SEA LEVEL MEASUREMENTS IN MEDITERRANEAN COAST

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Abstract – The great travels for the geographical studies made it necessary, in order to establish the height of the elevations, to refer all the heights to the same surface to which to attribute the zero level, to make the results comparable. The sea surface was immediately thought of as a reference level, but unfortunately it is neither the same nor constant throughout the Earth and, moreover, it varies over time. As early as the 17th century, measurement protocols were proposed to establish the sea level. However, only in the first half of the 19th century, with the advent of tide gauge with automatic recording, were obtained, for many seas, sufficiently numerous and reliable series of measurements to establish a shared methodology to define the tide level zero. From that moment on, procedures and instruments quickly improved to the current satellite instruments that measure altitudes with the uncertainty of about 2 centimeters. This work is limited to the first stages of this fascinating story referring, in particular, to the Mediterranean basin.

1 Introduction

The great travels around the world in the 18th and 19th centuries and the affirmation of physical geography as a discipline of study, highlighted that to establish the height of mountains or the depth of terrestrial depressions, it needed to refer to a starting level, reference datum zero or zero elevation, common to all.

In the volume *La Terra nelle sue relazioni col cielo e coll'uomo: ossia Instituzioni di geografia matematica, fisica, e politica: secondo le più recenti mutazioni e scoperte e con copiose notizie statistiche, commerciali, ecc.* [23], published in 1869 the geographer Alfeo Pozzi wrote at page 125: […] *I continenti le isole e le varie loro parti si elevano a differenti altezze. A poter misurare tutte queste altezze in modo che sieno fra loro confrontabili bisogna trovare un termine a tutte comune, un punto di partenza uguale, una superficie in somma ugualmente distante in tutti i punti dal centro del globo. Questa superficie è quella dell'Oceano. Il livello dunque del mare è il termine fisso da cui si parte per valutare l'elevazione di qualsivoglia punto terrestre. L'elevazione di un luogo cosi valutata dicesi altitudine o altezza assoluta* […][1].

The quote of the sea zero level, *going upwards,* allows to establish the tides levels, the altitudes of the countries, the heights of the mountains, etc., all starting from the same reference; the geographers highlight this aspect by placing, after the value of the height and

[1] [...] *The continents, the islands and their various parts rise to different heights. In order to measure all these heights so that they are comparable to each other, it is necessary to find a term common to all, an equal starting point, a surface in sum equally distant in all points from the center of the globe. This surface is that of the Ocean. The sea level is therefore the fixed term from which we start to evaluate the elevation of any point on earth. The elevation of a place evaluated in this way is called absolute altitude or height* [...]. (Translated by the Authors).

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the unit of measurement, the abbreviation a.s.l. (above sea level). The zero quote also allows, *going downwards*, to establish the depression of the areas, the deepest depression is that of the Dead Sea about 400 m below sea level, the depth of the seas and ocean trenches, the deepest is that of the Marianas in the Pacific Ocean of 11 521 m.

But the level of marine surface is neither the same nor constant on whole Earth; if there were no currents, waves and tides in the seas, their surface would be orthogonally arranged in the direction of the acceleration of gravity and the size and shape of the Earth could be defined as the average level of the sea. In fact, in any point on Earth, the average sea level, in addition to being conditioned by the terrestrial rotation, is generally higher at the end of summer, when the water is warmer, than at the end of winter, when the water is colder and is deposited, in greater quantities, on mainland as surface water, snow and ice. In some parts of the world, especially where the effect of the monsoons is more intense, seasonal variations in sea level are more sensitive to the decisive changes of wind and currents, but annual variations are also observed mainly due to the melting of the polar ice caps and the oceans warming [6].

In the first case there is an increase in the mass of liquid water, in the second case there is a thermal expansion of this. In other words […] *sea levels in areas of warm water are higher than sea levels in areas of cold water. A rise in sea level of an average of 3 mm/yr was observed between 1993 and 2008* [worldwide]. *This rise, however, was not the same everywhere. In some regions it was much higher than average, while in others it was much lower* [1001]. For example, in the Atlantic Ocean the increase was about 0.5 mm / year while in the Mediterranean Sea it was from 0.6 to 1.5 mm / year, depending on the various areas [3].

All this has led to have to establish a method for defining the *altimetric zero* in reference to the average level of the marine surface, a level to be re-evaluated at least each decade as a result of the aforementioned annual variations.

The close link between the tidal reference and the quote of terrestrial objects is well highlighted by Giorgio Poretti of the University of Trieste in [22]: […] *The Italian measurements in the Alps are, for example, referred to the mareograph in Genoa, the Austrian ones to the mareograph of Trieste, while those of the Swiss State Office for Geodesy and Topography refer to an average between the mareograph of Genoa and that of Bordeaux. For this reason, the Italian and Swiss measurements present a constant difference of about 20 centimetres* […].

We report in this work some notes relating to the first stations for the detection of the *marine altimetric zero* of the Mediterranean coastal areas, carried out by the nineteenth century with some mentions to the current situation.

2 The first measurements

The oldest protocol for a rigorous sea level survey is by Robert Moray[2] (1666), where indications are also given on how to build the observatory and with which devices and instruments to equip it, including also meteorological instruments [17].

Moray refuted some theories circulating at the time, that he considered invalid. Then he drew up a protocol on the procedures to be followed to detect, uniformly in each site, the sea level. Moray also provided guidance on how the observatory was to be built and how the

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[2] Sir Robert Moray (1609 - 1673), scientist and statesman, was one of the principal architects in 1660 of the *Royal Society of London for the Improvement of Natural Knowledge.*

various devices were to be installed. In his work he did not only indicate two possible detection sites, Bristol (south-west England) and Chepstow (south-east Wales), but also, he specified the temporal cadence of the measurements, he explained the operation of the various equipment and he described the meteorological measurements to be carried out to complement the marine ones: wind intensity and direction, air temperature and humidity, atmospheric pressure. Several documents attest that both Moray and other scholars carried out surveys in accordance with the aforementioned protocol, but unfortunately the data obtained either have not been published or have been lost.

The first observations of sea level on the Atlantic coast of Brittany, published in France in 1683, were from the period 1679 - 1681. The "official" surveys on the Mediterranean coast French were carried out between 1777 and 1778 in Toulon, at the time the only maritime arsenal on this coast, at the eastern end of the Gulf of Lion.

The first automatic recordings of sea level were conducted by the English engineer Henry Robinson Palmer (1793 - 1844) with a marigraph of his own invention described in 1831 in the *Journal of Philosophical Transaction of Royal Society* [18]. The measures were conducted at Sheerness on the east coast of England. It will be necessary to wait until 1842 to have the French coasts equipped with the first automatic marigraph made by the hydrologist Antoine Marie Rémi Chazallon (1802 - 1872).

The first marigraph on a "geographically" Italian coast was installed in Trieste in 1859. The clarification is necessary because the city, in the year indicated, was still part of the Habsburg Empire. Starting from the Middle Ages Trieste, while remaining a free municipality, first came under the influence of the Republic of Venice, then it came under the rules of the County of Gorizia, then the Patriarchate of Aquileia and finally Trieste was annexed to the Duchy of Austria; until in the second half of the fifteenth century it submitted to the Habsburgs of Austria. On June 2, 1717, Emperor Charles VI of Habsburg declared freedom of navigation in the Adriatic and in 1719 established the free port of Trieste whose rights, extended by his daughter Empress Maria Theresa of Austria (1717 - 1780), led, in the eighteenth century, to an intense development of the city. After the Napoleonic parenthesis, Trieste under the Habsburg government continued to develop, becoming both the capital of the province of the "Austrian Littoral" and the main commercial port of the Empire, following the entry into operation, in 1857, of the railway connection with Vienna.

In 1864 the European countries met in Berlin (for Conference of Central European degree measurement [8]) to adopt the following provisions: "*The heights of each country will be referred to a single zero point, strictly established; all these starting points will be connected to each other by precision leveling. The average level of the different seas will have to be determined in the largest number of ports, and preferably by means of recorders instruments [...]. According to the results of all these measures, the general plan of comparison for all heights of Europe will be chosen subsequently*" [5]

3 The measurement instruments

We have mentioned above an automatic mareograph that is an instrument that draws on a strip of paper the rises and falls in sea level (tide gauge) due basically to tidal variations: the average of the values recorded in the time interval considered (daily, weekly, monthly, annual), allows to establish the average sea level to which to attribute the zero altimetric value.

A method for determining the average sea level is based on the calculation of the average of all hourly heights detected by marigraphs over an interval of several years. A second criterion is to calculate the average all high and low tides obtained from mareograms. The difference between the two procedures indicated is negligible since it does not exceed 0,1 mm [21].

To avoid the problem of the operator who had to average the values of water level indicated by the mareograph, which records moment by moment, Charles Lallemande (1857 - 1938) in 1888 invented an instrument that automatically performed the average, not through a calculation but by means of a particular realization of the instrument, which he called *medimaremeter* (in French *médimarémètre*), where the prefix *medi* wants to indicate the specificity of the instrument [11]. To better understand the difference between the two instruments, below, we report a very brief description of the principle of their operations.

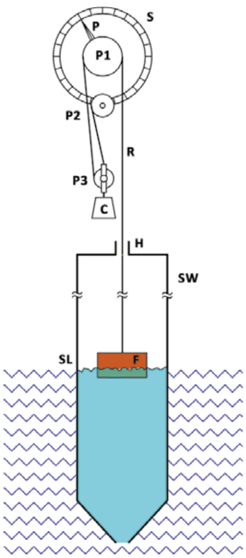

Figure 1 – Marigraph scheme:
the float follows the variations of:
sea level, then, with a pulleys system, sends this movement to a pointer or to a recorder, which show the instantaneous values of the marine level.
F float
SL sea level
SW stilling well
R rope
C counterweight
P1, P2, P3 pulleys
P pointer
S scale
H hole for passage of R

- *Marigraph*: the instrument, in its essence, it is a float that follows the ups and downs of the sea level, and transmits this movement to an indicator device, a pointer on a scale, or a paper tape recorder, moved by clockwork gears, on which a writing system traces the movement of the float. Figure 1 shows a scheme of marigraph: a cylindrical float F follows the vertical motion of the SL level of the sea, protected, in its movement, by a cylinder that constitutes the SW stilling well, with which the ripples of the sea are reduced. SW is open on the bottom, to let water in, and it has a hole, on top, to pass the rope R to which F is tied. The motion of F is transmitted to the R rope, always held in tension by the counterweight C, through the pulleys P1, P2, P3. The movement of F transmitted via R to P1 causes the rotation of P1 which in turn shifts the pointer P on the S scale, that it is divided into degrees ranging from the minimum level to the maximum, which can reach the sea at that site.

Obviously, the average value of sea level, in a certain time interval, had to be calculated by performing, manually, the average of the instantaneous values. This last aspect was somehow made "automatic" by the medimaremeter.

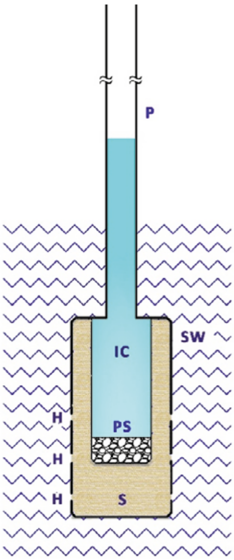

Figure 2 – Medimaremeter scheme:
as a result of the sand and porous septum, in the stilling well, the variations of water level are slower and less entity, in other words the instant level values are not recorded but the device records the average values.
P pipe
SW stilling well
H holes
PS porous septum
IC interior chamber
S sand

- *Medimaremeter*: the fundamental part of this instrument was in the stilling well SW (figure 2), which, unlike the marigraph, was closed on the bottom and with H holes in the side wall, also had a porous septum SP that separated it from the interior chamber IC, finally between SW and IC there was sand S. Sea water entered through the holes, and sand prevented the ingress of impurities. As a result of the sand and porous septum, in the stilling well, the variations of water level in P were slower and less entity, in other words the instant level values were not recorded but the device recorded the average values.

In the only version carried out there were no recording mechanism, and the readings were performed manually with a metric rod that was inserted, from above to the porous septum, in the P pipe, which reached a height above the maximum tide level. On the rod, for each measure, a sensitive paper tape was placed that blackened on contact with water. Reading on the rod the value at the end of the blackening of the paper, you had a sort of average value of sea level over time between two consecutive readings. The maintenance of the porous septum, which tended to occlude itself, made complex the functionality of the system.

Today, despite technological evolution, mechanical marigraph, although improved over time, with float position electronic detectors and with the automatic calculation of the average, are still in operation on the coasts of many countries. The same cannot be said of the medimaremeters that showed inconveniences related to their maintenance, detected by the inventor himself [12] and, over time, also by other authors [2], [30].

4 The zero tidal of Mediterranean Sea

As indicated by the already mentioned Provisions of Berlin of 1864, to define local variations in sea level, it was necessary to establish a conventional quote with respect to which to measure the level moment by moment, in order to then calculate, for a given interval of time, the average level.

For this purpose, in ports, in maritime stations, in hydrographic institutes, a quote called zero tidal or zero hydrometric (benchmark) was established to which to refer to detect, over time, the variations in the level of the free surface of the water. These variations are defined by the difference between two consecutive measurements of the distance of water from the benchmark. Such a definition made these differential measures independent of the quote at which the benchmark was set, provided that it was above the maximum tide level.

In the subsequent paragraphs we briefly describe the first tidal observatories in which the benchmarks of the main Mediterranean countries are indicated.

4.1 Italy

Trieste was the first town to have a marigraph in 1859 [25], as already mentioned, at that moment the city was Italian only geographically; the instrument was carried out at the *Imperial Regia Accademia di Commercio e Nautica* (today, *Istituto Nazionale di Oceanografia e di Geofisica Sperimentale - National Institute of Oceanography and Applied Geophysics – OGS*). The instrument was placed in the *Casa Rossa* at the end of the *Molo Sartorio* (Sartorio Pier). The hydrometer for the control measurements consisted of a vertical cast iron pipe buried in the pier; the upper edge of this tube, placed at ground level, defined the *"Zero of the Sartorio Pier"*. Mareographic data of Trieste were published from 1869 by the *Commission for the Adriatic Sea* [20], [28]. The Trieste marigraph is still the mareographic reference for Austria.

Previous, to the aforementioned marigraph, a hydrometer was installed near the *Ponte Rosso*. It was an indicator of a level carved in the stone and graduated in Paris feet (in French *pied du roi*) and inches (in French *pounce*)[3] who could date back to 1785 [20]. The zero of this hydrometer is known as a *Zero Ponte Rosso*. The hydrometer is likely to serve for occasional sea level observations, useful for the transit of boats in the channel.

Rimini was equipped with a marigraph, installed in the canal port in 1867, and in 1896-7 Ravenna also had one. Currently the first is managed by the Municipality of Rimini, since it serves the sewerage network, while the second is part of the National Tide Gauge Network which has thirty-five measurement sites (see figure 3).

In Venice, the first reference level, called the *Comune Marino*, was defined in 1825 as the average level of high tides, coinciding with the *"line of green"* formed by the algae present on the walls of the buildings and on the *fondamenta* (roads flanking the canals). This quote was materialized on the walls of some buildings by carving a horizontal line and a letter C. The zero was then set at 1,50 m below the *Comune Marino*, so as not to have to use negative numerical values [1002]. However, in Venice, the systematic measurements of the sea level, as well as of the maximum and minimum tides, began 1871, when Tommaso Mati (1823 - after May 1894) carried out the first marigraph at *Palazzo Loredan* in *Campo Santo Stefano*, at the headquarters of the Public Works Department. This date represents the beginning of the tide recordings according to the Berlin provisions, that is with the introduction of a reference level from which the tide heights recorded, with the established procedures, at specific times could be inferred. Due to its tides of such amplitudes that are not comparable with those of the rest of Italy, Venice has always referred to autonomous *benchmarks.* The last tidal zero was established in 1923 at *Punta della Salute*, in the Giudecca Canal, averaging the values measured from 1885 to 1909 and setting the central year of the period (1897) as a reference

[3] 1 foot = 12 inches, 1 inch = 27,07 mm.

value. The introduction of this reference, connected to the Venetian soil, makes it possible to compare high waters of the same height, but which occurred at different times. In fact, in these cases the same percentage of flooding should occur in the city of Venice. [1002], figure 3.

In Genoa there is the *hydrometric zero* of the Italian survey network, which is indicated by benchmark, inside a marigraph (carried out in 1883), managed the Italian Navy Hydrographic Institute. The level was defined using the average of observations, of the sea level, carried out in the period 1937 - 1946 and it has conventional value of 3,249 m on the m.s.l. (mean sea level). The height of all the benchmarks of the peninsular leveling network (about 18 000 km, physically marked with a benchmark about each kilometer) are derived from the Genoa's one (figure 3) [15], [27].

For the larger islands, the reference role is played by the marigraph of Catania (installed after 1896) which calculated the mean of the sea level values observed during the year 1965, and by the marigraph of Cagliari (installed after 1896) which considered the period 1955-1957 [7]. After 1896 marigraphs were installed in: Imperia, Leghorn, Civitavecchia, Naples, Ancona, Palermo, La Maddalena; Finally, other mareographic sites were carried out in the twentieth century. [10].

Figure 3 – The 35 stations of The National Tide Gauge Network (Italy):
Trieste, Venice-Lido, Ravenna, Ancona, San Benedetto del Tronto, Ortona, Isole Tremiti, Vieste, Bari, Otranto, Taranto, Crotone, Reggio Calabria, Messina, Catania, Porto Empedocle, Sciacca, Lampedusa, Palermo, Ginostra, Palinuro, Salerno, Naples, Cagliari, Carloforte, Porto Torres, Ponza, Gaeta, Anzio, Civitavecchia, Marina di Campo, Leghorn, La Spezia, Genoa and Imperia. Source: [1003].

4.2 France

The French mediterranean mareographic surveys, subsequent to the aforementioned Toulon surveys, began in 1884 when another tide gauge was installed in Marseille. The survey station was carried out, on the basis of an 1879 resolution of the *Commission Centrale du Nivellement Gènèral de la France,* to determine the exact average sea level in order to establish an altimetric reference for the subsequent leveling of the territory French. On the indication of Charles Lallemand it was chosen a *totalizer* (*totalisateur* in French) marigraph (published in 1878) equal to the one that the civil engineer F. H. Reitz [31] had already installed on the island of Helgoland (Germany, North Sea) and in the port of Cadiz (Spain, Atlantic Ocean).

From February 1st, 1885 the average sea level was placed at 0,471 m below the […] *Zero of the tide scale* […] established without any measurement, in 1860, by the director of the Port of Marseille in reference […] *traces more or less apparent than waters, in their movements of rise and decrease, leave against the quay walls* […] [5]. In Corsica, the altimetric zero quote was fixed following the observations of the tide made in Ajaccio from 1912 to 1937. Figure 4 shows the sites of the mareographic stations installed by France on the Mediterranean coast: eleven mareographs from Port-Vendres, at the western end of the Gulf of Lion, to Nice, followed by a survey station of the Principality of Monaco; while four mareographs are placed in Corsica [1004].

Figure 4 – The 13 Mediterranean French Mareographic stations:
1 Port Vendres, 2 Port La Nouvelle, 3 Sete, 4 Fos sur Mer, 5 Marseille, 6 Toulon, 7 Port Ferréol, 8 La Figuerette, 9 Nice, 10 Centuri, 11 Ile Rousse, 12 Ajaccio, 13 Solenzara.

4.3 Spain

The first Spanish marigraph, permanently installed to establish the altitudes of the terrestrial reliefs, was placed in Alicante, a Mediterranean port south of Valencia and north of Cartagena. Here the average sea level was calculated from the first data collected in the decade 1870 - 1880 with reference to a benchmark sited on the first step of the stairs of Alicante town hall. In this measuring station the sea level records continued until 1920 for daily average measurements, afterwards hourly averages were done. In 1953 a second marigraph was carried out in Alicante; both instruments are still active. Therefore, the mareographic data series of Alicante represents the longest series of the Mediterranean Sea [14]. In 1876 the second Spanish marigraph was made in Santander, on the Atlantic coast, at the extreme west of the Gulf of Biscay [14]. As regards the measurement of the heights of the islands, the average local sea level obtained from marigraphs permanently installed on them is used. Currently Spain has installed on its Mediterranean coasts several mareographic stations, all carried out or upgraded between the end of 1990 and 2012; fourteen are located from Tarifa, on the Strait of Gibraltar, to Barcelona, seven are on the Balearic Islands and two in the small Spanish enclaves of Morocco: Ceuta, in front of Gibraltar and Melilla, at the eastern end of the Morocco, figure 5 [1004].

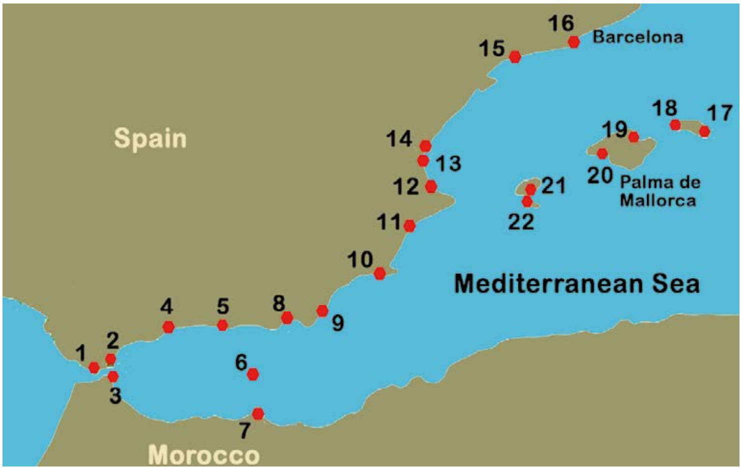

Figure 5 – The 22 Mediterranean Spanish Mareographic Stations:
1 Tarifa, 2 Algeciras, 3 Ceuta, 4 Malaga, 5 Motril, 6 Alboran, 7 Melilla, 8, Almeria, 9 Carboneras, 10 Murcia, 11 Alicante, 12 Gandia, 13 Valencia, 14 Sagunto, 15 Tarragona, 16 Barcellona, 17 Mahon, 18 Ciutabella, 19 Alcudia, 20 Palma de Majorca, 21 Ibiza, 22 Formentera.

4.4 Eastern Adriatic Sea

Going down from Trieste along the coast of the republics of the former Yugoslavia, up to the whole of Albania, there are practically no monitoring stations of any importance, capable of forming an albeit minimal detection network of sea level. A first station is present on the Greek island of Corfu, that is after passing the Otranto canal that separates the Adriatic Sea and the Ionian Sea (1 in figure 6).

4.5 Greece

We did not find sufficiently meaningful references on the marigraphic stations of Greece in the period of our interest. A 1987 publication [24] talks about of short recordings of sea level measurements made in the years before 1969: too "modern" for our purposes. We therefore limit ourselves to indicate in figure 6 the current situation of the mareographic network of the Greek Hydrographic Service.

Figure 6 – The 23 Greek Mareographic stations:
1 Kerkira (Corfù), 2 Preveza, 3 Katakolo, 4 Kyparissia, 5 Kalamata, 6 Koroni, 7 Kapsali, 8 Kasteli, 9 Paleochora, 10 Hrakleio, 11 Ierapetra, 12 Gavdos, 13 Kalathos, 14 Kos Marina, 15 Kos, 16 Syros, 17 Peiraias, 18 Corinth, 19 Itea, 20 Panormos, 21 Aigios, 22 Thessaloniki, 23 Plomari (Lesbos).

Figure 7 – The 11 Mediterranean Turkish Mareographic stations:
1 Gokcead, 2 Bozcaada, 3 Mentes, 4 Bodrum, 5 Marmaris, 6 Fethiye, 7 Anthalia, 8 Bozzyazi, 9 Tasucu, 10 Erdemli, 11 Iskenderun.

4.6 Turkey, Syria, Lebanon

As with Greece, even in the past of the Turkish coast there is not enough indication of its mareographic stations. Even worse is today's situation of the Turkey's marine level monitoring network which is absolutely lacking (figure 7). The other two nations indicated, Syria and Lebanon, from this point of view and not only, are even worse off than Turkey.

4.7 Cyprus

After passing under the control of different states, from the end of the 16th century to the second half of the 19th century, the island was dominated by the Turks. It is with a convention of 1878 that in fact Cyprus passes under Great Britain, while remaining nominally Turkish, but only in 1925 the island obtains the status of British Crown colony. Following the irredentist movements against the British administration and the clashes between the Greek Cypriot and Turkish Cypriot factions in 1960, Cyprus became an independent republic governed by representatives of the two ethnic groups. Soon the two factions came into conflict supported by their respective nations of origin. In 1975 the island was in fact divided, horizontally, in two distinct national entities: the Turkish one in the north and the Greek one in the south; the capital of both states was the city of Nicosia crossed by the border line.

In the southern part (Greek Cypriot area) there are two British military bases that, most likely, have influenced the carrying out of four mareographic stations, while on the north coast (Turkish Cypriot area) no station is active (figure 8).

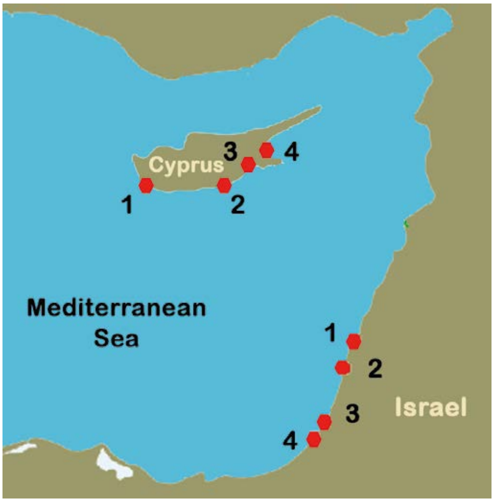

Figure 8 – Marigraphs on the coasts of:
- Cyprus: 1 Paphos, 2 Zygi, 3 Larnaca, 4 Paralimni;
- Israel: 1 Haifa, 2 Hader, 3 Ashod Port, 4 Ashkleton.

4.8 Israel

The historical events of this region are known, to which, politically, after the Second World War, this name was attributed, while geographically it can still be called Palestine.

Absolutely singular is the history of altimetry in this region. In fact, for cartographic reasons (at least originally it was not required great accuracy for heights) the method of triangulation was used. The method allows to obtain the height of an object, with respect to the ground, by referring to objects of known height, completely neglecting the *marine altimetric zero*.

In 1779 a cartographer French Pierre Jacotin drew the first elevation map of the Palestinian reliefs by triangulating them with respect to the Egyptian Great Pyramid of Giza.

In 1841 J. F. Anthony Symonds carried out triangulations, with a leveling network, Acre (north of Haifa) with Lake Tiberias or Kinneret (Sea of Galilee), and a second network was made from Jaffa (Mediterranean port of Tel Aviv) to the Dead Sea, via Jerusalem, in order to determine the quotes of the Dead Sea and Lake Tiberias compared to the Mediterranean.

During the period 1861 - 1864 further surveys, conducted by Arthur Mansell included the Israeli coast as far south as Syria. The map indicated the depth of the water in relation to a fixed point established on land, for each stretch of sea. In 1865 with a leveling network realized by Charles W. Wilson, measures were carried out by Jerusalem in the direction of both Jaffa's Dead Sea. In 1881 with all the maps produced, twenty-six sheets divided in three volumes were published by the Palestine Exploration Fund [4]. The good accuracy of the cartographers of the time that chose, to determine the altitudes, a terrestrial reference, and not a marine one, is to be attributed to the fact that the Mediterranean coast of Israel has not had vertical tectonic variations for at least 22 000 years [9], [26, while sea level is strongly influenced by climatic conditions.

The first instrumental measurements of the average sea level were carried out in 1927 in the old port of Jaffa with a medimaremeter. In 1928 a similar instrument was installed in Haifa and a second in Jaffa; the measurements were carried out daily at 7:30 and 13:30 [13]. The medimaremeter measurements became reference measurements for the Israeli leveling network beginning in 1934, figure 8 [29].

4.9 Malta

In 1814 Malta officially became a part of the British Empire. After the Suez Canal opened (1869), the island became fundamental for the British in the new route for India. For this strategic function London granted it a partial autonomy suspended in 1930 and definitively repealed to the outbreak of the Second World War. In 1957 there was a first step in the British disengagement in the Mediterranean, with the dismantlement of the naval arsenal of La Valletta (capital of the Island), the main support of the island economy. In July 1964 an agreement of mutual defense and assistance guaranteed the uses of Maltese bases to Great Britain. In September of the same year Malta was proclaimed independent state in the context of the Commonwealth. In December 1974 the State of Malta became the Republic of Malta always within the Commonwealth. Also, in this case the strong presence of the British ships, in the Maltese ports, was decisive for the carrying out of the two marigraphs in the archipelago (figure 9).

Figure 9 – Maltese Mareographs:
1 Malta, 2 Portomaso.

4.10 Northern Africa

Unfortunately, the geographical distribution of instruments and their quality are of very low level. There is not even a basic instrumentation that could be extremely useful to allow quick decisions in the event of *tsunami*, on a coast where important cultural and touristic town are hosted.

5 Conclusions

Over time, with the development of new measurement methodologies, other definitions of average sea level and tidal zero have been elaborated, given in turn according to the applications and in relation to the different geodetic representations of the Earth: *zero of the port (*or *harbour zero), tide gauge zero*, *geodetic datum*, *hydrographic zero (or nautical chart zero)*, etc. [10], [16], [19]. With reference only to the definition of the hydrographic zero, the Italian Navy Hydrographic Institute states that [19]:

- Since the infrastructural works in the coastal or port area are carried out over time and space, strictly speaking it is not enough to consider the mere *local average sea level* as *hydrographic zero.* In fact, it is also necessary to detect, in a regular and systematic way, the excursion of the sea level both at the time of the infrastructure installation and in its operational phase.
- The above requires the estimate of the tides trend in the local area, in relation to:
  - the fundamental astronomical components which cause the phenomenon;
  - the local meteorological component which, especially in the Mediterranean, determines a significant aspect of the phenomenon amplitude.

Today the sea level is measured using tide gauges based on technologies at all different from those of the first instruments, which we mentioned previously. Ultrasonic altimeters are widely used. With these instruments, the measure of the distance between a reflective surface (the water in this case), and an ultrasonic emitter/receiver device, is deduced from the measure of the round-trip time of the ultrasonic wave transmitted ([1] p. 93) [28]. The radar altimeters of the new generations are based on the same principle, but with the use of electromagnetic microwave generators [10]. In any case, in today's measurement stations to the transmitter/receiver a floating level sensor is associated, which uses a linear *encoder*, with chart recorder: for the punctual verification of the measures, for the analysis of particular events and phenomena and for the recovery of data in the event of the main instrument failure [15]. The most recent measurement systems are based on satellite altimetry. This technique uses radar altimeters mounted on orbiting spacecraft, to measure height of: mainland; ice; ocean and sea waves, with accuracy of about 2 cm [1001]. Each second, the altimeter installed on the satellite radiates the Earth's surface with microwave trains and picks up the echoes reflected by it, correcting the interference, on the measurement, produced by the atmosphere. The precise orbital position of the satellite is controlled by two laser systems and GPS that make it an absolutely reliable reference [1005]. Today, in the presence of even more marked climate change, the study of sea level becomes always more important because of reduction of the glaciers and polar ice cap, with consequent raising of the sea level. Moreover, with the use and urbanization of the land closest to the low coasts it is increasingly important to have alarm systems that in the presence of a rapid propagation, along the coasts, of the rise in the water level, due to tsunamis, can promptly give alarm signals; something easily obtainable with a system of tide gauges connected to each other in an international network.

6. References

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