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Efficient, Safe and Sustainable Traffic at Sea

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Annotation

This document describes the Wave Height and Period Analysis Software solution called WHAPAS that is intended for shore side calculation of significant wave height in marine area where navigational buoys equipped with TelFiCon™ GSM/GPRS telematics units implementing 3-axial acceleration measurement are deployed. Explanation of the operating principles of the software components as well as results of testing conducted for buoy calibration and wave height calculation algorithm verification are provided.

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Wave Height and Period Analysis Software - WHAPAS

1 Introduction

1.1 Scope and purpose

This document describes the Wave Height and Period Analysis Software solution called WHAPAS, explaining the purpose, architecture, and functionality by software component. Description and results of the verification experiments performed in 2010 are provided.

The WHAPAS software system is intended for shore side calculation of significant wave height in the marine areas where navigational buoys equipped with TelFiCon™ GSM/GPRS telematics units implementing 3-axial acceleration measurement are deployed. WHAPAS calculates the wave heights based on the buoy acceleration data and individual parameters of equipment used (sensor calibration and buoy model) and stores them in a database or files. WHAPAS output data is pre-formatted to be utilised for provision of an e-Navigation service of broadcasting the calculated wave heights over the AIS shore side network using AIS M8 hydro-meteorological data messages. This requires application of an external software component developed by Cybernetica AS – AIS Router with Hydrometeorological Data Module.

Wave period is not analysed by the current implementation of WHAPAS.

The WHAPAS software was developed by Cybernetica AS in cooperation with the Estonian Maritime Administration and the Marine Systems Institute of the Tallinn University of Technology within the framework of the *Efficient, Safe and Sustainable Traffic at Sea (EfficienSea)* project that was part of the *Baltic Sea Region Programme 2007-2013*.

1.2 Background

Measurement of the significant wave height on the waterways with following timely provision of this information to the mariners is an important aspect of marine navigation safety while cost-efficient implementation of it is not an easy task. Dedicated wave height measurement equipment is expensive to procure and maintain while emerging satellite based methods are not expected to provide reasonable resolution neither in time nor in coastal area coverage. Marine weather stations are often deployed in locations where actual open sea wave parameters are influenced either by nearby structures or shallow water depth. Although the measurement of wave height using accelerometric sensors installed onboard regular navigational buoys results in a significant trade-off between precision of the results and additional power consumption of the remote system when compared to dedicated wave following buoys, it can provide usable estimation of sea states in near real time when data processing is performed at the server side. The main difference of the wave height measurement enabled by the TeViNSA / WHAPAS solution is utilisation of the existing infrastructure deployed for remote monitoring of visual aids to navigation and AIS message broadcasting with value adding functionality, without the need for additional investments into the existing hardware infrastructure. Resulting additional communication and energy costs are expected to remain insignificant in comparison with benefits from near real time in-situ wave height measurement.

1.3 Abbreviations used

Abbreviation	Explanation
AIS	Universal *Automatic Identification System* used for marine navigation safety related ship-to-ship, ship-to-shore and shore-to-ship digital communications based on the standard ITU-R M.1371
AtoN	*Aid to Navigation*; refers either to a marine visual aid to navigation site in general, or to a set of electro-optical systems of an AtoN outstation for provision of visual light signalling.
cron	Time based task activation application in Unix-like operating systems
DTD	*Document Type Definition;* description of an XML document
FFT	*Fast Fourier Transform*; an algorithm for calculation of spectra.
GPRS	*General Packet Radio Service;* a GSM cellular network service for TCP/IP based data communications
GSM	*Global System for Mobile Communication*; a digital radio communication network standard (900/1800 MHz in Europe)
HTTP	*Hypertext Transfer Protocol* is used for serving of digital content to standard web browsers (based on RFC-1945).
IPv4	*Internet Protocol version 4*; the current digital data exchange protocol with 32 bit addressing of hosts on the Internet.
JAR	*Java Archive;* a file format for compressing of several Java files into a single file.
Java	An object-oriented high-level computer programming language developed by Sun Microsystems
JVM	*Java Virtual Machine;* runtime environment for executing software applications created using Java
MSI	The *Marine Systems Institute* of the Tallinn University of Technology
SQL	*Structured Query Language*; standard format for performing data queries from relational databases.
TCP/IP	*Transmission Control Protocol/Internet Protocol* for reliable connection less digital packet data transmission used in the Internet (based on RFC 793)
TelFiCon	*Telematics Field Controller*; a GSM/GPRS/GPS based AtoN telematics hardware module developed and manufactured by Cybernetica AS
TeViNSA	*Telematics for Visual Navigation Situational Awareness*; a set of software and hardware components developed by Cybernetica AS for remote control and monitoring of remote AtoN site systems, measurement and broadcasting over AIS of relevant e-Navigation data

Abbreviation	Explanation
WHAPAS	*Wave Height And Period Analysis Software*

1.4 References

1. Telematics Controller Telficon E9261. Instructions for Use. Cybernetica AS, 9261.004

2. GPRS keskus. Tarkvara arhitektuur. Cybernetica AS, N-B76250-13

3. AIS Router – a module for routing AtoN-specific AIS messages M8, M12, M14 and M21. Cybernetica AS, Y-399-28

4. Hydrometeorological Data Module for AIS AtoN Router. Owner's Manual. Cybernetica AS, Y-399-44

2 System Summary

2.1 System Configuration

The WHAPAS system is intended for installation either on a single institutional server or a constellation of distributed servers for operation as an autonomous „back office“ application, requiring no user intervention unless re-configuration is needed. The software has practically no user interface, it analyzes the input data retrieved from a pre-configured source locations in the local area network, and places the calculation results to pre-configured locations for use by other applications.

The WHAPAS software is hardware independent; it was developed in Java SE 6 environment (by Sun Microsystems) and will run on all platforms supporting the corresponding runtime environments. For the purpose of guaranteeing high availability, it is recommended to run the core software component responsible for data analysis on a dedicated server hardware with GNU Linux compatible operating system since fast calculation of wave height from multiple sources can become resource demanding.

WHAPAS is supplied in a single Java Archive (JAR) file that contains all necessary components. The WHAPAS JAR file contains a tool called HSQL Database Manager (http://hsqldb.org/doc/guide/apf.html) that is intended for facilitating the work with the configuration database.

For meaningful use, in addition to TCP/IP network WHAPAS needs the following external infrastructure to be operational and properly configured:

- TeViNSA system software with AtoN equipment settings and operational information database;
- TelFiCon telematics units mounted on navigational buoys, regularly uploading buoy acceleration data to the TeViNSA server;
- AIS Router with Hydrometeorological Data Module and a functional shore side AIS network for broadcasting of M8 messages to the mariners.

Both input and output data of WHAPAS are in the form of files and database records. Due to the fact that WHAPAS operates practically in the background, outside of human operator's attention, it is recommended to establish automated monitoring of WHAPAS performance – specifically in case when AIS M8 broadcasts are activated. WHAPAS is equipped with plug-ins for integration with open source software for online computer network monitoring Nagios (http://www.nagios.org/).

2.2 WHAPAS Architecture

The WHAPAS (Wave Height And Period Analysis Software) software distribution consists of six separate software components that are operated either on a single server, or on several distributed computers:

- Three core software components responsible for retrieval of the input data from TeViNSA server, calculation of significant wave height, and exporting of the results in relevant formats;
- One external software component for the management of WHAPAS settings, working with a dedicated database;
- Two supporting software components for logging and synchronisation of WHAPAS settings with the TeViNSA database.

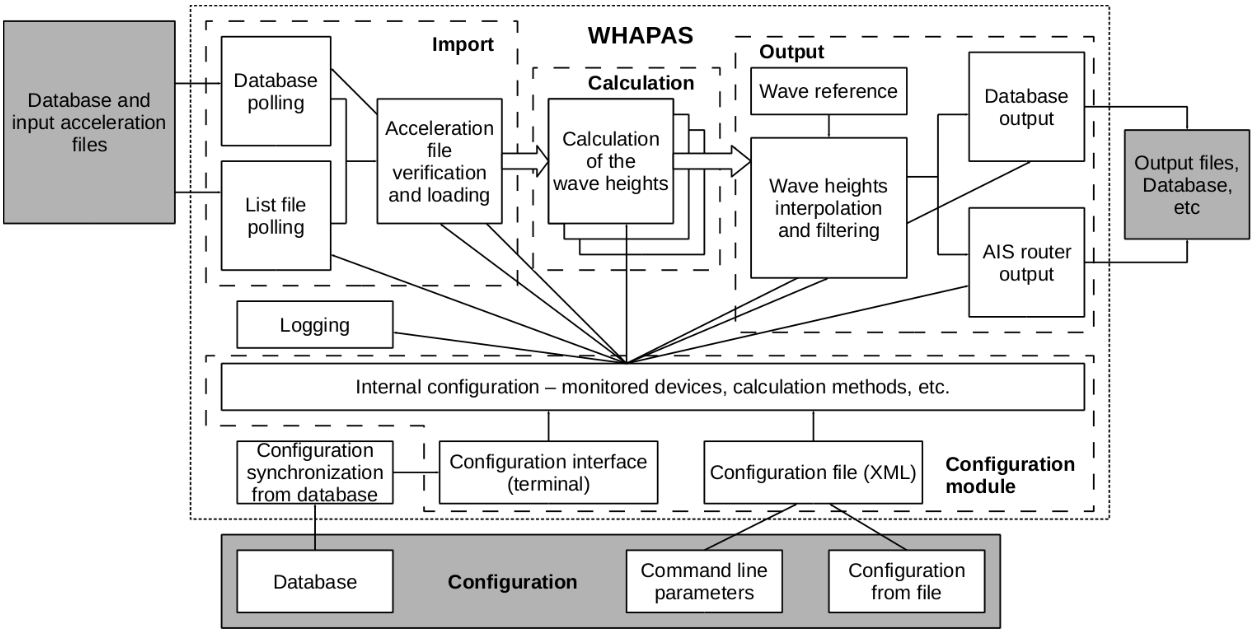


Figure 1. Architecture of WHAPAS

Architecture of WHAPAS is provided in Figure 1 with core component names shown in bold. All three core components are fully autonomous software modules that share only the settings and log management components. Data exchange between the components is arranged by the means of TCP/IP (IPv4) socket interfaces shown in Figure 1 with large arrows.

2.2.1 Data Retrieval Software Component

The Data Retrieval Software Component (DRSC; shown as „Import“ in Figure 1) is responsible for retrieval of acceleration data from binary data files uploaded by TelFiCons deployed at seas and saved by the TeViNSA Core. The information in those data files represents acceleration values measured at the outputs of a three-axial accelerometer sensor and compressed in proprietary lossless format. In addition to checking whether a new data file is available, the DRSC performs integrity checking of the files, relevance checking by the TelFiCon serial number in the file, orientation correction of the data axes in accordance with the specifics of TelFiCon mounting onboard a particular buoy, and preliminary filtration based on data file length and time stamp. Simplified diagram of the DRSC is provided in Figure 2.

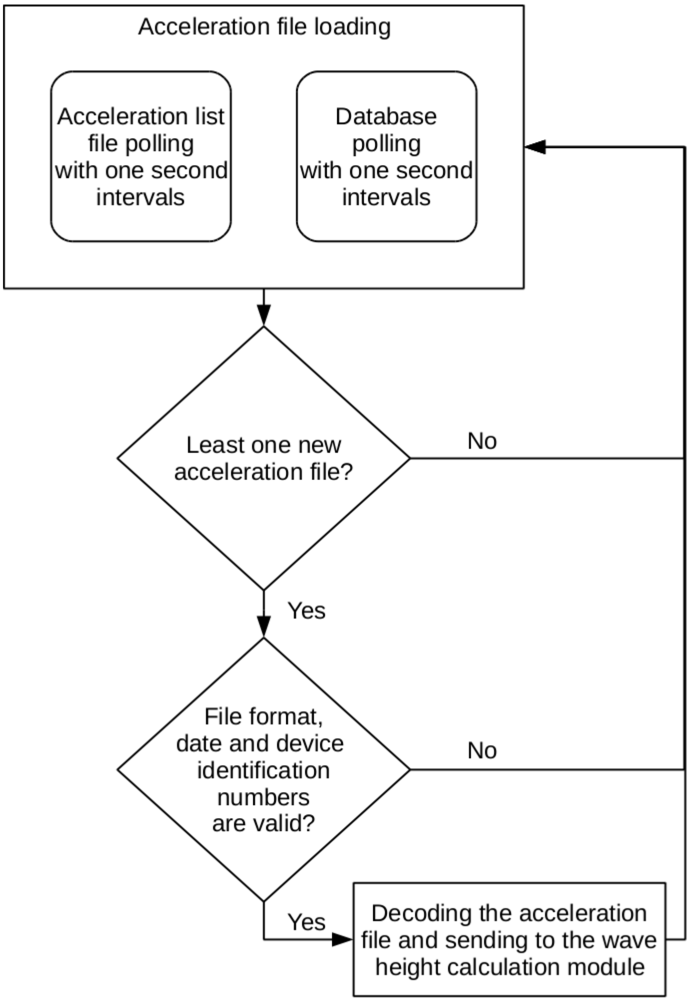


Figure 2. Flow diagram of DRSC operation

The DRSC performs checks to discover new data files becoming available with the interval found in WHAPAS settings, by default once every second. Two methods are available that can be employed simultaneously: checking based on TeViNSA database, or based on a listing of acceleration data files that has relevant files added to the end once an acceleration data file is complete. If a file is compliant to pre-set conditions, it is opened, decoded, and the acceleration data vectors are handed over to the Wave Height Calculation Software Component (WCSC).

Depending on the needs dictated by the configuration of TeViNSA components, WHAPAS allows installation of several DRSC modules in parallel on several hosts of a local area network, with all of them feeding the decoded acceleration data to a single WCSC.

2.2.2 Wave Height Calculation Software Component

The Wave Height Calculation Software Component (WCSC, shown as „Calculation" in Figure 1) is responsible for calculation of an average wave height in the location of a navigational buoy from which the acceleration data received from a DRSC originate as a single task. On a single server, a number of WCSC modules equivalent to the number of processor cores may be run in parallel. Simplified work algorithm of a WCSC is provided in Figure 4, with the algorithm described in more detail in section 3 .

The WCSC waits until acceleration data is received from some of the Data Retrieval Software Components. Upon receiving a batch of new acceleration data, WCSC checks for data integrity and validity, then forwards valid data to a software module that analyzes the three axes and establishes a common vertical acceleration axis which is arranged „upright" using mathematical methods. Heel angle of this derived vertical acceleration axis will change very little in time, allowing to calculate the wave height and period.

The method used for wave height calculation can be unique for each acceleration data source (buoy) when prepared this way. At this time WHAPAS uses only a single FFT based analysis method.

Once the wave height (and period) are calculated, the corresponding values are transferred to the Results Output Software Component (ROSC).

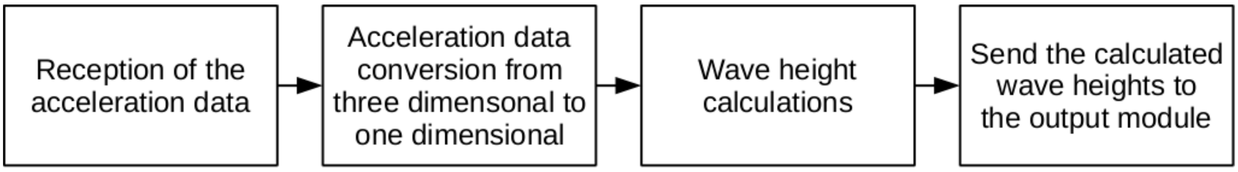


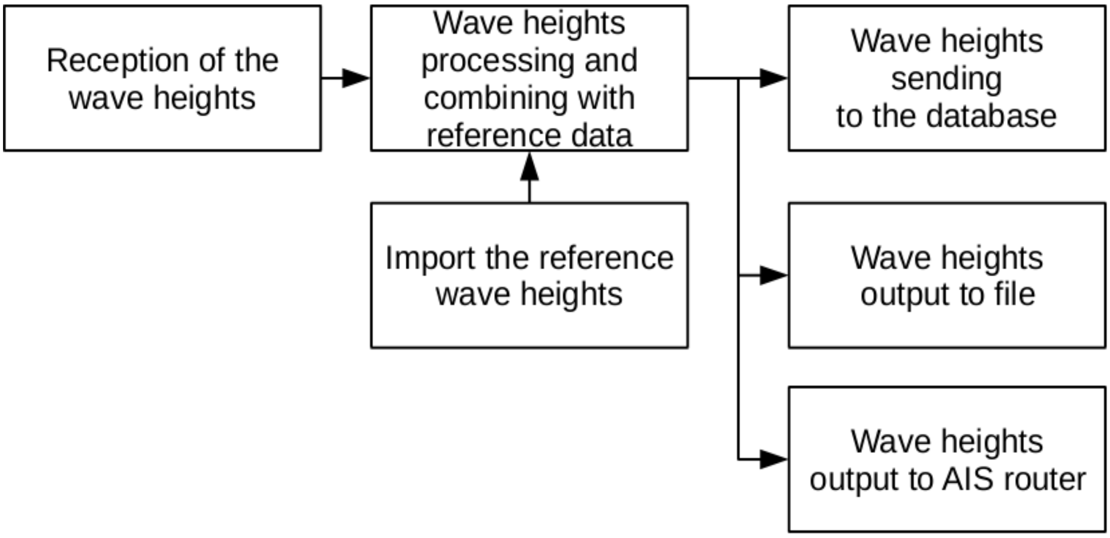
Figure 3. Flow diagram of WCSC operation

Similarly to the DRSC's, it is also possible to operate several correspondingly configured WCSC's on separate computers on a computer network, having them feeding the calculation results to a single ROSC.

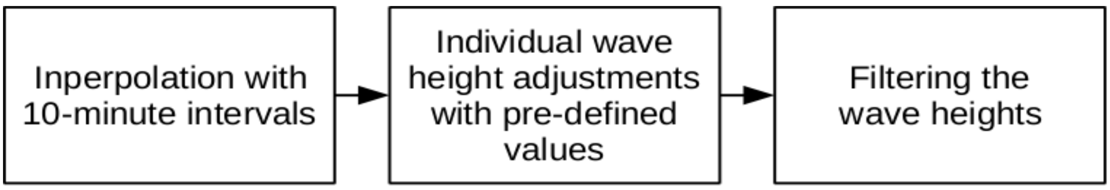
2.2.3 Results Output Software Component

The Results Output Software Component (ROSC, shown as „Output" in Figure 1) is responsible for interpolating all wave height data received from WCSCs to a 10 minute time interval, filtering the data, and formatting the output values in accordance with the input specification of the Hydrometeorological Data Module of an AIS Router that regularly scans the output directory of the ROSC. In addition, output data can be saved to the TeViNSA AtoN database and even to a specified CSV file.

A simplified diagram of the ROSC is provided in Figure 4. Wave height values received from the WCSC are processed to evaluate their correctness and if found to be correct, the values are transferred to the post processing software module (Figure 5) that divides the data set using a discrete step of 10 minute time intervals, applies buoy specific individual correction factors, and filters the results in the form of averaging over a two hour time period to suppress the noise. The correction factors for a specific buoy need to be derived in advance from the comparison of a set of wave height calculation results obtained from WHAPAS with time-matched results of nearby reference measurements recorded during the calibration process of a buoy. In addition to the hydrodynamic properties of a specific buoy hull, the calculation results may be influenced by the length and type of the mooring, water depth in the deployment area, and distance from coastal structures. WHAPAS provides the capability to prepare a set of reference wave height measurement data set time matched to the results of its own calculated results for calibration of a buoy: the correction factors can be derived by comparing resulting two data sets. When use of reference wave height data is enabled by the settings, such data file at a pre-set location is processed to



interpolate the wave height values for obtaining a data set suitable for direct comparison with the wave height values calculated by WHAPAS based on received buoy accelerations. Such reference values are not corrected or filtered; the results are recorded in accordance with the current WHAPAS settings.



2.2.4 Configuration Management Software Component

The Configuration Management Software Component (CMSC, shown as „Configuration“ in Figure 1) is responsible for WHAPAS configuration and management of configuration settings. In addition, it is used for reading the initial configuration settings from

Figure 4. Flow diagram of ROSC operation

Figure 5. Operations inside the wave height processing module

corresponding files and the command prompt, changing the configuration settings based on direct user input in terminal mode, and updating of the current active settings with new settings.

2.2.5 Log Management Software Component

The Log Management Software Component (LMSC, shown as „Logging“ in Figure 1) is responsible for management of all WHAPAS logs, including saving of log records received from software components, and regular archiving of log files based on pre-configured time intervals or file size. In addition, LMSC monitors the WHAPAS operation for malfunctions and significant events, providing the assigned maintenance personnel with timely e-mail notifications.

Software components responsible for configuration and logging can service the core components only within the limits of a single Java virtual machine. Therefore, in case when WCSC and ROSC are run on a single server but on separate JAVA virtual machines, they need separate instances of CMSC and LMSC to be run on corresponding virtual machines.

2.2.6 Settings Synchronisation Software Component

The Settings Synchronisation Software Component (SSSC, shown as „Synchronisation“ in Figure 1) is a part of code responsible for copying of AtoN equipment data from the TeViNSA database into the configuration database of WHAPAS. Apart from the other WHAPAS components, SSSC is completely separated from the rest of WHAPAS components and is only activated manually to update the WHAPAS settings database when such need emerges. Such setup is optimal due to the fact that all the changes at TeViNSA database affecting WHAPAS operation are performed manually anyway. Nevertheless, when fully automated activation of SSSC with a pre-configured time interval is considered necessary, such arrangement can be made by the use of external scripts like the *cron* service of Unix-like operating systems.

2.3 WHAPAS Operation

WHAPAS has no user interface; it is started up on the server hosting the software either by an automated start-up script run at the operating system start-up in case of regular use, or in manual mode for temporary use by entering WHAPAS at the command prompt of the GNU/Linux operational system console.

To request the help information on command line parameter options, the operator must enter at the command prompt:

WHAPAS –h

Configuration settings of WHAPAS are maintained in an XML file that is not accessible for direct editing, changes can be implemented either by logging into the CMSC terminal, or by copying the settings from TeViNSA database.

A detailed manual with all commands, configuration options and XML configuration file contents is provided to system administrators.

3 Calculation of Significant Wave Height

3.1 Calculation Algorithm

Calculation of significant wave height performed by WHAPAS is based on the assumption that the analysed waveform is a good approximation of a sinusoidal wave. This allows calculating the amplitude of the waveform using the following formula:

$$x = X\sin(2\pi f t) \quad (1)$$

where:

t – Time instance

f – Frequency of oscillation

X – Peak amplitude of oscillation

x – Oscillating variable at the time instance t

Time derivative of this formula provides velocity of the level displacement:

$$v = \frac{dx}{dt} = 2\pi f X\cos(2\pi f t) \quad (2)$$

Since the (significant) wave height is described by the wave's peak-to-peak amplitude (crest to through), double extent of the amplitude provides the actual displacement:

$$D = 2X \quad (3)$$

where:

D – Displacement of the water level

Inserting the result of formula 3 into formula 2 results in the following:

$$v = \frac{dx}{dt} = \pi f D\cos(2\pi f t) \quad (4)$$

Time derivative of formula 4 provides instantaneous acceleration:

$$a = \frac{dv}{dt} = 2\pi^2 f^2 D\sin(2\pi f t) \quad (5)$$

where:

a – Instantaneous acceleration

The components before the „sin“ in formula 5 present the amplitude of the acceleration; since we have no need to monitor the changes of the acceleration in time, the following simplification can be used:

$$A = 2\pi^2 f^2 D \tag{6}$$

where:

A – Amplitude of the acceleration

Expressing the displacement from formula 6 results in:

$$D = \frac{A}{2\pi^2 f^2} \tag{7}$$

The amplitude of acceleration can be expressed as follows:

$$A = g \cdot G_{meas} \tag{8}$$

where:

$g = 9.80665\, m/s^2$ – Acceleration of free fall

G_{meas} – Value of acceleration in g units measured by a TelFiCon mounted onboard a navigational buoy

After inserting the expression 5 into formula 7 and performing necessary elementary calculations, we arrive at the following simplified association between the measured acceleration and the corresponding water level displacement (significant wave height):

$$D = 0.4968 \frac{G_{meas}}{f^2} \tag{9}$$

The remaining analysis is performed by applying spectral analysis (FFT) with selected window functions to the selected subsets of the three arrays of acceleration values (data arrays) received from the TelFiCon units mounted onboard navigational buoys. In addition, due to the different low-pass filtering behaviour of different buoy types, a set of correction factors will be applied to compensate for deviations in several wave height ranges. Such correction factors are in fact buoy model parameters that present a simple description of dynamic behaviour of a specific buoy type. Currently, the only way of determining these factors is conducting of reference measurements utilising precision wave height measurement equipment deployed by the side of the buoy subject to calibration for acquisition of statistically sufficient amount of reference points over the range of wave heights, and deriving the sufficient amount of wave height range dependent correction factors from the comparative analysis of the results of both measurements to bring the calculation results up to acceptable wave height estimation uncertainty. WHAPAS settings database accepts definition of several range related correction factors per each AtoN subjected to wave height analysis. In addition, a capability to introduce new calculation methods and then select them for use with new AtoN objects is foreseen.

3.2 Verification Results

Tests were conducted in cooperation with the Marine Systems Institute of the Tallinn University of Technology for calibration of the algorithm for wave height calculation for specific navigational buoy, and for verification of the results of server side calculation. Two measurement sessions were conducted by the MSI with precision wave height measurement sensors deployed at the close vicinity of buoys No. 157 „Kuradimuna W“ and No. 186 „Karbimadala W“ in September and November 2010, resulting in 22195 reference points taken at 10 minute intervals. The measurement results of the reference sensor used by the MSI are expected to provide approximately 0.05m measurement uncertainty. At first the results of reference measurement were used to determine buoy specific correction factors in an incremental fitting process. Next, the factors producing smallest differences compared to reference data were applied at the analysis of the same set of buoy acceleration data at the input of WHAPAS and the final deviations from reference values were noted.

Due to the different measurement and averaging methods utilized by the reference sensor and the TelFiCon sensor, non-synchronized sampling as well as a positioning difference of about 20m, certain differences in results were expected and are not necessarily presenting a measurement uncertainty. Differences between the reference values and best fit values calculated by WHAPAS with application of correction factors derived from the same experiment are presented in Table 1.

Table 1. Differences between wave height reference measurement and WHAPAS results

Percentage of calculation results within the maximum difference	Maximum difference in calculated significant wave height [m]	
	Range: 0.0 m to 2.0 m (21794 reference points)	Range: 2.25 m to 5.0 m (401 reference points)
68.27%	0.29	0.63
90.00%	0.37	0.78
95.00%	0.41	0.86
95.45%	0.41	0.87
99.73%	0.53	1.10

Graphical distribution of the differences of the calculated wave heights in comparison with reference measurements conducted by the MSI is provided in Figure 6 in two ranges, under and over a 2m wave height.

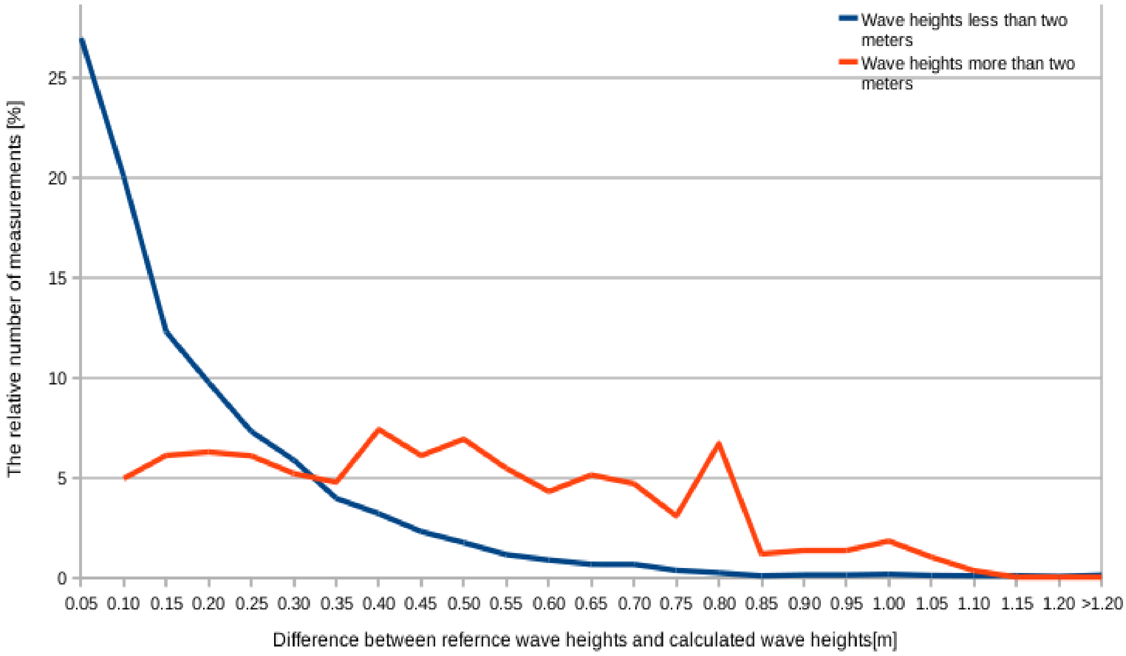


Figure 6. Relative distribution of differences in height between the wave heights calculated by WHAPAS and wave heights obtained for the matching time periods by a reference sensor.

APPENDIX 1 Reference measurements for WHAPAS software calibration

Waves are probably the most important factors influencing navigation conditions at the sea as well as other basins usable for navigation throughout the year. Waves are generated by wind and by knowing wind forecast the prognosis for wave field could be derived. This works well in the open sea. However, in coastal sea-areas number of other factors influences the realization of wave situation in certain weather conditions, just to name the most important of these factors – bottom topography and coastline morphology, currents, presence of the ice, etc. Generally it's so that the closer to the coastline wave field gets, the more complicated, and dynamics of waves become more active. Latter is the case for shipping, especially for navigation of smaller ships, also for anchoring safety of bigger ships and ship maneuvers. The Baltic Sea has a very complicated shape, elongated to NE-SW direction Baltic Proper, W-E directional Gulf of Finland, almost round-like Gulf of Riga – and all these bordering the Estonian coastal sea. It's obvious that the same wind generates very different wave fields in particular sea areas. From navigational point of view wave information is essential; for smaller ships navigation is prohibited with certain wave height, for bigger ships restrictions for certain maneuvers apply. Therefore, collection of information about wave conditions is very important. Most of historical wave data and information are however based on visual observations at hydro-meteorological coastal stations and some limited amount observations form on board of ships. All these visual observations are probably satisfactory to get basic wave statistics, but can't be applicable operationally. There exist some limitations in space and time wave measurements out in the sea from last couple of years, but these are really snapshots of a couple of weeks long in some points and can't be enough to describe wave field. On the other hand numerical modeling is improving very fast and principally applicable as in hind- and forecast mode in order to support safe navigation with wave information. Still, one has to be careful using wave models in sea areas with complicated morphometry, as is the case for Estonian coast. In open sea, yes, most of wave models work good, but in coastal sea measurement, data is definitely needed first to set up the model, then validate; the best results will come if data is assimilated into the model continuously.

As navigational buoys are installed in a number of locations along the Estonian coast and also the open sea, and most of cases into navigationally critical places, an idea to use those as wave measurement platforms naturally came into use. On the other hand, buoys are technologically equipped with acceleration sensors for other purposes, but could still be used for estimates of wave parameters. There are several problems: slightly different shape of the buoys, their different weight etc. but this didn't stop us from trying the idea.

At first approach effort was undertaken to estimate parameters of wave field around the certain navigation buoys and then try to find most suitable algorithm to get wave data from acceleration sensor output. For that purpose two measurement campaigns were planned, both using two pressure sensor based wave gauges in two different locations near the navigation buoys, in Karbimadal and Kuradimuna. From these two Karbimadal is a more inner location in the Muuga Bay and Kuradimuna reflects wave regime in the open Gulf of Finland much better. Also, attempt to cover two different seasons – September as late summer and October- November as autumn is taken into account in case of measurement campaigns. Current report gives first overview of some basic aspects of ocean waves' importance in context of proposed measurement technology and applying acceleration sensors. Then description of measurements campaigns performed to get set up and validation data from new technology of wave estimation. Finally, first evaluation to the method of wave estimation with navigation buoys applying acceleration sensors is given through comparisons with pressure wave gauge results.

1.1 General approach to ocean waves

In fluid dynamics, wind waves or, more precisely, wind-generated waves are surface waves that occur on the free surface of oceans, seas, lakes, rivers, and canals or even on small puddles and ponds. They usually result from the wind blowing over a vast enough stretch of fluid surface. Waves in the oceans can travel thousands of miles before reaching land. Wind waves range in size from small ripples to huge rogue waves. When directly being generated and affected by the local winds, a wind wave system is called a wind sea. After the wind ceases to blow, wind waves are called swell. Or, more generally, a swell consists of wind generated waves that are not — or hardly — affected by the local wind at that time. They have been generated elsewhere, or some time ago. Wind waves in the ocean are called ocean surface waves.

Five factors influence the formation of wind waves:

- Wind speed
- Distance of open water that the wind has blown over (called the fetch)
- Width of area affected by fetch
- Time duration the wind has blown over a given area
- Water depth

All these factors work together to determine the size of wind waves: the greater each of the variables, the larger the waves. Waves are characterized by:

- Wave height (from trough to crest)
- Wavelength (from crest to crest)
- Wave period (time interval between arrival of consecutive crests at a stationary point)
- Wave propagation direction

Waves in a given sea area typically have a range of heights, not a single number for height. For weather reporting and for scientific analysis of wind wave statistics, their characteristic height over a period of time is usually expressed as significant wave height. This figure represents an average height of the highest one-third of the waves in a given time period (usually chosen somewhere in the range from 20 minutes to twelve hours), or in a specific wave or storm system. Given the variability of wave height, the largest individual waves are likely to be about twice the reported significant wave height for a particular day or storm.

In the context of wave dynamics, the Baltic Sea wave field is characterized by very complex nature, much more complex than in the ocean for example. This stems for multiple factors. The Baltic Sea is divided into number of sub-basins – Gulf of Finland and Riga, Bothnian Bay, Baltic Proper etc. Each one of these sub-basins has its own distinctive wave regime (Jönsson, 2002). A pronounced seasonal variability also exists, where waves are higher in autumn and winter and lower in spring and summer (Jönsson, 2002). The wind regime is frequently anisotropic, especially in the Baltic Proper, thus giving rise to predominated wave propagation directions also (Soomere, 2003). In wintertime nearly half of the Baltic Sea is commonly ice covered, in hard winters even up to 85%. Presence of ice of course modifies, again, wave field remarkably.

As an example of wave fields in the Baltic Sea, two situations are presented on Fig 1 and 2. The first one represents the average significant wave height integrated over all months and years during the period 1970-2007. These results are presented by Räämet and Soomere (2010). Largest average significant wave height is found at the Baltic Proper, where it is up to 1m.

Contrary to average situation, in the windstorm Gudrun which attacked the Baltic Sea countries on 8-9 January 2005, significant wave height grow over 9m in the southern Baltic Proper and was over 7m in Estonian territorial sea, according to SWAN wave model results (Fig.2). In both cases regions of highest waves are located more or less in the same places, one of those West from Estonian Archipelago. Pattern in the Gulf of Finland is slightly different as filed of average wave heights show secondary maximum in the middle of the Gulf, which is averaging result of westerly and easterly winds creating waves. In reality wave field decay in the Gulf is going easterly in case of westerly winds and roughly vice versa with easterly winds, as seen also on Fig 2. Measurement location in our case lay well inside the Gulf of Finland, reflecting more wave conditions of the open Gulf in Kuradimuna and Muuga bay wave field in case of Karbimadal.

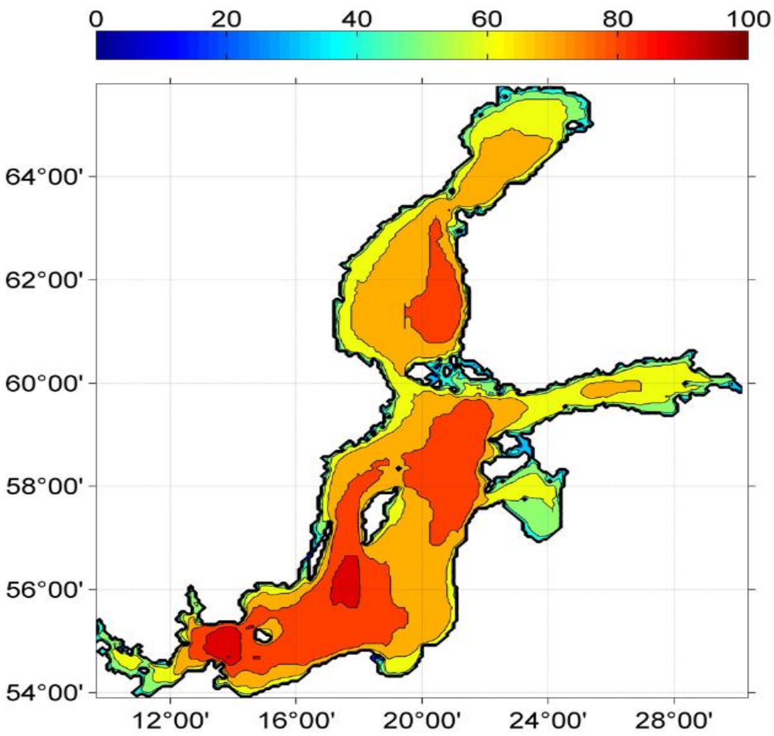


Figure 1 Average significant wave height in the Baltic Sea. Color bar of the scale is in cm. Results from the wave model WAM.

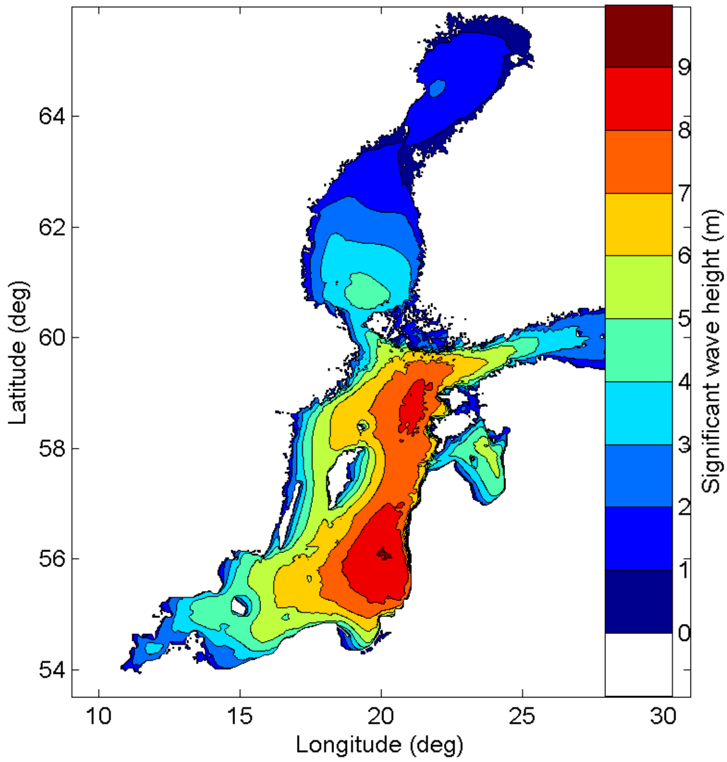


Figure 2 Significant wave height during storm Gudrun on January 9th, 06:00 UTC. Results from wave model SWAN. Scale on color bar is in meters.

In next chapters from 1.1 to 1.3 we give answers to some most important questions needed to be clarified in order to establish a link between the wave parameters measured with acceleration sensors on board of navigation buoys and wave parameters registered with pressure based probe as well as modeling results showing wave field realizations in certain sea areas at given time moments, forced by atmospheric conditions.

1.2 Depth dependence of wave parameters

Three physical processes contribute to the evolution of wind waves over basin of variable depth and size. The first is the generation of wind waves by wind; secondly the nonlinear transfer of wave energy between harmonics which allows for the generation of longer waves and lastly, the dissipation which is the sum of whitecapping, bottom friction and depth induced wave breaking.

The dissipation due to whitecapping is always present, no matter how deep the sea is. However, depth induced breaking and bottom friction becomes important only in shallow waters and also depends on the wave period. The bottom slope is important as well.

Numerical experiments with the wave model SWAN indicate that in Estonian coastal regions bottom friction becomes important in water depths less than **30m,** and depth induced breaking in water depths less than 10 m (Alari, Raudsepp and Kõuts 2008; Alari and Raudsepp 2010)

1.3 Dependence of wave parameters from morphometry of the coastline

Morphometry of the coastline in certain area together with depth profile are major components forming the local wave field realization. Number of other circumstances drive the wave field variability, most important of those is of course wind, but also currents, presence of ice or algae alter the wave parameters, depending on their intensity, accordingly as well. There can't be sorted out universal methods or algorithms giving general key to solve those local peculiarities of wave field. That's the reason why, if it's necessary, local wave field is modeled individually in the interested area. Using real bottom topography and coastline, forcing (wind) can be both idealized, to show wave field realization in extreme cases as well as real, to show natural evolution of wave field and compare the model results with measurements. Before using local scale model in certain sea area, validation and local set up of the model with *in situ* measurements is an essential precondition in order to gain acceptable results. As particular example from Estonian coastal sea, a numerical experiment with a phase resolving model COULWAVE (TTÜ Meresüsteemide Instituut, 2007) was undertaken in order to study the interaction between Naissaar harbor jetty and fast ferry wakes. The results showed that the reflected wave did not propagate more than **200m** from the harbor constructions. In case of wind waves (which are shorter) and normal coastline (where bottom dissipates much energy), the propagation of reflected wave is even more restricted. As harbour jetty is a vertical wall in water, its wave reflecting features are much better than most of the coastline, we can summarize that wave field is directly affected by coastline, wave reflection stays inside the 200m zone.

As an example of the large scale alteration of wave field due to coastline, consider a wave field realization in Tallinn Bay during a W storm. Naissaar Island not only damps waves (Fig.3), but the underwater slope at the southern tip of the island refracts waves to an extent, where pure westerly waves change their direction up to 90 degrees.

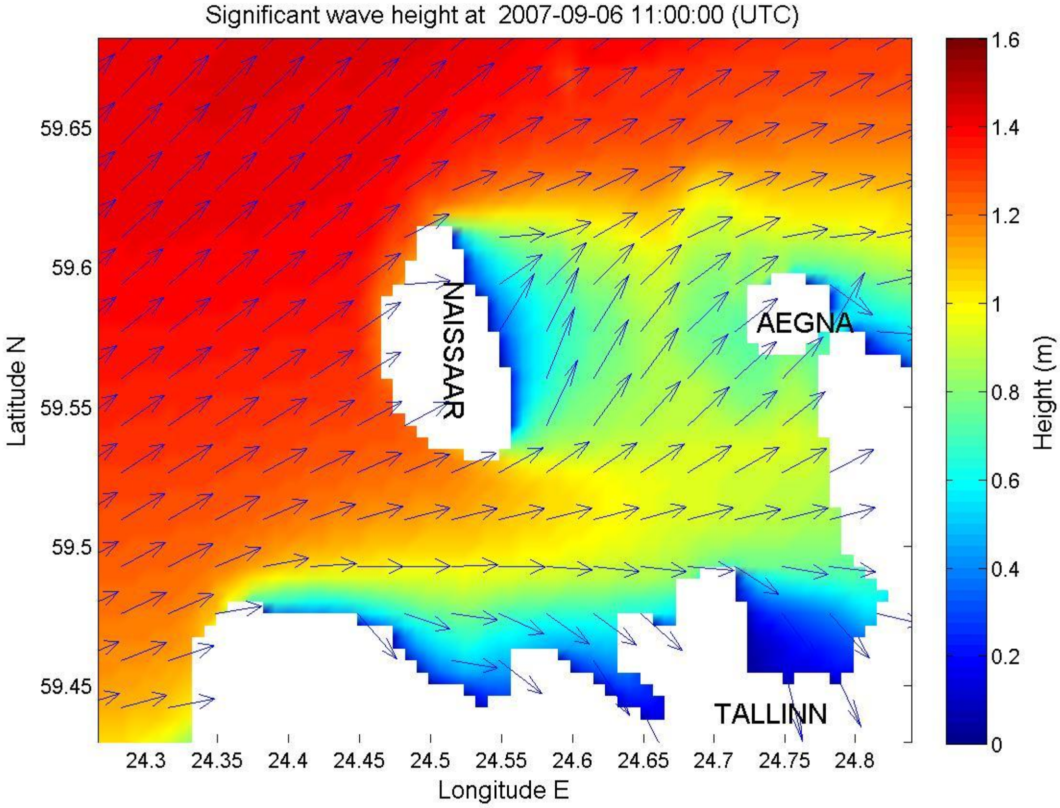


Figure 3 Significant wave height in Tallinn Bay, as modeled with SWAN wave model. Arrows indicate wave propagation directions.

A more localized impact of coastal morphology upon wind waves is seen on Fig .4 and 5. In the former case the shoaling and depth induced breaking of wind waves is described, in the latter case the wave reflection and diffraction near vertical wall. Note that the coast absorbs much of the incoming wave energy and reflection is negligible.

Figure 4 Wave shoaling and depth induced wave breaking at western coast of Tahkuna peninsula, as seen aero photography (Estonian Land Board).

Figure 5 Complicated nature of multiply wave diffractions and reflections near Lehtma jetty, as seen aero photography (Estonian Land Board).

1.4 Shape of the wave shape and particularly wave shape in the Baltic Sea

Considering the shape of wave spectrum, the SWAN wave model can be used to accurately reproduce the shape of the waves. Realization of certain wave spectrum is the sum of sine and cosine elementary waves with alternating phases and amplitudes, the actual wave field infrequently resolve a pure elementary wave.

Waves come in groups, as can be seen on Fig. 6, where 10 minute long time series of *in situ* wave height is presented – this is frequently the period for which wave information is generalized. In fact, no solid physical mechanism behind wave group formation exists, yet alone for their spatio-temporal prediction. Fig. 6 gives an idea of complexity of actual wave situation, based on which some generalized picture is actually created. Besides the wave groupings, waves also have a pronounced crest-trough asymmetry. This is best seen at time moments of 180s and 285s. In the first case, the crest height is 1.9m and the trough depth is -2.6m. In the second case, the crest height is 1.2m and the trough depth is -2.3m. Almost all the asymmetries resemble “holes in the sea” asymmetries, which in certain cases could pose a particular threat for navigation.

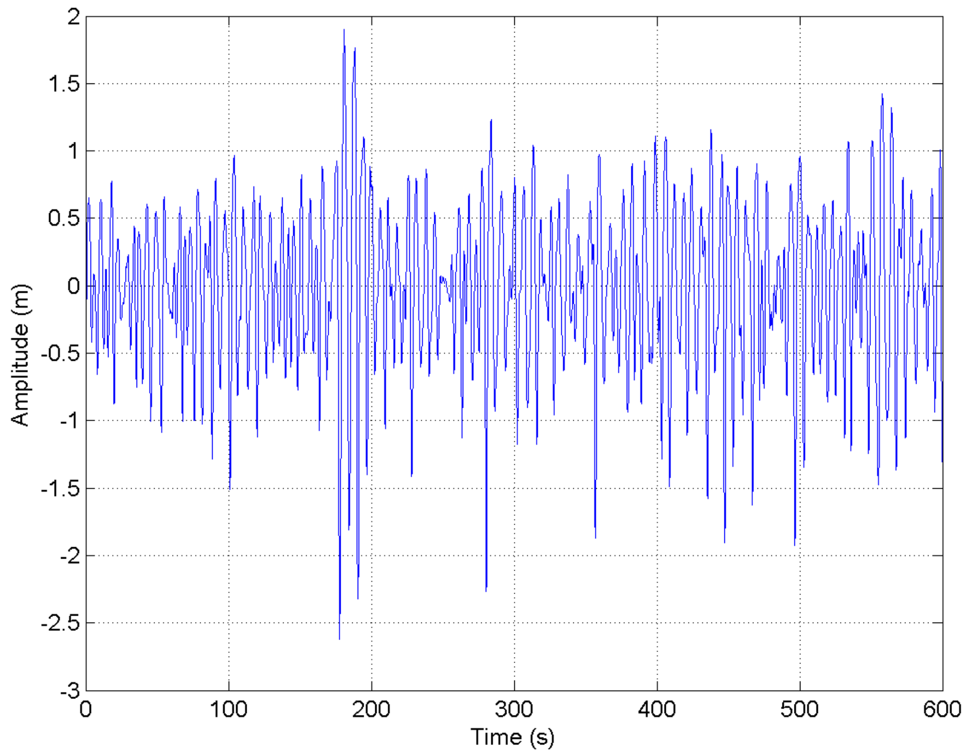


Figure 6 Snapshot of *in situ* wave package during 10 minute long time sequence, measured with pressure sensor, high variability in wave heights during that short time period could be easily observed from the graph.

1.5 Wave measurements in vicinity of navigational buoys at Karbimadal and Kuradimuna

In summer and autumn 2010 two wave measurement sessions were carried out – at the Kuradimuna Bank in the Gulf of Finland and at the Karbimadal Bank in the Muuga Bay. Purpose of measurements was to obtain time series of basic wave parameters as typical for summer and autumn wind conditions in order to compare wave data with these obtained experimentally from navigational buoys. Measurement sites were chosen so that these were in close vicinity of navigation buoy reporting wave parameters for same measurement periods. Two measurement sites should also represent typical conditions inside the coastal bay (Karbimadal in the Muuga bay) and more open sea conditions as recorded in Kuradimuna.

Two wave recorders LM2 were used (Fig 7), the working principle of which is based on measurement of pressure at fixed position of the probe with absolute pressure sensor (Keller Ltd.). Instrument is installed 5-8m below sea surface (Fig. 8) and measured pressure is converted to height of water column with 4Hz sampling rate, while water temperature variations are automatically compensated by sensor electronics. All data is recorded in internal memory, which is SD type card. Pressure sensor based measurements of wave parameters are used primarily for validation of wave calculation algorithm, wave height data originated from the acceleration sensor of the navigational buoys.

Wave measurements were made during two periods, 31.08–30.09.2010 and 20.10–17.11.2010, first one representing summer wind conditions and second autumn. Limiting factor for the length of measurement period here was the memory capacity, as measurements were performed in 4Hz regime, 2 Hz mode would prolong the measurement period about twice. In order to get best possible data quality, we went for denser recording rate. In other words, having the sampling frequency four times per second, the endurance limit for one sampling session is approximately three weeks. The depth was 20 meters at both sites, the wave recorders were mounted five meters below the water line. Wave recorder was kept at the given level in the water column, with a float, but as sea level changes, then the depth of the instrument also wasn't constant – this feature was filtered during the data processing. A mark buoy was added to simplify the recovery of the buoy stations (Fig 8).

In order to ensure an unchangeable position of the buoy stations in difficult sea conditions, what both measurement sites actually are, an extra anchor was attached to the main anchor. The connecting rope was left floating to make it easier to find and recover the buoy station if the mark buoy should get lost. Both wave recorders were placed west of the aforementioned banks (Fig 9), in the vicinity of the west navigational buoys that were equipped with acceleration sensors. The bank name and necessary information was marked on the buoy stations, should other persons find them and to avoid mix up of data series. Launching and recovering of mooring stations was done with the research vessel SALME (Marine Systems Institute at Tallinn University of Technology). Coordinates are given in Table 1.

Table 1 Coordinates of mooring stations where wave measurements were performed in summer-autumn 2010.

Period		Station/depth	Lat		Lon	
1	31.08–30.09.2010	Karbimadal/20m	59°	33.284	24°	56.758
		Kuradimuna/20m	59°	41.946	24°	52.882
2	20.10–17.11.2010	Karbimadal/20m	59°	33.298	24°	56.733
		Kuradimuna/20m	59°	41.862	24°	52.807

1.6 Measurement equipment

Instrument for wave measurements we used in this case, is wave/pressure recorder LM2 developed and built by Estonian local company PTR Group OÜ. Measurement sensor is piezoelectric pressure sensor by Keller Ltd (Switzerland) All signal processing and data storage electronics was designed and built by PTR Group OÜ already in late 1990-s. Instrument principally records pressure values at given rate of 2,4 or 8Hz. In most cases measurement rate is 4Hz, which should be enough to catch waves with shortest periodicity of 2-3s, in the coastal zone. In open sea wave period goes to 4-5s and in case of extreme storms even to 6-7 seconds. From that point start wakes generated by fast going ships, and wave periods can be from 8-15s. This instrument is previously used both, for measurement of natural and ship generated waves, all over the Estonian coast as well as in the open sea. Results of measurements are published in a number of peer reviewed papers, also a comparison with other wave recording instruments (SeaBird, Aanderaa Data Instruments, etc.) has been made in the past and sometimes parallel measurements are also repeated today. Pressure sensor has been built in temperature compensation. Pressure data together with water temperatures are written on SD memory cards. Downloaded pressures are used then for calculation of wave parameters using method described in Chapter 2.4.

Ranges

- Pressure 0..1 bar (0..10 m water column)
- Temperature 0..50 ° C
- Sampling frequency 25 per second up to1 per hour

Other data

- PC interface - USB
- Sampling starts with magnetic key

- No cable required, runs on 4 “D” cells
- Logs pressure and temperature
- Records up to 30 million lines on a 128 Mb MMC memory card
- Dimensions – 100 mm by 470 mm
- Weight 4 kg (in air)
- Programmable sampling frequency
- Uses Keller PA-10 absolute pressure sensor

Figure 7 Wave/pressure recorder LM2 and its main technical features

Installation of wave recorder is very important as this should be fixed under water to measure as precise as possible height of water column above the sensor. For that purpose mooring scheme presented on Fig. 8 is used. In order to catch waves with period less than 4s (hydraulic effect of wave decay), and in the Baltic Sea coastal zone they are usually below 4s, the instrument should be installed not deeper than 10m, the closer to the surface the better. Still, it has to be taken into account that waves could be as high as 4-5m, and fine tuning of measurement depth is essential and lays in best case between 6-8m. Sometimes even shallower, in this case it's coastal zone and known that wave height does not exceed 2-3m, so the instrument can even be installed at 3-5m below surface. As an example, Fig 10 shows depth of the wave recorder during the entire second measurement period in Karbimadal and this lies well inside 0.8m. Parts of variability are sea level changes as well as changes in air pressure. So we can say that this type of mooring shown in Fig. 8 well fixes instrument under water. During data processing low frequency water level changes are filtered out and the important thing is that there can be no sudden fluctuations of the instrument depth, which may show instable mooring!

This instrument has proved itself well in the past, most important raw data for wave calculation is available and if needed, several different methods of calculation could be used, in our case still the method described in Chapter 2.4.

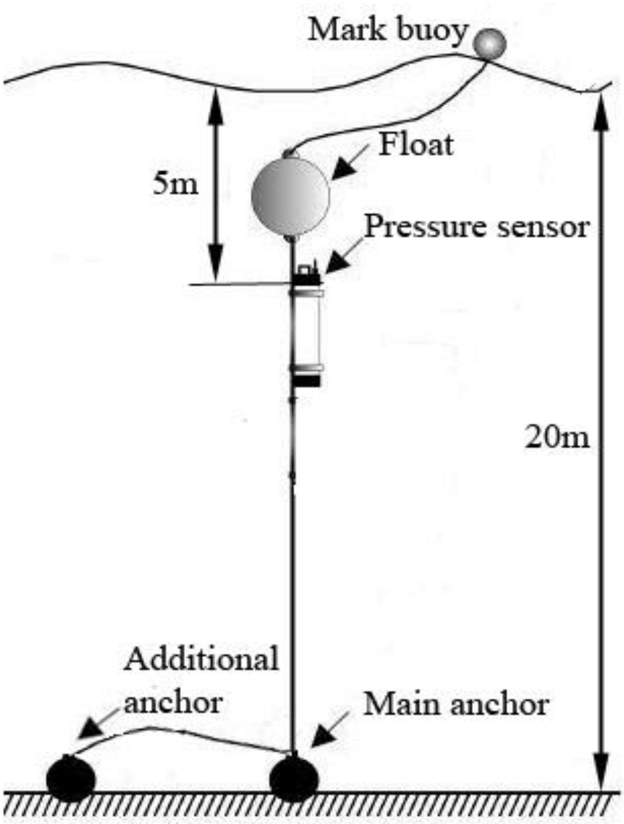


Figure 8 Scheme of the mooring at the wave measurement stations in Karbimadal and Kuradimuna

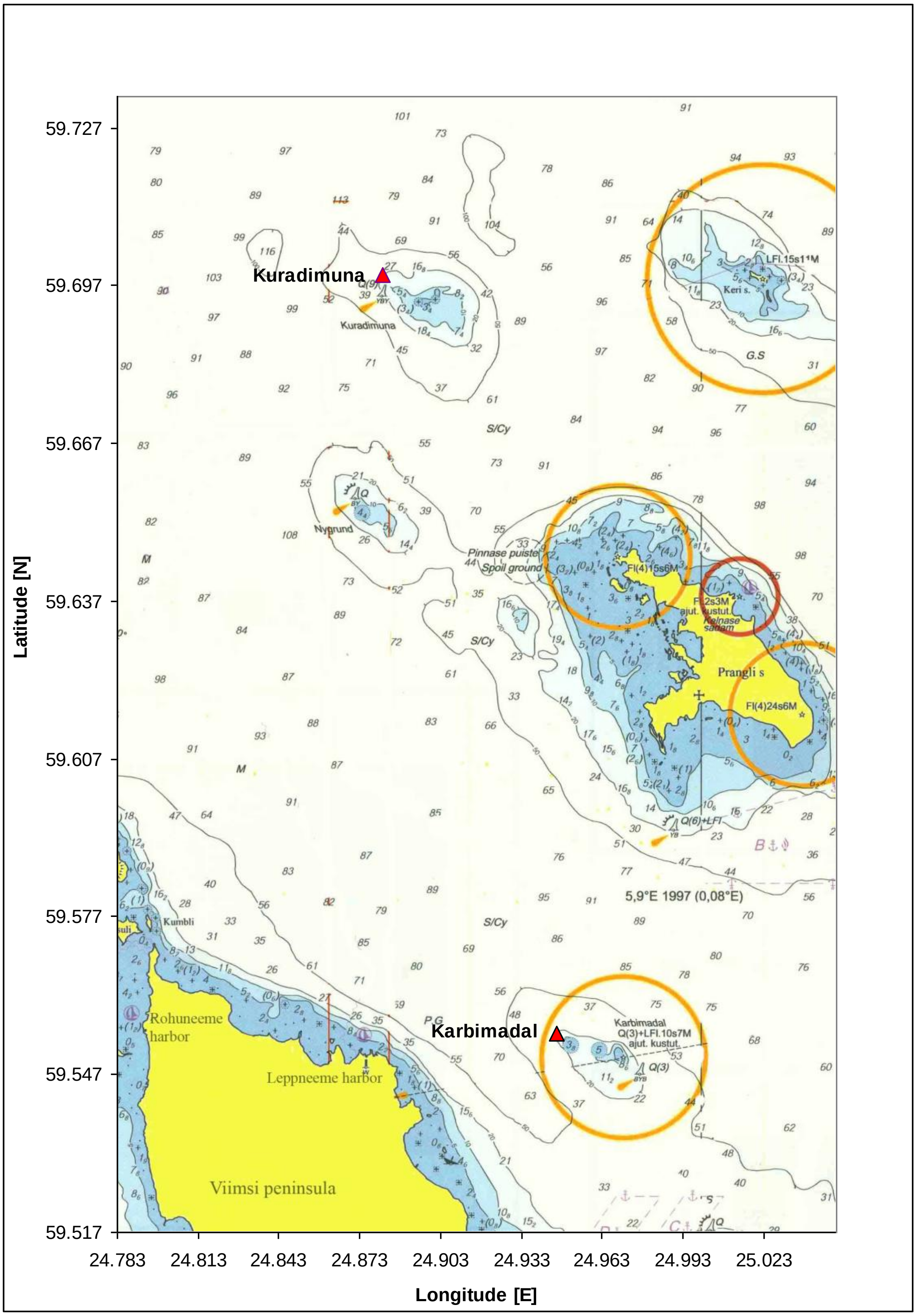


Figure 9 Overview of Kuradimuna and Karbimadal, where wave measurements with wave recorder LM2 were performed, with red triangles marking mooring station coordinates.

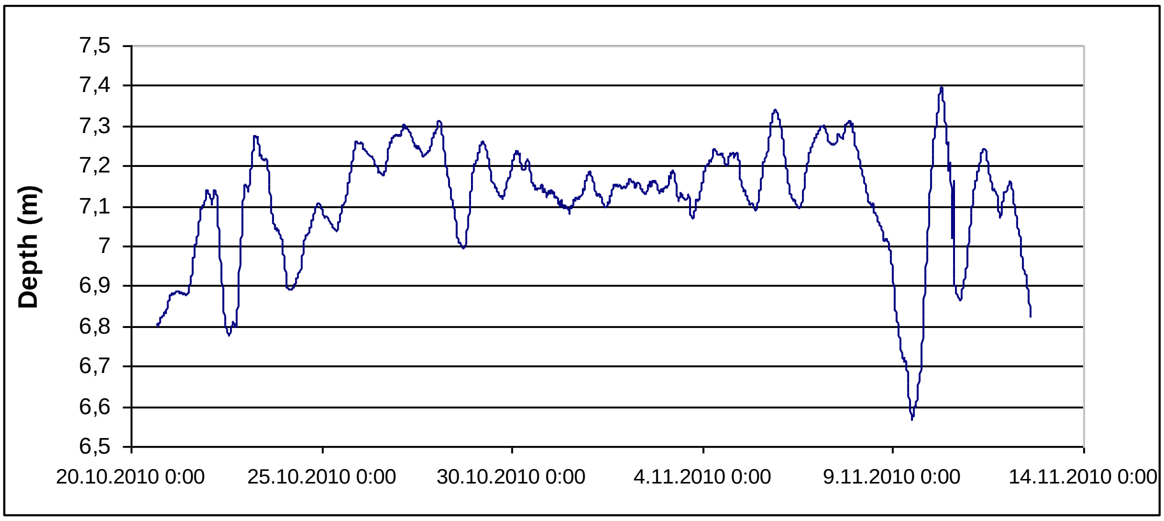


Figure 10 Graph showing the depth of the instrument during second measurement period.

1.7 Conversion of measured sub-surface pressure into surface elevation spectra

As used in case of these measurements probe records hydrostatic pressure, a conversation procedure is applied to get wave parameters out of raw data series. Sub-surface pressure transducers measure the instantaneous pressure that is the sum of air pressure, hydrostatic pressure and wave-induced dynamical pressure. If air pressure and hydrostatic pressure are assumed to remain constant, the dynamic pressure under water is expressed with equations derived from the linear wave theory (Tsai et al, 2005). That pressure is a function of three parameters: the height of the pressure sensor from the seabed, wave frequency and water depth. At an intermediate water depth, pressure decreases hyperbolically with depth, therefore a sub-surface attenuation coefficient has to be applied in order to get a realistic picture of wave height.

First the pressure time-series (units of pressure) is converted to a subsurface elevation time series (units of height). Then the time series is divided into five-minute sections called wave packets. Additionally, the packets are de-averaged and de-trended. The mean value is used in order to calculate gauge depth, which is needed for the calculation of the attenuation coefficient. Further on, power spectral density is estimated by using the Welch method, and a Hanning window is used to smooth the spectrum. The obtained subsurface elevation spectra $Ss\eta$ are converted to surface elevation spectra (S_η) using the linear wave theory:

$$S_\eta = Ss\eta\left(\frac{\cosh kd}{\cosh k(d+z)}\right)^2, \tag{1}$$

with *k* denoting the wave-number calculated from the linear dispersion equation, *d* water depth, and *z* elevation of the pressure gauge relative to the mean water surface (negative downwards). The linear dispersion equation at intermediate water depths reads:

$$\omega^2 = gk\tanh(kd), \tag{2}$$

where g is the acceleration due to gravity and ω is the angular frequency. In practice the transcendental equation (2), which needs iterative solvers, is replaced with a polynomial approximation to reduce calculation time.

From the surface elevation spectrum, two important characteristics are derived: significant wave height and the period corresponding to the first moment of the spectrum. Significant wave height is defined as follows:

$$H_s = 4\sqrt{\int S_\eta(f)df}\ . \tag{3}$$

The period corresponding to the first moment reads:

$$T_{01} = \frac{\int S_\eta(f)df}{\int fS_\eta(f)df}\ . \tag{4}$$

The term in the brackets of equation (1) is the linear pressure transfer function. It is usually defined above the low-frequency and below high-frequency cut-off, respectively. While the low-frequency cut-off is 0.05 Hz, the high-frequency cut-off varies dynamically as does the height of the water column above the pressure sensor. The high frequency cut-off reads:

$$f_h = 0.282\sqrt{\frac{g}{z}}\ . \tag{5}$$

We will illustrate the end result of conversion of subsurface pressure to surface wave time-series by graphing the significant wave height, maximum wave height and peak wave period during the three week measurement campaign at Kuradimuna in October-November 2010 (Fig 11).

Although the significant wave height is very variable, its average value for the three week period is 0.8m. Maximum significant wave height reaches 3.7m on 9 November, whereas the corresponding maximum wave height is 5.5m. Interestingly even the wakes from fast ferries are clearly visible on the graphs as sudden peaks during low wave conditions. In general the peak period grows during the growth of wave height.

Time series of measured wave parameters were conditioned same way for each of measurement location and period, stored in ASCII files and given to Cybernetica AS for set up of calculation algorithm for waves from acceleration sensor output.

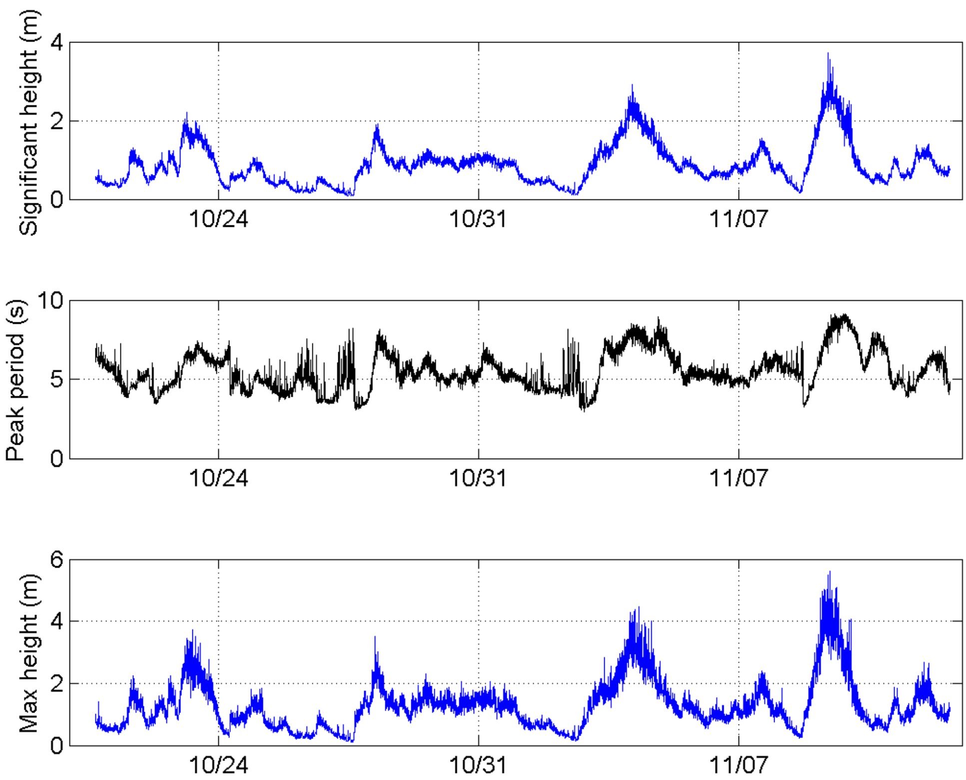


Figure 11 Example of wave measurement time series registered in Kuradimuna, October-November 2010. Wave parameters are derived form pressure measurements using method described in Chapter 2.4. Graphs from the top: significant wave height, wave peak period and maximum wave height.

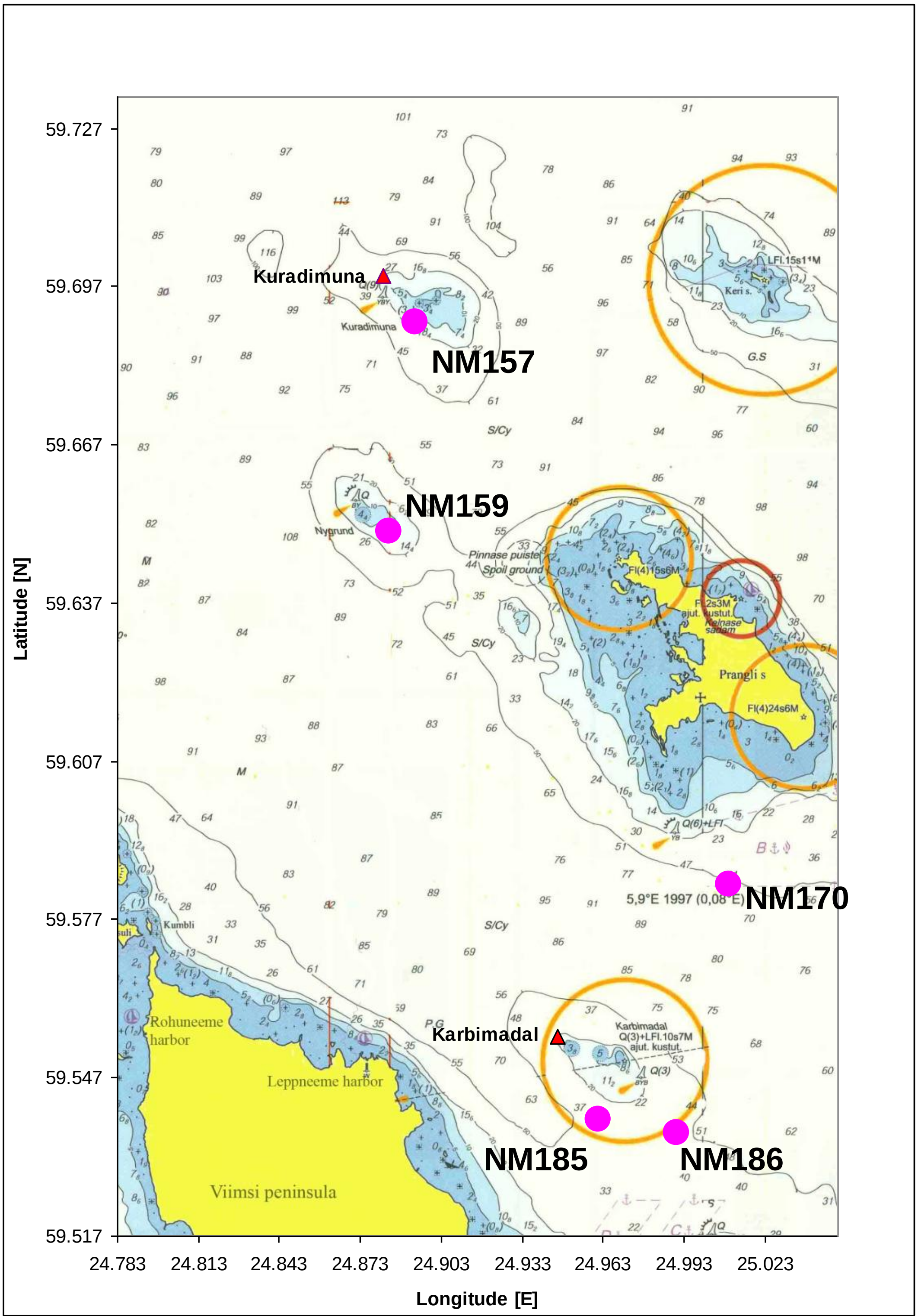


Figure 12 Location of navigation buoys on board of those waves were measurements using acceleration sensor performed and data compared with pressure based wave measurements, with red triangles.

Part-financed by the European Union

1.8 Comparison of wave heights measured with two different methods

For comparison of wave heights obtained from navigation buoys and those measured with special probe with pressure sensor show generally good agreement between those two. Agreement is best in case of closest buoy and reference measurement site, which is natural as obviously wave field can't be homogeneous even over several square miles in the region because of morphologic features – reflections, diffraction effects, varying depth profile along the coast etc. Algorithm used to calculate wave parameters from acceleration data on navigational buoys, called WHAPAS (Wave Height An d Period Analysis Software), is rugged self contained software module running on data acquisition servers. Acceleration data as raw time series are transmitted over some time sequence and then analyzed (WHAPAS User Manual). Calculation method passed several simplifications and at the send it is simple straightforward formula containing two variables, measured on board navigational buoy acceleration and wave period. Still, an important correction factor naturally tied into calculation scheme is the so-called "buoy parameter", depending on the shape of the buoy, length of the chain, etc., so quite individual in every case. It must be cleared that WHAPAS analyses only significant wave height, not the maximal one as inertia of the navigational buoy is quite remarkable and therefore max wave heights are hard to estimate. In our comparison experiment at least depth of the sea at the locations used for comparisons is quite similar, shape of the buoys does vary in some extent, but not that much.

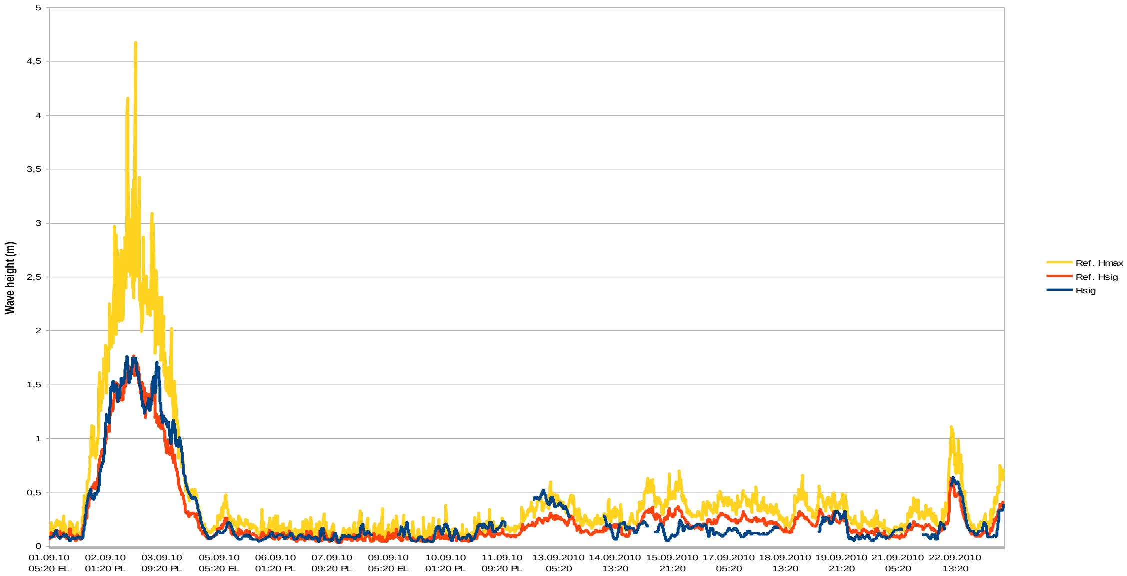


Figure 13 Significant wave height as measured by acceleration sensor on navigation buoy NM186 (blue) and pressure sensor based probe (red) in Karbimadal, first measurement period. Yellow line shows maximum wave height recorded by pressure probe.

1.8.1 Wave heights comparison for first measurement period: 1.-23.09.2011

Analyzing the measurements of the first measurement period, one can conclude that significant wave height calculated from acceleration sensor data and pressure probe fit with each other quite well, especially for Karbimadal. In fact, measurement period was quite interesting, as the main intention with late summer measurement period was to catch wave dynamics of a calm season; in fact, we got a severe NW-NNW storm with average wind speeds over 20m/s (Fig.14) already at the very beginning. This storm was exactly from that direction which creates highest waves in the study area, so significant wave heights up to 1.6m in Karbimadal and 2.8m in Kuradimuna were measured, while maximum wave height reached 4.5m and 5m respectively (Fig.13 and 15). Storm lasted just one day and was followed by calmer period, which is typical for that season, wind speeds still increased step by step, up to 10-12m/s, but direction was dominantly S, the wind being from the land, so the significant wave height stayed well below 0.5m during the first measurement period in Karbimadal and 1m in Kuradimuna. It is easily observable on Fig.15 that Kuradimuna represents more open sea conditions than Karbimadal, as even wind over land can induce maximum wave heights up to 3m in this location.

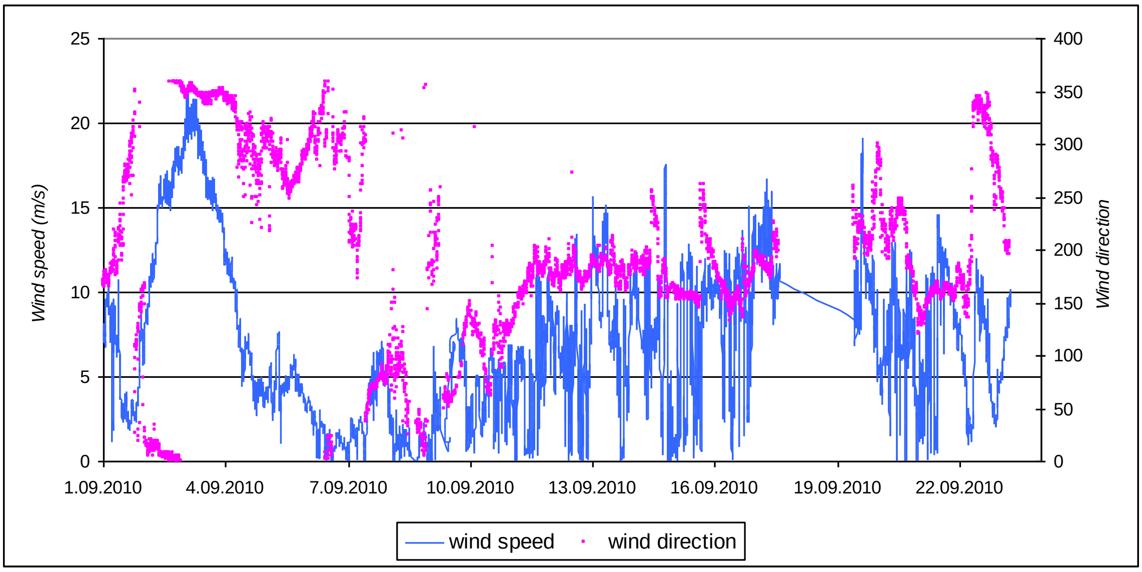


Figure 14 Wind speed and direction during the first measurement period.

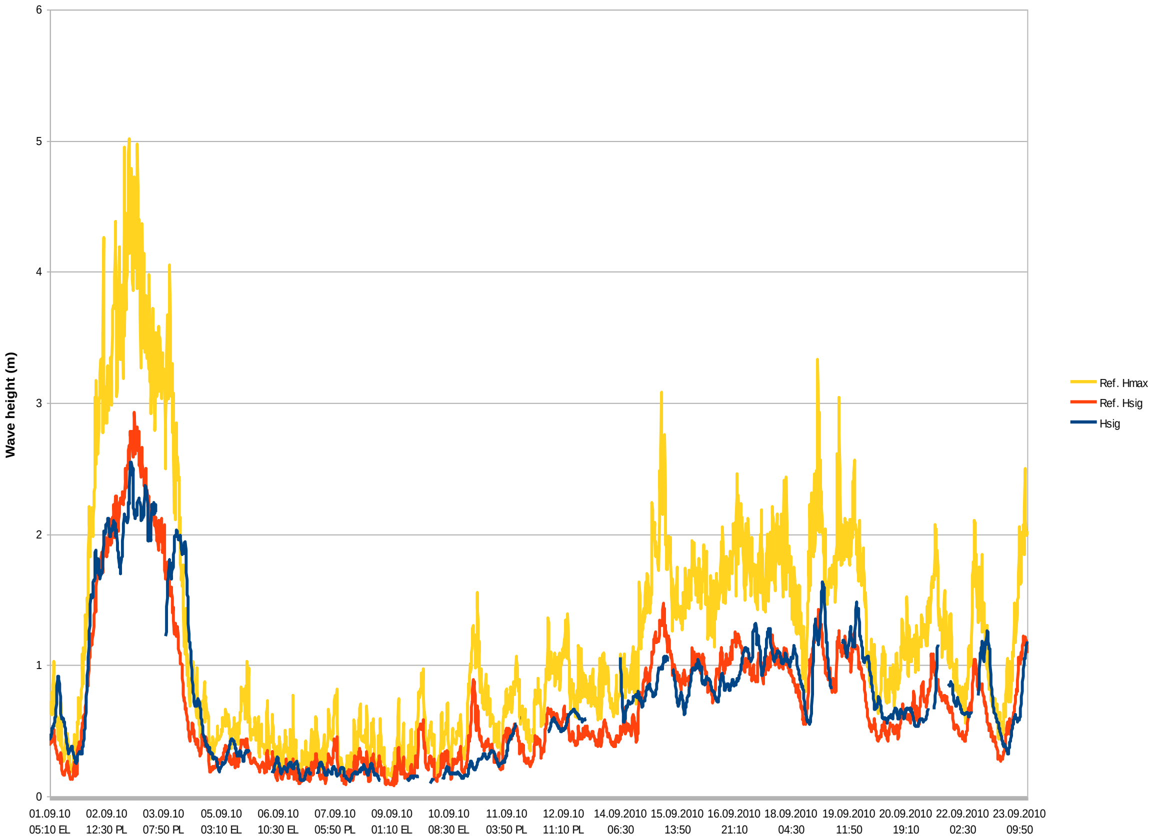


Figure 15 Significant wave height as measured by acceleration sensor on navigation buoy NM157 (blue) and pressure sensor based probe (red) in Kuradimuna, first measurement period. Yellow line shows maximum wave height recorded by pressure probe.

Statistically two datasets from two different methods look well fitting with each other over the entire measurement period –average difference in significant wave height comes in order of several cm-s up to 10cm. Still looking more detailed in differences of obtained significant wave heights for the first measurement period, given on Fig. 16 and 17 some more can be observed. In Karbimadal reference wave measurements are compared with wave data from three neighboring navigation buoys and in Kuradimuna from two buoys, see Fig.12 for location of navigation buoys.

In case of Karbimadal the best fit of two data series is achieved in case of NM186, which is actually the closest buoy to the wave measurement site, difference not more than 0.2m during the whole period. In general difference of significant wave height is biggest during the mentioned-above severe storm. In case of other buoys, differences are up to 0.8m (Fig.16), but obviously this is because of wave field spatial variability and not caused by measurement methodology.

In case of Kuradimuna the comparison results are not so good and that is the case for both navigation buoys NM157 and NM159. During storm difference of significant wave height reaches 1m (Fig.17), to remember wave height itself was up to 2.8m during that event. Still looking at comparison graph of two datasets (Fig.15), one can observe that navigation buoy has some inertia, starting later show higher waves and decay of waves comes a bit later – from those major deviations. That is quite reasonable as navigation buoys are heavy, together with chains maybe several tons and have, for sure, inertial effect if moving with waves. Otherwise, in Kuradimuna case, comparison of buoy and reference dataset difference show quite similar pattern in case of both navigation buoys, which show that wave field in Kuradimuna is comparably homogeneous in space. It should also be noted that in some time-moments wave height from navigation buoys fails for some period, and before failure spikes of wave height difference in reference measurements could be observed. Reason for that can't be estimated by using within current dataset, because of a problem with calculation software or feature coming already from acceleration sensor.

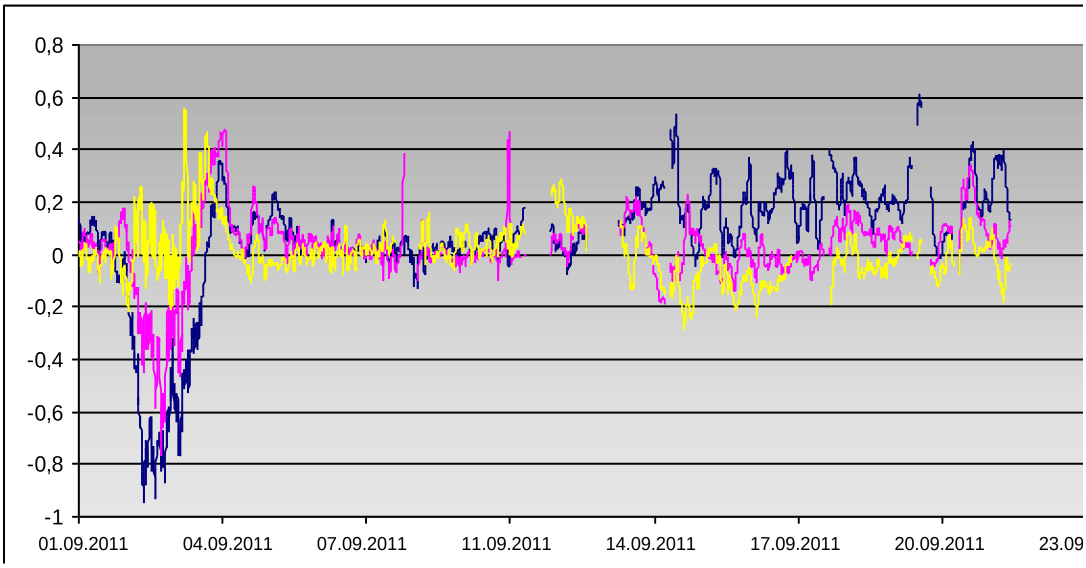


Figure 16 Graph showing difference in significant wave heights (in meters) as measured by acceleration sensor of three different navigation buoys close to the wave measurement site in Karbimadal, first measurement period.

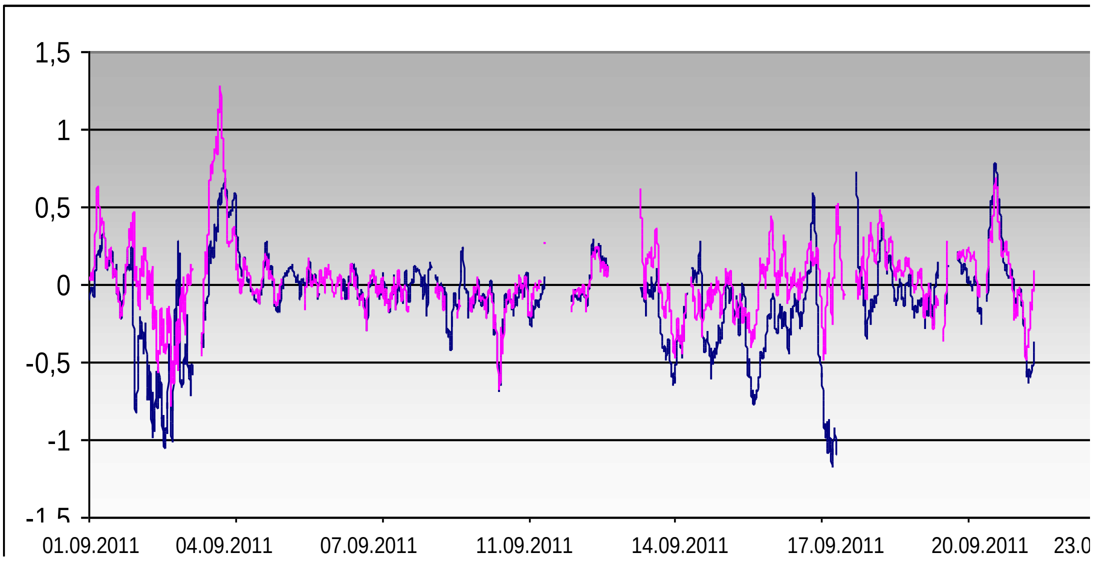


Figure 17 Graph showing difference in significant wave heights (in meters) as measured by acceleration sensor on navigation buoys close to the wave measurement site in Kuradimuna, first measurement period.

1.8.2 Wave heights comparison for second measurement period: 20.10 - 15.11.2011

The second measurement period is characterized by intense wave activity, especially at the Kuradimuna Bank. Wind forcing the wave generation several times reach 20m/s in average and once around Nov.10th even up to 25m/s. Wind direction was varying, with somewhat dominating SW direction, but the strongest wind events appeared from NE and other stronger wind blew from NW-N sector. In Kuradimuna the timing of both wave measurement time series compared to reference measurements are well coherent with each other. At some time instances the accelerometer data from navigation buoys overestimates pressure based measurements and sometimes underestimates. Due to the problems in data transfer during the strongest storms, we can't say, how well the navigational buoy data measured. Not going into depth of wave height calculation algorithm, one can say that the growth and dissipation phases during the two highest wave events, around Nov. 4th and 10th, were well reproduced by accelerometer data at Kuradimuna, which allows us to assume, that the wave event maximums were also well determined by this measurement method. Failure of data transmission during major wave events is of course a problem, as we didn't get very valuable comparison data for extreme wave situations, which in fact are rare, but very important from navigational point of view.

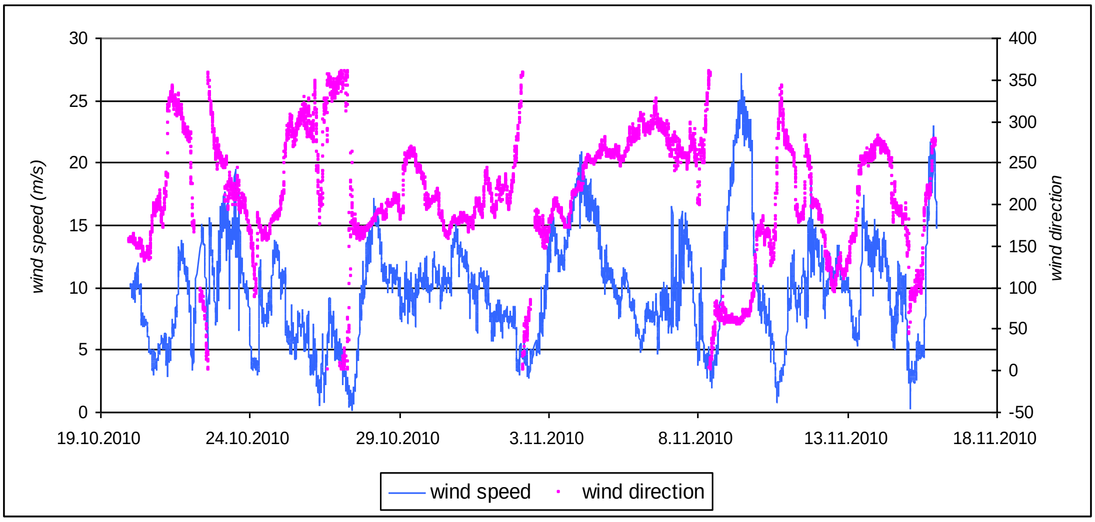


Figure 18 Wind speed and direction during the second measurement period.

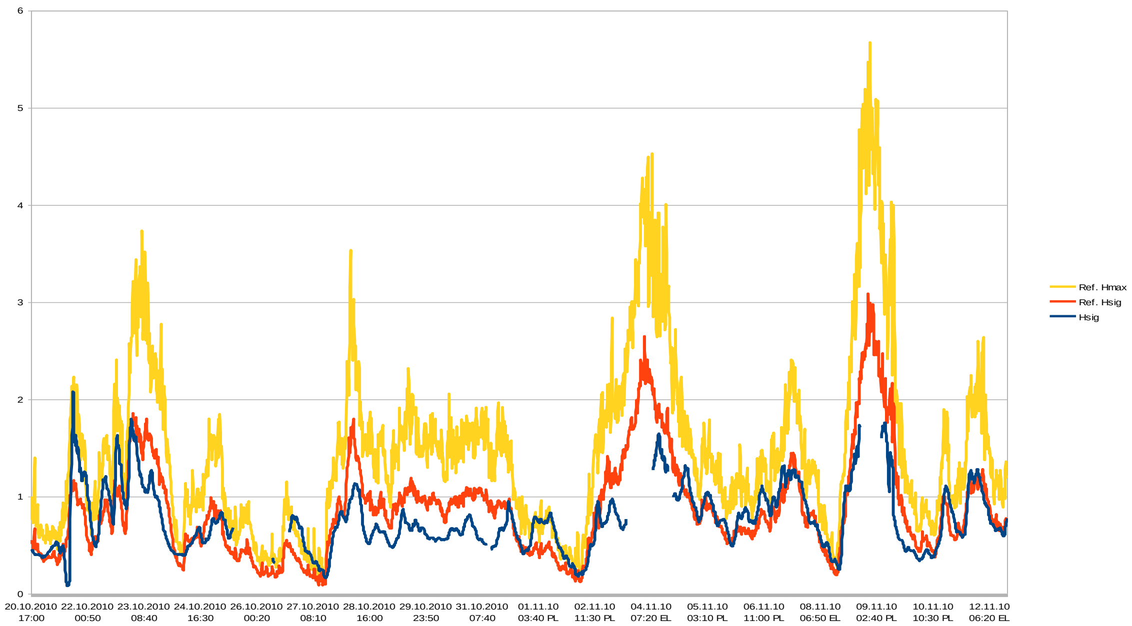


Figure 19 Significant wave height as measured by acceleration sensor on navigation buoy NM159 (blue) and pressure sensor based probe (red) in Kuradimuna, second measurement period. Yellow line shows maximum wave height recorded by pressure probe.

In the Karbimadal bank the accelerometers also capture significant wave heights quite well, but a drastic underestimation occurs in 4th November, when speed of SW wind reached about 20m/s. This underestimation is nearly 0.8 m (Fig. 22) and may be an instrumental/calculation algorithm failure, but can also be attributed to natural spatial variability of wave field in this particular case. In that context there can be pure wave field deformation because of sea bottom topography as well as too small wave period that navigation buoys badly represent. Still, positive is that in this strong wave case, where maximum wave height was reaching 1.8m in Karbimadal and 4m in Kuradimuna was at least in Karbimadal's case well captured by both measurement methods. Results, however, need further investigation to find out the reason for such a big difference between two data series in this quite prominent storm case. During another major storm event on Nov.10 data transfer from navigation buoys was unfortunately interrupted and we don't have comparison data with reference measurements for this event. Looking at dissipation phase of wave height time series, one can find out that in this part wave dynamics is well captured by both methods.

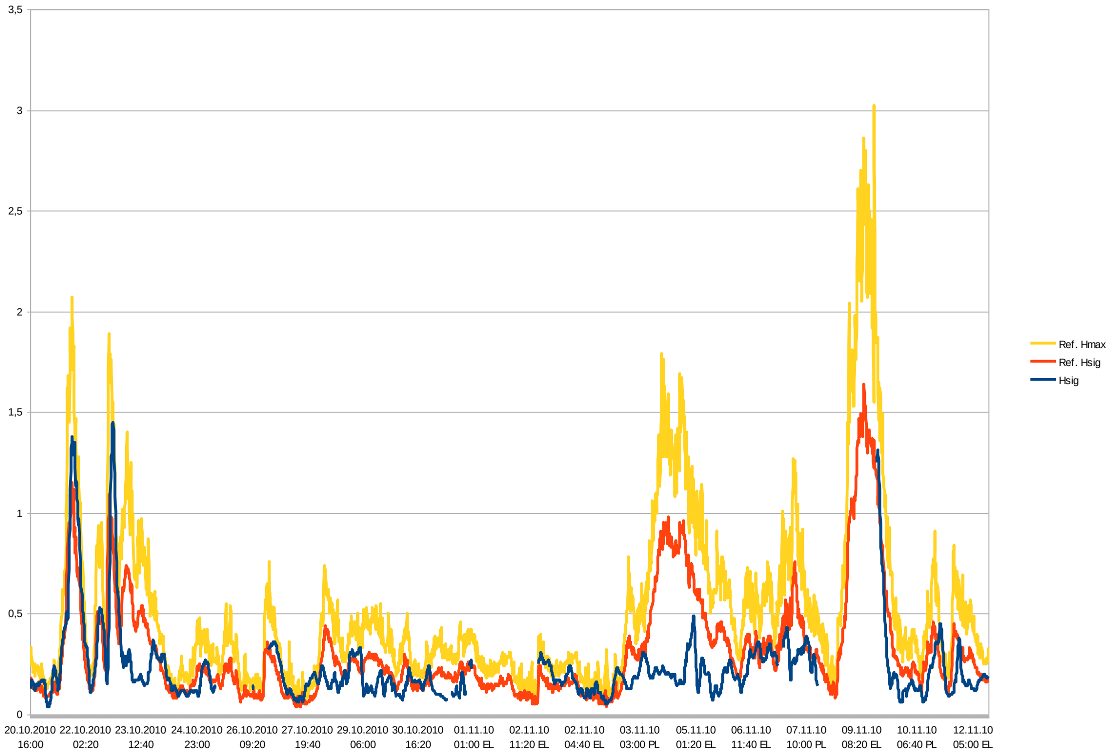


Figure 20 Significant wave height as measured by acceleration sensor on navigation buoy NM186 (blue) and pressure sensor based probe (red) in Karbimadal, second measurement period. Yellow line shows maximum wave height recorded by pressure probe.

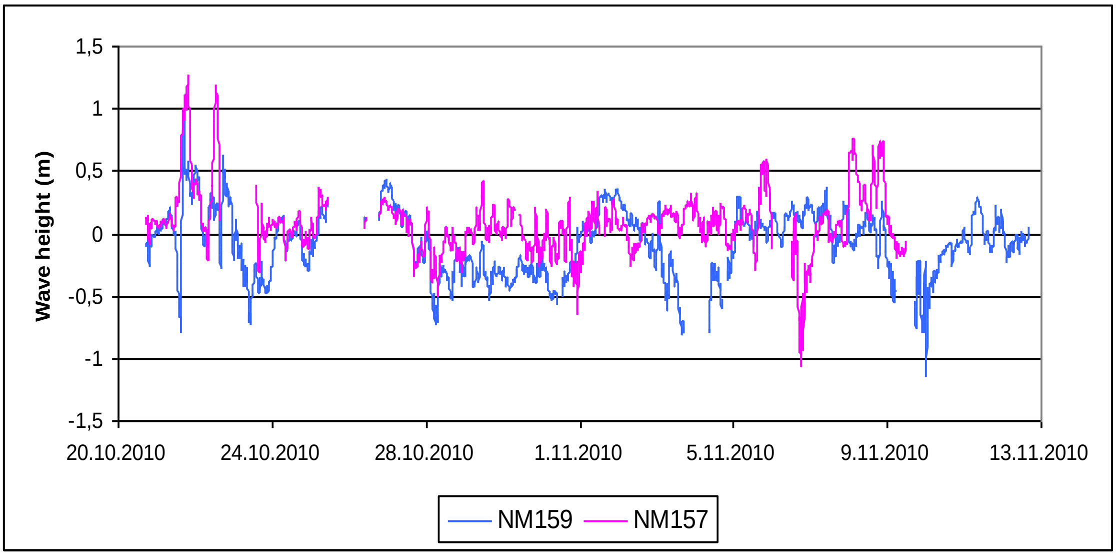


Figure 21 Graph showing difference in significant wave heights as measured by acceleration sensor on navigation buoys close to the wave measurement site in Kuradimuna, second measurement period.

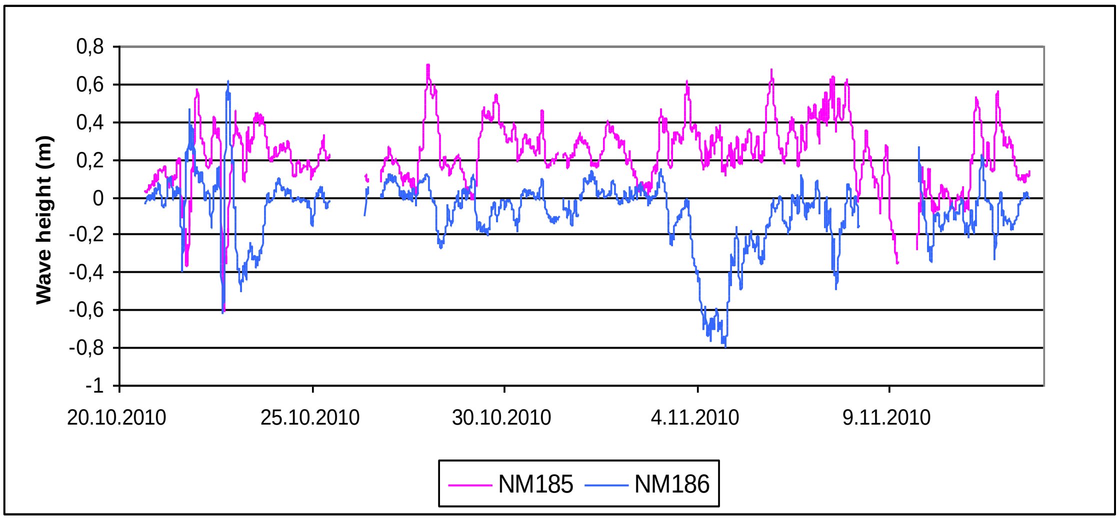


Figure 22 Graph showing difference in significant wave heights as measured by the acceleration sensor on navigation buoys close to the wave measurement site in Karbimadal, second measurement period.

1.9 Wave height comparison experiment general outcome

As these two measurement periods showed, general rating to the wave height data coming from the navigation buoys equipped with acceleration sensors is SATISFACTORY. Idea with the experiments was to make comparison of wave data from navigation sensors with data from pressure based wave probe data, both measurements made in very close vicinity of navigation buoys at Kuradimuna and Karbimadal. Open sea conditions (Gulf of Finland) were represented by

Kuradimuna and more coastal sea was represented by Karbimadal (Muuga bay). To cover seasonality, one measurement period was settled in August-September and another in October-November, which was not 100% successful as during late summer measurement period we observed the most intensive storm event at the very beginning of the period already. Nevertheless, when pressure based probe data are complete and continuous for both measurement periods, then navigation buoy data have significant breaks in, mainly because of communication failures. As method of wave measurement with acceleration sensors now means transfer of full package of raw acceleration data from buoy into server and processing in server, then obviously dependence from stability of communication line is high.

By analyzing wave height measurement results with two different methods, one can observe that average differences in wave heights between accelerometer's data and pressure based wave probe data are low, in some cases even very low - being lower than 10cm for most of the time series and reaching 20 cm only in some cases. Still there are some problems and these are the cases of high wave height, because of communication failure there are several cases when storm event was observed, with differing wave heights in Kuradimuna and Karbimadal, but no comparison data from navigation buoys. First storm at the very beginning was well captured in that sense, but measurement period in October-November was not very successful. As a result we have comparably few comparison data for higher wave heights, which in turn is not good as data from navigation buoys is dedicated for the navigation aid and high waves are a risk to notify about. As a result of comparison we also got that accelerometers (or current version of calculation algorithm) better represent lower waves, in case of higher than 2m waves differences with reference measurements were up to 1.5m (about 50%) in extreme cases. As we also observed, local variability pattern of wave field is important to take into account and most efficient way to do that is to implement wave modeling for this task. There exist several wave models, both for larger and also variable local scale, as usually navigation buoys are anchored at peculiarities of seafloor, usually shallows, then definitely in most sensitive places, like fairways, anchoring places etc. Occurrence of actual wave field needs detailed investigation, both with modeling and experimental tools. Shallows can create quite dangerous waves in one or another side depending on the wind that is described in literature as well observed by mariners. Modern navigation support systems should take these risks into account and reflect these in information systems in the best possible way. Another thing is, of course, improvement of existing wave calculation software WHAPAS, also in this case modeling could largely benefit.

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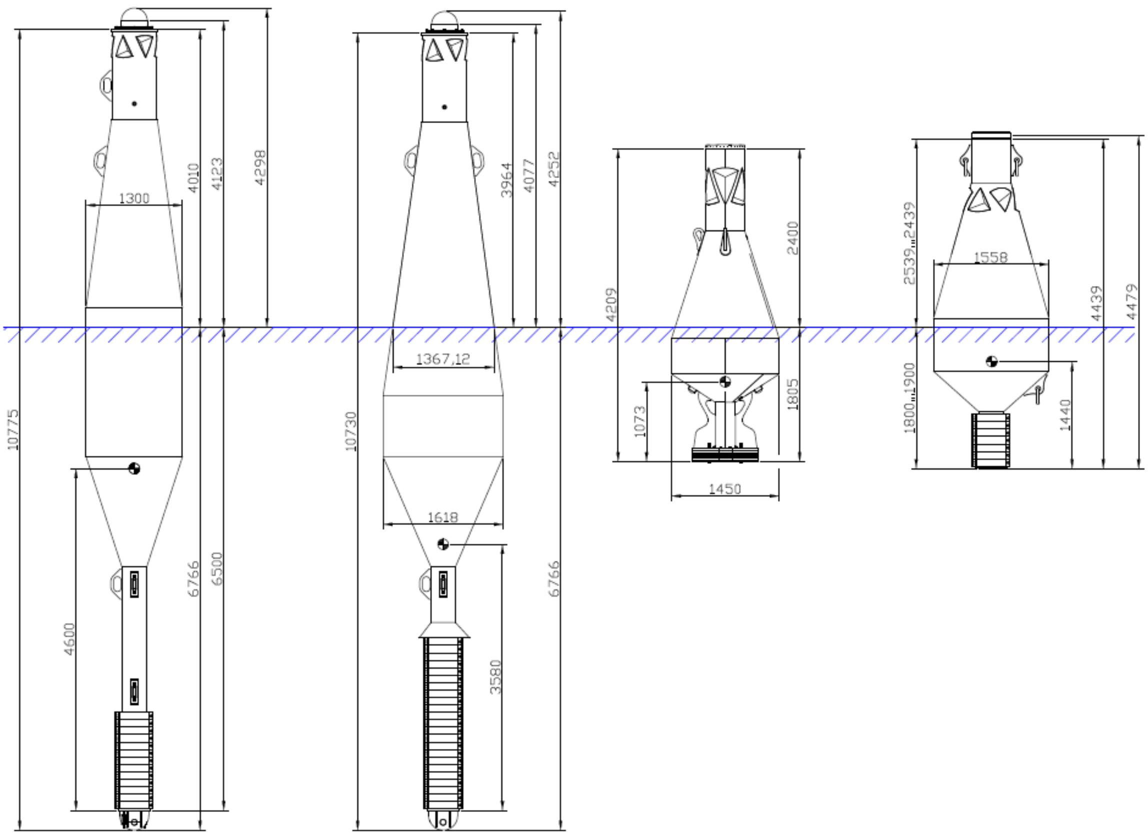
APPENDIX 2 Different buoy types, equipped with 3D acceleration sensors

Estonian Maritime Administration using 4 new buoy hull types SJP, AJP VJP and VJP2 for multi seasonal floating aids to navigation. Simultaneous field experiments for calibration measurements with pressure sensor were made in vicinity of buoy type SJP up till now.

Buoy characteristics	Buoy SJP	Buoy AJP	Buoy VJP	Buoy VJP2
Hull weight	2.2 t	2.5 t		0.8 t
Total weight	3.5 t	4.8 t	1.5 t	1.5 t
Length	10.8 m	10.7 m	4.2 m	4.4 m
Height over water level	4.0 m	4.1 m	2.5 m	2.7 m
Draught	6.8 m	6.8 m	1.8 m	1.9 m
Maximum diameter	1.3 m	1.6 m	1.5 m	1.6 m
Depht for centre of gravity [1]	1.90 m	2.92 m	0.73 m	0.46 m
Minimum depth	16 m	20 m	2 m	2 m
Mooring weight for min. depth [2]*	358.4 kg	430,08 kg	4.48 kg	4.48 kg
Maximum depth	55 m	100 m	20 m	20 m
Mooring weight for max. depth [2]*	1232.0 kg	2240.0 kg	430,1 kg	430,1 kg

[1] - with total weight [2] - with 32 mm chain

Ice buoy SJP Ice buoy AJP Ice buoy VJP Ice buoy VJP2



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APPENDIX 3 TelFiCon E9263.1 product data and user manual

3.1 SCOPE

3.1.1 This document is intended for provision of guidelines for installation and use of the Telematics Field Controller (TelFiCon) E9263.1 set. Technical information is presented only to the extent necessary for application of the set.

3.1.2 The E9263.1 is designed for industrial/institutional use in accordance with requirements of the standard "*Maritime navigation and radiocommunication equipment and systems. General requirements. Methods of testing and required test results", EN 60945*, in addition to European safety and EMC requirements. Once installed on an aid to navigation (AtoN) object and powered up, a TelFiCon interacts with the TeViNSA (Telematics for Visual Navigation Situational Awareness) remote control and monitoring centre at a pre-programmed IP address.

3.2 SAFETY INFORMATION

3.2.1 A TelFiCon is an extra low voltage device (power supply voltage below 24 VDC) and has no exposed metal surfaces subjected to voltages in relation to each other, or the GND terminal. A PE terminal is not present.

3.2.2 During the installation of the set on the navigation aid structure, attention should be paid to handling of the carrier plate edges (if supplied) in order to avoid damaging the skin.

3.3 DESCRIPTION

3.3.1 The TelFiCon product family is designed at Cybernetica AS for implementing communication, control and measurement functions in remote visual aid to navigation systems connected to the TeViNSA control and monitoring centre over public GSM-900/1800 GPRS based IP networks. The TelFiCon architecture integrates a microcontroller running proprietary firmware with standard GSM and GPS sub-modules and internal sensors.

3.3.2 The set consists of an electronics module E9263.1 (Figure 1) with an E9264 circuit board inside, and of a combined GSM/GPS magnetic mount antenna TecSys AU-3S-GSM (Figure 2) with GSM and GPS cables of 2m to 5m length. Typically, an E9264 is supplied in integrated form within some of LED lanterns manufactured by Cybernetica AS, offering better protection from environmental factors. The E9263.1 module is intended for use during short term experiments onboard a navigational buoy to determine buoy movement by the means of registering accelerations in three axes of the buoy, sampling the outputs of a three-axial micromechanical accelerometer sensor mounted on the E9264 circuit board, and sending measurement values to the TeViNSA centre for processing. The module is designed for installation inside an equipment container / compartment of a navigational buoy, protecting the module from direct contact with salt water and mechanical factors.

3.3.3 The E9264 circuit board is housed within a rectangular ABS plastic enclosure of gray colour with screw terminals and coaxial cable receptacles located on the right side

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surface. It mounts to flat surface with screw hole pattern 90 x 110 mm (Figure 3). A metal carrier plate with application specific location of the mounting holes can be ordered.

3.3.4 Direction of the acceleration sensor axes is marked on the top lid and side of the enclosure with stickers pointing out the direction of acceleration regarded as positive for measurement values registered on X, Y, and Z axes. The sensor itself is located practically on the vertical centreline of the enclosure, 25 mm to the centre from the outer right edge.

Figure 1. Electronics module of the TelFiCon E9263.1 Set, view from above.

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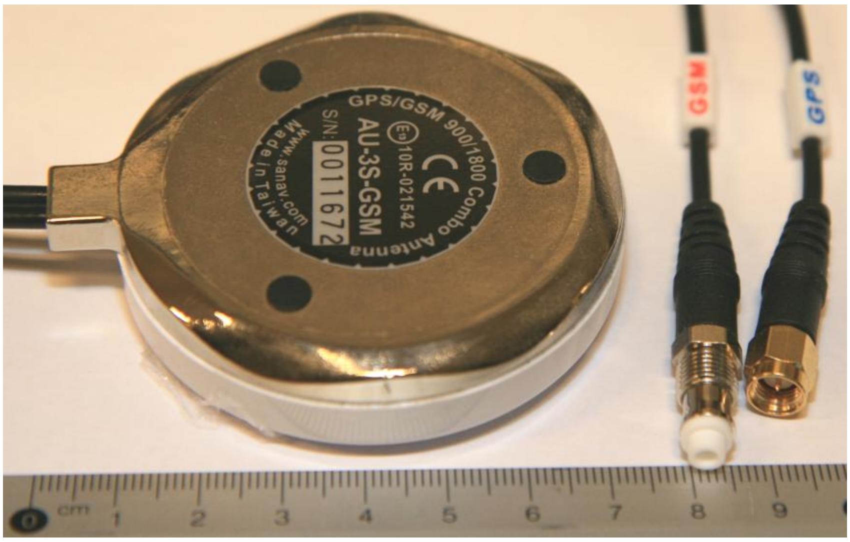

Figure 2. GSM/GPS antenna TecSys AU-3S-GSM with magnetic mount supplied in the E9263 Set

3.4 ELECTRICAL SPECIFICATIONS

3.4.1 Power supply voltage: 8 VDC to 20 VDC.

3.4.2 Power consumption at 25°C is provided in Table 1.

Table 2. Power consumption modes of TelFiCon E9261

Power mode	State of GSM/GPS submodules		Current consumption at power supply voltage	
	GPS (incl. antenna)	GSM	12 VDC	20 VDC
1	OFF	OFF	2.2 mA	2.0 mA
2	OFF	ON / Reception	4.0 mA	3.5 mA
3	ON	OFF	16.2 mA	11.5 mA
4	ON	ON / Reception	18 mA	13.0 mA
5	ON	ON / Transmission	70 .. 120 mA	< 90.0 mA

NOTE: Both the GSM and GPS submodules are constantly powered (mode 4) in acceleration measurement application, with the power consumption increasing periodically

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when the module enters the transmission power mode (5) for up to one second every time it has acquired a full buffer (252 Bytes) of measurement samples (63 samples from each axis).

Example: Average current consumption in continuous buffered acceleration measurement mode with 50 ms sampling interval within excellent GSM signal coverage:60 mA (12 VDC) / 40 mA (20 VDC), resulting in daily consumption of 1.44 A / 0.96 A.

3.4.3 Reverse polarity circuit protection: implemented.
3.4.4 Power supply terminations: screw terminals for up to 1 mm wires and 3mm blade screwdriver.

3.5 CONTROL AND COMMUNICATION SPECIFICATIONS

3.5.1 When powered up, a TelFiCon unit attempts to establish a connection over GSM/GPRS IP network with the control and monitoring centre server running at Cybernetica AS, Estonia, to report its current status and position, and to download optional mission parameters. Settings necessary to enter the IP network of a specific service provider need to be pre-configured using dedicated maintenance software before deploying the unit.

3.5.2 In case of a typical application scenario, a TelFiCon monitors status and position of an aid to navigation outstation, using a proprietary RS485-based local area network to connect to flashers and power supplies of **ekta™** brand manufactured by Cybernetica AS, reporting to TeViNSA control and monitoring centre at the intervals configured by the centre over the air.

3.5.3 Acceleration measurement within ±3 g on three axes with the resolution of 0.01 g is an optional feature of a Telficon unit. An acceleration measurement mission is activated by the TeViNSA centre in either continuous or periodic mode, resulting in data traffic corresponding to sampling interval and the duration of data acquisition sessions as described in Table 2.

3.5.4 The sampling interval, data acquisition interval, and data acquisition session length can be changed using the TeViNSA centre over the air in the beginning of a communications session with TelFiCon. The acceleration values recorded can be made available for detailed analysis in the form of CSV files.

3.5.5 A TelFiCon features built-in capability for acceleration based buoy heel angle calculation with a resolution of 1 degree, variable sensor output sampling times, and time averaging for average angle as well as excessive and critical heel angle alarms. To obtain meaningful heel angle statistics, averaging times must not exceed the regular reporting interval length.

3.5.6 To conduct uninterrupted communications over the GSM/GPRS IP connection, GSM signal level at the E9263.1 input should be - 70 dB and above. Use of antenna with 5m cables is not recommended in borderline areas of GSM coverage.

3.5.7 In addition to heel angle calculation and monitoring, a TelFiCon can be used for monitoring and reporting of collisions detected when acceleration sensor output exceeds pre-configured level.

3.5.8. After implementation of the Firmware-over-the-Air (FOTA) capability in 2010, in addition to the remote changing of settings, the firmware of the TelFiCon E9263.1 can be updated in full from the remote monitoring centre over the GSM/GPRS network connection in case of updated firmware version becoming available, or significant change in mission objectives.

Table 2. Expected approximate gross data rates required for transfer of acceleration data from TelFiCon E926X to shore server over cellular IP network

No.	Data acquisition and transfer mode	Sampling interval, ms	Data acquisition session initiation interval, minutes	Data acquisition session length, minutes	Hourly gross data rate, kB/hour	Daily gross data rate, MB/day	Monthly gross data rate, MB/month
1	Continuous	50	continuous sampling	continuous sampling	375	8.8	273
2	Continuous	200	continuous sampling	continuous sampling	96	2.3	70
3	Periodic	50	30	10	126	3.0	92
4	Periodic	200	30	10	32	0.8	24

3.6 PHYSICAL SPECIFICATIONS

3.6.1 Maximum Height of E9263.1: 65 mm

3.6.2 Maximum Width of E9263.1: 133 mm

3.6.3 Maximum Depth of E9263.1: 122 mm

3.6.4 Maximum Weight of E9263.1, excluding antenna: 0.35 kg

3.6.5 Materials:

3.6.5.1 E9263.1 enclosure: ABS

3.6.6 Ingress Protection:

3.6.6.1 E9263.1 enclosure: IP64 (EN 60529)

3.6.6.2 GSM/GPS antenna: IP67 (EN 60529)

3.6.7 GSM/GPS antenna TecSys AU-3S-GSM size (excluding cables and cable entry hood):

64.5mm (D) x 14mm (H)

Cable length: 5m for antenna with magnetic mount (optional: 1.2m or 2m, through-hole mount)

Weight: 0.15 kg with magnetic mount and 2m cables

3.6.8 Description of E9263.1 mounting hole pattern: 4x 4mm holes in the corners of a E9263.1 box measuring 110x90 mm (Figure 3): using these holes for fixing needs opening of cover of E9263.1

3.6.9 Description of antenna mounting: magnetic mount, required area 80 x 80 mm (hole pattern for through-hole antenna: one 12.5 mm hole, optimal thickness of structure 5 mm)

3.7 ENVIRONMENTAL CONDITIONS OF USE

3.7.1 The electronic module E9263.1 is designed for application in the following environmental conditions:

3.7.1.1 Temperature of the environment between –25°C to +70°C

3.7.1.2 Relative humidity of the air of 90% at +30 °C

3.7.2 Ingress protection class of the E9263.1 module is IP 64

3.7.3 Vibration tolerance limits: up to 5 g, 10 Hz – 2 kHz (EN 60945-8.7, EN 61068-2-6)

3.7.4 Shock tolerance limits: up to 6 shocks of up to 10 g in any of 3 axes (EN 61068-2-27)

3.7.5 EMC immunity: within the limits of EN 60945 p.10, EN 61 000-4-2, EN 61000-4-3,

EN 61000-4-4, EN 61000-4-5, EN 61000-4-6, EN 61000-4-8, EN 61000-4-11

3.7.6 EMC emissions: within the limits of EN 60945 p.9, EN55016-1-1, EN55016-1-2, EN55016-1-3, EN55016-1-4

3.8 INSTALLATION AND ELECTRICAL CONNECTIONS

3.8.1 For obtaining best results at acceleration measurement, it is recommended to mount the E9263.1 electronic module as close as possible to the centre of gravity of a navigational buoy with one of the side surfaces of the box strictly co-aligned with the vertical axis of the buoy. When possible, it is recommended to mount the box horizontally (label up; upper drawing in Figure 3); this way the Z-axis of the sensor registers the vertical movement.

Note: To obtain correct results of the buoy heel angle calculation and shore-based wave height measurement, the settings of a TelFiCon need to be updated when the vertical axis is not Z.

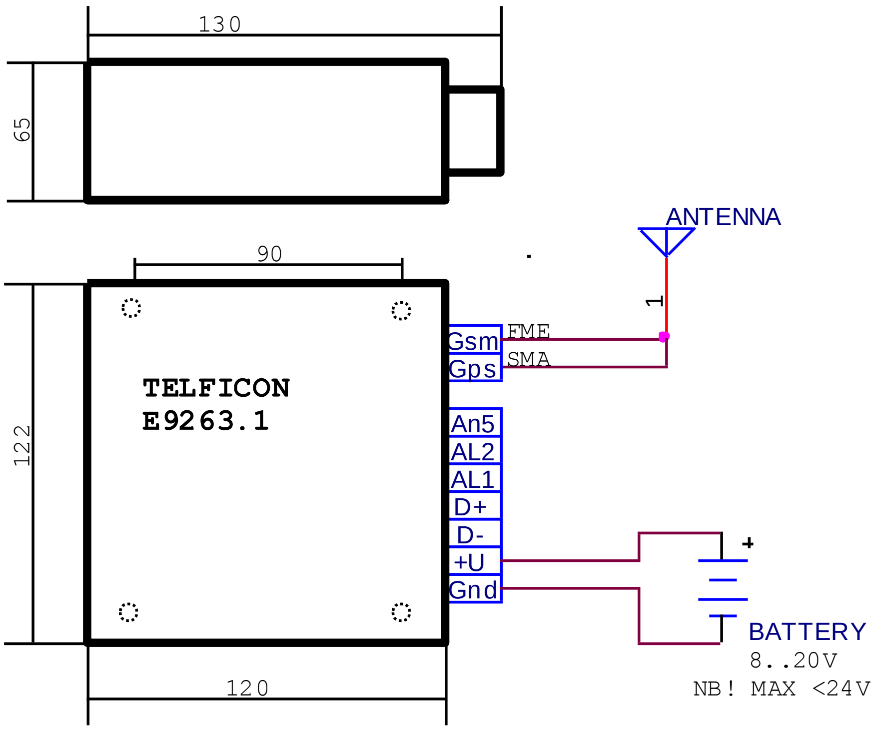

Figure 3. TelFiCon E9263.1 dimensions and connections

3.8.2 Determine the suitable locations for installation of the E9263.1 and the antenna (with unobstructed viewing of the sky for best GSM and GPS reception), considering sufficiency of antenna and power cable lengths. Do not bend the cables under sharp angles, paying attention to the cables exiting the antenna with magnetic mount. Observe all relevant safety rules and regulations when performing the works on aid to navigation structures.

3.8.3 In case that the TelFiCon is supplied without a metal carrier plated, the top lid needs to be removed by loosening four screws in each corner using a screwdriver with Pozidriv PZ2 head. Note: It is strongly not recommended to open the TelFiCon enclosure in conditions of rain, snowfall, or other similar conditions creating a risk for any substances entering the enclosure.

3.8.4 Prepare the surfaces as necessary and fix the parts firmly on host structure. Do not fix the antenna with magnetic mount using materials blocking its RF signals. Do not install the E9263.1 enclosure on uneven surfaces where firm contact with host structure cannot be achieved, or the enclosure would remain under mechanical tension.

3.8.5 Route the antenna and power cables to the inside of the equipment cabinet and fix them firmly to the structure to prevent damage from vibration (as foreseen by the navigation mark design), observing good practice of handling coaxial RF cables.

3.8.6 Make all the connections to the E9263.1 terminals with de-energized power circuit in accordance with Table 3, starting with antenna connections (SMA and FME). A screwdriver with 3mm blade is recommended for making the electrical connections to screw terminals.

3.8.7 Power up the E9263.1. **Before deploying the buoy, make sure that the E9263.1 has established a connection with TeViNSA remote control and monitoring centre server by contacting the Cybernetica AS telematics team.**

3.8.8 In order to establish the acceleration sensor positioning offset after installation of a TelFiCon on a buoy, is recommended to perform transmission of acceleration measurement and heel angle data to the TeViNSA centre from the buoy maintained in stable upright position for the duration of at least 10 minutes, whenever possible. Corresponding times need to be marked and the Cybernetica telematics team notified correspondingly.

3.8.9 Input terminals AL1, AL2 and AN5 can be utilized for monitoring of digital and analog signals. A TelFiCon needs to be properly configured in order to activate alarm message transmission to the TeViNSA centre. Contact Cybernetica AS for detailed specifications when necessary.

Table 3. Electrical and signal connections to E9263.1 (listed from bottom up)

No.	Marking	Description
1.	GND	Power supply “-“; 0V
2.	+U	Power supply “+”; +8..+20VDC NOTE: Absolute short-term maximum rating is 24VDC
3.	DAT-	Digital communication port for configuration and maintenance using proprietary tools (RS-485)
4.	DAT+	
5.	AL1	Digital input signal lines

6.	AL2	
7.	AN5	Analog input; Measurement range 0..3.3V; 10 bit ADC
Coaxial connectors		
8.	GPS	SMA Female connector; to active GPS antenna
9.	GSM	FME Male connector; to GSM 900/1800 antenna

3.9 CONTACT INFORMATION OF THE SUPPLIER

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