Detection of Tsunami and Other Sea level Induced Hazards Using Low Latency Sea Level Measurements A Conceptual Approach

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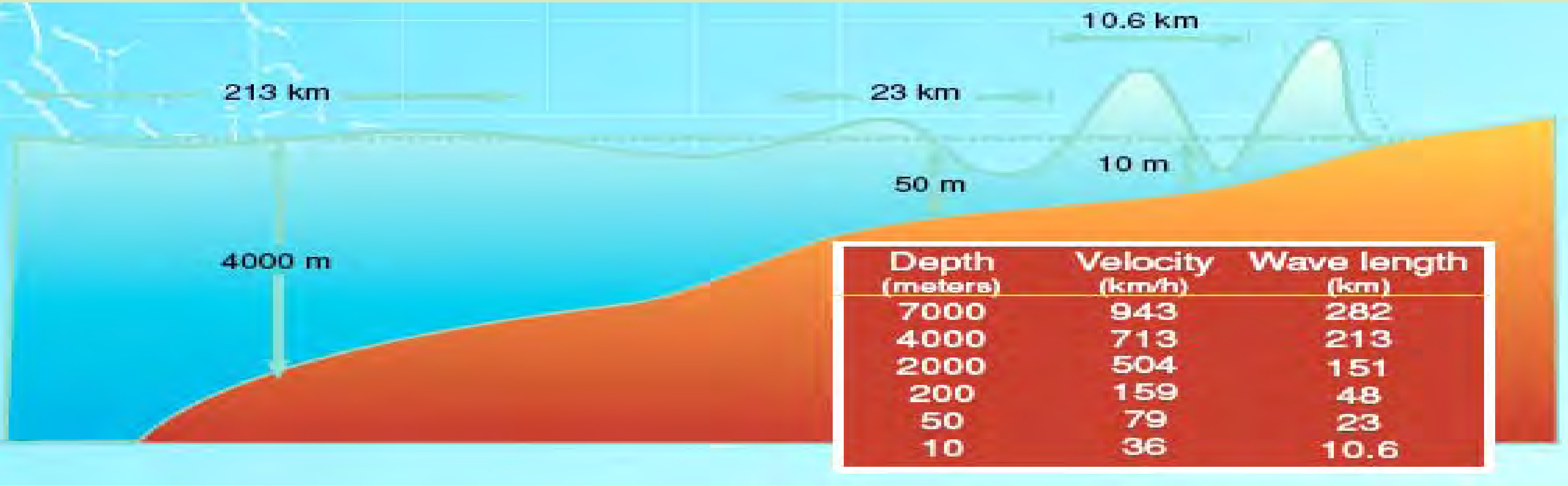
The Intergovernmental Coordination Group for the North East Atlantic, the Mediterranean and connected sea Tsunami Warning System (ICG/NEAMTWS) recommended at its second meeting last year in Nice, that the NEAMTWS should be based on a multi-parameters and multi-hazard warning system to be able to cope also with the various additional hazards related to sea level which are due to:

- **Atmospheric pressure fluctuations (meteo-tsunamis),**
- **Wind gusts,**
- **Local coast and bathymetry features**

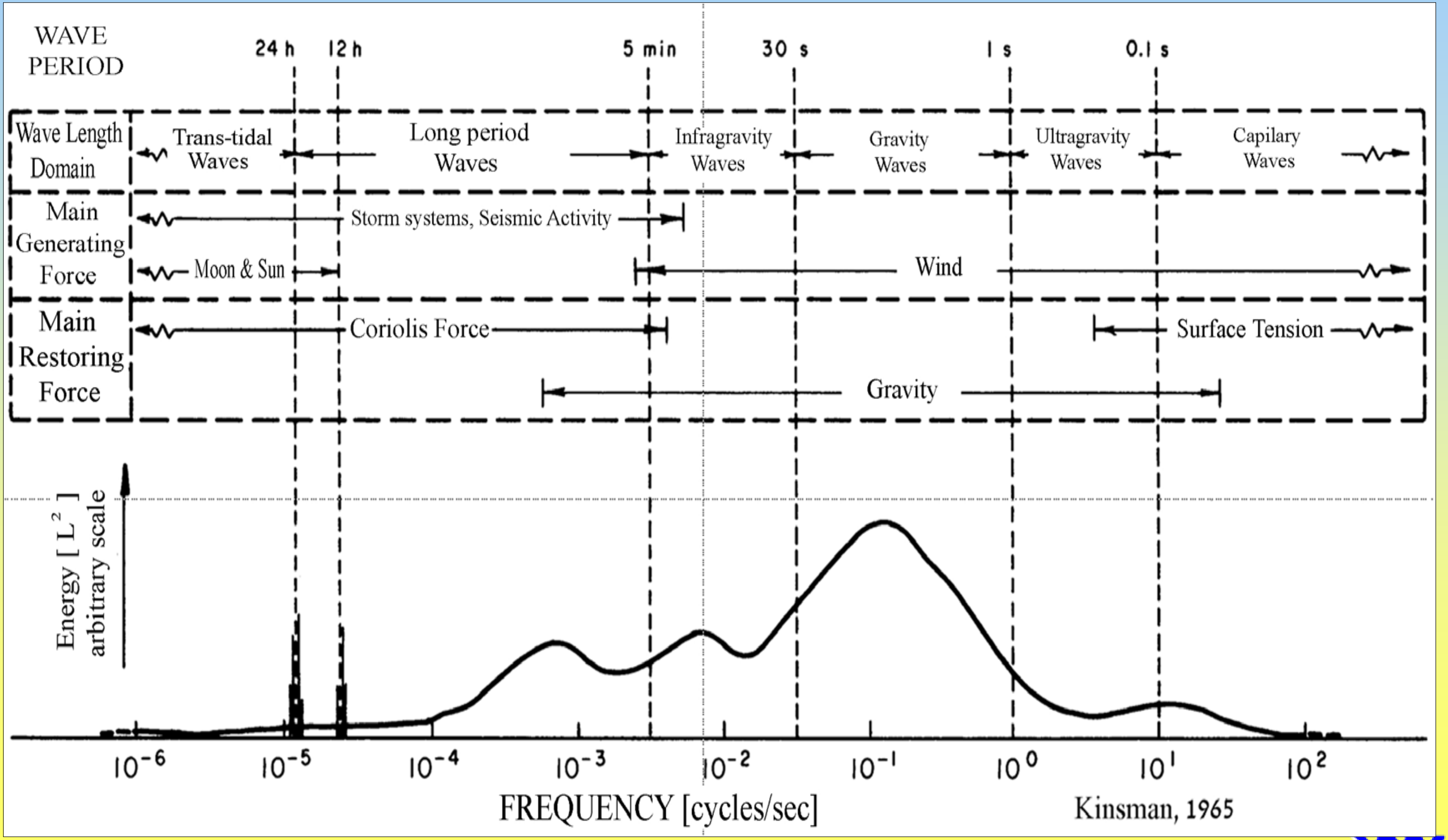
What is Tsunami?

- Source in Japanese : Tsu-naa-mee means harbour wave
- The tsunami is a very long gravity wave with its period between 10 to 60 minutes
- In deep water its height is about 30-60cm, length and wave celerity (speed) are shown in table below.
- In shallow water the wave shoaling and refraction effects increase its height and decrease its length, and celerity as shown in the table.
- At waterline the wave climbs on the shoreface as run-up, which can reach values from 0.2m to a few 10s of meters, and the speed is about 25km/h (7m/s).



Depth (meters)	Velocity (km/h)	Wave length (km)
7000	943	282
4000	713	213
2000	504	151
200	159	48
50	79	23
10	36	10.6

Water wave frequencies domain and their forcing factors



The sea level induced hazards may be divided in 2 groups:

a. Due to rise of sea level at coast:
- Tsunami run-up flooding,
- Storm surge induced flooding,
- High wind waves induced superelevation
- Strong onshore winds
- Extreme atmospheric low
- Extreme spring tides
- Combination of the above

b. Due to lowering of the sea level near the coast by:
- Tsunami wave initial waterline recession (in part of the cases)
- Offshore blowing strong winds
- Extreme neap tides
- Combination of the above

Monitoring and identification methods of the tsunami waves hazard as a function of the location of the monitoring station (deep water, transient depth, surf zone, inside a harbour).

a. Monitoring in deep water based on

- **Sea bottom located accurate pressure sensors (e.g. DART)**
- **Sea bottom located seismometers,**
- **Buoys equipped with GPS (Japan)**
- **Sea level monitoring at offshore platforms**

The detection is based on detection of long waves with periods in the tsunami periods range (5' - ~60') from the pressure signal, not the surface signal, in some cases in combination with the detection of seismic waves. Alternatively, from the sea surface spectrum by detection of long waves in the tsunami range.

The identification can be biassed by the presence of atmospheric instabilities leading to sea surface fluctuations with similar periods as those of tsunamis. Proper identification of the source can be done by parallel continuous monitoring and processing of atmospheric pressure changes and/or by the lack of strong recording seismic activity.

Another potential means is the use of forecasts of salinity and temperature of the water masses using operational oceanography model 7 days forecasts updated daily, defining trends at the daily time scale.

b. Monitoring in transient water based on

- Sea bottom located accurate pressure sensors
- Sea bottom located seismometers,
- Buoys equipped with GPS
- Sea level monitoring at offshore platforms

The detection is based on detection of long waves with periods in the tsunami periods range (5' - ~60') from the pressure signal, in some cases in combination with the detection of seismic waves. Alternatively, from the sea surface spectrum by detection of long waves in the tsunami range.

The identification can be biassed by the presence of atmospheric instabilities leading to sea surface fluctuations with similar periods as those of tsunamis or by the presence of edge waves or standing waves in large basins or bays . Another source may sometimes be due to wind gusts induced local sea surface fluctuations.

Proper identification of the source can be done by parallel continuous monitoring and processing of atmospheric pressure changes, of the local wind and of the sea level fluctuations and/or by the lack of strong recording seismic activity.

c. Monitoring in shallow water is based on

- **Sea level monitoring**
- **Sea bottom located seismometers,**

The detection is based on detection of long waves with periods in the tsunami periods range (5' - ~60') from the pressure signal, in some cases in combination with the detection of seismic waves.

The identification can be biassed by the presence of atmospheric instabilities or by the presence of infragravity waves due to transfer of wave energy to the infragravity range in the shoaling and breaking process or by the re-reflection and amplification of free or bounded long waves entering in basins, ports or bays, or by wind gusts induced sea level fluctuations, all within the tsunami periods range.

Proper identification of the source can be done by parallel continuous monitoring and processing of atmospheric pressure changes, of wind and of the sea level fluctuations and/or by the lack of strong recording seismic activity.

Another means to identify tsunami events from other factors is by monitoring fast changes in the mean sea level, whereas a fast significant lowering of the sea level in a matter of minutes would be most probably a tsunami.

Proposed approach to be used for detection of tsunami waves from sea level signals

1. Monitor in parallel additional factors: atmospheric pressure, wind gusts
2. Monitor long term mean conditions to be able to distinct fast or significant changes from the background state.
3. Use 5 sliding windows on the monitored data, to be able to detect early changes for the whole range of tsunami periods: a 5 minutes window, a 10 minutes window, a 20 minutes window, 60 minutes window and a 3 hours window.
4. Process the data by routine spectral analysis, as well as by comparing the changes every few minutes against the mean values of the 5 sliding windows.

Conceptual approaches to be used for rapid detection of hazards: Multi-sliding data windows and short term trend analysis, identification of the infragravity waves due to bounded long waves via Smoothed Instantaneous Wave Energy History (SIWEH) analyses (Funke and Mansard,1979), run length (Battjes and Van Vledder, 1984), temporal and spatial group steepness via Hilbert transform (Haller and Dalrymple, 1995).

The approach chosen for the development of software for rapid detection of hazards for those MedGLOSS sea level stations using the submerged pressure sensor and selected for participation in the initial NEAMTWS will be based on all these methods mentioned above, using a data scanning rate of 2Hz, enabling not only FFT analyses of the sea surface data gathered at ½ minute averaged by integration, but also Hilbert Transform and SIWEH groupiness analyses, as well as cross-correlation spectra of the wave, wind, atmosperic pressure data for determining the coherence degree.

Tide-gauge station network selected for the Initial NEAMTWS

Stations based on Paroscientific Intelligent pressure sensor:

1, 2, 3, 4, 6, 9

Thank you for your attention !

SIWEH is a running time series of wave energy that is averaged over the peak wave period by means of a smoothing Bartlett lter The SIWEH is found by the following:

$$E(t) = \frac{1}{T_p} \int_{-\infty}^{\infty} \eta^2(t+\tau) Q(\tau) d\tau$$

where Et is the energy envelope function Tp is the peak spectral period of the incident waves and Q is a Bartlett window smoothing function as defined by:

$$Q(\tau) = \begin{cases} 1 - |\tau|/T_p & |\tau| < T_p \\ 0 & |\tau| \geq T_p. \end{cases}$$