Preface

Within the history of shipping, there are numerous examples of ships that have been lost at sea as a consequence of bad weather, but also in cases where bad weather is not the main cause of accident, severe weather impedes rescue operations and leads to escalation of events. Tragic accidents such as the sinking of the passenger ship Estonia in 1994 and the breaking up of the oil tanker Erika in 1999 easily comes to mind. Both these maritime disasters occurred in rough weather and resulted in severe consequences in terms of human fatalities or environmental damage; 852 lives were lost in the Estonia accident and thousands of tons of oil were released into the sea in the Erika accident, killing marine life, polluting nearby shores, and making it one of the greatest environmental disasters to ever hit France. Furthermore, several thousand containers are lost at sea each and every year during maritime transportation and rough seas are often to blame.

These are merely examples of how heavy weather may contribute to maritime accidents but there are numerous others with catastrophic consequences in terms of lives lost, severe environmental damage and property loss; they serve to illustrate the influence of the ocean wave climate on maritime safety. Obviously, a roughening of the ocean wave climate also has the potential to severely impact other areas of society as well, related to maritime, offshore, and coastal activities. Combined with sea level rise and other possible effects of climate change, coastal areas throughout the globe may be seriously affected.

Ships and other marine structures are constantly exposed to the wave and wind forces of its environment, and extreme ocean climate represents a great risk to marine operations, as illustrated by the examples above. According to maritime casualty statistics, bad weather is a major cause of ship accidents, and this stresses the importance of taking extreme sea state conditions adequately into account in ship design. This is important to ensure that the ships can withstand the environmental forces they are expected to encounter throughout their lifetime. Hence, a correct and thorough understanding of meteorological and oceanographic conditions, most notably the extreme values of relevant wave and wind parameters, such as the significant wave height (H_s) is of paramount importance to maritime safety, and there is a need for appropriate statistical models to describe the variability of these phenomena.

With the climate change that the globe is currently experiencing the future ocean wave climate may change and it may no longer be sufficient to base design codes and safety standards on current knowledge about the past and present ocean environment. The implicit assumption that the future will be like the past may no longer be even approximately valid and there is a need to consider how wave parameters are expected to change in the future, as a consequence of climate change. Thus, there is a need for time-dependent statistical models that can take the long-term time-dependency of integrated wave parameters properly into account. Furthermore, there is a need for methods to take potential impacts of such long-term trends on the environmental loads of ships and other marine structures into account.

The models presented in this monograph are stochastic models, probabilistic counterparts to physical models that are more deterministic, with treatment of uncertainties as an integral part of the models. In a historic perspective, it is noted that for a long time following the scientific revolution in the sixteenth century, the predominant world-view was deterministic. It was believed that if exact knowledge of initial conditions and causal laws governing a system were available, the exact state of the system could be determined at any later point in time. In such a mechanistic world, randomness would not exist and failure to precisely predict future events would be entirely due to incomplete knowledge of initial states and universal laws. However, in the late nineteenth and early twentieth century, new scientific discoveries cast serious doubts on a strictly deterministic world-view. Chaos theory explained how even an infinitesimally small perturbation of initial conditions of a purely deterministic non-linear system can lead to large changes in the development of the system (the butterfly effect). Furthermore, the development of quantum mechanics and the formulation of the Heisenberg uncertainty principle demonstrated that reality, at least at atomic scales, does not seem to be absolutely deterministic, suggesting a more probabilistic understanding of the world.

Regardless of whether the world is fundamentally probabilistic or if it is deterministic but with uncertain knowledge of the underlying physical laws, physical environmental processes inevitably display some seemingly causal relationships along with a considerable degree of randomness. Hence, it is argued that it would make sense to describe such phenomena probabilistically, i.e., using probability theory and statistics to model physical processes as stochastic processes, where there are several possible ways for a system to evolve. Notwithstanding, the probabilistic modeling approach presented in this monograph is presented as a complementary alternative to more geophysics-based deterministic wave and climate models. Physical models remain the primary approach for investigating the impacts of climate change, but it is believed that the results obtained from probabilistic models can be used to complement such models and yield increased insight into these complicated processes.

One of the more practical advantages of using a stochastic model is that estimates of the uncertainties are given explicitly. These are important when future projections are to be incorporated in risk analyses or utilized in probabilistic load calculations as illustrated by an example herein. The case study reveals that the effect of the predicted trend in the ocean wave climate on environmental loads of ships are far from being negligible, and that this may need to be taken into account in design and construction of ships.

This monograph presents recent research on the statistical modeling of ocean wave climate in space and time, with a particular interest in the modeling of long-term trends, possibly as a result of climate change. The research was mainly carried out at the Statistics Department at the Mathematical Institute of University of Oslo, Norway as a part of my Ph.D. thesis in statistics [2]. The material presented in this monograph summarizes and is to a large degree based on seven recent publications in various academic journals. The literature survey presented in Chap. 2 was first published in [1]. Chapter 3 which outlines the main Bayesian hierarchical space–time model for H_s is based on the paper published in [5], but contains some additional results pertaining to monthly maximum data, previously presented at the Geostat 2012 conference [7]. The work on including a logarithmic transform of the data was originally published in [6], but again Chap. 4 is extended with results for monthly maximum data [7]. Chapter 5, which extends the base model with a CO_2-regression component is based on [8] and Chap. 7 concerning the potential impact on ship's environmental loads and structural responses is an extension of [3], where also the trends estimated from the models with CO_2-regression are considered. Finally, the case study in Chap. 8 where the model is applied to different ocean areas worldwide, is based on [9]. An additional chapter, Chap. 6 which is based on [4], is included where the modeling framework is applied to oceanic surface wind speeds over the same area.

Some appendices are included at the end of this book, where some important concepts and general results that have been utilized in the research are briefly outlined. Appendix A contains a brief introduction of Markov chain Monte Carlo (MCMC) methods, which has been used in the implementation of the model. In particular, the main ideas behind the Gibbs sampler and the Metropolis–Hastings algorithm are described. Appendix B introduces some of the most common methods of modeling extreme values, i.e., the block maxima approach and the peaks over threshold approach, and some basic results pertaining to Markov Random Fields are briefly introduced in appendix C. In appendix D, the derivation of the full conditionals of the Bayesian hierarchical space–time model is presented, which have been used in the MCMC simulations. Finally, appendix E presents a straightforward method for obtaining samples from an arbitrary multi-normal distribution based on independent samples of the univariate standard normal distribution which has been exploited in the simulations of the model.

It is believed that this research monograph should be of interest to anyone with an interest in stochastic modeling in general and to those with a special interest in environmental research and effects of climate change in particular. Furthermore, the research has practical applications related to ocean and coastal engineering and should be of interest to various stakeholders within the maritime industries such as designers, classification societies, ship owners and operators, flag states, and intergovernmental agencies such as the IMO. The intended audience for this publication includes, but is not limited to, statisticians, environmental researchers, climate researchers, ocean and coastal engineers, naval architects, oceanographers, meteorologists, maritime policy makers, and risk analysts.

References

1. Vanem, E.: Long-term time-dependent stochastic modelling of extreme waves. Stoch. Environ. Res. Risk Assess. **25**, 185–209 (2011)
2. Vanem, E.: Bayesian hierarchical space–time models for significant wave height data. Ph.D. dissertation, University of Oslo (2012)
3. Vanem, E., Bitner-Gregersen, E.: Stochastic modelling of long-term trends in the wave climate and its potential impact on ship structural loads. Appl. Ocean Res. **37**, 235–248 (2012)
4. Vanem, E., Breivik, O.N.: Bayesian hierarchical modelling of North Atlantic windiness. Nat. Hazards Earth Syst. Sci. **13**, 545–557 (2013)
5. Vanem, E., Huseby, A.B., Natvig, B.: A bayesian hierarchical spatio-temporal model for significant wave height in the North Atlantic. Stoch. Environ. Res. Risk Assess. **26**, 609–632 (2012)
6. Vanem, E., Huseby, A.B., Natvig, B.: Modeling ocean wave climate with a Bayesian hierarchical space–time model and a log-transform of the data. Ocean Dyn. **62**, 355–375 (2012)
7. Vanem, E., Huseby, A.B., Natvig, B.: A stochastic model in space and time for monthly maximum significant wave height. In: Abrahamsen, P., Haugen, R., Kolbjørnsen, O. (eds.) Geostatistics, pp. 505–517 Springer, Oslo (2012)
8. Vanem, E., Huseby, A.B., Natvig, B.: Bayesian hierarchical spatio-temporal modelling of trends and future projections in the ocean wave climate with a CO_2 regression component. Environmental and Ecological Statistics (2013, in press)
9. Vanem, E., Natvig, B., Huseby, A.B.: Modelling the effect of climate change on the wave climate of the world's oceans. Ocean Sci. J. **47**, 123–145 (2012)

http://www.springer.com/978-3-642-30252-7

Bayesian Hierarchical Space-Time Models with
Application to Significant Wave Height
Vanem, E.
2013, XX, 262 p. 85 illus., 14 illus. in color., Hardcover
ISBN: 978-3-642-30252-7