Multiparametric Analysis of Gulf of Pozzuoli

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Abstract

The topic of this work is a multiparametric analysis of Gulf of Pozzuoli, a partially semiclosed basin situatated in NW part of Gulf of Naples in Southern Tyrrhenian Sea, South of Italy. More precisely, the monitored parameters have been sea water temperature and sea water current velocity, this latter in its components zonal and meridional. Data used for the work have been acquired by a 3D-Dimensional current meter belonging to M.E.D.U.S.A, an underwater infrastructure of Osservatorio Vesuviano (section of Naples of National Institute of Geophysics and Volcanology) implemented for monitoring sea activity of Campi Flegrei, the most dangerous volcanic caldera in the world to which Gulf of Pozzuoli is integral part. Data acquired for this work belong to period January 2017 – May 2020. Sampling frequency is 1 Hz, but data have been averaged at 1 hour to obtain a more data compactness. So, besides time series, a Continuous Wavelet Transform has been performed in a way to obtain a picture of signal frequencies with a good resolution, preserving time information. Then, time series of zonal and meridional velocity for periods November-December 2017 and November-December 2018 have been treated separately in a way to have a comparison with previous works. Obtained results have substantially coherent with previous works in the area and the most interesting result is the presence of a possible correlation between signals and several earthquakes swarms typical of the area.

Keywords: Gulf of Pozzuoli, Campi Flegrei, temperature, current velocity, wavelet analysis

1. Introduction

The Gulf of Pozzuoli is one of the more interesting areas for studies of several disciplines. It is a partially closed tiny basin that can be considered as the NW portion of Gulf of Naples, Italy. Its principal characteristic is the presence of volcanic caldera of Campi Flegrei, the most dangerous one in the world. At the same time, the Gulf of Pozzuoli is a natural laboratory for the study of sea behaviour in a semiclosed basin, above all for the circulation and particular oscillations (for example, seiches and Kelvin waves). These last ones are the reasons why the behaviour of this gulf is monitored by several instruments. Among these ones, there are the instruments of monitoring infrastructure M.E.D.U.S.A (acronym of Multiparametric Elastic-Beacon Devices and Underwater Sensors Acquisition system) belonging to Osservatorio Vesuviano, a research observatory situated in Naples. In this work, two physical parameters of Gulf of Pozzuoli have been analysed: temperature and velocity. The study has been realised using data acquired by a 3-D current meter placed in M.E.D.U.S.A buoy CFB3 at 40 m depth. The choice of this instrument has been made because it is equipped by several sensors, included temperature and velocity one. So, it is possible to develop an only acquisition system. But, apart this practical question, the most relevant aspect is that the instrument is placed in the internal part of Gulf of Pozzuoli, at 1,5 kilometers far away the coast. In this way, it is possible to obtain a double monitoring. First, the comparison of obtained temperature and velocity with those theoretical ones illustrated by previous works. Second, the eventual presence of a correlation between the sea behaviour and activity of volcanic caldera. To reach this goal, a spectral analysis has been implemeted and it has been obtained by means of a Continuous Wavelet Transform, performed by the specific Matlab function. The work is structured in following way: state of art of Gulf of Pozzuoli about circulation and temperature is briefly described in paragraph 2. In paragraph 3, there is a brief illustration of volcanic caldera of Campi Flegrei and of M.E.D.U.S.A infrastructure. Paragraph 4 is focused on description of data and methods used for the analysis. Finally, results and future perspectives are described in paragraph 5.

2. The Gulf of Pozzuoli

The Gulf of Pozzuoli is a tiny body of water that represents the NW portion of Gulf of Naples. Its horizontal extension measures almost 9.5 km, considering distance between Capo Miseno and Capo Posillipo. It is a natural observatory for several scientific disciplines as biology, chemistry, physics. And volcanology and oceanography, too. Indeed, the Gulf of Pozzuoli is an integral part of volcanic caldera of Campi Flegrei. This latter is the most dangerous volcanic caldera in the world. This because it is situated in an area where there is a high exposure of people who live there (550,000 inhabitants ca.). With a diameter of 12-15 km, this volcanic caldera expands all the way both to land and to Gulf of Pozzuoli, so to sea. Actually, it is in quiescence and it is composed of craters, tiny volcanic cones and location of secondary volcanism, the bradyseism above all. Bradyseism is a typical phenomenon of Campi Flegrei and it represents an uplift and/or a descent of part of the ground surface placed on the top of magma chambers caused respectively by the filling or emptying of these ones or by hydrothermal activity.

Hydrologic structure of Gulf of Pozzuoli is composed of one substantially homogeneous layer, essentially made up of Atlantic water. Its maximum depth is 100 m, its density ranges from 1026.63 to 1028.65 kg/m^3 , while salinity varies from 37.2 to 37.8 psu. Regarding to temperature, this last one ranges from 18°C in summer to 14°C in winter. In this season, temperature is almost constant because of continuous mixing of water column.

Regarding to circulation, regulated by equations of motion in shallow water, it is essentially due to large scale circulation forced by geostrophic and ageostrophic currents (Kelvin waves) present along the lateral boundaries of the Gulf, . In fact, the contribute of Ekman currents due to local winds is negligible. Drilling down, circulation in Gulf of Pozzuoli has essentially a zonal component and it has an interesting behaviour in autumn, when circulation is stronger (almost one order of magnitude) in left boundary, corresponding to Canale of Procida, than in right one. This because the particular conformation of Gulf of Pozzuoli inhibits in left part of basin that external currents could insinuate into it.

Fig.1 - collocation and bathymetry of Gulf of Pozzuoli

3. The M.E.D.U.S.A infrastructure

The Campi Flegrei are an area in the west of Naples (Italy), with a huge interest in geophysical community being a volcanic caldera among the most dangerous in the world. Reason of this is high exposure of people who live in that area (550,000 inhabitants ca.). Volcanic activity of the Campi Flegrei is monitored by Osservatorio Vesuviano, the oldest volcanology observatory in the world (founded in 1841). Among several monitoring infrastructures afferent to Osservatorio Vesuviano, in these last years the monitoring infrastructure M.E.D.U.S.A is standing out. This last one is based on four instrumented buoys (CFB1, CFB2, CFB3, CUMAS) operating in the Gulf of Pozzuoli within the local surveillance system of the Campi Flegrei volcanic caldera equipped with geophysical and oceanographic instrumentation and continuous and real time data acquisition and transmission to the Monitoring Center of INGV in Naples, where data are integrated to those acquired by the land networks. Among various instruments placed in each buoy, there is a current meter where the data for the analysis has been obtained from. This is a 3-Dimensional current meter equipped by sensors of temperature, velocity, direction, tilt and pressure. For each sensor, data acquisition occurs with a sampling frequency equal to 1 Hz. In following table, characteristics of the 3-Dimensional current meter are described.

Parameter	Type	Range	Accuracy	Resolution
Velocity	Acoustic	0-300 cm/s	± 2% of Reading or 1 cm/s	0.01 cm/s
Direction	3 Axes Fluxgate	0-360°	± 2°	0.01 °
Tilt	2 Axes Accelerometer	0-30°	± 0.5	0.01 °
Temperature	Thermistor	-2°-35° C°	± 0.05 °C; ± 5 °C	0.01 °C
Pressure	Precision Machined Silicon	User specified	± 0.15 % full scale	0.02 % full scale

Table 1 - Description of characteristics of 3-D Dimensional current meter used for the analysis

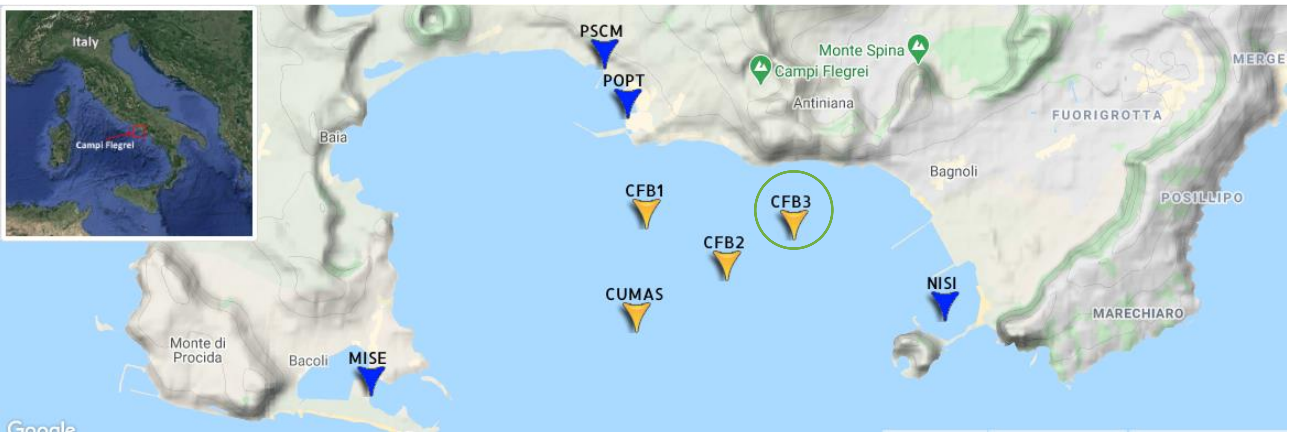

Fig. 2 – Ubication of the four buoys (in yellow) of M.E.D.U.S.A infrastructure in Gulf of Pozzuoli. In the circle, the buoy CFB3 where there is the 3-D dimensional current meter used for the analysis

4. Data and methods

The database used for the analysis is made up of data acquired by 3-D Dimensional current meter belonging to CFB3 buoy of MEDUSA infrastructure, situated at 40 m depth in Gulf of Pozzuoli (see Fig. 2). More precisely, data consist of temperature and velocity acquired by the previously mentioned instrument in period January 2017 – May 2020. Data are sampled at frequency of 1 Hz, but, for obtaining a data compactness, they are averaged at 1 hour. In this way, 29184 temperature and velocity (regarding to this latter, data have been acquired both for zonal and meridional component) data have been sampled. Because of instrument's electronic problems, several sampled data have been missed, especially in first four months of acquisition (January – April 2017). So, original database is lightly reduced and it is made up of 26741 data for temperature and zonal velocity, while for meridional velocity new database is made up of 26699 data. In percentage, the reduction is approximately 8.4%. The process of data reduction has been occurred by means of specific MATLAB function "rmissing". Then, the work has been structured in following way. For temperature, entire time series has been plotted in a way to verify its seasonal tendency. After this, a Continuous Wavelet Transform (CWT) of time series has been performed. This specific typology of analysis has been made for two reasons. First, the CWT ensures the maintenance of time information when the passage from time dependence to frequency one happens. Second, CWT produces a better resolution compared to other similar methods that preserve both time and frequency information, as Short Time Fourier Transform (STFT). By means of CWT, the goal of verifying eventual prevalent frequencies and when these latter ones occur has reached. The entire procedure has been done again both for zonal and meridional velocity component, too. But, regarding to these latter, a more step in the procedure has been made. In fact, besides the treatment of the whole time series, a comparison between zonal and meridional velocity in autumn has been performed. This because the goal is the obtaining of a direct verify about circulation in Gulf of Pozzuoli in this determined season (see par.2). This particular procedure has been made through time series of zonal and meridional velocity components acquired in November-December 2017 and November-December 2018. The analogous time series November-December 2019 has not been considered because of strong electric noise present. As for entire time series, for the two short time series previously mentioned, first a plot of comparison has been made and after CWT of them has been performed. Both plot and CWT of considered time series have been realised by means of opportune MATLAB functions, respectively "plot" and "cwt", this latter after having put sampling frequency equal to $\frac{1}{3600}$ Hz.

5. Results and conclusions

First of all, figures of results obtained by data analysis are shown. Following figures regard temperature time series (time is expressed in hours) and its CWT (time is expressed in years).

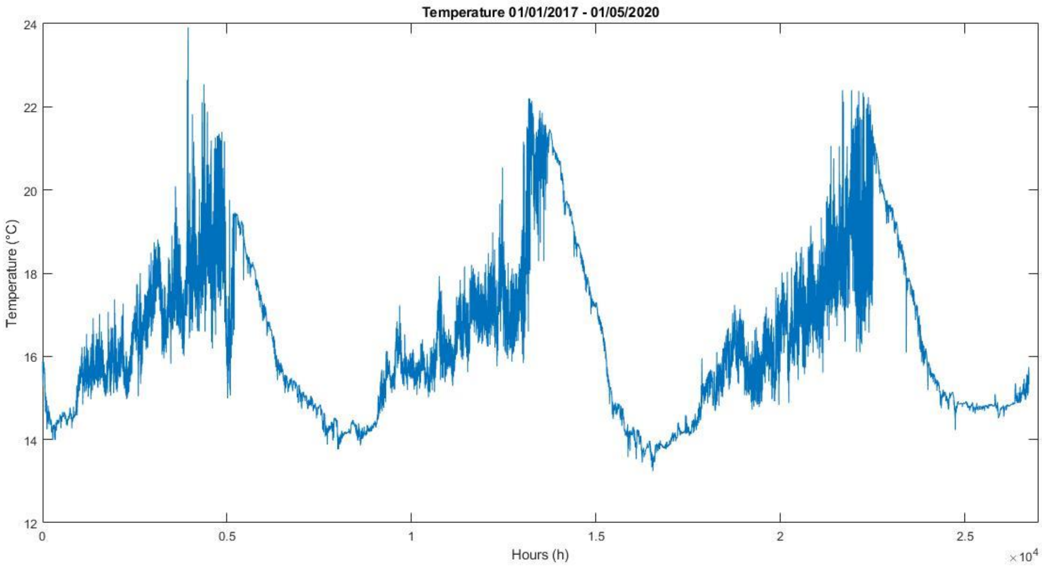

Fig. 3 – Temperature acquired by 3D dimensional current meter in period January 2017 – May 2020

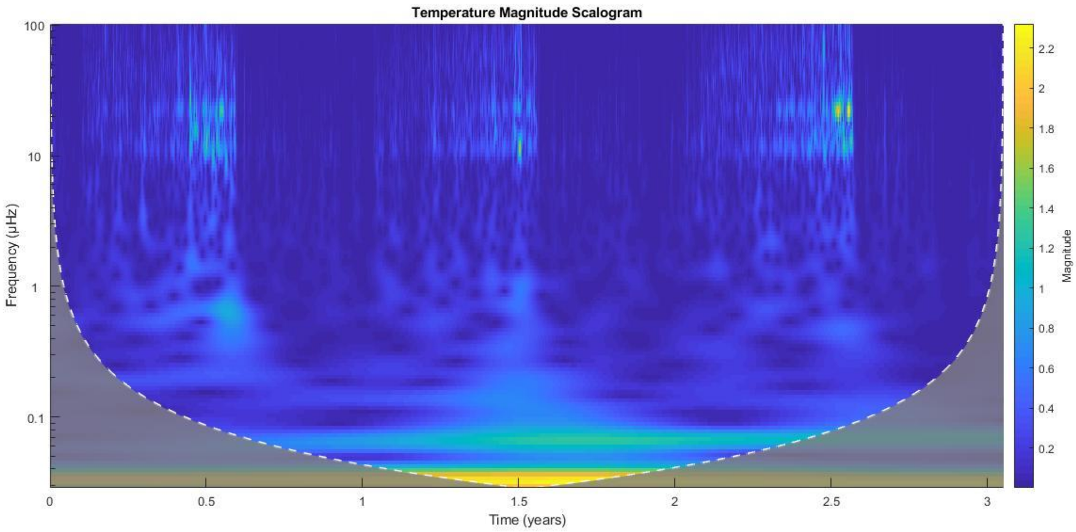

Fig. 4 – CWT of Temperature acquired by 3D dimensional current meter in period January 2017 – May 2020

From fig. 3, it is possible to observe as temperature has a behaviour like "wave", with an "oscillation" of approximately 8760 hours, corresponding to a year. The confirm of this is in CWT in fig. 4, where in range frequency [2 μHz ; 4 μHz] peak of magnitude 1.4 appear along entire time axes. As expected, temperature in autumn-winter months, corresponding to 7000-9000, 16000-18000, 24000-26000 hours, is almost constant and equal to 14°C. During spring and summer, instead, temperature increases with a maximum in August 2017, 2018 and 2019 (corresponding to approximately 4000, 13000 and 20000 hours) included in range [20° C, 22°

C]. Near maximum (except for spikes due to electronic noise), there are a lot of oscillations that result in CWT in fig.4 with maximum in frequency at 22.3 μHz. A seasonal variability is substantially confirmed.

In the following figures are shown the time series of zonal velocity component and its CWT.

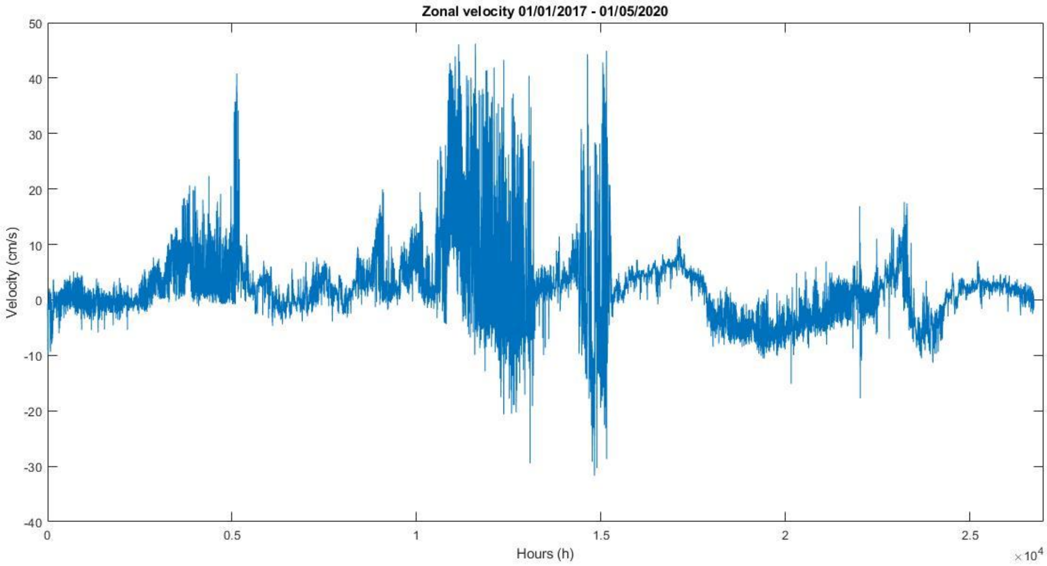

Fig. 5 – Zonal velocity acquired by 3D dimensional current meter in period January 2017 – May 2020

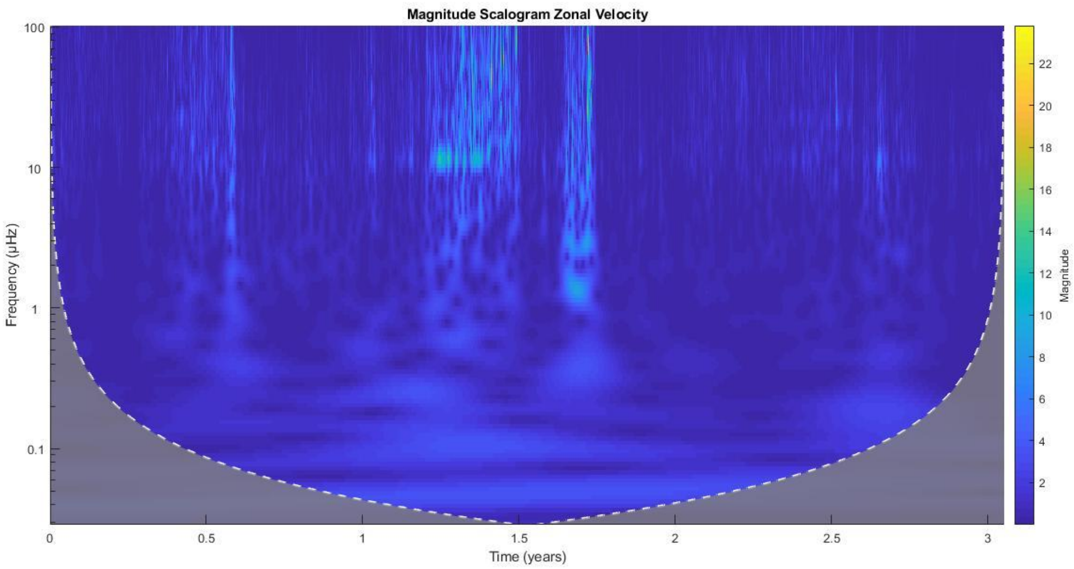

Fig. 6 – CWT of zonal velocity acquired by 3D dimensional current meter in period January 2017 – May 2020

Figures 7 and 8 regard meridional velocity component and its CWT

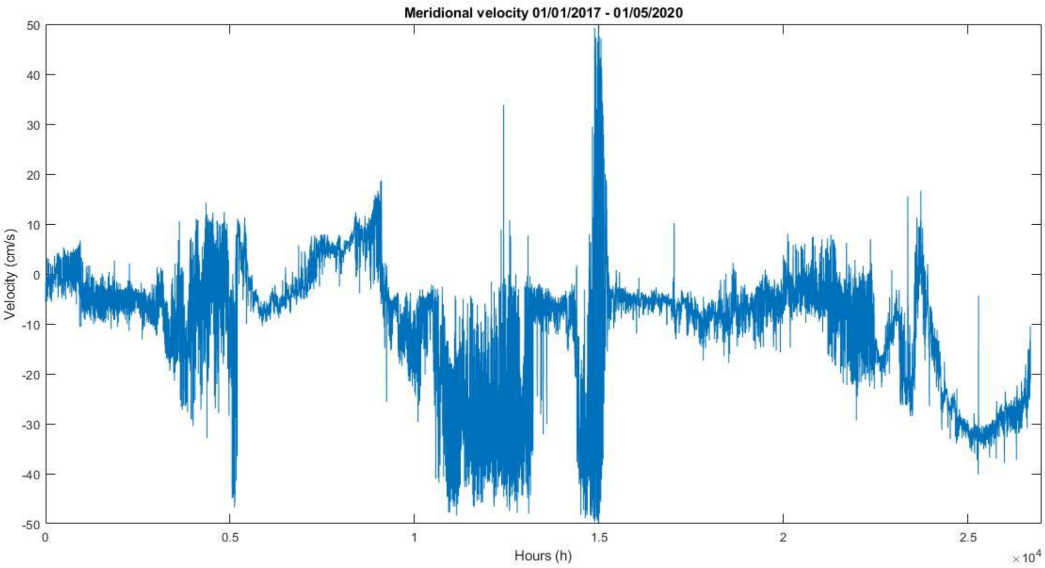

Fig. 7 – Meridional velocity acquired by 3D dimensional current meter in period January 2017 – May 2020

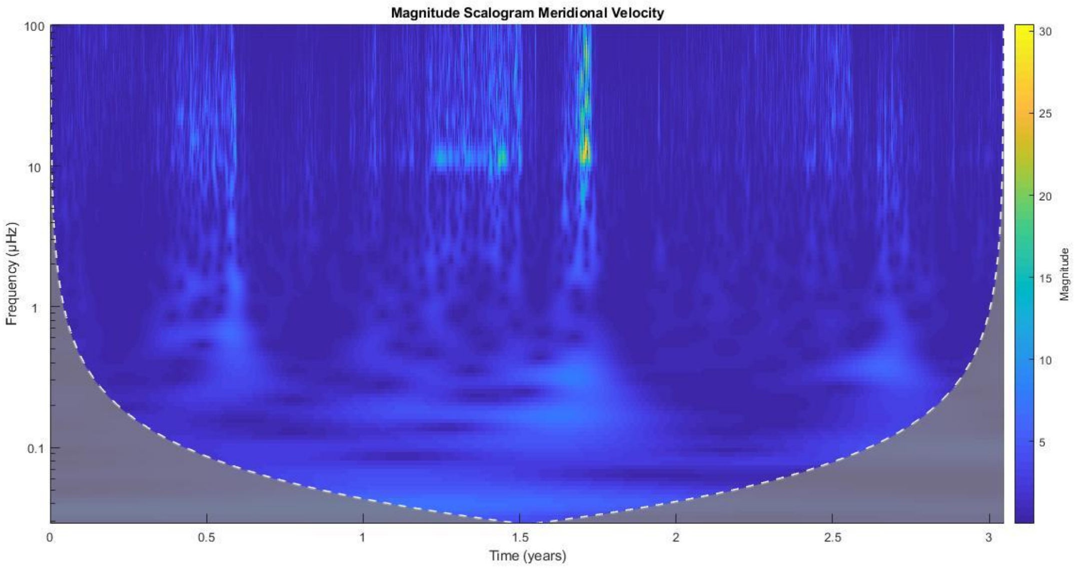

Fig. 8 – Meridional velocity acquired by 3D dimensional current meter in period January 2017 – May 2020

As it is possible to observe, in the time series of zonal and meridional velocity, fig.5 and in fig.7, there are ranges that produce strong anomalies in [1200 hrs, 1400 hrs], corresponding to March-April 2018 and in [1500 hrs, 1700 hrs], corresponding to September-October 2018. These inconsistencies could be explained with two possible reasons: possible strong electronic noise and possible correlations with earthquake swarms happened in area of Campi Flegrei in that period. An observation corroborated by two CWTs in fig. 6 and fig. 8, where in the same ranges there are peaks of frequencies at 10 μHz in [1200 hrs, 1400 hrs] and at [10 μHz, 100 μHz] in [1500 hrs, 1700 hrs], that is frequencies proximate seismic ones.

Then, following figures are plots of comparison between zonal and meridional velocity components (time expressed in hours) and their CWT in period November-December 2017 and same period in 2018 (time expressed in days)

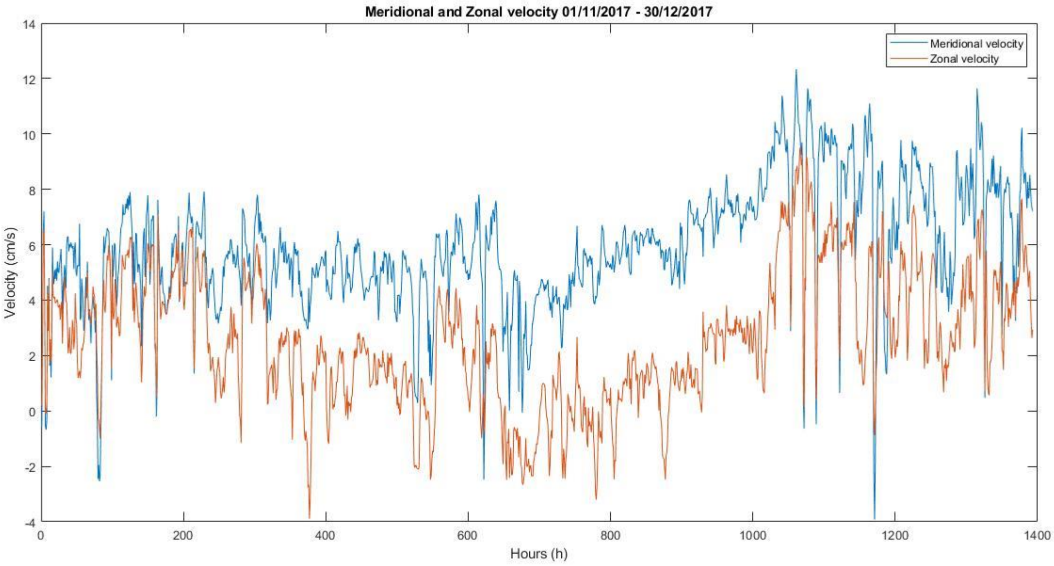

Fig. 9 – Zonal and Meridional velocity acquired by 3D dimensional current meter in period November-December 2017

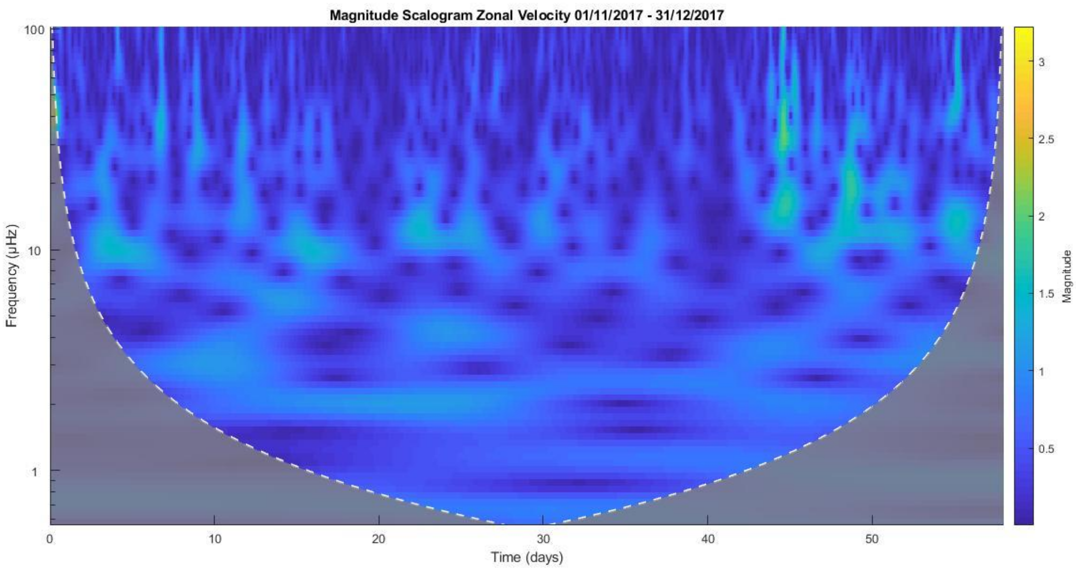

Fig. 10 – CWT of zonal velocity acquired by 3D dimensional current meter in period November 2017 – December 2017

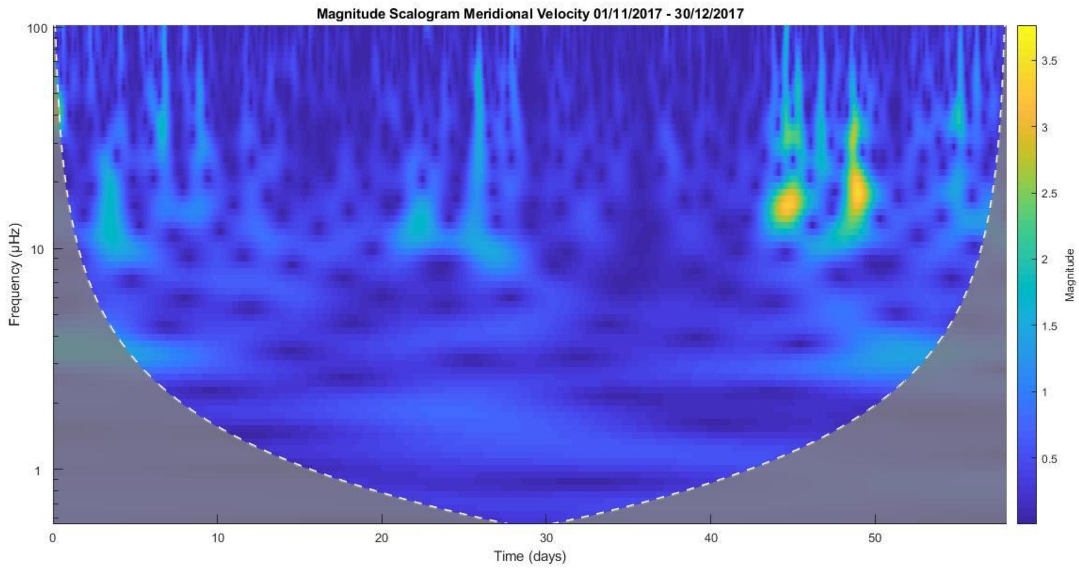

Fig. 11 – CWT of meridional velocity acquired by 3D dimensional current meter in period November 2017 – December 2017

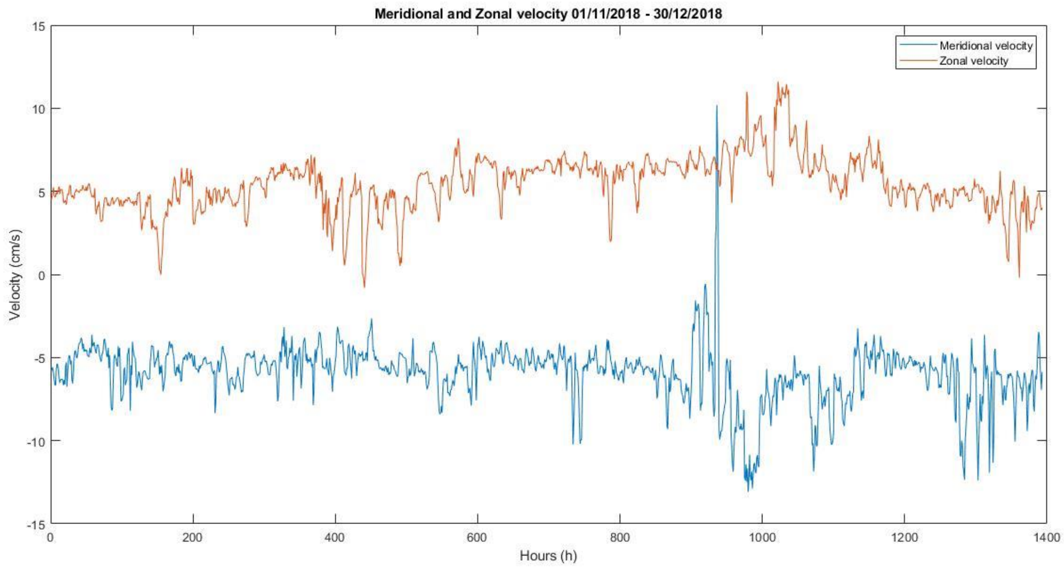

Fig. 12 – Zonal and Meridional velocity acquired by 3D dimensional current meter in period November-Dicember 2018

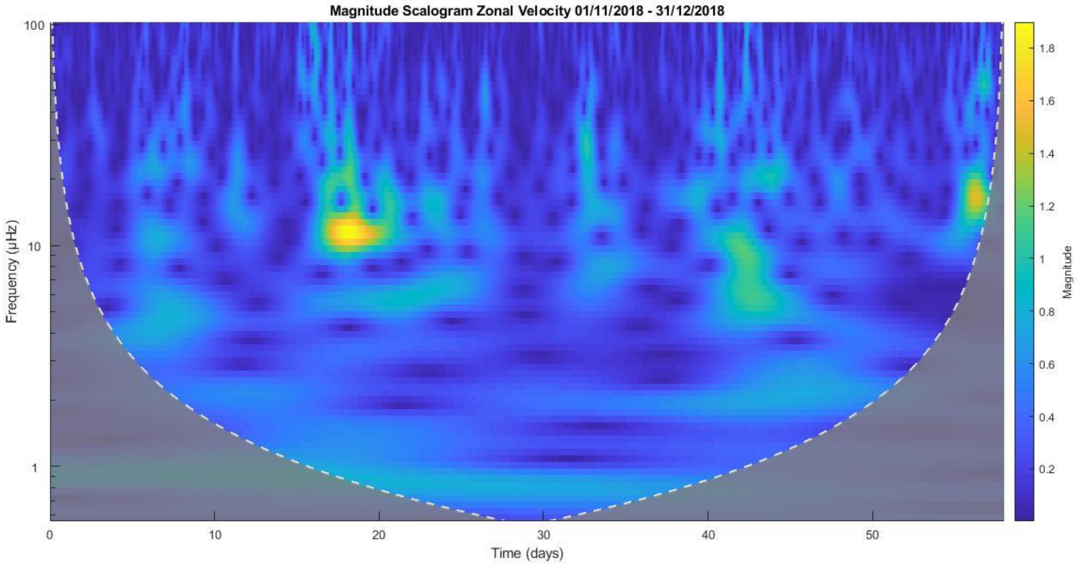

Fig. 13 – CWT of zonal velocity acquired by 3D dimensional current meter in period November 2018 – December 2018

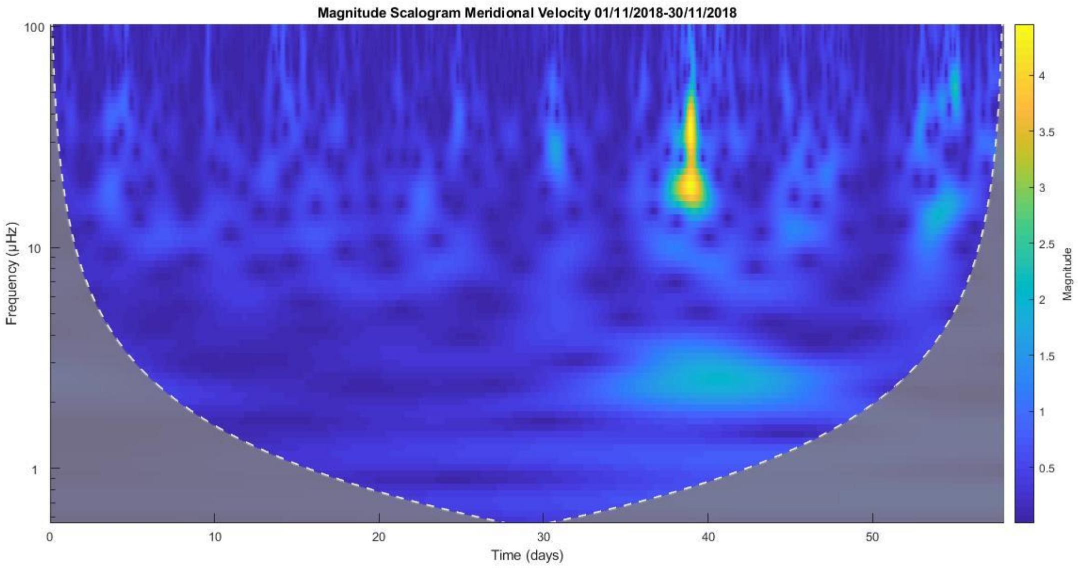

Fig. 14 – CWT of meridional velocity acquired by 3D dimensional current meter in period November 2018 – December 2018

Finally, fig. 9 and 12 show the comparison between zonal and meridional velocity respectively in period November-December 2017 and November-December 2018. While in fig.12, zonal component has stronger than meridional one as expected by previous works, in fig.9, the meridional velocity component is dominant. From perspective of CWTs, fig.10 and fig.11 show a coherence between two time series because strong peak happens in same period (first ten days of December 2017) and at the same frequency, 17 μHz, while fig.13 and fig.14 don't show same kind of coherence.

In conclusion, data of temperature and velocity (zonal and meridional components) acquired in period January 2017 – May 2020 by a 3D-dimensional current meter belong to buoy CFB3, situated at 40 m of depth in right part of Gulf of Pozzuoli (see fig. 2) of infrastructure M.E.D.U.S.A performed by Osservarorio Vesuviano have been analyzed. Besides time series, Continuous Wavelet Transform have been performed for verifying eventual interesting frequencies. For temperature, a seasonal variability is substantially confirmed and a peak of frequency of 22.3 μHz appears at maximum temperature. For zonal and meridional velocity component, there are two interesting results. First, the dominance of meridional velocity component as compared to zonal one in period November-December 2017. Second, the possible "contamination" of data velocity with earthquake swarms in Campi Flegrei. A result that could represent a future prospective, acquiring data from other current meters in other three M.E.D.U.S.A buoys and performing a direct comparison between these data and data obtained by other instruments of monitoring network of Campi Flegrei, as mareographs, seismometers and wind gauges.

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Appendix – The Continuous Wavelet Transform

To analyze not stationary signals, a conventional Fourier Analysis is not adequate for having a complete picture of frequencies. This because Fourier Analysis decomposes signal in regular sinusoids that could not individuate “irregular” frequencies. Then, another goal to reach is maintenance of time information, which is impossible to obtain with Fourier Analysis. Therefore, in order to realize an advance analysis of these experimental data, a wavelet approach has been used. Choice of this kind of analysis has been preferred because it allows to have information not only on frequencies but even on time. Then, it is an efficient method to obtain all the frequencies which have present in signal with a good resolution. This factor is relevant in choice of a wavelet approach. For example, the Short Time Fourier Transform is time-frequency localized, but the introduction of the window function to cover signals brings with its resolution problems because the chosen window is the same for the entire signal. So, spectral analysis has been obtained by a wavelet approach. In this way, signal is decomposed in shifted and scaled versions of a wave function, the so-called “Wavelet Mother”. This function must have the following properties: mean value equal to 0, asymmetric and basically irregular. If $\psi(t)$ is a Wavelet Mother, its shifted and scaled version is given by:

$$\psi_{s,\tau} = \frac{1}{\sqrt[2]{s}}\,\psi\left(\frac{t-\tau}{s}\right) \quad (1)$$

Assuming that signal is given by function f(t), the Continuous Wavelet Transform (CWT) is given by:

$$\gamma\,(s,\tau) = \int_{-\infty}^{+\infty} f(t)\psi^{*}_{s,\tau}\,(t)dt \quad (2)$$

where $\psi^{*}_{s,\tau}$ (t) is the complex conjugate of (16).

An example of Wavelet Mother is the Gabor-Morlet wavelet, chosen for the analysis in this work. This choice has been made because Gabor-Morlet wavelet is a complex function modulated by a Gaussian window. This characteristic makes it extremely suitable for the scientific applications. Its form is the following:

$$\psi_{s,\tau}\,(t) = e^{\frac{-t^2}{s^2}}\; e^{-ik_0 t} \quad (3)$$

Where k_0 is the so-called modulation frequency, that is a frequency chosen in an opportune way so function $\psi(t)$ could satisfy the admissibility conditions.

Scales have been selected by means of following equations:

$$s_j = s_0\, 2^{j\delta_j} \quad (4)$$

where s_0 is the smallest resolvable scale and it is equal to sampling time times two. δj is a resolution parameter about chosen scale and j is an index which identifies a determinated scale. It goes from 0 to J. The latter is the largest scale and it is given by following equation:

$$J = \frac{1}{\delta_j}\log_2\frac{N\delta t}{s_0} \quad (5)$$

where N is the number of data and δt is the sampling rate. Usually, Wavelet analysis is accompanied by so-called Cone of Influence. It is an array of real numbers plotted in a conic form that shows areas in the scalogram potentially affected by edge-effect artefacts. These are effects in the scalogram that arise from areas where the stretched wavelets extend beyond the edges of the observation interval. Within the unshaded region delineated by the white line, it is almost sure that the information provided by the scalogram is an accurate time-frequency representation of the data. Outside the white line in the shaded region, information in the scalogram should be treated as suspect due to the potential for edge effects.