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MEMO
Memo no.: 1
Assignment no.:

To: Norconsult/ T Isaksen

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Date: 2014-06-25

MetOcean data at Gamnes, Kirkenes, Norway

Table of Contents

VERSIONS

2014-06-25: Original version (internal) for comments

2014-06-30: Version b, corrected **from** "(i. e. land rising faster in Vardø)" **to** "(i. e. land rising faster in Sør-Varanger)" on page 5

2014-06-30: Version c, corrected estimates of low water levels, Table 6

2014-08-29: Version d, corrected stated return period of highest water level on record from 430 to 334 years

INTRODUCTION

A new port is planned at Gamnes in Korsfjorden, near Kirkenes, Norway, Figure 1. Preliminary outline of berths is shown in Figure 2. This memo provides data on:

- air temperatures
- wind speeds
- snow
- tide and storm surge levels
- wave heights.

Some preliminary information on sea ice is also provided.

The directional convention in this memo is North = 0º/360º, East = 90º, and wind and wave direction are directions coming from.

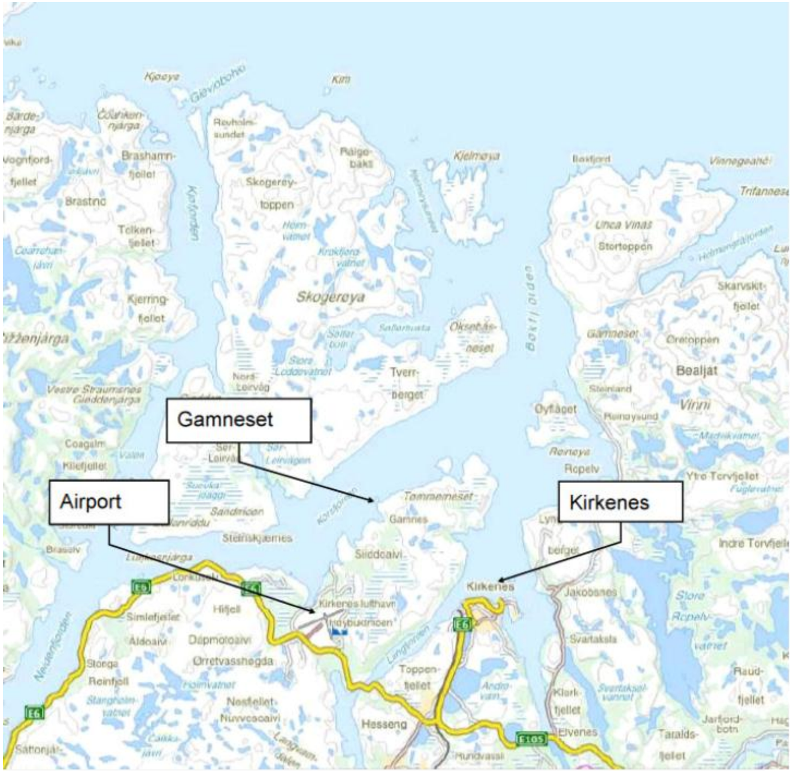

Figure 1 Map of Kirkenes area. Distance from the airport to Gamneset is approximately 5 km

Figure 2 Aerial photo of site (with possible access roads). North is towards the right in this image.

DATA SOURCES

Data sources for this study are:

- Wind speed and direction data from Kirkenes meteorological station at Høybuktmoen Airport (met.no) 1980 – 2011
- Temperature data from Kirkenes meteorological station at Høybuktmoen Airport (met.no) 1980 – 2011
- Statistical summary of offshore wave data at location N 70.19º / E 33.34º
- Sea charts and maps.
- Observations of sea ice in the fjords Jan – Apr 2013, (Kirkenes Port Authority)

TEMPERATURE

Air temperature data from Kirkenes Airport, Høybuktmoen have been collected for the period 2003 – 2013. The seasonal variation in all years is shown in Figure 7 and Figure 8. The data for all years taken at fixed observation times at 3 hrs intervals at 0700, 1000, 1300, 1600, 1900 and 2200 hrs are shown in Figure 7.

The same data are condensed into minimum, average and maximum for each observation time point in Figure 8.

Finally, Figure 9 shows the *monthly* minimum, average and maximum values 2003 – 2013.

Table 1 Recorded air temperature by month at Kirkenes Airport; minimum, average and maximum for each month 2003 – 2013; in ºC

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
min	-31.1	-31.6	-25.8	-17.6	-6.7	-1.0	3.5	-0.6	-2.1	-14.7	-23.7	-26.0
average	-9.4	-11.5	-6.5	-0.6	4.7	9.0	12.0	11.1	7.4	1.9	-3.9	-6.2
max	4.7	4.5	5.0	11.5	28.3	28.1	29.7	27.2	19.1	13.5	6.9	6.0

WIND SPEED

Wind data are modeled using a 3-parameter Weibull distribution, and probabilities of exceedance are calculated for 30º sectors. Wind speeds are adjusted as follows:

1. Adjustments for duration of storms vs duration of measurements; the stated wind speed is the expected highest 10 minute mean wind speed to occur during a storm of 3 hrs. duration
2. A manual adjustment of wind speeds based on an assessment of the local topography
3. An (optional) adjustment of wind directions, where the wind is allowed to alter direction category in a conservative direction; i. e. the wind speed assigned to one direction is the maximum of the calculated wind speeds of itself and its two neighboring directions.
4. No adjustment for height has been made

The assumed topographic sheltering is shown in Figure 3, Resulting extreme wind speeds are shown in Figure 10 and Figure 11 for the following cases:

- Figure 10: Extreme values of 10 minute wind speed (highest 10 minute mean to occur during a 3 hrs. storm), assuming topographic sheltering and *no directional change*.
- Figure 11: Extreme values of 10 minute wind speed (highest 10 minute mean to occur during a 3 hrs. storm), assuming topographic sheltering and allowing wind directions to change by one 30º sector in conservative direction.

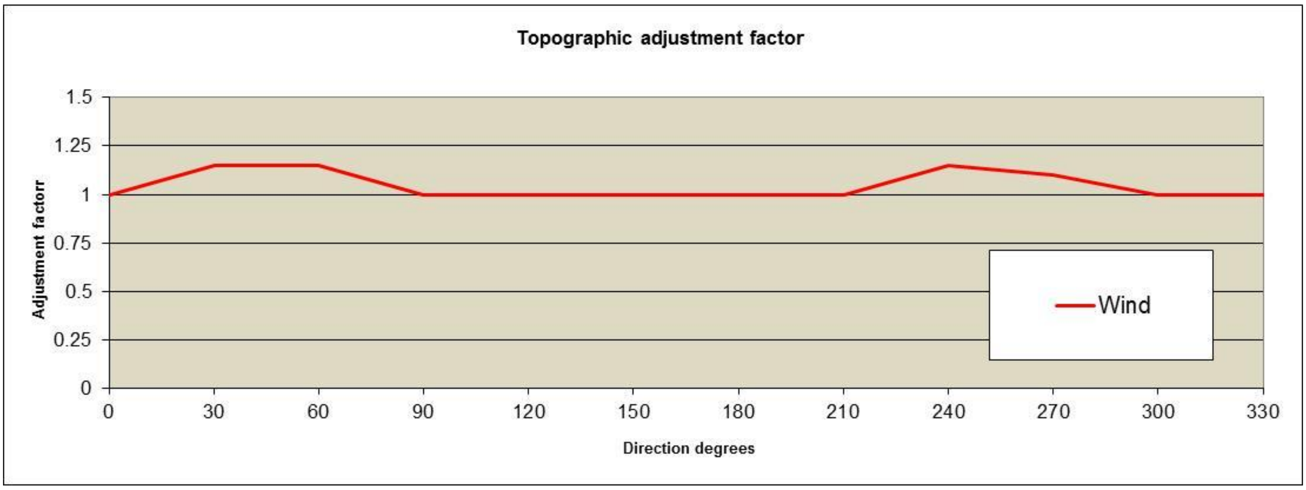

Figure 3 Assumed topographic adjustment factor Airport to Gamnes. A value greater than 1.0 indicates more severe wind at Gamnes.

Table 2 Extreme values of 10 minute wind speed in m/s (highest 10 minute mean to occur during a 3 hrs. storm), assuming topographic sheltering and allowing wind directions to change by one 30° sector in conservative direction

Return period years	**Wind direction ° (blowing from)**											
	0	**30**	**60**	**90**	**120**	**150**	**180**	**210**	**240**	**270**	**300**	**330**
1	20.0	18.4	18.4	12.5	15.2	17.2	17.3	16.7	19.2	19.9	20.0	20.0
5	23.6	21.7	21.7	14.2	17.5	19.3	19.7	18.8	21.7	23.2	23.6	23.6
10	25.1	23.0	23.0	14.9	18.4	20.2	20.7	19.7	22.7	24.5	25.1	25.1
25	26.9	24.8	24.8	15.7	19.6	21.3	21.9	20.8	23.9	26.1	26.9	26.9
50	28.3	26.0	26.0	16.3	20.5	22.1	22.8	21.6	24.8	27.3	28.3	28.3
100	29.6	27.2	27.2	16.9	21.3	22.8	23.7	22.3	25.7	28.5	29.6	29.6
200	30.8	28.4	28.4	17.5	22.2	23.6	24.5	23.0	26.5	29.6	30.8	30.8
500	32.5	29.9	29.9	18.2	23.3	24.5	25.6	24.0	27.5	31.0	32.5	32.5
1000	33.7	31.1	31.1	18.7	24.1	25.2	26.4	24.6	28.3	32.1	33.7	33.7

SNOW

No data on snow cover or snow loads are available at this time. The standard snow load from the national standard NS-EN 1991-1-3:2003/NA: 2008 gives a characteristic snow load on flat ground

$$S_{k,0} = 4 \text{ kN/m}^2,$$

with 1 kN/m^2 to be added for each 100 m elevation above 150 m.

SINTEF Building Technology (Byggforsk) has given a review of NS-EN 1991-1-3:2003/NA: 2008 in a report dated 2013-05-30. A revision of $S_{k,0}$-values for certain regions in Norway is recommended, but Sør-Varanger is not recommended for revision.

TIDE AND STORM SURGE LEVELS

All elevations in this section are referenced to the National Datum NN1954 unless otherwise stated. The most important relationships are as follows in Table 3. The values are taken from the nearest hydrographical station at Vardø.

Storm surge (high water level)

Storm surges include all known causes of temporary high sea water levels, such as tides, air pressure, wind stow-up, wave stow-up, fresh-water run-off, etc. Wave run-up on the shoreline, seiching and accidental sea level fluctuations (as e. g. from earthquakes) are not included.

The storm surge levels are calculated in two separate steps.

1. Storm surge based on present-time data. Data are extrapolated from extreme values published by the Norwegian Hydrographic Service in annual tide tables.
2. Future sea level rise is estimated using data from Nilsen & al 2012 (ref. 2). This report gives estimates of net sea level rise along the coast of Norway in scenarios in 2062 and 2112. The net sea level rise estimates are based on predicted global sea level rise with deduction for factors like isostatic rebound, changes in Earth gravity, etc. The sea level rise estimates are based on a mean of all models surveyed (mean, most likely), and estimates within 68 % and 95 % confidence limits.

The calculations are based on data from the hydrographic station at Vardø, approximately 80 km to the north across the Varanger fjord. Storm surge conditions at Kirkenes and Vardø may be assumed to be similar, but reference 2 estimates that the isostatic rebound (land rise) in Sør-Varanger is 3 cm greater in 2062 and 10 cm greater in 2112 (i. e. land rising faster in Sør-Varanger).

Applying this correction to the data model, we obtain results as shown in Table 4 for predicted storm surges (high water levels).

Table 3 Datum levels (Vardø)

Reference level	Value (above chart datum)
Highest on record (return period 334 years)	+430 cm
Highest Astronomical Tide (HAT)	+373 cm
National Datum NN1954	+204 cm
Mean water level	+190 cm
Sea chart datum (LAT)	0
Lowest on record	-22 cm

Table 4 Table showing storm surge levels in cm above NN1954 for the present (2014) and including future sea level rise (2062 and 2112). See text for details.

Return period years	2014	2062			2112		
		mean	68 % conf. limit	85 % conf. limit	mean	68 % conf. limit	85 % conf. limit
1	176	185	193	197	207	231	246
100	215	225	232	236	247	271	286
500	230	239	246	251	261	285	300
1000	236	246	253	257	268	292	307

Low water levels

The investigation in reference 2 shows a range for the predicted sea level rise in Sør-Varanger, see Table 5. The isostatic rebound rate near Sør-Varanger and Kirkenes is currently 3.5 – 4.0 mm/year. This land rise and the shift in the Earth gravity are the major reasons why the extreme event predicts that the sea level may not rise or even sink near Kirkenes (Table 5).

For the calculation of extreme low water events now and in the future, the present-day mean water level (MWL) should therefore be used.

No extreme-value analysis of low-water events has been made. However, we may use data on the highest and lowest recorded events at the hydrographic stations. Figure 12 shows these observations for the coastline of Norway and the ratio highest/lowest observed value (in %). We see that there is near parity between the high and the low value as we pass Tromsø heading north, and that the high values tend to dominate as we turn eastwards at Honningsvåg (North Cape). At Vardø the amplitude of the highest recorded is 114 % of the amplitude of the lowest recorded.

Bearing in mind that a value of this ratio nearer 1.0 (100%) would be more conservative, we suggest that a value of 1.1 (110 %) is used. These values are shown in Table 6.

Table 5 Predicted range of net sea level rise in Sør-Varanger, in cm

Year and location	68 % confidence limits, low - high	95 % confidence limits, low - high
2112 Sør-Varanger	5 - 65	(-5) - 85

Table 6 Suggested extreme values of low water level, in cm below NN1954, assuming no sea level rise.

Return period years	Extreme low level, cm below NN1954
1	-187
100	-222
500	-236
1000	-241

WAVE HEIGHT

Wind data and offshore wave data are modeled using a 3-parameter Weibull distribution, and probabilities of exceedance are calculated for 30º sectors. Wind waves are calculated using SINTEF's software HSCOMP, and wind waves are assumed to occur only when the local wind occurs. Wind speeds are adjusted as follows:

- Adjustments for duration of storms vs duration of measurements; the stated wind speed is the expected highest 10 minute mean wind speed to occur during a storm of 3 hrs. duration
- For calculation of wind waves, the wind speed is adjusted to reflect the required duration for the stated wave height to develop (duration taken at 50 years return period)
- A manual adjustment of wind speeds based on an assessment of the local topography
- An (optional, but applied here) adjustment of wind directions, where the wind is allowed to alter direction category in a conservative direction; i. e. the wind speed assigned to one direction is the maximum of the calculated wind speeds of itself and its two neighboring directions.

Transmission of ocean waves is calculated using a visible sector method, based on an assumption that wave energy follows a Gaussian distribution with a standard deviation (assumed 20º) about the mean direction. The visible sector method is applied three times:

1. from the open ocean to Bøkfjord
2. from Bøkfjord to Korsfjord
3. from Korsfjord to Gamneset.

The results of these calculations are extreme values of wind waves and swell at the location. The data model may, however, also be used to calculate predicted down-time (in e. g. hrs/year) by specifying limit values of wind speed, wind wave height and swell height and direction of ship axis.

Waves generated by wind directly incident upon Gamneset are shown in Figure 13 (significant wave height) and Figure 14 (peak spectral periods).

Swell data are given in Figure 15.

Numerical values for wind waves and swell are given in Table 7 and Table 8. Period range for the swell is T_p = 10 – 16 s.

Table 7 Extreme values of significant wave height by locally generated wind waves.

Return period years	Wind and wave direction º (coming from)											
	0	30	60	90	120	150	180	210	240	270	300	330
1	0.72	0.70	0.54				0.30	0.55	0.76	0.67	0.60	0.61
5	0.89	0.87	0.67				0.36	0.65	0.89	0.81	0.74	0.75
10	0.97	0.95	0.72				0.39	0.69	0.94	0.87	0.80	0.81
25	1.06	1.04	0.79				0.42	0.74	1.01	0.95	0.88	0.89
50	1.13	1.11	0.85				0.44	0.78	1.06	1.01	0.94	0.95
100	1.20	1.18	0.90				0.46	0.81	1.11	1.06	1.00	1.01
200	1.26	1.25	0.95				0.48	0.85	1.16	1.12	1.05	1.06
500	1.35	1.34	1.02				0.51	0.89	1.22	1.19	1.13	1.14
1000	1.41	1.40	1.07				0.53	0.92	1.26	1.24	1.18	1.19

Table 8 Extreme values of significant wave height by swell waves.

Return period years	Offshore wave direction direction º (coming from)											
	0	30	60	90	120	150	180	210	240	270	300	330
1	0.10	0.08	0.01									0.02
5	0.12	0.10	0.01									0.02
10	0.13	0.10	0.01									0.02
25	0.14	0.11	0.01									0.03
50	0.15	0.12	0.01									0.03
100	0.16	0.12	0.02									0.03
200	0.16	0.13	0.02									0.03
500	0.18	0.14	0.02									0.03
1000	0.18	0.14	0.02									0.04

ICE

No firm or long-time data on frozen sea ice are known at this point. According to Kirkenes Port Authority (KPA), the ice season (when ice breaking will be carried out as needed) lasts from 01 Dec – 31 Mar. KPA will break ice within its own port district and in the approach lanes to Kirkenes.

A limited survey of ice conditions was carried out by the crew of tug/icebreaker "Kraft Johansen" during the winter 2012/2013, from January to April 2013, see Figure 4 and Figure 5. The survey consisted of sea charts with ice cover and measured/assumed ice thickness for the Korsfjorden, Bøkfjorden and Langfjorden area. The observations are intermittent, and *we assume that the observations are taken during ice-breaking at a time when icebreaking was needed, and that no ice or non-restricting ice prevailed at all other times*.

The ice data from this period have not been analyzed in detail, and only a brief summary is available at this time. This summary is shown in Figure 16. The figure shows simultaneous observations of wind speed, wind direction and air temperature (at Kirkenes Airport) and reported ice breaking activity.

It should be noted, however, that the need for ice breaking could have existed anywhere in the area, and that Figure 16 does not necessarily indicate the presence of ice at Gamnes, nor does it show ice thickness.

The figure appears to show a very clear (and intuitively obvious) correlation between air temperature and ice, but wind direction also appears to be an important factor. The greatest reported ice thickness at Gamnes or the approaches to Gamnes is 20 cm (2013-04-03 & 2013-04-09, i. e. after the end of the assumed ice season), typical thickness is approximately 5 cm.

In a preliminary analysis to describe the ice formation in Korsfjorden we have subdivided the approach lane to Gamnes into 18 squares 600 x 600 m^2, and recorded the ice cover in each square for the events that are covered by the ice survey conducted by KPA. This subdivision is shown in Figure 6. The sea ice classification is initially done using the "Baltic Sea Ice Code /Section SB Ice Thickness".

Figure 17 - Figure 19 show the plot of ice extent (i. e. the length of the number of 600 m boxes that are ice-covered) vs air temperature, wind speed and wind direction. Air temperature, wind speed and wind direction are taken as *mean values over the whole day* for the 19 cases when ice is present in the area covered by squares1 – 18. No clear tendencies can be found, except for the directional variation (Figure 19). A majority of the events occur at a wind direction from the south (180º± 45º).

The same tendencies are present for ice thickness vs air temperature, wind speed and wind direction. As an example, values for square no 6 near Gamneset are shown in Figure 20 - Figure 22. From these figures, we see again that there is little correlation with air temperature and wind speed, and a clear predominance of southerly wind directions when ice does occur.

The final plot showing ice occurrence, Figure 23, shows the maximum recorded ice thickness in squares 1 – 18 in the period Jan – Apr 2013.

The limited ice survey carried out in 2013 is too short and not sufficiently systematic to draw firm conclusions about the ice cover at and near Gamnes. The temperature data show, however, that the measurement period Jan – Apr 2013 is close to a typical year, with average values close to the long term average (Figure 9).

Figure 4 Measuring thickness of newly broken ice (Kraft Johansen)

Figure 5 Lane cut in ice by tug/icebreaker (Kraft Johansen)

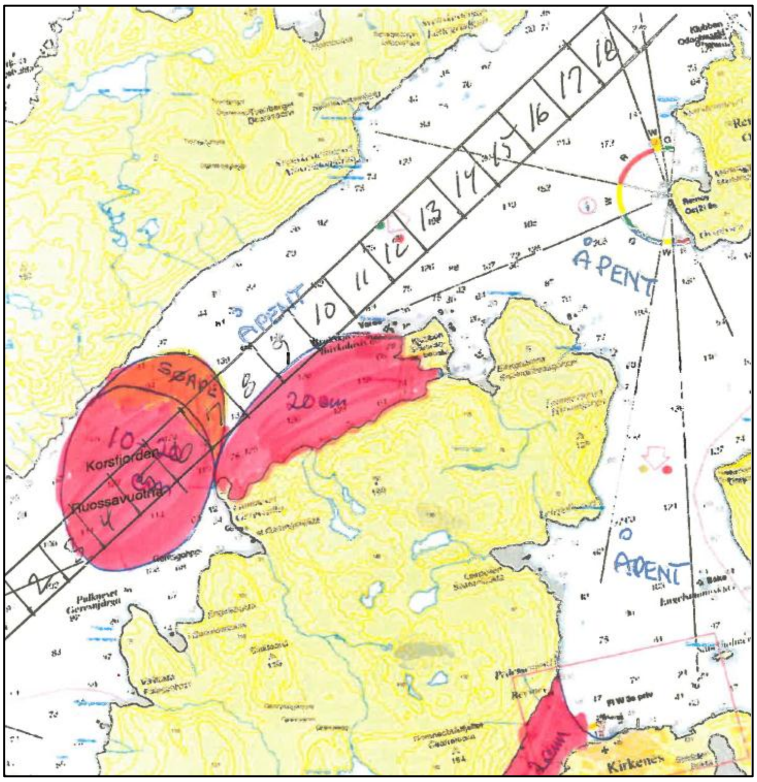

Figure 6 *Subdividing the approach lane to Gamneset into 600 x 600 m^2 squares; shown on a sample of the ice cover records Jan – Apr 2013.*

REFERENCES

1. Kvande & al: Klima- og sårbarhetsanalyse for bygninger i Norge, SINTEF report 102003348 2013-05-30
2. J.E.Ø. Nilsen, Drange, H., Richter, K., Jansen, E., Nesje, A. (2012). Endringer i fortidens, dagens og framtidens havnivå med spesielt fokus på vestlandskysten. NERSC Special Report 89, Bergen, Norge. 48 s

Trondheim, 2014-06-25

Arne E Lothe

FIGURES

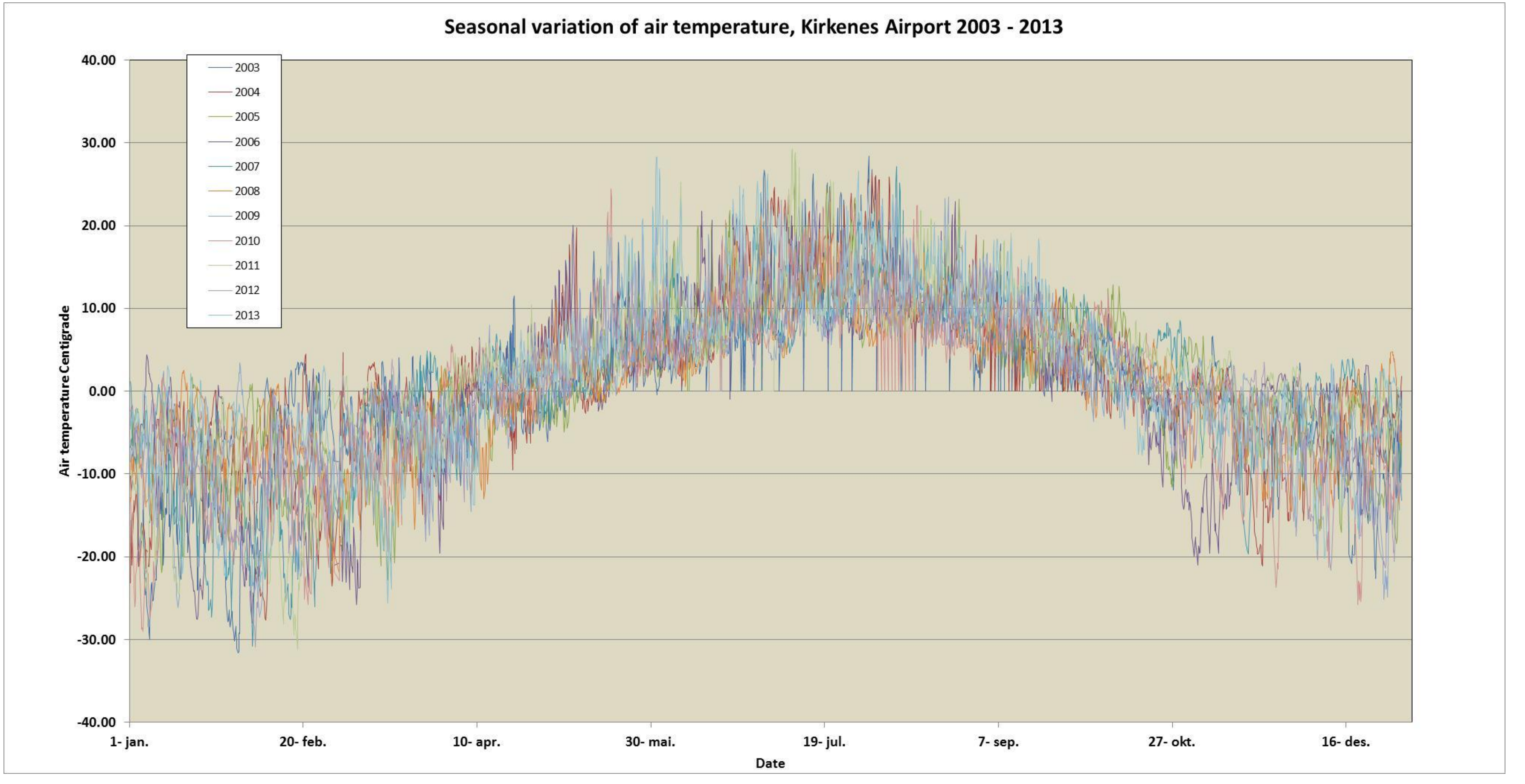

Figure 7 Seasonal variation of air temperature in ^{o}C at Kirkenes Airport 2003 – 2013, taken at 6 daily observations each year 2003 – 2013.

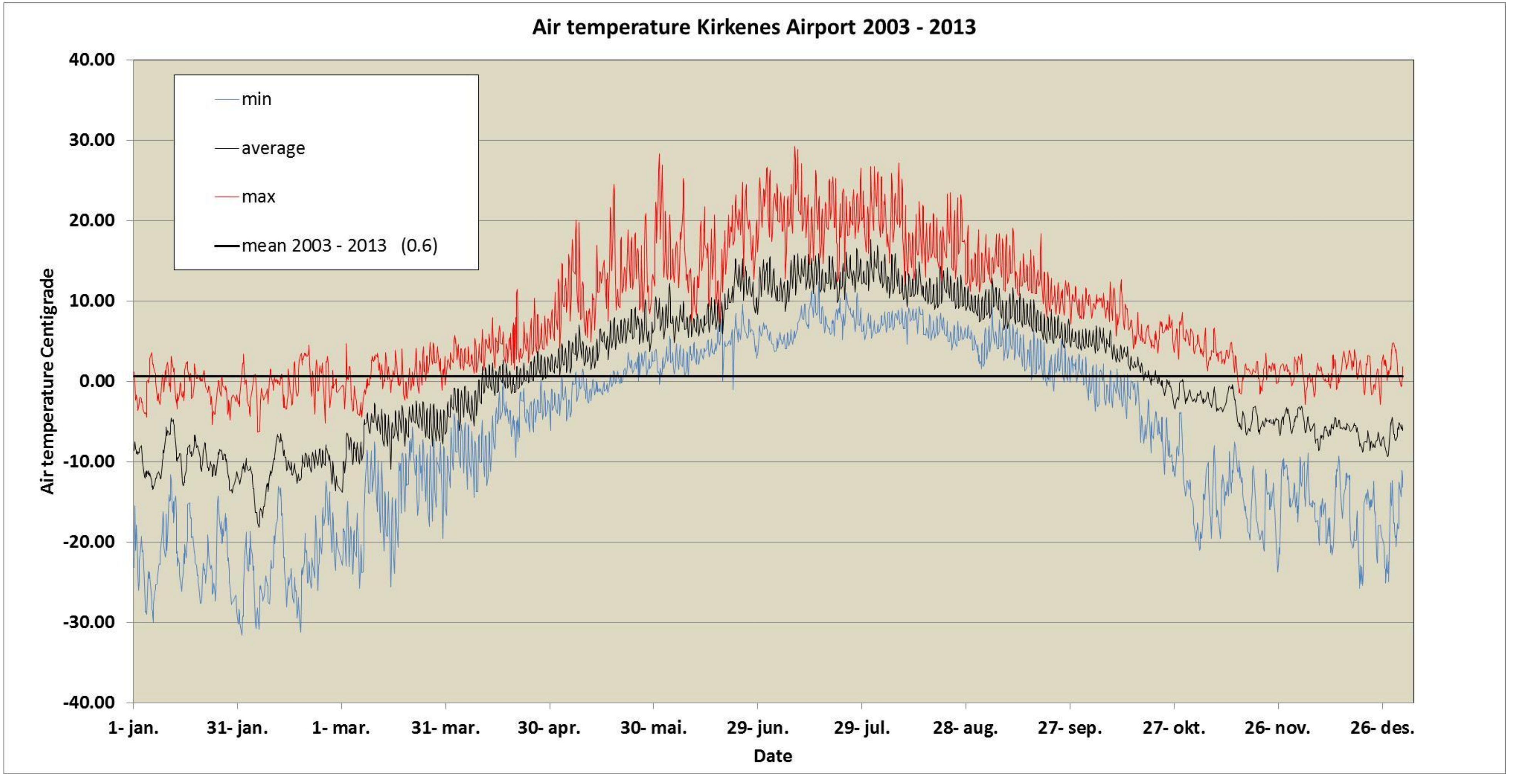

Figure 8 *Seasonal variation of air temperature in ºC at Kirkenes Airport 2003 – 2013. The graphs show the highest recorded, the average and the lowest recorded air temperature for 6 daily observations. Also shown is the mean temperature for the whole period.*

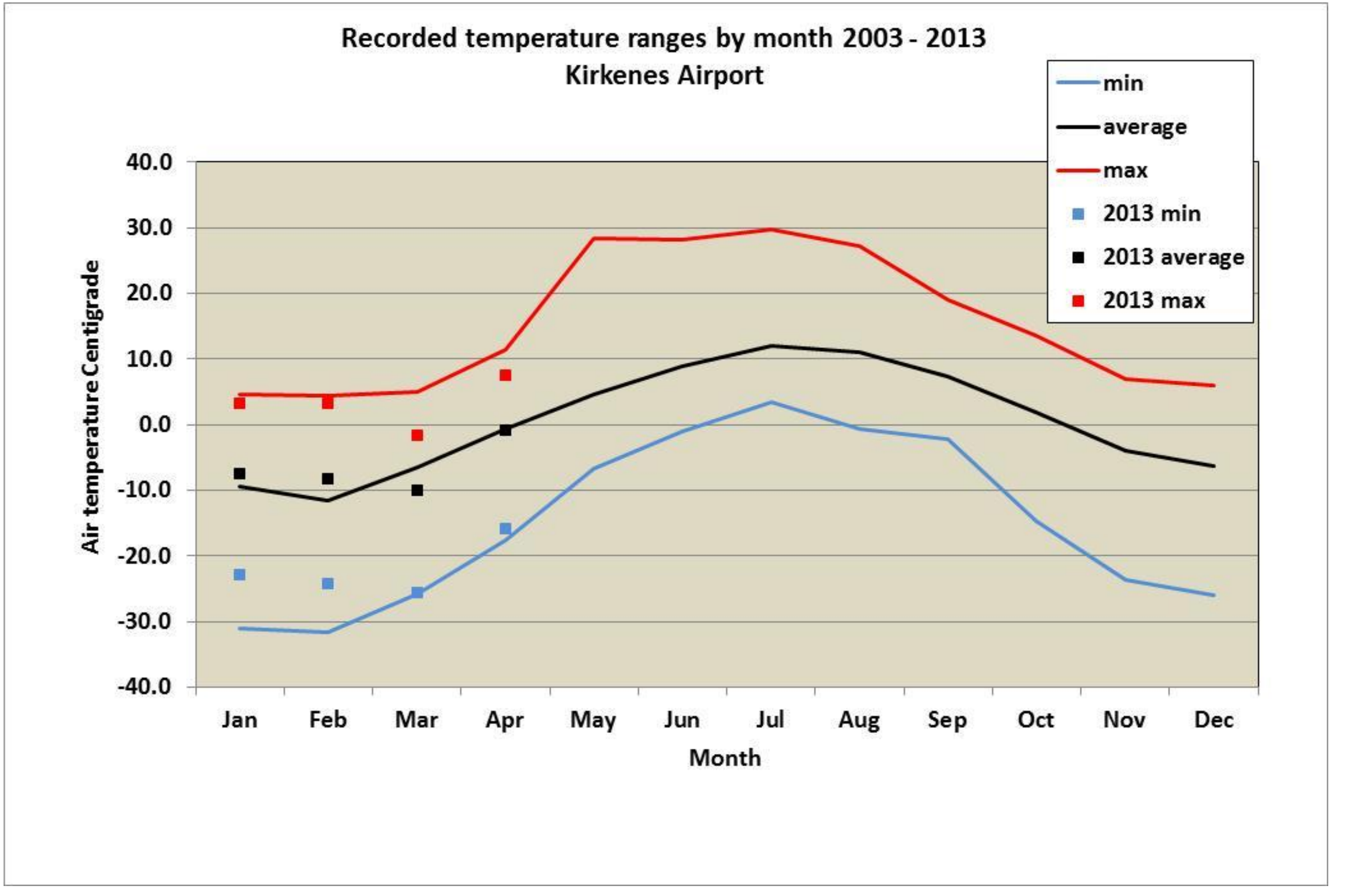

Figure 9 *Recorded air temperature by month at Kirkenes Airport; minimum, average and maximum for each month 2003 – 2013. Monthly min, average and max values for Jan – Apr 2013 are also shown for reference in the ice observations.*

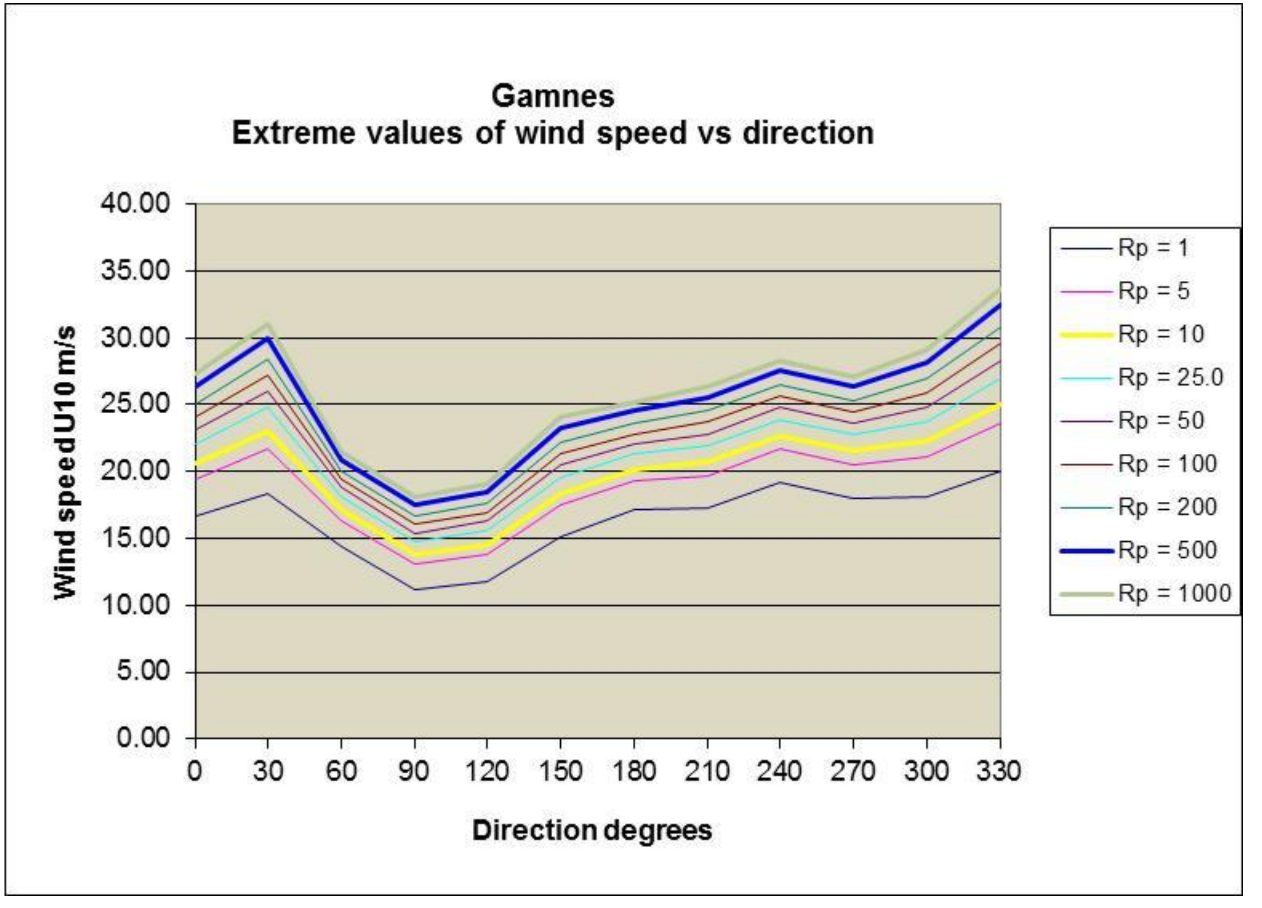

Figure 10 *Extreme values of 10 minute wind speed (highest 10 minute mean to occur during a 3 hrs. storm), assuming topographic sheltering and no migration across directions.*

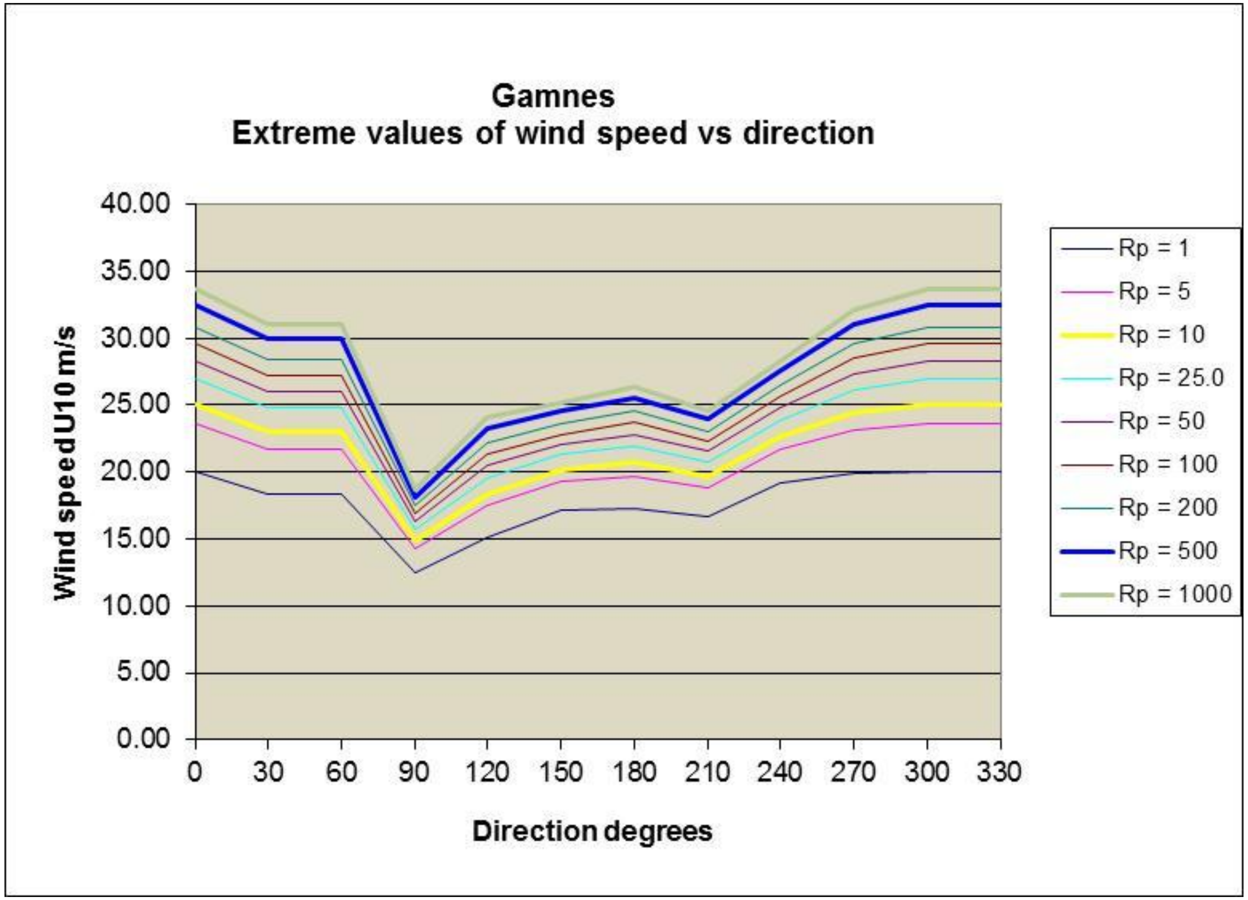

Figure 11 *Extreme values of 10 minute wind speed (highest 10 minute mean to occur during a 3 hrs. storm), assuming topographic sheltering and allowing wind directions to change by one 30^o sector in conservative direction*

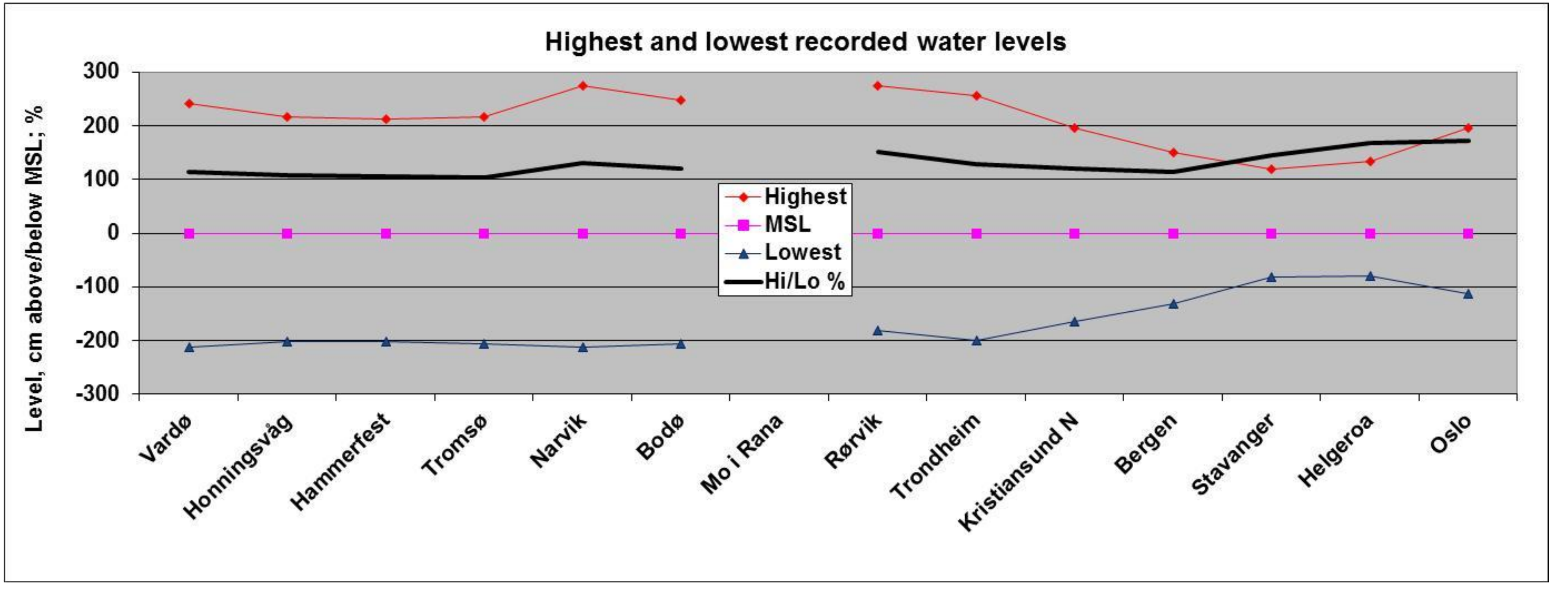

Figure 12 *Graph showing highest and lowest recorded water level relative to mean sea level (MSL) at the hydrographic recording stations from north to south in Norway.*

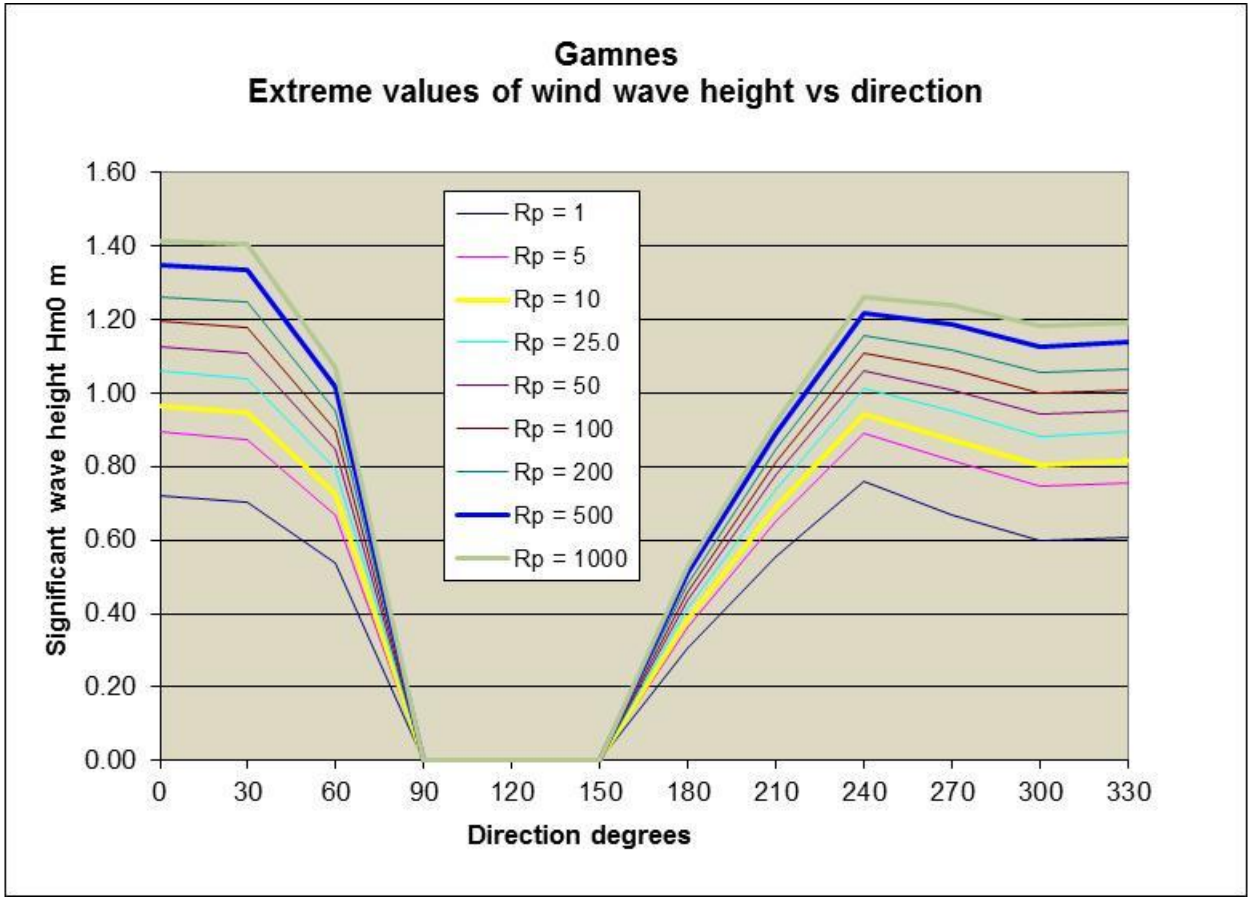

Figure 13 Extreme values of significant wave height by locally generated wind waves.

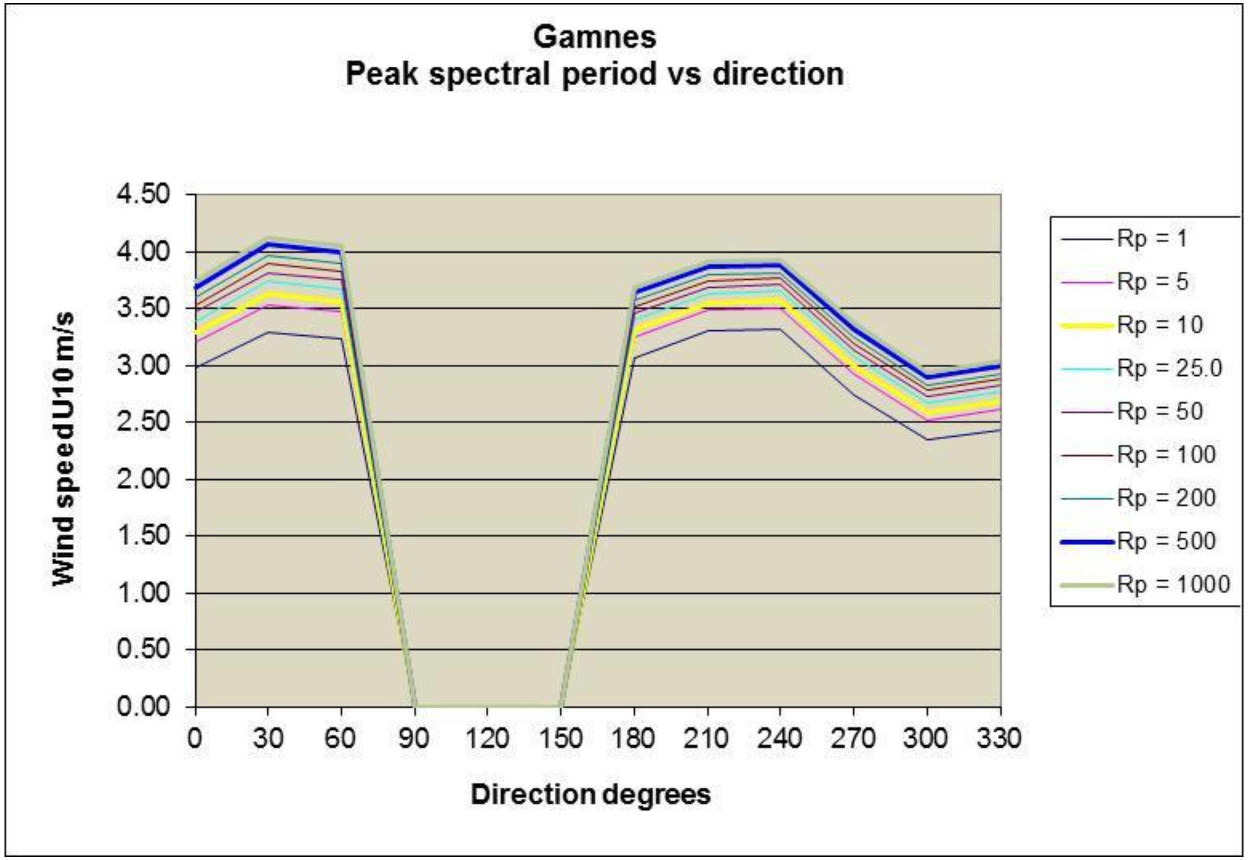

Figure 14 *Peak spectral periods of wind generated waves. The return period is the return period of the associated significant wave height in Figure 13*

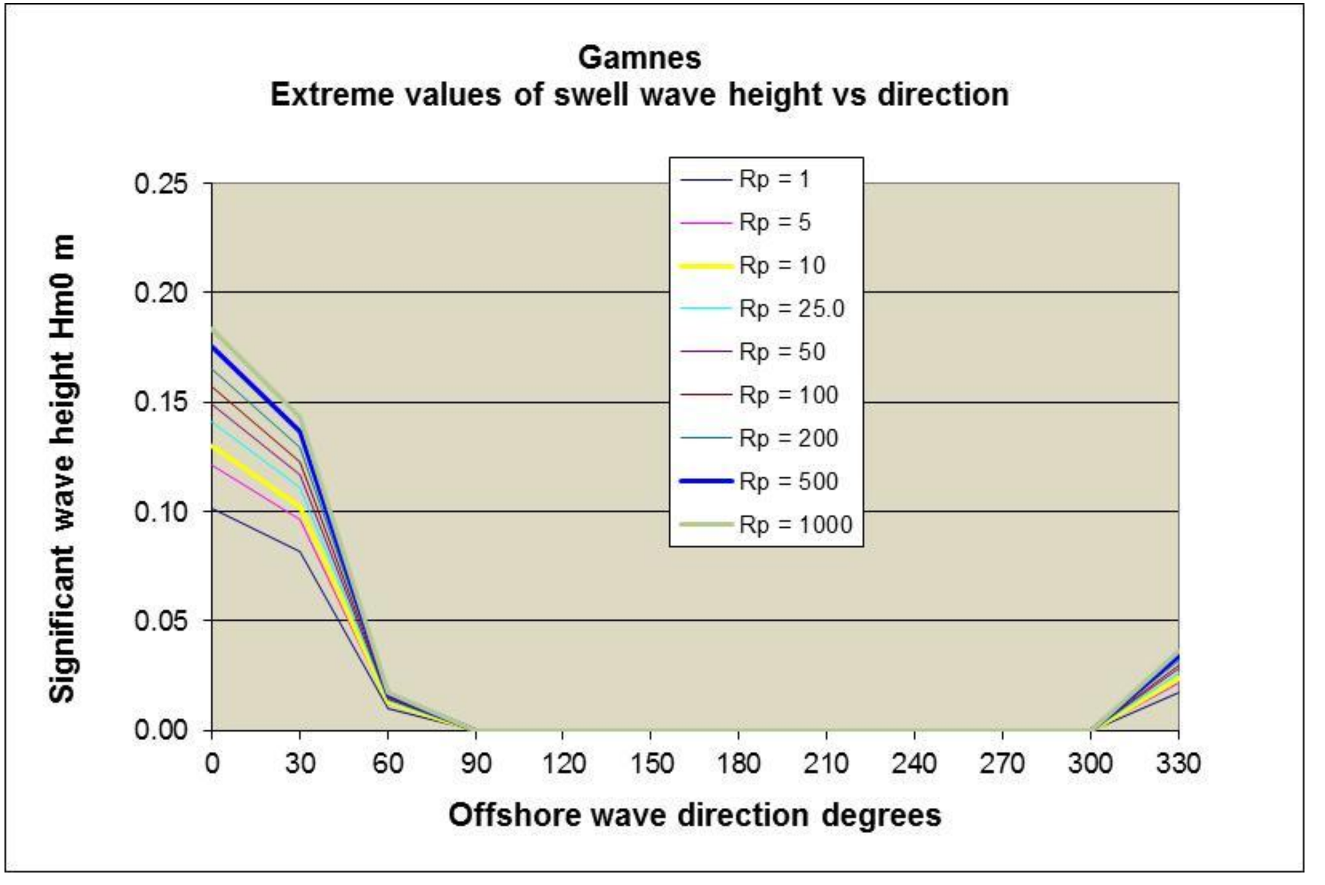

Figure 15 *Extreme values of significant wave height by swell waves.*

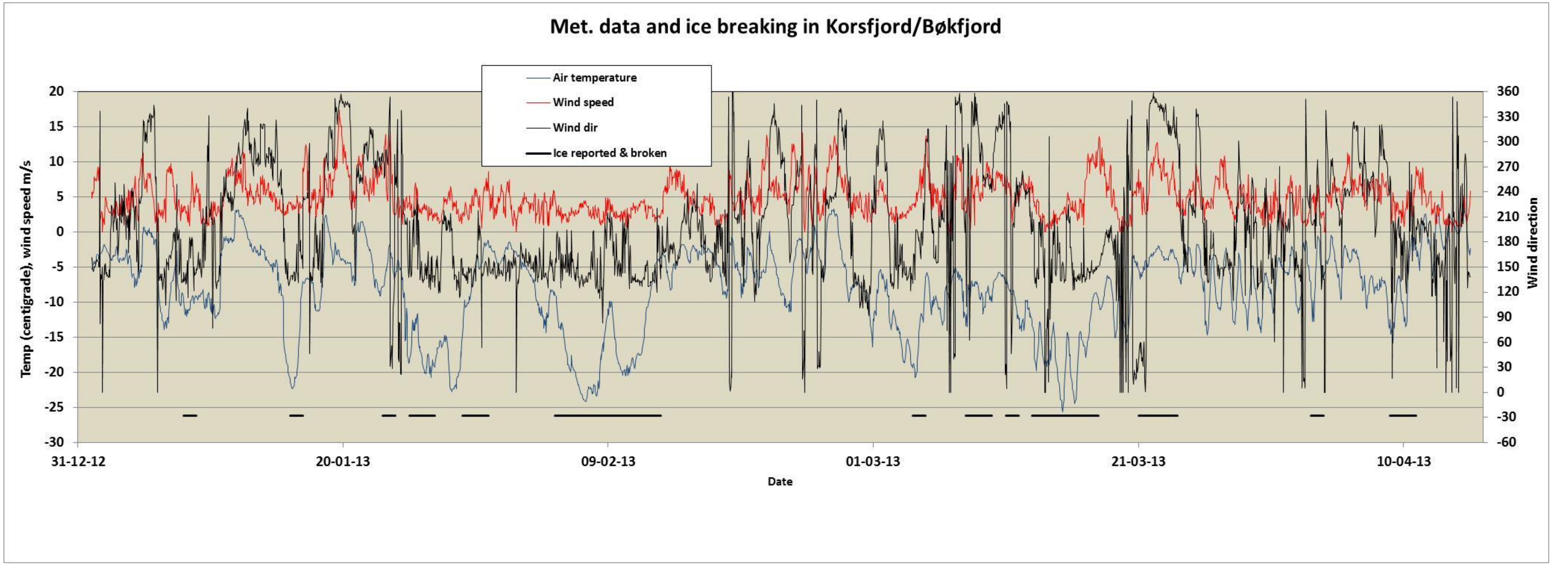

Figure 16 *Graph showing air temperature, wind speed and direction and periods when ice has been reported and ice has been broken. Notice that the need for ice breaking may have existed anywhere in the Korsfjorden/Bøkfjorden area.*

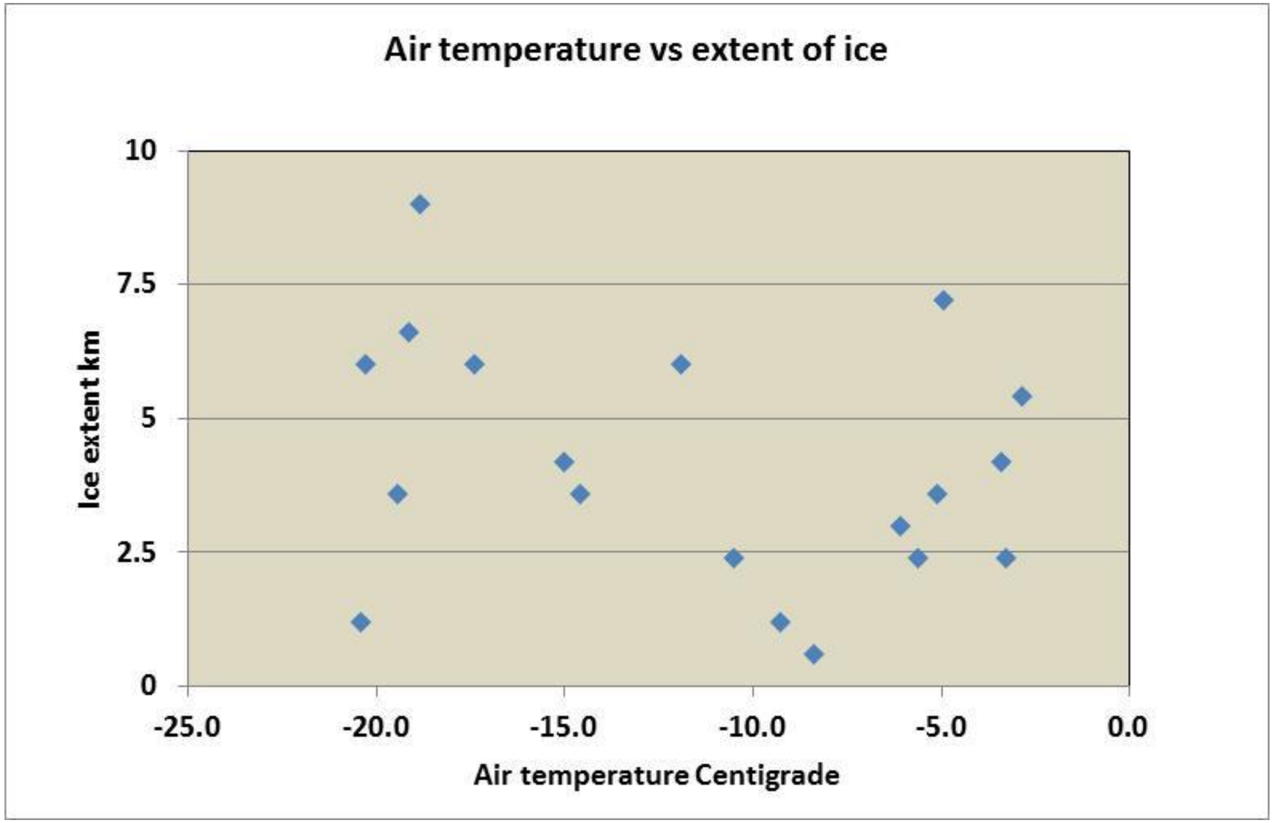

Figure 17 Extent of ice cover (i. e. length) along the approach lane vs air temperature Jan 2013 – Apr 2013.

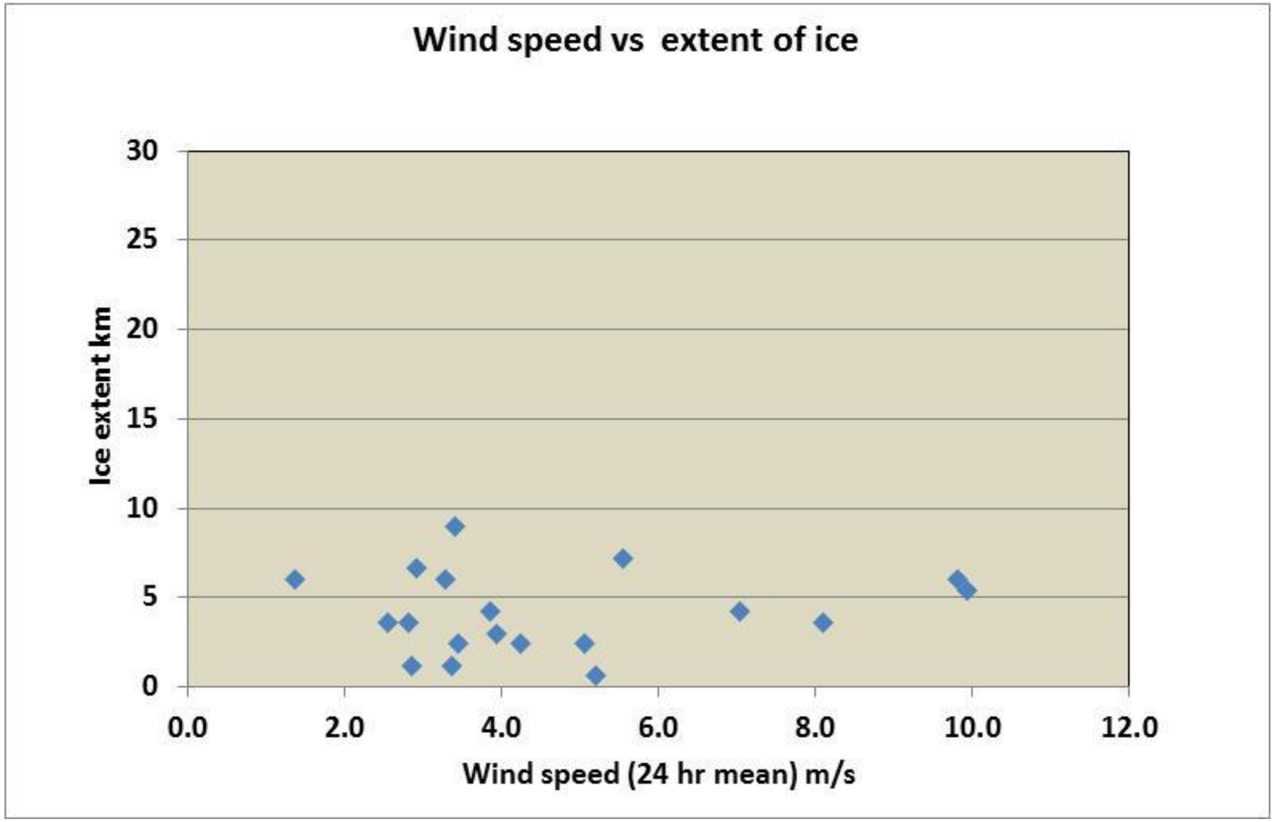

Figure 18 Extent of ice cover (i. e. length) along the approach lane vs wind speed Jan 2013 – Apr 2013.

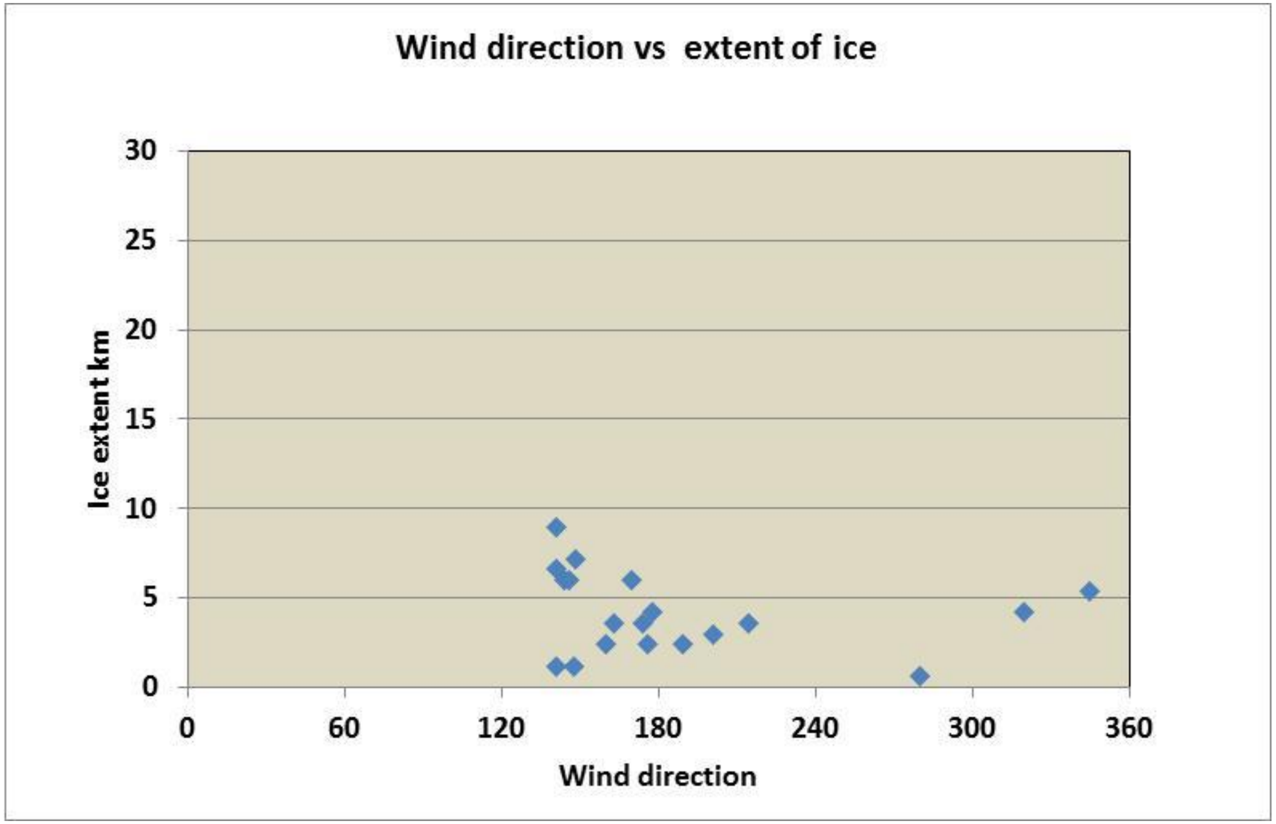

Figure 19 *Extent of ice cover (i. e. length) along the approach lane vs wind direction Jan 2013 – Apr 2013.*

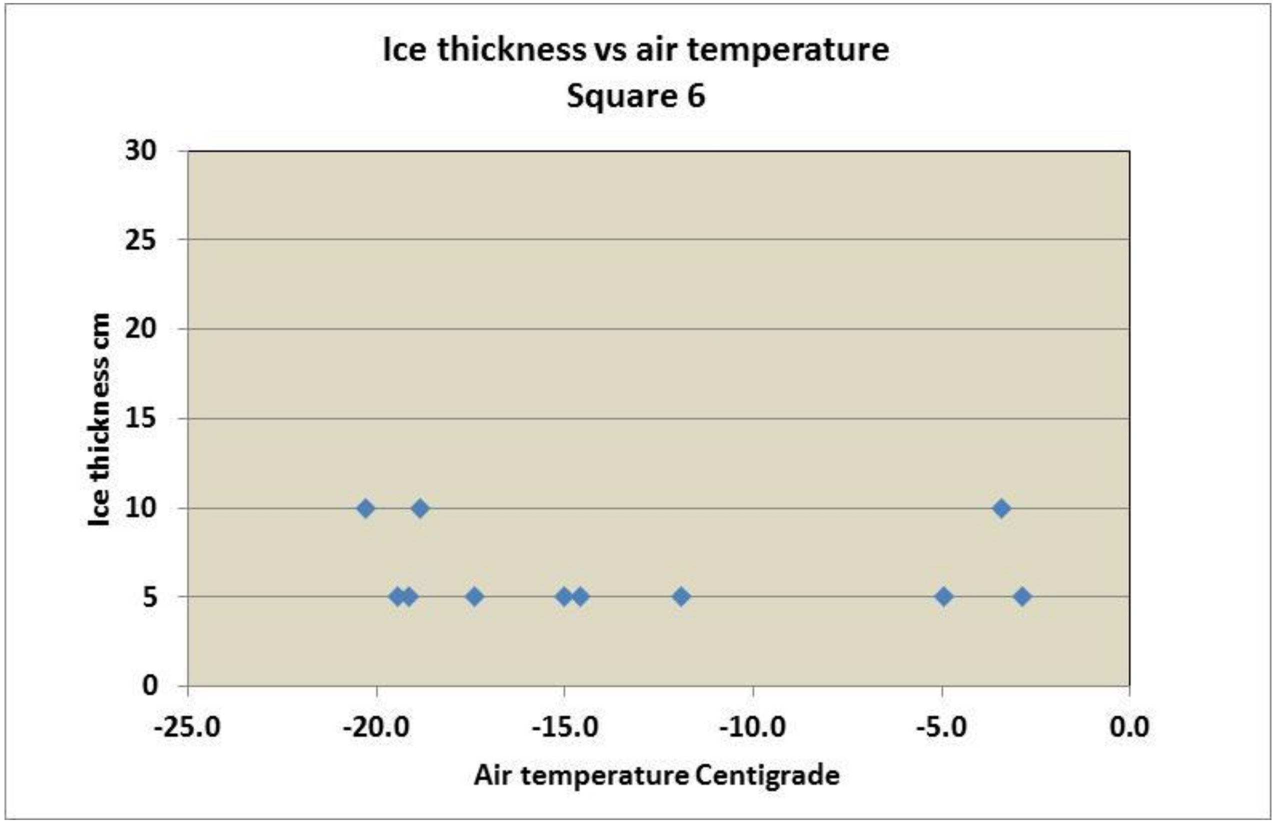

Figure 20 Ice thickness vs air temperature square no 6

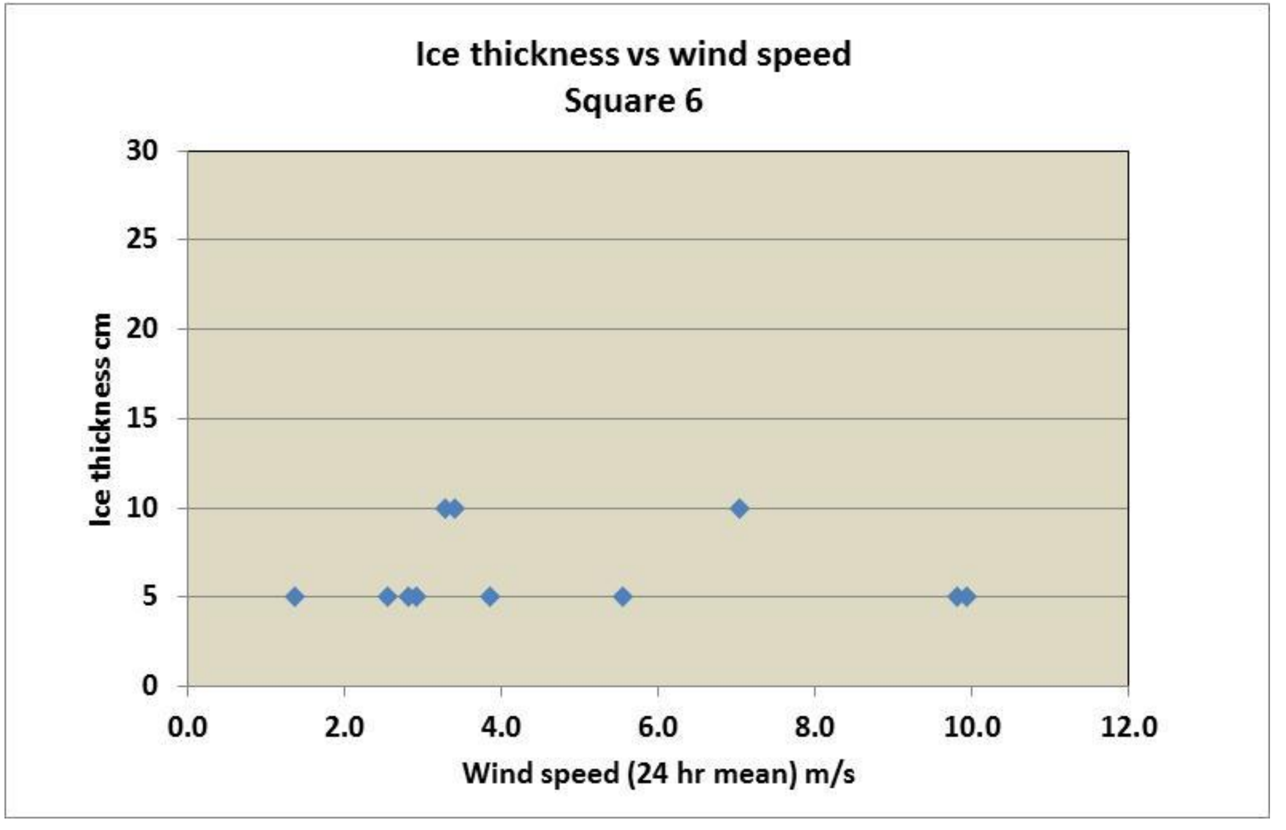

Figure 21 Ice thickness vs wind speed square no 6

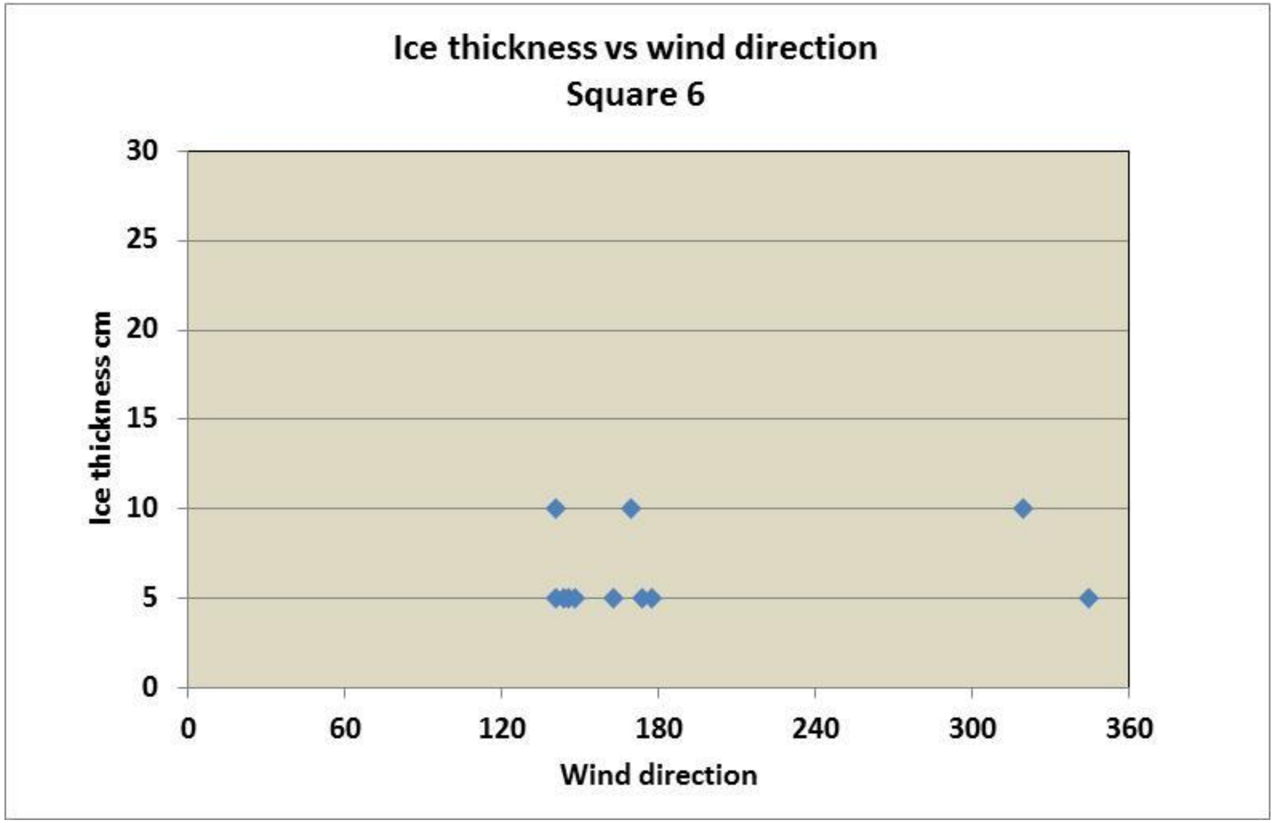

Figure 22 Ice thickness vs wind direction square no 6

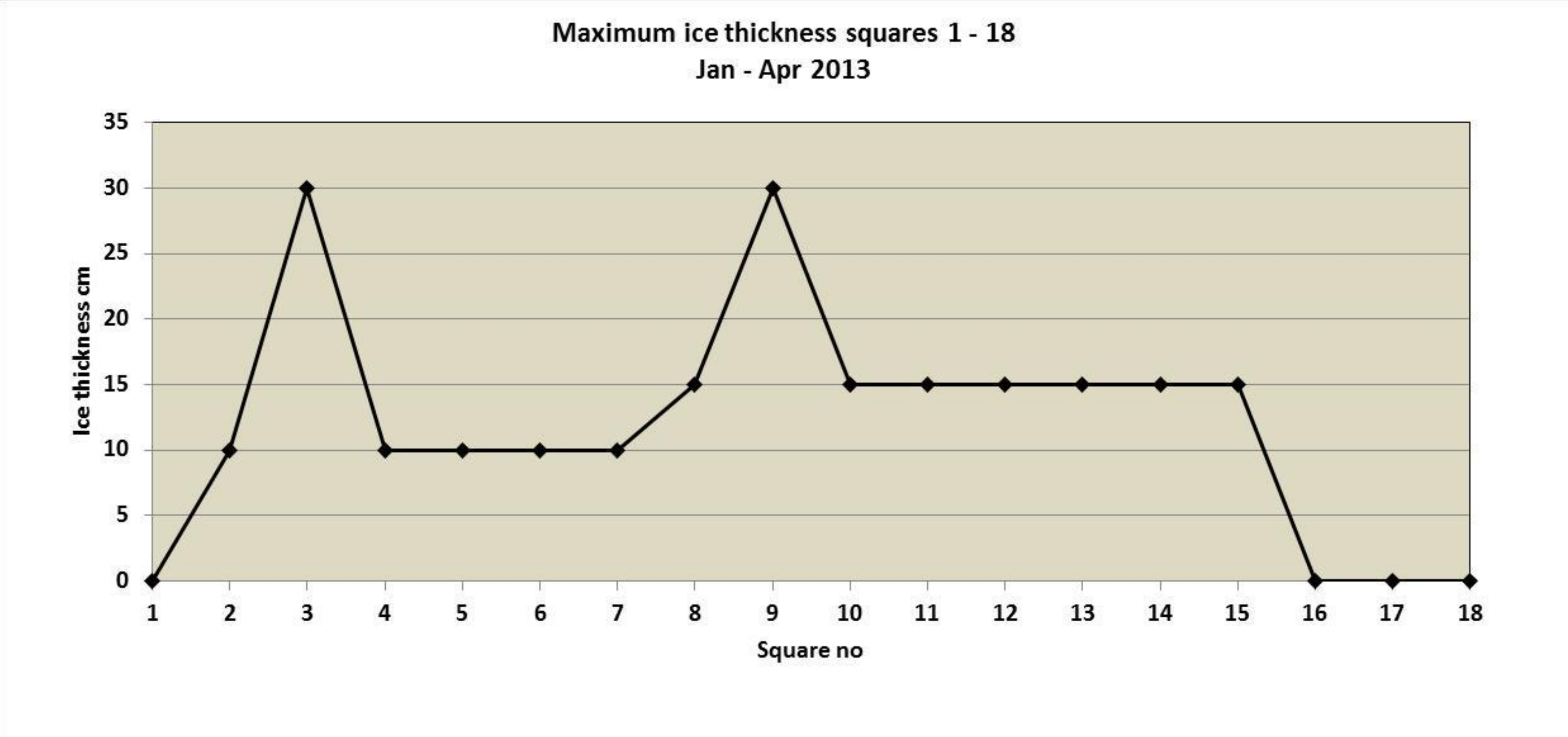

Figure 23 Maximum recorded ice thickness for squares 1 – 18, Jan – Apr 2013. Gamnes is located at squares 6 and 7.