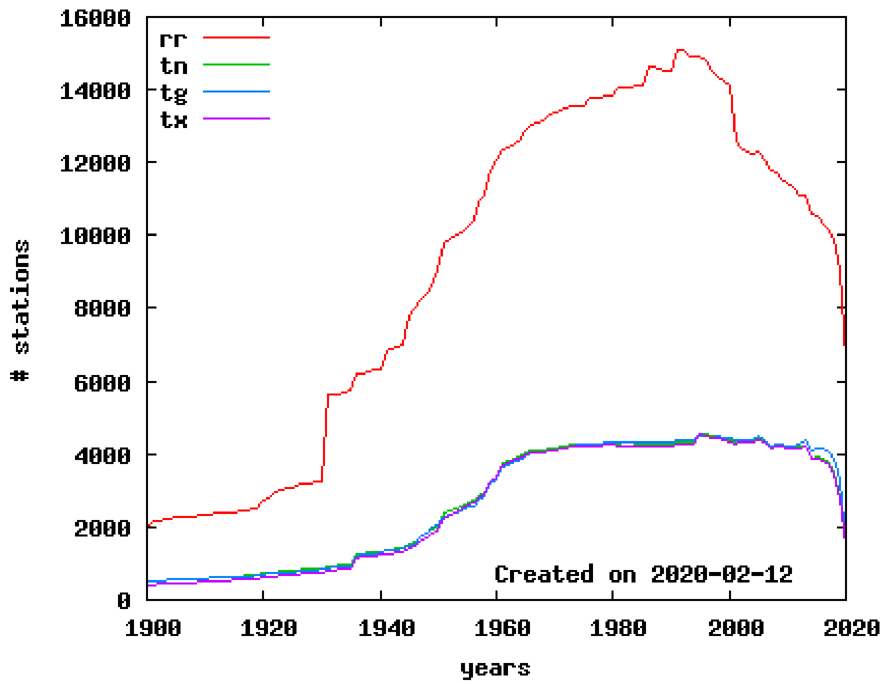


Figure 2.2.2: The number of stations which provide precipitation (red) and temperature (green, blue, purple) vs. time. (Courtesy: https://cds.climate.copernicus.eu/cdsapp#!/dataset/insitu-gridded-observations-europe?tab=doc, E-OBS product user guide).

The E-OBS position is unique in Europe because of the relatively high spatial resolution, the daily resolution of the dataset, the provision of precipitation, temperature, sea level pressure, global radiation, wind speed and relative humidity, and the length of the dataset. All variables provided in E-OBS start in 1950, except for wind speed which starts in 1980.

E-OBS comes as an ensemble data set, and it is constructed through a conditional simulation procedure. For each of the ensemble members a spatially correlated random field is produced using a pre-calculated spatial correlation function. Then the ensemble mean is calculated and provided as the “best-guess” fields. The spread is calculated as the difference between the 5th and 95th percentiles over the ensemble to provide a measure indicating the 90% uncertainty range.

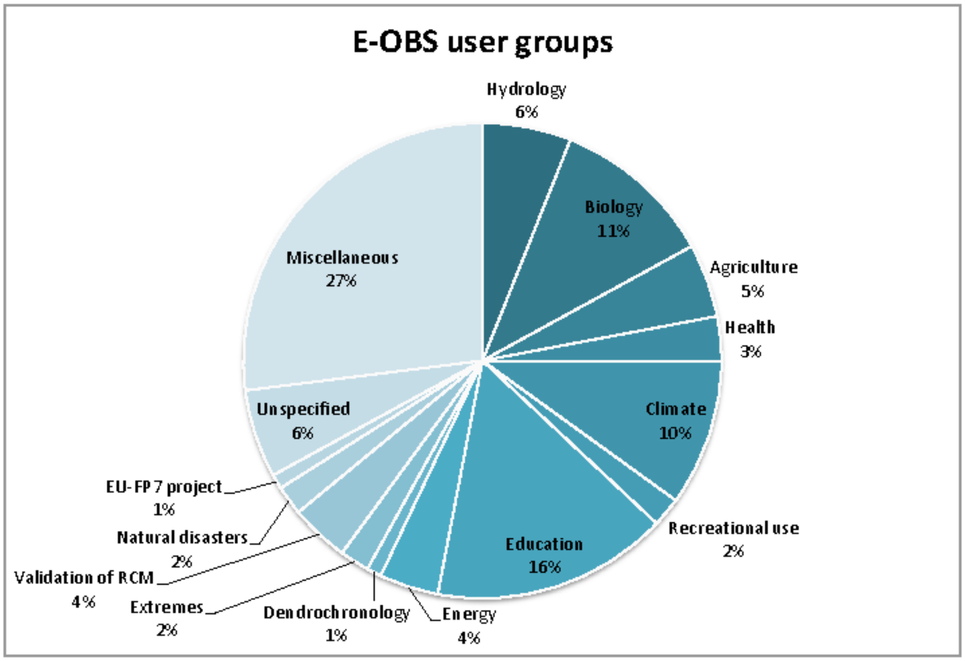


Figure 2.2.3: Pie chart of the user's groups of ECA&D and E-OBS based on a survey from 2013 (courtesy:https://cds.climate.copernicus.eu/cdsapp#!/dataset/insitu-gridded-observations-europe?tab=doc).

2.2.2) Rainfall observational dataset

Considering the rainfall dataset, we have used the cumulative rainfall dataset, it starts from pluviometric observations and is interpolated with the GRISO interpolation method. The dataset was obtained by the Italian Civil Protection Department network with the cooperation of CIMA Research Foundation, Savona, Italy. We retrieved the rainfall dataset as the monthly rainfall, and it consists of the entire Italian region; this dataset spans from 2006-07 to 2021-22. We have also retrieved the daily cumulative rainfall dataset for the daily rainfall analysis in winter seasons, it has the period from 2006-07 to 2020-21. Both the monthly and the daily rainfall datasets are at a grid space of 0.02-degree (2.2 km) resolution. For our study area it consists of 32000 pixels (200x160). In general, Hydrological monitoring in Italy is obtained by the Decentralized Functional Centers (CFD) network and which is coordinated by the Italian Civil Protection

Department and its Central Functional Center (CFC). Figure 2.2.4 shows the rain gauge network in Italy, the network is composed of about 4500 stations in telemetry that record continuous measurements of rainfall accumulation and transmit them to the CFD and the CFC. Our dataset probably has used less stations than current stations because the data period starts from 2006. Figure 2.2.5 shows an example for the rainfall map which was obtained from the Italian Civil Protection Department rain gauges network. It shows an example for the monthly rainfall in Italy and our study area.

The spatial distribution and position of the rainfall fields estimation is a crucial task while modeling the rainfall nowcasting and modeling the catchment response to rainfall. There were several studies made on the spatialization of rainfall from rain gauge and many methods were invented. One of the famous methods was kriging, which is also known as gaussian process regression, is a method of interpolation based on Gaussian process governed by prior covariances. GRISO (Generatore random di interpolazione spaziali da osservazioni incerte) is another interpolation algorithm method, implemented by the CIMA Research Foundation for the rainfall data processing (Pignone et al., 2010). GRISO is similar to kriging, so the output map maintains the observed real rainfall value on the rain gauges position but is conditioned to reach the mean of the field far from the gauges. Compared to kriging, GRISO interpolation method have improved computational time with associated map of variance and above all the possibility of using more than one semi variogram for spatialize the information.

The GRISO interpolation algorithm calculates a continuous precipitation field F (x, y) starting from the point values, (V*i*) from the precipitation heights observed by the pluviometric network sensors. The algorithm is structured in such a way the interpolated precipitation field F satisfies the conditions concerning, the maintenance of the same precipitation value measured by the rain gauge in correspondence with the relative physical point within the interpolated field and the achievement of an imposed value μV to be reached where the influence of the correlation structures of the rain gauge is zero. In order to obtain the interpolated field to have the aforementioned characteristics, it is important to define some mathematical parameters relating to the input variables, such as a single rain gauge station's covariance kernel K (x, y) and the correlation length (range) λ.

Nowadays, it is widely used for the merging between rain gauges and radar derived rainfall data. This method is feasible at large-scale rainfall observation and represents effective early warning systems for flash floods. However, for our research we needed the analysis from 2006 so that we used only the rain gauges data to have a homogeneous observation. In general, the Modified Conditional Merging (MCM) algorithm with the GRISO interpolation is using to generate rainfall estimates by blending data from national radar and rain-gauge networks (Bruno et al., (2021).

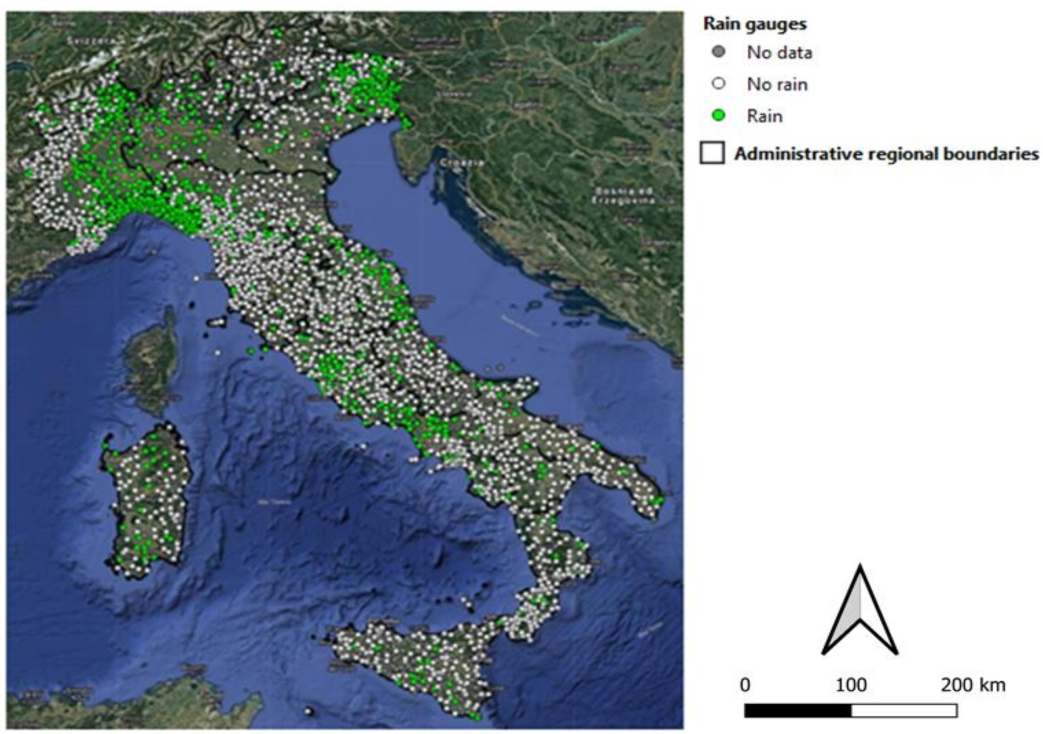
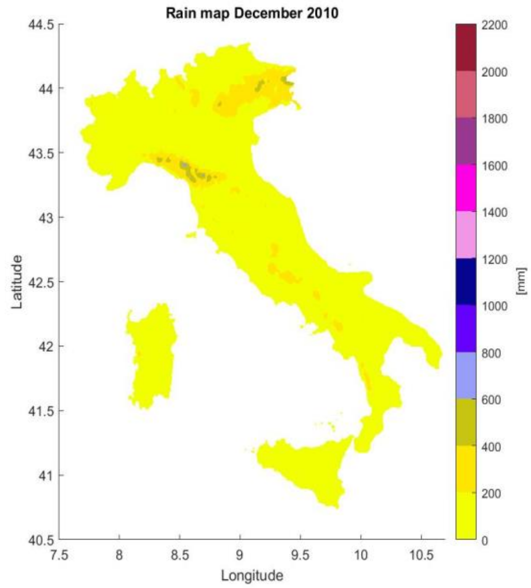


Figure 2.2.4: Italian rain gauge network (Courtesy: Bruno G et al., 2021)



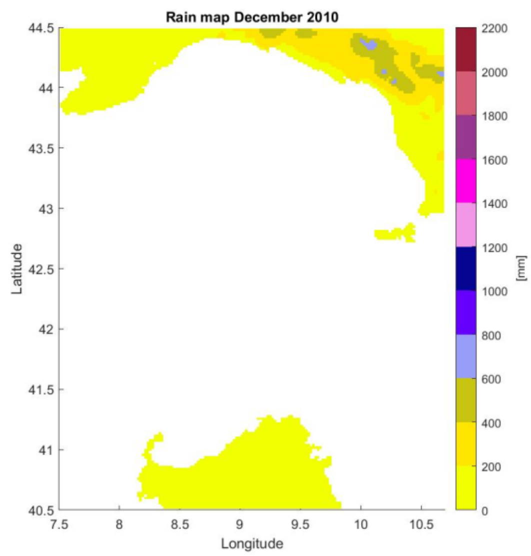


Figure 2.2.5: i) Monthly rainfall over Italy (December 2010, 0.02 grid space, 363,456 pixels) ii) Monthly mean temperature over Pelagos sanctuary surrounding region (0.02 grid space, 32000 pixels).

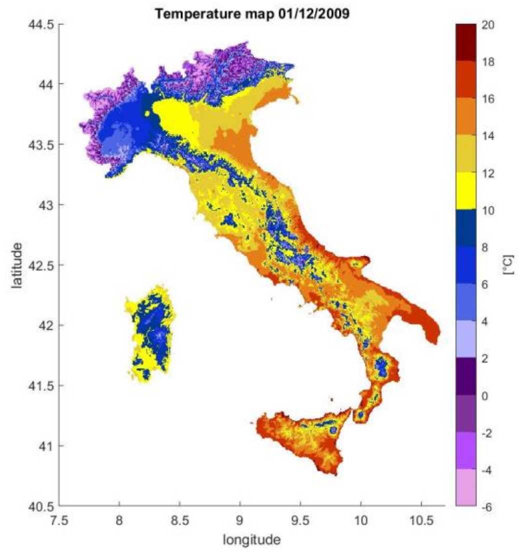
2.2.3) Temperature observational dataset

Temperature dataset also retrieved from the Italian Civil Protection Department network, concerning the thesis work we used the daily average temperature dataset, and it spans from 2006-07 to 2021-22. Currently the temperature stations network is about 3800 stations. Because of our period of interest, the temperature station's number used for our dataset is probably lower than current stations. The temperature dataset has the grid space at 0.02-degree (2.2 km) resolution, and it consists of the entire Italian territory, for our work we cropped over the Pelagos sanctuary surrounding region. The figure 2.2.6 shows the example of the temperature maps which is obtained from the temperature stations, the figure shows an example of daily average temperature in Italy and the Pelagos sanctuary surrounding region.

The temperature dataset is constructed using the interpolation method of linear regression with altitude, General procedure for this interpolation method is convert air temperature (Ta) measurements to sea level potential temperatures (θa), spatially interpolate θa points to a grid space using algorithm and use the inverse of potential temperature function to map the θa surface to DEM elevations. The following equation is used to compute sea-level reference temperature (Ts1),

$$Ts1 = Ta - \lambda z,$$

where Ts1 is the sea-level reference temperature (°C), Ta is the measured air temperature (C km-'), and z is the station elevation (km) (Dodson and Marks, 1997).



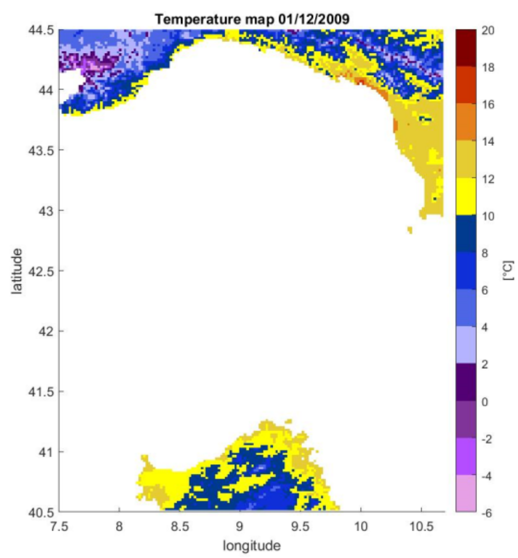


Figure 2.2.6: i) Daily mean temperature over Italy (December 1, 2009), (0.02 grid space, 363,456 pixels). ii) Daily mean temperature over Pelagos sanctuary surrounding region (December 1, 2009) (0.02 grid space, 32000 pixels).

2.3) Methods

The data analysis is completely done with the MATLAB software. The seasonal average values of temperature and rainfall for the autumn and the winter seasons from the period of 2006-07 to 2021-22 have been calculated. Afterwards, the seasonal average values of each year compared with the past seasonal climatological value of rainfall and temperature. The climatological value is averaged over a 30 years period (1979-2008). The map view elaborates the spatial distribution of climatic variables which helps to understand areas that have higher/lower values of temperature and rainfall.

Daily analysis of the rainfall mainly done for the winter season which span from 2006-07 to the 2020-21. This analysis will give a detailed view of rainy days in winter seasons to assess the rainfall distribution along the season. Finally, our results are compared with the fin whale data to evaluate possible correlations between fin whale distribution and anomalous winter seasons with respect to climatology.

Chapter three
Data analysis results

In this chapter the focus is on the data analysis results of the temperature and the rainfall in our period of interest. Furthermore, a first attempt of possible relationships between the fin whale distribution and different kinds of winter seasons is also presented. This chapter is divided into four sections, the first part is discussing the detailed rainfall analysis, the second part concerns the temperature analysis, and the third part regards daily rainfall distribution in the winter seasons. Eventually, the fourth part tries to assess a first comparison between the meteorological results and fin whale distribution data derived from a previous thesis.

3.1) Rainfall Analysis

This section deeply focuses on the seasonal rainfall in the Pelagos sanctuary surrounding region. This part is mainly dedicated to the comparison of the seasonal rainfall average values with the climatological value both in terms of general seasonal mean and rainfall spatial distribution in the Pelagos sanctuary surrounding region.

The rainfall climatological analysis is done for the autumn (September, October, November) and winter (December, January, February) seasons with respect to the climatological value calculated on the period 1979-2008.

3.1.1) Autumn rainfall analysis

There is a significant number of low rainfall autumn seasons with respect to the climatological value. Figure 3.1.1 shows the seasonal average rainfall in autumn seasons from 2007 to 2020 with respect to the climatological value obtained from the period between 1979-2008. The climatological average value in the autumn was about 349 mm. During 2019 the highest autumn rainfall is recorded in the domain, with rainfall 587 mm, and which exceeded almost 240 mm the climatological value. In autumn 2010, rainfall had an average value of nearly 526 mm and exceeded almost 176 mm of rainfall the climatological value. During 2017 the driest record among considered years, with a value of 221 mm. It was the driest autumn season in our period of interest. During 2007 the rainfall recorded a low value of 261 mm, which was almost 88 mm lower than the climatological value. The year after, in 2008, the rainfall mean value exceeded the climatological value and shows about 424 mm of rainfall. Then, the autumn rainfall graph (Figure 3.1.1) shows an increased and decreased trend compared to the climatological value in the next few years. For the 2014 autumn season rainfall recorded almost 443 mm in the domain. During autumn 2014 in fact, a very intense flash flood occurred in the Genoa area with a large amount of the seasonal rainfall fell down in a few hours (Lagasio et al.,2017, Fiori et al.,2017, Faccini et al.,2018). The Figure 3.1.1 also shows that 2012 and 2018 recorded more than 400 mm rainfall in the considered domain. Overall, Figure 3.1.1 shows there are three dry seasons compared to the climatological value (2007-08, 2015-16, and 2017-18) in our period of interest (2007-2020).

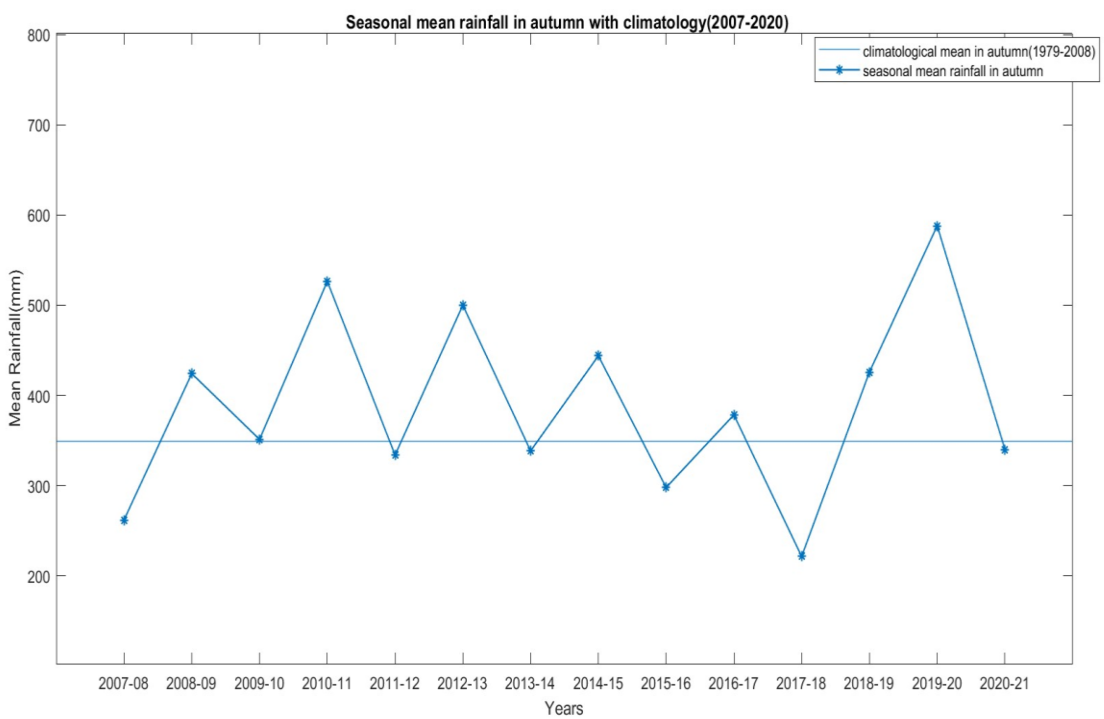


Figure 3.1.1: Seasonal mean rainfall in autumn with climatological value (2007-2020) in Pelagos sanctuary surrounding region.

3.1.2) Winter rainfall analysis

The winter rainfall amount is probably one of the crucial factors for the spring season's primary bloom production in the western Mediterranean basin. Because of the freshwater input bringing nutrients from the land area to the sea, rainfall can influence the bloom primary production and therefore it can influence the presence of marine mammals in this area. The climatological winter rainfall average is around 250 mm. The highest winter rainfall value was observed in 2013-14, it shows an average value of 557 mm, which exceeded almost 307 mm the climatological mean value. Another heavy rainfall in winter was 2020-21, which had the value of 491mm rainfall in the domain and it is almost 241 mm above the climatological value. For 2008-09, the rainfall exceeded the climatological mean value of almost 231 mm and recorded 481 mm. Instead, 2011-12 winter was extremely dry, with the lowest value of 151 mm recorded showing almost 100 mm lower than the climatological value. During 2018-19 rainfall recorded 196 mm and it was another dry winter in considered years, it shows almost 54 mm lower than the climatological value. In 2021-22, rainfall recorded a low value of 172 mm, and it was 78 mm lower than the climatological value. The results show at least three different winter seasons were below 200 mm rainfall (2011-12, 2018-19, 2021-22). During the 2007-08 winter, rainfall recorded a value of 240 mm which was close to the climatological value. Overall, between 2006-07 to 2021-22 three seasons (2011-12, 2018-19, 2021-22) were observed in the considered domain. During the last six years, the winter rainfall recorded at least four years of dry or close to the climatological value conditions. Its significance the increasing frequency of the dry season in winter season

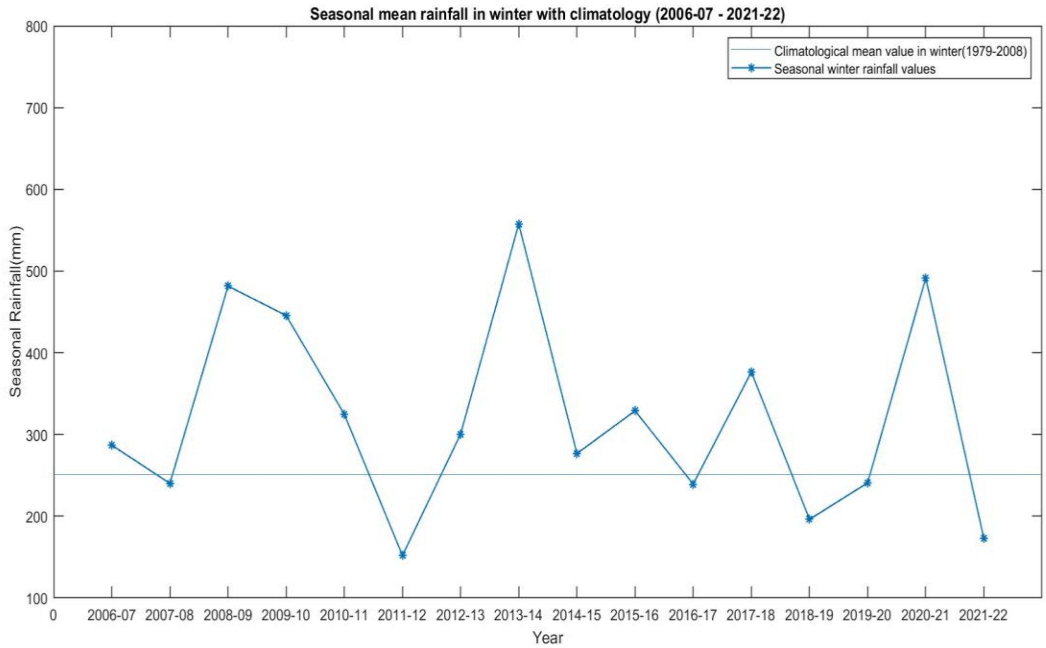
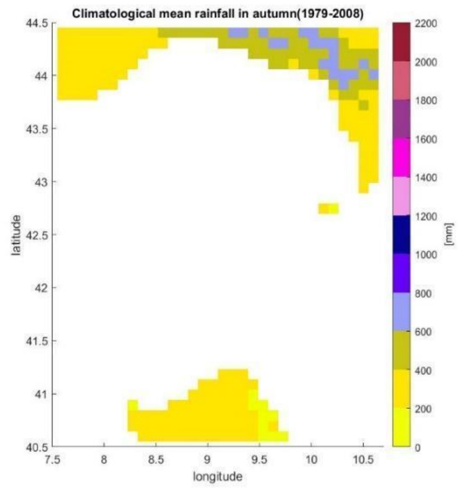


Figure 3.1.2: Seasonal mean rainfall in winter with climatological value (2006-07 to 2021-22) in Pelagos sanctuary surrounding region.

3.1.3) Autumn and winter climatological rainfall maps

The rainfall in this study area is heavily influenced by the topographical features, especially due to the orographic effects that have been described in chapter 2.1. Due to the air masses orographic lifting that favours condensation and cloud formation, more rainfall is present in the Apennines, north-eastern side of the Liguria region (Figure 3.1.3). The north-east and north-central sides of the domain particularly show 400 to 800 mm of rainfall in the autumn while in the winter it shows almost 200 to 600 mm rainfall. The Tuscany coast shows 200 to 400 mm rainfall in autumn while in winter it shows a maximum value of up to 200mm of rainfall. The north-west side (Savona, Imperia) is characterised by 200 to 400 mm rainfall in the autumn, while in winter the maximum is up to 200 mm of rainfall considering the coastal area. During autumn mostly the Sardinia region shows 200 to 400 mm of rainfall except in the east side shows a maximum of 200 mm of rainfall. In winter the coastal side of the Sardinia region has maximum up to 200 mm rainfall and far from the coastal areas which have almost 400 mm of rainfall. In general, the autumn season in the north-east side of the domain recorded more rainfall in the climatological spatial distribution.



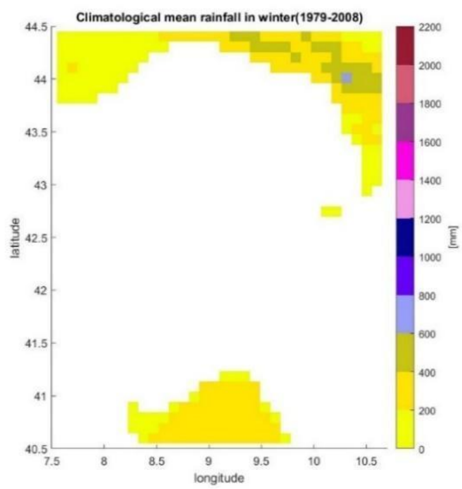


Figure 3.1.3: Climatological winter and autumn rainfall spatial distribution in Pelagos sanctuary surrounding region.

3.1.4) Autumn rainfall maps with respect to climatological distribution

Figure 3.1.4 shows the autumn rainfall maps from 2007 to 2020 and the climatological autumn map has the period of 1979-2008.

During 2019 was the highest autumn rainfall recorded among considered years (Figure 3.1.1). The spatial distribution shows that all over the domain had heavy rainfall mainly due to two intense floods during October 2019 (Lagasio et al., 2022). In fact, in that year Genoa's west and near Savona area recorded the highest rainfall, which had a maximum of 2200 mm of rainfall, and the near coast of this area had a minimum of 1400 mm, also Liguria's west to east coastal area marked heavy rainfall compared to the climatological map.

During 2014 the rainfall was heavy in the upper side of the domain, especially in the central part of the Liguria region had high rainfall, the Genova area almost recorded a maximum of 1800 mm in that season due to an intense flash flood recorded on 9 October 2014 (Fiori et al., 2017, Lagasio et al., 2017). Also, Liguria's west coast recorded about 800 mm of rainfall. On the contrary, in northern Sardinia, it was a dry autumn compared to the climatological map that had a maximum of 200 mm of rainfall.

Figure 3.1.1 shows that 2007 autumn was the dry season, and the spatial distribution indicates all the three considered regions (Liguria, Tuscany, north Sardinia) were dry compared to the climatological map.

During 2010 the north-east side recorded a maximum of 1600 mm rainfall and the coastal side recorded almost 800 mm of rainfall. The north-west coastal side shows almost 400 mm of rainfall in that season. Another year worth to be noticed is 2012, which recorded an average of 800 mm rainfall in the north-east coast side that was above climatology and also the hinterland area shows rainfall of about 1600 mm, again above the climatological values.

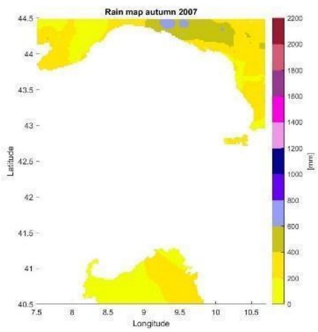
Moreover, during 2016 more rainfall was recorded in Liguria's west side, even though the other areas of the domain were dry in that season. Liguria's west coast shows almost 400 mm rainfall and far from the coastal areas recorded a maximum of 1000 mm in that season.

During 2017 autumn the north-east side of the domain recorded low rainfall compared to the climatological map. Also, the north-west side and Sardinia region were dry compared to the climatological map.

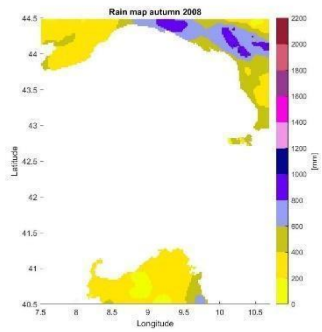
In autumn 2018 more rainfall recorded in north-west areas especially west side of the Genova area and near Savona province had almost a maximum of 1400 mm of rainfall.

The northern Sardinia region also had more rainfall in that season, in which Sardinia's east side recorded a maximum of 600 mm of rainfall.

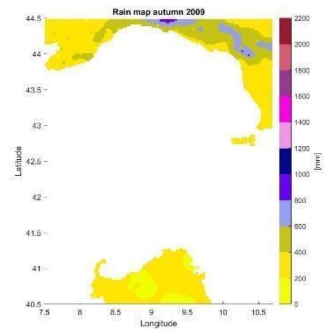
For autumn 2020 the upper side of the domain shows very low rainfall, on the contrary the northern Sardinia had high rainfall compared to the climatology.



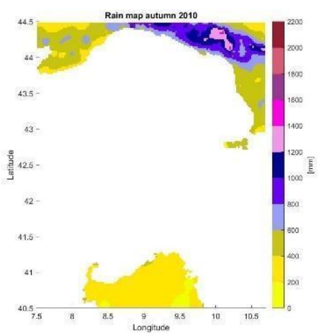
a) autumn 2007



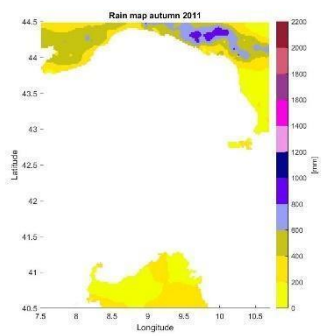
b) autumn 2008



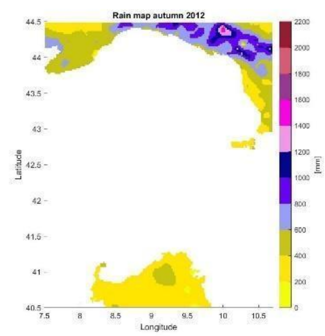
c) autumn 2009



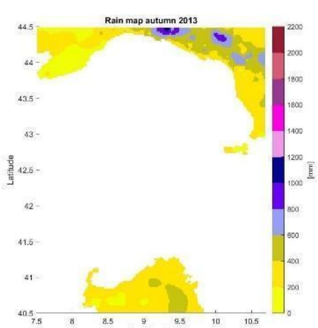
d) autumn 2010



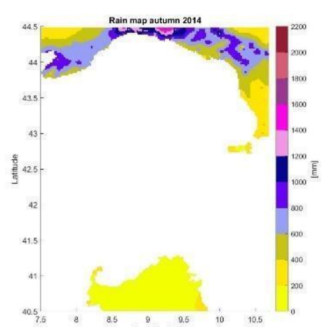
e) autumn 2011



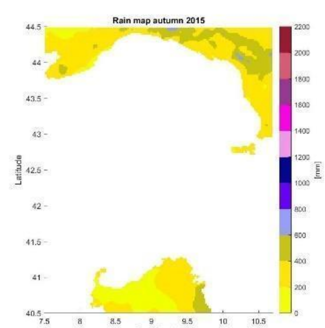
f) autumn 2012



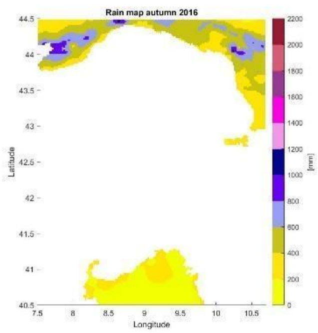
g) autumn 2013



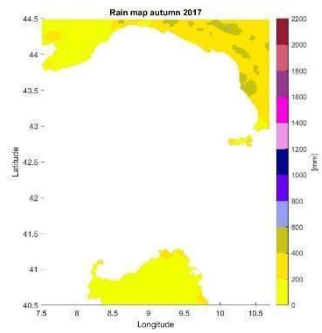
h) autumn 2014



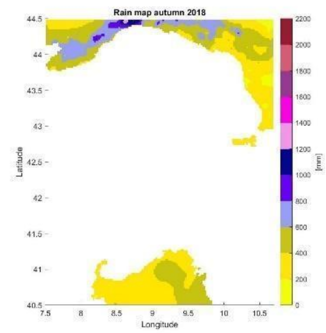
i) autumn 2015



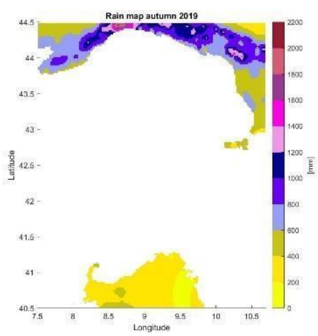
j) autumn 2016



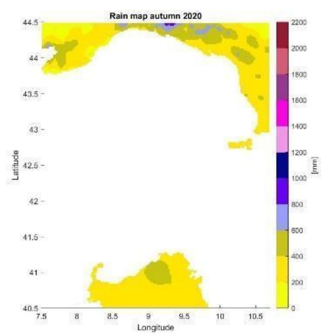
k) autumn 2017



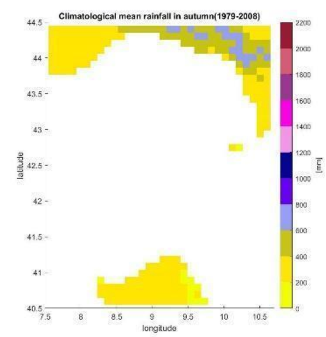
l) autumn 2018



m) autumn 2019



n) autumn 2020



o) climatological autumn (1979-2008)

Figure 3.1.4: Comparison between autumn rainfall maps (2007-2020) with climatological autumn rainfall map (1979-2008) in Pelagos sanctuary surrounding region.

3.1.5) Winter rainfall maps with respect to climatological distribution

Figure 3.1.5 represents the comparison among climatological rainfall distribution and winter seasonal average rainfall maps from 2006-07 to 2021-22.

During 2013-14 was the highest winter rainfall in the considered domain (Figure 3.1.2). Wet conditions have been observed all over the Liguria region and Tuscany region. The Imperia coast recorded almost 1400 mm rainfall and the north-eastern coastal area recorded a maximum rainfall of about 2200 mm, but on the contrary in northern Sardinia the rainfall was comparatively low with respect to the climatological map, especially the eastern side of the coast.

During 2007-08 winter the average rainfall was close to the climatology, in which the northern Sardinia area shows drier compared to the climatological average. The Liguria area had comparatively low rainfall but near to the Imperia province had more rainfall than climatological average.

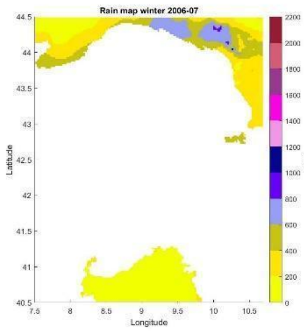
The following two winter seasons (2008-09, 2009-10) recorded high rainfall in the north-eastern side compared to the climatology, especially the coast from Genoa to la Spezia had high rainfall. In the 2008-09 winter, the north-east side recorded a maximum of 1400 mm and Genoa to La Spezia coast had 600 to 1000 mm of rainfall. The Tuscany coast also recorded 400-600 mm of rainfall. Liguria's west coast (400-600 mm) and Sardinia coast also observed more rainfall compared to the climatological map.

For the 2011-12 winter season the entire domain shows much dry conditions in all the regions including the coastal areas. The coast side of the Genoa to La Spezia recorded only the maximum of 200 mm of rainfall.

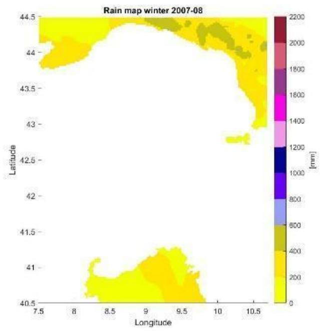
During the 2015-16 winter the upper domain shows comparatively more rainfall, but the northern Sardinia region recorded low rainfall. The 2016-17 winter was another lowest rainfall season in the period of interest. In which the north-east side recorded very low rainfall amounts. Compared to the climatological spatial distribution, the 2018/19 winter showed low rainfall in the north-east and Sardinia region.

In 2019-20 average rainfall was close to the climatological value (Figure 3.1.2) and compared to the climatological spatial distribution, the rainfall was low in the northern Sardinia area.

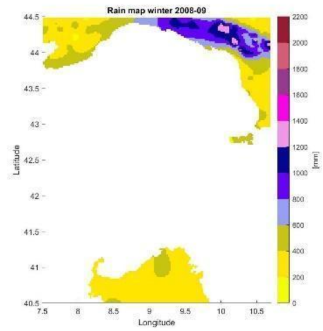
Overall, the comparison between winter seasonal rainfall distribution maps and the rainfall distribution climatological map shows that the northern Sardinia region is particularly characterised by low rainfall compared to the climatology and high rainfall events observed in the north-east side of the domain.



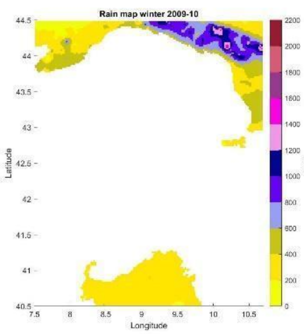
a) winter 2006-07



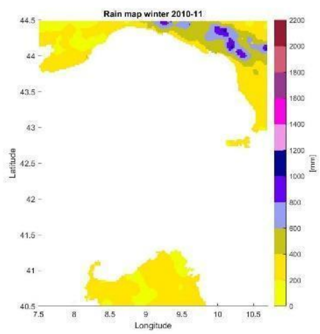
b) winter 2007-08



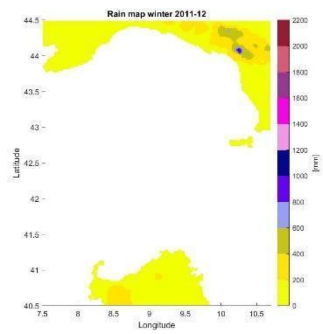
c) winter 2008-09



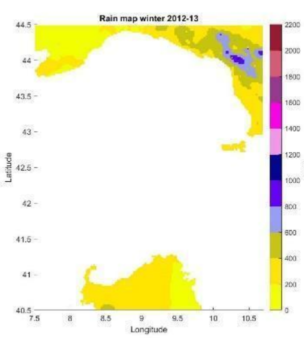
d) winter 2009-10



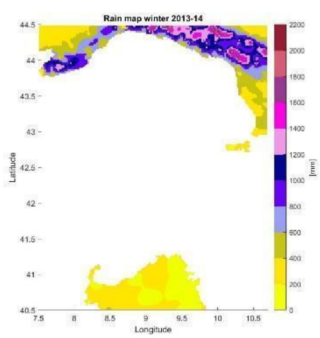
e) winter 2010-11



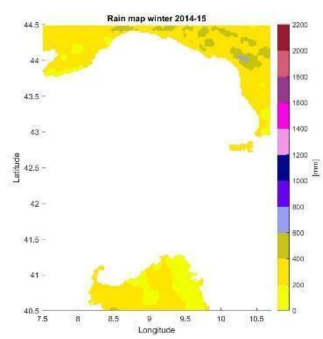
f) winter 2011-12



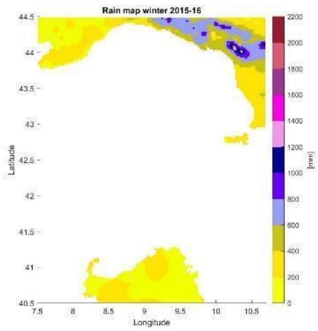
g) winter 2012-13



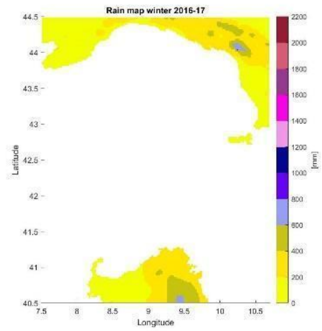
h) winter 2013-14



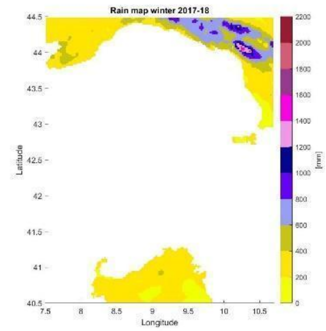
i) winter 2014-15



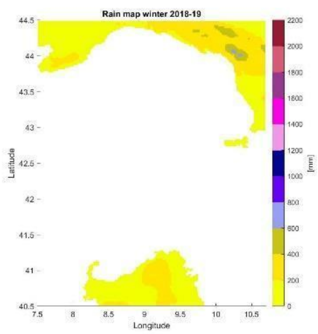
j) winter 2015-16



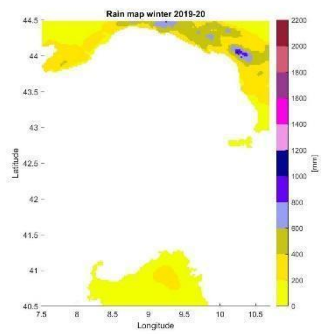
k) winter 2016-17



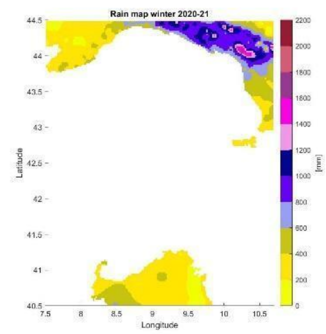
l) winter 2017-18



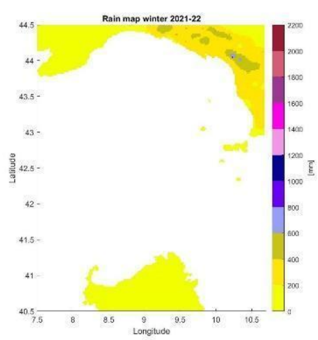
m) winter 2018-19



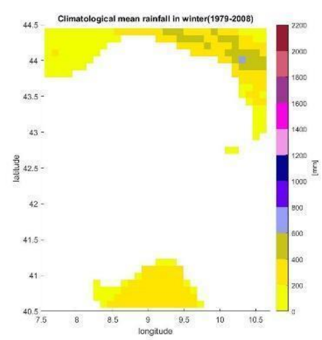
n) winter 2019-20



o) winter 2020-21



p) winter 2021-22



q) climatological winter (1979-2008)

Figure 3.1.5: Comparison of winter rainfall maps (2006-07 2021-22) with climatological winter rainfall map (1979-2008) in Pelagos sanctuary surrounding region.

3.2) Temperature Analysis

This section analyses the seasonal temperature with respect to climatological values and investigates its spatial distribution.

Also in this case, the temperature climatological analysis is done for both the autumn and winter seasons, this analysis assesses possible temperature variations in the Pelagos sanctuary surrounding region with respect to climatology.

3.2.1) Autumn temperature analysis

Consider Figure 3.2.1 which shows the autumn seasonal mean temperature from the period of 2007 to 2020 compared to the climatological value. The climatological average value for the autumn is around 14 °C. The first four years of autumn temperature are under or in line with climatological value and the 2007-2008 and 2010-2011 autumn was the colder in the considered period. Then a period of four consecutive years hotter than the climatological mean with the extreme year in 2014-15. In the following years again, the autumn was in line or under the climatological mean with the exception of 2019-20 and 2020-21 autumns.

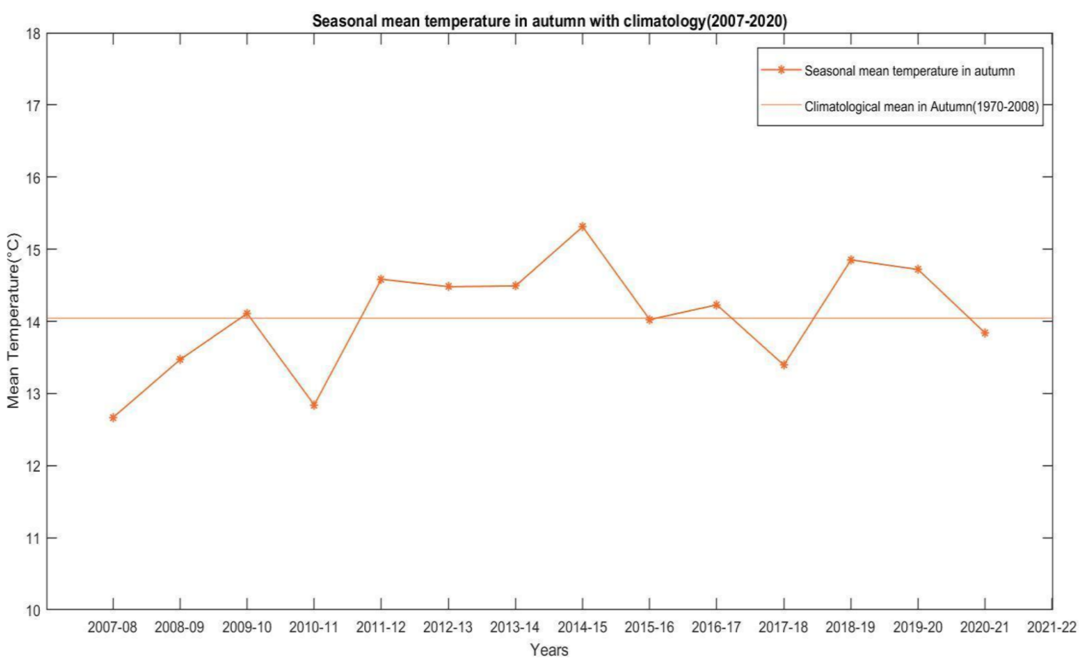


Figure 3.2.1: Seasonal mean temperature in autumn with climatological value (2007-2020)

3.2.2) Winter temperature analysis

Figure 3.2.2 shows the winter temperature seasonal average starting from 2006-07 to 2021-22. The climatological average value of the winter is 6 °C (averaged over 30 years, 1979-2008). Most of the considered years have winter colder than climatological mean, among them the coldest winter was in 2008-09, it was almost 2 °C below the climatological value. The only four years hotter than climatology are 2013-14, 2015-16, 2019-20 and 2021-22 with 2019-20 that was the hottest winter among the considered ones, it was almost 2 °C warmer than climatology. During the 2006/08, 2016/17, and 2018/19 temperatures were close to the climatology. During this 16 years period (2006-07 to 2021-22), five warm winter seasons were recorded. It is important to note that they all occurred in the last nine years and its significance is that hotter year frequency is increasing.

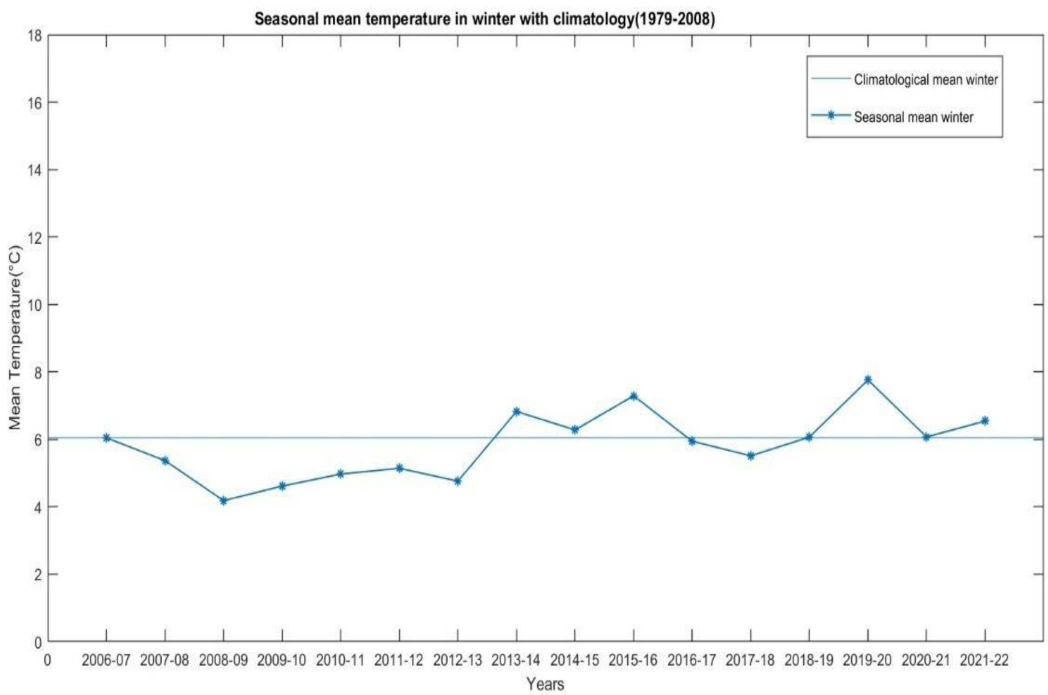


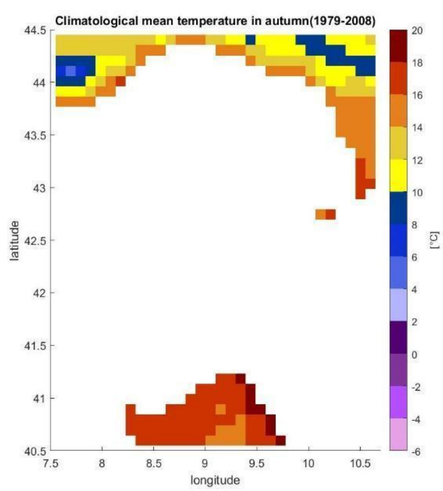
Figure 3.2.2: Seasonal mean temperature in winter with climatological value (2007-08 to 2020-21).

3.2.3) Autumn and winter climatological temperature maps

Figure 3.2.3 shows the autumn and winter climatological maps of the average temperature values over 30 years starting from 1979-2008. During autumn the Sardinia region had a minimum temperature of 14 °C while the east coastal side recorded the maximum up to 20 °C. In winter the average temperature was nearly 10 to 12 °C on the Sardinia coast.

In Liguria, in autumn, the coastal side recorded 14 to 16 °C of temperature and far from the coast, it was about 4 to 8 °C. In winter, the Liguria coast had an average of 6 to 8 °C and far from the coastal areas which had -2 to 4°C. Overall, in Liguria coastal areas recorded higher temperatures with respect to the interland mainly due to the altitude difference. In fact, this region is characterised by steep orography close to the coastline.

In Tuscany, in autumn, near coastal areas recorded 14 to 18 °C while in winter it is about 6 to 8 °C.



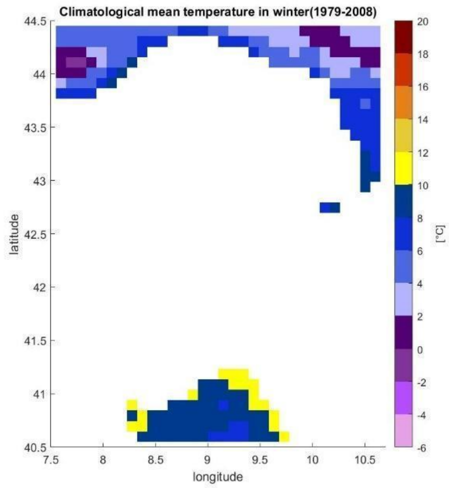


Figure 3.2.3: Climatological winter and autumn temperature spatial distribution in Pelagos sanctuary surrounding region.

3.2.4) Autumn temperature maps with respect to climatological distribution

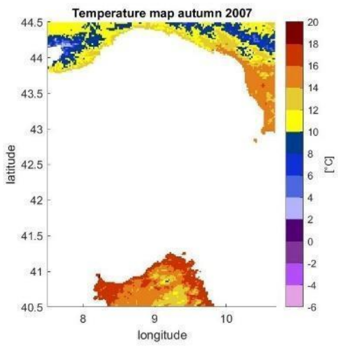
Figure 3.2.4 shows the comparison between autumn temperature maps (2007-2020) and the climatological spatial distribution (1979-2008).

The highest autumn temperature was in 2014 (Figure 3.2.1), and the spatial distribution shows the temperature in the domain was particularly high compared with the climatological map. Also, the temperature across northern Sardinia coastal areas was high, and it was about 18 to 20 °C.

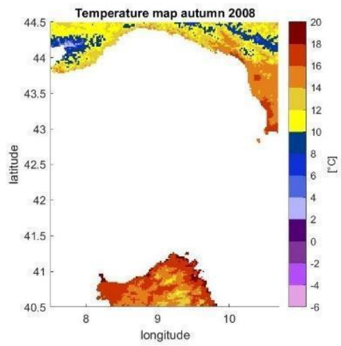
During 2007 and 2008 the temperature near the Ligurian coast recorded low values, especially in the west coastal areas; it was about 12-14 °C.

In autumn 2009, the temperature in the north-west coast recorded almost 14 to 18 °C and the northern Sardinia coast recorded a maximum temperature of 20 °C.

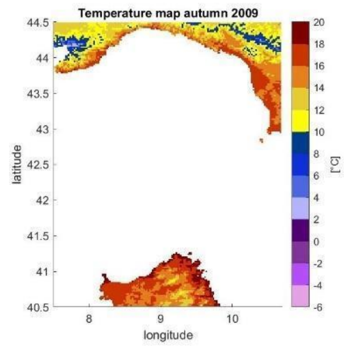
During 2010, the temperature in north-western side of the domain shows low values in some areas especially far from the coast, it shows a minimum of 2 °C. In 2011 and 2012 the coastal areas of the domain observed high temperatures compared to the climatological map. During 2018 and 2019 the temperature was above the climatological average (Figure 3.2.1) and spatial distribution shows that most of the areas in the domain had above average values.



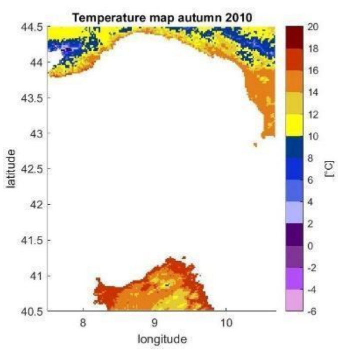
a) autumn 2007



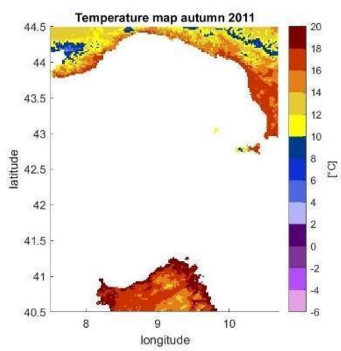
b) autumn 2008



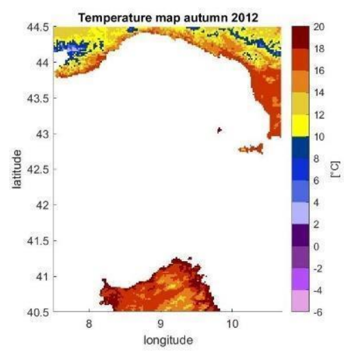
c) autumn 2009



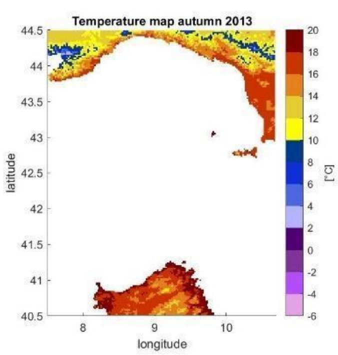
d) autumn 2010



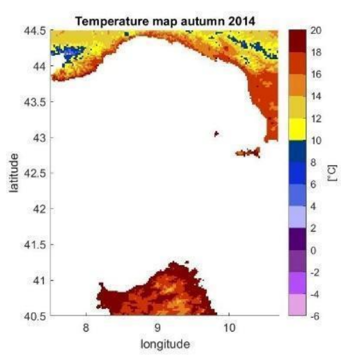
e) autumn 2011



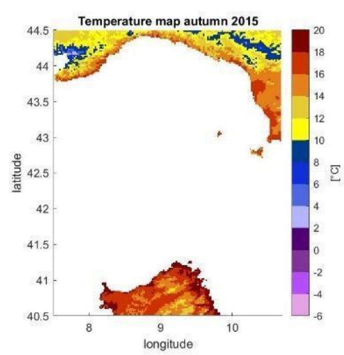
f) autumn 2012



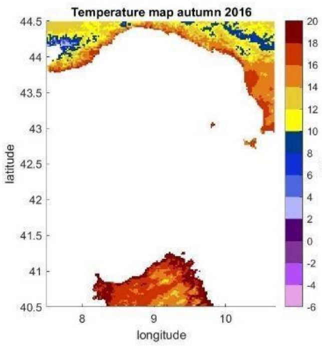
g) autumn 2013



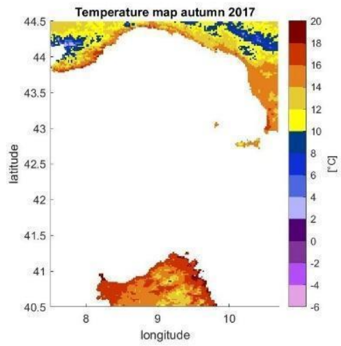
h) autumn 2014



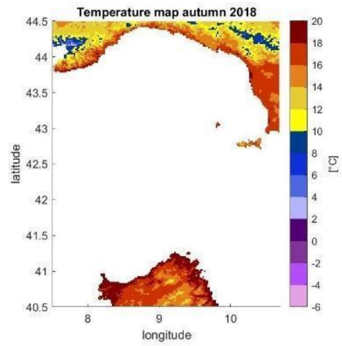
i) autumn 2015



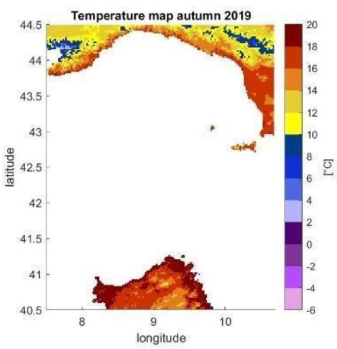
j) autumn 2016



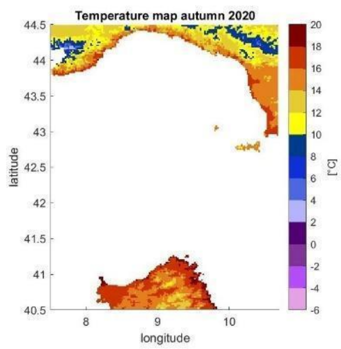
k) autumn 2017



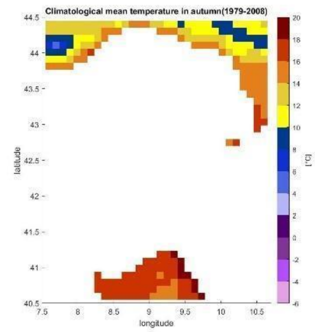
l) autumn 2018



m) autumn 2019



n) autumn 2020



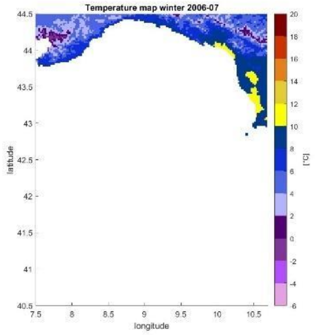
o) climatological autumn (1979-2008)

Figure 3.2.4: Comparison between autumn temperature maps with climatological autumn temperature map in Pelagos sanctuary surrounding region.

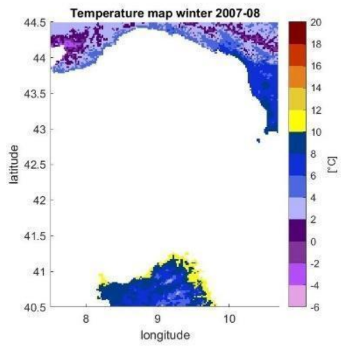
3.2.5) Winter temperature maps with respect to climatological distribution

Figure 3.2.5 shows the comparison between winter seasons temperature maps (2006-07) and the climatological temperature map. The 2019-20 winter had the highest seasonal winter temperature value (Figure 3.2.2) and spatial distribution shows all the areas were warmer compared to the climatological map. Sardinia's coast recorded a maximum of 14 °C and Liguria's west coast, Tuscany coast, had 10-12 °C of temperature.

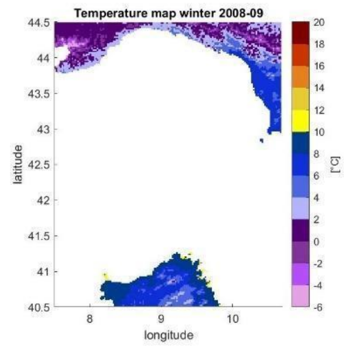
During the 2007-08 and 2008-09 winter season Liguria's west coast recorded low values compared to the climatological map, in 2007-08 and 2008-09 these areas had 4-6 and 2-4 °C of temperature. Also, the Sardinia coast recorded a low value in 2008-09 which was about 8 to 10 °C. The average temperature in winter 2013-14 was about 6.8 °C (Figure 3.2.2). In that year the temperature near the Tuscany coast recorded almost 10-12 °C.



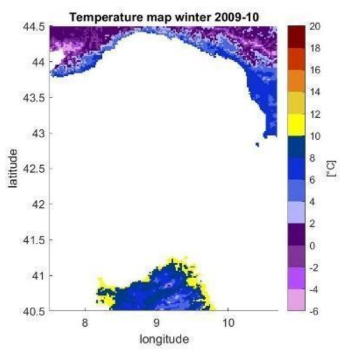
a) **winter 2006-07**



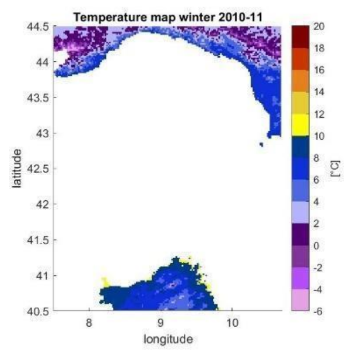
b) winter 2007-08



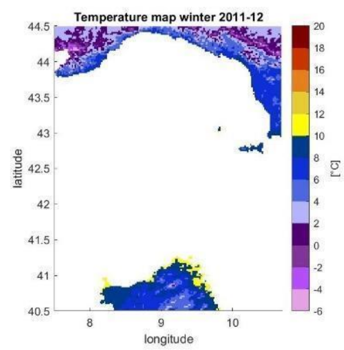
c) winter 2008-09



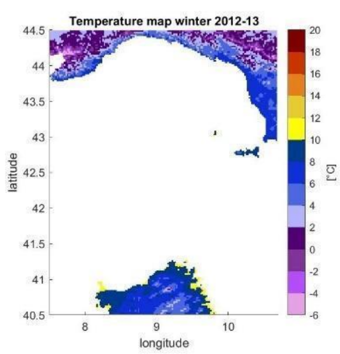
d) winter 2009-10



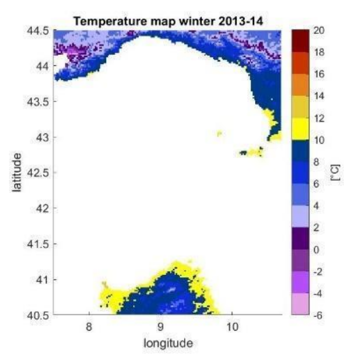
e) winter 2010-11



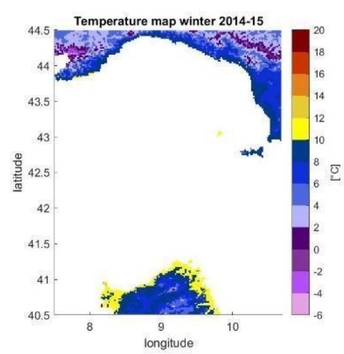
f) winter 2011-12



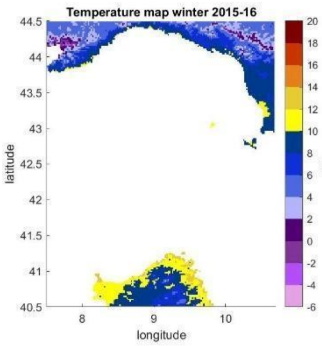
g) winter 2012-13



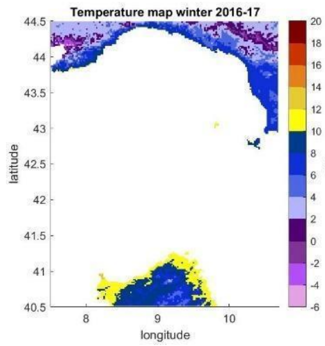
h) winter 2013-14



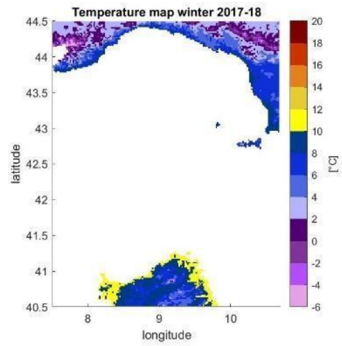
i) winter 2014-15



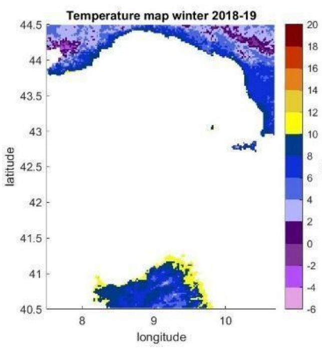
j) winter 2015-16



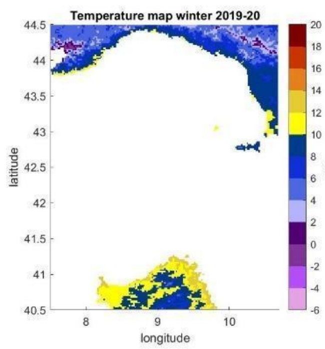
k) winter 2016-17



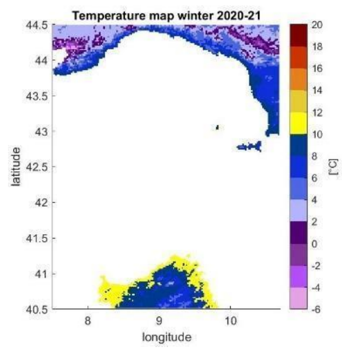
l) winter 2017-18



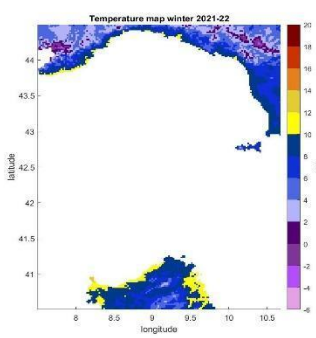
m) winter 2018-19



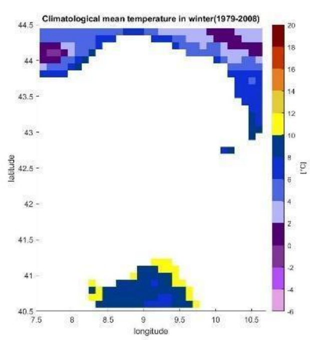
n) winter 2019-20



o) winter 2020-21



p) winter 2021-22



q) climatological winter (1979-2008)

Figure 3.2.5: Comparison between winter mean temperature with climatological mean winter map in the surrounding region of the Pelagos sanctuary.

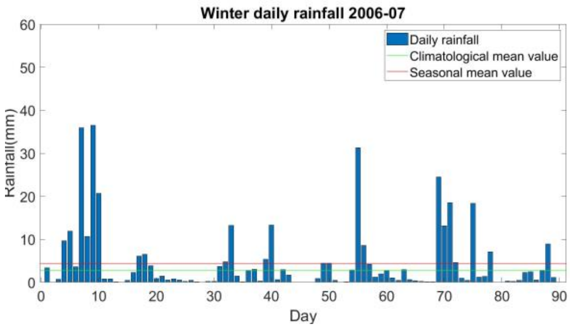
3.3) Daily rainfall distribution in winter seasons

Figure 3.3.1 illustrates the daily rainfall distribution during each winter season, which characterises the rainy days in the considered domain. The figure also highlighted the comparison with the seasonal daily average with respect to climatological daily value to assess the dry/wet days.

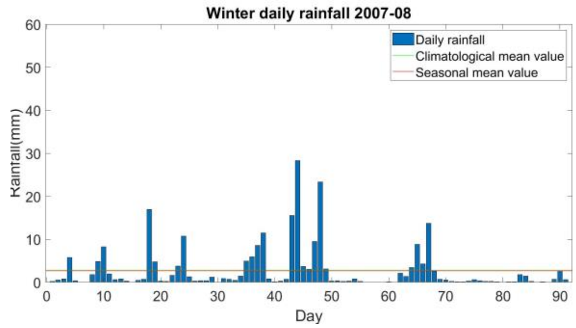
One of the rainiest years was 2013-14. The first 20 days of 2013-14 winter was rainless and then, from the end of December to February rainfall shows a homogeneous distribution, similar results also obtained in some other years such as 2015-16, 2017-18, 2020-21 and winter. The Figure (3.3.1) also remarks the rainfall peak on December 12th of 2017-18.

During the 2018-19 winter a lot of rainless days were observed, especially in the end of December to half of January and also at the end of February recorded less rainfall. In 2019-2020, after some peak rainfall days in December, almost rainless days were observed in the end of January and mid of February. This winter was almost close but little under the climatological seasonal mean. However, in this season most of the rainfall is recorded in December after that very low rainfall distribution observed in January and February.

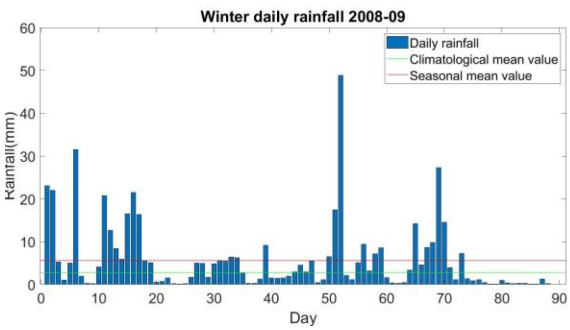
The dry days as well as peak rainfall days in winter can probably make an impact in the spring primary production in western Mediterranean basin because these rainfall variations affect the river discharge to the Pelagos sanctuary, which is the one of the nutrient sources in the Mediterranean Sea and may affect the primary production trigger and growth.



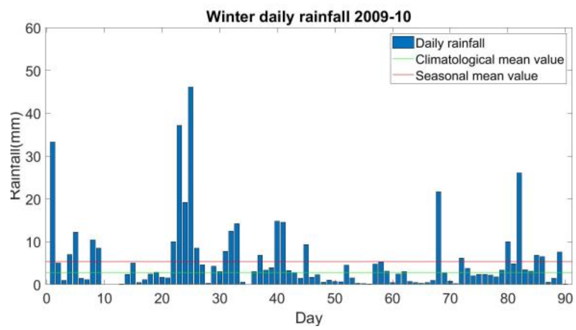
a) winter daily rainfall 2006-07



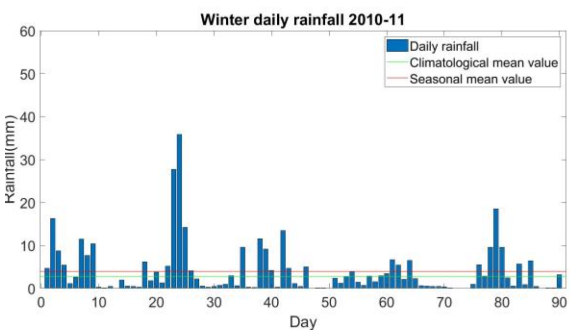
b) winter daily rainfall 2007-08



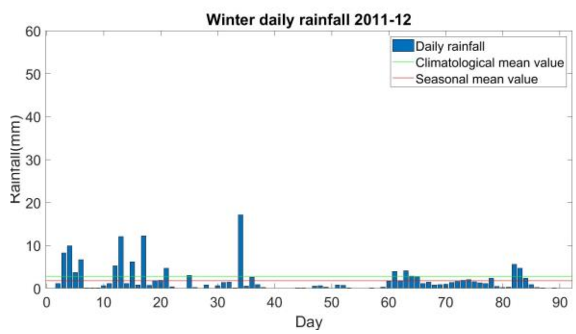
c) winter daily rainfall 2008-09



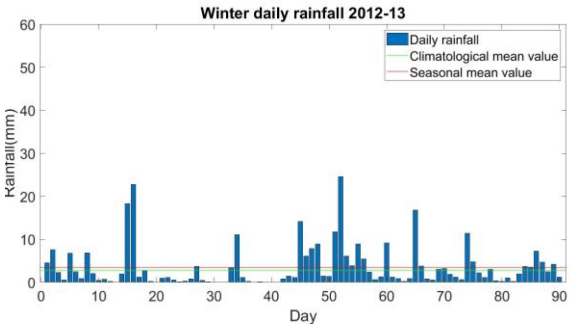
d) winter daily rainfall 2009-10



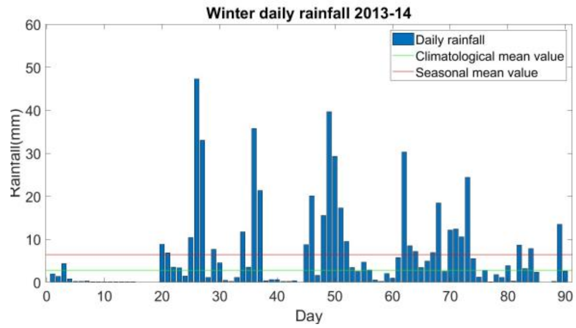
e) winter daily rainfall 2010-11



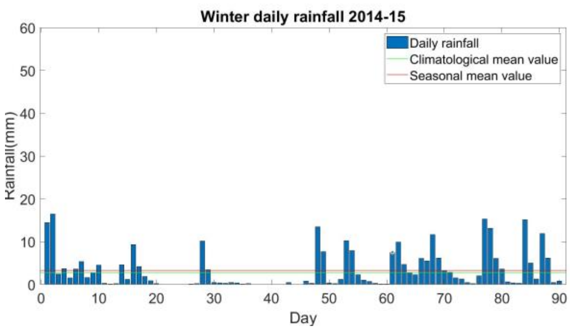
f) winter daily rainfall 2011-12



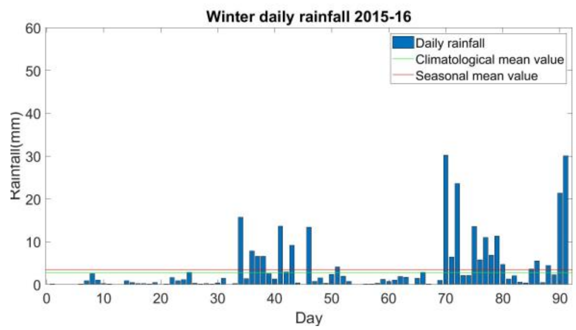
g) winter daily rainfall 2012-13



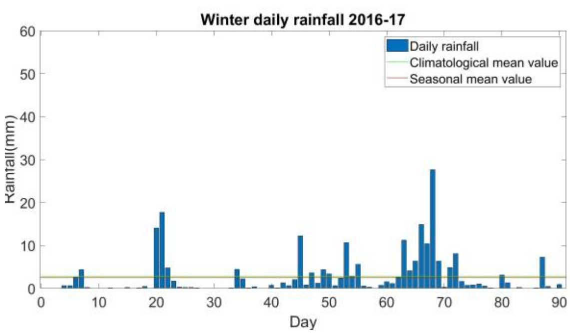
h) winter daily rainfall 2013-14



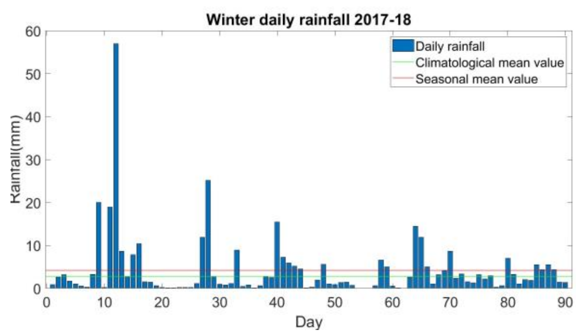
a) winter daily rainfall 2014-15



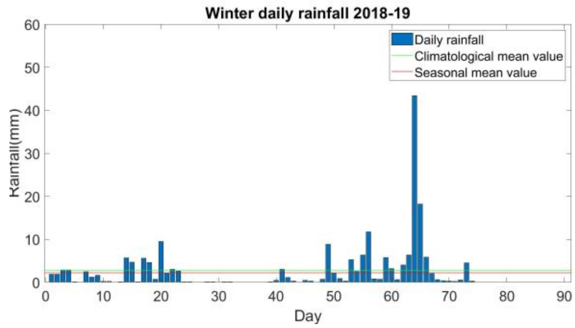
j) winter daily rainfall 2015-16



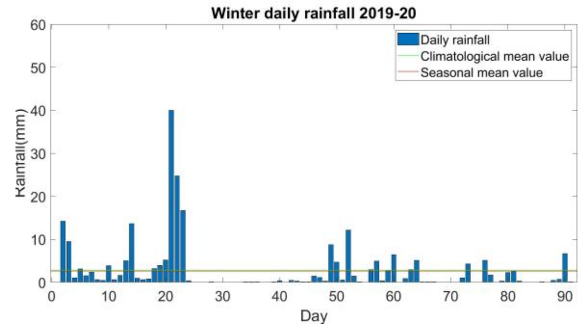
k) winter daily rainfall 2016-17



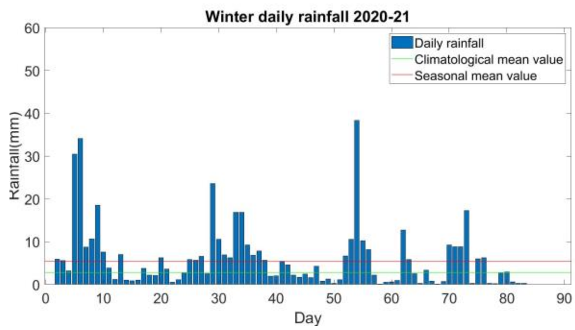
l) winter daily rainfall 2017-18



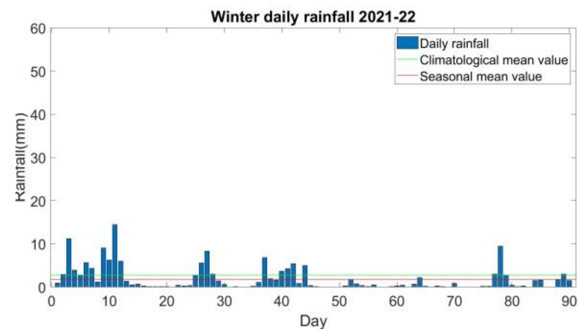
m) winter daily rainfall 2018-19



n) winter daily rainfall 2019-20



o) winter daily rainfall 2020-21



p) winter daily rainfall 2021-22

Figure 3.3.1: Daily winter rainfall from 2006-07 to 2020-21 winter (December to February).

3.4) Comparison among winter rainfall, temperature, and the fin whale distribution data

In this section an attempt of comparison among seasonal mean rainfall, daily rainfall distribution, seasonal mean temperature, and the fin whale distribution in the Pelagos sanctuary is presented. The information about the fin whale distribution was collected from the thesis work of ‘Anomalies in fin whale distribution in the Pelagos sanctuary’ done by Federica Tonello (http://hdl.handle.net/20.500.12608/10214).

In general, the fin whale presence shows in a water depth of more than 2000m (Grossi et al.,2021). Recently their sightings in shallow water are increasing in the Pelagos sanctuary area. Figure 3.4.1 shows the interannual differences of the fin whale distribution using the frequency of fin whale surveys and encounter rate (ER) for each depth class.

The Encounter rate is the number of sightings divided by the number of surveys. The ER>0 in shallow water has been recorded in 2007, 2019 and 2020. During these three years fin whales are sighted near to the coast, The 2019, 2007 and 2020 years were anomalous in terms of ER>0 in shallow waters. However, 2007 is less anomalous because the presence of fin whales was also in deep water congruent with their proper habitat, with the ER peak corresponding to the 2000m water depth. Instead, in 2019 and 2020 the ER peak is for both years in shallower water at 1500m and 1000m respectively. During 2020 most of the sightings were in shallow waters between 500m and 1000m, this was the most anomalous year. During this summer covid restrictions affected the number of surveys, however using the ER to evaluate the fin whale distribution is useful to avoid problems related to different samplings, because it is obtained by dividing the number of sightings and the number of surveys. Thus, in such a particular year the ER value will still be representative of the fin whale distribution without being affected too much by the lower sampling.

The rainfall in winter 2006/07 was above the climatological value (Figure 3.1.2) and the daily rainfall distribution was almost homogeneous (Figure 3.3.1). This year the temperature in the surrounding region was close to the climatology (Figure 3.2.2). In winter 2018/19 rainfall was below the climatology (Figure 3.1.2) and daily rainfall distribution shows that there are a lot of dry days in between half of December to half of January (Figure 3.3.1). This year the temperature was close to the climatological value (Figure 3.2.2). During 2019/20 winter rainfall was close to the climatology (Figure 3.1.2) and the daily rainfall distribution shows that half of December to half of January and the last 15 February days were very dry (Figure 3.3.1). During this winter season the temperature was above the climatological value (almost 2 °C exceeded) (Figure 3.2.2). During 2016 and 2017, the fin whale presence mostly shows in their usual habitats (>2000 m, Figure 3.4.1). The daily distribution of rainfall in the 2015-16 shows a dry December with rainfall peaks starting from early January and most of the rainfall recorded during February (Figure 3.3.1). In 2016-17 the rainfall was dry December and early January with just a rainfall peak around 20 December rainfall with a homogeneous distribution starting from half of January until half of February then again, a dry period (Figure 3.3.1).

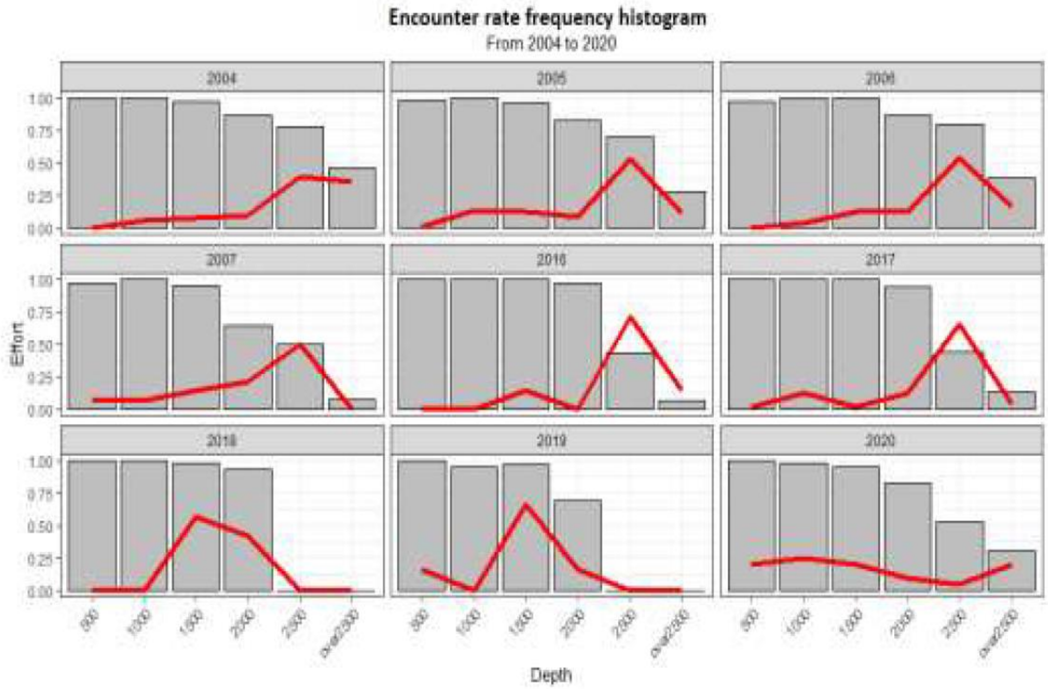


Figure 3.4.1: Frequency of fin whale surveys and ER (encounter rate) for each depth class: Grey represents the frequency distribution of trips and red represents the yearly ER computed for the corresponding depth class.

https://thesis.unipd.it/bitstream/20.500.12608/10214/1/Tonello_Federica.pdf)

The 2018/19 and 2019/20 winter seasons showed more dry days in the Pelagos sanctuary surrounding land areas. Compared to 2015-16, these two years have particularly low rainfall between half of the December to half of the January and end of the February. Consequently, 2019 and 2020 fin whale distribution in the Pelagos area showed some evident anomalies. The dry rainfall distribution might affect the river discharge into the Pelagos sanctuary sea area. As a result, this might affect the primary production and fin whale distribution. Compared with other anomalous whale distribution years and winter seasons, the 2006-07 winter had more rainy days, there were some rainfall peaks in December after that it only showed a few dry days.

During 2007, the main peak of fin whale distribution remained at 2500 m, which is the normal behaviour corresponding to the typical fin whale habitat (Figure 3.4.1). Alternatively, during 2019 and 2020 the main peak was at 1500 m and 1000 m respectively. Hence, these years had less ER when it should be their usual habitat (above

2000 m). Moreover, in these years the presence in shallow water (500m) is higher than in 2007. Also, comparing the 2018/19, 2019/20 winters with 2006-07 there is an evident difference in terms of rainfall amount along the season and dry days.

Usually, mammals have a memory capacity in terms of tendency of going where they had previously found food or anyway where they know they have it (Abrahms et al.,2019). Furthermore, rainfall is not the only parameter influencing fin whale behaviour, and in 2007 the sea surface temperature in the north-western Mediterranean Sea was high (5-6 °C higher than usual average, Tepsich et al.,2008). This might be also a reason for their anomalous presence in shallow water.

The 2021/22 winter conditions were similar to the ones in 2018-19 and 2019-20 in terms of rainfall amounts and dry periods (Figure 3.3.1). Therefore, probably fin whale anomalies are expected in this summer season (2022). This year the sighting season is ongoing, however the fin whale presence in shallow water has already been recorded in some occasions, like as an example in Capo Noli, Liguria. At this stage the season assessment is not rigorous, it will be better investigated at the summer ending.

Eventually, the potential relation between winter conditions and bloom will give an insight also for the 2008-2015 period affected by a lack of whale watching data.

Chapter four

Concluding remarks and future works

The thesis work has been developed to investigate possible relationships between winter seasonal characteristics and the fin whale distribution in the Pelagos sanctuary. This work provides the first insights of possible relations paving the way for further developments and improvements in future works. The work started with an assessment of Mediterranean climate, Pelagos sanctuary and the fin whale distribution in the sanctuary. Moreover, during the research first part, a view of future climate projections in the Mediterranean region and Europe, done by the various research groups has been presented. Then, a description of possible dataset used for climatological studies and the datasets chosen for the analysis chosen in this work is shown. The E-OBS dataset has been used as climatological reference using years from 1979 to 2008, moreover the rainfall and temperature datasets from the Italian Civil Protection Department has been used to compare years between 2006 and 2022 with respect to climatology. Before starting the analysis, a study area has been selected for the climatological analysis to evaluate only the land conditions surrounding the Pelagos sanctuary. Eventually, the seasonal analysis results of rainfall, temperature with respect to the climatology and first assessment of daily distribution rainfall in winter season obtained. Finally, a first attempt of possible relation between results obtained for winter seasons and fin whale distribution data, especially focusing on the encounter rate above 0 in shallow water, has been presented.

Both the winter and the autumn season had more wet seasons compared to the climatological average among considered years. The spatial distribution shows the north-east side recorded more rainfall events, which is mainly due to the orographic effect on the Apennine Mountain. An increasing trend of hot seasons has been observed from the winter seasonal average of temperature analysis, especially in the last decade. Temperature in the 2019-20 winter was particularly high because it exceeded almost 2 °C of temperature from climatology. Furthermore, an increasing trend of dry season in winter rainfall seasonal average was observed, especially in the last six years. Both the hot and dry conditions could have an impact in the phytoplankton bloom development in the Pelagos sanctuary area and consequently on the fin whale distribution.

The comparison among the fin whale distribution and winter seasonal results has been presented in the last thesis section. The encounter rate (ER) is chosen because it is the number of sightings divided by the number of surveys, thus it is useful to avoid problems related to different samplings. It showed that most of the fin whales are present in more than 2000m depth areas, which is their usual habitat. All years except 2007, 2019 and 2020 had ER = 0 in shallow water (below 1000m depth). The ER>0 in shallow water was recorded in 2007, 2019 and 2020 years. The highest anomalous years were in 2019 and 2020, while in 2007 whale presence was less anomalous because, despite the sightings in shallow water, their presence was mainly observed in usual habitats (2000 m). The seasonal mean rainfall compared to whale distribution in 2007, 2019 and 2020 shows that 2006/07 mean rainfall was above the climatology value, 2018/19 was below the climatology value and 2019/20 was close to the climatology value. During the 2015 and 2016 fin whale presence has been observed in their usual distribution (>2000m) and the rainfall mean wasn't too far from the climatological value, so these years are used as a benchmark. The daily distribution in these two years was mainly dry in December with then January and February almost homogeneously rainy months. During 2019 and 2020 the ER peak has been observed in the box corresponding to 1500m and 1000m respectively. Consequently, these two years the anomaly was not only in the fin whale presence in shallow water but also the almost complete absence in deeper water that is the typical habitat. Furthermore, dry periods were observed in 2018/19 and 2019/20 with respect to other winter seasons during January and February. These dry periods in winter might affect the spring phytoplankton bloom in the Pelagos sanctuary area and consequently the whale's distribution. Eventually, during the 2021/22 winter was also recorded hotter and drier conditions with respect to the climatology, and some sightings of fin whales in shallow water have already been registered. This year will be better analyzed at the end of the sighting season.

The increasing trends of heat waves and droughts are becoming more evident in the ongoing climate change. Nowadays, the seasonal rainfall amount is becoming not anymore homogeneously distributed along the season, with rainfall often falling in a few days (or even few hours in some case) with dry periods in the middle. This scenario is expected to become more frequent (IPCC 2022). Thus, it is important to further investigate the possible relationship between such winter conditions and the bloom characteristics, because it will probably affect the growth of the phytoplankton and fin whale distribution in the Pelagos sanctuary area.

Future works will be devoted to clustering the dry/rainy days using climatological indices to have a more quantitative estimation allowing to better distinguish the different winter characteristics. In parallel, clustering the phytoplankton bloom type, as an example in terms of initiation day, duration, and intensity to identify how it changes as a consequence of the different winter conditions. Then, the bloom will be used as a proxy of fin whale distribution. Eventually, the possible outcomes can allow to start an assessment about the implication of ongoing changing climate and its impact on the Pelagos sanctuary.

In general, we have only few information about the adaptation capability of any marine mammal species; overall the available evidence suggests that many populations are highly vulnerable to the impacts of climate change. It is increasingly clear that future conservation and management regimes for marine mammals need to take climate change into account. Especially due to the rising global warming which can turn into highly vulnerable ecosystems.

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