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Estimation of characteristic snow loads on offshore structures in the Barents Sea

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ABSTRACT

Snow accumulating on offshore structures can reduce freeboard and stability, block equipment and valves, and reduce operability of the platform or ship. It is thus important to assess risk related to snow accumulation prior to offshore operations in cold climates. However, offshore snow conditions in the Barents Sea are largely unquantified.

In the present study, methods are developed to investigate snow loads on offshore structures in the Barents Sea. A model to establish time series of snow loads using a 10-day snowfall model, with or without snow transport by wind has been implemented. Methods to estimate extreme value statistics have also been applied, specifically using the generalized extreme value distribution. These models have been used with input from meteorological data from NORA10 hindcast grid points covering the entire Barents Sea to provide estimates of extreme snow loads. The results for a 10-day snowfall model without drift show 100-year return levels of snow load to be in the range 0.7kPa to 1.15kPa in large parts of the Barents Sea. Indication of a declining trend in the extreme values has also been found in the southern Barents Sea. In this area, the trend indicates a 20% decrease in extreme snow accumulation during the 58years of study. The hindcast archive NORA10 was validated against observations to evaluate uncertainties in the hindcast. NORA10 estimates on average more precipitation than observed at all locations, but the distribution of extreme precipitation is similar to the observations. Due to an expected undercatch of snow in the observations, it is likely that NORA10 underestimates extreme precipitation.

1. Introduction

According to the U.S. Geological Survey (Gautier et al., 2009), areas north of the Arctic Circle account for 13% of undiscovered oil resources and 30% of undiscovered natural gas, most of this offshore. Even though moving petroleum activity further north can potentially give access to large resources, it also introduces different challenges compared to exploration and production of hydrocarbons at lower latitudes. Of the new challenges, the present study is focused on extreme snow loads on offshore structures, specifically in the Barents Sea.

Before starting field development, it is important to investigate the meteorological conditions in the area. The physical environment in the Barents Sea is, due to its remoteness, not as well mapped and understood as e.g. the North Sea or the Norwegian Sea. Syversen et al. (2015) investigated knowledge gaps in meteorological conditions in the Barents sea, and found that heavy snowfall and snow accumulation offshore were poorly understood problems which needed further investigations.

Snow accumulation can have adverse effects on installations operating in cold climate regions. It can lead to reduced operability, blocking of mechanisms, slippery deck and ladders, inoperability of evacuation systems, and in the worst case compromise the structural integrity or stability, which could cause the loss of the vessel/platform and all lives aboard (Ryerson, 2011). It is thus necessary to estimate the extra loads and risks from snow when designing ships or platforms for cold climate regions. This is a requirement in the international standard for Arctic offshore structures (ISO FDIS 19906, 2010). Reducing conservatism in estimates of snow accretion loads may also free up loading capacity on existing structures.

Presently, there is very limited information on offshore snow loads in the open technical literature. Most of earlier efforts on atmospheric icing and snow loads have focused on land applications, like power lines (Makkonen, 1989; Nygaard et al., 2014; Makkonen and Wichura, 2010) and rooftops (DeGaetano and O'Rourke, 2004; Meløysund et al., 2007; Thiis and O'Rourke, 2015). The recently revised Norwegian

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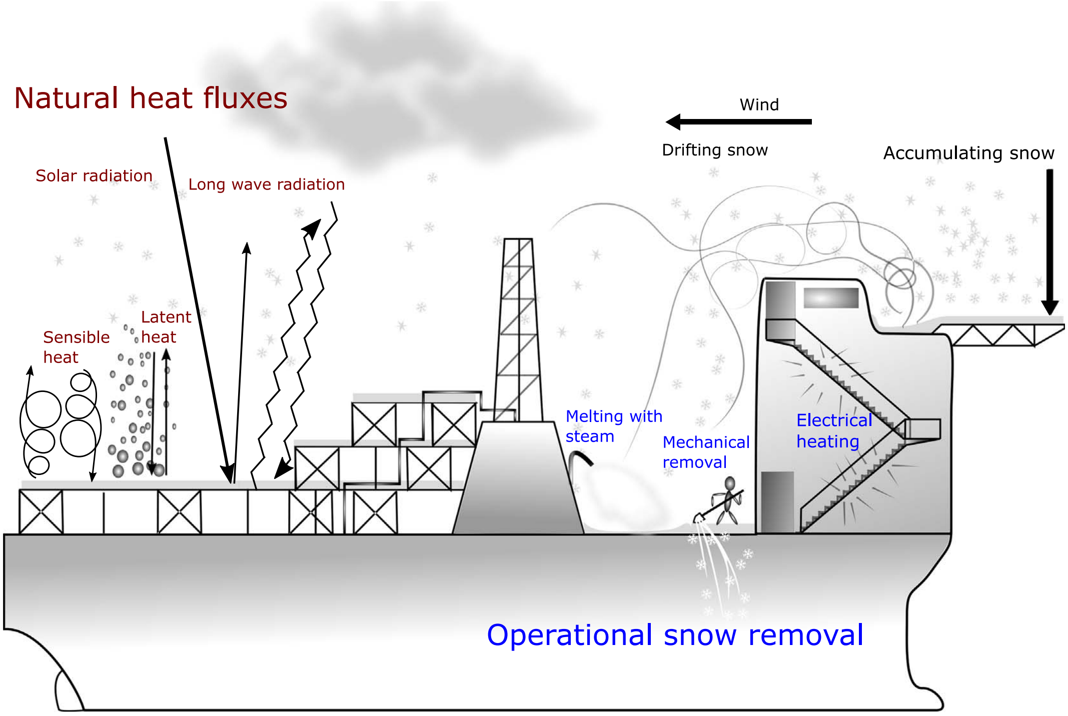

Fig. 1. The most important processes which affect the snow pack on an offshore structure.

offshore standard (NORSOK N-003, 2017) recommends a characteristic snow load of 0.8 kPa on the Norwegian continental shelf north of 70°N.

Estimating return levels for snow loads and precipitation amount on land is an old problem and has been treated by various authors (Marty and Blanchet, 2011; Meløysund et al., 2007; Marty and Blanchet, 2011; Serinaldi and Kilsby, 2014). For rooftops on land, a common strategy is to base the roof snow load on simple expressions for the relationship between snow load on the ground and snow load on the roof (ISO FDIS 43566, 2013; NS-EN-1991-1-3, 2008; Thiis and O'Rourke, 2015). The load is then adjusted by coefficients to account for the effects of roof geometry, drifting snow, exposure and heat transfer through the roof. There are several differences between offshore snow loads compared to onshore loads. There is no ground snow load and structures are always in a wind exposed environment; there are no trees, hills or other buildings which can screen from wind. The ocean also acts as a sink for snow, except in ice covered waters, and drifting snow will only blow off the platform or shift loads locally.

Fig. 1 shows a sketch of common processes which affect the snow pack. Solid precipitation accumulate as snow. Different processes then reduce the amount of snow by either melting or transporting the snow off the structure. The figure shows both natural processes and possible operational measures to reduce the snow loads. In the present study, heat fluxes from natural sources, like solar radiation, are neglected.

A structure should be designed not only to withstand daily environmental actions, but also extreme and abnormal actions. According to regulations, characteristic environmental actions on offshore structures are defined by annual exceedance probabilities of 10^{-2} and 10^{-4} (NORSOK N-003, 2017), which translates to loads which can be expected to be exceeded once per 100 and 10 000 years, respectively. To determine the characteristic actions, extreme value statistics has to be used. To model extreme precipitation on land, the so-called ' block maxima' (often ' annual maxima') method (Spreitzhofer, 2000; Marty and Blanchet, 2011; Papalexiou and Koutsoyiannis, 2013) is often used. With this method, the Generalized Extreme Value distribution (GEV)—or other distributions like Gumbel or Frechet—are fitted to block maxima. When modeling block maxima, dependence in the data can often be ignored given that the dependence only spans a short time scale compared to the length of a block (Coles, 2001, Ch. 5). It is also possible to use extreme value theory to model temporal changes in the extreme distributions. The approach has been used for climate data such as wind speed (Hundecha et al., 2008), and precipitation (Beguería et al., 2010), but only a few studies have used the non-stationary approach on snow (Marty and Blanchet, 2011; Nicolet et al., 2016).

One of the largest difficulties encountered when trying to estimate snow and ice loads is to obtain accurate meteorological data (Makkonen, 2000). The density of weather stations is very low in the Arctic, and mostly limited to coastal areas or islands. A possibility is to use output from hindcast archives or reanalysis data like the Norwegian Reanalysis Archive (NORA10) hindcast (Reistad et al., 2011) or ERA-interim reanalysis (Dee et al., 2011). Output from these models are widely used in studies of the Arctic atmospheric circulation and wind and wave loads (Bruserud and Haver, 2016; Aarnes et al., 2012). These models estimate the state of the atmosphere as well as various fluxes, like precipitation, radiation, and evaporation, through assimilation of observations. Studies have found good agreement between NORA10 wind fields and observations (Reistad et al., 2011). The uncertainties in hindcast precipitation are not very well understood and need to be investigated further (Syversen et al., 2015).

The present study is investigating snow loads on offshore structures in the Barents Sea. The scope is limited to characteristic snow load. The study was done in three steps. First, the accuracy of precipitation in the NORA10 hindcast was validated by comparing precipitation in NORA10 with observed precipitation at meteorological stations in the Barents Sea. The validation was focused on establishing snow load design criteria for offshore structures. Next, a case study of snow load on a helicopter deck was carried out. In the case study, time series of snow load were estimated using a 10-day snowfall model. To estimate extreme snow load at the location, the annual maximum snow loads were fitted to a Generalized Extreme Value distribution. A simple wind drift model was also included to investigate the effects of wind drift on the extreme snow loads. Last, the characteristic snow loads on a basin wide grid in the Barents Sea were studied. 100-year return levels for 10-day snowfall were estimated. Also, temporal trends in the extreme snow