

Water waves/jets. Linear wave theory, long waves, short waves, wave/coast interaction, jets, jet/wall interaction Part I

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APAT

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1 – Introduction to large scale problems

In order to carry out coastal studies by the means of numerical models it is generally needed to perform a two steps approach. Before being able to apply a detailed model for a beach or a costal structure, a large scale simulation on a wider domain (size greater than 100 km²) around the area of interest must be carried out. This approach allows to get a general overview of the hydrodynamic of the area and to evaluate the boundary conditions that must be applied on the small scale model.

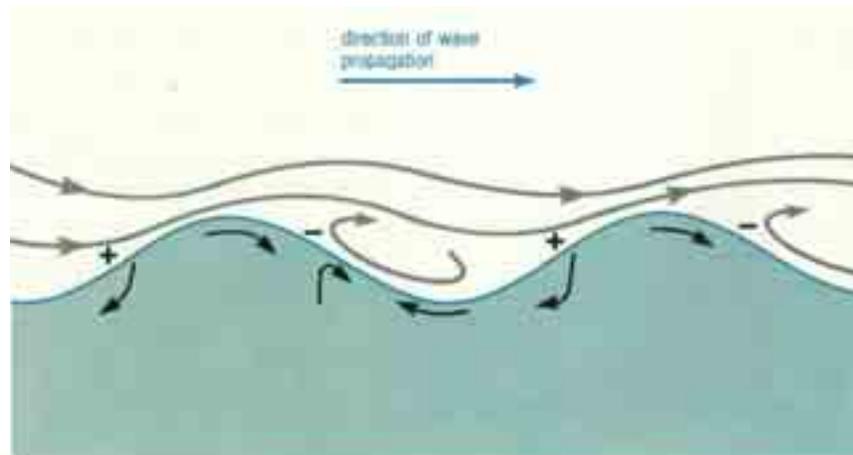
This presentation is aimed to describe the main features of the waves that must be considered when dealing with large scale domains, and what are the main aspects on which the attention must be focused.

2 - Wind waves (period 1->30 s)

Waves generation

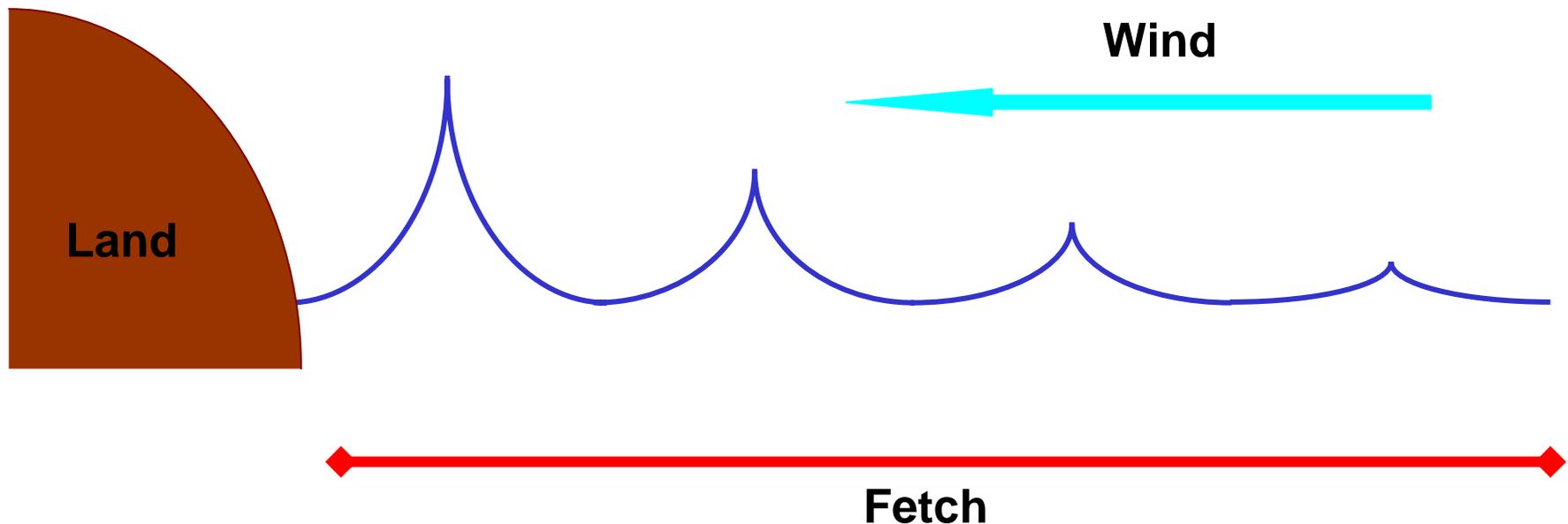
As it is clear from the name, wind waves are waves generated by the wind. The wind blowing over the sea transfers energy to it giving rise to the generation of waves. Although it could seem trivial, it is not true that a strong wind generates high waves. Actually the wave height is linked mainly to the strength of the wind, to the length of the water body over which the wind is blowing (**fetch**) and to the period during which the wind blows. The link between wave height and wind intensity is almost straight only when there are **fully developed sea conditions**. It means that a constant wind has blown for a period of time long enough to transfer the maximum amount of energy to the sea for a given fetch length.

The surface of the sea exerts a frictional drag on the bottom layer of a wind (an air flux) blowing over it, this layer exerts a frictional drag on the layer above it and so on. The top layer has the least frictional drag exerted on it. This means that the layers of air move forward at different speeds. The air tumbles forward and finally develops a circular motion. This motion causes a downward pressure on the surface at its front, and an upward pressure at its rear, and this causes the surface to take on the form of a wave. The back of the wave tumbles forward but it moves back later and slows the forward movement at the front of the wave (Miles, 1957). Then as the wave propagates in the generation area, its height and period grow.



2 - Wind waves (period 1->30 s)

The distance the wind blows over the water with similar speed and direction is called **fetch**. The longer is the fetch the higher will be the waves. It is important to point out that the wind is assumed to blow with constant speed and direction both in the space and the time domains.



2 - Wind waves (period 1->30 s)

Swell

Once the waves leave the area of generation, i.e. the area where the wind is blowing, they propagate freely. Such waves are called **swell**. They continue to propagate until all the energy they own is dissipated. It is very important to take into account the swell when performing an analysis of the wave climate. Often there are not measured wave data available, so the wave parameters are estimated by the means of numerical models or simple engineering formulas based on the local wind characteristics (for instance SMB method, Sverdrup and Munk, 1947 and Bretschneider, 1952). Those kind of analysis do not take into account the swell because it is not related to local winds.

Swell waves could be as dangerous as other waves, so when performing studies in order to design a coastal structure if the swell is not taken into account, it could lead to big problems.

2 - Wind waves (period 1->30 s)

Waves characteristics

There are a lot of characteristics needed in order to define a wave properly. Height, length, period, direction, etc. However when working at a large scale we usually do not focus on a single wave but on a **sea state**. A sea state describes the waves on the surface of a large body of water for a defined time period. It is identified by the means of 4 main parameters: significant wave height (H_{m0} or H_s), mean direction (D_m), peak period (T_p) and mean period (T_m). Those parameter are not related to a single wave but to the whole sea state.

2 - Wind waves (period 1->30 s)

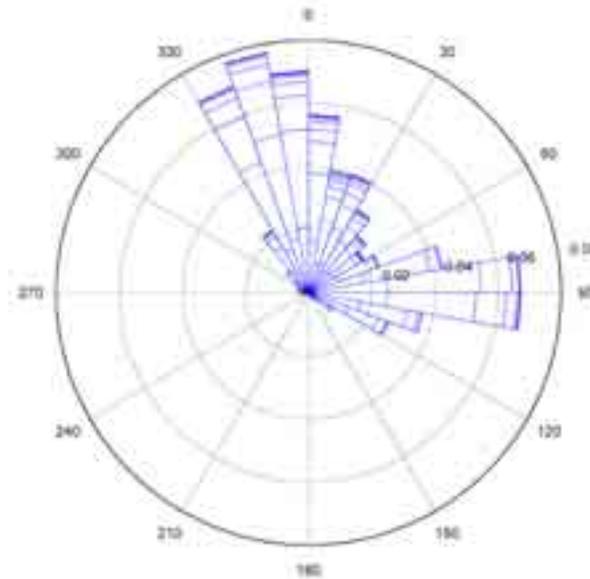
Significant wave height

The **spectral** significant wave height H_{m0} is probably the most interesting parameter describing the sea state. It has an empirical counterpart called just significant wave height H_s . The two parameters have roughly the same value. The latter is evaluated taking into account the height of each wave observed during a certain period and it is the average height of the highest one-third of the waves. This value is approximately the height an experienced observer will report when visually estimating the height of waves at sea. The former is instead evaluated taking into account the wave spectrum and it is 4 times the square root of the total amount of energy density of the spectrum.

2 - Wind waves (period 1->30 s)

Mean wave direction

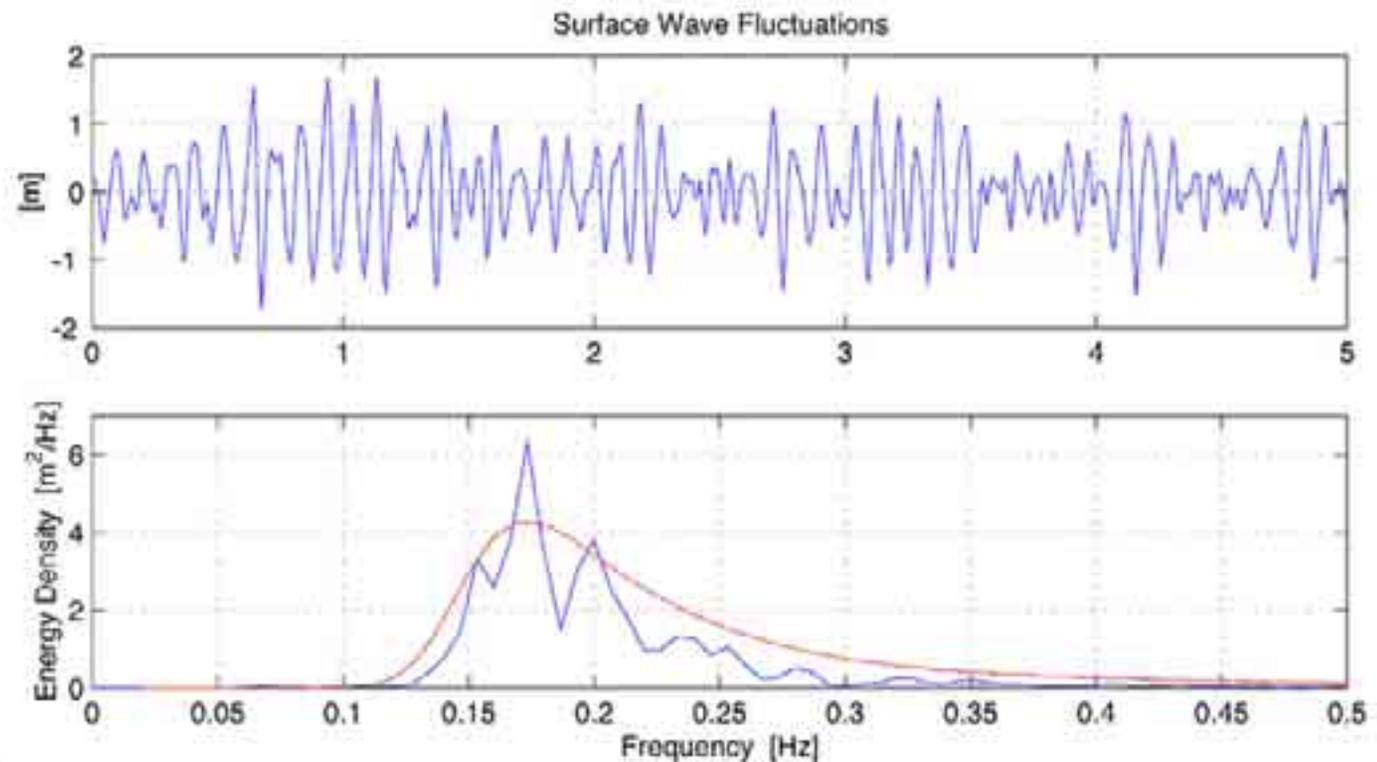
The mean direction is the average of the wave directions (or of the wave spectrum components directions) observed during a fixed period. It is generally expressed using the **nautical convention**. This means that it is expressed in degree with the 0 pointing North and with a clock-wise order. Furthermore it point the direction form which the waves come from, like what is done with wind data.



2 - Wind waves (period 1->30 s)

Wave 1D-spectrum

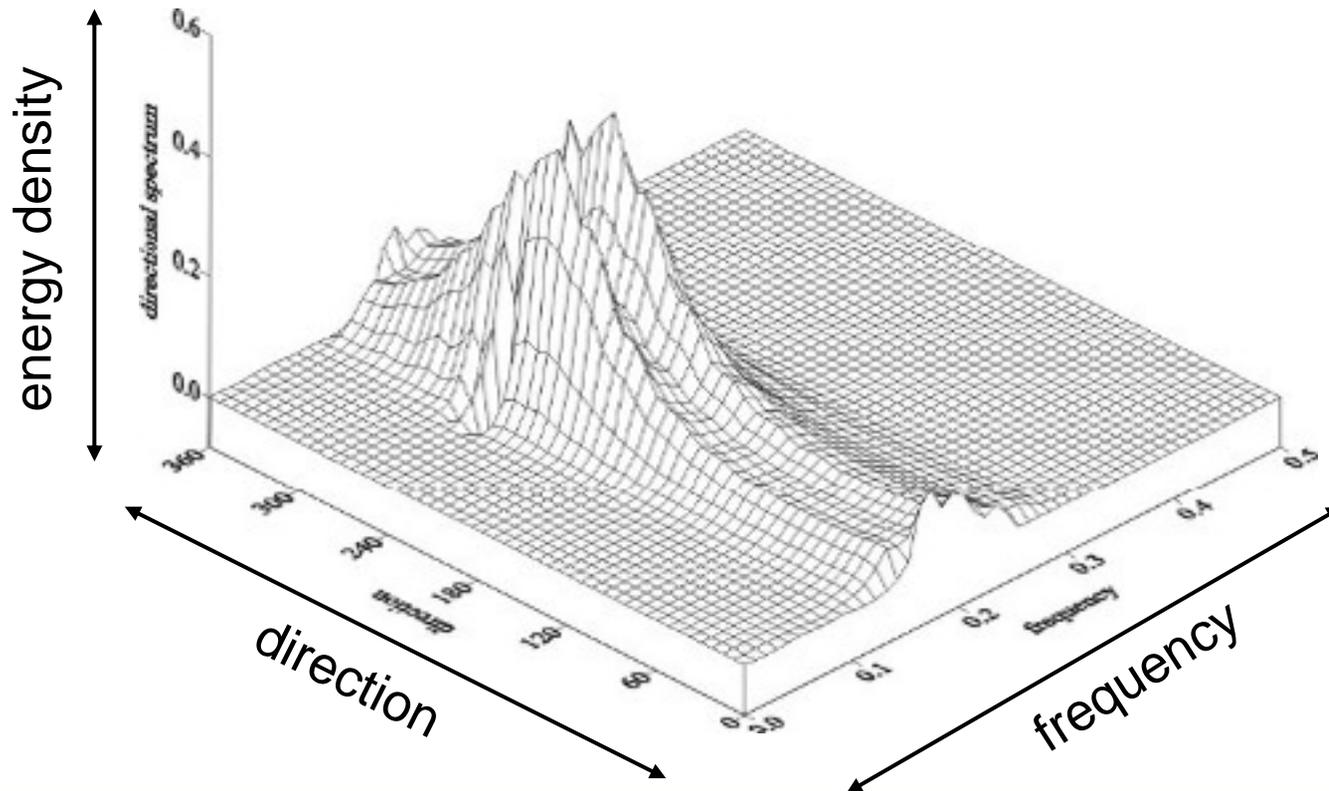
Observed/
 Measured
 waves



Wave
 spectrum

2 - Wind waves (period 1->30 s)

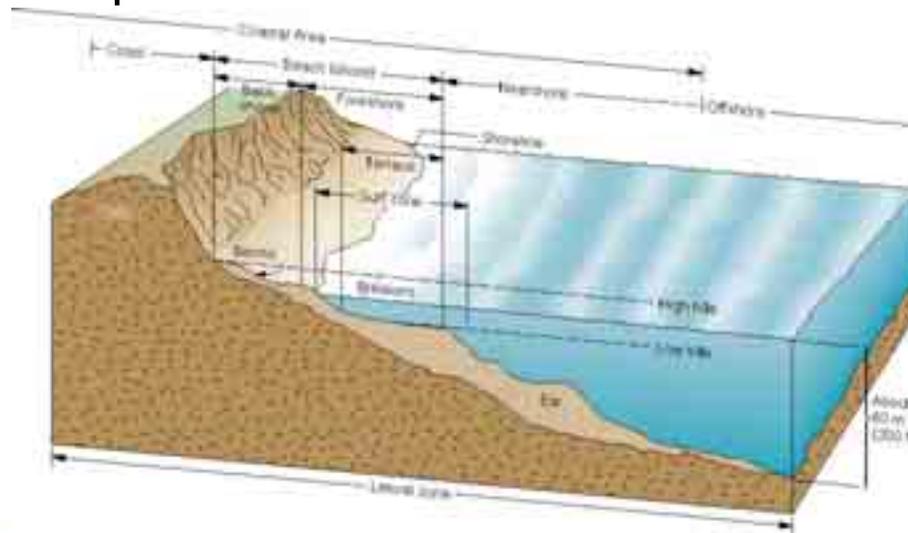
Wave directional spectrum



Wave propagation

When propagating in deep water the waves are affected mainly by the wind. Once they reach transitional or shallow water (nearshore zone) their characteristics are also modified by the interaction with the sea bed.

When working at a large scale there are two main phenomena that must be taken into account: shoaling and refraction. These phenomena modify the height and the direction of the waves. Actually there is a third phenomenon that is the diffraction, but at a large scale it is much less important than the others.



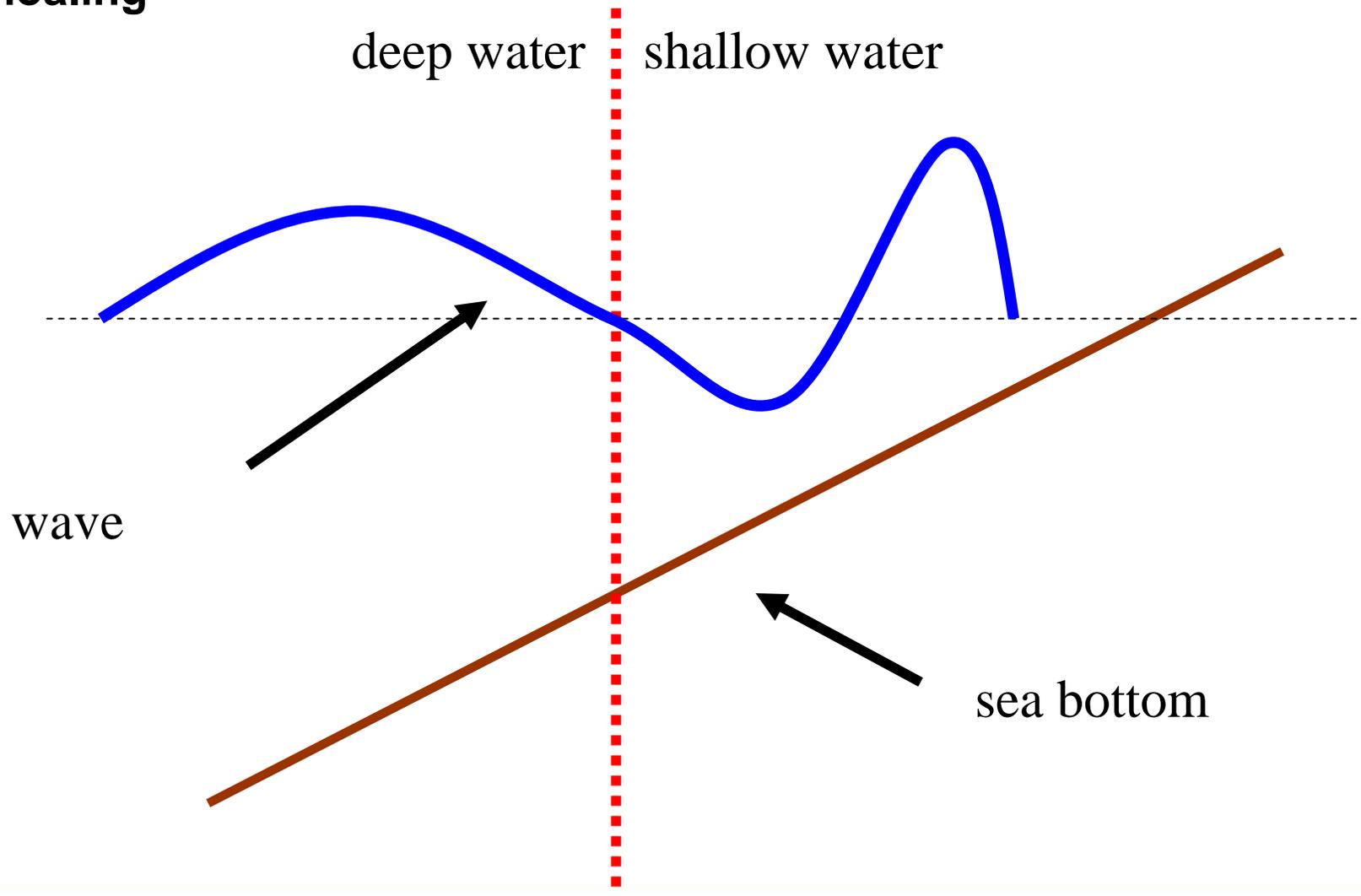
2 - Wind waves (period 1->30 s)

Shoaling

Shoaling occurs when the waves enter shallower water. The wave speed and wave length decrease in shallow water, therefore the energy per unit area of the wave has to increase and so the wave height increases. The wave period remains the same.

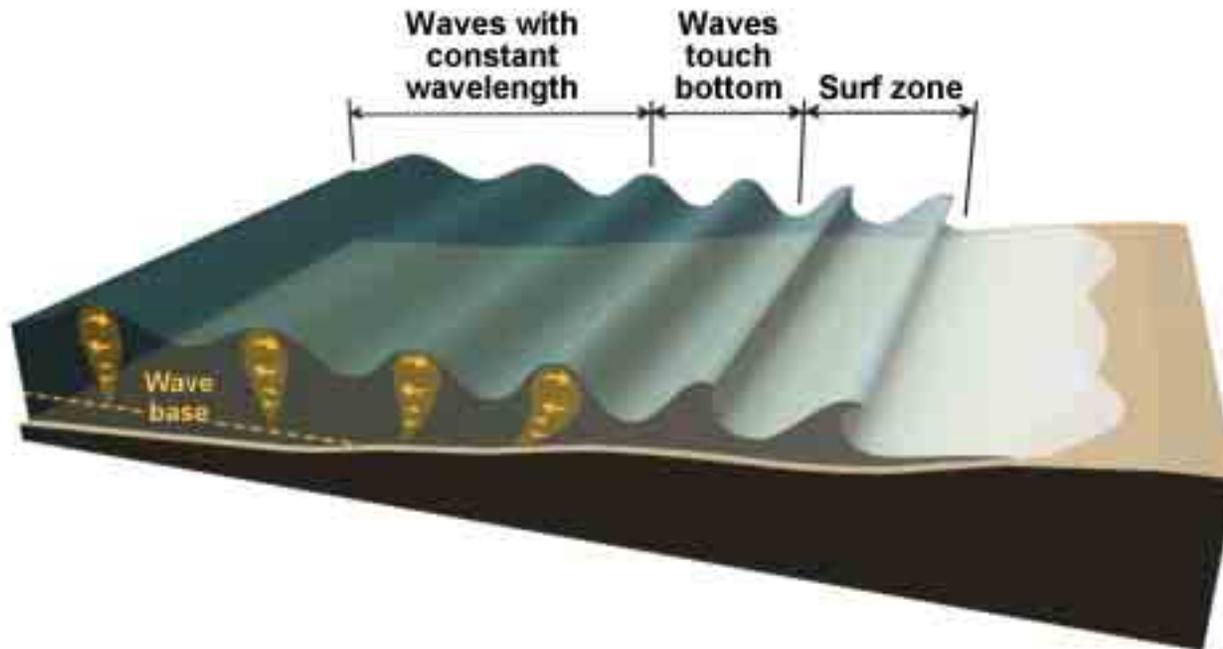
2 - Wind waves (period 1->30 s)

Shoaling



2 - Wind waves (period 1->30 s)

Wave Shoaling

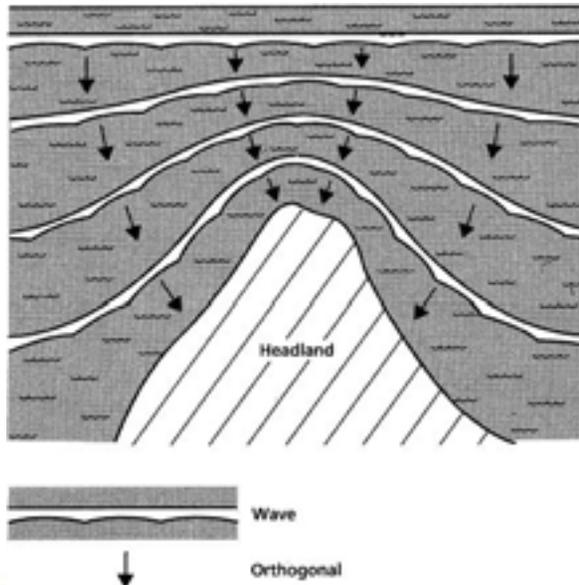


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2 - Wind waves (period 1->30 s)

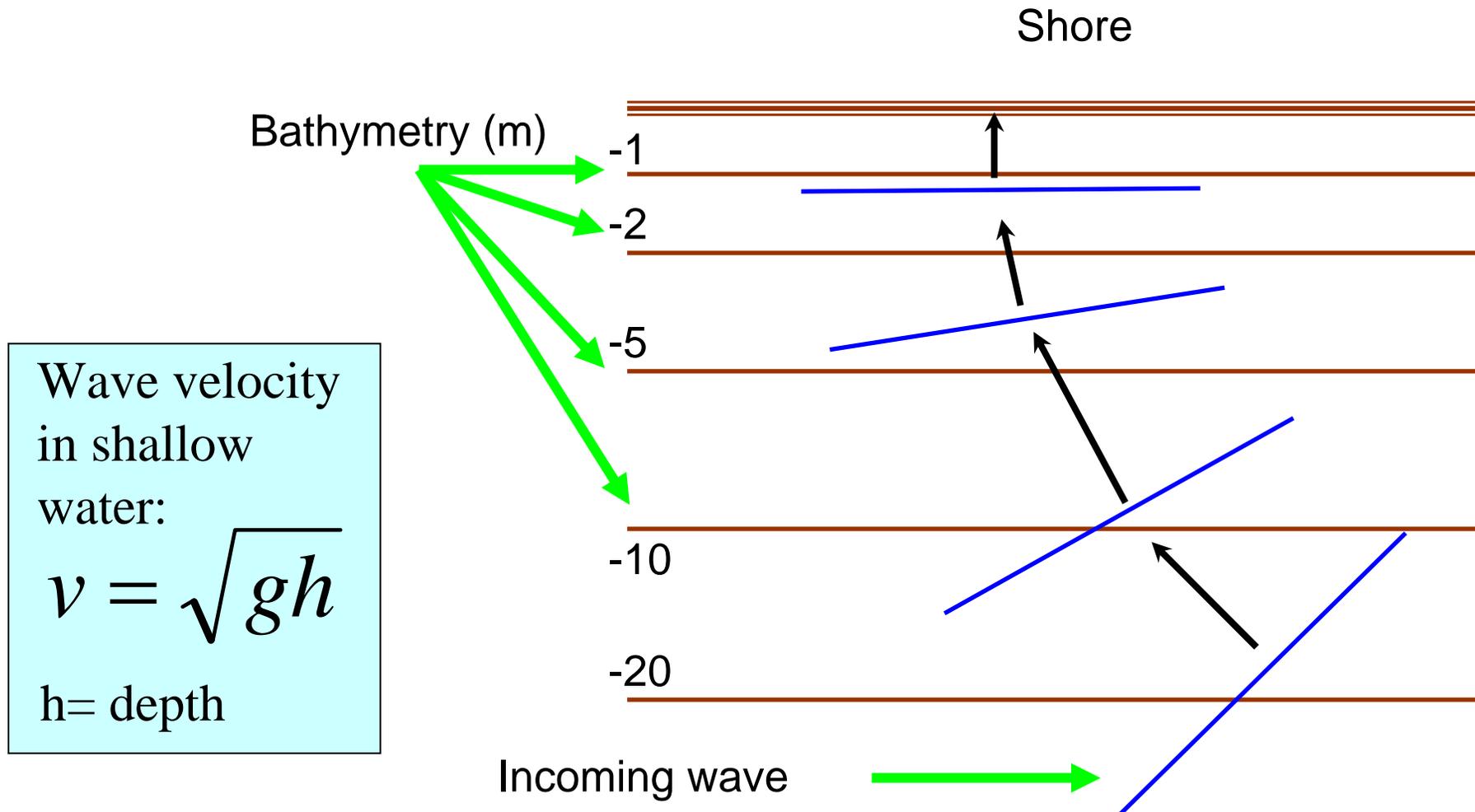
Refraction

Wave refraction occurs in transitional and shallow water because wave celerity decreases with decreasing water depths, so the portion of the wave crest that is in shallower water propagates forward at a slower speed than the portion that is in deeper water. The result is a bending of the wave crest accordingly to the orientation of the bottom contours.



2 - Wind waves (period 1->30 s)

Refraction

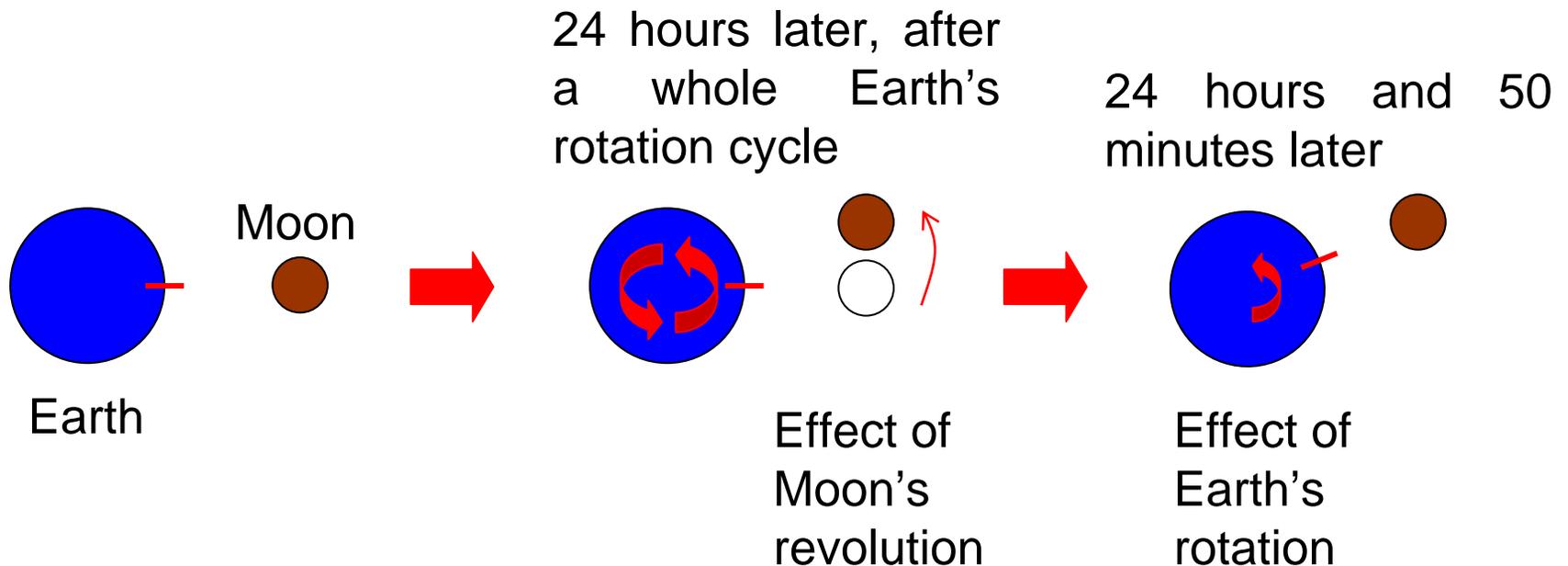


3 – Tides (Period 12 – 24 h)

Introduction

The tide is a very long wave generated by the attraction of celestial bodies on Earth's water bodies. Since the celestial bodies have different mass and distance from the Earth, the resulting attraction is mainly due to the nearest (the Moon) and the biggest (the Sun) ones. Although the Sun's mass is 10 millions times greater than that of the Moon, since the Moon is closer it results that its attraction is almost twice the one generated by the Sun. There are 390 active tidal components related to celestial bodies and their phases having period ranging from 8 hours to 18.6 years, but most of them are quite small and can be neglected. The 8 major components are all related to the Moon or to the Sun.

The timing of tidal events is related to the Earth's rotation and the revolution of the Moon around the Earth. If the Earth and Moon were stationary in space, the tidal cycle would be 24 hours long. However, the Moon is in motion revolving around the Earth so the interval between two successive upper transits of the Moon over the same meridian of a place is approximately 24.84 solar hours (24 hours and 50 minutes). This is called **tidal day** and is the main period to which one must refer when dealing with tides.



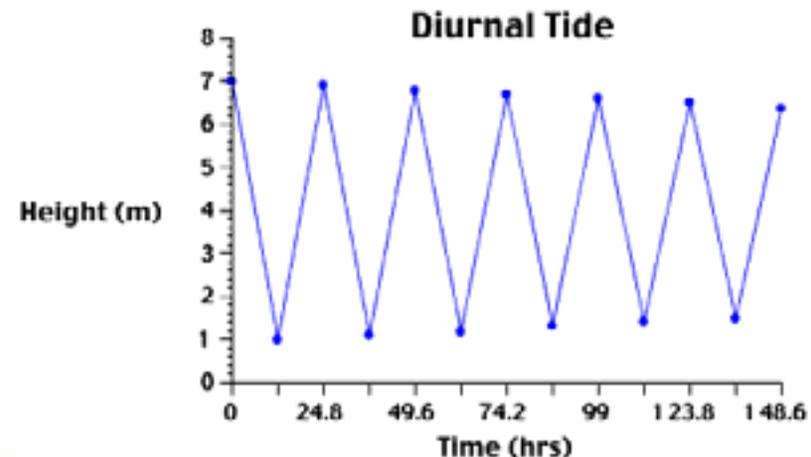
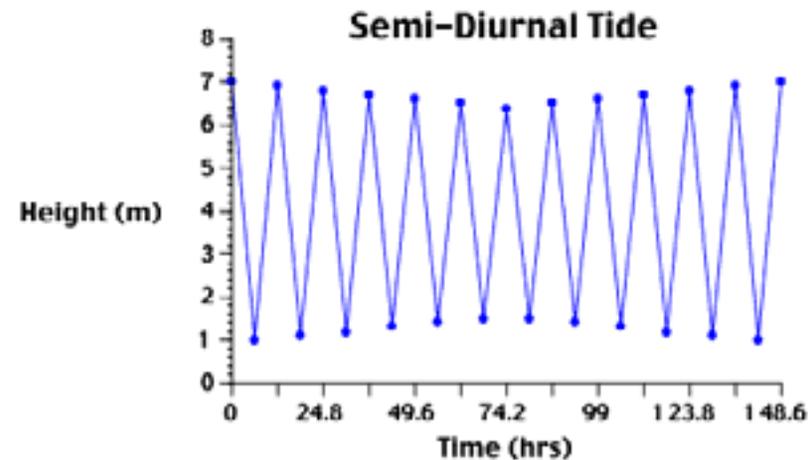
3 – Tides (Period 12 – 24 h)

Tide classification

It is possible to classify tides into three types:

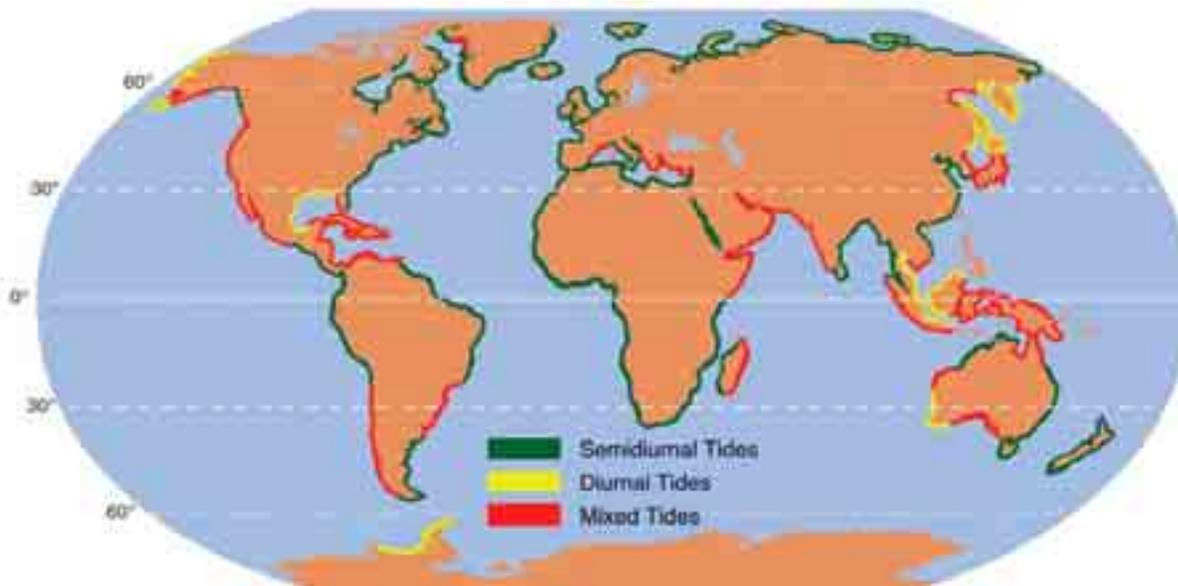
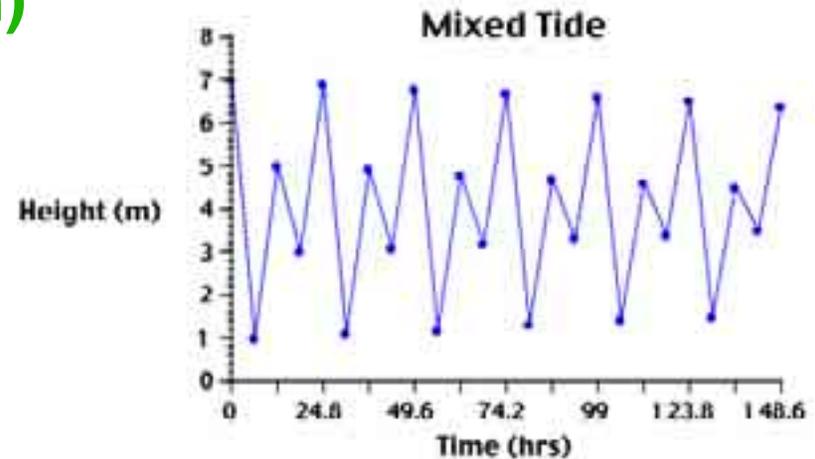
Semidiurnal: There are two high and two low water levels each tidal day with approximately the same vertical variation. This is the predominant type of tide.

Diurnal: There is only one high and one low water level each tidal day.



3 – Tides (Period 12 – 24 h)

Mixed: there is a large inequality in the vertical range of the two daily cycles. Typically there is a cyclic transition from mixed to semidiurnal and back.

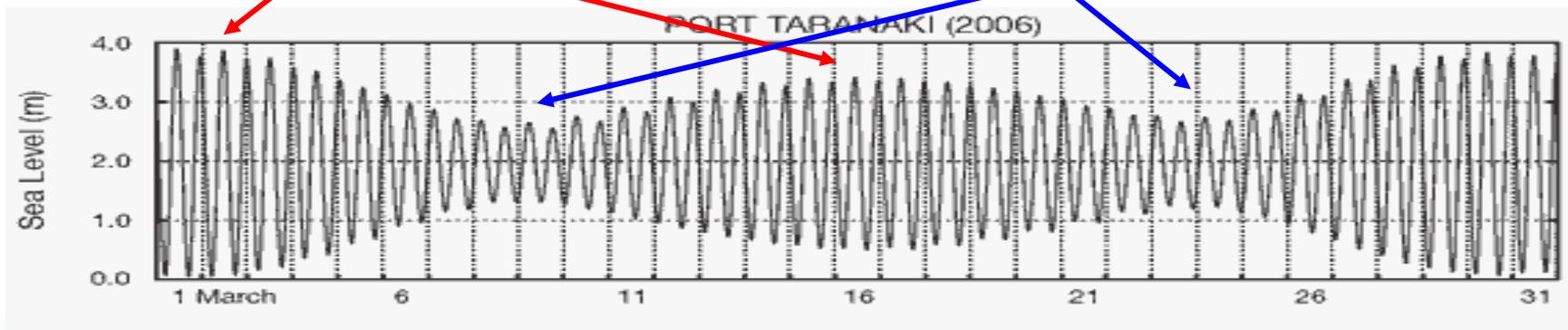
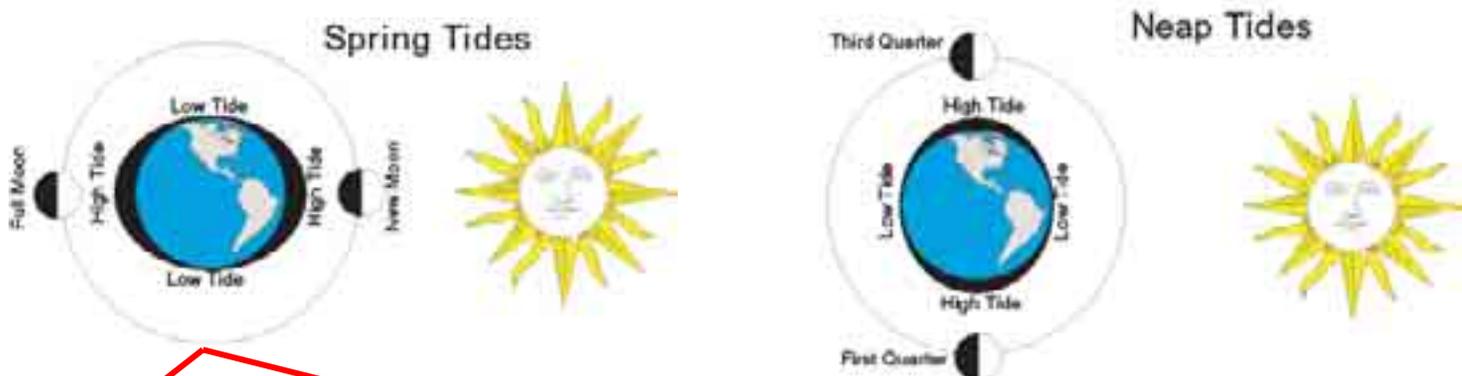


Regional
classification of
tides

3 – Tides (Period 12 – 24 h)

Moon phases and tide variations

The height of the low and high water levels is subject to the Moon phases as shown by the sketch below.



3 – Tides (Period 12 – 24 h)

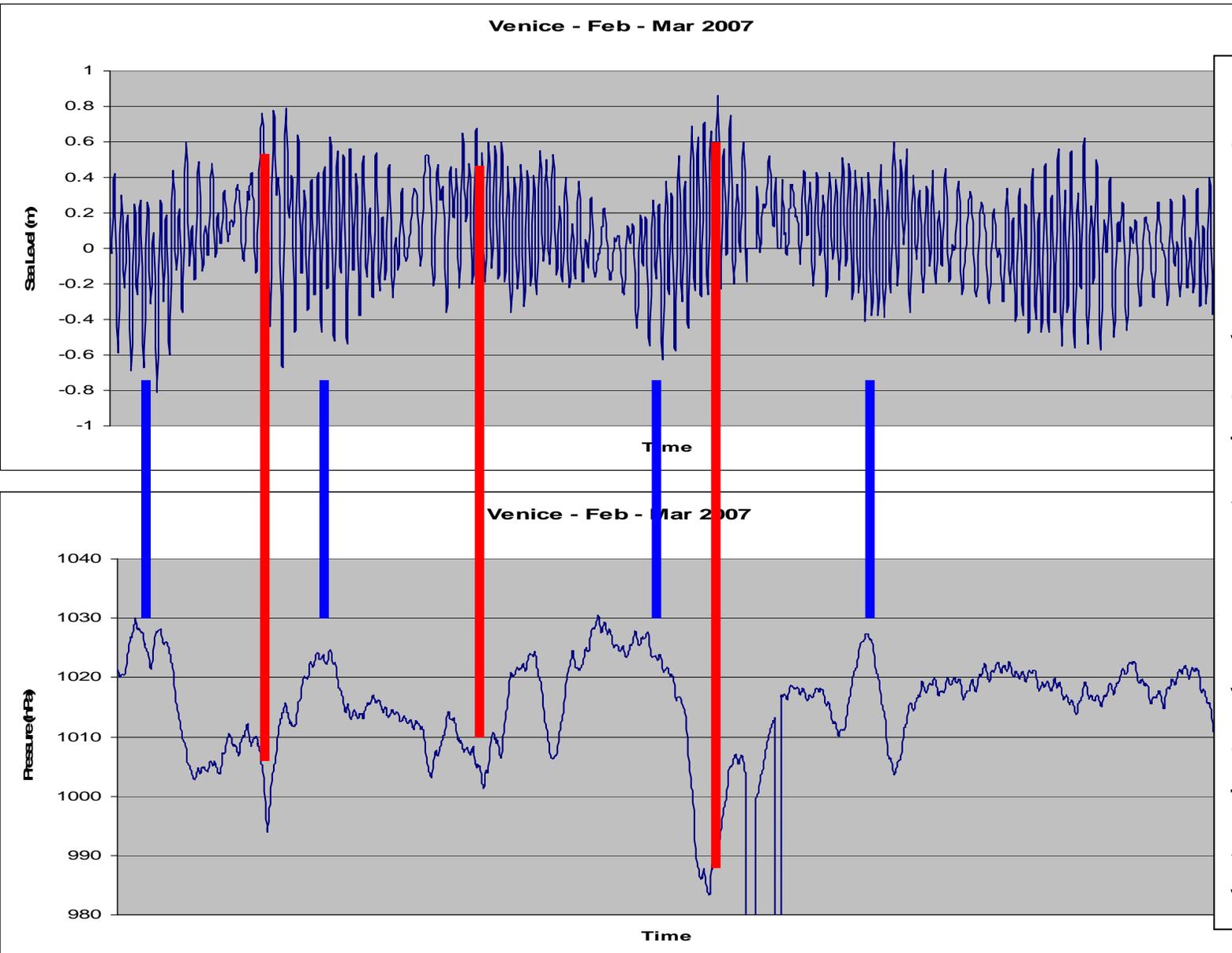
Tide effects on coastal areas

Since the tide is a very long period wave it is not generally 'seen' as a proper wave but just as a variation of the sea level. So when dealing with coastal studies that cover a period long enough to take into account these variations the tide effect is considered just as variation in level and not as a propagating wave. However coastal morphology interact with the tidal wave just as with other waves. So the tide grows in height while propagating towards coast and is subject to refraction just like wind waves. This means that although it is generally not necessary to resolve the tide as a wave, it must be paid attention towards areas where these effects could cause a sensible variation in the tide level.

4 - Storm surge

A storm over shallow nearshore coastal waters can generate a large water fluctuation if the storm is sufficiently strong and the water body is shallow over a large enough area. This is commonly known as storm surge or meteorological tide. Storm activity can cause both a rise (setup) and a fall (setdown) of the water level.

Specific causes of the water level change include: surface wind stress, atmospheric horizontal pressure gradients, wind wave setup and long wave generation caused by the moving pressure disturbance.



Storm surge effect on sea level. Minima in the pressure values correspond to peaks of sea level maxima and maxima in pressure values correspond to minima in sea level values

5. Conclusions

Wind waves, tides and storm surge are the main kinds of waves to be taken into account when operating at large scale in coastal studies. Although they are all waves and they are theoretically the same thing, they are treated in different ways because of the big differences in period. A few seconds for the first one and hours for the other ones.

According to the local features they could be more or less important, it is up to the researcher to decide whether they are to be included in the study or to be neglected.

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