Spatial Variability of the Wave Field Generated in an Offshore Basin

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ABSTRACT

Results of a study on the spatial variability of irregular wave fields generated in an offshore basin are presented. The available data set consists of approximately 3-hour deep and shallow water time series of the free surface elevation. Some of the shallow water wave fields include a simultaneous current. The spatial variability has been checked by means of nonparametric and parametric statistical significance tests. The nonparametric methods serve to validate the conclusions of the parametric ones, since they are considered more reliable when samples with non-Gaussian statistics are checked. The statistical tests were applied to various sets of data from two locations and also multivariate tests were performed for the whole set of 15 gauges deployed in the basin.

Keywords: *Wave spatial variability, Statistical tests, Model tests*

1. INTRODUCTION

The model tests in a tank are of importance for the study of the physical processes observed in the real sea and are currently used to determine the motions and loads of ships and offshore platforms. They are especially important to understand non-linear phenomena, such as ship stability in waves and capsizing. The offshore basins offer the possibility of testing self-propelled ship models and this is very useful for studying stability of ships in waves.

The problem of using the whole area of the basin for the model tests is to ensure that the wave field is properly generated and the wave properties are maintained spatially. The limited size of the basin generates effects that are not observed in the open ocean, as reflection of the incident waves from the end wall of the basin and interaction effects from the sidewalls among others. They can change the wave field, such that it can have different statistical properties in the affected areas of the basin. It is therefore important to determine those regions where the wave characteristics can be considered identical from a statistical point of view.

The other problem concerns the duration of the generated time series, which are expected to be sufficiently long for analysis, but this raises the question of maintaining stationary conditions during the process of measurements. Moreover, the model tests are carried out assuming identical wave conditions not only in time (stationarity), but also in space (homogeneity). Thus, the wave field at different locations in the tank is expected to follow similar statistical representation.

In order to check the consistency between the wave statistics in space and time, two types of statistical tests can be used: parametric ones, based on a preliminary assumption of the form of the underlying distribution and nonparametric, which are distribution-free

(Conover, 1980; Hogg and Tanis, 1993; Sprent, 1989).

The parametric tests assume that the initial population has a Gaussian distribution or the distribution is slightly skewed. However, when the process is non-Gaussian the parametric tests are expected to yield non-reliable statistics. In case of highly skewed data sets, the sample mean and variance become more dependent and it makes the Student's distribution inappropriate for testing the means of two samples. Moreover, this test loses its power when applied to samples with observed outliers, since the distribution should be symmetric. When the distributions are almost Gaussian but differ in variances the *T*-statistics should also be avoided.

In these cases, nonparametric tests are applied as an alternative and better option. The reason is that they are based on weaker initial assumptions; they are more powerful, i.e. have increased potential to show significant result when the true value of the obtained test statistic is estimated towards the alternative hypothesis and refer to the robust methods, which are less affected by the presence of outliers in the samples.

The results of the tests also depend on the imposed level of significance, since it determines the size of the critical region for the tested null hypothesis. Usually, the level of significance is set at 0.05, which means that in no more than one in twenty statistical tests type I error can occur. However, in the case of multiple tests performed, the risk of making such an error increases, due to statistical variability in the total experiment.

A way to avoid this problem is to use the Bonferroni correction. The method reduces the level of significance of each individual test, in order to assure that the overall experiment-wise level of significance for the total number of performed tests is conserved.

The paper presents the results of a study of the spatial variability of waves in an ocean basin laboratory by using statistical tests to determine if the statistical properties of the samples of waves measured at different locations of the tank are consistent, i.e. if they all belong to the same population.

The aim of the paper is not only the spatial analysis of the specific basin characteristics, but also to present an approach that can be adopted in other cases of studying the spatial variability of the data. Although the approach adopted uses well established statistical tests, the authors are not aware of any papers showing results from investigations of the spatial variability of waves in an offshore basin, using these methods.

The statistical significance tests are briefly reviewed in section 2. Description of the data sets and the samples used for the statistical tests is given in section 3. Analysis and discussion of the results is done in section 4. The general conclusions about the spatial variability of the wave field in an offshore basin are presented in section 5.

2. STATISTICAL TESTS

2.1 Parametric Statistical Tests

Location Test of the Equality of Two Independent Normal Distributions The null hypothesis of the test, $H_0 : \mu_X = \mu_Y$, states that two randomly chosen samples, X and Y, derived from normally distributed populations, $N(\mu_X, \sigma_X^2)$ and $N(\mu_Y, \sigma_Y^2)$, that have equal variances, $\sigma_X^2 = \sigma_Y^2$, have also equal means, $\mu_X = \mu_Y$. The test statistic, *T*, follows the Students' distribution with $r = n + m - 2$ degrees of freedom.

$$T = \frac{\overline{X} - \overline{Y}}{\sqrt{\left[\frac{(n-1)S_X^2 + (m-1)S_Y^2}{n+m-2}\right]\left(\frac{1}{n} + \frac{1}{m}\right)}} \qquad (1)$$

where *n* and *m* are the sizes of *X* and *Y*; $\overline{X}$ and $\overline{Y}$ are the sample means; S_X^2 and S_Y^2 are the sample variances. The alternative hypotheses and the corresponding critical regions are shown in Table 7.4-1 in Hogg and Tanis (1993).

Two-sample variance test The test statistic has F-distribution with $r_1 = n-1$ and $r_2 = m-1$ degrees of freedom. The critical regions are given in Table 7.4-2 in Hogg and Tanis (1993).

$$F = \frac{(n-1)S_X^2 / \left[\sigma_X^2(n-1)\right]}{(m-1)S_Y^2 / \left[\sigma_Y^2(m-1)\right]} = \frac{S_X^2}{S_Y^2} \tag{2}$$

One-way ANOVA test The test checks the equality between several independent normal distributions, $N(\mu_i, \sigma_i^2)_{i=1,\ldots,m}$, with unknown means and unknown, but equal variances. The test statistic is the ratio between two unbiased estimators of the populational standard deviation σ^2, i.e. *SS(T)* - the sum of squares among the treatments and *SS(E)* - the sum of squares within the treatments

$$\frac{SS(T)/(m-1)}{SS(E)/(n-m)} = F \tag{3}$$

The statistic has F-distribution with $r_1 = m-1$ and $r_2 = n-m$ degrees of freedom. The critical region for the null hypothesis, $H_0 : \mu_1 = \ldots = \mu_{i=1,\ldots,m}$, is $F \geq F_\alpha(m-1, n-m)$, where the reference value F_α is calculated from Table VII of the Appendix in Hogg and Tanis (1993).

2.2 Nonparametric Statistical Tests Based on Ranks

Wilcoxon-Mann-Whitney Test for Two Sample Means The assumptions are independence within and between the considered random samples and similar shapes of the populational distributions, which can be also asymmetrical. Each data in the ordered sample $X_{i1}, X_{i2}, \ldots, X_{in_i}$, where $n_{i=1,2}$ denotes the sample size, has a rank from 1 to $n = n_1 + n_2$. The test statistic, T, equals the sum of the assigned ranks to one of the populations

The null hypothesis $H_0 : F(x) = G(x)$, where F and G correspond to the considered sample distributions, is accepted if there is no trend towards larger or smaller positions in the combined ordered sample. In the case of ties the correspondent T-statistic is given by Conover (1980).

Variance Test for Two Samples The absolute deviation from the mean of each data is ranked. The test statistic is defined as the sum of squares of the ranks assigned to one of the populations, e.g.

$$T = \sum_{i=1}^{n_1} \left[R(U_i)\right]^2 \tag{4}$$

In the case of ties, the rank is obtained as an average of the associated ranks.

Location Test of the Equality Between Several Samples – Kruskal-Wallis Test The test is an expansion of the two-sample Wilcoxon test to several independent samples, say m, of size $n_{i=1,..,m}$, $X_{i1}, X_{i2}, \ldots, X_{in_i}$. The procedure is the same as in the Wilcoxon test: the samples are combined and set in ascending order and to each value is given a rank or mid-rank in case of tied observations. Let $R(X_{ij})$ be the rank of X_{ij} and R_i - the rank assigned to the *i*th sample

$$R_i = \sum_{j=1}^{n_i} R(X_{ij}),\ i = 1, \ldots, m \tag{5}$$

The test statistic is given by

$$T = \frac{1}{S^2}\left(\sum_{i=1}^{k} \frac{R_i^2}{n_i} - \frac{n(n+1)^2}{4}\right) \tag{6}$$

with n designating the total number of observations and

$$S^2 = \frac{1}{n-1}\left(\sum_{allranks} R(X_{ij})^2 - \frac{n(n+1)^2}{4}\right) \tag{7}$$

The decision about the test depends on the rules defined in Conover (1980).

Variance test for several samples The nonparametric variance test for two samples is extended to the case of m samples. The test statistic is formulated as

$$T_2 = \frac{1}{D^2}\left[\sum_{i=1}^{m}\frac{S_i^2}{n_i} - n\left(\bar{S}\right)^2\right] \tag{8}$$

where n_i is the number of observations in sample i; $n = n_1 + n_2 + ... + n_m$; S_i is the sum of squared ranks in ith sample; $\bar{S} = \frac{1}{n}\sum_{i=1}^{m} S_i$ is the average of the squared ranks; $\sum R_i^4$ is the sum calculated after raising each rank to the power of four and $D^2 = \frac{1}{n-1}\left[\sum_{i=1}^{n} R_i^4 - n\left(\bar{S}\right)^2\right]$. The full description of the test is given in Conover (1980).

Bonferroni Correction The Bonferroni correction is applied to the multiple tests - the level of significance of each individual test is decreased, in order to assure that the experiment-wise level of significance remains the same. Although this adjustment decreases the risk of making type I error, it has a disadvantage of increasing the chance of making type II error at the same time.

Considering that the number of gauges is n=15, the total number of performed tests will be $N_{total} = n(n-1)/2 = 105$. The correction is given as the ratio between the level of significance of the entire set of experiments, α, and the number of performed tests N_{total}.

2.3 Statistical Test for Stationarity

Nonparametric run test is applied to check the stationarity of the process (Bendat and Piersol, 1971). The test considers a sequence of N random observations, $X_{i=1...N}$. If the sample mean is $\bar{X}$, then each observation obtains a sign (+) if $X_i \geq \bar{X}$, and sign (-), if $X_i < \bar{X}$. Subsequently, the run, r, is defined in the sequence of positive and negative signs as the sequence of identical observations, preceded by a different observation, or no observation at all. The region where the hypothesis should be accepted is determined as

$$r_{\frac{N}{2},1-\frac{\alpha}{2}} < r \leq r_{\frac{N}{2},\frac{\alpha}{2}} \tag{9}$$

The corresponding r values are calculated from Table A.6 in Bendat and Piersol (1971).

3. DESCRIPTION OF THE DATA SETS

The study uses time series of the surface elevation recorded in the offshore basin of MARINTEK. The measurements were performed by total of 23 gauges, but the set of data in the study is referred to 15 of them, deployed in the tank as shown in Figure 1.

Two wave generators were applied, BM2 and BM3 located at the beginning of the basin and at one of its side walls, respectively. The tank has a beach at the wall opposite to BM2, which serves to absorb the energy of the incident waves.

The basic characteristics of the generated deep and shallow water sea states are given in Table 1 and Table 2. The information includes the significant wave height, H_s; the spectral peak period, T_p; the type of the spectrum and the current velocity, U_c, when current has also been generated. The last column shows the associated wavemaker.

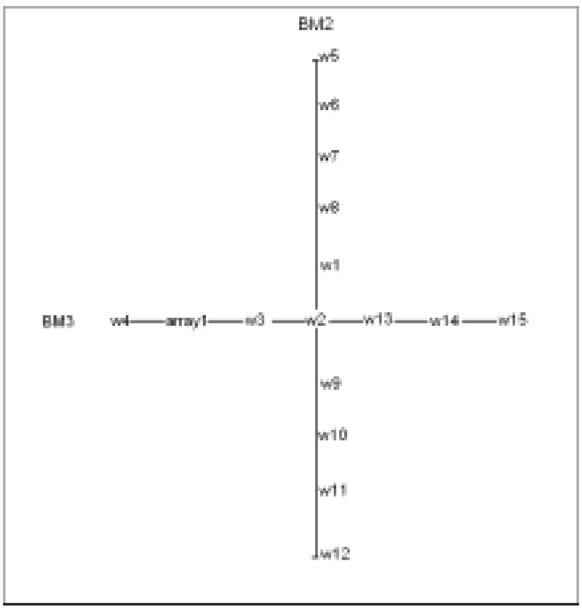

Figure 1. Location of the wave gauges and wave generators

In the deep water tests the water depth was maintained at 100m (in scale). The test runs 8201, 8202, 8219 and 8241 correspond to unidirectional irregular wave fields generated by BM2 and represented by a JONSWAP spectrum with a peak enhancement factor $\gamma = 3$. In the first three tests the peak period is constant, $T_p = 10$ s, while the significant wave height has values of 3.5m, 7m and 9m. In test 8241 the significant wave height is $H_s = 3.5$ m and the peak period is smaller, $T_p = 7$ s. The multidirectional tests are designated by 8233, 8234 and 8235 for angles of propagation of 60º, 120º and 90º, respectively. The waves were generated by both BM2 and BM3 wavemakers and correspond to a two-peaked spectrum (Guedes Soares, 1984) with individual components representing a JONSWAP spectrum with peak factor $\gamma = 3$.

Table 1. Deep water irregular waves, h=100m

Test	**Hs [m]**	**Tp [s]**	**Spec**	**Wave dir θ [deg]**	**Wave maker**
8201	3.5	10	J3	0	BM2
8202	7.0	10	J3	0	BM2
8219	9.0	10	J3	0	BM2
8241	3.5	7	J3	0	BM2
8233	3.6/3.6	7/20	2P J3/J3	0/60	BM2/BM3
8234	3.6/3.6	7/20	2P J3/J3	0/120	BM2/BM3
8235	3.6/3.6	7/20	2P J3/J3	0/90	BM2/BM3

Table 2. Shallow water irregular waves, h=20m

Test	**Hs [m]**	**Tp [s]**	**Spec**	**Wave dir θ [deg]**	**Uc [m/s]**	**Wave maker**
8001	3.5	10	J3	0	-	BM2
8002	7.0	10	J3	0	-	BM2
8051	3.5	10	J3	0	1.0	BM2
8052	7.0	10	J3	0	1.0	BM2
8101	3.5	10	J3	0	2.0	BM2
8102	7.0	10	J3	0	2.0	BM2
8151	3.5	10	J3	0	3.0	BM2
8152	7.0	10	J3	0	3.0	BM2

The shallow water data are described in Table 2. The water depth is constant, set at 20m (in scale). Two types of seas were generated: irregular waves without current and irregular waves with uniform collinear current in the direction of propagation of waves. The current mean velocity corresponds to three cases: U_c=1m/s, U_c=2m/s and U_c=3m/s. As could be seen from the table, the tests are coupled, namely, each value of current velocity, U_c, is associated with two sea states with significant wave heights of 3.5m and 7m. The peak period is constant for all tests considered. The sea state is given by a one-peak JONSWAP spectrum. The applied generator in all shallow water tests is BM2.

All deep and shallow water tests correspond to total of 12088s (3.36h) of measurements with a sampling frequency dt=0.1768s. Hence, the number of observations in the time series is 68371, on the average. The only exception is test 8001, where the record length is 12371s (3.44h), which corresponds to approximately 69972 measurements.

The time series of the free surface elevation were processed as follows. Each record was truncated at the beginning, in order to leave out the part with no recordings, due to the distance between the wavemaker and the gauges. Since the gauges are located at different distances from the wave generators, the resulting records will contain different number of observations. In order to avoid this problem, the longer series were further truncated at the end, such that eventually they have the same number of observations, as the shorter ones. Subsequently, the truncated records were split into ten approximately 20-minute records.

The linear trend in each segment record was removed and the mean level was adjusted to zero. The significant wave height was calculated by means of the spectral definition, $H_{m0} = 4\sqrt{m_0}$, where m_0 is the variance of the elevation process. Consequently, a sample of ten values of the significant wave height was associated with each gauge. These samples were further used as an input for the statistical significance tests.

4. ANALYSIS OF THE RESULTS FROM THE STATISTICAL TESTS

Parametric and nonparametric significance tests were applied to the samples of significant wave heights at each gauge, in order to check the hypothesis of equality between the means and variances of the sample distributions. The nonparametric tests are useful, since they do not assume an exact form of the initial distribution which makes them suitable for testing non-normal and highly skewed data. This is exactly the present case, because the significant wave heights are not normally distributed. Furthermore, the nonparametric tests are preferred, because they are more powerful and are not largely influenced by the presence of outliers in the samples. Consequently, they can be used to validate the results from the parametric tests.

Due to space limitation, detailed numeric results from the statistical tests are not provided here. Only the basic results concerning the final conclusion on the variability in space of the wave field and the stationarity within the generated time series are presented in the following in two subsections for the deep and shallow water tests, respectively.

4.1 Deep Water Irregular Waves

The measured time series were first checked for stationarity. A run test, as described in Bendat and Piersol (1971), was used for the purpose. Different statistical parameters were calculated and the values were compared with the corresponding median values.

The number of runs for each considered statistics was found and the critical regions were defined according to Eq. (9). With *r* denoting the observed runs, the two critical regions are: $r \le r_{\frac{N}{2},1-\frac{\alpha}{2}}$ and $r > r_{\frac{N}{2},\frac{\alpha}{2}}$. The lower bound of the critical interval for N=10 (since the time series are divided in 10 segments of equal length) and level of significance 5% is determined as $r_{5,0.975} = 2$ and the upper limit is determined as $r_{5,0.025} = 9$ (Table A.6; Bendat and Piersol, 1971). Hence, the hypothesis of stationarity will be rejected at the chosen level of significance, if the number of runs is less than 2, or more than 9.

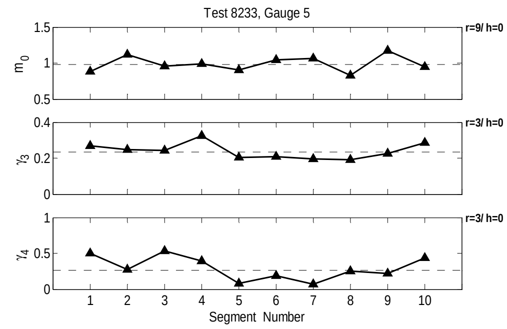

Figure 2. Test for stationarity of the deep water time series - test 8233, gauge 5

As an example of the run tests applied to the deep water records, the one based on the time series recorded by gauge 5 of test 8233 is illustrated in Figure 2. The plot represents the runs about the medians of three sample parameters: the coefficient of skewness, $\gamma_3 = \mu_3 / \sigma^3$, the excess of kurtosis, $\gamma_4 = \mu_4 / \sigma^4 - 3$ and the zero spectral moment, m_0, where μ_3 and μ_4 are the third and fourth order central moments, respectively. The number of calculated runs is given to the right of the relevant figure along with the test significance denoted by *h*. The variable *h* can be either 0, in case of the null hypothesis being accepted, or 1, in case of significant result, i.e. the null hypothesis being rejected. The results are *r*=9 for the variation of m_0 and *r*=3 for γ_3 as well as for γ_4. Consequently, since none of the runs fall in the defined critical regions, the hypothesis of stationarity is accepted. No significant results were reported by any of the run tests applied to the records in the considered deep water wave fields.

After the stationarity was validated for the generated time series, parametric and nonparametric tests checking the spatial variability in the wave field were performed.

The samples used in the tests constitute of ten significant wave height values calculated at each of the ten segments of approximately 20-minute duration in the truncated original records.

The results from the multivariate parametric ANOVA test and nonparametric Kruskal-Wallis test are presented in Table 3. The tests check the consistency between the distributions throughout the group of fifteen gauges in the tank. The null hypothesis states that the means of all distributions are equal, namely $H_0 : \mu_1 = ... = \mu_{15}$, where $\mu_{i=1,..,15}$ represents the mean of the ith sample. The final conclusion, whether the null hypothesis is accepted or not, is based on the comparison of the output test statistic with the reference critical value. For the chosen level of significance $\alpha = 0.05$ the critical value, $F_{0.05}(14,135) = 1.6966$ is calculated from Table VII in Hogg and Tanis (1993). The corresponding critical value of the Kruskal-Wallis test is $\chi^2_{0.95}(14) = 23.68$ (Table A2; Conover, 1980). The hypothesis of equality between the sample means is rejected if the obtained test statistic is larger than the critical one. As can be seen from Table 3, the results from the ANOVA test and the Kruskal-Wallis test are in agreement.

Table 3. Statistical results from the performed ANOVA and Kruskal-Wallis tests – deep water sea states

Test	**ANOVA test *F***	**Kruskal-Wallis T_1**	**Variance test T_2**
8201	5.0880	48.3305	5.5354
8202	1.4721	18.9866	10.7875
8219	1.5649	18.4318	6.6782
8241	5.1738	53.1378	8.8311
8233	36.4850	116.3381	8.8484
8234	67.2692	132.5520	15.8630
8235	27.0093	97.7612	14.6637

The equality between all sample means is accepted only for tests 8202 and 8219. The large values of the test statistics obtained for the directional deep water cases (8233, 8234 and 8235) clearly state rejection of H_0. The smallest found statistics in the directional sea states pertain to test 8235 - two wave systems, propagating perpendicularly to each other.

Analyzing the obtained results with respect to the properties of the performed tests given in Table 1, it is possible to conclude that the higher sea states correspond to smaller test statistics and consequently represent more consistent wave field. For example, tests 8202 and 8219 have the largest significant wave heights, 7m and 9m, respectively. In both cases the tests do not give significant difference between the considered samples for the chosen level of significance of 5%.

In case of significant results reported by the tests comparing more than two samples, multiple comparisons were further performed, in order to find the pairs of samples that tend to differ, i.e. such tests were run for all directional tests and for the unidirectional tests 8201 and 8241.

The two-sample tests include the parametric *T*-test and the nonparametric Wilcoxon and Kruskal-Wallis tests. The 5% initial level of significance was reduced for each test to approximately 0.0005 by the applied Bonferroni correction. As was expected, the significantly decreased critical region produced an increase in the number of gauges found to have the same distribution. Nevertheless, large number of gauges was still reported as significantly different in the directional sea states.

The probability value, *p*-value, is used as a representative statistic of the test significance. It is associated with the probability to have a statistic as large, or larger than the observed one in the direction of the alternative hypothesis, calculated when H_0 is true. Comparisons between the obtained *p*-values in the multiple comparison tests have shown that for the highest sea states, referred to tests 8202 and 8219, all *p*-values are larger than the Bonferroni corrected critical level 0.0005. Following the definition of the *p*-value, it can be concluded that the observed significant differences between the sample means are probably due to chance fluctuations and the null hypothesis has to be accepted.

The other quantity of interest is the sample variance. Moreover, the parametric tests for equality between the means assume that the variances are unknown but equal. As in the case for checking the hypothesis of equal means, parametric and nonparametric tests were applied for the variances. The obtained results allow saying that the considered samples have distributions with equal variances. In all tests, the nonparametric variance test on several samples showed statistics that did not fall in the determined critical region for $\alpha = 0.05$ and for the total of fifteen gauges, which is defined as $T_2 > \chi^2_{0.05}(14) = 23.68$.

The results for the nonparametric variance tests are shown in the last column of Table 3. On the other hand, the parametric multiple variance χ^2 tests and the two-sample variance F test detected few or none significant differences in each considered test.

Finally, the regions of consistency deduced from the test results at a level of significance 0.05 and assuming the Bonferroni correction in the multiple comparisons are shown in Table 4. The first column represents the corresponding gauge number. Equal numbers are further used to designate the regions where the tests accept the hypothesis of equality between the distributions in the case of several regions of homogeneity defined. It is seen that the unidirectional wave fields numbered as 8202 and 8219 do not show significant variability in space. In the other two unidirectional tests, 8219 and 8241, where the ANOVA and Kruskal-Wallis tests reject the equality between the samples (Table 3), gauges 13 to 15 have been excluded since they are significantly different from the others. Gauge 5 of test 8241 was also excluded for the same reason.

The statistical test results are in agreement with the conclusion that the severer sea state reflects increased homogeneity in the wave field. Comparison between tests 8201 and 8241 having equal significant wave height of 3.5m but different peak periods, 10s and 7s, respectively, shows that the test statistics of the waves with smaller peak period are larger. The most outstanding gauge in test 8241 is gauge 5.

Table 4. Regions of consistency in the deep water sea states

Test / GNo	8201	8202	8219	8241	8233	8234	8235
1	1	1	1	1	2	-	2
2	1	1	1	1	2	2	2
3	1	1	1	1	2	2	2
4	1	1	1	2	-	-	2
5	1	1	1	-	1	-	-
6	1	1	1	1	1	1	1
7	1	1	1	1	1	1	1
8	1	1	1	1	1	4	4
9	1	1	1	1	2	-	2
10	1	1	1	1	3	3	3
11	1	1	1	1	3	3	3
12	1	1	1	1	3	3	3
13	2	1	1	2	2	2	2
14	2	1	1	2	4	2	2
15	2	1	1	2	4	-	2

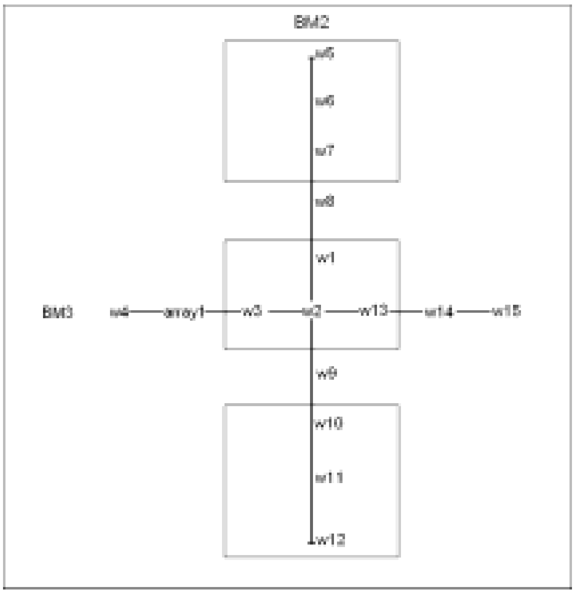

Figure 3. Regions of consistency in the deep water directional sea states

Significant differences were reported for all directional sea states, even for the highly decreased level of significance of 0.0005. The results from the tests of the directional waves show that special attention should be paid when such types of wave fields are generated. From the three directional cases shown in Table 3, 8235 was found to have the smallest statistics. This tendency is seen also in the multiple comparisons tests. In all directional sea states, gauges 5 to 7 located at the beginning of the tank were found to form a separate region. Comparisons between the obtained results for the rest of the gauges in the three directional wave fields make it possible to define three regions of consistency, as shown in Figure 3.

4.2 Shallow Water Irregular Waves

The stationarity tests for the shallow water time series do not yield significant results either. The procedure is the same as for the deep water data. The calculated number of runs in the performed tests at different gauges and tests do not fall into the critical regions of the test. Consequently, the stationarity hypothesis can be considered to hold true for all tests run.

The shallow water run tests are illustrated in Figure 4 with the time series recorded by gauge 6 of test 8101 being considered. The runs in the three sample statistics were found to be equal to r=7. For rejecting the null hypothesis they have to be smaller than 2 or larger than 9. Hence, the result is not significant, h=0, and the stationarity hypothesis is accepted.

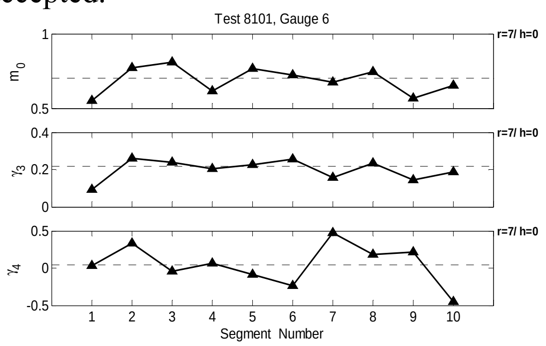

Figure 4. Test for stationarity of the shallow water time series - test 8101, gauge 6

Table 5 demonstrates the results from the ANOVA and the Kruskal-Wallis tests based on the shallow water sea states. The critical regions are the same as for the deep water cases. Significant differences are observed between the samples in all tests. The largest statistics correspond to test 8001 with the smallest significant wave height and no current effect. Considering the couples of tests with equal current velocity but different significant wave heights, i.e. 8051-8052, 8101-8102, 8151-8152, a clear trend observed before in the deep water tests is found, i.e. the consistency of the wave field is increasing with increase in the significant wave height.

Table 5. Statistical results from the performed ANOVA and Kruskal-Wallis tests - shallow water sea states

Test	**ANOVA test** F	**Kruskal-Wallis** T_1	**Variance test** T_2
8001	24.8223	108.1555	4.8274
8002	12.6356	85.2492	10.2666
8051	24.5094	103.6681	11.6055
8052	16.5147	90.4016	20.3945
8101	18.4400	90.1558	11.0799
8102	12.6129	79.0603	11.0926
8151	19.0290	100.2808	8.5295
8152	12.4671	80.2289	8.3427

On the other hand, definite conclusion on how the current velocity affects the wave field statistics can not be made, due to the limited number of sea states considered. A decrease in the test statistics is observed between the cases corresponding to U_c=1m/s and U_c=2m/s, but subsequently the statistic increases again for U_c=3m/s.

Considering the obtained p-values from the parametric and nonparametric tests, values much smaller than the reduced level of significance 0.0005 were found for all parametric and nonparametric shallow water tests. These cases correspond to clear rejection of the hypothesis of equal means.

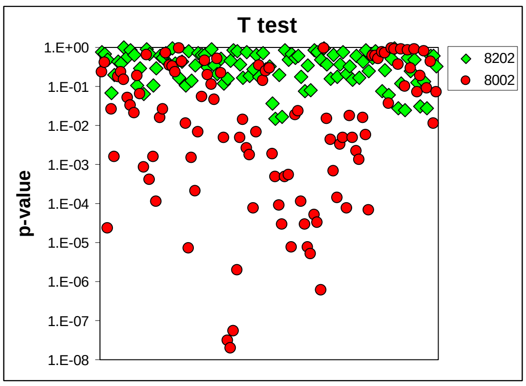

Figure 5. Comparison between the p-values of the model tests 8202 and 8002

Figure 5 compares the obtained p-values of the performed T-tests for the model tests 8202 and 8002. The two sea states have the same wave characteristics, i.e. significant wave height H_s=7m and spectral peak period T_p=10s, but refer to deep and shallow water, respectively. It is seen that the shallow water waves have very small p-values, which are associated with significant differences between the samples.

Table 6. Regions of consistency in the shallow water sea states

Test / GNo	8001	8002	8051	8052	8101	8102	8151	8152
1	-	1	-	1	1	1	1	1
2	3	2	2	2	2	2	3	2
3	3	2	2	2	2	2	3	2
4	4	-	-	2	-	-	-	-
5	1	1	1	1	1	1	1	1
6	1	1	1	1	1	1	1	1
7	1	1	1	1	1	1	1	1
8	1	1	1	1	1	1	1	1
9	2	2	2	2	2	2	3	2
10	2	2	2	2	2	2	2	2
11	2	2	2	2	2	2	2	2
12	2	2	2	2	2	2	2	2
13	3	2	2	2	2	2	3	2
14	4	2	2	3	2	2	3	2
15	4	-	2	3	2	2	3	2

The nonparametric variance tests performed on the total of 15 gauges for all shallow water data do not reject the null hypothesis of equality between the sample variances. They are shown in the last column of Table 5. However, the parametric variance χ^2 test and the F test show more cases with significant differences, than the deep water tests.

The regions of consistency, based on the obtained results from the location shallow water tests, are shown in Table 6. It is seen that the shallow water wave fields vary more, as compared to the generated deep water sea states. Nevertheless, gauges 5 to 8 can be considered to form a region where the wave statistics differ from the statistical representation of waves at the opposite side of the tank, i.e. at gauges 9 to 12.

Furthermore, it is seen that for all shallow water data there is a region where the tests always yield consistency between the sample distributions. Consequently, for all shallow water time series two regions, as depicted in Figure 6, can be deduced.

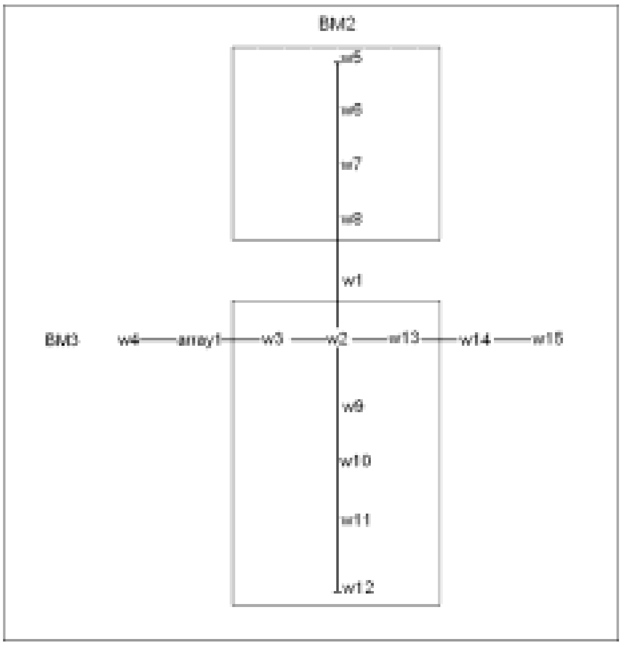

Figure 6. Regions of consistency in the shallow water sea states

5. CONCLUSIONS

A method has been described to study the spatial variability of waves in an offshore basin both in deep and shallow water. It is based on well-known statistical tests checking for significant differences between samples at various locations.

The stationarity of the generated 3-hour time series was validated by means of run tests.

The results of the statistical tests for the deep water unidirectional cases allow considering the sea states at the various locations as consistent, except for three gauges close to the wall opposite to BM3, which in some cases have different properties. It has been concluded that the higher sea states correspond to increased consistency between the gauges, which is reflected in the smaller test statistics obtained.

However, significant difference has been observed for all deep water cases in which two different spectra were generated from two walls. The smallest variability pertains to the case of two wave systems propagating perpendicularly to each other.

The shallow water wave tests demonstrate pronounced variability in space. The tests detect significant differences between the samples in all tests. The trend observed in the deep water tests is also seen here, namely, the consistency of the wave field is increasing with increase of the significant wave height. In shallow water tests two regions of homogeneous conditions were found as shown in Figure 6.

The results from the variance tests performed over the group of all fifteen gauges in the tank, for both deep and shallow water data, showed that the samples can be considered as having the same variance.

6. ACKNOWLEDGMENTS

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