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Climate change and safe design of ship structures

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ABSTRACT

The paper addresses projected changes of wave climate in the North Atlantic and their impact on the safe design of ships, with a particular focus given on associated uncertainties. The Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) uses four scenarios for future greenhouse gas concentrations in the atmosphere called Representative Concentration Pathways (RCP). Two of these scenarios are applied to investigate how sensitive the future North Atlantic wave climate is to the emissions they represent. Winds obtained from six global climate models have been used to simulate waves for a historical period at the end of last century and to project waves for a future period towards the end of this century for these two scenarios. Based on these projections, possible changes in extreme wind and waves are investigated and the associated uncertainties are discussed. The occurrence of rogue-prone sea states which may trigger generation of rogue waves in the past and future climate is also studied. It is shown how the scientific findings on uncertainties related to climate change projections and rogue waves can be incorporated in the risk-based approach used in current design practice of tankers, and ship structures in general. The potential effect of climate change on the safety level of current design practice for tankers is demonstrated. Finally, the paper discusses how structural design of ships can be upgraded to account for climate change and rogue waves without necessarily leading to significant economic consequences.

1. Introduction

Marine safety is one of the main concerns of the shipping and offshore industry in general and Classification Societies in particular. The importance of including the state-of-the-art knowledge about meteorological (temperature, precipitation, wind) and oceanographic (waves, current) conditions in ship and offshore standards has been discussed increasingly by industry and academia in the last decades in several international forums, e.g. International Ship and Offshore Structures Congress (ISSC, 2009, 2012, 2015), ISSC-ITTC (International Towing Tank Conference) Workshops (Bitner-Gregersen et al., 2014; Kim, 2016).

Global warming and extreme weather events reported in the last years have attracted a lot of attention not only in academia (e.g. Wang and Swail 2006a,b; Hemer et al., 2010, 2013; Wang et al., 2015) and media but also in the shipping as well as offshore and renewable energy industry (e.g. ISSC, 2015; Bitner-Gregersen et al. 2013a,b; 2015; Hagen et al., 2013). A central question for the marine industries is: to what degree will climate change affect future ship traffic and design of ships as well as offshore and renewable energy structures?

The observed climate changes include natural variability of climate and anthropogenic climate change. Natural climate variability is due to the Earth's system dynamics, short term externally forced climate changes (volcanic activity, short term changes in solar radiation) and long term external forcing such as tectonic movement, solar radiation, changes in the Earth's orbit and asteroid bombardment. It has always been present. Anthropogenic climate change is due to human activities and is mostly associated with emissions of greenhouse gases to the atmosphere from burning of fossil fuels, but other factors such as land usage changes and deforestation also play a role. It leads to warming of the Earth's surface (IPCC, 2007; 2013). These two types of climate variations, natural and anthropogenic, interact with each other. Anthropogenic climate change brings trends in the mean value of metocean parameters, which can be neglected when talking about natural variability of climate in a more limited period of time, not covering

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thousands or millions of years. It may be also leading to changes of extremes as well as shapes of distributions of metocean parameters.

By now, a consensus has been reached within the scientific community that human activities contribute significantly to the observed warming of the Earth's surface resulting in changes of climate (IPCC, 2007, 2013). This also leads to changes in metocean conditions. Notice that natural variability of climate has been taken into account when relevant return values are calculated for use in design by considering sufficiently long meteorological and oceanographic (metocean) data records.

The Fifth Assessment Report (AR5), which was issued by the Intergovernmental Panel on Climate Change (IPCC, 2013), uses four scenarios for future greenhouse gas concentrations in the atmosphere called Representative Concentration Pathways (RCP) with radiative forcing of 2.6, 4.5, 6.0 and 8.5 W/m^2 by the end of the 21st century referred to as RCP 2.6, RCP 4.5, RCP 6.0 and RCP 8.5, respectively. It summarises the latest scientific findings regarding climate change. A significant development has taken place since the issue of the Fourth Assessment Report (AR4) (IPCC, 2007), particularly in the increased use of quantitative statistical measures simplifying synthesis and visualization of climate model performance (see e.g. Sahany et al., 2012). However, similarly as in AR4, also in AR5 temperature, sea water level, precipitation, and ice extent received more attention compared to wind and waves. AR5 confirms the conclusions of AR4, that there are large regional variations in observed and projected climate-driven changes in metocean conditions.

Changes in wave and wind climate are expected to have the largest impact on marine structure design in comparison with other environmental phenomena since for most of marine structures wave induced loads are dominating. Changes in sea level combined with storm surge have little potential to affect ship design directly but may impact offshore and coastal installations. On the opportunity side, retreating arctic sea ice may open new areas for commercial ship traffic, but this is associated with additional risks related to operations in remote and harsh environments.

Climate change in terms of increased storm activity (intensity, duration and fetch) in some ocean areas, and changes of storm tracks, may lead to secondary effects such as increased frequency of occurrence of extreme wave events (abnormal waves also called rogue or freak waves), see e.g. Toffoli et al. (2011), Bitner-Gregersen and Toffoli (2014, 2015), Bitner-Gregersen (2016).

At present climate change and rogue waves are not explicitly included in Classification Societies' rules and Offshore Standards due to lack of sufficient knowledge about uncertainties associated with climate change projections and no full consensus about the probability of occurrence of rogue waves.

Although large uncertainties are associated with climate change projections, adaptation processes to climate change have already started in the marine industry to support safe design as at present in some ocean regions changes of metocean conditions cannot be excluded. In the Norwegian Standard NORSOK (2007), it is recommended to increase extreme significant wave height and wind speed by 4% on q-probability values due to climate change. Further, it is worth to mention that some changes in industry standards have also been introduced to account for rogue waves. The oil company STATOIL (see ISSC, 2013) has already introduced an internal requirement accounting in a simplified way for rogue waves when designing the height of a platform deck. This requirement is now implemented in the revised version of NORSOK (2007). Also, some revisions of the DNV GL rules for design of superstructures of passenger ships that account for rogue waves have also taken place as a result of the EC EXTREME SEAS (2013) project coordinated by legacy DNV (see e.g. Bitner-Gregersen et al., 2015).

A decision about possible systematic updates of Classification Societies' rules and standards for ships and other marine structures should be based on the state-of-art knowledge about climate change projections. The marine industry needs to know what changes in metocean conditions can be expected due to climate change in different parts of the ocean, what potential consequences they may have on design and safety of marine operations, and what methods can be used to account for these changes. Further, to be able to provide design and operational criteria accounting for climate change, relevant uncertainties associated with climate change projections need to be identified and quantified. This is of particular importance as uncertainties associated with climate change projections are currently large.

It may be argued that the potential effects of climate change on ship design can partly be compensated for by adjusting ship routes based on improved weather forecasts and with the support of advanced routing systems. However, weather forecasts are affected today by uncertainties and may not ensure avoidance of every storm, and not all types of ships are routing to the same degree. Further, the technology for deriving wave heights from marine radars has not yet fully been demonstrated in a satisfactory approach and is still under investigations. Finally, some ocean areas where an increase of significant wave height can take place may be difficult to avoid, e.g. for ferries, supply ships and FPSOs. Notice that a discussion of whether ship routing can be accounted for in current design practice is outside the scope of the present study.

The need to address climate changes in guiding documents became increasingly evident for DNV GL and was a motivation for initiation in 2013 investigations, summarized in the present paper, which were partly funded by Research Council of Norway (Bitner-Gregersen et al., 2013a). One of the main objectives was getting better insight into climate changes of wave conditions in the North Atlantic, as well as the associated uncertainties. Notice, that the North Atlantic wave climate is used today as a basis for ship design (IACS, 2001). To the authors knowledge the first time not only impact of climate changes on the significant wave height but also on the spectral wave period, associated wave steepness and wave spectra were investigated. Further, apart from the effects of climate change on total sea, the effects on wind sea and swell were also studied separately.

Although the present study concentrated on ships when investigating impact of climate change on loads and safety level of current design, the results addressing wind and wave are applicable also to offshore and renewable energy structures.

The paper is organised as follows. Section 2 is dedicated to identifying types of uncertainties associated with wind and wave projections; Section 3 shows projected changes of wind and wave climate in the North Atlantic and discusses associated uncertainties of these projections. Occurrence of rogue waves in the future climate is addressed in Section 4, while impact of climate change on design is discussed in Section 5. The paper closes with recommendations for future research needs and conclusions.

2. Type of uncertainties associated with climate projections

Climate models do not include any direct information about ocean waves, and dynamical or statistical downscaling must be employed to obtain information about waves from the climate model results. One possible approach is to use surface winds from climate models as input to numerical spectral wave models, e.g. WAM, WAVEWATCH III or SWAN, routinely used in operational wave forecasting by meteorological offices throughout the world. An alternative approach is to employ empirical relationships between the significant and the mean sea level pressure through a statistical downscaling approach, see e.g. Wang et al. (2006b, 2012, 2014). Such an approach is naturally much less computationally demanding than the dynamic wave modelling approach, but also gives a more limited information about the properties of the wave field.

The dynamical approach has been adopted for the present study and uncertainties associated with its application for projections of climate changes of wind and wave characteristics are discussed below in the perspective of the definitions of uncertainties given in Appendix A.

Projections of future wind and wave climate include several steps shown schematically in Fig. 1. Different uncertainties are associated with these steps. They will all impact projected wind and wave conditions, but

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