"Capacity Building and Strengthening Institutional Arrangement"

Analysis and sampling of water and water pollution

# Wave Dynamics

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APAT

Agency for Environmental Protection and Technical Services

# Wave Dynamics

- **wave physical description**:

short period waves vs long period waves

- **wave mathematical description**

- **data analysis**: wave and tide

# Wave Dynamics

**The predominant natural forces are**

- pressure or stress from the atmosphere
- wind
- Earthquakes
- gravity of the Earth and celestial bodies (the Moon and Sun)
- Coriolis force (due to the Earth's rotation)
- surface tension

**Waves may be characterized by their PERIOD**

# Wave Dynamics

## Ocean Waves Classification

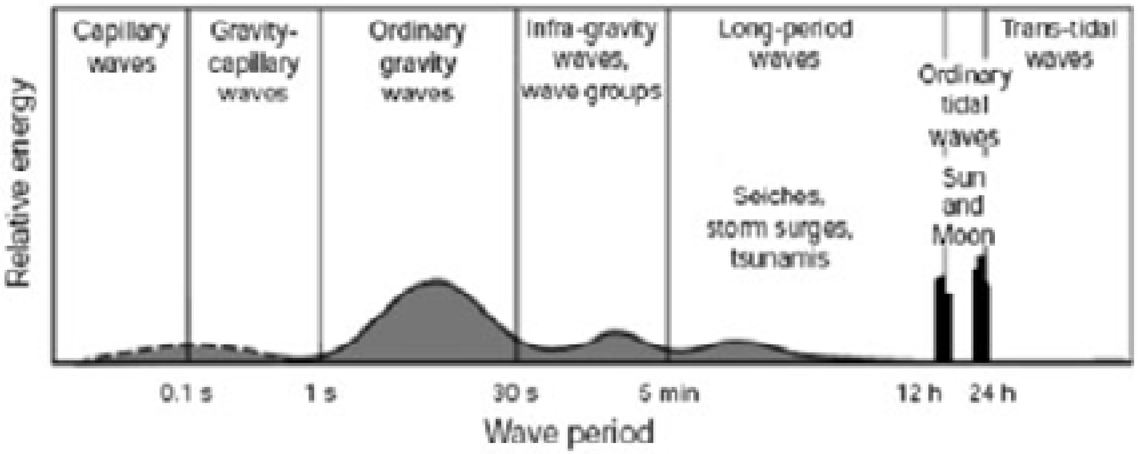
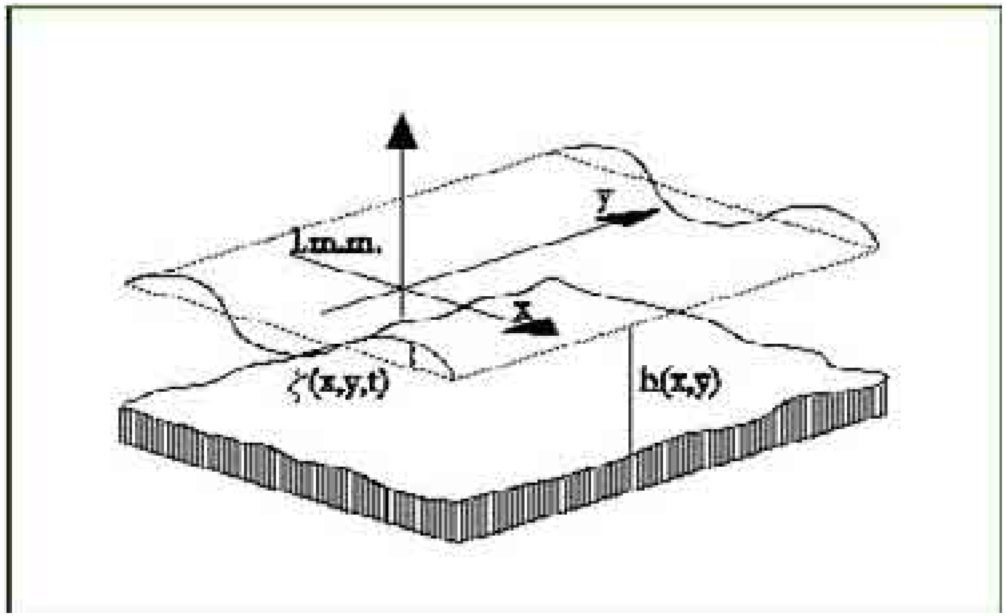


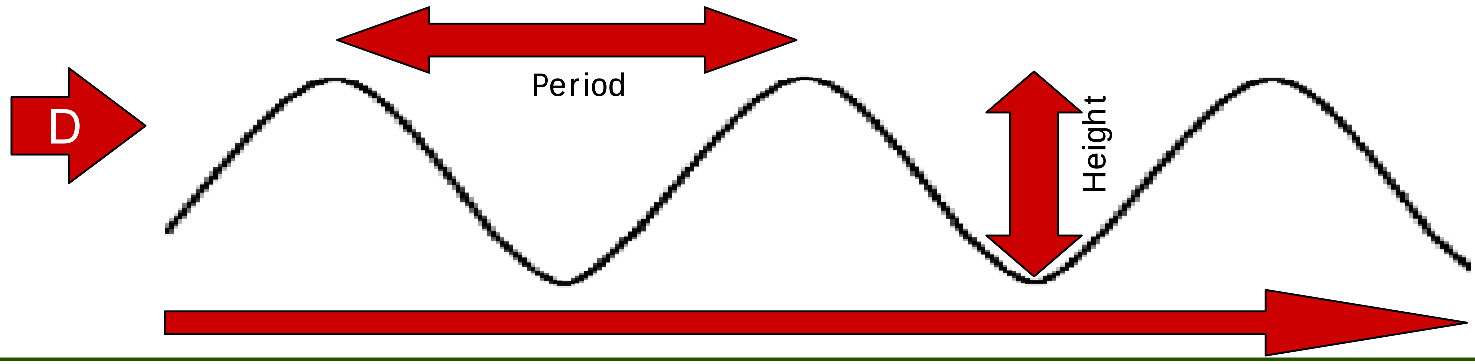

Figure 1.1 — Classification of ocean waves by wave period (*derived from Munk, 1951*)

# Wave Dynamics




**Periodical perturbation with constant characteristics on planes**

# Wave Dynamics




**H** = height = distance between the lowest and the highest point
**a** = amplitude = H/2
**L** = lenght = distance between two lowest points
**T** = period = time required for two wave crests to passe through a fixed point
**D** = direction of wave propagation
**ε** = steepness = H/L

# Wave Dynamics

$$\zeta(x, y, t) = ae^{i\left(\vec{k}\cdot\vec{x} - \omega t\right)}$$

**Space point fixed**

**Time Period**

**Period** $T=2\pi/\omega$
**Frequency** $f=1/T$
**Angular frequency** $\omega=2\pi f$

**Fixed time $t=t_0$**

**Space Period**

**$Period_x$** $2\pi/k_x$
**$Period_y$** $2\pi/k_y$

**PHASE FUNCTION**

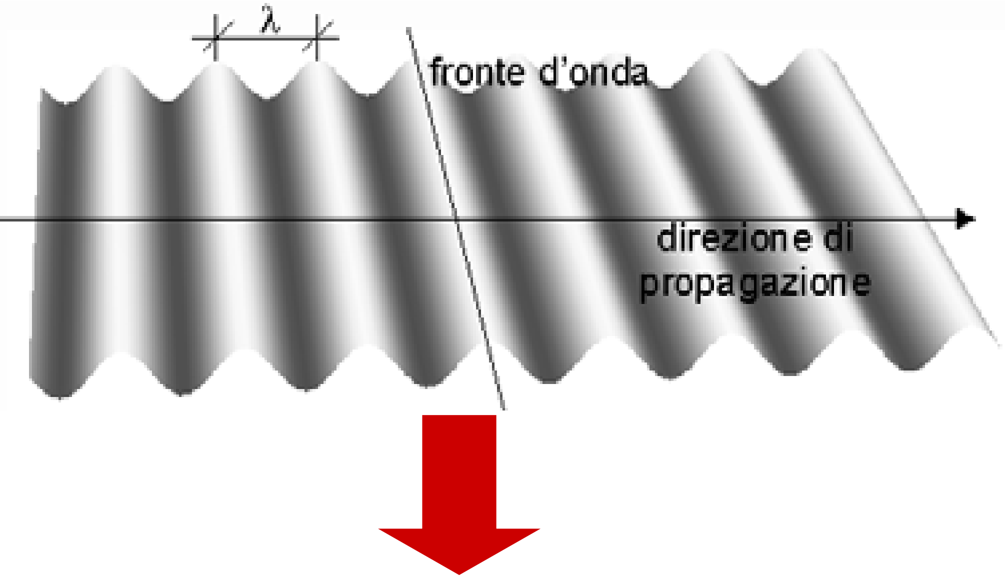
$$S(x,y,t)= k_x x+k_y y-\omega t$$

# Wave Dynamics

$$S(x,y,t) = k_x x + k_y y - \omega t$$

$$S(x,y,t_0) = S_0 = cost$$

**PHASE LINES:**
Constant free surface elevation




$$c = \omega / k$$

$$c = L/T$$

**PHASE QUICKNESS**

# Wave Dynamics

**$S(s,y,t) = k_x x + k_y y - \omega t$**

$$\vec{k} = \nabla S$$

$$-\omega = \partial S / \partial t$$

$\vec{k}$ **Wave Number**

Phase variation in space

$\omega$ **Angular Frequency**

Phase variation in time

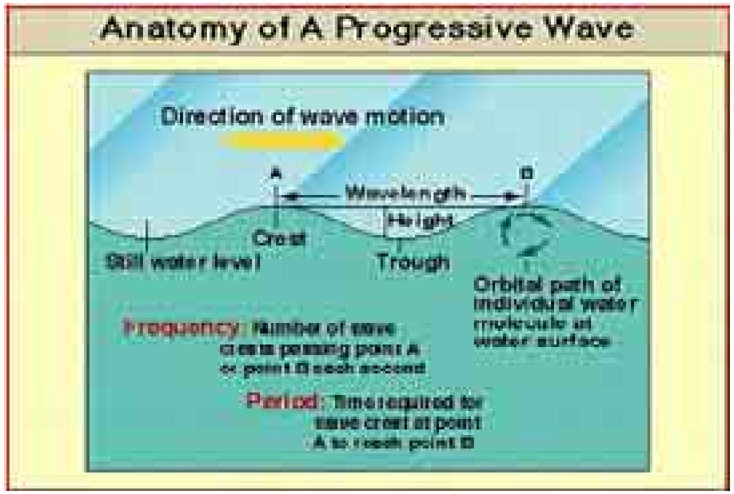
# Wave Dynamics

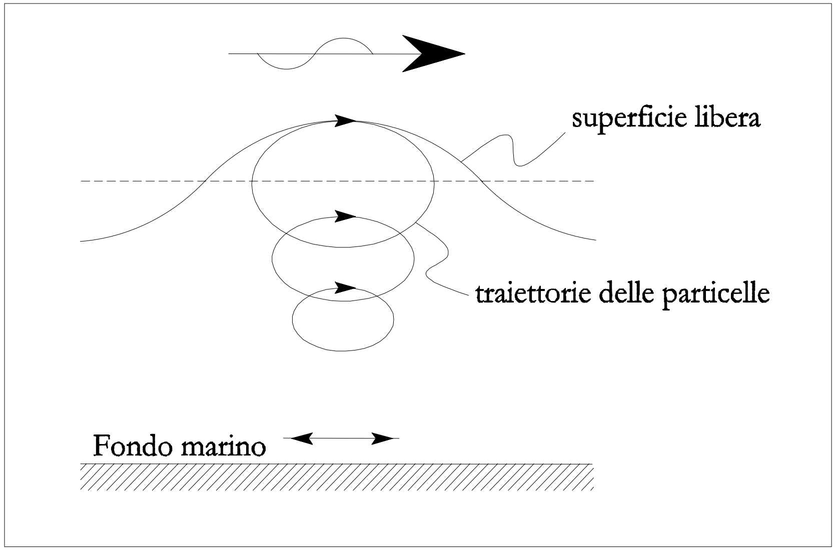
## Wave Characteristics Are Due To:

- **Wind direction, intensity, and duration**
- **FETCH**
- **Bottom depth**
- **Currents that could interact with wave propagation and characteristics**

# Wave Dynamics

- **Waves propagating in a direction**
- **Energy and quantity of motus transport, not mass transport**
- **Orbital path of individual water molecule at water surface**



# Wave Dynamics

**SHORT PERIOD WAVES**

**VS**

**LONG PERIOD WAVES**

# Wave Dynamics

## SHORT PERIOD WAVES

- wind waves
- swell

# Waves

## The waves on the ocean are broken into two categories

**Sea – steep, irregular waves.**

**Sea dissipates quickly after the wind dies**

**Swell – regular, longer, low, and rounded waves that are left after the wind dies down, or that propagate away from the windy region**

**Swell can propagate for thousands of miles**

# Wave Dynamics

## Wind Waves Generation

**wind waves: in open sea if wind speed is greater than 1 m/s**

- **RIPPLES: first step in waves generation**

**L = 5 – 10 cm**
**H = 1 – 2 cm**

# Wave Dynamics

## Wind Waves Generation

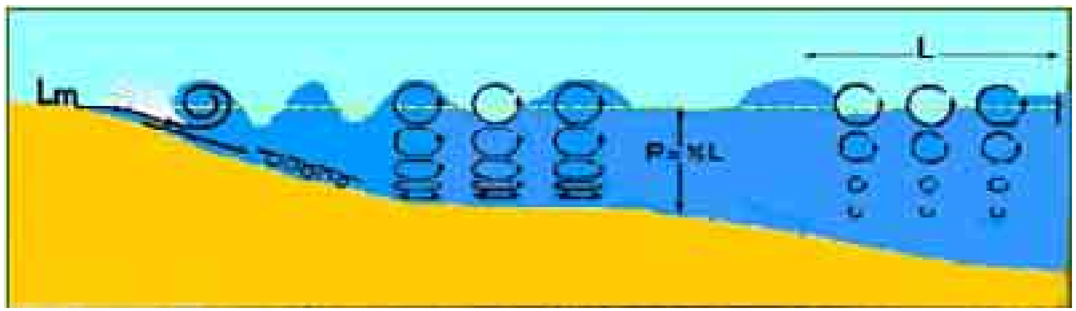
- **If wind action persists, it will give rise to H, L, T growth**

- **maximum value depends on wind speed, duration and fetch length**

**H = 10 m**
**T = 20 s**

# Wave Dynamics

## Waves Phenomena

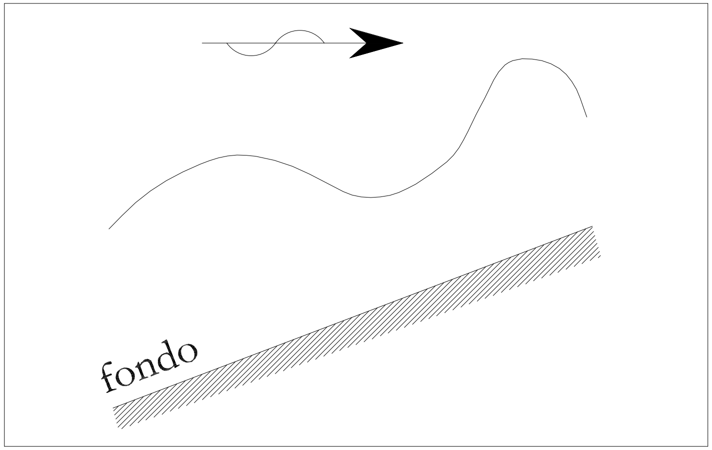


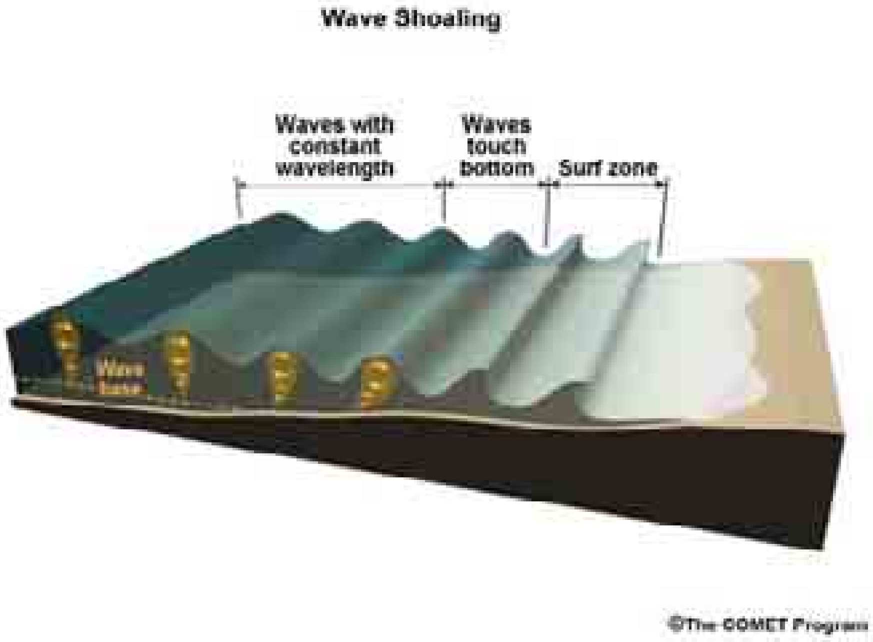

**Wave – bottom interaction is classified by means of h and L ratio, h/L**

- **if h/L < 1/20** → **shallow water**
- **if 1/20 < h/L < 1/2** → **middle water**
- **if h/L > 1/2** → **deep water**

# Wave Dynamics

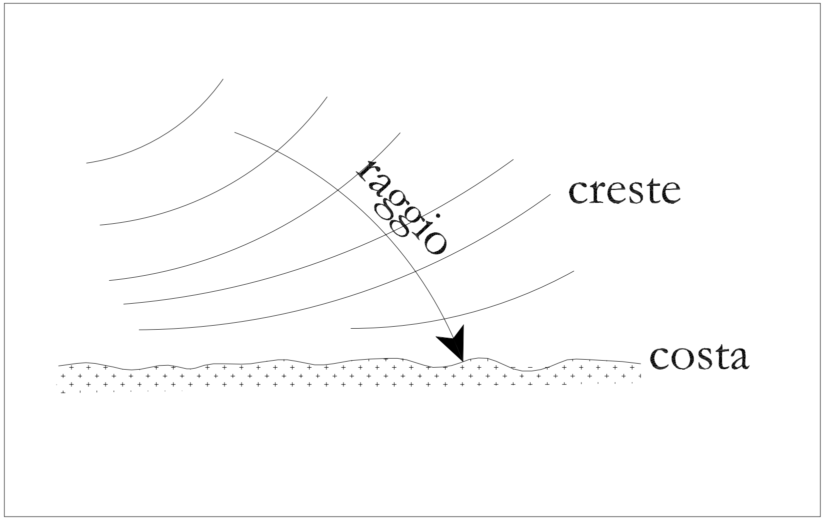
## Shoaling

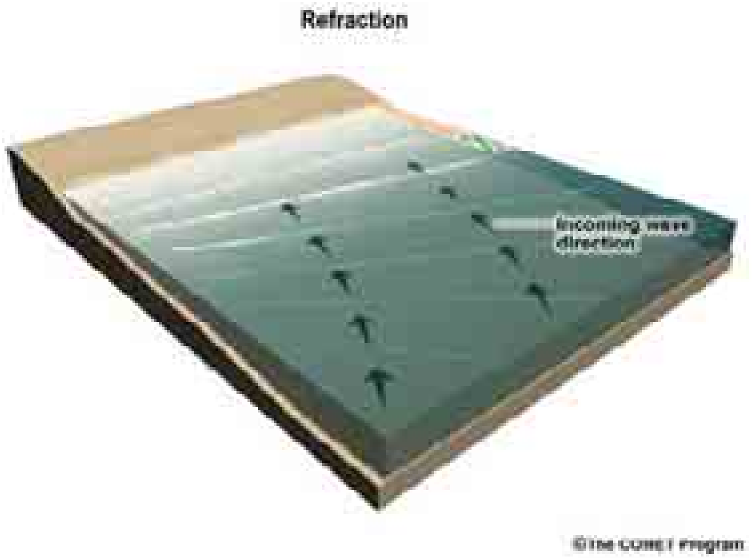


# Wave Dynamics

## Bottom Refraction



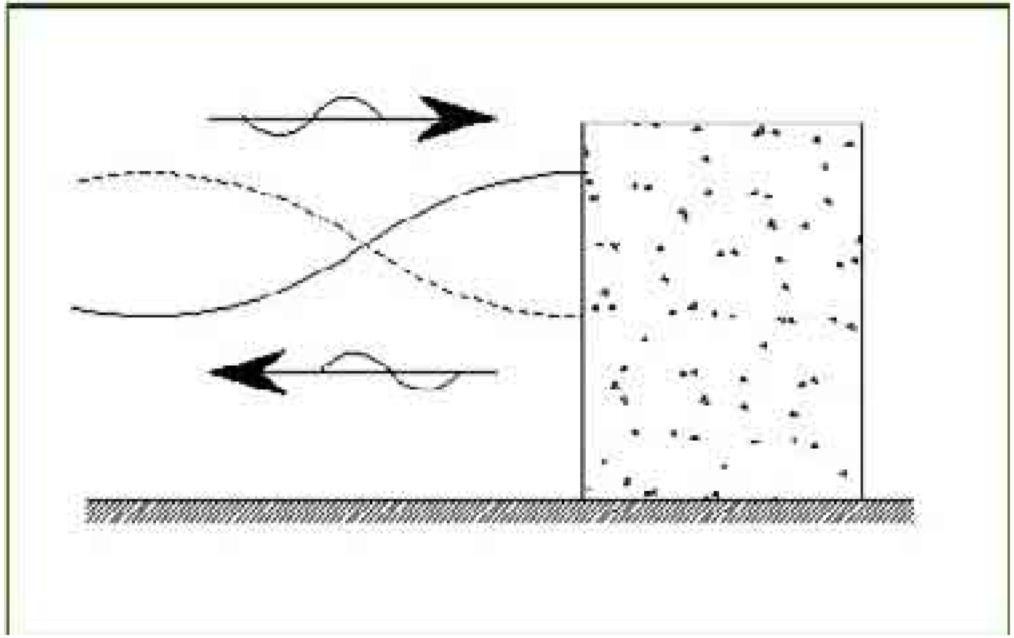
# Wave Dynamics

## Waves – Obstacles Interaction

- reflection
- transmission
- overtopping
- diffraction
- wave breaking

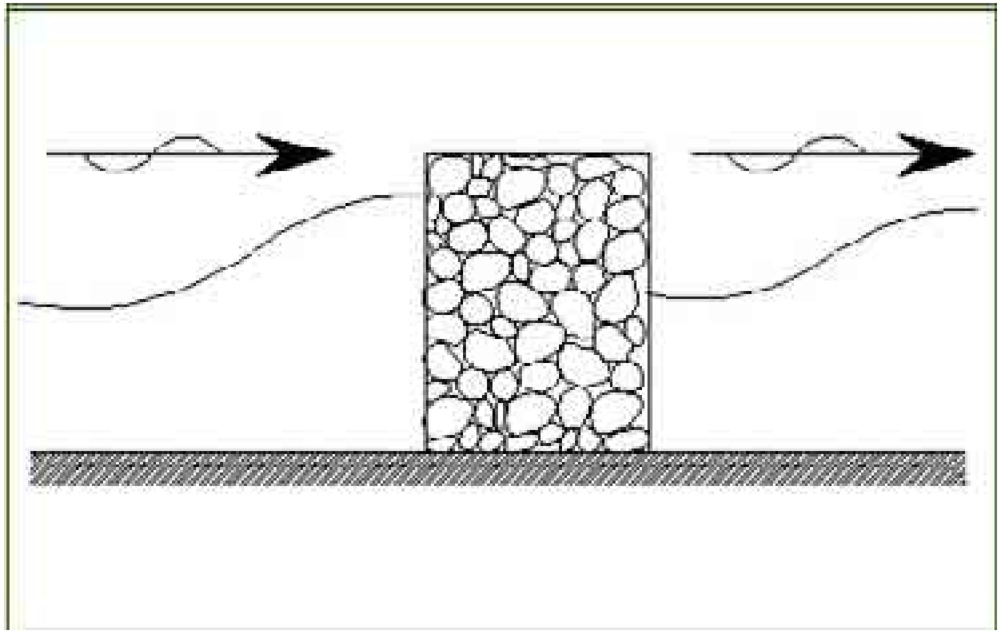
# Wave Dynamics

## Reflection



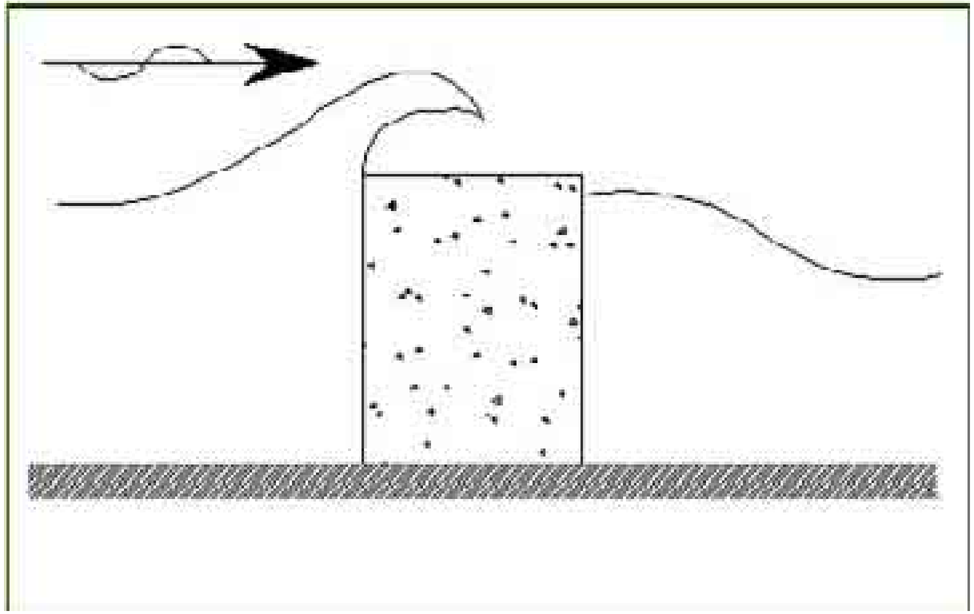
# Wave Dynamics

## Transmission



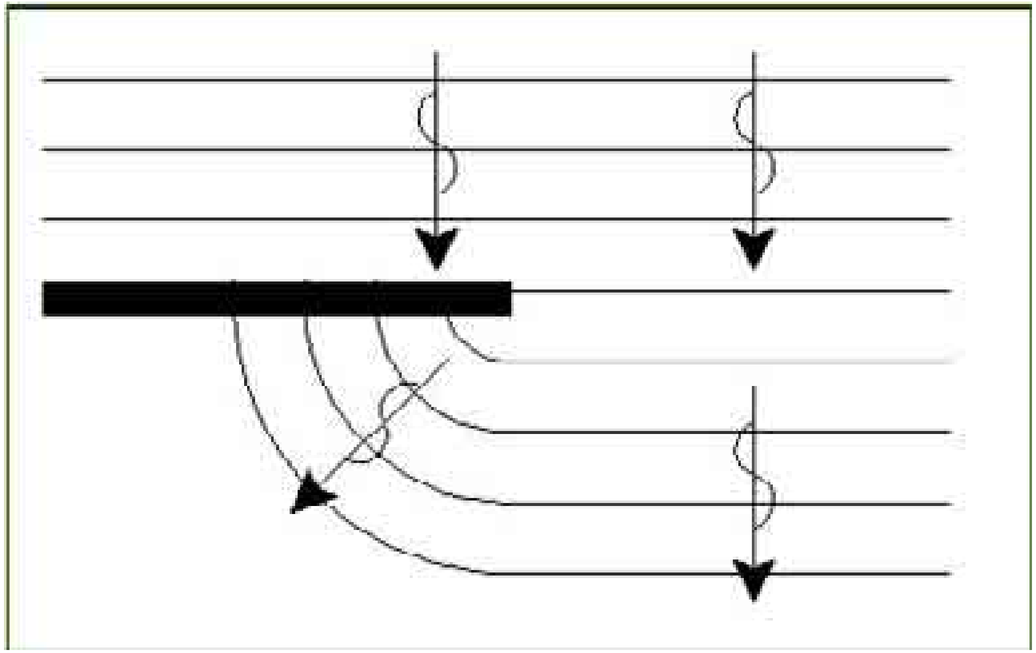
# Wave Dynamics

## Overtopping



# Wave Dynamics

## Diffraction



# Wave Dynamics

## Long Period Waves

- **low steepness: L = 1 – 100 Km, H = dm**
- **frequently shallow water conditions**
- **resonance phenomenon: their periods could be similar to basins ones**

# Wave Dynamics

## Long Period Waves

- **Tides**
- **Tsunami**

# Wave Dynamics

## Long Period Waves

## Tides

↓

**GRAVITATIONAL EFFECTS DUE TO MOON - EARTH INTERACTION**

# Wave Dynamics

## LONG PERIOD WAVES

↓

**EARTHQUAKE, IMPULSIVE PHENOMENA**

# Wave Dynamics

- **wave physical description**:

short period waves vs long period waves

- **wave mathematical description**

- **data analysis**: wave and tide

# Wave Dynamics

## EQUATIONS

- mass conservation

$$\frac{dM}{dt} = 0$$

- quantity of motus conservation

$$\sum_{i=1}^{N} F_i = \frac{d(M\mathbf{v})}{dt}$$

BOUNDARY CONDITIONS

# Wave Dynamics

## SCALAR EQUATIONS

- mass conservation

$$\frac{\partial u}{\partial t}+\frac{\partial v}{\partial t}+\frac{\partial w}{\partial t}=0$$

- quantity of motus

$$\sum_{i=1}^{N} F_i = \frac{Mdv}{dt}.$$

$$u = u(x, y, z, t)$$
$$v = v(x, y, z, t)$$
$$w = w(x, y, z, t)$$

Three speed components in x, y e z directions

# Wave Dynamics

## ACTING FORCES

- gravity
- pressure
- friction

Navier Stokes equations

$$-\frac{\partial p}{\partial t}+v\left(\frac{\partial^2 u}{\partial x^2}+\frac{\partial^2 u}{\partial y^2}+\frac{\partial^2 u}{\partial z^2}\right)=\frac{\partial u}{\partial t}+u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}+w\frac{\partial u}{\partial z}$$

$$-\frac{\partial p}{\partial t}+v\left(\frac{\partial^2 u}{\partial x^2}+\frac{\partial^2 u}{\partial y^2}+\frac{\partial^2 u}{\partial z^2}\right)=\frac{\partial v}{\partial t}+u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y}+w\frac{\partial v}{\partial z}$$

$$-\frac{\partial p}{\partial t}+v\left(\frac{\partial^2 u}{\partial x^2}+\frac{\partial^2 u}{\partial y^2}+\frac{\partial^2 u}{\partial z^2}\right)=\frac{\partial w}{\partial t}+u\frac{\partial w}{\partial x}+v\frac{\partial w}{\partial y}+w\frac{\partial w}{\partial z}$$

$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}+\frac{\partial w}{\partial z}=0.$$

# Wave Dynamics

## Boundary conditions

↓

- initial conditions, imposed on the space (x, y, z, t) in time t=0
- spatial boundary condition (t varying)

# Wave Dynamics

- **wave physical description**:

short period waves vs long period waves

- **wave mathematical description**

- **data analysis**: wave and tide

# Wave Dynamics

## Ocean Waves Classification

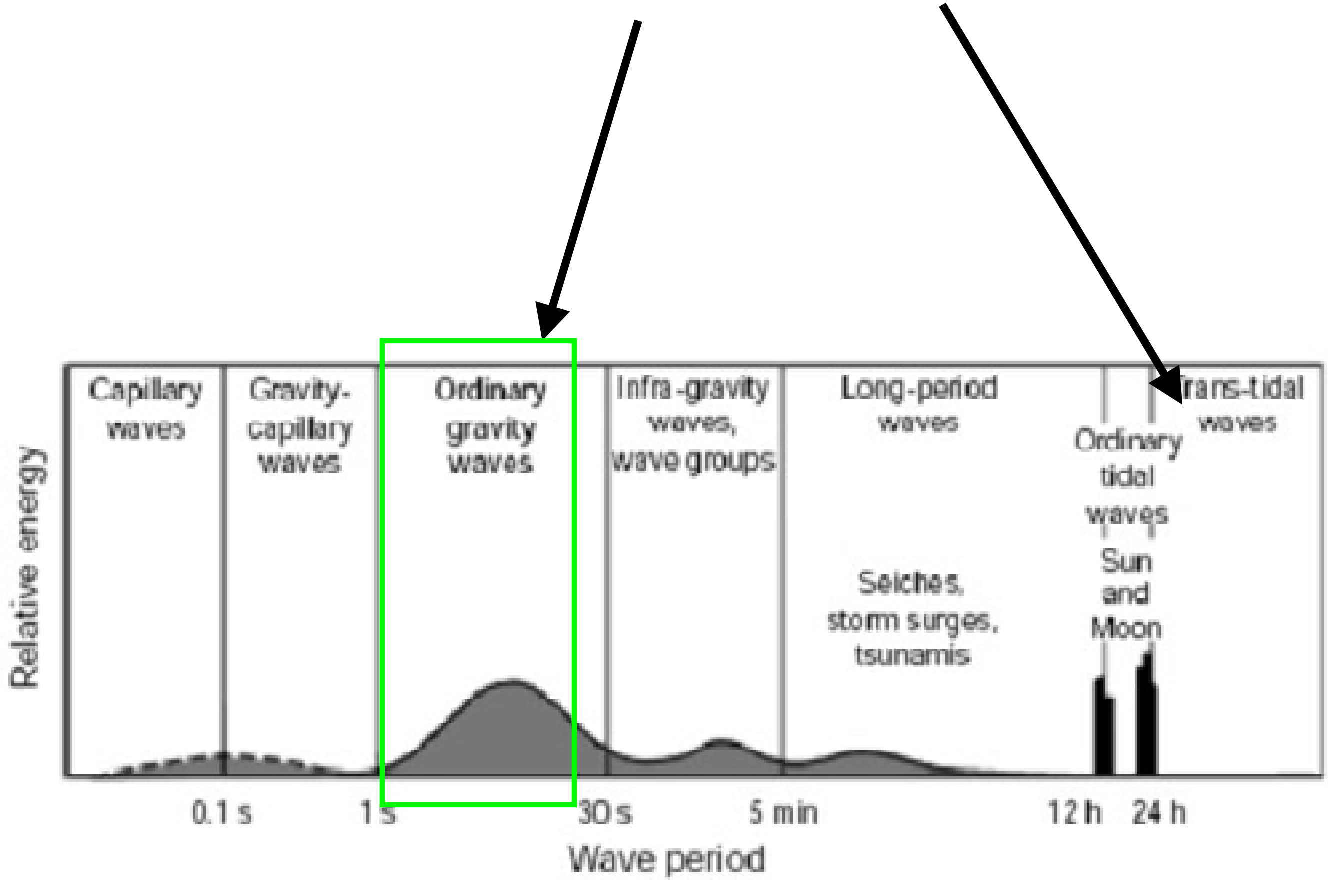



Figure 1.1 — Classification of ocean waves by wave period (*derived from Munk, 1951*)

# RON 1989 - 2002


**OPERATIONAL**

-1989 - 1999, 8 directional wave buoys (WAVEC)

-1999 –2002, 10 directional wave buoys (WAVEC)

# RON 2001-2003


-14 directional wave buoys (TRIAXIS)

- NEW SITES:

Chioggia
Civitavecchia
Siniscola
Palermo

- upgrading onshore stations and control centre in Rome
- introduction of real-time services

# Contents

## Wave Data Analysis

- PERFORMANCE ANALYSIS
- GAP ANALYSIS AND DATA VALIDATION
- ZERO CROSSING ANALYSIS
- DIRECTIONAL SPECTRAL ANALYSIS
- CLIMATE ANALYSIS
- EXTREME EVENTS

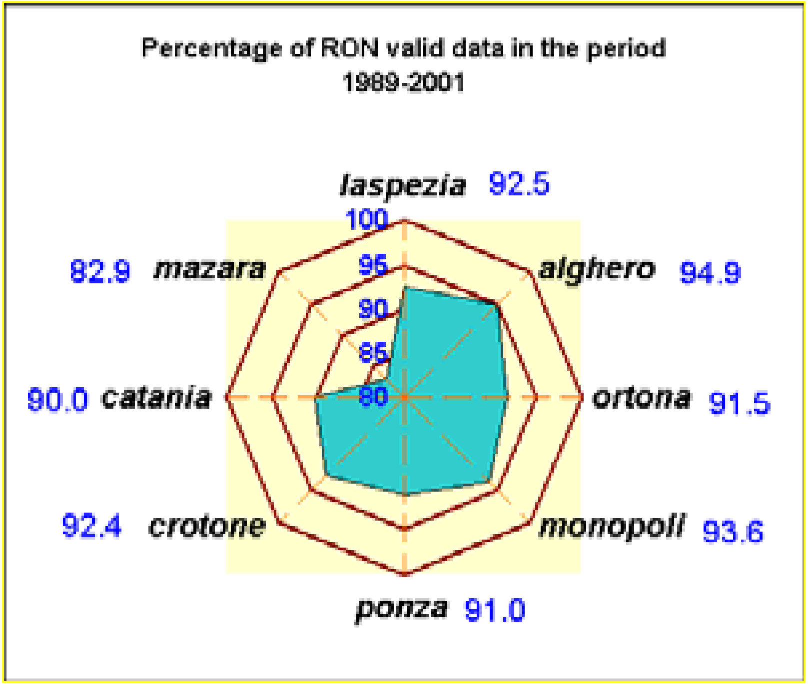
# Wave Data Analysis

## Performance Analysis

- **DATA COLLECTION:** $H_s$, $T_p$, $T_m$, $\theta_m$ every ½ hrs (on local coastal station)
- **DATA RECORDING**: every 3 hrs in Rome

**STATION EFFICIENCY**

$$\eta = n_{oss} / T_{oss}$$

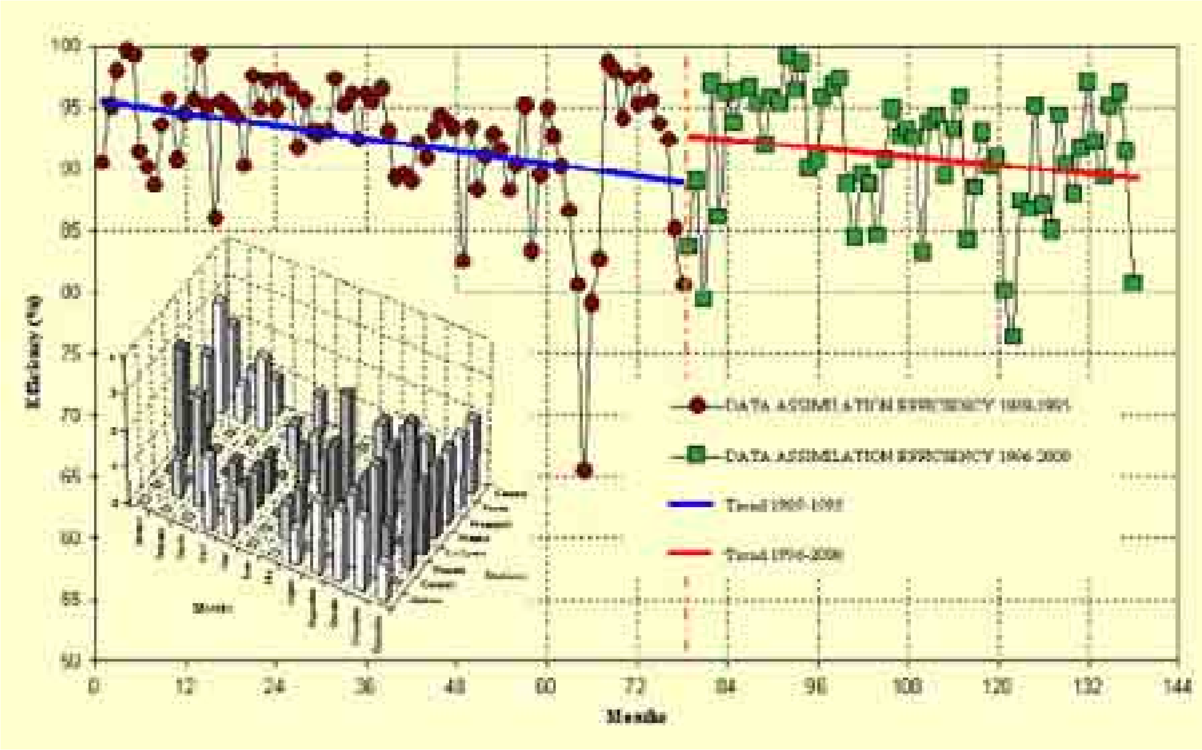



$n_{oss}$ is the number of (1/2 hrs) Hs observations

$T_{oss}$ is the expected total number (1/2 hrs) Hs observations

# Wave Data Analysis

## Performance Analysis




**Winter months are critical for the efficiency of the most of the stations**

# Wave Data Analysis

## Data Analysis Methods

**AFTER WAVE DATA ARE COLLECTED, THE ANALYSIS OF THAT DATA IS TYPICALLY APPROACHED THROUGH EITHER**

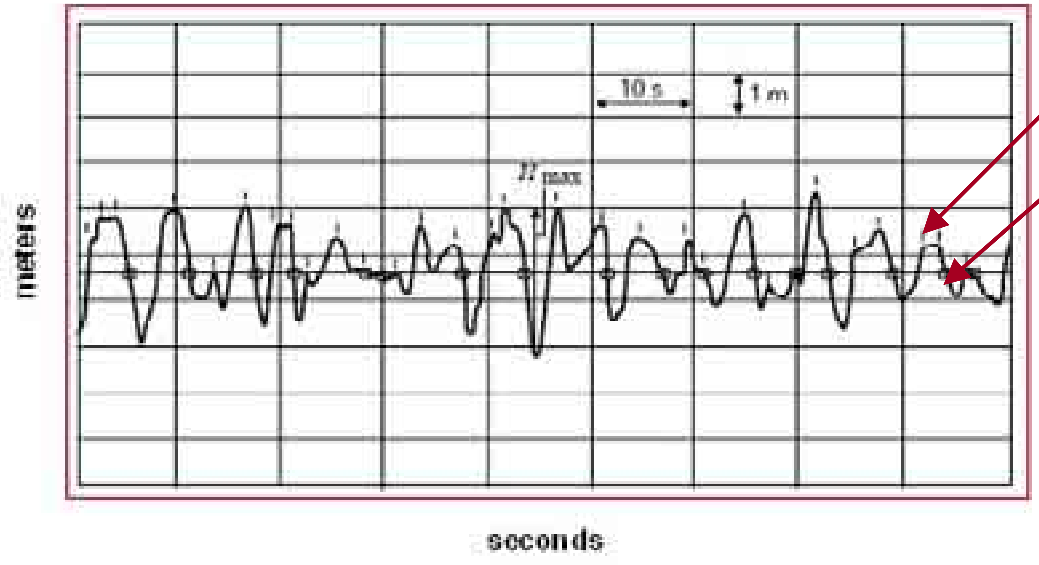
↓

- **STATISTICAL ANALYSIS (ZERO CROSSING ANALYSIS)**
- **SPECTRAL ANALYSIS**

# Wave Data Analysis

## Statistical Analysis (Zero Crossing)

Basic information on the wave climate: maximum wave height of the record, average wave height and root mean-square wave height




**Wave crests are indicated with dashes and all zero-downcrossings are circled**

**T: time distance between two consecutive downcrossing (or upcrossing)**
**H: vertical distance between the highest and the lowest value of the wave record between two zero-downcrossing**

# Wave Data Analysis

## STATISTICAL Analysis (ZERO CROSSING)

### Statistical Parameters

**H10**: Average height of the waves, which comprise the top 10% of record

**Maximum Wave Height** (Hmax): Maximum wave height for a given interval of time (typically 17 or 20 minutes)

**Mean wave height** (Hmean)

**Mean Period or Zero crossing period** (Tz)

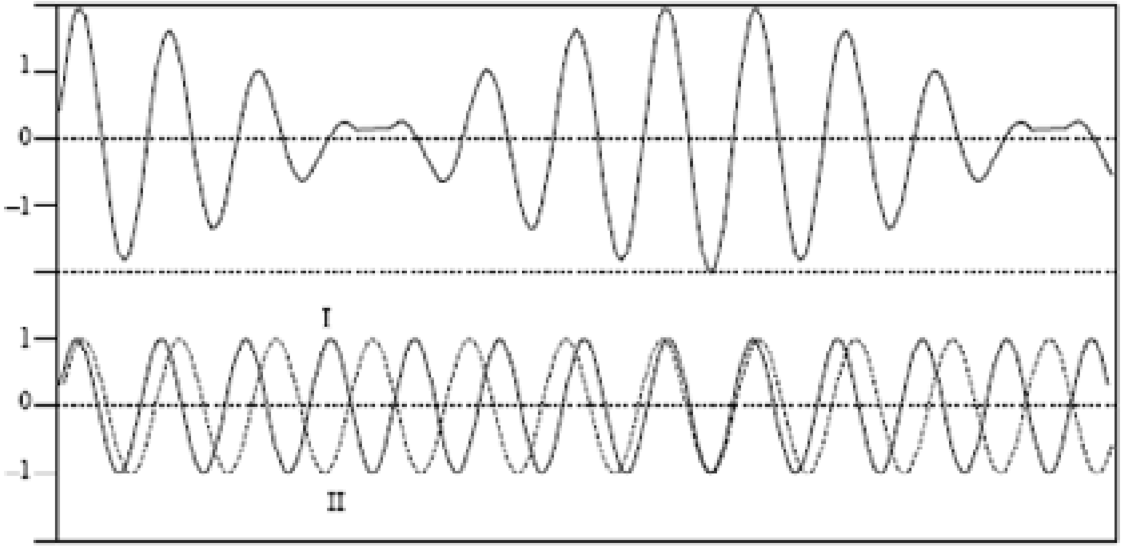
**Root Mean Square Wave Height** (Hrms)

**Significant Wave Height** (Hsig): Average of the highest one - third of the waves measured over a given interval of time

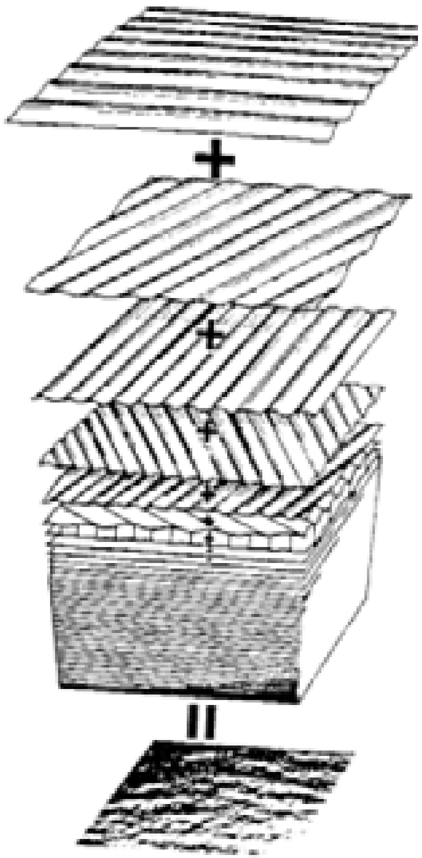
**Significant Wave Period** (Tsig): Average period of the highest one - third of the waves determined from large, well defined groups of waves

# Wave Data Analysis

## Superposition Of Waves




**The upper profile is equal to the sum (superposition) of two simple waves, I and II, shown in the lower part of the figure. The horizontal dimensions are greatly shortened with respect to the vertical ones**

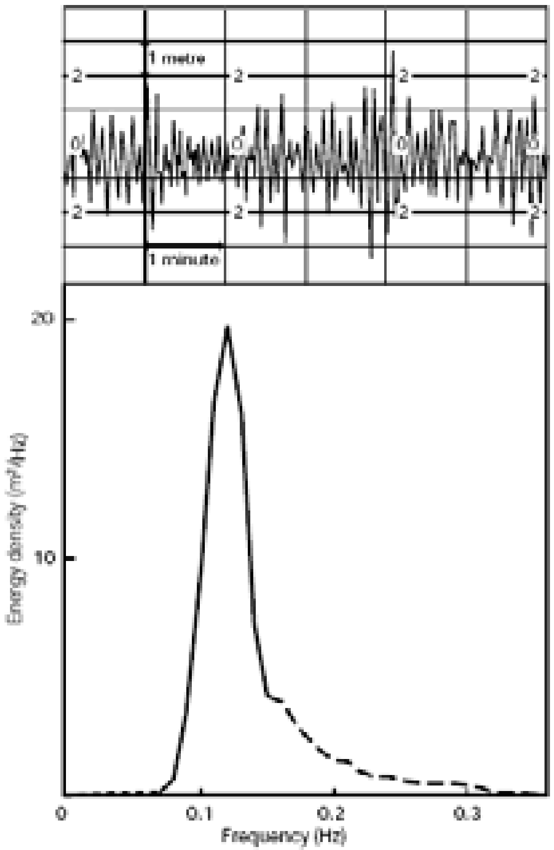


**The sea surface obtained from the sum of many sinusoidal waves (*derived from Pierson, Neumann and James, 1955*)**

# Wave Data Analysis

## Spectral Analysis

Basic information on the complicated mixture of waves produced by different storms; it describes the complete distributions of wave energies and periods




Directional Wave Spectrum provides the most complete description of a wave climate and makes it possible to determine the period of the waves with the most energy

# Wave Data Analysis

## Spectral Analysis

Harmonic analysis (fast-Fourier transform (FFT)):

- **wave record decomposition into a large number of sinusoidal waves (different frequencies, directions, amplitudes and phases)**

$$\eta(t) = \eta_0 + \sum_{j=1}^{n} a_j \sin(j\omega_0 t + \phi_j)$$

**$\eta(t)$ = recorded elevation of water surface at time t**

**$\eta_0$ = mean elevation**

**$\omega_0$ = angular wave frequency of the longest wave fitted to the record**

**j = number of wave component**

**$a_j$ = amplitude of the jth component**

**$\Phi_j$ = phase angle of the jth component**

**n = total number of components**

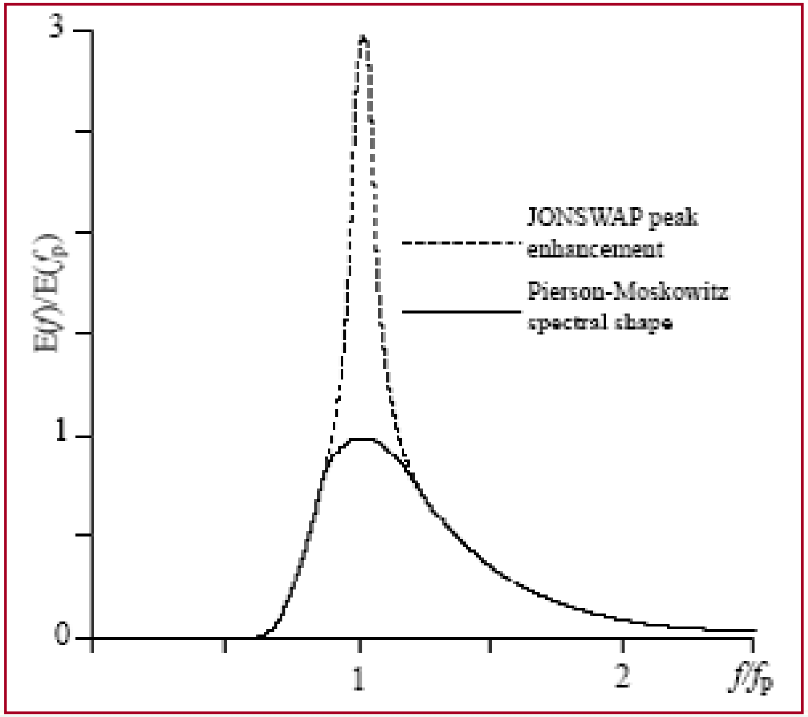
- **distribution of the energy of the various wave components, *E*(*f*, θ)**
  **Models of the spectrum from a limited number of parameters (H, T)**

# Wave Data Analysis

## Spectral Analysis

**The PIERSON - MOSKOWITZ spectrum (Pierson and Moskowitz, 1964): used for a fully developed sea, an idealized equilibrium state reached when duration and fetch are unlimited**

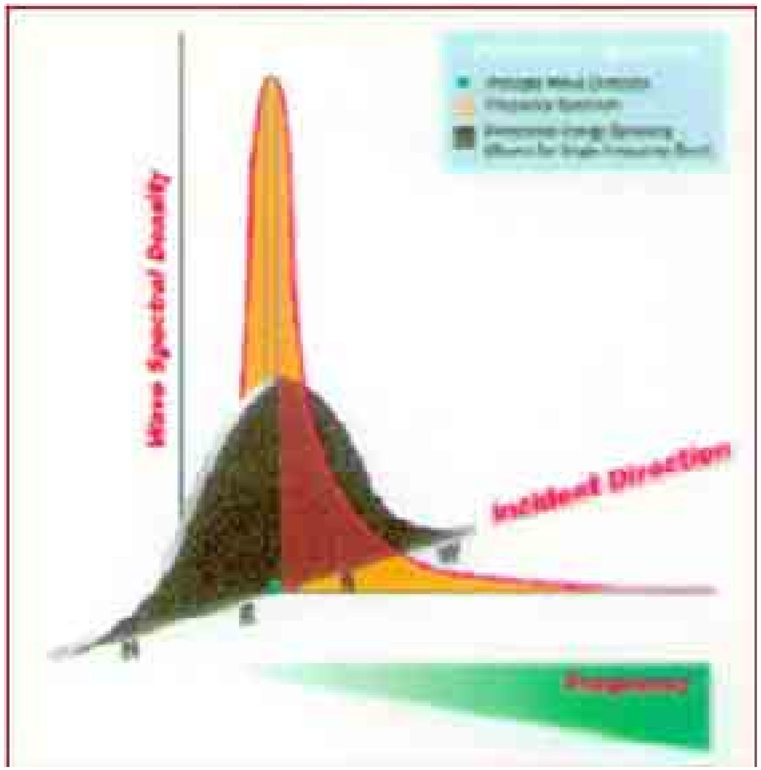
**The JONSWAP spectrum (Hasselmann et al., 1973): used to describe waves in a growing phase, in fetch-limited conditions**



# Wave Data Analysis

## Directional Spectral Analysis

### DIRECTIONAL WAVE ENERGY SPECTRUM



# Wave Data Analysis

## Climate Analysis

**Wave climates indicate the statistical characteristics of wave parameters**

**joint – occurrence frequency of wave height – direction (ratio between the number of events falling within the considered class and the total number of data)**

# Wave Data Analysis

## Joint Frequency Functions Tables (Hm0, Dir)

| N.D.A. | N.D.P. | N.D.M. | N.Calme |
|---|---|---|---|
| 42376 | 39094 | 3282 | 3856 |

| | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 549 | 189 | 114 | 71 | 65 | 54 | 49 | 47 | 46 | 52 | 89 | 429 | 1443 | 1755 | 1309 | 1535 | 2305 | 2168 | 1875 | 2857 | 8483 | 6596 | 1770 | 1388 | 35238 |
| >=9.8 | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | 0 |
| 9.5 | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | 0 |
| 9.0 | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | 1 | 1 | - | - | - | 2 |
| 8.5 | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | 1 | 1 | - | - | - | 2 |
| 8.0 | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | 4 | 1 | - | - | 5 |
| 7.5 | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | 8 | 9 | - | - | 17 |
| 7.0 | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | 1 | 20 | 13 | - | - | 34 |
| 6.5 | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | 2 | 32 | 40 | - | - | 74 |
| 6.0 | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | 1 | 44 | 40 | - | - | 85 |
| 5.5 | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | 1 | 2 | 3 | 2 | 78 | 75 | - | - | 161 |
| 5.0 | - | - | - | - | - | - | - | - | - | - | - | - | - | - | 2 | 1 | 2 | 4 | 7 | 7 | 31 | 99 | 1 | - | 254 |
| 4.5 | - | - | - | - | - | - | - | - | - | - | - | - | - | - | 1 | 2 | 12 | 14 | 6 | 14 | 72 | 153 | 1 | - | 375 |
| 4.0 | - | - | - | - | - | - | - | - | - | - | - | - | - | 2 | 1 | 3 | 13 | 11 | 17 | 32 | 269 | 238 | 4 | 3 | 593 |
| 3.5 | - | - | - | - | - | - | - | - | - | - | - | - | 1 | 2 | 1 | 8 | 30 | 42 | 30 | 60 | 437 | 347 | 11 | 2 | 971 |
| 3.0 | 1 | - | - | - | - | - | - | - | - | - | - | - | - | 1 | 8 | 35 | 90 | 68 | 59 | 71 | 95 | 451 | 18 | 3 | 1400 |
| 2.5 | 9 | - | - | - | - | - | - | - | - | - | - | 1 | 5 | 7 | 21 | 66 | 208 | 136 | 105 | 137 | 789 | 586 | 44 | 1 | 2125 |
| 2.0 | 13 | 5 | - | - | - | - | - | - | - | - | 4 | 9 | 24 | 52 | 61 | 117 | 287 | 238 | 139 | 267 | 1029 | 717 | 90 | 46 | 3098 |
| 1.5 | 52 | 9 | 7 | 3 | 3 | 3 | 1 | 1 | 2 | 3 | 6 | 52 | 144 | 150 | 149 | 209 | 359 | 361 | 247 | 374 | 1330 | 949 | 131 | 116 | 4661 |
| 1.0 | 161 | 67 | 27 | 20 | 16 | 6 | 3 | 13 | 5 | 4 | 15 | 122 | 446 | 422 | 285 | 404 | 519 | 448 | 408 | 659 | 1611 | 1152 | 289 | 315 | 7417 |
| 0.5 | 313 | 108 | 80 | 48 | 46 | 45 | 45 | 33 | 39 | 45 | 64 | 245 | 323 | 1119 | 780 | 690 | 784 | 844 | 854 | 1228 | 1932 | 1726 | 1181 | 892 | 13964 |
| - | 0 | 15 | 30 | 45 | 60 | 75 | 90 | 105 | 120 | 135 | 150 | 165 | 180 | 195 | 210 | 225 | 240 | 255 | 270 | 285 | 300 | 315 | 330 | 345 | |

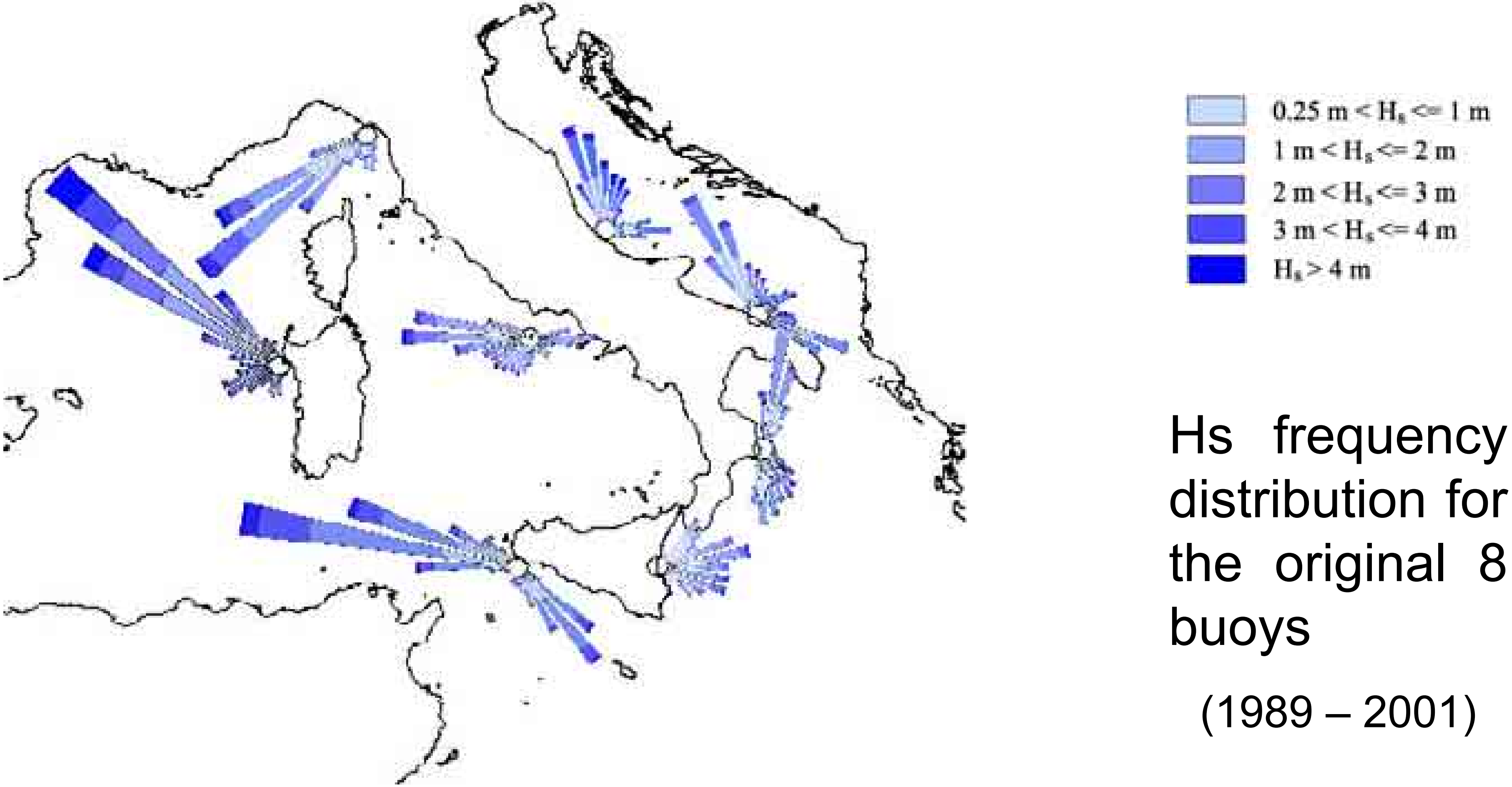
Classi di $H_{m0}$ (m)

Classi di direzione media di provenienza - (deg N)

Tab 5: Tabella a doppia entrata $H_{m0}$- ĞAlghero Ğdati triorari: 01/07/1989 Ğ31/12/2003; periodo: intero

# Wave Data Analysis

## Climate Analysis



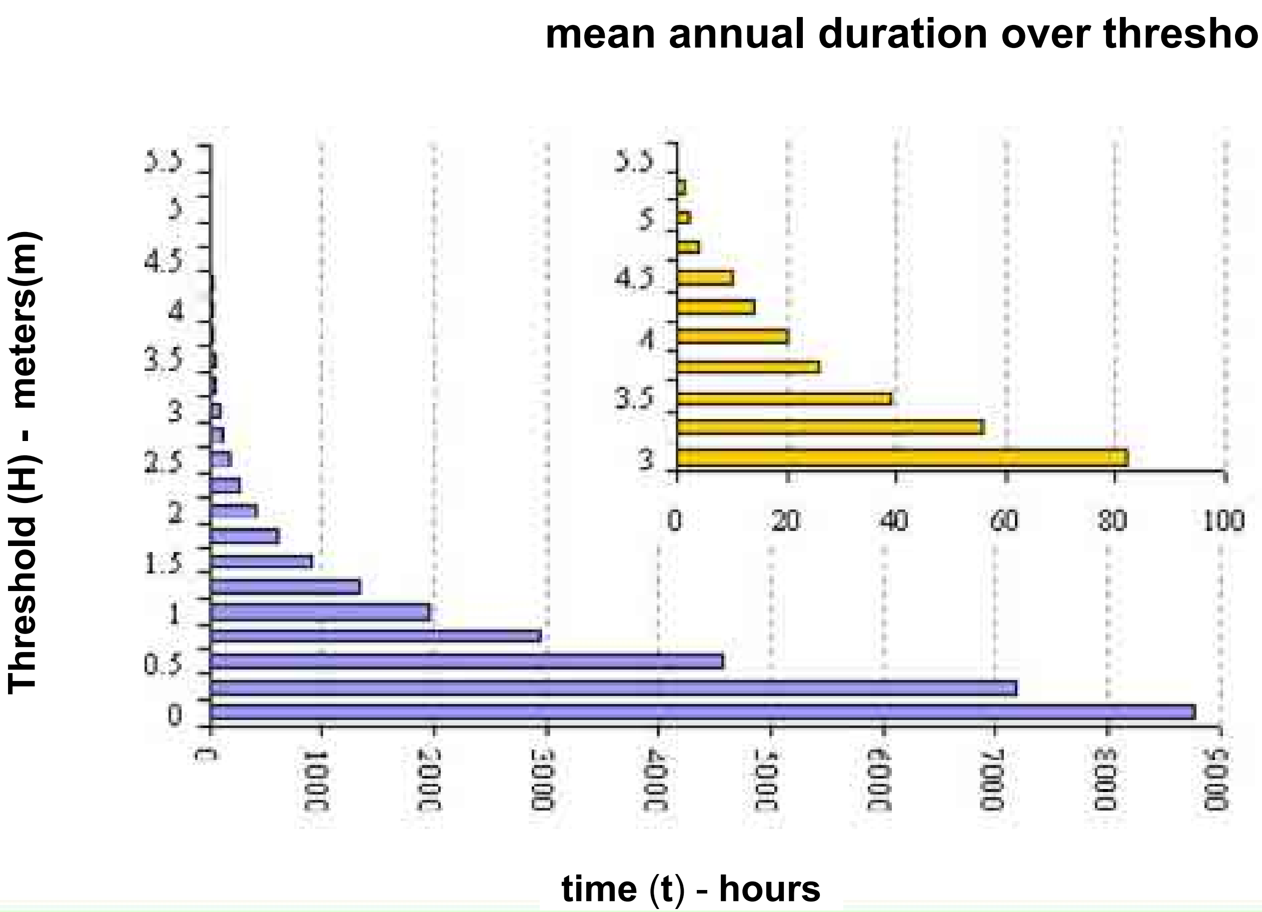

Hs frequency distribution for the original 8 buoys

(1989 – 2001)

# Wave Data Analysis

## Climate Analysis

### Persistence over threshold (PESCARA)




- wave height over threshold persistence

- mean annual duration of sea states above a fixed wave height threshold

# Data Reduction

## Quality Control Check

- Analysis of data format
- Unmoorings
- Joint Frequency Functions Tables
- Spikes
- Repeated measurements

# Data Reduction

Analysis of data format

Risultati dettagliati per il periodo I

| Inizio periodo | Fine periodo | Errore | Correzione |
|---|---|---|---|
| | | **Alghero** | |
| 1993-06-14 12:00 | 1993-08-07 15:00 | esistono misurazioni del tipo 1993-0-0 0:00 0 0 0 0 | Eliminate le misurazioni con 1993-0-0 0:00 0 0 0 0 0 |
| | | **Ancona** | |
| 2001-12-07 00:30 | 2001-12-07 00:30 | registrato come 2001-12-17 00:31 | Correzione dellÕorario |
| 2001-12-17 00:30 | 2001-12-17 00:30 | registrato come 2001-12-17 00:31 | Correzione dellÕorario |
| | | **Catania** | |
| 1996-00-0 23:30 | 1996-00-0 23:30 | data non corretta | Eliminato |
| 1997-11-0 23:30 | 1997-11-0 23:30 | data non corretta | Eliminato |
| | | **Crotone** | |
| 1993-10-07 18:00 | 1993-10-07 18:00 | manca il valore di | Eliminato |
| 1993-10-14 15:00 | 1993-10-14 15:00 | manca il valore di | Eliminato |
| 1993-10-21 12:00 | 1993-10-21 12:00 | manca il valore di | Eliminato |
| 1993-10-28 09:00 | 1993-10-28 09:00 | manca il valore di | Eliminato |
| 1993-10-31 21:00 | 1993-10-31 21:00 | manca il valore di | Eliminato |
| 1993-11-07 18:00 | 1993-11-07 18:00 | manca il valore di | Eliminato |
| 1993-11-14 15:00 | 1993-11-14 15:00 | manca il valore di | Eliminato |
| 1993-11-21 12:00 | 1993-11-21 12:00 | manca il valore di | Eliminato |
| 1993-11-28 09:00 | 1993-11-28 09:00 | manca il valore di | Eliminato |
| 1993-11-30 21:00 | 1993-11-30 21:00 | manca il valore di | Eliminato |
| 1993-12-07 18:00 | 1993-12-07 18:00 | manca il valore di | Eliminato |
| 1993-12-14 15:00 | 1993-12-14 15:00 | manca il valore di | Eliminato |
| 1993-12-21 12:00 | 1993-12-21 12:00 | manca il valore di | Eliminato |
| | | **La Spezia** | |
| 2000-11-04 20:30 | 2001-12-30 07:00 | Esistono acquisizioni con valore dei minuti diversi da 0 o 30 | Correzione del campo dei minuti nellÕorario |
| | | **Ortona** | |
| 1999-11-08 01:00 | 1999-11-08 01:00 | Acquisizione registrata come 1999-11-08 01:01 | Correzione del campo dei minuti |
| 1999-11-08 12:00 | 1999-11-08 12:00 | Acquisizione registrata come 1999-11-08 12:01 | Correzione del campo dei minuti |

# Data Reduction

Joint Frequency Functions Tables
(Hm0, Dir)

| N.D.A. | N.D.P. | N.D.M. | N.Calme | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 42376 | 39094 | 3282 | 3896 | | | | | | | | | | | | | | | | | | | | | | |
| | 549 | 189 | 114 | 71 | 65 | 54 | 49 | 47 | 46 | 52 | 89 | 429 | 1443 | 1755 | 1309 | 1535 | 2305 | 2168 | 1875 | 2857 | 8483 | 6596 | 1770 | 1388 | 36238 |
| ≥9.9 | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | 0 |
| 9.5 | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | 0 |
| 9.0 | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | 1 | 1 | - | - | - | 2 |
| 8.5 | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | 1 | 1 | - | - | - | 2 |
| 8.0 | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | 4 | 1 | - | - | 5 |
| 7.5 | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | 8 | 9 | - | - | 17 |
| 7.0 | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | 1 | 20 | 13 | - | - | 34 |
| 6.5 | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | 2 | 32 | 40 | - | - | 74 |
| 6.0 | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | 1 | 44 | 40 | - | - | 85 |
| 5.5 | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | 1 | 2 | 3 | 2 | 78 | 75 | - | - | 161 |
| 5.0 | - | - | - | - | - | - | - | - | - | - | - | - | - | - | 2 | 1 | 2 | 4 | 7 | 7 | 131 | 99 | 1 | - | 254 |
| 4.5 | - | - | - | - | - | - | - | - | - | - | - | - | - | - | 1 | 2 | 12 | 14 | 6 | 14 | 172 | 153 | 1 | - | 375 |
| 4.0 | - | - | - | - | - | - | - | - | - | - | - | - | - | 2 | 1 | 3 | 13 | 11 | 17 | 32 | 209 | 230 | 4 | 3 | 525 |
| 3.5 | - | - | - | - | - | - | - | - | - | - | - | - | 1 | 2 | 1 | 8 | 30 | 42 | 30 | 60 | 437 | 347 | 11 | 2 | 971 |
| 3.0 | 1 | - | - | - | - | - | - | - | - | - | - | - | - | 1 | 8 | 35 | 90 | 68 | 59 | 71 | 595 | 451 | 18 | 3 | 1400 |
| 2.5 | 9 | - | - | - | - | - | - | - | - | - | - | 1 | 5 | 7 | 21 | 66 | 200 | 136 | 105 | 137 | 700 | 596 | 44 | 11 | 2125 |
| 2.0 | 13 | 5 | - | - | - | - | - | - | - | - | 4 | 9 | 24 | 52 | 61 | 117 | 287 | 238 | 139 | 267 | 1029 | 717 | 90 | 46 | 3098 |
| 1.5 | 52 | 9 | 7 | 3 | 3 | 3 | 1 | 1 | 2 | 3 | 6 | 52 | 144 | 150 | 149 | 209 | 359 | 361 | 247 | 374 | 1330 | 949 | 131 | 116 | 4661 |
| 1.0 | 161 | 67 | 27 | 20 | 16 | 6 | 3 | 13 | 5 | 4 | 15 | 122 | 446 | 422 | 205 | 404 | 519 | 440 | 408 | 659 | 1611 | 1152 | 209 | 315 | 7417 |
| 0.5 | 313 | 108 | 80 | 48 | 46 | 45 | 45 | 33 | 39 | 45 | 64 | 245 | 823 | 1119 | 780 | 690 | 784 | 844 | 854 | 1228 | 1932 | 1726 | 1181 | 892 | 13964 |
| - | 0 | 15 | 30 | 45 | 60 | 75 | 90 | 105 | 120 | 135 | 150 | 165 | 180 | 195 | 210 | 225 | 240 | 255 | 270 | 285 | 300 | 315 | 330 | 345 | |

Classi di $H_{m0}$ (m)

Classi di direzione media di provenienza - α (deg N)

1

Tab 6: Tabella a doppia entrata $H_{m0}$ - Ğ Alghero Ğ dati triorari: 01/07/1090 Ğ31/12/2003; periodo: intero

# Tidal Data Analysis

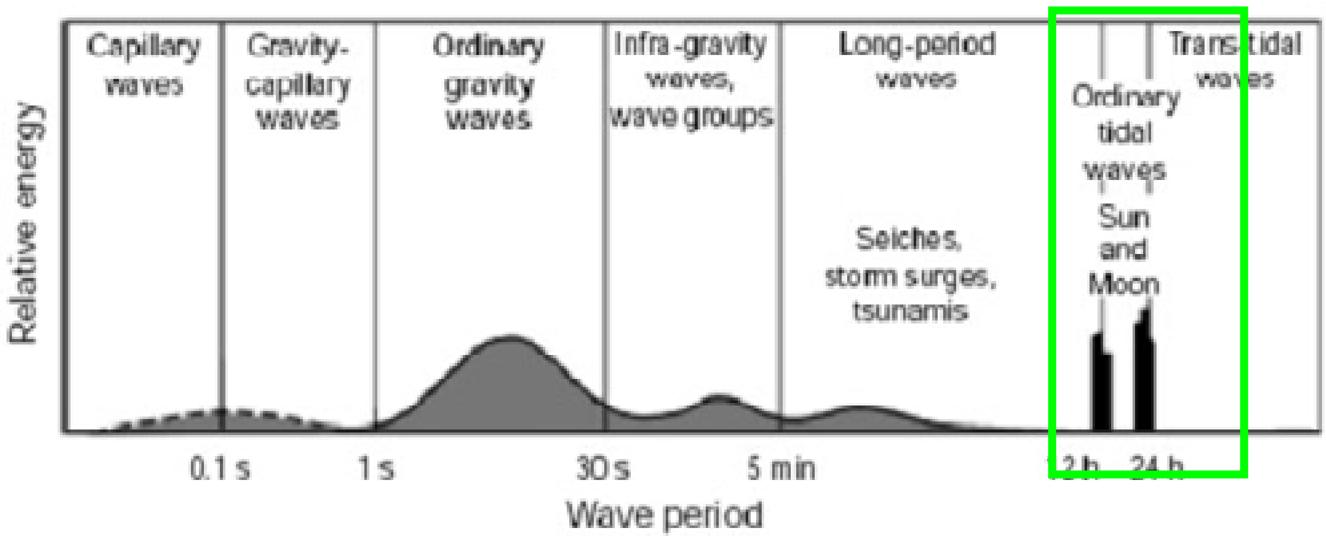
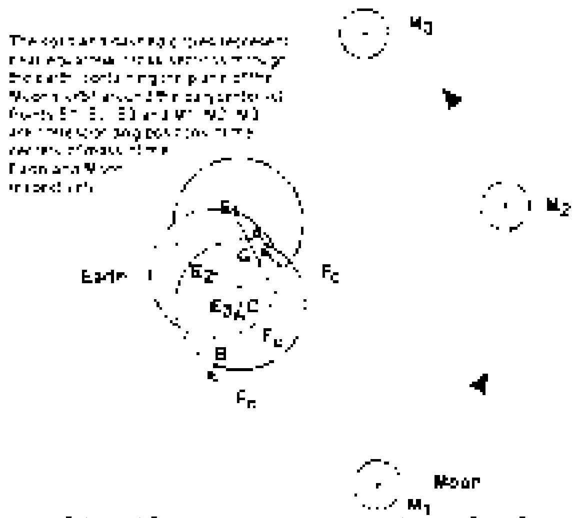



Figure 1.1 — Classification of ocean waves by wave period (*derived from Munk, 1951*)

# Tidal Data Analysis

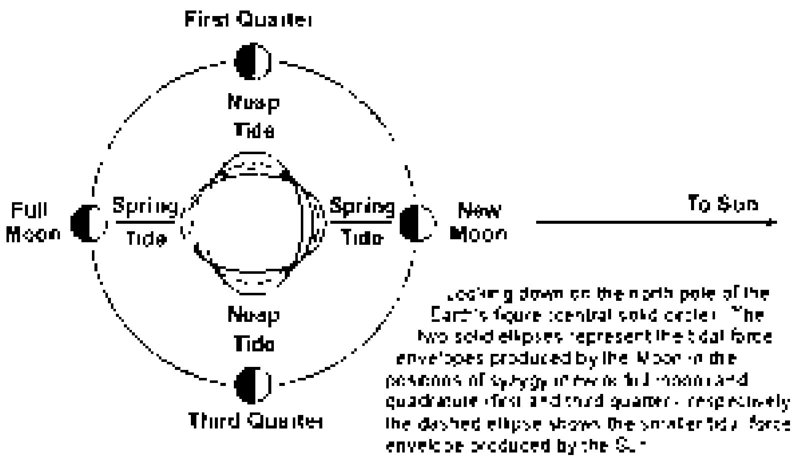
## The tide-raising forces at the earth's surface result from a combination of basic forces




- the force of gravitation exerted by the moon (and sun) upon the earth
- centrifugal forces produced by the revolutions of the earth and moon (and earth and sun) around their common centre-of-gravity (mass) or barycentre

# Tidal Data Analysis

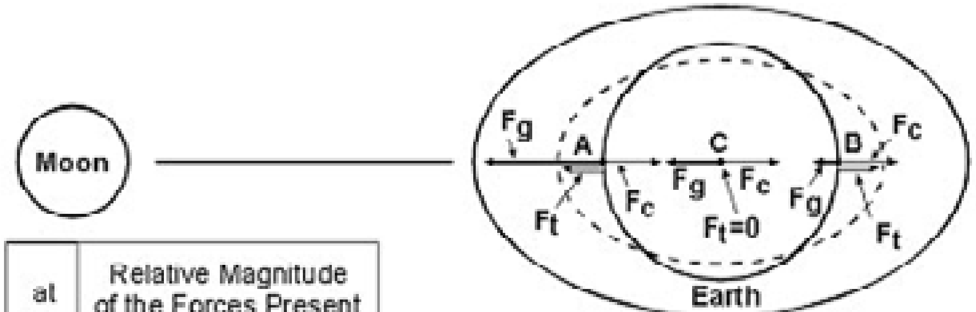
**With respect to the centre of mass of the earth or the centre of mass of the moon, the above two forces always remain in balance (i.e., equal and opposite). In consequence, the moon revolves in a closed orbit around the earth, without either escaping from, or falling into the earth - and the earth likewise does not collide with the moon**




**However, at local points on, above, or within the earth, these two forces are not in equilibrium, and oceanic, atmospheric, and earth tides are the result**

# Tidal Data Analysis

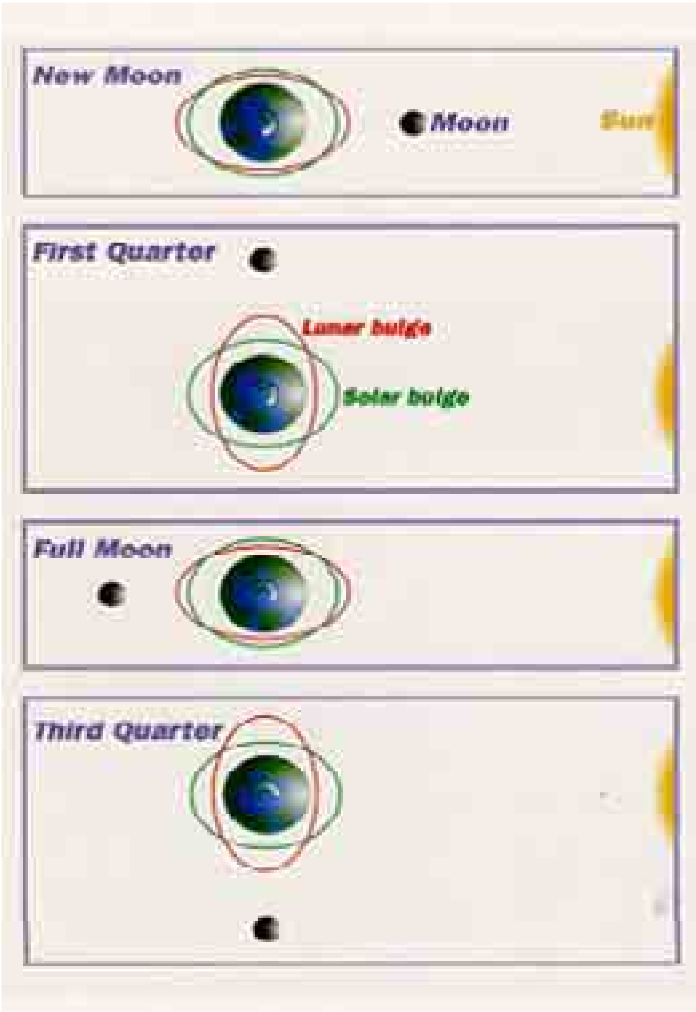
| Type of Force | Designation |
|---|---|
| $F_c$ = centrifugal force due to Earth's revolution around the barycenter | thin arrow |
| $F_g$ = gravitational force due to the Moon | heavy arrow |
| $F_t$ = the resultant tide-raising force due to the Moon | double shafted arrow |




| at | Relative Magnitude of the Forces Present | | | | |
|---|---|---|---|---|---|
| A | $F_g$ | > | $F_c$ | > | $F_t$ |
| | v | | ‖ | | v |
| C | $F_g$ | = | $F_c$ | > | 0 |
| | v | | ‖ | | ∧ |
| B | $F_g$ | < | $F_c$ | > | $F_t$ |

A north-south cross-section through the Earth's center in the plane of the Moon's hour angle; the dashed ellipse represents a profile through the spheroid composing the tidal force envelope; the solid ellipse shows the resulting effect on the Earth's waters.

# Tidal Data Analysis




## TIDES GENERATION

distortion of the sea surface due to

THE GRAVITATIONAL ATTRACTION OF MOON AND SUN

# RMN

## Objectives

- Measure sea water level variations and influencing meteorological parameters
- Give time series at national scale

## History

- The data collection of sea level observation last twenty years in many sites
- The RMN was restructured and upgraded in 1998

# RMN

## Description

- 26 tide gauge stations, nearly-real time monitoring network of meteorological and marine data

- centre connects by phone with all the stations during the day

- centre performs a preliminary analysis of the data and arranges the information in a data-set

# Italian Sea Level Network


IMPERIA
GENOVA
LIVORNO
CIVITAVECCHIA
PORTO TORRES
CARLOFORTE
CAGLIARI
NAPOLI
SALERNO
PALINURO
PALERMO
PORTO EMPEDOCLE
LAMPEDUSA
CATANIA
MESSINA
REGGIO CALABRIA
CROTONE
TARANTO
OTRANTO
BARI
VIESTE
ORTONA
ANCONA
RAVENNA
VENEZIA LIDO SUD
TRIESTE

# RMN

- **Active sensors at the stations provide observations of**

  **sea level**

  **water temperature**

- **And the following atmospheric data**

  **10 m wind speed and direction**

  **atmospheric pressure**

  **air temperature**

# RMN

## Centre of data elaboration and archive

- configure and monitoring the connection with the stations
- retrieve data  and check the values of the parameters
- elaborate, archive and graphically display the observations recorded

# RMN

## Acquisition of data

- from remote by phone line and/or GSM
- reading the local recording

## Remote transmission of data

- from an automatic procedure of request of data from the national centre
- after the operator of the national centre request
- from the local station after an technical or operative alert signal

# RMN

## Archiving And Export Of Data

- date and hour of the measurement
- station
- sensor
- measurement
- elaboration interval
- quality check

# Tidal Analysis And Prediction

## Tidal Analysis

The purpose is to represent the water level by a superposition of harmonics, or sine waves, each of them having a specific amplitude and phase: **TIDAL CONSTANTS**

**Australian National Tide Tables (ANTT)** → **22**

**National Tidal Centre (NTC)** → **112**

The main method for analysis
**THE HARMONIC METHOD**

# Tidal Data Analysis

a sequence of high and low water observations, yi, and the corresponding times ti, at which they occurred

$$y(t) = A_0 + \sum_{j=1}^{M} A_j \cos 2\pi(\sigma_j t - \phi_j).$$

function to fit data

**$A_j$ and $\phi_j$ to be chosen**

so that the values, y(ti), of the fitting function at the sampling instants, ti, agree as well as possible with the contemporaneous observed elevations, yi

# Tidal Analysis And Prediction

The result of the least squares analysis is to find for a constituent with frequency $\phi j$, the optimal amplitude Aj and phase $\phi_j$ value for the tidal signal Aj cos $2\pi(\sigma j\ t - \phi j)$.

↓

Given a set of amplitudes and phases from an analysis, the prediction of sea level can be performed by many different software packages

**RESIDUALS**

# Tidal Data Analysis

difficult to find bibliography that set out in detail the process of analysis for the tidal constants, and prediction

↓

**Manual for Tidal Heights Analysis and Prediction**
(Foreman, 1977)

# Tidal Data Analysis

## Harmonic Tidal Analysis

- Tidal Prediction
- Residual Evaluation and Analysis
- Statistical Analysis
- Yearly, Monthly and daily Averages
- Comparison with nearby tide gauge data

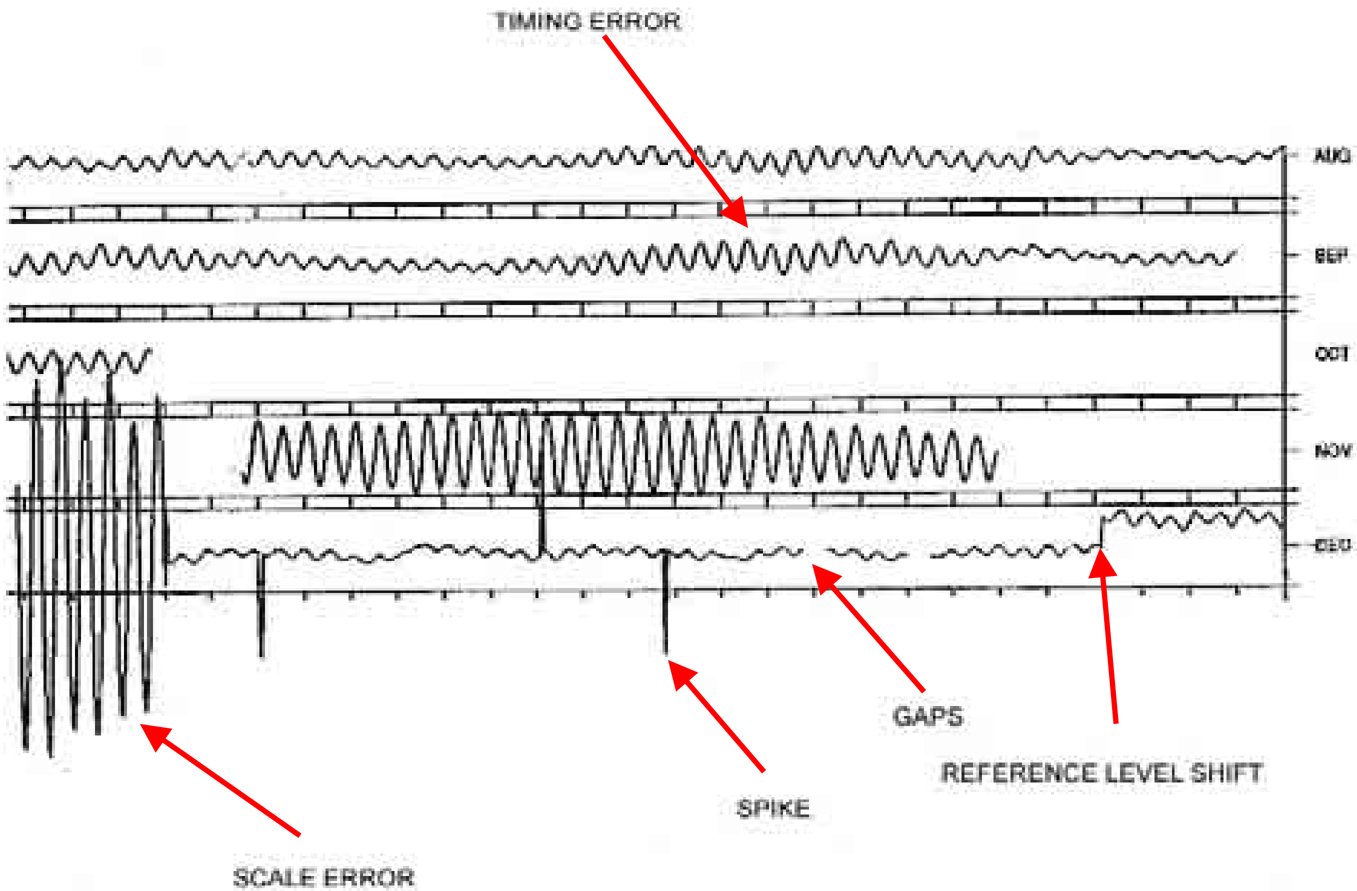
# Data Reduction

## Quality Control Check

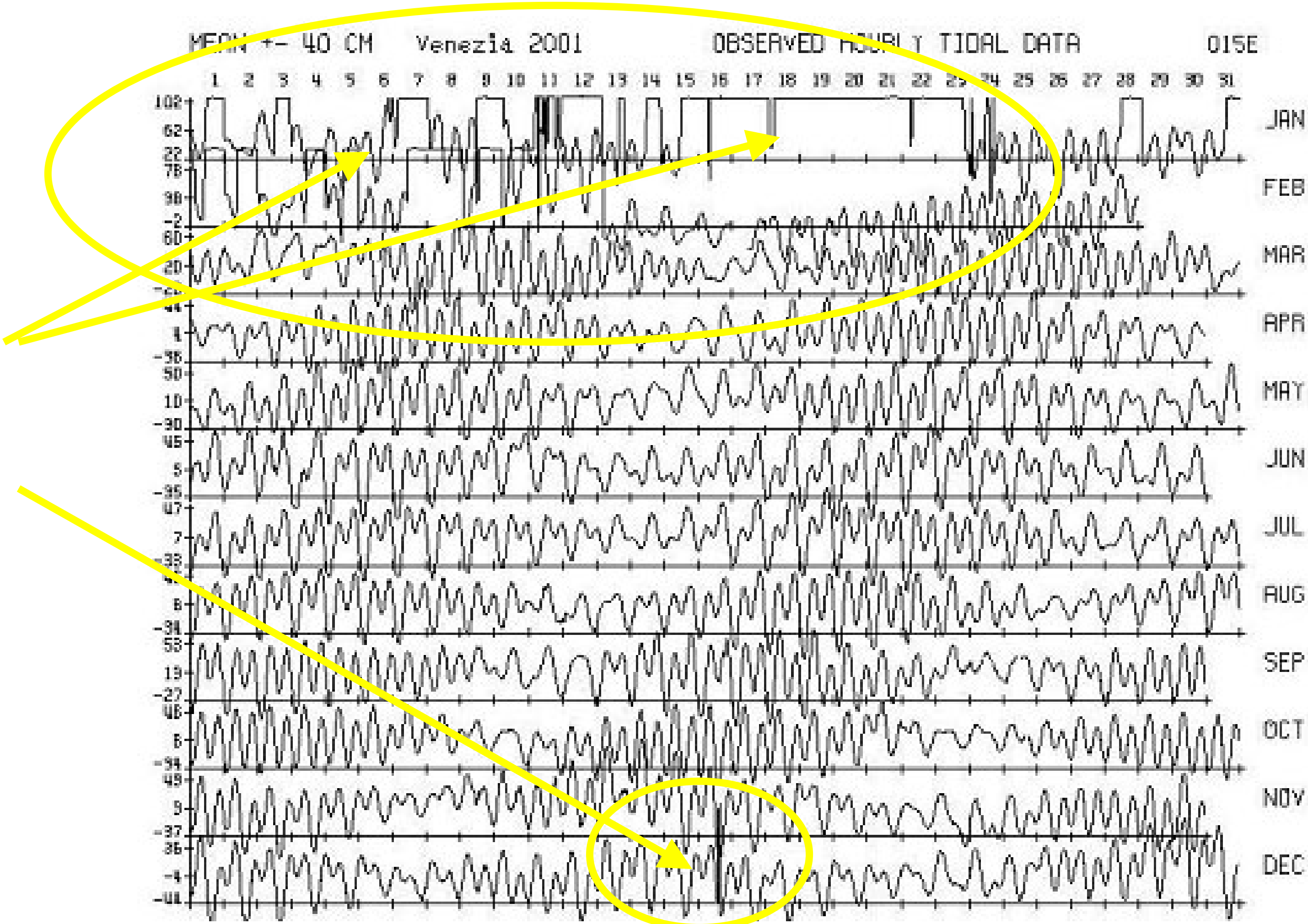
- Analysis of Data/Time Format
- Gaps and missing values
- Out of range data
- Spikes
- Constant values
- Suspicious Values
- Filtering

# Data Reduction

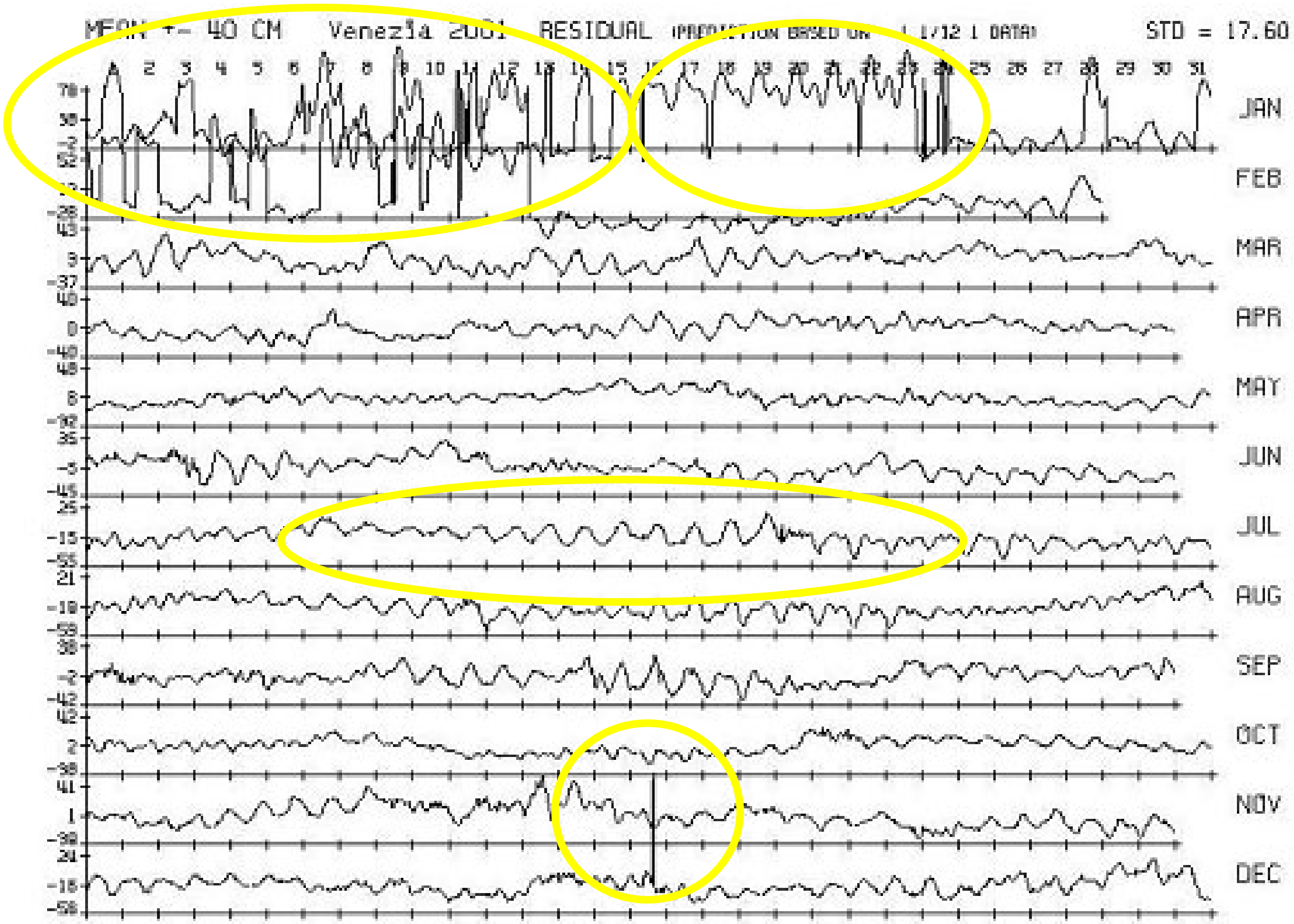
## Quality Control Check



# Tidal Data Analysis



# Tidal Residuals



# Tidal Residuals