The effect of changes in wind strength and wave heights on the safety of vessels in shipping

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Abstract

This article investigates whether changes in oceanographic conditions can be filtered out to measure their effect of the overall safety level of ships. The article is based on a unique dataset of 3.2 million observations from 20,729 individual vessels for the time period 1979 to 2007 in the North Atlantic and Arctic region. It combines ship particular information, ship safety inspections, casualties, ship economic cycles and oceanographic data. Standard econometric models are used to measure whether the effect of significant wave height and wind strength towards the probability of casualty can be measured and tests whether it changed over the time period on hand since changes in oceanographic conditions have been confirmed in the literature for the North Atlantic. The results show that the effect of wind strength and significant wave height can be measured towards the probability of casualty although there is no clear seasonal pattern while overall; the probability of casualty is influenced by seasonality with the winter month showing the highest probability of casualty. With respect to changes over time periods, significant wave height shows an increasing effect in January, March, May and October while wind strength show a decreasing effect over time, especially in January, March and May. The results for significant wave height might be relevant for the policy maker such as the International Maritime Organization (IMO) in the context of developing goal based standards for ship constructions or revising common structural rules used for the design of ships.

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[3] Disclaimer for Knapp and Shen: ‘The views expressed in this article represent those of the authors and do not necessarily represent those of the International Maritime Organization (IMO)’

1. Introduction

Little quantitative research has been performed on measuring the impact of climate changes on the level of maritime safety since data on ship inspections and change of ship particulars are not easy to obtain in the commercial shipping industry. The article builds on the criteria highlighted in the *Aberdeen Declaration* [1] based on the EU Green Paper *"Towards a future for the Union: A European Vision for the Oceans and Seas"* [2] which promotes a holistic approach towards maritime policy. In addition, the *European Parliament's resolution [3] on the future maritime policy for the European Union* further identifies the importance of climate change and its potential challenge for maritime policy for the European Union.

This article will measure the effect of changes in oceanic conditions on the safety level of the commercial shipping industry over time. Some of these effects are associated with the rise in sea levels, greater wave height and an increasing frequency and force of storms [4]. The Forth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) further confirms that anthropogenic forcing is likely to have contributed to changes in wind patterns including the strengthening of winds in both hemispheres since the 1960s and an increase of storm activities in the North Atlantic since about 1970 [5]. Tsimplis *et al.,* (2005) [6] quantify one of the potential effects that the peak storm waves in the north Atlantic are increasing by 2 cm/year. No study so far has measure the effect of such changes on the level of safety of a vessel.

The study will emphasize on the North Atlantic and Arctic Region. New shipping routes will be opened due to the decrease of the ice coverage by 80% [7] of its level in 1970 during the summer period. For this particular region, the Arctic Climate Impact Assessment [8] of the Arctic Council expresses a concern of increased traffic in oil tankers and chemical tankers due to the change of ice coverage. This might lead to more difficult navigation initially due to increased ice movement or other changes of oceanographic conditions. The retreat of the ice and permafrost further allows an extension of the shipping season (an estimation of 120 days) and the accessibility to additional natural resources which will open new areas of exploitation and therefore increase shipping traffic.

Although the underlying dataset on oceanographic data covers world wide observations, this article in its first instance concentrates on the North Atlantic region since it has been confirmed by Woolf et *all* [9] that this region is believed to experience changes in its oceanographic conditions. In addition, the World Meteorological Organization (WMO) report 'The State of Polar Research [10] and the International Maritime Organization's (IMO) revised guidelines for the Arctic [11] also highlight the changes in the Arctic and in the case of IMO, the importance to prepare for these changes. Similar types of analysis can be applied to other regions if the effect of interest can be measured in the North Atlantic region.

In addition to the changes in the Arctic, wave and wind conditions are important for shipping in the context of stability calculations and design loads as outlined in the common structural rules of the International Association of Classification Societies[4] (IACS) as well as long-term stresses and fatigue life for the hull structure due to the bending on waves which are subject of the discussions at IMO with reference to the development of goal based standards [12,13].

[4] The classification societies in shipping are entities which are responsible for the design and construction of ships based on their structural rules which are based on the requirements in international conventions. A group of classification societies have created a set of common rules to harmonize construction standards in the shipping industry.

Furthermore, the IMO Code on Intact Stability [14] outlines design criteria with reference to severe wind and rolling criterion.

Section 2 provides a description of the dataset which was used for this article and the type of corrections that were made to the oceanographic variables while section 3 describes the variables and model combinations used to measure the effects of interest. Section 4 presents and discusses the results of the models and section 5 provides the conclusions and recommendations for the policy makers.

2. Description of dataset used and corrections made for oceanographic data

2.1. General description of data sources to construct dataset

In order to measure the effect of changes in oceanographic conditions on safety, various datasets need to be combined such as data which is used to determine the general risk profile of a vessel (ship particulars, their changes over the time period, information on safety inspections and audits), ship economic conditions, casualties and oceanographic conditions.

Most of the data on ship particulars, casualties and ship economic cycles comes from a dataset used by Bijwaard and Knapp [15] with the addition of oceanographic data. The time period used for this article is 1979 to 2007 and the total dataset used for the analysis contains 3.2 million observations for general cargo vessels, dry bulk carriers, tankers, container vessels, passenger vessels and other ship types (unknown ship types and fishing vessels since the sample for fishing vessels does not provide a good representation of the fishing fleet in general are exclude). The combination of data is given in Table 1 where we identify each of the data sources:

Table 1: Combination of data and data sources used for the dataset

Data type	Data Source
Ship particulars (eg ship type, tonnage, age, etc.) and their changes over time (eg. flag, classification societies)	Lloyd’s Register Fairplay (LRF)
Safety inspections and ISM audits	• Various Port State Control Regimes • Industry Inspections from RightShip, Chemical Distribution Institute (CDI) and the Oil Companies International Marine Forum (OCIMF) • Flag state inspections and ISM audits from various flag states*)
Casualty data	• Lloyd’s Register Fairplay (LRF) • Lloyd’s Maritime Intelligence Unit (LMIU) • International Maritime Organization (IMO)
Ship economic cycles	Shipping Intelligence Network, Clarksons Research
Oceanographic data	International Comprehensive Ocean-Atmosphere Data Set (ICOADS)

**) The flags states would like to remain anonymous*

The oceanographic dataset is the basis for this analysis to be complemented with data from Bijwaard and Knapp [15] since it provides the oceanographic variables (wave, swell and wind data and vessel traffic information. The data comes from the International Comprehensive Ocean-Atmosphere Data Set (ICOADS) for the time period January 1979 to December 2007 and contains approx. 44 million worldwide observations which were reduced to observations in the North Atlantic.

ICOADS is the largest available compilation of surface meteorological observations from Voluntary Observing Ships (VOS), complemented for recent decades by data from buoys and other automated platform types. The VOS observations form a baseline data source for the analysis of marine climate stretching back over 200 years and the scheme is operated under the auspices of the Joint WMO/IOC Technical Commission for Oceanography and Marine Meteorology (JCOMM). A peak in the total number of VOS was reached in 1984/85, when 7,700 ships worldwide were listed as participating in the VOS Scheme. However, the number of ships declined to around 6,000 by mid-2005.

The ICOADS dataset of 44 million observations was reclassified into regions based on longitude and latitude and the North Atlantic region was selected for this article. The dataset was then merged against ship particular data from LRF using the call sign to match the corresponding IMO number (IMO is a unique ID) to be able to add ship particular data, their changes over the time period in question and inspection data. From the original 7.5 million observations of the North Atlantic region, 3.9 million could be identified by IMO number and excluding fishing vessels and unknown ship types, 3.2 million observations of 20,729 individual vessels form the basis for the analysis.

The data on safety inspections include the results of port state control inspections from various port state control regimes and industry inspections. The industry inspections are called vetting inspections and are performed by the Chemical Distribution Institute (CDI) on chemical tankers and oil tankers, by RightShip[5] primarily on dry bulk carriers and by the Oil Companies International Marine Forum (OCIMF) on oil tankers. The inspection system of OCIMF is called SIRE which is used in this article.

For the dataset used for the models, the ICOADS dataset is merged with the casualty data for the same regions and time period. The safety inspection data then complements the dataset where all observations six months prior to the event date (e.g. casualty or observation without casualty) is taken into consideration. For safety inspection, emphasize is given on detentions[6] and the number of deficiencies found during an inspections besides the fact that an inspection was performed. Finally, the dataset also accounts for changes in ownership, Document of Compliance Company (DoC), registration of the vessel and class withdrawals for a time period of one year prior the event date. In this way, the effect of these variables is accounted for as investigated by Knapp and Franses [16]. In addition, ship economic data such as earnings (USD) is added to account for ship economic cycles and which can also influence the safety level of a ship according to Bijwaard and Knapp [15]. Earnings are based on data received from Clarksons and was deflated to account for inflation[7].

As a final step, casualties are classified into their seriousness according to definitions from the International Maritime Organization (IMO) which is *very serious, serious or less serious* or by casualty category (e.g. collision, contact, fire, hull related failures, eg.). The definitions of the seriousness of casualties are given in MSC/Circ. 953, MEPC/Circ. 372 [17] and MSC Resolution MSC.255(84) [18][8].

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[5] RightShip is an independent vetting inspection system located in Melbourne, Houston and London and performs inspections on all ship types but primarily dry bulk carriers

[6] A vessel is detained when it is found in severe violation of the international conventions and is only released after the rectification of its deficiencies.

[7] Historical monthly inflation rates can be obtained from http://www.inflationdata.com

[8] It is worth noting that the IMO Maritime Safety Committee (MSC84) adopted MSC Resolution 255(84) on 16 May 2008 where the definitions were slightly changed and no longer distinguish between serious and less serious casualties. The definition for very serious casualty remains however unchanged. The reporting requirements will also change in the future.

Relevant for the analysis and the dependent variables used in the models in section 3 are the distinction between casualties that are *weather related* or *not-weather related.* Weather related casualties cover the following categories: *flooding, foundering, capsizing, hull related failures, wrecked, stranded and grounded*. Table 2 provides an overview of the total amount of observations of the final dataset, the amount of observations without casualties and the amount of casualties with their respective split up into being weather related or not.

Table 2: Observations per ship type and casualties

	Observations		**Casualties**		
Ship types	**grand total**	**no casualties**	**weather related**	**not weather related**	**total casualties**
general cargo ships	1,055,906	1,048,906	2,303	4,697	7,000
container vessels	883,076	882,157	258	661	919
tankers	450,735	445,535	1,628	3,572	5,200
dry bulk carriers	293,282	290,278	1,116	1,888	3,004
other ship types (cargo)	492,757	492,271	142	344	486
passenger ships	106,904	105,950	292	662	954
Total	**3,282,660**	**3,265,097**	**5,739**	**11,824**	**17,563**

2.2. Correction for wind and wave data

For some of the oceanographic variables used in the analysis such as the wind and wave data[9] some corrections need to be applied before it can be used in order to correct for biases due to the different measurement techniques. For the wind data, the method describes by Thomas *et all* [19] to homogenize the wind speeds is used. The data is divided into wind speed which was derived by measurement and wind speed derived from visual estimation. For wind speeds derived from measurements, the correction formula given in equation 1 is used while for the adjustment of visual estimates, the correction formula given in equation 2 was applied – both equations are based on Thomas *et all* [19].

$$W_{cor} = W_u\, 8.7403/\ln(\mathrm{HOA}/0.0016) \quad (1)$$
$$W_{cor} = 0.0161 + 1.1888W_u - 0.0221W_u^2 + 0.0004W_u^3 \quad (2)$$

Wcor of equation 1 or 2 is the corrected wind speed, *Wu* is the uncorrected wind speed and *HOA* is the height of the anemometer when given (the value 25 was used for missing values). For the wave and swell correction and in order to calculate the significant wave height (SWH), a correction formula given by Gulev and Grigorieva [20] is used and which is presented in equation 3 where *WH* represents the wave height and *SH* the swell height.

$$SWH = \sqrt{(WH^2 + SH^2)} \quad (3)$$

For the casualty dataset which was added to the overall dataset, the significant wave height and wind strength are derived from average daily values based on the total North Atlantic region (7.5 million observations) where we match the average daily value within a Marsden grid (10 x 10 square). Some outliers (7,311 observations).for the wave data are identified an since their values are unusual high and far above the normal range with a maximum of 20 meters (refer to Holliday et *all* [21]), they are excluded from the final dataset

[9] The exact variables used are: wind speed, the wind speed indicator, the wave and swell height

3. Description of estimation method and model combinations

The model use in the analysis measures the effect of the oceanographic data towards the probability of casualty (which is for weather related casualties and split into seriousness) and also tests whether their effect changes over time. The model estimates the probability (*P*) of a ship having a casualty where the dependent variable (*y*) can take the value 1 (for a casualty) or 0 (no casualty). This type of model is called binary regression model where a latent variable y^* gets mapped onto a binominal variable *y*. When this latent variable exceeds a threshold, which is typically equal to 0, it gets mapped onto 1, other wise onto 0.

The model estimates the probabilities on an individual ship level (*i*) where the general model can written in the form of equation 4. The term $x_i\beta$ given in equation 5 changes according to the model since a separate model per ship type and casualty type is estimated. In equation 5, *k* is an index from 1 to n_ℓ where n_ℓ is the total number of variables within each variable group of ℓ (FS, CL, etc.) and which vary per model.

In addition to the models given in equation 5 and 4 and in a two step approach, we first estimate the model in equation 5 only with dummies for each month versus the multiplicative dummies in order to test seasonality towards the probability of casualty which was confirmed with the winter months, especially December and January showing a stronger effect than the other month.

$$P_i = \frac{e^{(x_i\beta)}}{1+e^{(x_i\beta)}} \tag{4}$$

$$\begin{aligned} x_i\beta = {} & \beta_0 + \beta_1 \ln(\mathrm{AGE}_i) + \beta_2 \ln(\mathrm{SIZE}_i) + {} + \sum_{k=1}^{n_3-1} \beta_{3,k}\,\mathrm{CL}_{k,i} + \sum_{k=1}^{n_4-1} \beta_{4,k}\,\mathrm{FS}_{k,i} + \beta_5 \mathrm{CL\_wdr}_i \\ & + \beta_6 \mathrm{FL\_chgd}_i + \beta_7 \mathrm{OWN\_chgd}_i + \beta_8 \mathrm{DoC\_chgd}_i + \beta_9 \mathrm{Inspect}_i + \beta_{10} \mathrm{Def}_i \\ & + \beta_{11} \mathrm{Det}_i + \beta_{12} \mathrm{Earnings}_i + \sum_{n=1}^{n_p} \sum_{n=1}^{n_r} \beta_{13,r,p}\,\mathrm{SWH}_{r,p,i} + \sum_{n=1}^{n_p} \sum_{n=1}^{n_r} \beta_{14,r,p}\,\mathrm{W}_{r,p,i} \end{aligned} \tag{5}$$

The second step then estimates the model given in equation 4 and 5 but uses multiplicative dummy variables for significant wave height (SWH) and wind (W) where the variables are multiplied with dummies for each month denoted by *r* (January to December with n_r=12). In addition, the models further distinguish between two time periods (*p*) within the total time frame (1979-2007) in order to test weather the effect is significantly different from one time period to another. The monthly dummies for SWH and W are therefore further multiplied by the two time periods (*p*) which are 1979-1991 and 1992 to 2007. This leads to a total of 24 variables for SWH and W.

To estimate the parameters, quasi-maximum likelihood (QML) estimation is used which is a standard option[10] in Eviews, the software used to estimate the models. The variables are given in Table 3 and are split up into three groups where the first two groups are variables which can also have an effect on the probability of casualty as explained previously and therefore need to be included into the models in order to filter out the effect of interest which are for the oceanographic variables. The groups are as follows:

- *Group 1:* a group of variables dealing with basic ship particulars such as age, gross tonnage, flag, the classification societies and changes of ship particulars within a certain time frame

[10] QML (Huber/White) standard errors & covariance

- *Group 2:* variables which can influence the safety level of ships such as the various inspections and ship economic cycles.
- *Group 3:* the variables of interest which are the oceanographic variables and seasonality. We use dummies to account for the interaction of the oceanographic variables and seasonality and further distinguish between two time periods.

Table 3: Summary of variable groups and variables used in the models

Variable group (ℓ)*)	**Variable description**	n_ℓ
1. Ship Particulars and changed over time		
AGE (1)	age of vessel - logarithm	1
SIZE (2)	gross tonnage of vessel - logarithm	1
CL (3)	classification societies	3
FS (4)	flag states	5
CL_wdr (5)	total class withdrawals 1 year prior to event	1
FL_chgd (6)	total flag changes 1 year prior to event	1
OWN_chdg (7)	total owner changes 1 year prior to event	1
DOC_chgd (8)	total DoC company[11] changes 1 year prior to event	1
2. Inspection variables and ship economic cycles		
Inspect (9)	total safety inspections and audits within 6 months prior to event	1
DEF (10)	total deficiencies within 6 months prior to event	1
DET (11)	total detentions within 6 months prior to event	1
Earnings (12)	deflated earnings - matched per month and ship type	1
3. Oceanographic variables and seasonality (variables of interest)		
SWH (13)	significant wave height multiplied by 12 monthly dummies and 2 time periods (1979-1991 and 1992-2007)	24
W (14)	wind strength multiplied by 12 monthly dummies and 2 time periods (1979-1991 and 1992-2007)	24
	Total base variables	**66**

*Note: *) ℓ is given in brackets after each abbreviation of variable group*

In order to decrease the amount of variables per model, the flags were grouped into five major country groups and following a classification used by UNCTAD[12] as follows: 1) industrialized countries, 2) least developed countries, 3) developing countries, 4) former eastern European countries and a group for 5) unknown flags. The classification societies were grouped into IACS[13] or Non-IACS classification societies and one group for unknown classification societies.

A separate model per ship type (general cargo, container, dry bulk, tanker, passenger vessels and other ship types) and casualty seriousness is estimated where only weather related casualties are taken into consideration and seriousness is grouped into very serious and another group for serious and less serious casualties. This leads us to a total of 12 models in step 1 and step 2 with 66 base variables per model. Only the results of the final models are presented in this article.

As final step and to test whether the effect of either wind or waves towards the probability of casualty changed over time, the Wald-Test for testing restrictions[14] is used and based on each of the models, the following hypothesis is tested where we apply the test on a subset of the

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[11] The Document of Compliance Company is the designated company responsible for the safety management of a vessel as required by the 1974 SOLAS (Safety of Life at Sea) Convention of the International Maritime Organization (IMO)
[12] United Nation Conference on Trade and Development
[13] International Association of Classification Societies
[14] for further detail on this test, please refer to Greene H.W [22]

matrix where ℓ in this case are the two variable groups for SWH and W for each month (*n*) and time period (*p*):

> H_o: *the coefficients within each variable group* ℓ*n *across p do not vary*
> H_a: *the coefficients within each variable group* ℓ*n *across p do vary*

Testing for significance is restricted to significant variables from the models at either 1% or 5% significance level. When H_o is rejected, it can be concluded that the effect of the variables of interest differ from one period to another towards the probability of casualty.

For section 4, this article only concentrates on the results of the final models (step 2) and the variables of interest (the multiplicative dummy variable groups for significant wave height and wind strength for each time period) and does not report on the outcomes of the variables in group 1 and 2 of Table 3 since they are only in the model as correction factors and to account for other effects that influence safety.

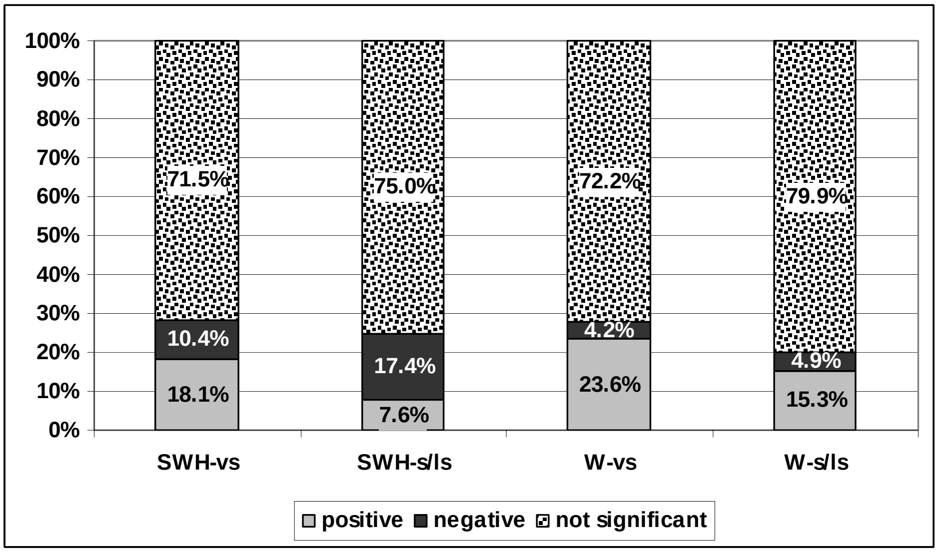
4. Discussion of results for the effect and changes of oceanographic conditions towards the probability of casualty

The summary of the statistics of the 12 final models is given in Appendix 1 including the number of observations in each model, the Mc Fadden R^2, the hit rate and the p-value of the HL-Statistic. The results are acceptable for each model type. The results of the parameters of interest as well as the result of the Wald-Test for testing restrictions are given in Table 4 to 9 for each ship type. We indicate the significance level with either 1% (*) or 5% (**) and also indicate when we reject the null hypothesis for the Wald-Test for testing restrictions.

To discuss the results, we first look at the significance level of the parameters of interest and whether the effect can be measured, is positive or negative towards the probability of casualty. We then concentrate on the results of the changes of these variables over time. Out of 288 (6 models times 12 month and 2 time periods) possible outcomes for each of the wind or wave variables, the results show that for about 71% to 79% of the possible outcomes (depending on the models), the effect of both variables cannot be measured but for the parameters which are significant, one can predominately see a positive effect for wind while the split up is more evenly distributed for significant wave height. The effect is stronger for the models for very serious casualties (18.1% positive and 10% negative for wave height and 23.6% positive and 4.2% negative for wind strength).Figure 1 presents some high level results for each type of casualty. A positive effect is stronger for very serious casualties for both variables compared to serious or less serious casualties.

The test of the Wald-Test restrictions confirm that for significant wave height, 16% of the total combinations and for wind, 20% of the total combinations show an effect which changes over time where the change can be positive or negative or where its significance can change from one time period to another. The effects of the changes are mostly increasing (69.9%) for significant wave height and mostly decreasing (69%) for wind strength. The total combinations for testing in this case are 144 possible outcomes (6 models times 12 month) where the test is performed over the two time periods for each month for each ship type. With respect to changes over time periods, significant wave height shows an increasing effect in January, March, May and October while wind strength show a decreasing effect over time, especially in January, March and May.

Figure 1: High level summary of effects for significant wave height and wind, all ship types



Note: vs=very serious, s/ls = serious and less serious casualties

4.1 Effect of significant wave height and changes over time

The detailed results in Tables 4 to 9 combined with the restriction tests further reveal that the positive effects for significant wave height can be measured *for general cargo* in January (vs[15]), February (vs), April (vs), June (vs), August (vs) and September (vs) of which only the parameters in January are significantly different over the time periods. For the *container vessels*, the positive effect can be measured in January (vs), February (vs), April (vs) and June (vs) of which the effect is significantly different in the two time periods for April and July. For the container vessels, we also found changes in negative effects which differ for the month of October (vs), April (s/ls) and May (s/ls). These negative effects decreased over time which indicates that there effect increased although it is still negative in the later time period.

For the ship type *tanker*, the positive effect can be measured for February (vs) and December (vs) with no change across the time periods. One significant change is found in November where the coefficient is negative in the earlier time period and then changes sign to positive but remains not significant in the later time period. For *dry bulk carriers*, positive effects can be found in January (vs) and August where both change significantly over the time periods. A negative and significant change can be found in May (vs) and November (vs) where the effect decreases over the time periods.

For *other ship types*, a positive effect can be found in February (vs), April (s/ls), May (s/ls), June (vs), September (both), October (both), and November (vs). Significant changes over time are found in March, April, May, September and October. Finally for *passenger ships*, positive effects can be found in January (s/ls), February (both), April (s/ls), May (both), July (vs), August (both), September (both), October (s/ls) and November(vs) with significant changes over the time periods in January, March and May.

[15] Vs=very serious, s/ls = serious and less serious, both=very serious, serious and less serious casualties

Table 4: Parameters and results of restriction testing for SWH and W – general cargo ships

Significant wave height		**general cargo - very serious**				**general cargo - serious/less serious**			
month	**period**	**Coeff**	**SE**		**Restr.**	**Coeff**	**SE**		**Restr.**
January	1979-91	0.047	0.023	**	0.001	-0.041	0.031		
	1992-07	0.157	0.024	*	*reject*	-0.011	0.028		
February	1979-91	0.070	0.022	*	0.146	-0.030	0.035		
	1992-07	-0.006	0.048			-0.020	0.032		
March	1979-91	0.071	0.057			-0.037	0.042		
	1992-07	0.067	0.035			-0.034	0.037		
April	1979-91	0.088	0.043	**	0.974	-0.086	0.049		
	1992-07	0.089	0.029	*		-0.042	0.036		
May	1979-91	-0.031	0.064			-0.213	0.074	*	0.232
	1992-07	0.000	0.265			-0.094	0.068		
June	1979-91	0.079	0.045		0.766	-0.151	0.060	**	0.387
	1992-07	0.094	0.029	*		-0.082	0.054		
July	1979-91	0.066	0.068			-0.005	0.075		
	1992-07	0.035	0.061			-0.081	0.066		
August	1979-91	0.112	0.032	*	0.422	0.054	0.031		
	1992-07	0.071	0.041			0.030	0.045		
September	1979-91	0.041	0.034		0.096	0.004	0.081		
	1992-07	0.130	0.042	*		0.018	0.030		
October	1979-91	0.048	0.029			-0.067	0.042		
	1992-07	0.045	0.026			-0.049	0.032		
November	1979-91	0.013	0.035			-0.013	0.046		
	1992-07	-0.015	0.044			-0.028	0.024		
December	1979-91	-0.004	0.028			-0.053	0.027		
	1992-07	0.059	0.032			-0.033	0.032		
Wind strength		**general cargo - very serious**				**general cargo - serious/less serious**			
month	**period**	**Coeff**	**SE**		**Restr.**	**Coeff**	**SE**		**Restr.**
January	1979-91	0.063	0.020	*	0.005	0.100	0.022	*	0.252
	1992-07	-0.020	0.022		*reject*	0.067	0.019	*	
February	1979-91	0.058	0.019	*	0.800	0.087	0.025	*	0.349
	1992-07	0.068	0.033	**		0.056	0.022	**	
March	1979-91	0.059	0.044			0.064	0.028	**	0.591
	1992-07	0.029	0.028			0.045	0.024		
April	1979-91	0.019	0.032			0.065	0.029	**	0.286
	1992-07	-0.036	0.034			0.025	0.025		
May	1979-91	0.027	0.042			0.101	0.038	*	0.049
	1992-07	-0.046	0.157			-0.007	0.039		*reject*
June	1979-91	-0.025	0.036			0.055	0.035		
	1992-07	-0.033	0.035			0.015	0.034		
July	1979-91	-0.004	0.049			0.007	0.043		
	1992-07	-0.055	0.042			0.029	0.036		
August	1979-91	-0.036	0.035			-0.066	0.028	**	0.178
	1992-07	0.014	0.036			-0.011	0.031		
September	1979-91	0.053	0.028			-0.007	0.053		
	1992-07	-0.061	0.042			0.022	0.022		
October	1979-91	0.050	0.024	**	0.641	0.114	0.028	*	0.194
	1992-07	0.065	0.023	*		0.069	0.021	*	
November	1979-91	0.111	0.026	*	0.988	0.071	0.031	**	0.846
	1992-07	0.110	0.031	*		0.078	0.018	*	
December	1979-91	0.133	0.021	*	0.117	0.112	0.019	*	0.247
	1992-07	0.081	0.025	*		0.079	0.021	*	

*Note: * = 1% significance and **=5% significance, n/a= not in model or cannot be tested*

Table 5: Parameters and results of restriction testing for SWH and W – container ships

Significant wave height		**container - very serious**				**container - serious/less serious**			
month	**period**	**Coeff**	**SE**		**Restr.**	**Coeff**	**SE**		**Restr.**
January	1979-91	0.128	0.068	**	0.482	0.077	0.139		
	1992-07	0.077	0.020	*		-0.034	0.052		
February	1979-91	0.189	0.025	*	0.291	-0.079	0.080		
	1992-07	0.133	0.047	*		-0.099	0.058		
March	1979-91	0.054	0.435			-0.107	0.136		
	1992-07	-0.171	0.107			-0.072	0.042		
April	1979-91	0.167	0.061	*	0.029	-0.384	0.124	*	0.045
	1992-07	-0.001	0.052		*reject*	-0.090	0.080		*reject*
May	1979-91	n/a	n/a		n/a	-0.439	0.179	**	0.049
	1992-07	-0.285	0.089	*		0.035	0.163		*reject*
June	1979-91	0.137	0.037	*	0.730	0.089	0.055		
	1992-07	0.120	0.026	*		-0.058	0.111		
July	1979-91	0.203	0.050	*	0.024	-0.188	0.110		0.945
	1992-07	0.076	0.028	*	*reject*	-0.198	0.092	**	
August	1979-91	n/a	n/a			-0.212	0.207		
	1992-07	n/a	n/a			0.131	0.087		
September	1979-91	-0.587	0.087	*	n/a	0.062	0.098		
	1992-07	n/a	n/a			-0.084	0.070		
October	1979-91	-0.217	0.086	**	0.021	0.008	0.071		
	1992-07	0.019	0.055		*reject*	0.033	0.090		
November	1979-91	n/a	n/a			0.034	0.100		
	1992-07	0.104	0.064			-0.036	0.071		
December	1979-91	-0.025	0.100			0.030	0.065		
	1992-07	0.071	0.095			-0.046	0.027		
Wind strength		**container - very serious**				**container - serious/less serious**			
month	**period**	**Coeff**	**SE**		**Restr.**	**Coeff**	**SE**		**Restr.**
January	1979-91	0.025	0.060			-0.031	0.095		
	1992-07	-0.029	0.079			0.063	0.041		
February	1979-91	-0.066	0.053			0.087	0.061		
	1992-07	-0.066	0.074			0.063	0.040		
March	1979-91	-0.041	0.359		0.508	0.081	0.076		
	1992-07	0.202	0.066	*		0.020	0.036		
April	1979-91	-0.047	0.073			0.188	0.056	*	0.000
	1992-07	0.064	0.071			-0.138	0.062	**	*reject*
May	1979-91	n/a	n/a			0.171	0.083	**	0.053
	1992-07	0.129	0.092			-0.093	0.109		
June	1979-91	-0.086	0.099			-0.151	0.050	*	0.046
	1992-07	-0.098	0.107			0.018	0.069		*reject*
July	1979-91	-0.057	0.081			-0.074	0.076		
	1992-07	-0.072	0.103			0.056	0.057		
August	1979-91	n/a	n/a			0.006	0.124		
	1992-07	n/a	n/a			-0.119	0.077		
September	1979-91	0.323	0.084	*	n/a	-0.192	0.065	*	0.015
	1992-07	n/a	n/a			0.005	0.051		*reject*
October	1979-91	0.069	0.103			0.004	0.050		
	1992-07	0.087	0.052			-0.059	0.060		
November	1979-91	n/a	n/a			-0.152	0.078		
	1992-07	0.009	0.066			0.013	0.047		
December	1979-91	0.174	0.068	**	0.147	0.013	0.055		
	1992-07	0.007	0.089			0.045	0.027		

*Note: * = 1% significance and **=5% significance, n/a= not in model or cannot be tested*

Table 6: Parameters and results of restriction testing for SWH and W – tankers

Significant wave height		**tankers - very serious**				**tankers - serious/less serious**			
month	**period**	**Coeff**	**SE**		**Restr.**	**Coeff**	**SE**		**Restr.**
January	1979-91	-0.052	0.032			-0.011	0.018		0.067
	1992-07	0.081	0.052			-0.077	0.031	**	
February	1979-91	0.063	0.028	**	0.460	0.003	0.023		
	1992-07	0.013	0.062			-0.005	0.039		
March	1979-91	0.020	0.045			0.019	0.034		
	1992-07	-0.006	0.035			-0.001	0.036		
April	1979-91	-0.079	0.054			-0.081	0.036	**	0.811
	1992-07	-0.117	0.113			-0.095	0.049		
May	1979-91	-0.069	0.123		0.108	-0.214	0.063	*	0.366
	1992-07	-0.318	0.095	*		-0.127	0.072		
June	1979-91	-0.083	0.101			-0.042	0.043		
	1992-07	-0.017	0.125			-0.069	0.087		
July	1979-91	-0.034	0.133			-0.049	0.049		
	1992-07	-0.086	0.164			-0.053	0.054		
August	1979-91	0.013	0.097			-0.100	0.055		0.623
	1992-07	0.021	0.110			-0.143	0.069	**	
September	1979-91	-0.170	0.089			0.003	0.070		0.344
	1992-07	-0.095	0.076			-0.069	0.032	**	
October	1979-91	-0.060	0.056			-0.037	0.031		
	1992-07	0.028	0.058			-0.071	0.065		
November	1979-91	-0.247	0.108	**	0.014	-0.068	0.026	*	0.973
	1992-07	0.031	0.035		*reject*	-0.070	0.035	**	
December	1979-91	0.004	0.061		0.051	-0.017	0.025		
	1992-07	0.166	0.058	*		-0.019	0.025		
Wind strength		**tankers - very serious**				**tankers - serious/less serious**			
month	**period**	**Coeff**	**SE**		**Restr.**	**Coeff**	**SE**		**Restr.**
January	1979-91	0.111	0.026	*	0.039	0.086	0.013	*	0.003
	1992-07	0.009	0.043		*reject*	0.044	0.021	**	*reject*
February	1979-91	0.025	0.026			0.064	0.016	*	0.011
	1992-07	0.080	0.045			-0.003	0.026		*reject*
March	1979-91	-0.061	0.040			0.029	0.023		
	1992-07	0.023	0.035			-0.014	0.025		
April	1979-91	-0.083	0.062			0.092	0.022	*	0.003
	1992-07	0.053	0.067			-0.015	0.028		*reject*
May	1979-91	0.001	0.075			0.112	0.033	*	0.011
	1992-07	0.009	0.095			-0.026	0.043		*reject*
June	1979-91	0.096	0.055		0.002	0.027	0.027		0.004
	1992-07	-0.222	0.089	**	*reject*	-0.131	0.048	*	*reject*
July	1979-91	-0.277	0.093	*	0.126	0.019	0.030		
	1992-07	-0.078	0.088			-0.041	0.030		
August	1979-91	-0.016	0.066		0.089	0.046	0.030		
	1992-07	-0.228	0.108	**		-0.030	0.035		
September	1979-91	0.105	0.052	**	0.052	0.019	0.045		
	1992-07	0.057	0.052			0.031	0.021		
October	1979-91	0.062	0.044			0.082	0.021	*	0.041
	1992-07	-0.005	0.050			-0.012	0.041		*reject*
November	1979-91	0.180	0.062	*	0.008	0.105	0.018	*	0.005
	1992-07	-0.036	0.054		*reject*	0.022	0.024		*reject*
December	1979-91	0.063	0.041			0.104	0.016	*	0.000
	1992-07	-0.032	0.053			0.006	0.019		*reject*

*Note: * = 1% significance and **=5% significance, n/a= not in model or cannot be tested*

Table 7: Parameters and results of restriction testing for SWH and W – dry bulk carriers

Significant wave height		dry bulk - very serious				dry bulk - serious/less serious			
month	**period**	**Coeff**	**SE**		**Restr.**	**Coeff**	**SE**		**Restr.**
January	1979-91	-0.052	0.054		0.008	0.018	0.025		0.013
	1992-07	0.113	0.032	*	*reject*	-0.088	0.035	**	*reject*
February	1979-91	-0.045	0.060			-0.109	0.045	**	0.829
	1992-07	0.037	0.101			-0.125	0.056	**	
March	1979-91	-0.077	0.130			0.029	0.053		
	1992-07	0.057	0.090			-0.079	0.053		
April	1979-91	-0.043	0.097			-0.023	0.060		0.081
	1992-07	0.048	0.118			-0.154	0.045	*	*reject*
May	1979-91	-0.708	0.155	*	0.005	-0.059	0.055		
	1992-07	-0.203	0.092	**	*reject*	-0.082	0.052		
June	1979-91	-0.193	0.117		0.077	-0.266	0.091	*	0.303
	1992-07	-0.446	0.084	*		-0.156	0.055	*	
July	1979-91	-0.202	0.126		0.227	-0.045	0.071		
	1992-07	-0.433	0.146	*		-0.107	0.058		
August	1979-91	0.171	0.042	*	0.024	-0.075	0.053		
	1992-07	-0.112	0.119		*reject*	-0.052	0.033		
September	1979-91	-0.149	0.112		0.836	-0.143	0.045	*	0.105
	1992-07	-0.176	0.074	**		-0.046	0.041		
October	1979-91	-0.147	0.166		0.762	-0.077	0.028	*	0.288
	1992-07	-0.096	0.038	**		-0.015	0.051		
November	1979-91	-0.002	0.046		0.022	0.026	0.040		0.001
	1992-07	-0.153	0.048	*	*reject*	-0.130	0.029	*	*reject*
December	1979-91	0.028	0.055		0.063	-0.045	0.026		0.142
	1992-07	-0.123	0.061	**		-0.113	0.038	*	
Wind strength		**dry bulk - very serious**				**dry bulk - serious/less serious**			
month	**period**	**Coeff**	**SE**		**Restr.**	**Coeff**	**SE**		**Restr.**
January	1979-91	0.105	0.038	*	0.002	0.071	0.019	*	0.193
	1992-07	-0.052	0.036		*reject*	0.031	0.023		
February	1979-91	0.082	0.041	**	0.244	0.107	0.026	*	0.062
	1992-07	-0.006	0.062			0.019	0.039		
March	1979-91	0.077	0.077			0.039	0.038		
	1992-07	0.001	0.068			0.010	0.034		
April	1979-91	0.099	0.062			0.046	0.038		0.706
	1992-07	-0.083	0.101			0.064	0.029	**	
May	1979-91	0.230	0.060	*	0.009	0.049	0.036		
	1992-07	0.002	0.063		*reject*	-0.005	0.031		
June	1979-91	0.011	0.066		0.045	0.124	0.051	**	0.231
	1992-07	0.173	0.047	*	*reject*	0.053	0.030		
July	1979-91	0.016	0.094			-0.015	0.050		
	1992-07	-0.048	0.086			-0.040	0.035		
August	1979-91	-0.203	0.085	**	0.976	0.048	0.035		
	1992-07	-0.206	0.096	**		-0.016	0.022		
September	1979-91	0.089	0.061			0.054	0.028		
	1992-07	0.025	0.063			-0.037	0.028		
October	1979-91	0.024	0.085			0.085	0.020	*	0.007
	1992-07	-0.030	0.046			-0.021	0.034		*reject*
November	1979-91	0.052	0.036		0.216	0.010	0.031		0.214
	1992-07	0.116	0.038	*		0.057	0.021	*	
December	1979-91	0.022	0.036		0.031	0.071	0.018	*	0.869
	1992-07	0.141	0.042	*	*reject*	0.066	0.025	*	

*Note: * = 1% significance and **=5% significance, n/a= not in model or cannot be tested*

Table 8: Parameters and results of restriction testing for SWH and W – other ship types

Significant wave height		**other ST - very serious**				**other ST - serious/less serious**			
month	**period**	**Coeff**	**SE**		**Restr.**	**Coeff**	**SE**		**Restr.**
January	1979-91	-0.008	0.029			0.069	0.036		
	1992-07	0.054	0.029			-0.080	0.074		
February	1979-91	0.057	0.009	*	0.890	n/a	n/a		n/a
	1992-07	0.051	0.047			-0.178	0.074	**	
March	1979-91	-0.639	0.055	*	0.000	n/a	n/a		
	1992-07	0.110	0.030	*	*reject*	0.066	0.094		
April	1979-91	n/a	n/a		n/a	-0.045	0.044		0.021
	1992-07	-0.214	0.057	*		0.195	0.018	*	*reject*
May	1979-91	n/a	n/a			-0.002	0.051		0.025
	1992-07	0.070	0.081			0.252	0.024	*	*reject*
June	1979-91	n/a	n/a		n/a	0.126	0.034	*	0.517
	1992-07	0.113	0.045	**		-0.331	0.102	*	
July	1979-91	n/a	n/a			-1.346	0.134	*	0.684
	1992-07	n/a	n/a			0.102	0.050	**	
August	1979-91	n/a	n/a			-0.223	0.163		0.067
	1992-07	0.072	0.126			-0.115	0.459	*	
September	1979-91	n/a	n/a		n/a	0.179	0.052	*	0.041
	1992-07	0.091	0.046	**		-0.142	0.081		*reject*
October	1979-91	0.150	0.017	*	0.033	0.072	0.019	*	0.000
	1992-07	0.217	0.029	*	*reject*	-0.124	0.061	**	*reject*
November	1979-91	n/a	n/a		n/a	0.082	0.065		
	1992-07	0.121	0.016	*		0.040	0.055		
December	1979-91	-0.018	0.062			0.067	0.035		
	1992-07	-0.044	0.050			-0.007	0.074		
Wind strength		**other ST - very serious**				**other ST - serious/less serious**			
month	**period**	**Coeff**	**SE**		**Restr.**	**Coeff**	**SE**		**Restr.**
January	1979-91	0.179	0.035	*	0.032	n/a	n/a		n/a
	1992-07	0.021	0.063		*reject*	0.160	0.051	*	
February	1979-91	0.051	0.072			n/a	n/a		
	1992-07	0.055	0.072			0.140	0.080		
March	1979-91	0.347	0.069	*	0.001	0.071	0.069		0.522
	1992-07	0.069	0.047		*reject*	0.118	0.033	*	
April	1979-91	n/a	n/a		n/a	-0.192	0.094	**	0.009
	1992-07	0.164	0.074	**		0.093	0.048		*reject*
May	1979-91	n/a	n/a			-0.201	0.116		
	1992-07	0.117	0.060			0.044	0.039		
June	1979-91	n/a	n/a			0.152	0.085		0.680
	1992-07	-0.052	0.109			0.300	0.091	*	
July	1979-91	n/a	n/a			0.068	0.058		
	1992-07	0.093	0.081			0.075	0.094		
August	1979-91	n/a	n/a			0.039	0.193		
	1992-07	-0.045	0.088			-0.103	0.069		
September	1979-91	n/a	n/a			0.009	0.096		0.515
	1992-07	n/a	n/a			0.066	0.029	**	
October	1979-91	-0.041	0.082			-0.005	0.094		
	1992-07	0.025	0.042			0.034	0.045		
November	1979-91	n/a	n/a			0.064	0.047		0.017
	1992-07	0.073	0.042			0.079	0.030	*	*reject*
December	1979-91	0.196	0.058	*	0.514	0.119	0.057	**	0.238
	1992-07	0.137	0.055	**		0.239	0.063	*	

*Note: * = 1% significance and **=5% significance, n/a= not in model or cannot be tested*

Table 9: Parameters and results of restriction testing for SWH and W – passenger vessels

Significant wave height		**passenger - very serious**				**passenger - serious/less serious**			
month	**period**	**Coeff**	**SE**		**Restr.**	**Coeff**	**SE**		**Restr.**
January	1979-91	0.118	0.073			-0.054	0.058		0.004
	1992-07	-0.028	0.036			0.139	0.033	*	*reject*
February	1979-91	0.062	0.320		0.939	0.040	0.060		0.292
	1992-07	0.087	0.025	*		0.107	0.021	*	
March	1979-91	-0.433	0.188	**	0.004	-0.174	0.076	**	0.008
	1992-07	0.111	0.033	*	*reject*	0.104	0.071		*reject*
April	1979-91	0.071	0.045			0.005	0.086		0.426
	1992-07	-0.123	0.065			0.077	0.031	**	
May	1979-91	-1.425	0.186	*	0.000	-0.101	0.115		0.079
	1992-07	0.126	0.045	*	*reject*	0.110	0.037	*	
June	1979-91	n/a	n/a			-0.042	0.101		
	1992-07	0.042	0.139			0.086	0.058		
July	1979-91	-0.041	0.091		0.132	-0.007	0.091		
	1992-07	0.097	0.022	*		0.037	0.031		
August	1979-91	0.099	0.041	**	0.545	0.023	0.095		0.543
	1992-07	0.126	0.020	*		0.082	0.018	*	
September	1979-91	0.079	0.030	*	0.375	0.059	0.067		0.271
	1992-07	0.116	0.031	*		0.139	0.030	*	
October	1979-91	-0.056	0.057			0.094	0.067		0.992
	1992-07	n/a	n/a			0.095	0.048	**	
November	1979-91	0.042	0.086			-0.022	0.094		
	1992-07	-0.073	0.050			0.055	0.053		
December	1979-91	n/a	n/a		n/a	-0.131	0.098		
	1992-07	0.141	0.024	*		0.046	0.041		
Wind strength		**passenger - very serious**				**passenger - serious/less serious**			
month	**period**	**Coeff**	**SE**		**Restr.**	**Coeff**	**SE**		**Restr.**
January	1979-91	0.061	0.070			0.082	0.040	**	0.224
	1992-07	0.078	0.067			0.023	0.029		
February	1979-91	0.024	0.257			0.013	0.053		
	1992-07	0.030	0.054			-0.007	0.035		
March	1979-91	0.323	0.094	*	0.002	0.153	0.042	*	0.031
	1992-07	0.000	0.050		*reject*	0.017	0.046		*reject*
April	1979-91	0.118	0.050	**	0.469	-0.277	0.120	**	0.022
	1992-07	0.049	0.081			0.004	0.030		*reject*
May	1979-91	0.505	0.072	*	0.000	-0.135	0.085		
	1992-07	-0.068	0.095		*reject*	-0.020	0.039		
June	1979-91	n/a	n/a			0.082	0.062		
	1992-07	0.056	0.082			-0.022	0.044		
July	1979-91	0.163	0.067	**	0.105	0.063	0.063		
	1992-07	-0.068	0.127			0.015	0.036		
August	1979-91	0.126	0.056	**	0.217	-0.023	0.056		
	1992-07	-0.002	0.089			0.052	0.029		
September	1979-91	0.020	0.060			-0.183	0.065	*	0.039
	1992-07	0.087	0.050			-0.036	0.031		*reject*
October	1979-91	0.001	0.078			-0.077	0.070		
	1992-07	n/a	n/a			0.015	0.037		
November	1979-91	0.127	0.054	**	0.726	0.107	0.055		
	1992-07	0.096	0.071			0.054	0.038		
December	1979-91	n/a	n/a			0.075	0.064		
	1992-07	-0.005	0.059			0.053	0.031		

*Note: * = 1% significance and **=5% significance, n/a= not in model or cannot be tested*

4.2. Effect of wind strength and changes over time

For the results with reference to wind strength, positive effects can be found for the *general cargo* vessels in January (both), February (both), March (s/ls), April (s/ls), May (s/ls), October (both), November (both) and December (both). Significant changes can only be measured in January (vs). For *container vessels*, positive effects can be found in March (vs), May (s/ls), September (vs) and December (vs) while only negative effects show a significant change over time for April (s/ls), June (s/ls) and September (s/ls). For April, the effect decreases over the time period while for June and September, the effect changes from being negative in the earlier time period to being positive but not significant in the latter time period.

For *tankers*, positive effects of wind strength can be found in all month except March, June, July and August. The effect changes over time periods in most months where it already showed a positive effect but decreases in strength and sometimes changes sign and becomes a negative effect for the later time period. For *dry bulk carriers*, positive effects can be found in January (both), February (both), April (s/ls), May (vs), June (both), October (s/ls), November (both) and December (both). Changes over time periods are significant for January (vs), May (vs), June (vs) and December (vs) where the effect increases with the exception of December (vs) and October (s/ls).

For *other ship types*, positive effects can be found in January (vs), March (both), April (vs), June (s/ls), September (s/ls), November (s/ls) and December (both). Decreasing effects can be found for January (vs) and March (vs) and increasing effects for April (s/ls) and November (s/ls). Finally, for *passenger vessels*, positive effects can be found in all months with the exception for February, June, October and December. Significant increases are found in April (s/ls) while other changes are decreasing effects for March (both), May (vs) and September (s/ls).

In summary, one can conclude that the effect of significant wave height or wind strength can be measured towards the probability of casualty where the effect is stronger towards the probability of a very serious casualty. For about 71-79% of the possible outcomes, the effect cannot be measured while for the effects that are significant; one can mostly see a positive effect for wind compared to a more even distribution of positive and negative effects for the significant wave height. There is no clear seasonal pattern with respect to an effect of significant wave height and wind strength.

With respect to the change of the effect over time, one can find decreasing and increasing effects over the time periods. For significant wave height, 69.9% of the significant changes over the time periods show an increasing effect May followed by January, March and October while 30% show a decreasing effect mostly in November. For wind strength, the results provide the opposite picture with 31% of all significant changes being increasing effects in April, June and September and 69% being decreasing effects in January, March and May.

4.3. Visualization of results

This section visualizes some of the results in order to facilitate further interpretation of the model findings. First, the effect of significant wave height and wind strength is visualized for a particular ship type and in comparison to the two time periods to show the either negative or positive effect. This is then followed by using the models to calculate out average probabilities based on all ships in the models and visualizing them in monthly averages for various wave heights and wind strength for both time periods.

For the demonstration on how the probabilities change with respect to wave height and wind strength, average ship profiles for two ship types are chosen with one safety inspection (within 6 months) and one DoC company change (within one year) and average earnings. The only variable which changes between the time periods is the coefficient for SWH and the coefficient for the corresponding wind variable. The results are given in Figure 2 and 3 and visualize a positive effect and change over time for wave height and a positive effect but negative change of wind strength towards the probability of casualty.

Figure 2: Effect of significant wave height (SHW) on the probability of very serious casualty, general cargo ship, January

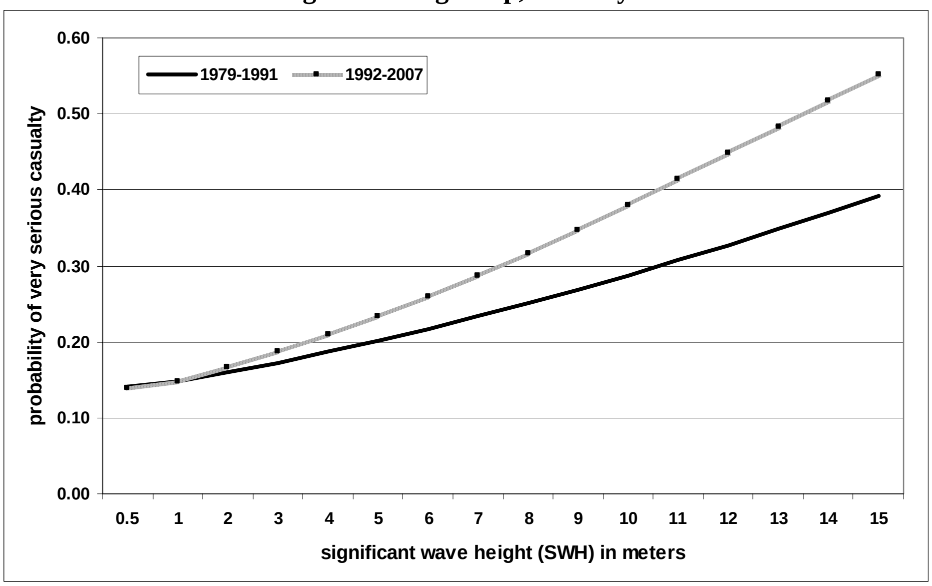
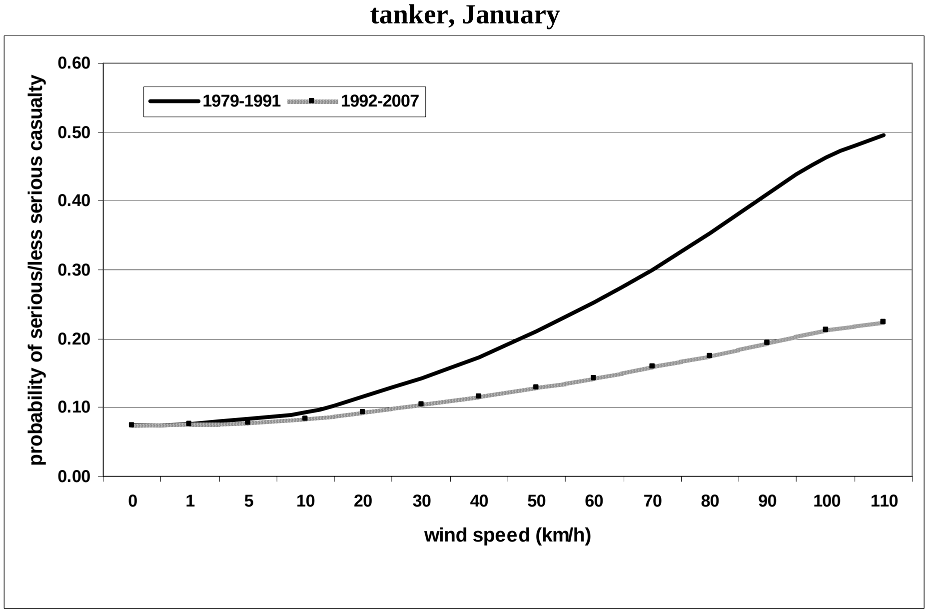


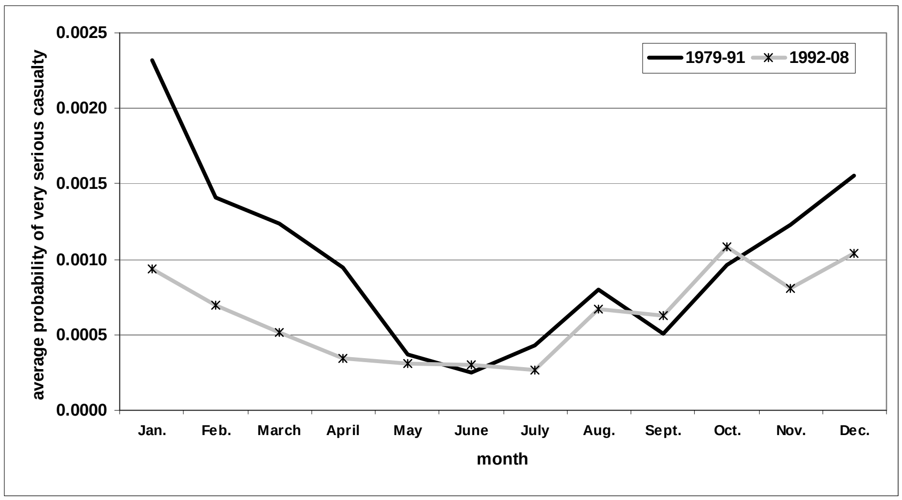
Figure 3: Effect of wind speed on the probability of serious/less serious casualty, tanker, January



The results from the models did not show a clear pattern for seasonality for the effect of significant wave height and wind but Figure 4 demonstrates seasonality in general towards the probability of casualty based on average probabilities for all ships for both time periods since this is of general interest.

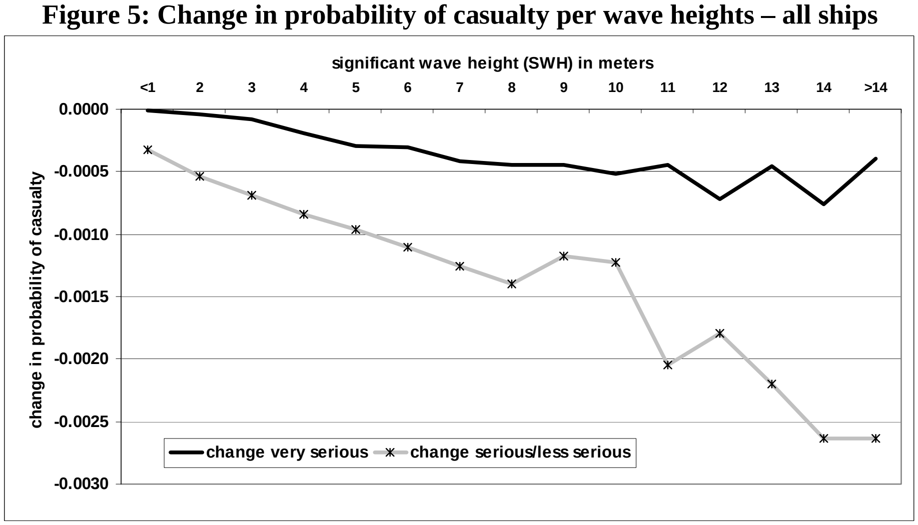
In order to produce the average probabilities, the models are used to estimate the probability of casualty for the whole dataset at each individual ship level. The data is then aggregated and grouped by month to obtain the average monthly probability given a certain time period. One can clearly see from Figure 4 that the highest probability of casualty is in the winter months for both time periods while for the later time period, the probability is slightly higher for September and October.

Figure 4: Seasonal effects based on average probabilities of casualty – all ships



Following the same principle described above to compute average probabilities, Figure 5 takes one step further and visualizes the change of the probability of casualty per significant wave height increment (meters) for all ships where the change is the difference from time period 1979-1991 to 1992-2007.

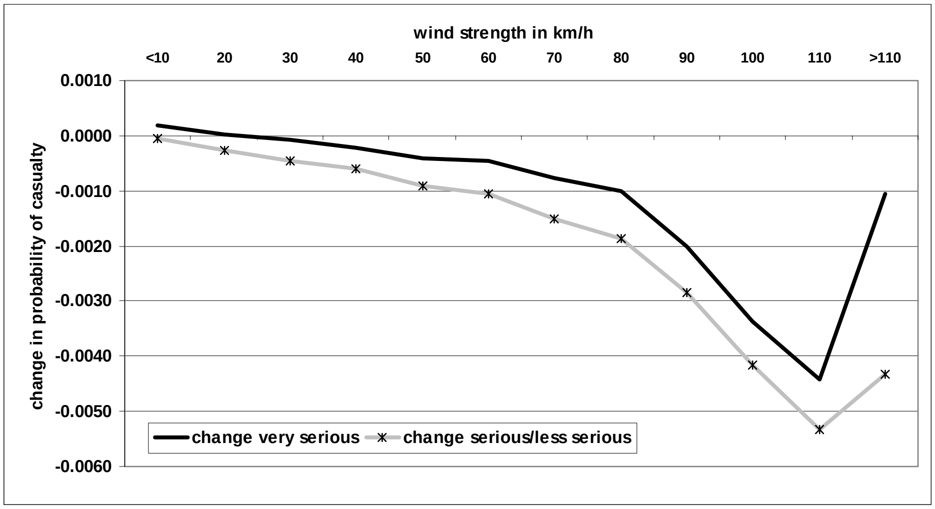
Figure 5: Change in probability of casualty per wave heights – all ships



Note: SWH increments are given for the maximum within the group (2 means between 1.01 and 2 meters)

Figure 6 visualizes the same for wind strength increment (km/h). One can see from Figure 5 that the changes across time periods for the average probabilities is minimal but the change towards the probability of very serious casualty is less pronounces compared to the serious and less serious casualty. For both categories, the changes in the average probabilities decrease over time. A similar picture can be seen from the change of the average probability of casualty per wind strength increment over the two time periods as given in Figure 6.

Figure 6: Change in probability of casualty per wind strength – all ships



Note: wind increments are given for the maximum within the group (20 means between 10.01 and 20 km/h)

5. Summary of Results, Future Research and Recommendations to the policy maker

This article uses a unique dataset of 3.2 million observations in order to investigate whether changes in oceanographic conditions (significant wave height and wind strength) can be filtered out towards the probability of casualty while correcting for other factors that can influence safety such as the basic ship profile, ship safety inspections or ship economic cycles. A total of 12 models (separate models per ship type and casualty type) are estimated using standard econometric techniques in order to see whether the effect of interest can be filtered out and to test whether it changed over time.

The article concentrates on the North Atlantic and Arctic region since changes in oceanographic conditions have been confirmed in the literature and the North Atlantic is mostly taken as the baseline for regulatory developments due to its severe conditions. The article concentrates on significant wave height and wind strength while other variables (ice conditions, precipitation and visibility) might be of interest in the future if data can be provided to redo a similar analysis and also be extended to other shipping areas.

The results show that the effect for significant wave height and wind strength towards the probability of casualty can be filtered out. For 71% to 79% of the 288 possible outcomes (depending on the models), the effect of both variables cannot be measured but for the parameters which are significant, one can predominately see a positive effect for wind while the split up is more evenly distributed for significant wave height. The effect is stronger for the models for very serious casualties (18.1% positive and 10% negative for wave height and 23.6% positive and 4.2% negative for wind strength).

One cannot determine a clear seasonal pattern of the effect of wind and wave height towards the probability of casualty but overall the probability of casualty is influenced by seasonality with the winter month showing the highest average probability.

For significant wave height, 16% of the total combinations and for wind, 20% of the total combinations show an effect which changes over time where the change can be increasing or decreasing or where its significance can change from one time period to another. The effects of the changes are mostly increasing (69.9%) for significant wave height in January, March, May and October and mostly decreasing (69%) in January, March and May for wind strength.

While the results for wind strength are less relevant for the attention of the policy makers, the results for significant wave height might be relevant for consideration, especially in the context of the development of goal based standards for ship construction standards as currently in process at the International Maritime Organization (IMO). It might also be relevant for the common structural rules used for the design of ships and SOLAS chapter 2-I dealing with construction standards and last revised in 2006 with Resolution MSC.216(82)[23] and the IMO Code on Intact Stability, especially for ships operating in the North Atlantic and the Arctic region.

Finally, Koivurova and Molenaar [24] analyze the regulatory and governance gaps of the Artic region and given the inherent risk of increased traffic in the region and the strong seasonality towards the probability of casualty, the development of a regional Memorandum of understanding (MoU) to perform safety inspections in the Arctic region in the future should help to reduce the risk. In this context and due to increased traffic, an expansion of search and rescue efforts in the context of the International Convention on Maritime Search and Rescue (1979) might also be relevant.

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Appendix 1: Summary of Statistics for models per ship type

	Ship Type: general cargo		Ship Type: container		Ship Type: tanker	
Model Type	**very serious**	**serious/ less serious.**	**very serious**	**serious/ less serious**	**very serious**	**serious/ less serious**
# of observations (0)	1,050,409	1,049,706	882,375	882,197	446,999	445,699
# of observations (1)	800	1,503	40	218	164	1,464
total observations	1,051,209	1,051,209	882,415	882,415	447,163	447,163
cut off value	0.00076	0.00143	0.00005	0.00025	0.00037	0.00327
Mc Fadden R2	0.326	0.287	0.206	0.191	0.126	0.143
% Hit Rate y=0	88.07	84.48	86.18	80.66	72.53	70.36
% Hit Rate y=1	84.38	82.70	70.00	66.51	79.88	78.55
% Hit Rate Tot	88.06	84.48	86.18	80.65	72.53	70.39
p-value of HL-Stat.	0.000	0.000	0.000	0.000	0.170	0.000
	Ship Type: dry bulk		**Ship Type: other ST**		**Ship Type: passenger**	
Model Type	**very serious**	**serious/ less serious**	**very serious**	**serious/ less serious**	**very serious**	**serious/ less serious**
# of observations (0)	291,221	290,451	492,376	492,308	106,192	106,000
# of observations (1)	173	943	37	105	50	242
total observations	291,394	291,394	492,413	492,413	106,242	106,242
cut off value	0.00059	0.00324	0.00008	0.00021	0.00047	0.00228
Mc Fadden R2	0.140	0.192	0.171	0.209	0.168	0.125
% Hit Rate y=0	73.73	75.39	82.35	76.29	81.13	75.54
% Hit Rate y=1	77.46	80.06	67.57	75.24	82.00	75.62
% Hit Rate Tot	73.73	75.41	82.35	76.29	81.13	75.54
p-value of HL-Stat.	0.119	0.000	0.511	0.584	0.995	0.555