Harbour resonance
Under long bound waves attack

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UNIVERSITÀ DEGLI STUDI

Layout of the presentation

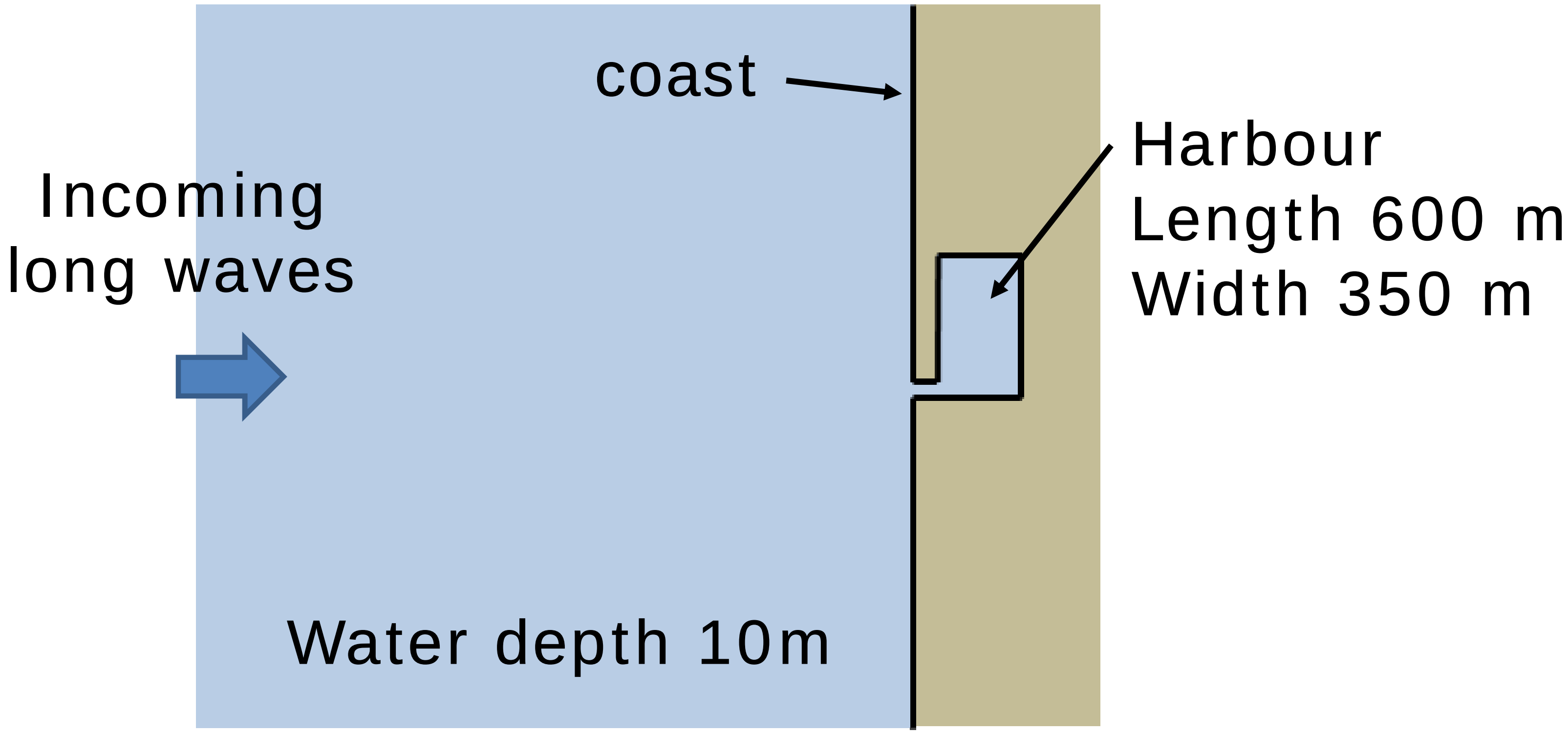
- Harbour resonance
- Long waves
- Study case: the Marina di Carrara harbour
- Numerical modelling of harbour resonance (two methods)
- Conclusions

Sheltering from short (wind) waves

Harbour resonance

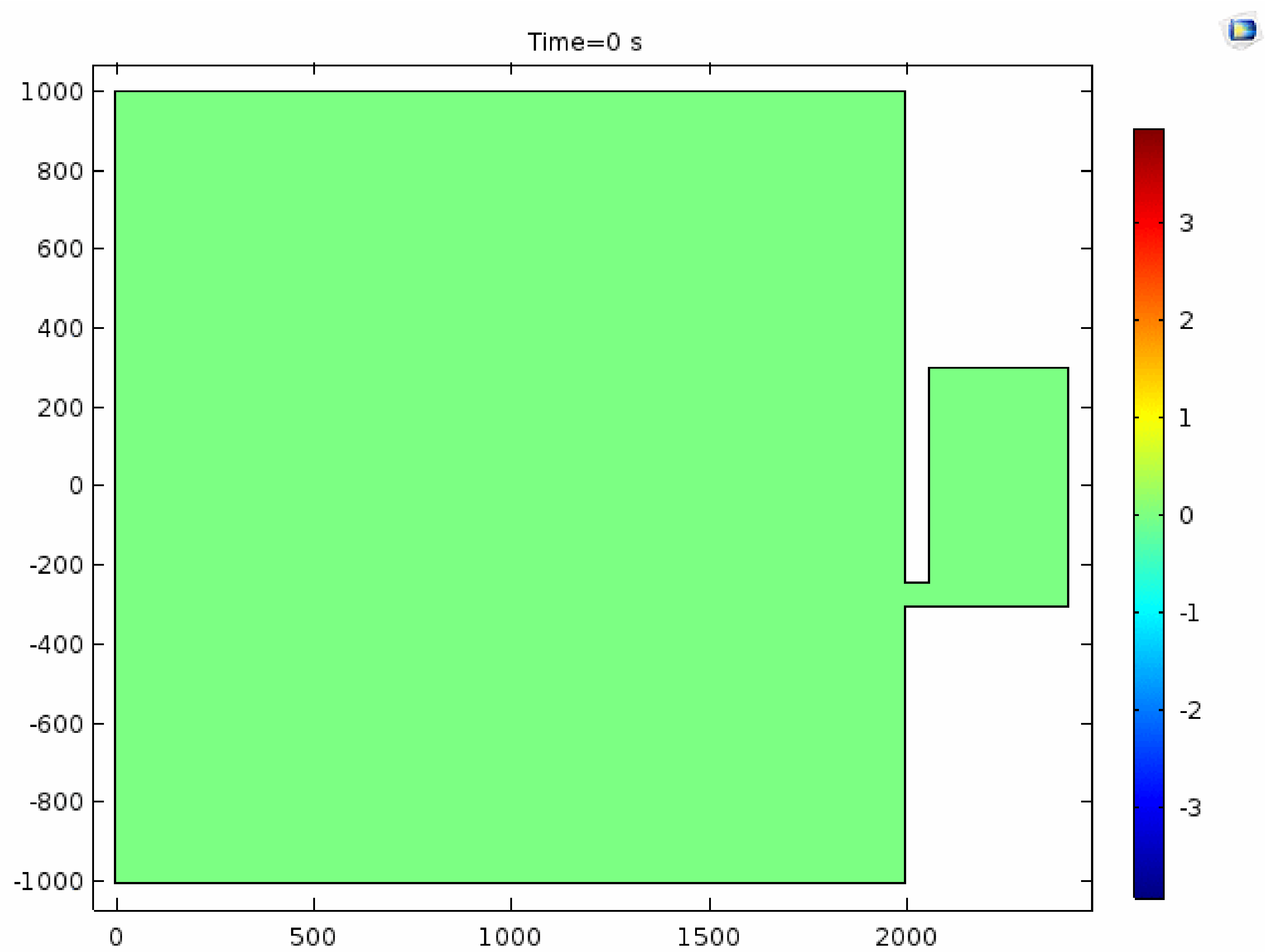
Two example computations: a simple rectangular harbour with entrance at a fully reflective coast. Two long waves periods (T) are selected, representing:

- Resonant condition (T=69.6638 s)
- Non resonant condition (T=80.0000 s)



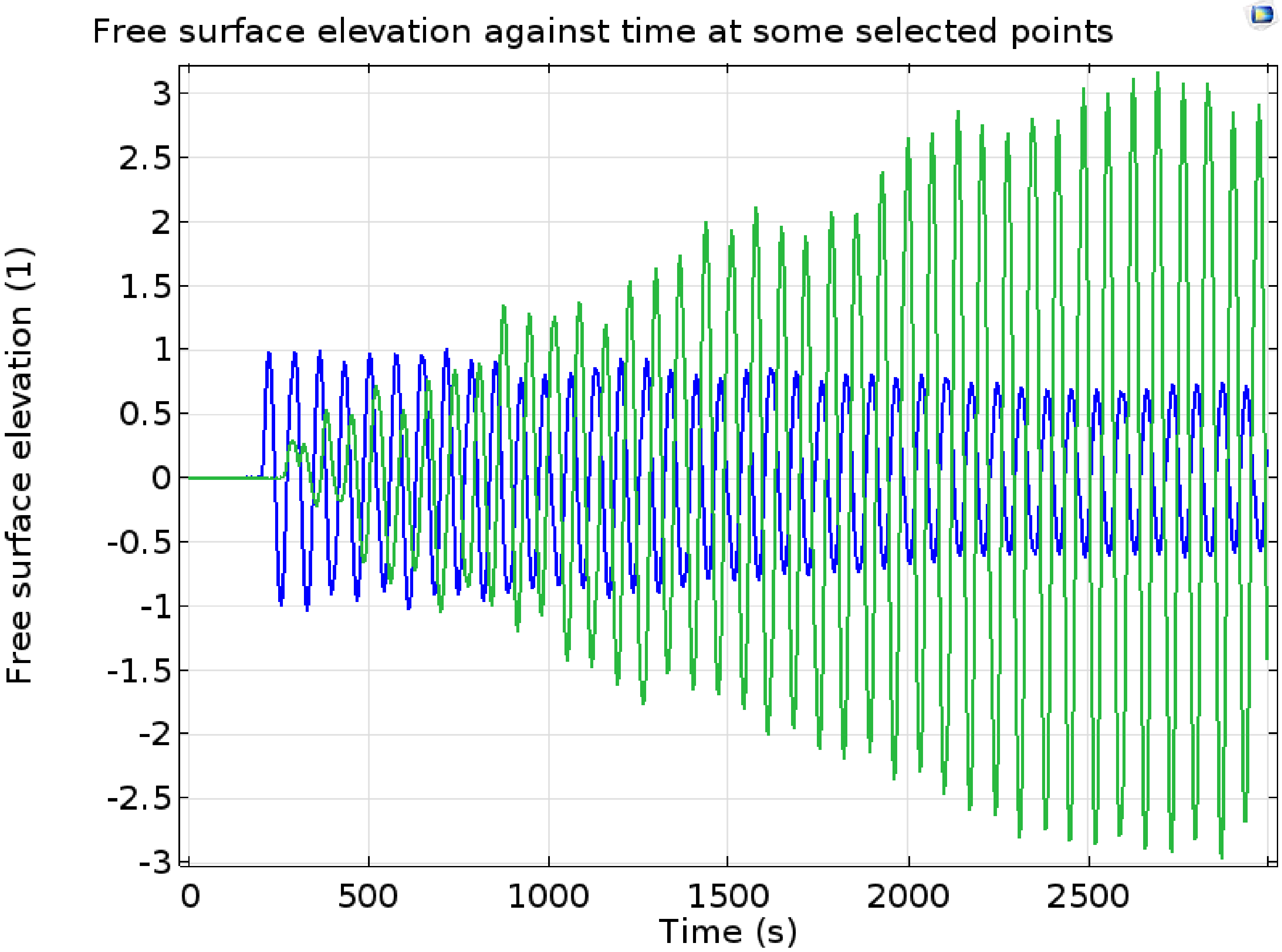
Harbour resonance

Resonant condition (T=69.6638 s)



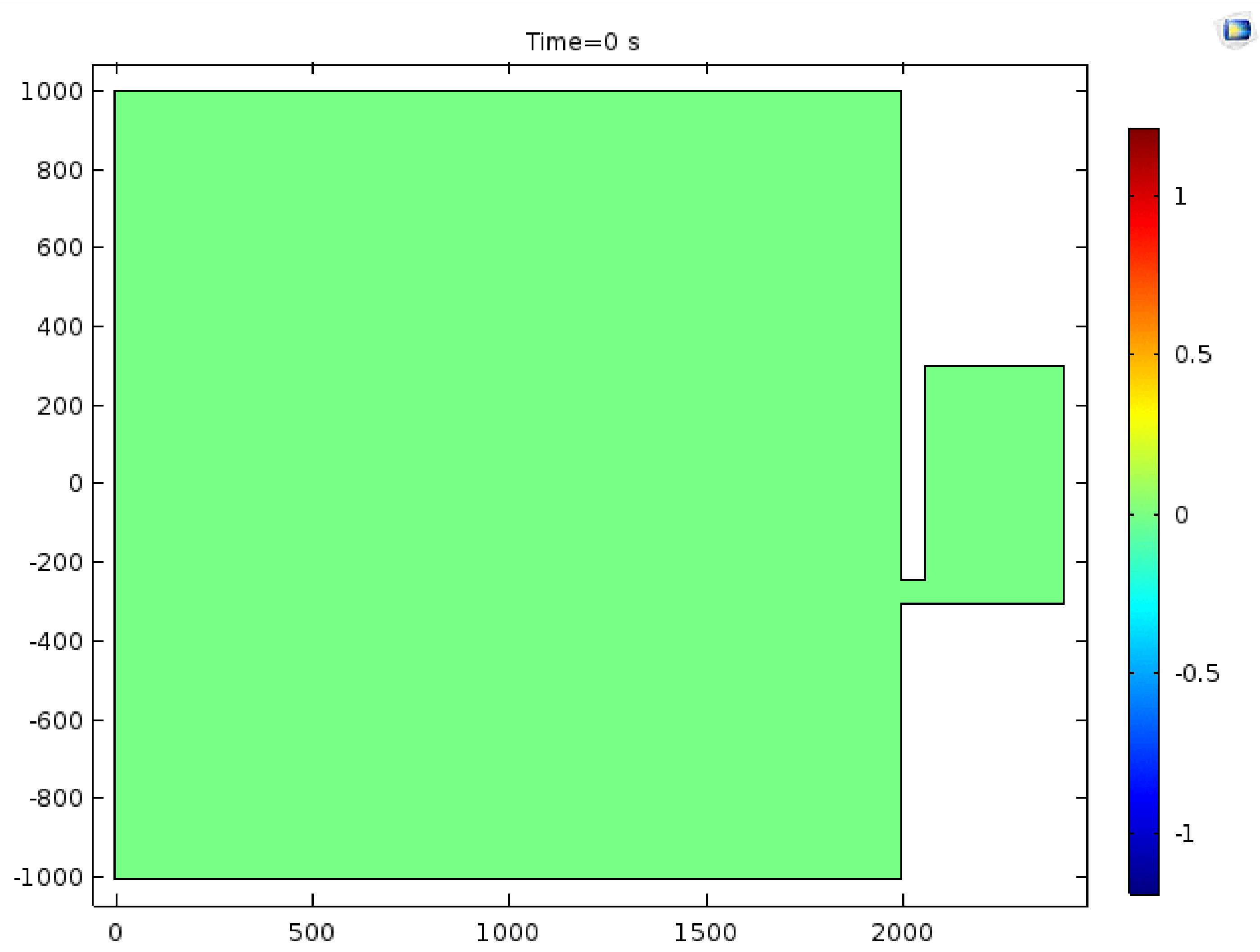
Harbour resonance

Resonant condition (T=69.6638 s)



Harbour resonance

Non resonant condition (T=80 s)



Harbour resonance

When the length of the incoming long waves is similar to the length of the waves ‘trapped’ inside the harbour, i.e. to the natural modes of free surface oscillation.

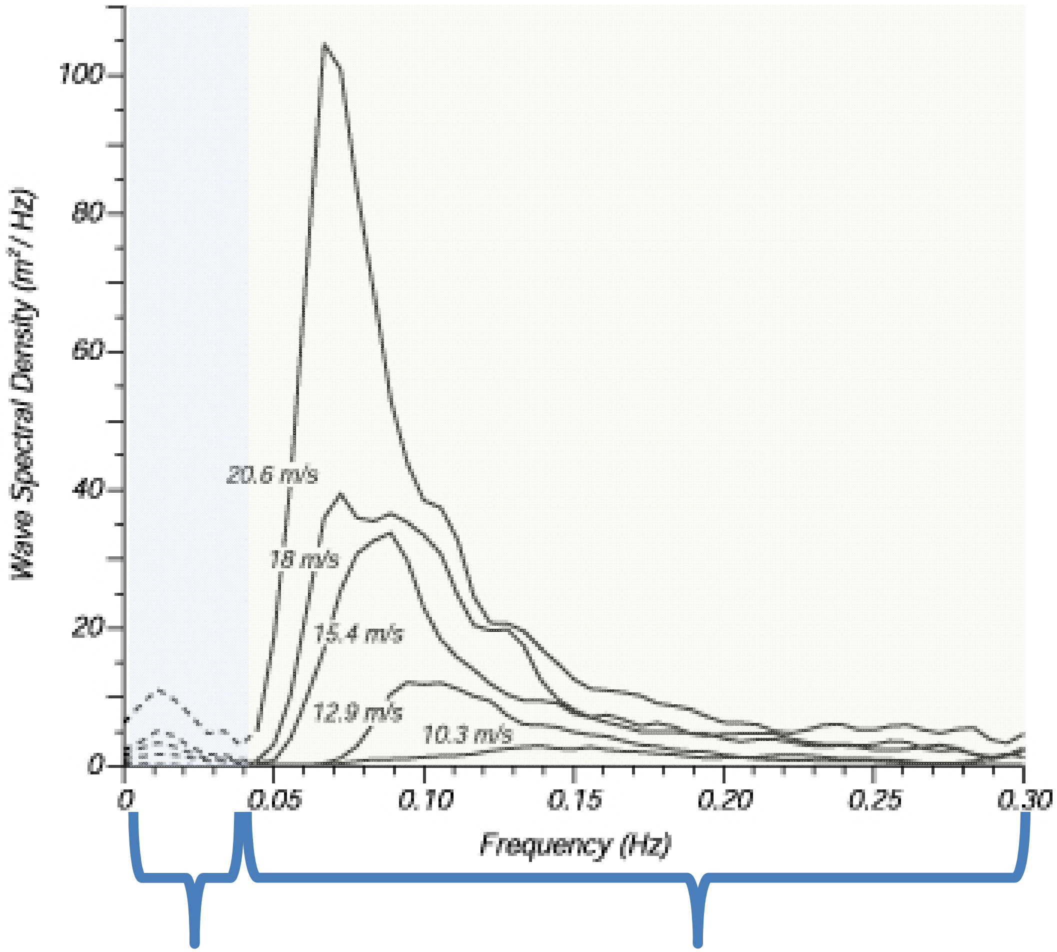
Under these conditions the long waves energy accumulates (is trapped) inside the harbour, leading to large free surface oscillations.

This does not happen with short waves, as their length and period are much smaller than the natural ones of typical harbours.

Long waves, where they come from?

They are generated by nonlinear effects when short waves become large and steep.

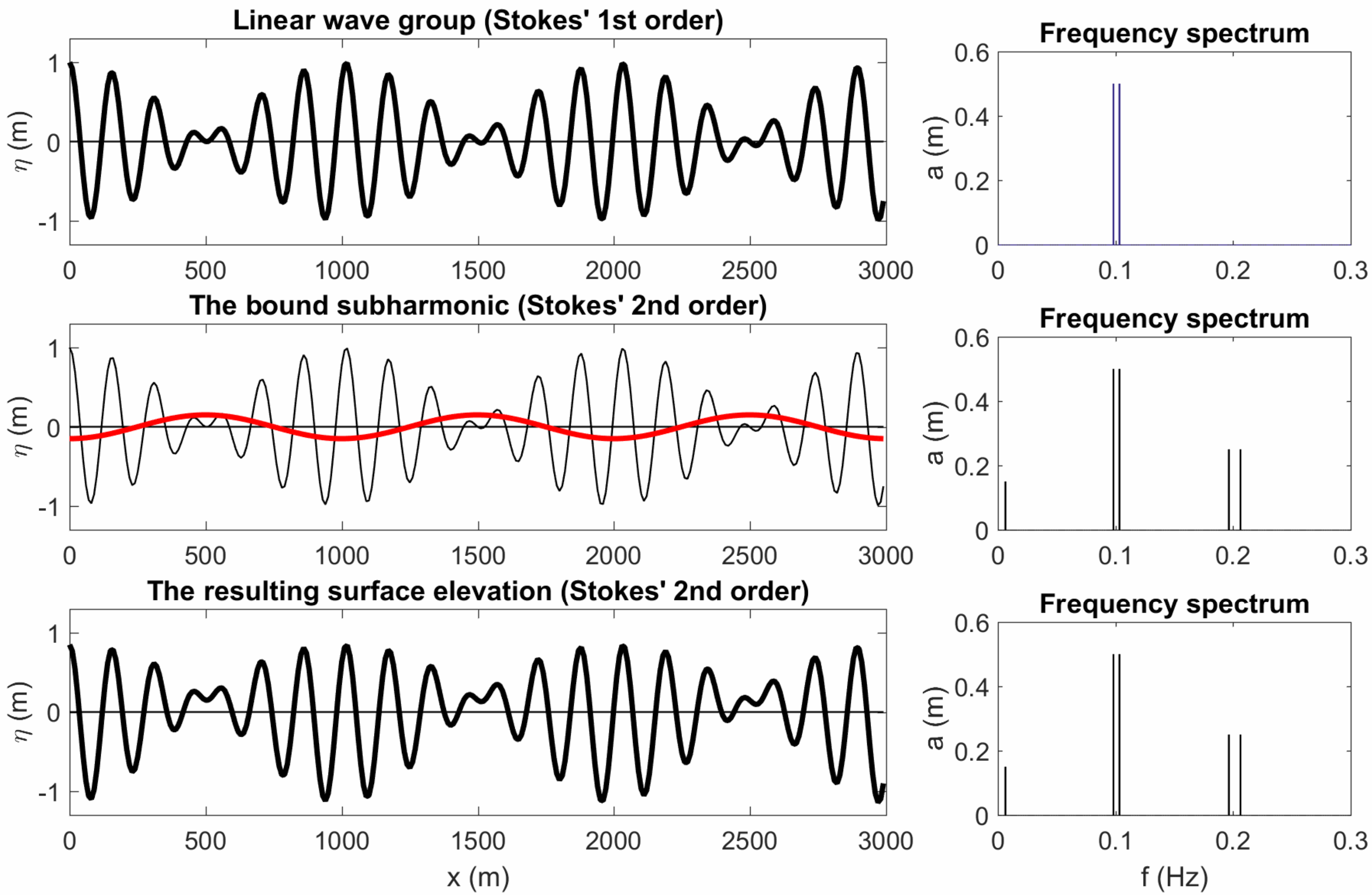
Also in the surf zone the breaking of wave groups can generate long waves, i.e. surf beats.



Long (infragravity) waves

Short (wind) waves and swell

Long waves generated by nonlinear interactions



This is an example of LONG bound wave

Long waves generated by nonlinear interactions

- Many sources of data are available for short waves (buoys, satellites, hindcast database)
- No measurement networks for long waves...
- The long waves properties are to be calculated from the short waves
- Need of calculation methods/models

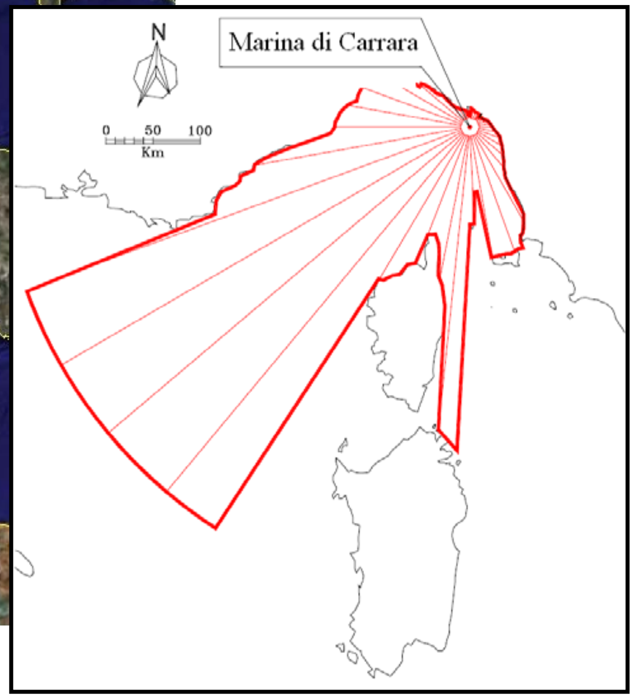
Harbour resonance and long waves

- Long waves are generated by short (wind) waves as they approach to the coast
- Long waves, T=O(100-1000s) can resonate into harbours
- The long waves amplification can lead to harbour operational problems: large oscillations of the moored ships, large forces (breaking) in the mooring lines
- <u>To be carefully addressed during the (first stages of the) design and the management of harbours</u>

Study case: the Marina di Carrara harbour

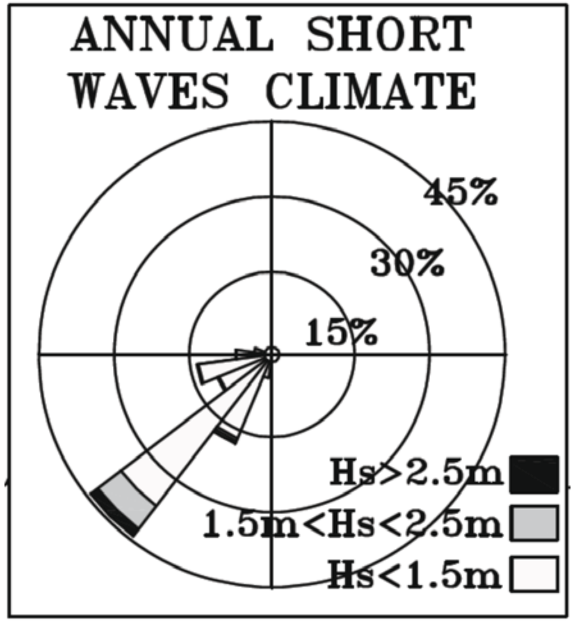
Study case: the Marina di Carrara harbour

The site is mainly exposed from S-SW waves

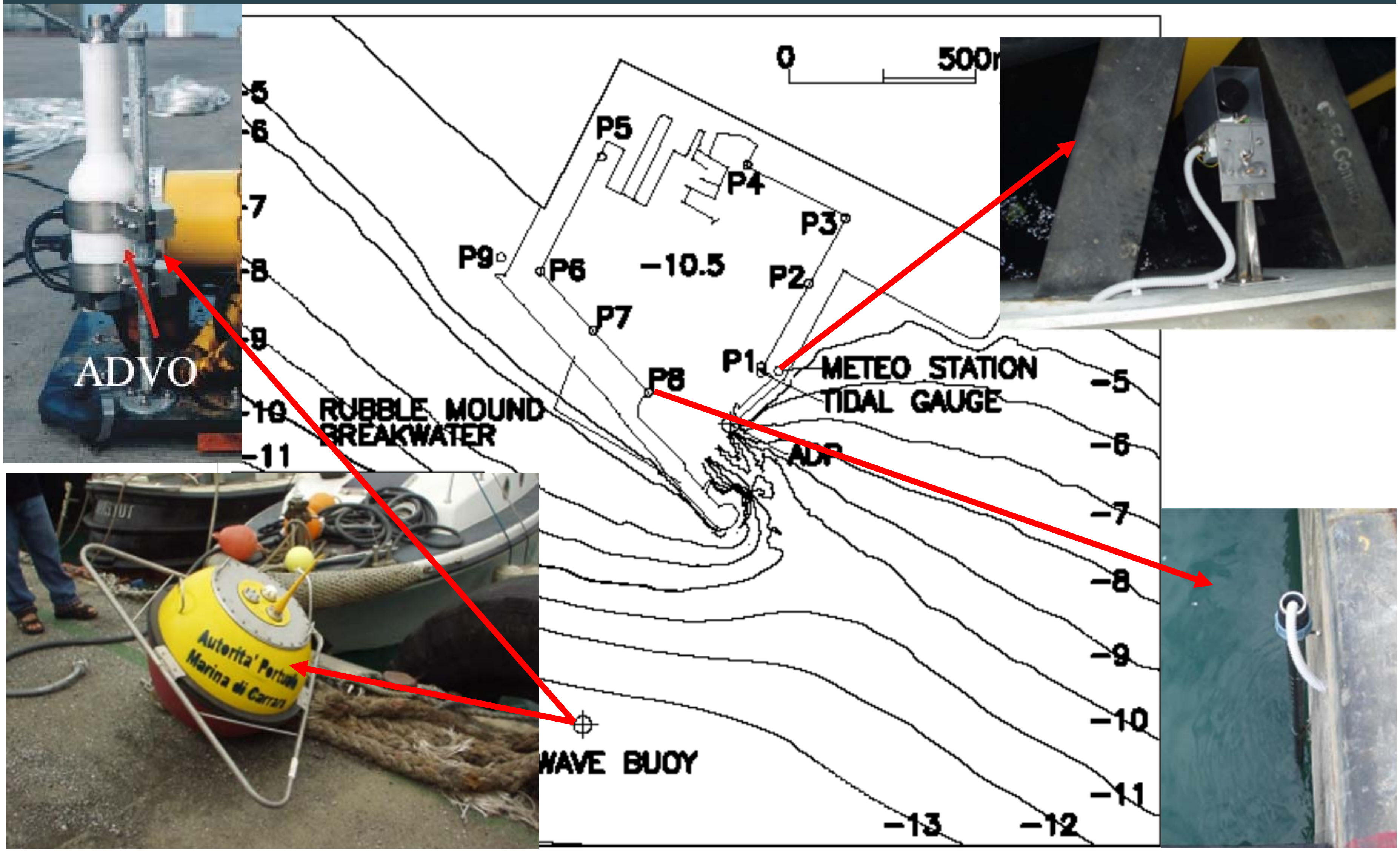


Study case: the Marina di Carrara harbour

The harbor has a rectangular plan-shape with a total surface of 362.000m^2, a water depth of 10.5m in the dredged basin and a total quay length of 1.650m.



The long waves measurements at the Marina di Carrara harbor



The long waves measurements at the Marina di Carrara harbor

SHORT waves climate in percentage of available measurements outside the harbor

Dec 2005->Oct 2008

H_{m0} range	0-0.5	0.5-1.0	1.0-1.5	1.5-2.0	2.0-2.5	2.5-3.0	3.0-3.5	3.5-4.0	4.0-4.5	>4.5
$2< T_p \leq 2.5$	1.6	-	-	-	-	-	-	-	-	-
$2.5< T_p \leq 3$	10.4	0.3	-	-	-	-	-	-	-	-
$3<T_p \leq 3.5$	18.8	2.3	-	-	-	-	-	-	-	-
$3.5<T_p \leq 4$	12.6	3.9	0.3	-	-	-	-	-	-	-
$4<T_p \leq 4.5$	6.6	4.8	1.6	0.2	-	-	-	-	-	-
$4.5<T_p \leq 5$	4.6	3.8	2.5	1.0	-	-	-	-	-	-
$5<T_p \leq 5.5$	2.1	2.6	2.2	1.2	0.3	-	-	-	-	-
$5.5<T_p \leq 6$	1.2	2.2	**1.4**	**1.1**	**0.9**	**0.2**	-	-	-	-
$6<T_p \leq 6.5$	0.3	1.2	**1.0**	**0.6**	**0.6**	**0.5**	**0.2**	-	-	-
$6.5<T_p \leq 7$	0.1	0.5	**0.5**	**0.5**	**0.4**	**0.3**	**0.3**	**0.1**	-	-
$7<T_p \leq 7.5$	-	0.2	**0.2**	**0.2**	**0.2**	**0.1**	**0.1**	**0.2**	**0.2**	-
$7.5<T_p \leq 8$	-	0.1	0.1	0.1	-	0.1	-	-	-	0.1

The long waves measurements at the Marina di Carrara harbor

The pressure gauges acquire 24h long bursts at 2 Hz.

Data have been further divided into 2 hours records and processed by separating:

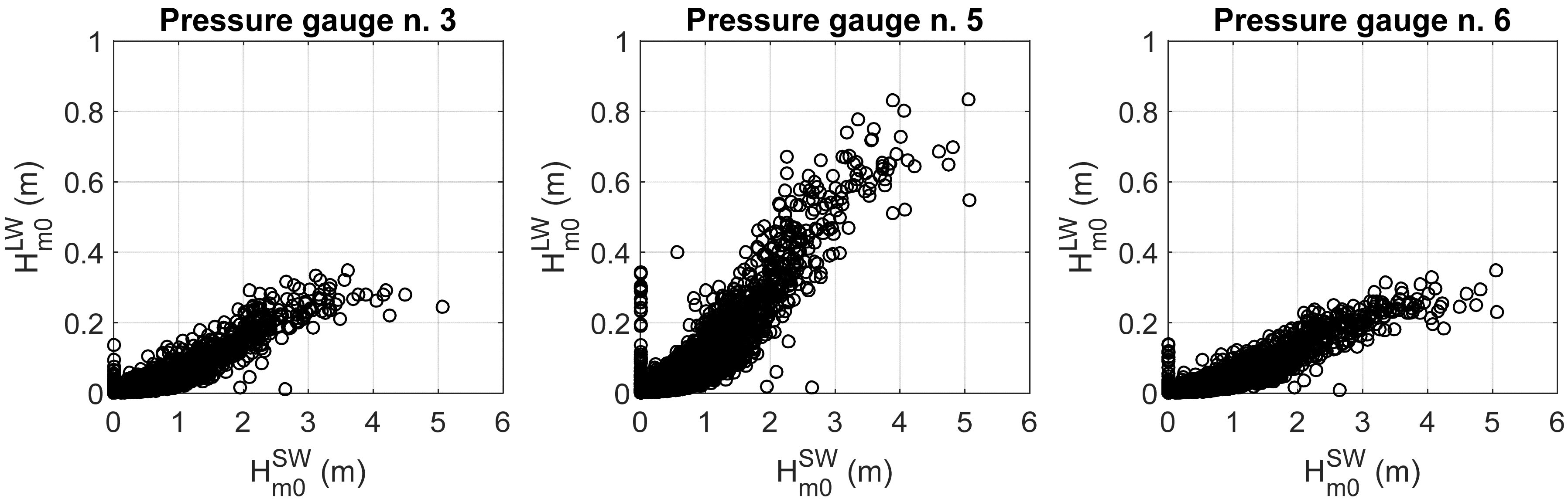
- very long waves (VLW), f < 0.003 Hz (T>333 s)
- long waves (LW), 0.003< f <0.030 Hz (33<T<333 s)

For each frequency band a significant wave height was calculated by integrating the energy density over the appropriate frequencies.

Result: bi-hourly time series of long waves (at the pressure gauges) and incoming short waves (at the buoy) for almost three years.

The long waves measurements at the Marina di Carrara harbor

Measured LW height against measured SW height



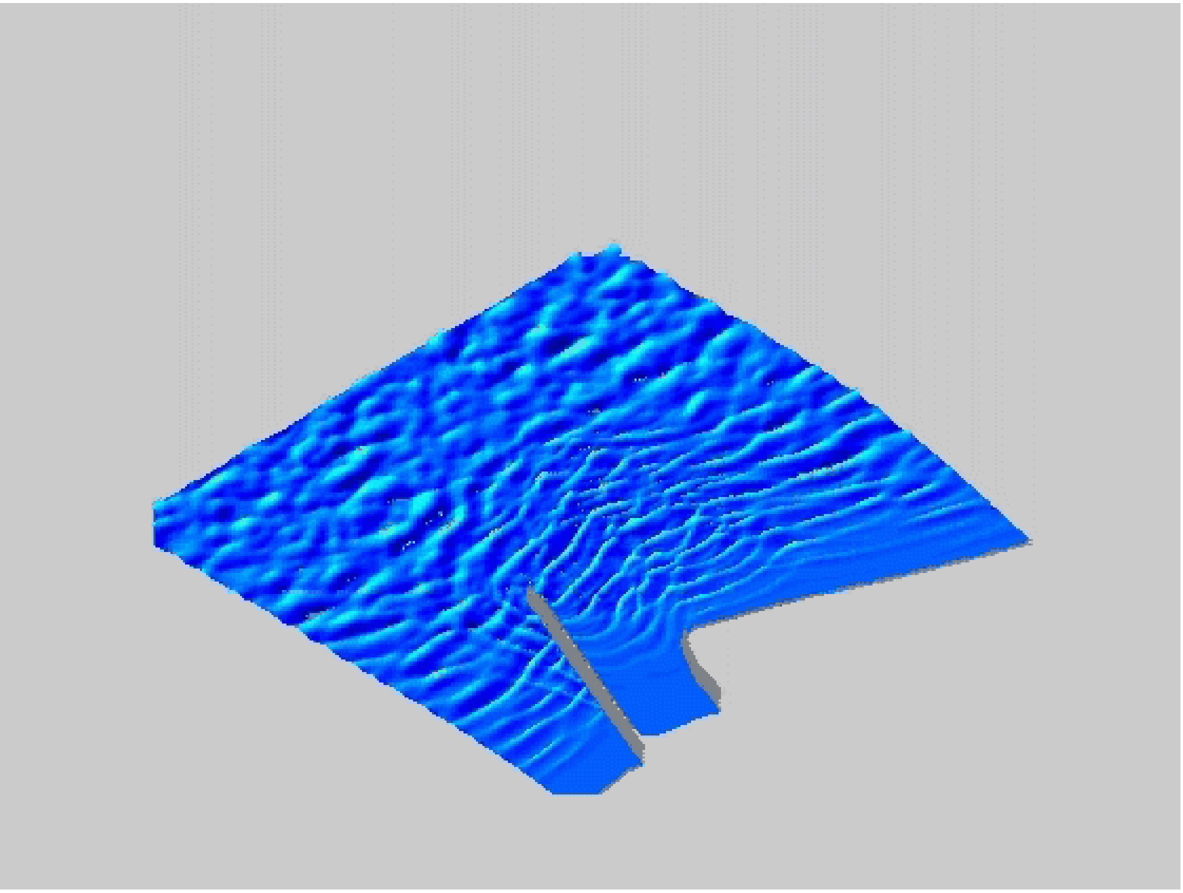
$$\frac{\text{LW height inside the harbour}}{\text{incoming SW height}} = 0.1 \div 0.2$$

Modelling harbour resonance with Boussinesq type model

BTE

Example result from Prof. Fengyan Shi (University of Delaware, USA)

http://www.coastal.udel.edu/~fyshi/



Modelling harbour resonance with Boussinesq type model

BTE

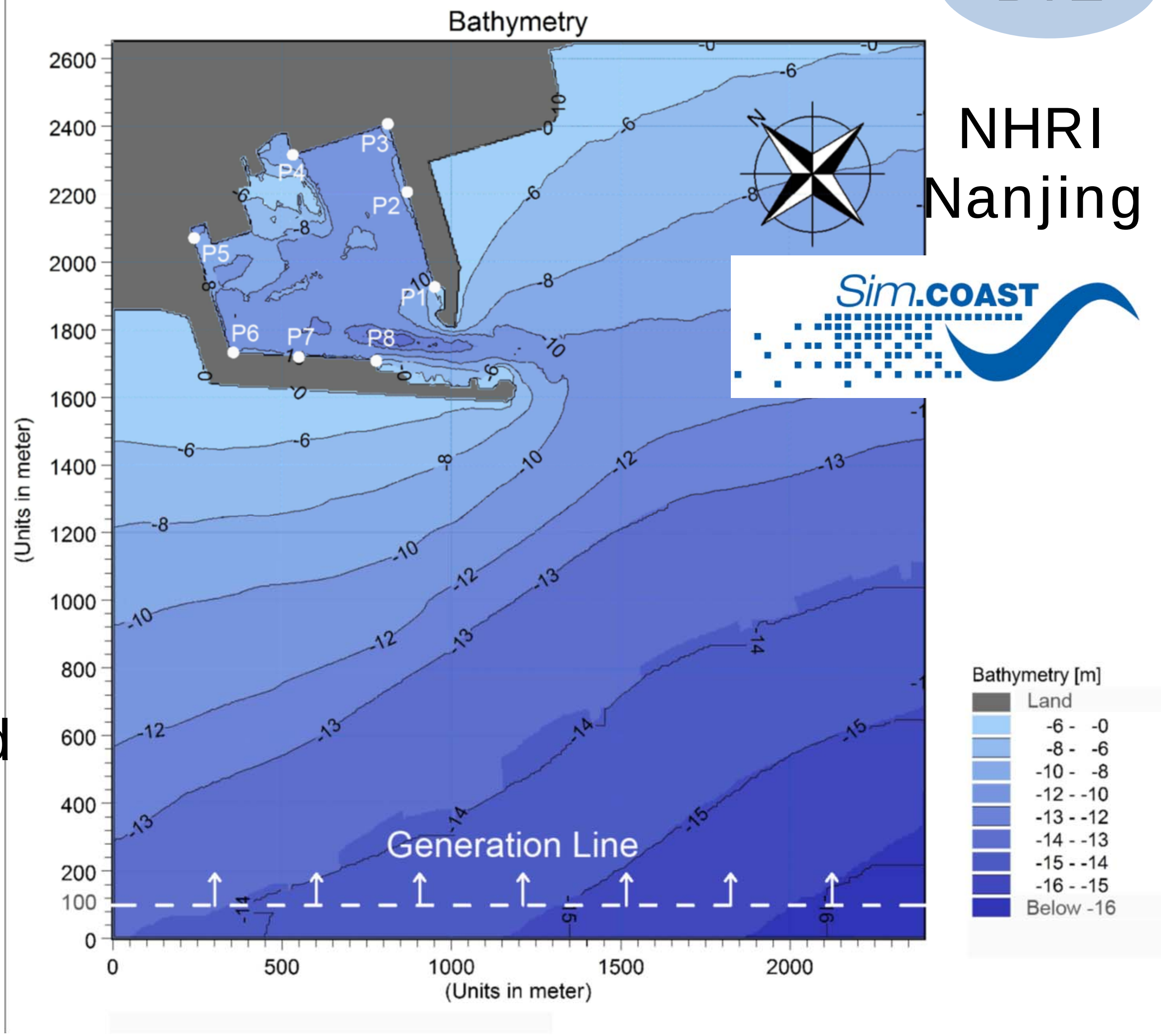
Nonlinear numerical models for short and long waves (Boussinesq Type Models)

- reproduce the short waves propagation considering the nonlinear effects: they also model the growth of the long waves.
- The penetration into harbours of both short and long waves is well reproduced including resonance.
- Drawback: high computational costs

Modelling harbour resonance with Boussinesq type model

BTE

- MIKE 21 DHI model has been applied
- Computational domain: 2395 m x 2650 m, dx=dy=5m
- Unidirectional random short waves generated at the SW boundary
- Long runs



NHRI Nanjing

Modelling harbour resonance with Boussinesq type model

BTE

Short waves climate outside the harbour

H_{m0} range	0-0.5	0.5-1.0	1.0-1.5	1.5-2.0	2.0-2.5	2.5-3.0	3.0-3.5	3.5-4.0	4.0-4.5	>4.5
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$7<T_p \leq 7.5$	-	0.2	**0.2**	**0.2**	**0.2**	**0.1**	**0.1**	**0.2**	**0.2**	-
$7.5<T_p \leq 8$	-	0.1	0.1	0.1	-	0.1	-	-	-	0.1

Only 22 selected sea states are reproduced

For each computation the LONG waves at the 8 pressure transducers is calculated

Modelling harbour resonance with the linear model (Mild Slope Equation)

MSE

- Linear models can be applied to predict the long waves amplification inside the harbour
- The LONG waves height can be predicted using the Bowers (1992) formula on the basis of the short waves properties

LONG WAVES Hs

$$LWH_{s_i} = k\frac{H_s^{\alpha} T_p^{\beta}}{d^{\gamma}},$$

SHORT WAVES significant wave height

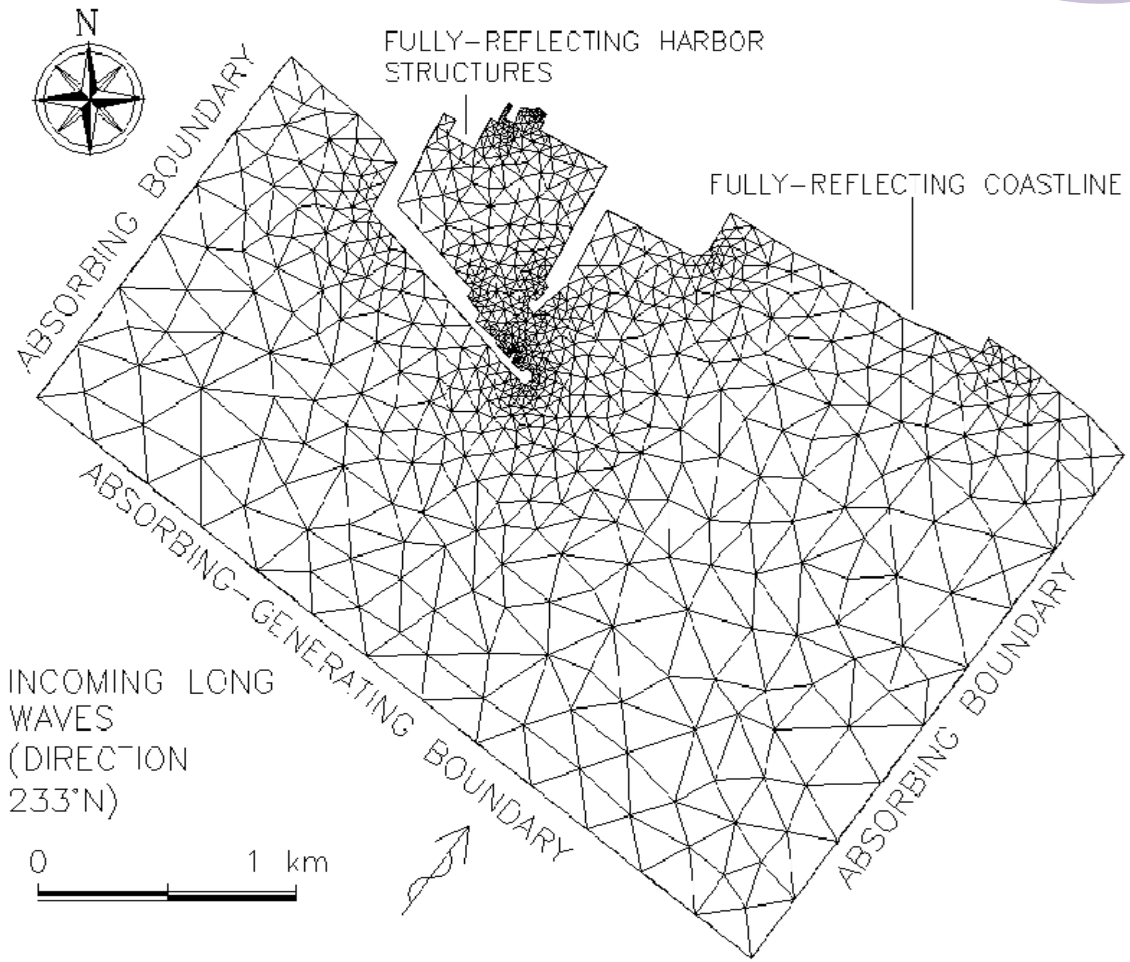
SHORT WAVES peak period

Water depth

Modelling harbour resonance with the linear model (Mild Slope Equation)

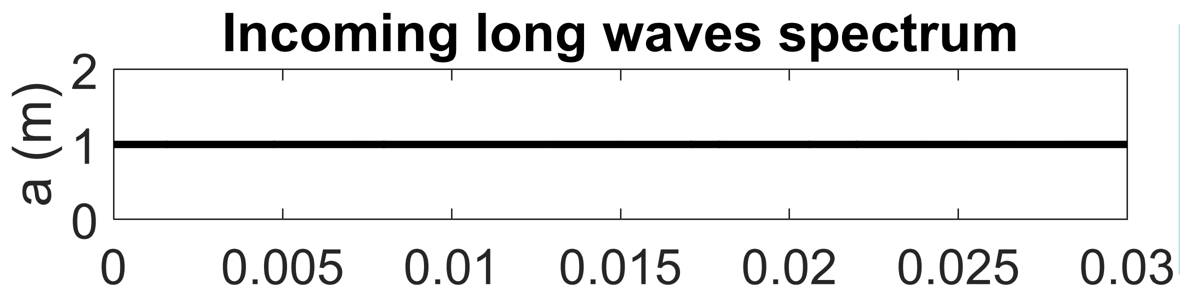
MSE

A linear MSE model is applied to reproduce the long waves propagation and amplification

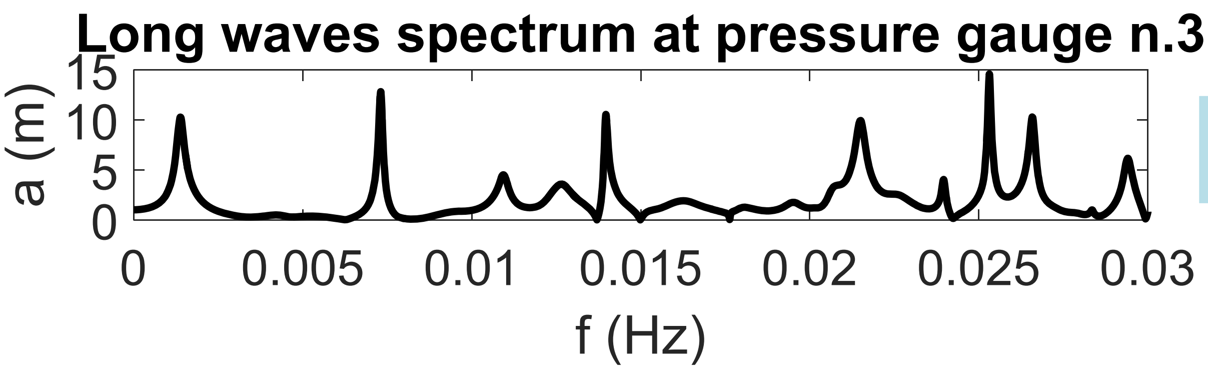


Modelling harbour resonance with the linear model (Mild Slope Equation)

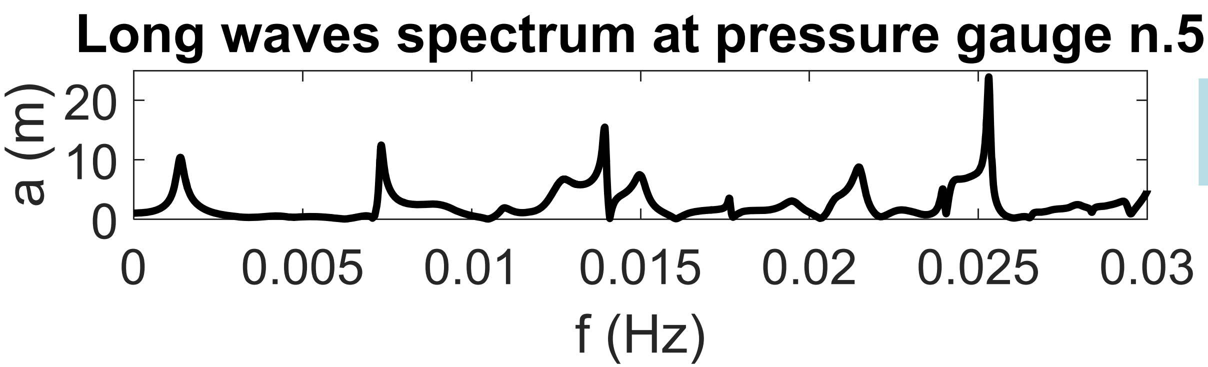
MSE



Average long wave amplification factors



2.12



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Measurement-modelling comparison

For each recorded sea state are available:

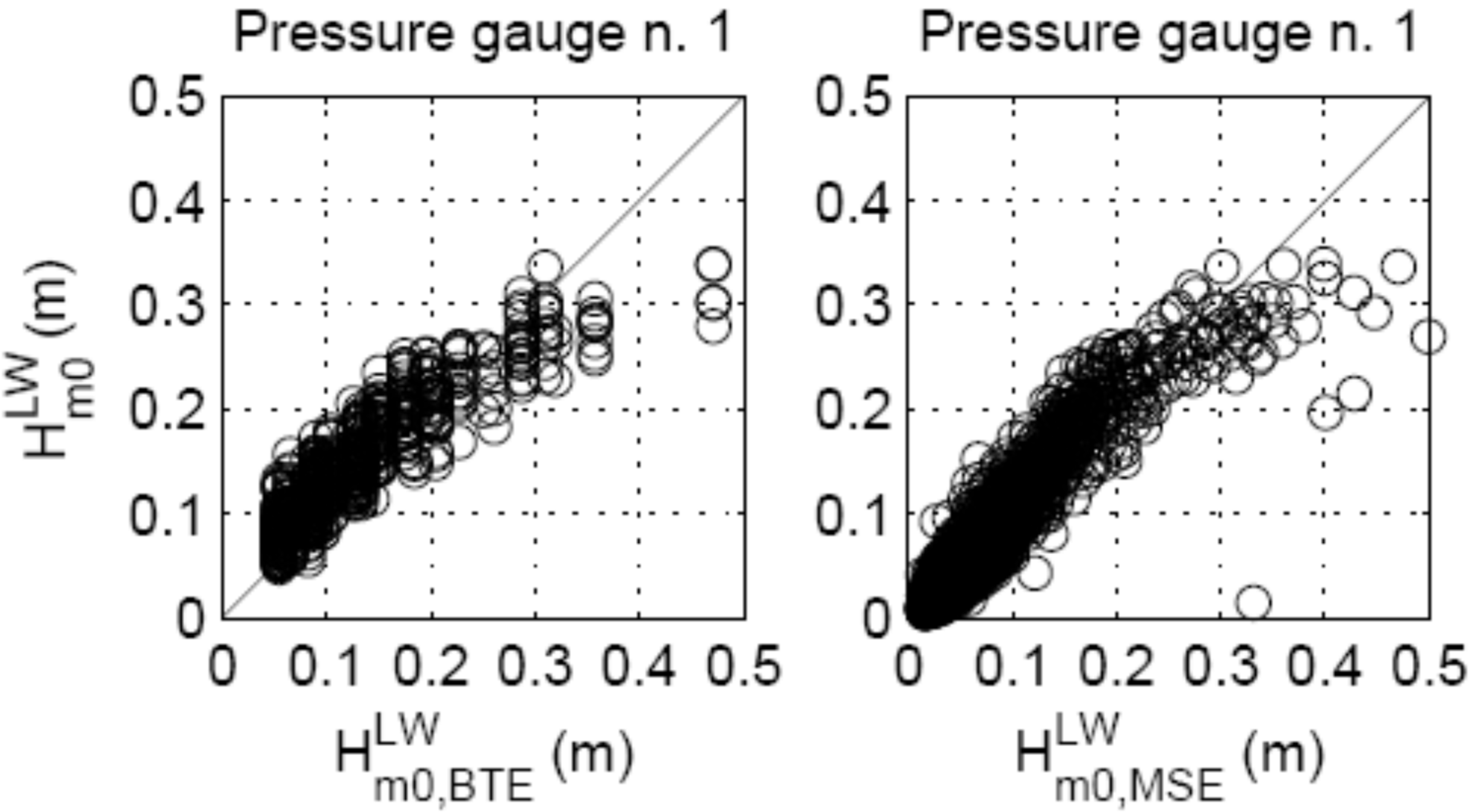
- The long waves height at the 8 pressure transducers (measurements)
- The long waves height at the 8 pressure transducers predicted by method 1 (BTE)
- The long waves height at the 8 pressure transducers predicted by method 2 (MSE)

Let us compare BTE and MSE results against measurements.

Measurement-modelling comparison

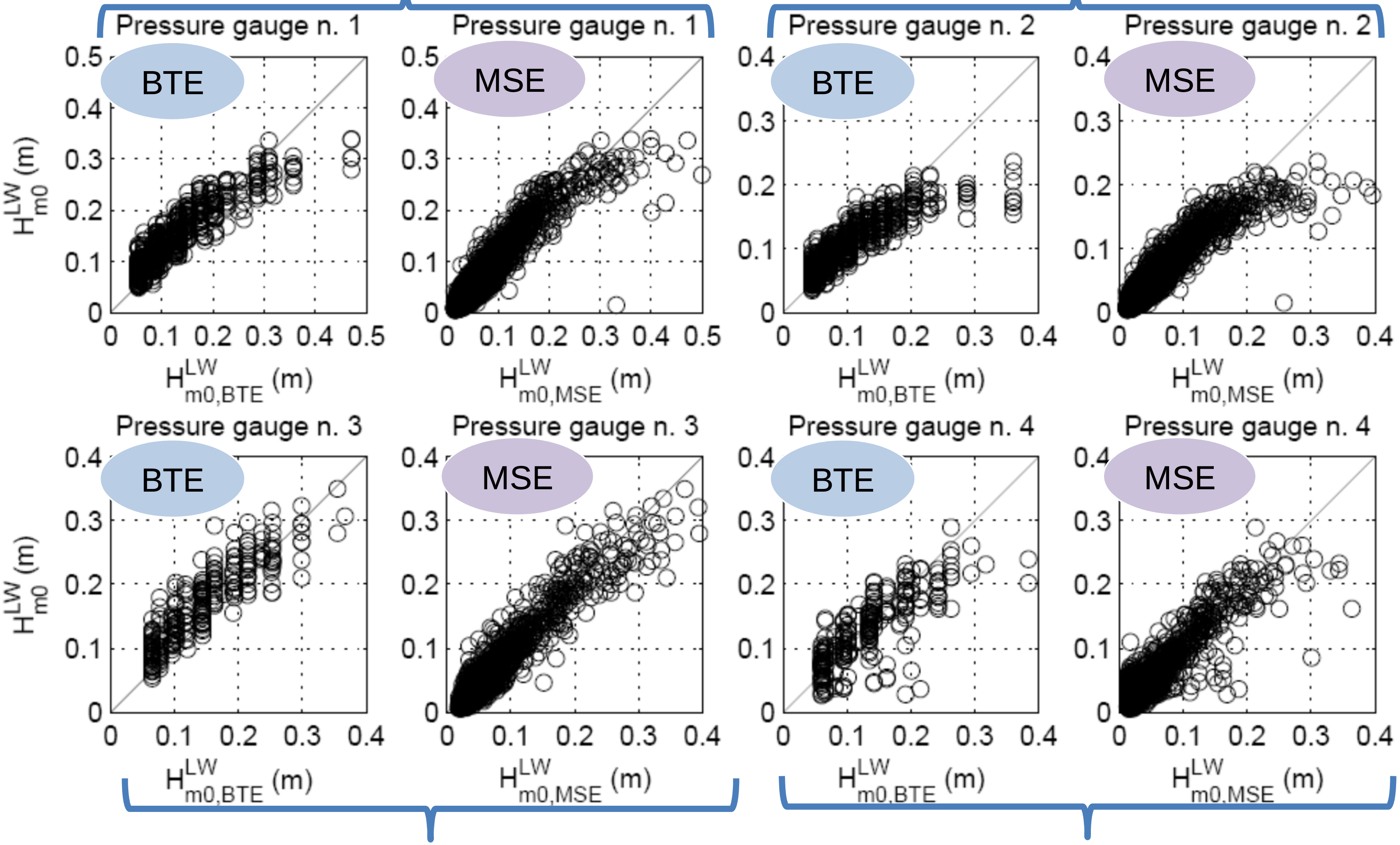
The Boussinesq Type model

The mild slope equation model



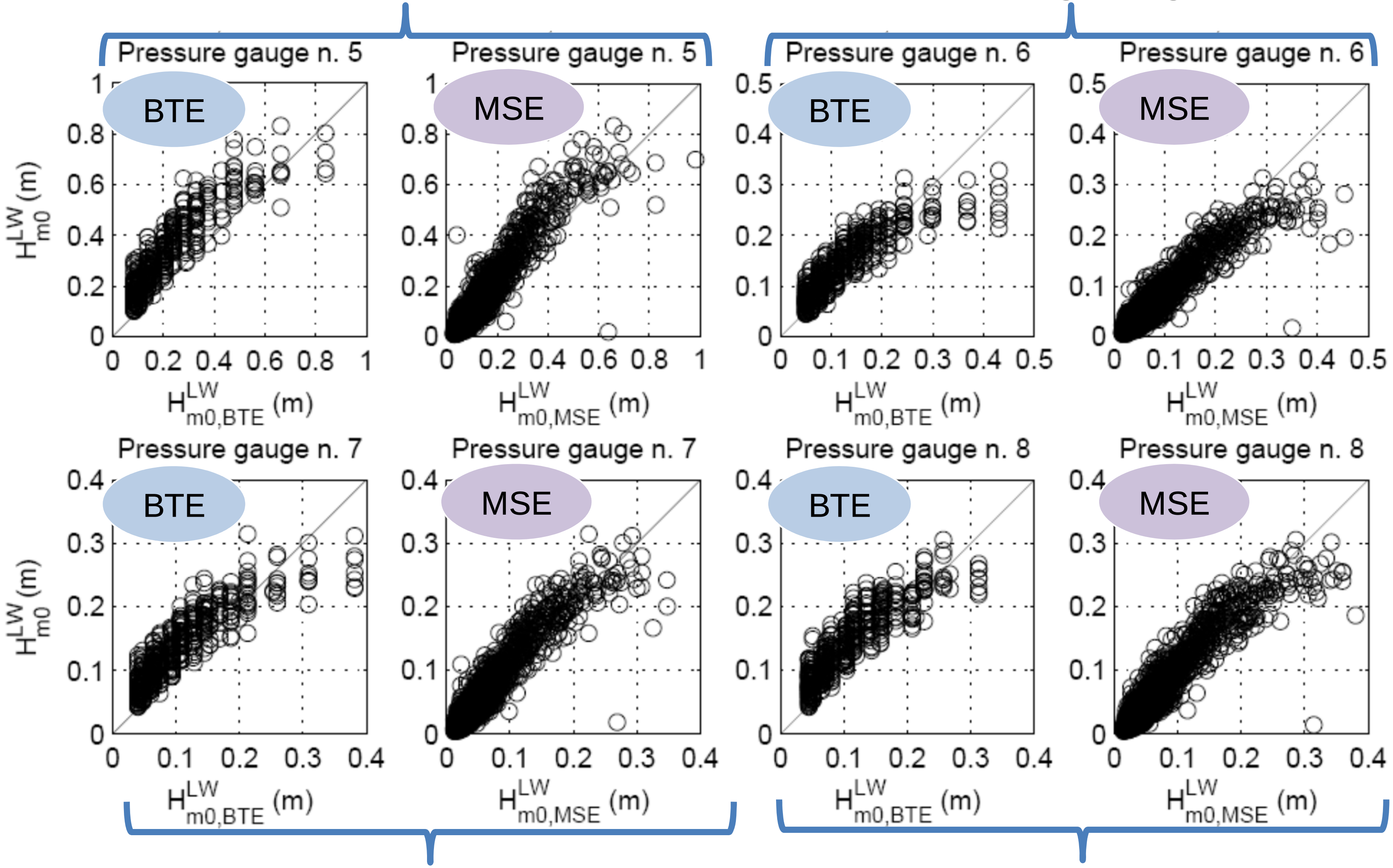
Measurement-modelling comparison

Pressure gauge n.1 Pressure gauge n.2



Measurement-modelling comparison

Pressure gauge n.5 Pressure gauge n.6



Conclusions

- Measurements of harbour resonance have been presented for the Marina di Carrara harbour
- Two alternative/complementary approaches for the numerical modelling of harbor resonance have been evaluated
- The BTE model has the advantage that a very detailed reproduction of the nearshore flows is obtained, but it is computationally demanding
- The MSE model is computationally cheap, but the incoming long waves must be specified apriori
- Harbour resonance can be very relevant and should be carefully addressed at all stages of engineering design, especially at early stages.