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THE EFFECT OF VARIABLE SEA ICE ON WAVE CONDITIONS FOR 6 CHOSEN LOCATIONS IN SVALBARD

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ABSTRACT

A study has been carried out to determine likely extreme wave conditions at 6 locations with active or abandoned communities with port structures at Svalbard; Longyearbyen, Barentsburg, Pyramiden, Ny-Ålesund, Svea and Coles Bay. The work was originally initiated as part of a survey of historical ports commissioned by the Governor of Svalbard/Svalbard Environmental Fund and carried out by SINTEF.

In a revision of the previous study, the effect of ice cover (the period during which no or negligible waves may occur) is examined by excluding input from wind and ocean wave data months where it is assumed that ice-cover exists at each site. In addition, the impact of deviation in ice-cover is examined by progressively shortening the ice-cover period. This revision of the data may be applied in two areas of interest.

1. For design purposes, it will lead to a reduction of the design wave heights for those sites where it can be demonstrated that ice-free conditions never occur.
2. In the context of climate change effects, the average wave loading on beaches and glacier fronts will increase if there is a reduction in the period of ice-cover in a typical winter. This may have a significant effect on the numerous shale and gravel beaches on Svalbard, presumably increasing the risk of erosion. In addition this may also have an adverse effect on existing port structures at the chosen locations.

STUDY AREA

The study was conducted at the 4 principal sites of human activity and 2 other sites in Svalbard, see Figure 1.

1. Longyearbyen (predominantly Norwegian, administration centre)
2. Barentsburg (Russian coal mining community)
3. Sveagruva (Norwegian coal mining community)
4. Pyramiden (Russian coal mining community, mostly abandoned)
5. Ny-Ålesund (Norwegian/international research community)
6. Coles Bay (abandoned coal export facility)

Figure 1. Map of Svalbard showing the 6 sites selected for study.

METHOD

Input data

Offshore wave data have been supplied by met.no, originally for a survey conducted by SINTEF for the Governor of Svalbard on the condition of quay facilities at historical port sites in Svalbard. This work was reported by Lothe and Finseth (2012). Wave data were calculated for each site, but the effect of ice cover was simplified by assuming that one wave year was equal to the length of the assumed period of ice free conditions at each site. The offshore wave data applied are hindcast wave data at a location at N 78.06º / E 12.43º, i.e. approximately 17 km SSE of the southern end of Prins Karls Forland (Figure 1).

Bathymetric data for the offshore wave models have been obtained from openly available data published by Scripps Institution of Oceanography, described by Becker & al (2009). Bathymetric data for the near-shore areas and the sites are based on manually digitized data from sea charts from the original work by Lothe and Finseth (2012).

Wind data have been downloaded from the Norwegian Meteorological Institute website (eKlima). Data were downloaded from stations at Longyearbyen (Airport) 1978 - 2014, Sveagruva 1978 - 2014, Pyramiden 2012 – 2014 and Ny Ålesund 1978 – 2014. Longyearbyen wind data have been used without modifications at Coles Bay, and with some adjustments at Barentsburg.

Wind data were sorted by month (for all years available) and direction in 30º sectors. The statistical method chosen is a 3-parameter Weibull distribution, and all parameters are collected in a single data base.

Offshore wave data are treated identically, applying the same sectors for monthly distributions. No wave data are reported in the original data series when ice is present. Ice is reported at the hindcast location in the months of December through June. The percentage of ice-free conditions at the hindcast point by month is shown in Figure 2. This graph shows that the month of February is the most likely to have ice cover (40 % of all observations in February are ice free), but the important conclusion from this graph is that there are sufficient wave data in each month to build a statistical data base.

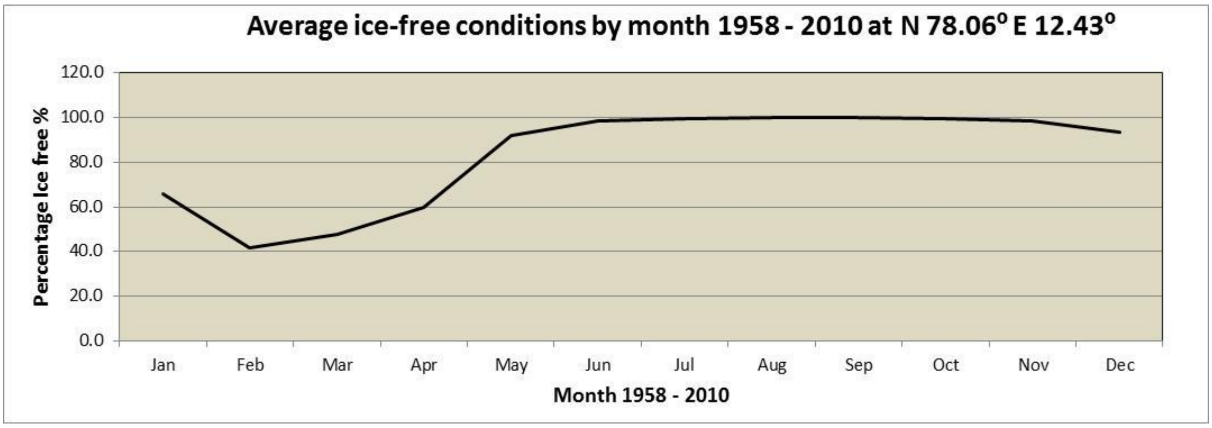

Figure 2. Graph showing monthly average ice-free conditions at N 78.06º / E 12.43º 1958 – 2010.

Wave modelling

The wave models applied for the modelling of ocean wave propagation from the open ocean to each site are taken from the SMS-package by Aquaveo, USA. The models STWAVE and CGWAVE have been applied. To enhance accuracy, the models have been applied in up to three stages, with increasing grid or mesh size resolution (result examples shown in Figure 3 to Figure 6). All spectral models have been run with a directional spread σ = 25º ($\cos^8$), JONSWAP γ = 2.5, and a still water level at 1.9 m above LAT. CGWAVE has been applied in monochromatic mode with periods T = 12.0 s, 14.0 s and 16.0 s.

Table 1 shows the stage-wise procedure for ocean wave calculations at 6 sites. CGWAVE has a variable mesh size, and the size value indicated in the table is the smallest cell size in the model.

Table 1. Table showing stages of model application for each site

Site	Model stages		
1. Longyearbyen	A. STWAVE 750 x 750 m^2	B. STWAVE 275 x 275 m^2	C. CGWAVE 10 m size
2. Barentsburg	A. STWAVE 750 x 750 m^2	B. STWAVE 275 x 275 m^2	
3. Sveagruva	No swell; wind waves only		
4. Pyramiden	A. STWAVE 750 x 750 m^2	B. STWAVE 275 x 275 m^2	
5. Ny-Ålesund	A. STWAVE 750 x 750 m^2	B. CGWAVE 10 – 15 m size	
6. Coles Bay	A. STWAVE 750 x 750 m^2	B. STWAVE 275 x 275 m^2	

At Svea, we assume that only locally generated wind waves are present due to the blocking effect of the bar island Akseløya, which leaves openings to the north and south of only 800 m and 400 m, respectively.

Wind waves have been calculated using the tool HSCOMP, developed by SINTEF. It calculates wind wave generation for complex fetches using a directional wave energy model.

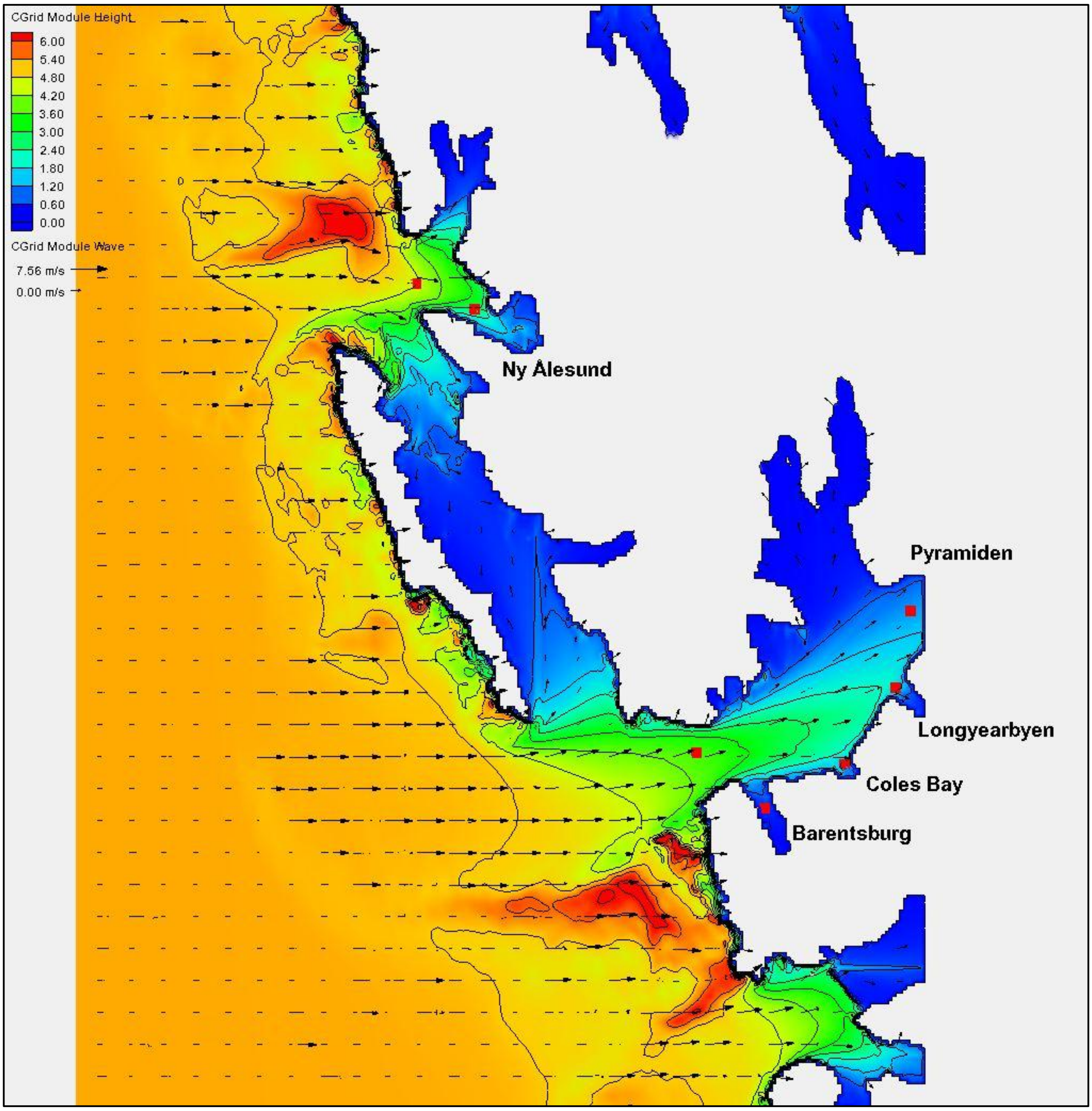

Figure 3. Figure showing the large STWAVE model (Stage A) with ocean waves approaching from the west. Incident significant wave height H_s = 5.0 m and peak spectral period is T_p = 14.0s.

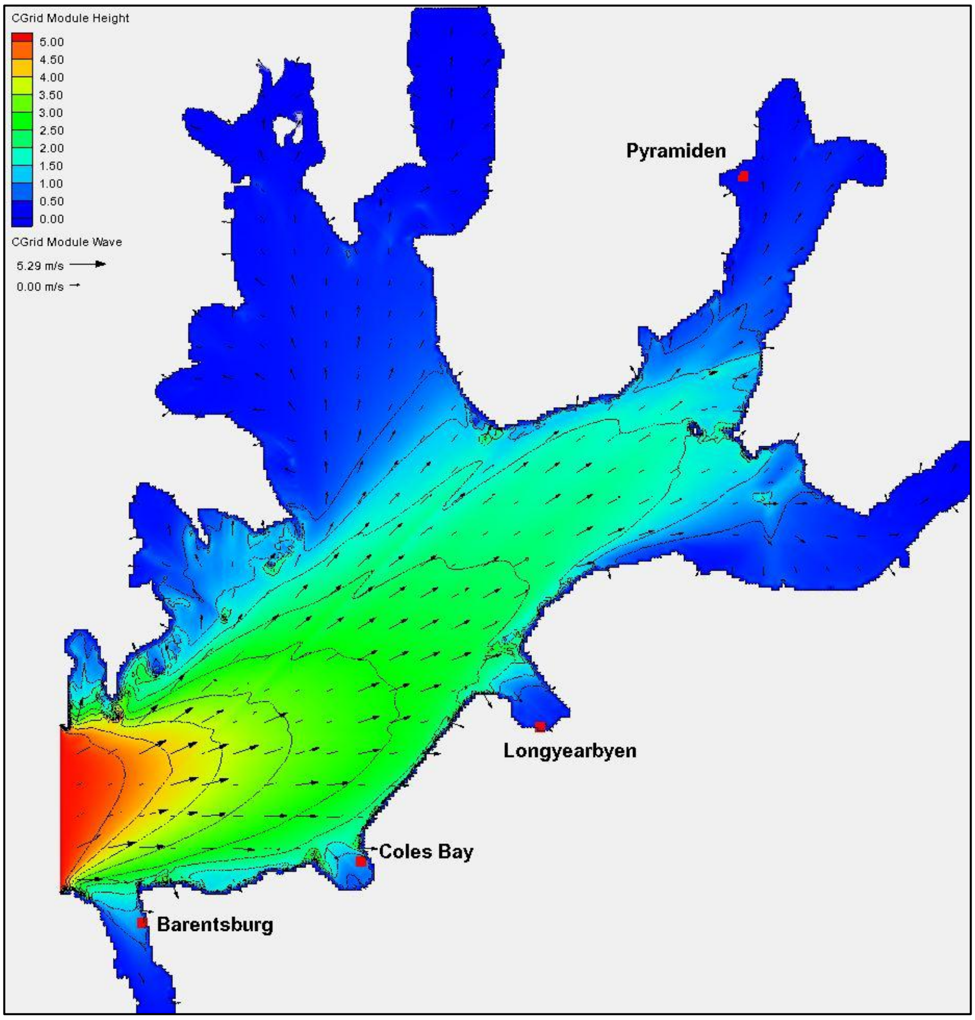

Figure 4. Figure showing small STWAVE model (Stage B) with ocean waves approaching from the west. Incident significant wave height H_s = 5.0 m and peak spectral period is T_p = 14.0 s.

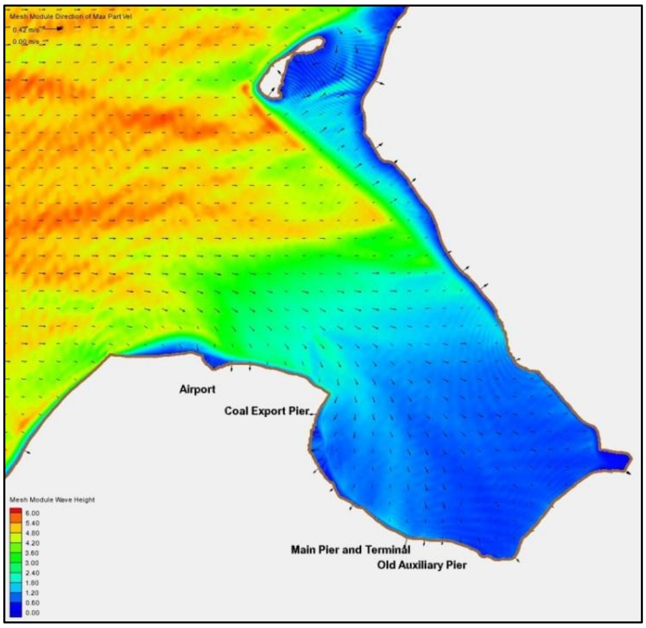

Figure 5. Figure showing CGWAVE model (Stage C at Longyearbyen) with ocean waves approaching from 270º. Incident wave height H = 5.0 m and period is T = 14.0 s.

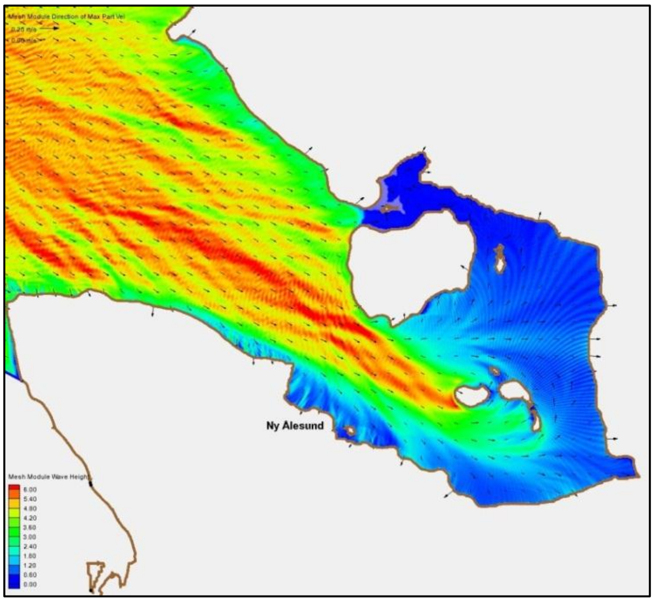

Figure 6. Figure showing CGWAVE model (Stage B at Ny Ålesund) with ocean waves approaching from 330º. Incident wave height H = 5.0 m and period is T = 14.0 s.

Statistical modelling

The data processing is based on modelling the wind and wave data using a 3-parameter Weibull distribution. The probability of exceedance is calculated for each month, and the total probability over one year is obtained by summarizing the probabilities for all relevant months in a year. The calculations are carried out for 3 base cases, and for one extra case for 2 sites where the assumed present day ice cover is more extensive.

Case 0: Present day assumed ice cover

Case 1: Ice cover reduced by 1 month in both ends

Case 2: Ice cover reduced by 2 months in both ends (Sveagruva and Pyramiden only)

Case 3: No ice cover

The assumed present day ice cover and the cases calculated are shown in Table 2.

Table 2. Table showing the assumed present-day normal yearly ice cover, total months per year and assumed individual months (ice cover indicated by shading). Numbers in ice-cover months indicate the stages of ice-cover removal in the calculations; 1 = removal of ice cover by 1 month in both ends, 2 = removal of ice cover by 2 months in both ends.

Site	Annual ice cover, months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Longyearbyen	8 - 9	1			1								
Barentsburg	7 - 8				1								1
Sveagruva	6	2				2	1						1
Pyramiden	6 - 7	2			2	1							1
Ny-Ålesund	8 - 9	1		1									
Coles Bay	3 - 4				1								1

The following assumptions are made in the calculations:

- An assumed ice cover will block ocean swell and wind waves. This means that a situation where, e.g. ocean waves are blocked by (offshore) ice while the near-shore waters are open and permit wind waves, is not accounted for.
- The average duration required for fetch-limited wind waves to develop in all cases is 60 minutes.
- The average duration of individual storms is 3 hours.
- The type of ice cover has not been considered. It is known that swell may penetrate deep into ice fields, and may even survive long passages under solid ice.

RESULTS

Results presented here are given at 1-year return period level. We presume that the average wave loading on, e.g. beaches and gravel slopes is of primary interest, so that annual maxima would be of greater use. We have also included a summary of results for 100 year return period to give an indication of extreme wave-heights for the various locations.

The calculated results for wind waves in Barentsburg are shown in Figure 7. The wind waves are dominated by waves from direction 330º, i.e. waves which are set up by wind across Isfjorden and which continue down Grønnfjorden. There is a very clear increase in wave heights as we move from Case 0 (ice cover December – April) via Case 1 (ice cover January – March) to a case without ice. The increase is, however modest for the most exposed directions.

Similar data for swell waves at Barentsburg are shown in Figure 8. Here we see a different kind of variation, where the predominant (offshore) direction gradually shifts from 270º to 240º as the ice cover is reduced from December – April to 'No Ice'. It should also be noted, however, that the inshore swell direction is nearly constant for all the sites, so that this effect would be noted only as an increase in wave height, in the order of magnitude of 0.1 m.

Summary results are shown for all sites in Figure 9 (return period = 1 year) and Figure 10 (return period = 100 years) for all cases of ice cover and wind waves and swell separately.

We observed the largest variations for Coles Bay at just under 0.3 m for both swell and wind waves with a return period of 1 year and 0.4 m for waves with a return period of 100 years.

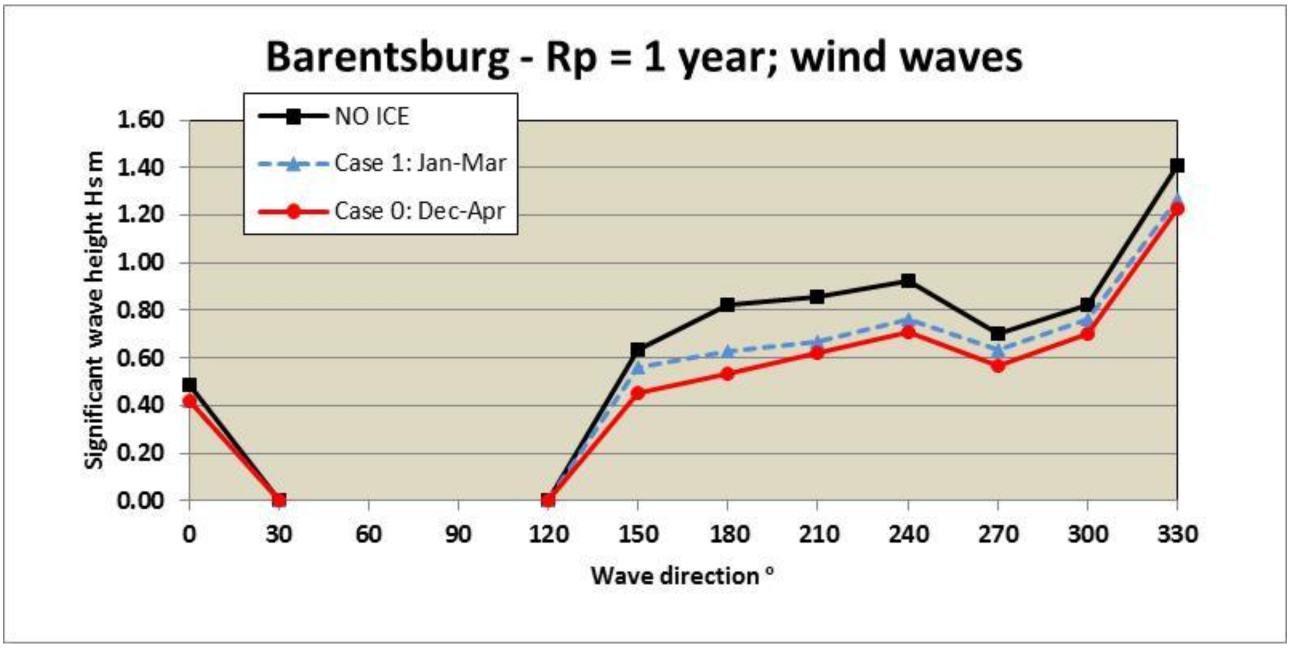

Figure 7. Distribution over directions of 1 year return period wind wave significant wave height at Barentsburg for 3 cases of ice cover

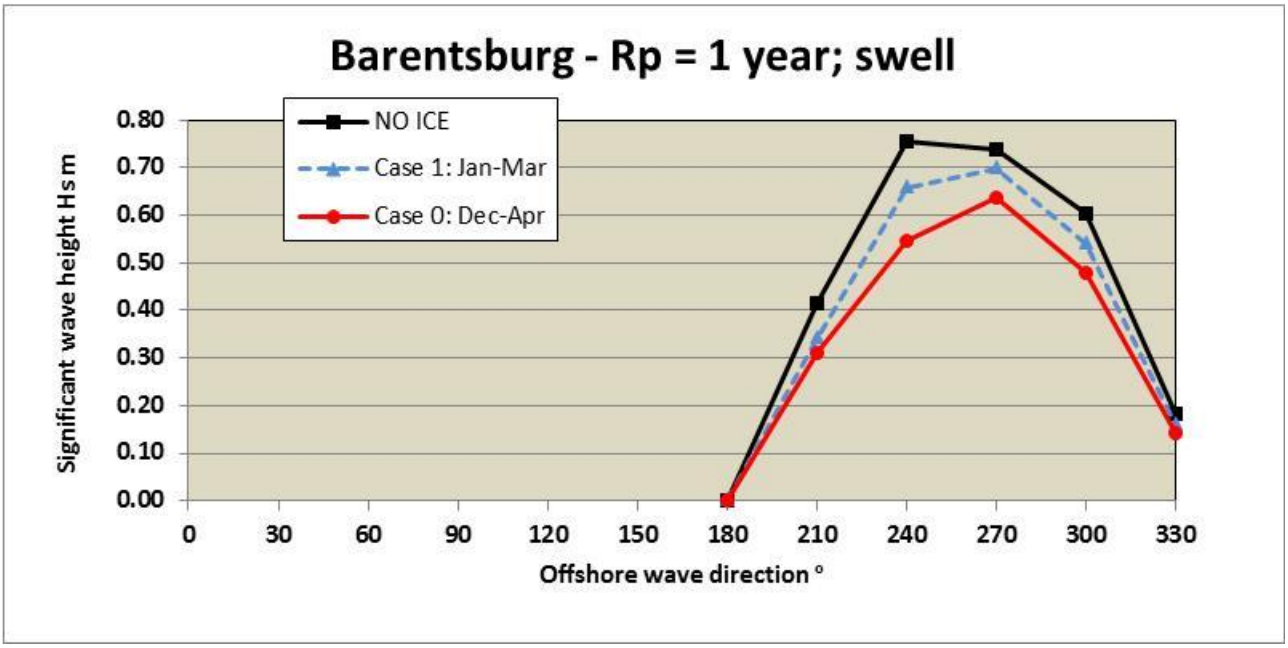

Figure 8. Distribution over directions of 1 year return period swell wave significant wave height at Barentsburg for 3 cases of ice cover

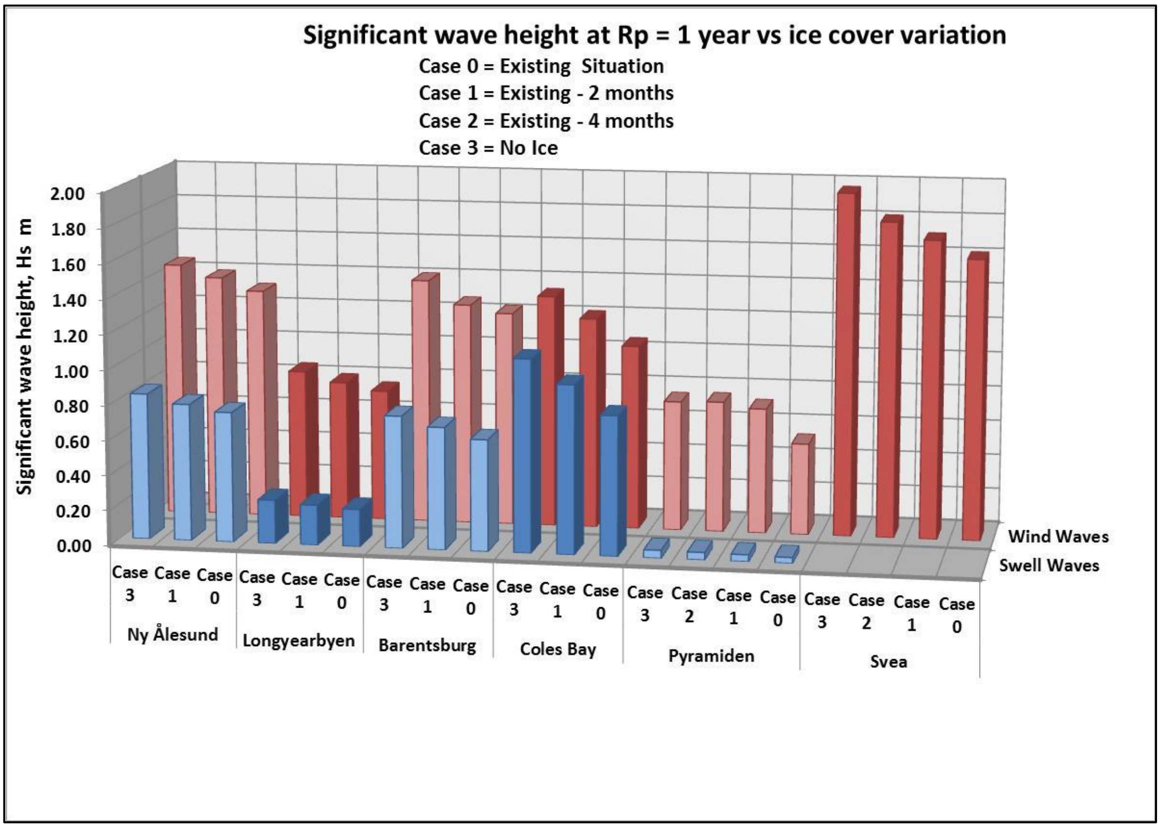

Figure 9. 3-dimensional plot showing the 1-year return period maximum significant wave height over all directions for the 6 sites investigated. Wind waves and swell are shown separately.

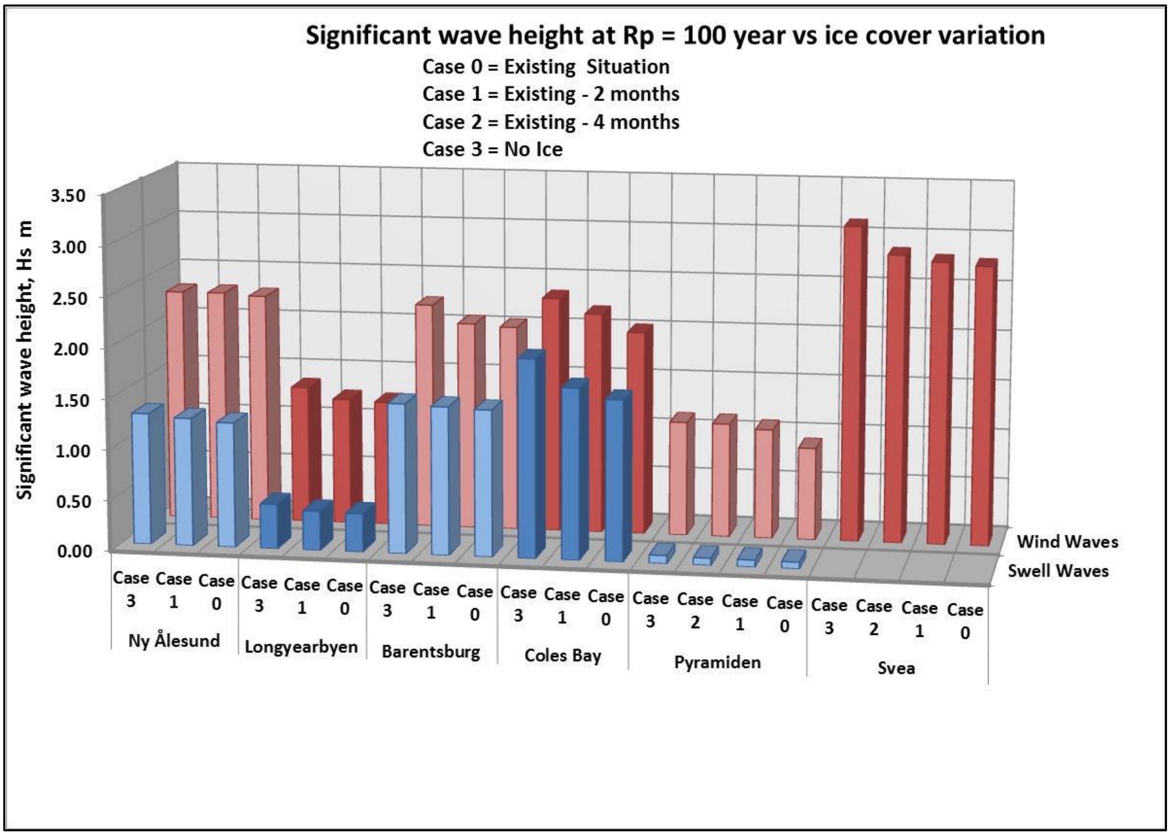

Figure 10. 3-dimensional plot showing the 100-year return period maximum significant wave height over all directions for the 6 sites investigated. Wind waves and swell are shown separately.

CONCLUSIONS

The investigations show that there will be a marked increase in significant wave height for both swell and wind waves if the period of ice cover at the 6 sites investigated were shortened by 2 months per season, 4 months per season and up to no ice cover at all. The increases are, however, small to moderate in all cases.

For some of the sites, most notably Barentsburg, reduced ice cover may influence the direction of the predominant waves. However, the general orientation of the fjords and refraction effects will cause the direction at each site to be limited to one direction for swell and one or two main directions for wind waves. Therefore this gradual shift in predominant direction will have little to no impact on the effective wave direction at the sites investigated.

The impact of shelter from ice cover was significantly less than might be expected when compared to distributions of wind data over time for, for example, northern Norway. This may indicate that wind distributions for Svalbard do not follow a similar pattern, and this could be an interesting area for further study.

REFERENCES

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