Tsunami-like occurrence detection and characterization: a comparison between time-frequency analysis methods

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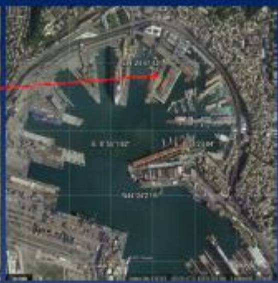
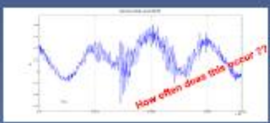


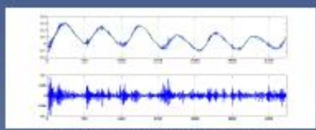
IIM Mareographic Station and W1-M3A Observatory

The mareographic station of Genoa is one of the oldest in the Mediterranean Sea. It is located in the Port of Genoa, Ligurian Sea,(44°24'43.3" N – 08°55'32.2" E) and it has been managed by the Hydrographic Institute since 1884. An OTT Thalimedes - float operated shaft encoder level sensor and an OTT RLS 24 GHz radar level sensor are now operating.
Starting from August 2008, sampling interval was set at 1 min for both the instruments. The station is also fitted with a barometric sensor.
W1-M3A observatory (yellow dot) is moored on a 1200 m deep sea bed in the open Ligurian Sea (37 nm from the coast). Two main component form the observatory: a spar buoy (50 m long and 12 tons weight) continuously operational since 2000 and a subsurface mooring periodically deployed close-by the buoy. The monitoring capability of the observatory complies with the concept of Essential Ocean Climate Variables allowing the monitoring of atmospheric parameters, physical and bio-geo-chemical properties of the water column from the surface to the ocean interior.

Data processing



On October 14, 2016 a meteotsunami was detected by sea-level measurements in the port of Genoa. The waves amplitude was about 50 cm, by far higher than the local tide. To investigate the occurrence and importance of these events, eight years long time series (2009-2016) of 1 minutes sampled sea level data were analysed. Very few (0.3%) missing or "bad" data were found. Lacks were interpolated by means of splines.

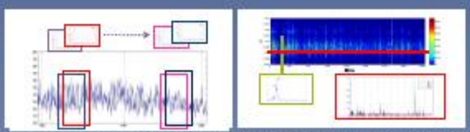


Original Sea level time series sample (top) and after filtering (bottom)

Filtering: to better focus on supratidal band, tidal components as well as other low frequency contributions (such as atmospheric variability) were filtered out. A quadratic least-square fit on 60-point moving average were subtracted from the signal, the residuals were grouped on annual basis and each yearly time series analysed.

Average annual mean power spectra and standard deviation

FFT analysis identified two main frequency peaks corresponding to 26.7 and 30.6 minutes period which were found in all the time series.

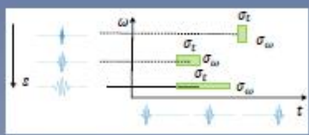


Example of time frequency analysis: Left) moving windows and power spectra. Right) green box : power spectrum on a windowed subsample, ; red box: time series of spectra amplitudes at fixed frequencies

Time-frequency analysis was used to detect the occurrence and importance of events characterized by a well-known periodicity. The spectrogram uses a centred window 720 minutes wide, moving at 180 min step Then the time series of the energy amplitudes in the band of interest (26-31 min) were extracted from each spectrogram. High energy indicates events characterized by high amplitude oscillations.

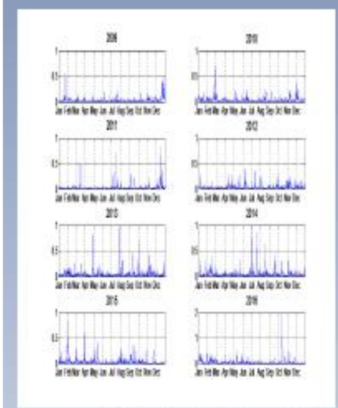
Wavelet analysis as implemented by Matlab® was performed by using Morse functions.

$\Psi(\omega) = U(\omega)a_{P,\gamma}\omega^{\frac{P^2}{\gamma}}e^{-\omega^\gamma}$ $\omega_{pk} = \left(\frac{P^2}{\gamma}\right)^{\frac{1}{\gamma}}$ $\psi_{\tau,s}(t) = \frac{1}{\sqrt{s}}\psi$ P^2=120 and γ=3. Wavelet transform acts like a band pass filter giving as result the spectrum of the analysed signal. It's localized in frequency and time, and has less limitations than Windowed Fourier Transform. It is designed to study short events, which the latter cannot analyse properly. Time-frequency diagrams have been obtained for every event and have been analysed thoroughly in the frequency band between periods 19-34 min.

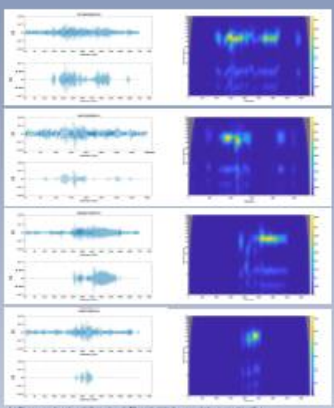


Uncertainty trend for wavelet analysis respect to scale (s), frequency (ω) and time (t)

Events detection and characterization



Results from time-frequency analysis: time series of signal amplitude in the band 26.7-31 min

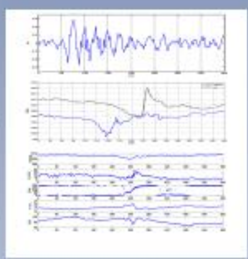


Left up: sea level variation (down) filtered data by wavelets reconstruction
Right) Results from wavelet analysis applied to the filtered data

Time frequency analysis identified the occurrence of several tsunami-like events. Oscillations in the 26-30 min band lasting from a couple, up to several hours having amplitude of the order of the local tide often occur. In one case (14 October 2016) the amplitude reached 50 cm.
Wavelet analysis allowed to better charaterize single events which, due to their short duration, could not be properly resolved by time frequency analysis. The main recurring features in wavelet transforms are roughly ellipses (single event with fixed frequencies), rotated ellipses (single event with decreasing frequencies in time), multiple ellipses (beats or similar phenomena). The most common temporal evolution of meteotsunami are impulse-like and resonant-like response.

Meteo- tsunamis and meteorological situation

14 October 2016 meteotsunami

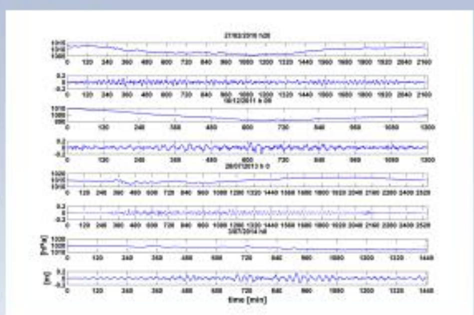


Sea level variation during the meteotsunami
-Atmospheric pressure at W1-M3A and at the mareographic station
-Meteorological observation from W1-M3A sampled at 1 min from 14 Oct 2016 h 06 h 19 From top : Atm. pressure,wind speed, wind direction, air temperature, rel. humidity)

A picture of the macroburst from the hills close to Recco (GE)
Meteorological situation on13 October 2016 h 18. (ARPAL, 28/3/2017)

The 14 October meteotsunami was a consequence of an impressive meteorological event. The approach of a cold front generated a squall line extended from Corsica to the Alps that hit the Genoese coast around 12 GMT. A powerful wet macroburst developed inside the convective system and some narrow but intense waterspouts were recorded along the coast.

Minor Events



After having the earthquakes excluded as possible generation mechanism, no clear cause-effect relation between local atmospheric pressure and minor tsunami-like oscillation occurrences was identified. Their developement can be associated to different baric disturbances at larger scales.

Atmospheric pressure from the mareographic station and sea level during minor meteotsunami events

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