# *Sea Surface Mapping With GNSS*

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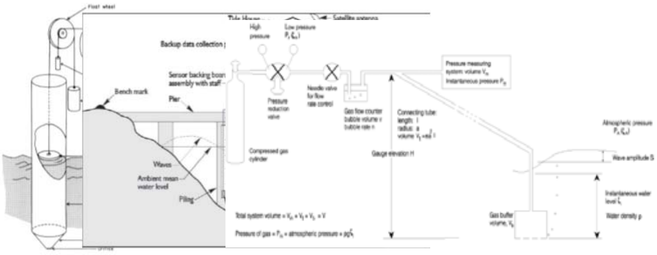
## Sea Surface Height - Background

- Sea surface height is constantly changing
- Great effect on life in coastal areas
- Today  measurements of the sea surface height mainly conducted by mareographs and satellite altimetry
- Results obtained with high accuracy, yet each method has its disadvantages

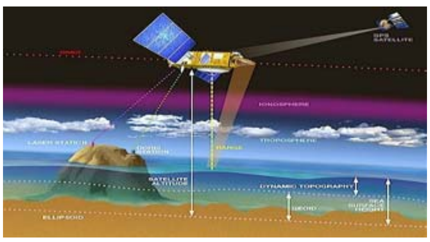
# Mareographs

- There are different types of mareographs
- Simple operation and data collection
- High accuracy
- Provides local measurements
- Collected data does not reflect the spatial reality of the sea surface height



# Satellite Altimetry

- Spatial coverage capability
- High accuracy



- Inferior performance in shallow and coastal areas
- Low resolution in time due to long repeat period of ground tracks

## What is the alternative?

A stand alone method for sea surface mapping

- Capable of spatial coverage
- Good performance in coastal areas and in open sea
- High accuracy results
- Available and does not require large logistical preparations

## How does it work?

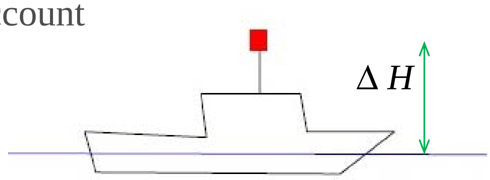
- Several GPS antennas should be placed on board a ship
- GPS measurements along a sailing route
- Data processing with PPP or with reference to a fixed station in order to receive ellipsoidal heights
- Applying corrections for the measured heights

## Factors affecting the measured height

- Antenna’s distance from the water level
- Ship’s attitude
- Squat effect
- Heave

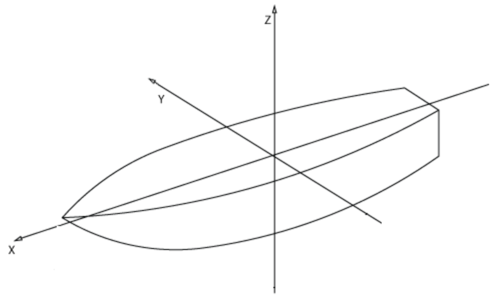
## Height reduction

- Initial observation of $\Delta H$ between antenna’s phase center and the waterline
- Reduction of the measured height by $\Delta H$ for each measuring epoch
- Hydrostatic and hydrodynamic changes of $\Delta H$ must be taken into account



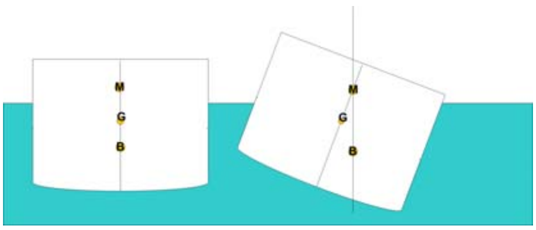
## Local reference frame determination

Height correction depends on antenna's position on the ship, therefore it is mandatory to define a local coordinate system



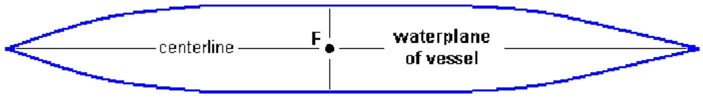

while ship's rotation center serving as the origin

## Center of rotation




- The metacenter is the center of the ship's spatial movement in the water
- While ship's inclination angels relatively small, the position of the metacenter does not change

# Center of floatation - LCF

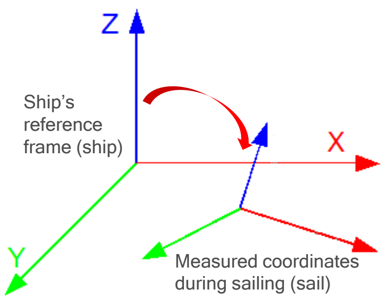



- LCF can be used as the center of the axes of rotation
- The center of the water plane area
- Positioned about half the ship's length along the longitudinal axis

# Inclination angles extraction

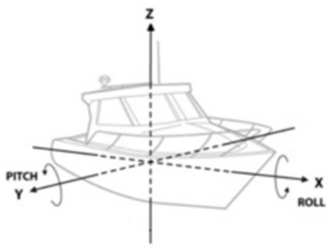
- Inclination angles calculated through a 3D transformation between antennas' position in the ship's reference frame and the coordinates obtained from the GPS measurements during sailing

$$\begin{bmatrix} x_{sail} \\ y_{sail} \\ z_{sail} \end{bmatrix} = \begin{bmatrix} dx \\ dy \\ dz \end{bmatrix} + k \cdot R \cdot \begin{bmatrix} X_{ship} \\ Y_{ship} \\ Z_{ship} \end{bmatrix}$$



# Height correction

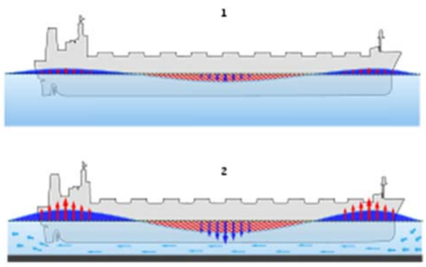
- Pitch is the rotation around the transverse axis and Roll is the rotation around the longitudinal axis
- The farther antenna's phase center from the rotation center, the greater the influence on the measured height
- To obtain the height correction we first multiply between the position vector and the rotation matrix then subtracting the height component from antenna's original height




$$\Delta H = Z_{ship} - (X_{ship}\sin(pitch) + Y_{ship}\sin(roll)\cos(pitch) + Z_{ship}\cos(roll)\cos(pitch))$$

# Squat

- Hydrodynamic phenomenon that causes the ship to be closer to the seabed than expected




- Depends on sailing speed and distance from the seabed
- Changes between various types of ships

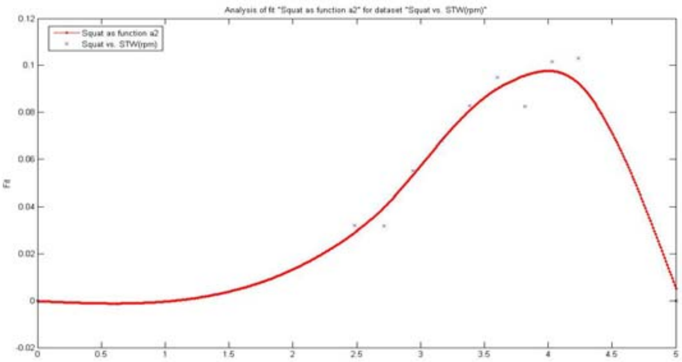
# Squat modeling

- There are several empirical function that allow approximate calculation of squat, made for use in large ships
- Using those function for squat estimation on a small boat will yield incorrect results
- The solution is to model the squat effect for the specific boat that is going to be used during survey

# Squat modeling (cont.)

- Sailing along a specific route several time in opposite directions while increasing the sailing speed gradually in order to neutralize the effect of the current on the ship's speed
- Obtaining ship's apparent draft change by calculating the height difference between the antenna and a reference station
- Using a dynamic reference station to neutralize the influence of the tide on the height difference

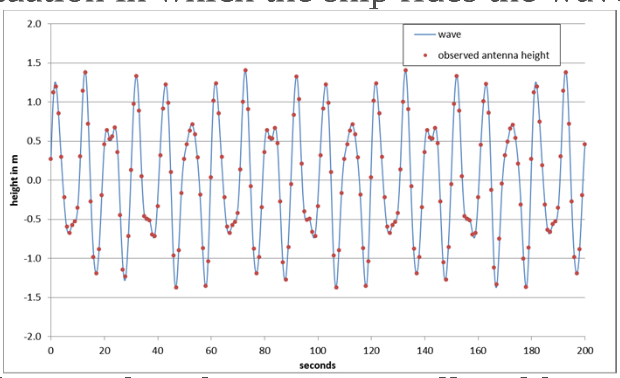
## Height correction for squat effect




- Curve fitting for the collected data
- Different curve for each antenna placed on board

## Heave

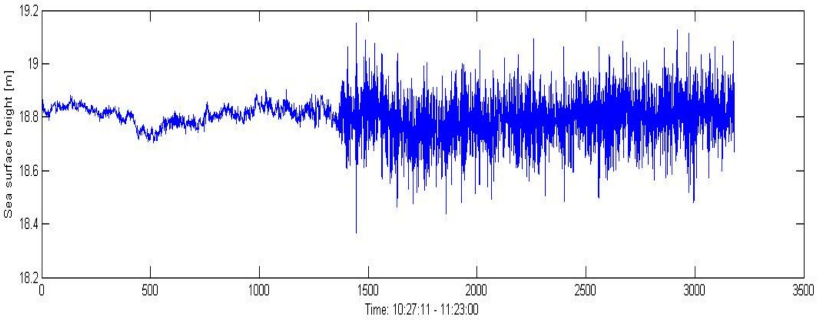
- A situation in which the ship rides the wave




- Neglecting this phenomenon will yield incorrect results

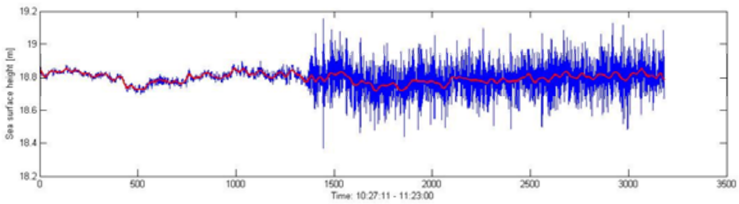
# Dealing with the heave effect

- Dealing with the phenomenon by filtering the data with a Low Pass Filter (LPF)

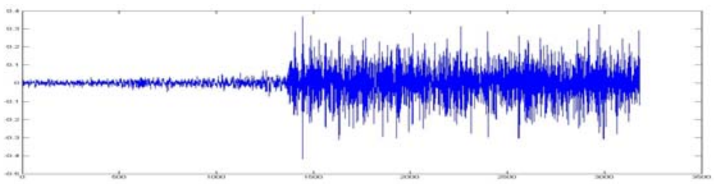



# Filtering results

- Data collected before and after filtering




- Height differences that were filtered out using LPF



## Error budget

- Accuracy of the resulting sea surface height is calculated through error propagation

$$m_f^{\,2} = \sum_{i=1}^{n} \left( \frac{\partial f}{\partial x_i} \right)^2 \cdot m_i^{\,2}$$

- Each height correction component contributes is error to the final result

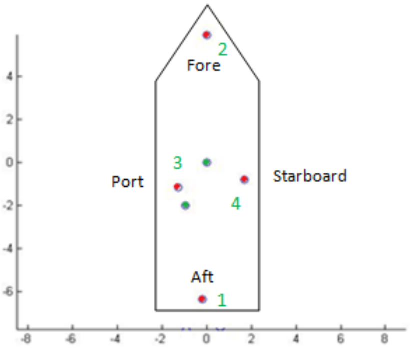
## The experiment

- The vessel chosen to carry out the experiment, the “Etziona”

- The buoy serving as a dynamic reference station

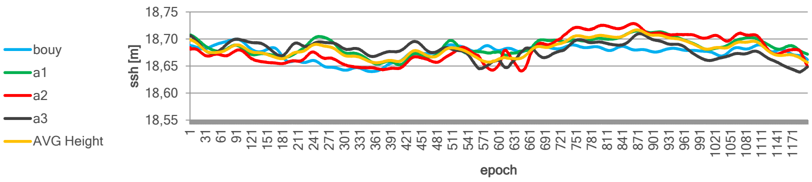
# The experiment

- Four antennas were placed on board (marked with red dots)
- In green marked the points which location in the ship's coordinate system are known
- Their location in ship's reference frame calculated based on Total Station measurements

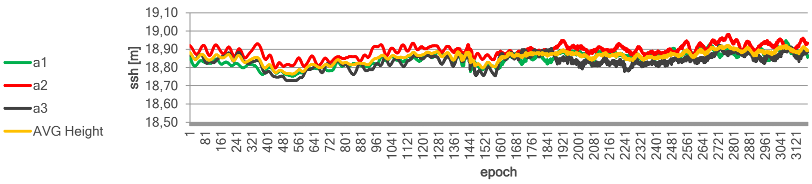



# Final results

- Calculated sea surface height while mooring

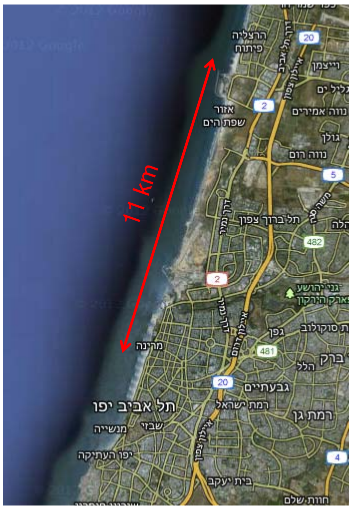



- Calculated sea surface height while sailing



# Final results

- Using the data from the mareograph located in Tel-Aviv for comparison was not possible. The distance between both locations is approximately 11 km, assuming sea surface height is equal would be a mistake




# Final results

- Comparison with the GNSS buoy results during mooring, comparison with the averaged sea surface height from all three antennas during sailing

| Antenna | Standard deviation [m] | |
|---|---|---|
| | Sailing | Mooring |
| A1 | 0.027 | 0.015 |
| A2 | 0.024 | 0.018 |
| A3 | 0.032 | 0.017 |

# Conclusions

- Differences between results from different antennas were within the estimated accuracy
- Squat modeling during calm sea state, better antennas attachment and more accurate antenna's phase center measurements can improve the final results and accuracies
- The next step will be achieving spatial time dependent sea surface height representation by integrating several sailing profiles

THANK YOU