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ORIGINAL RESEARCH ARTICLE

Comparison of meteorological conditions in Svalbard fjords: Hornsund and Kongsfjorden

Małgorzata Cisek *, **Przemysław Makuch, Tomasz Petelski**

Institute of Oceanology, Polish Academy of Sciences, Sopot, Poland

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Summary This paper presents the results of a comparison of basic meteorological parameters in two Arctic fjords situated on the west coast of Spitsbergen, the main island of the Svalbard archipelago. Air temperature, wind speed and direction, humidity and cloud cover from the period 2005 to 2016 are described and compared with previous (from 1975) analyses of meteorological conditions in the investigated region. Such a choice of dates coincides with the time the GAME project measurements were carried out. The main goal of this study was to compare meteorological conditions in two fjords: Hornsund and Kongsfjorden, during the time of rapid climate changes. The results are collated with research results available in literature from previous years. We discovered that in the investigated period the climate of the Hornsund region is more oceanic than in Kongsfjorden. The stable level of the difference in climate elements is manifested and is evident mainly through greater amplitudes in air temperatures in Kongsfjorden, and in stronger winds in Hornsund.

* Corresponding author at: Institute of Oceanology, Polish Academy of Sciences, Powstańców Warszawy 55, 81-712 Sopot, Poland. Tel.: +48 587311821; fax: +48 585512130.
E-mail address: gosiak@iopan.gda.pl (M. Cisek).
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1. Introduction

The comparison described in this paper regards two Svalbard fjords: Hornsund and Kongsfjorden. Both are located on the west coast of Spitsbergen, the main island of the Svalbard archipelago. They were both investigated within the GAME project (Growing of the Arctic Marine Ecosystem), which was focused on verifying the hypothesis that the Arctic marine ecosystem is aging due to global warming effects. The selected fjords have a similar area, shape and water circulation. Even though Hornsund is located more southward than Kongsfjorden, the water in this fjord is colder. Warm Atlantic Water reaches Kongsfjorden directly from the West Spitsbergen Current, whereas Hornsund is strongly influenced by the cold Sørkapp Current. Such a system impacts the meteorological conditions in both fjords. As a result, mean temperature values in the Hornsund stations are well correlated with the temperature of the Atlantic Water carried by the West Spitsbergen Current (Walczowski and Piechura, 2011). The climate of the west coast of Spitsbergen, including Hornsund and Kongsfjorden, has been studied for many years and is well described in literature (e.g. Forland et al., 1997; Hanssen-Bauer et al., 1990; Marsz and Styszyńska, 2007, 2013; Kejna, 2002; Kejna and Dzieniszewski, 1993; Kierzkowski, 1996; Przybylak, 2007, 2002). The influence of the atmospheric circulation on the climate of this region has been described by Niedźwiedź (1997), while the problem of precipitation in the Hornsund area was presented by Łupikasza (2009). In this paper, the authors focused on the differences in the main meteorological parameters in the Hornsund and Kongsfjorden fjords. The analyzed parameters included: wind speed and direction, air temperature, humidity and cloud cover, data from the last ten years (2005–2016) was also incorporated. The meteorological parameters that were analyzed are responsible for shaping the conditions of the ecosystems of the studied fjords.

2. Material and methods

Temperature, humidity and cloud cover data comes from the weather stations No. 01003 (Hornsund) and No. 01007 (Ny-Ålesund) of the World Meteorological Organization (WMO) and were taken from http://rp5.kz. This website is provided and supported by Raspisaniye Pogodi Ltd., St. Petersburg, Russia. Databases of meteorology and hydrometeorology are maintained on license from the Russian Federal Service for Hydrometeorology and Environmental Monitoring (Roshydromet). The time period from 2005 to 2016 was chosen to be long enough to allow appropriate comparisons. It also coincides with the time the GAME project measurements were carried out. However, a period longer than the duration of the GAME project was chosen in order to facilitate a comparison which provides more data on climatic impact than a single measurement. Real data from wind measurements at 10 m a.s.l., from stations located in the fjords: from the French-German Arctic Research Base at Ny-Ålesund (AWIPEV) station in Kongsfjorden (Maturilli et al., 2013) and from the Polish Polar Station in Hornsund, was analyzed and compared to winds at 10 m a.s.l. from the NCEP/NCAR reanalysis (Kalnay et al., 1996). Data from the later period (after 2013) was not available. Temperature and salinity values of the Atlantic Water in the West Spitsbergen Current come from the database of the Institute of Oceanology Polish Academy of Sciences (IOPAS) and was collected during the Arctic summer cruises of r/v *Oceania*.

To observe the climatic changes in the studied region the results obtained from the comparison of meteorological conditions in Hornsund and Kongsfjorden in recent years are collated with research results from previous years. However, the main goal of this paper is a comparison of weather conditions in the two fjords and not the study of climate change.

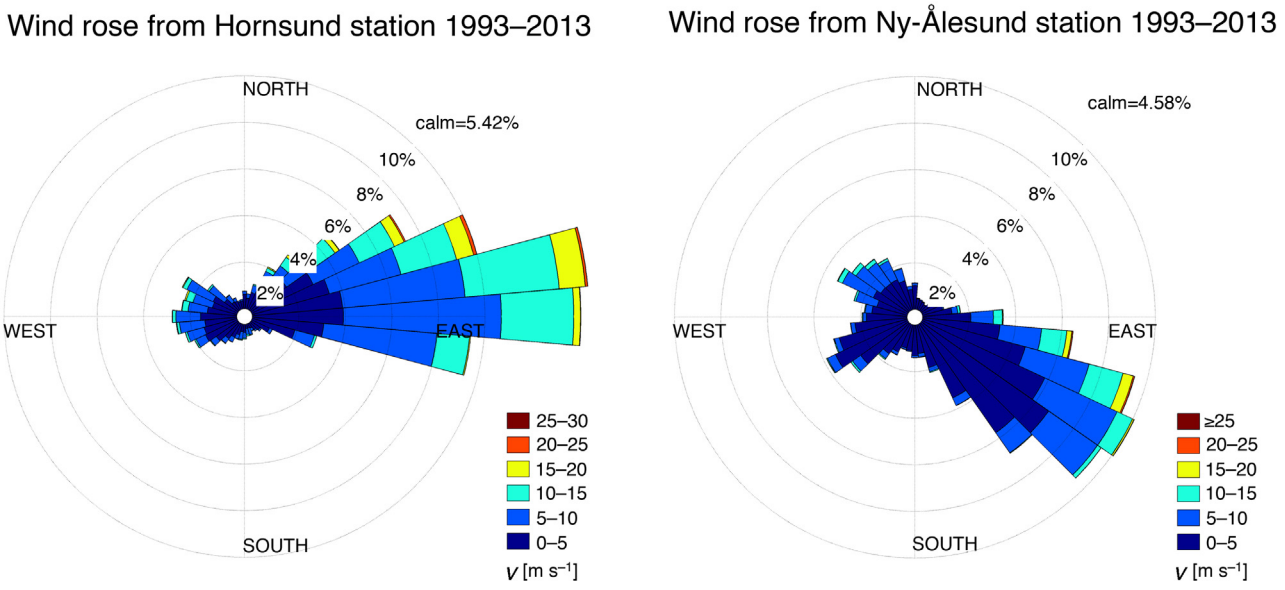

Figure 1 Local wind roses for the Hornsund station (left) and the Ny-Ålesund station (right) for the period from 1993 to 2013.

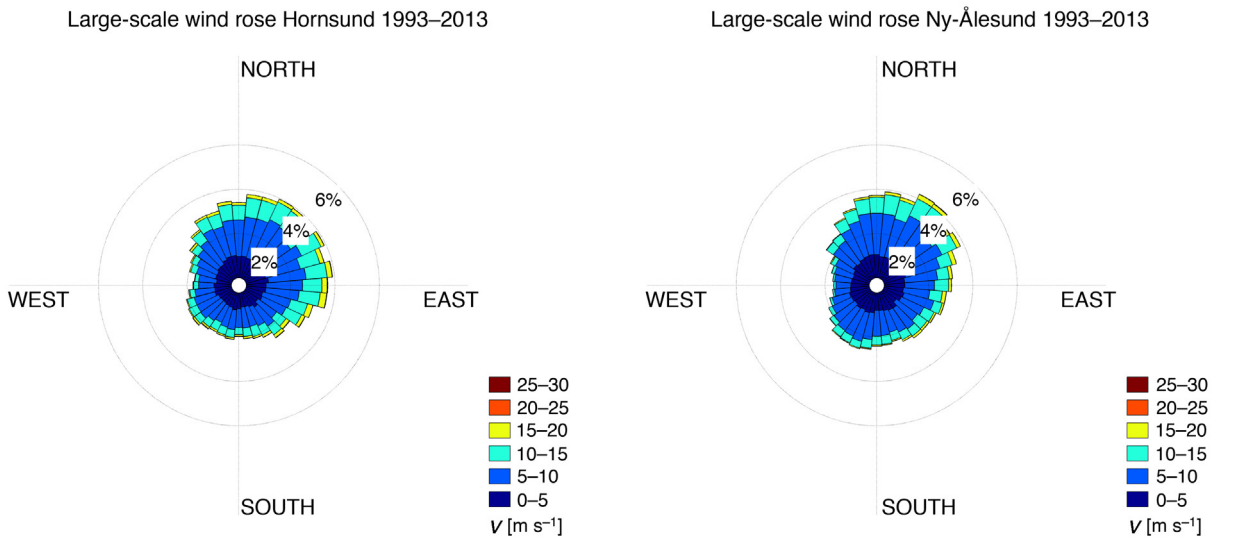

Figure 2 Large-scale wind roses (from NCEP/NCAR reanalysis) for the Hornsund station (left) and the Ny-Ålesund station (right) for the period from 1993 to 2013.

3. Results

3.1. Wind

The wind roses prepared with data from 1993 to 2013 for Ny-Ålesund (Kongsfjorden) and Hornsund are showed in Fig. 1. Fig. 2 shows surface wind directions from the NCEP/NCAR reanalysis data, interpolated for the position of the station. The wind roses of the reanalysis data are similar for both fjords (the pressure field in this area is the same in Hornsund and in Kongsfjorden) but 'in situ' measurements show that the wind is stronger in Hornsund (also Fig. 5) which indicates less friction and a more marine type of climate in the Hornsund region than in Kongsfjorden. Wind directions obtained from the reanalysis are based on a large-scale pressure field. The difference between the station measured winds and the geostrophic winds is distinct. The measurements of surface wind directions and speeds at coastal Arctic stations are often not representative of the neighboring regions. A recent paper on wind climate of the Hornsund station in Svalbard (Marsz and Styszyńska, 2013) states that the "Hornsund station is characterized by a special wind regime. [...] This is caused by a strong influence of local conditions". The situation is similar in other stations based in the Svalbard fjords. The climatology compiled by Hanssen-Bauer et al. (1990) shows that for Kongsfjorden, surface winds usually blow along the axis of the fjord. Esau and Repina (2012) provide a review of literature for the wind climate of Kongsfjorden. However, wind direction tunneling is not the only phenomenon influencing the local wind climatology. Other effects, such as, fen and fall (katabatic) winds are also significant. Using an eddy-resolving model, Esau and Repina (2012) showed that thermal land-sea breeze circulation dominates over katabatic winds in Ny-Ålesund (Kongsfjorden). The terrain orography determines the mean wind directions, and in many cases the horizontal temperature gradient controls its behavior. Cisek et al. (personal communication) reported that the breeze mechanism is one of the most important factors controlling wind directions on the west coast of Spitsbergen.

Calculations and results presented in this paper are based on absolute measured values of wind speed (independent of wind direction) in both fjords, and the differences between them over a period from 2005 to 2016. The mean wind speed values during the studied decade were 5.6 m s^{-1} and 4.1 m s^{-1} in Hornsund and Ny-Ålesund, respectively, while in Ny-Ålesund, the yearly mean for the period from 1975 to 2000 was 2.6 m s^{-1} (Przybylak and Araźny, 2006) and the multiannual yearly mean in Hornsund was 5.5 m s^{-1} (Marsz and Styszyńska, 2007).

Fig. 3 presents monthly mean wind speeds in both fjords. In both cases the trend is similar. It shows that it is very rare for winds in Kongsfjorden to be stronger than in Hornsund. It is even more evident in Fig. 4 where the differences between monthly mean wind speeds in both fjords are displayed. There are only 6 cases (out of over 130) when the monthly mean wind speed is greater in Ny-Ålesund than in Hornsund (shown where the graph of wind differences is below the zero value).

This difference in monthly mean values (Fig. 5) of wind speeds clearly shows that the multiannual monthly mean wind speed in Hornsund is 2.5 m s^{-1} higher than in Kongsfjorden (Fig. 5). The multiannual monthly mean wind speed in both stations reaches maximum values in February and minimum values in the summer months.

Wind patterns presented in Fig. 2 obtained from reanalysis data are similar. It means there are no difference in field pressure between Hornsund and Kongsfjorden and there should not be a great difference in measured wind speed in these fjords. However more marine character of Hornsund area and less air-land friction around cause that wind in Hornsund is stronger what can be noticed in Fig. 5.

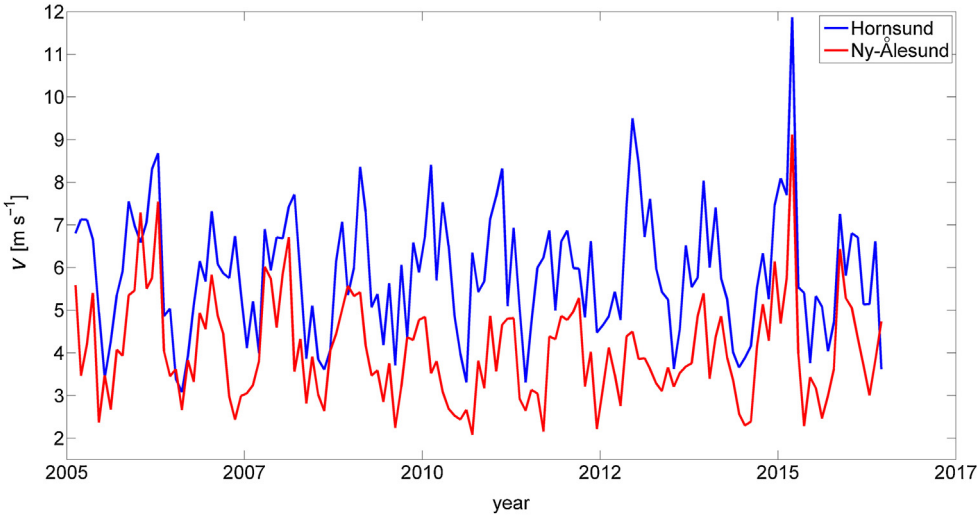

Figure 3 Monthly mean value of wind speed in Hornsund (blue line) and Kongsfjorden (red line) for the period from 2005 to 2016. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of the article.)

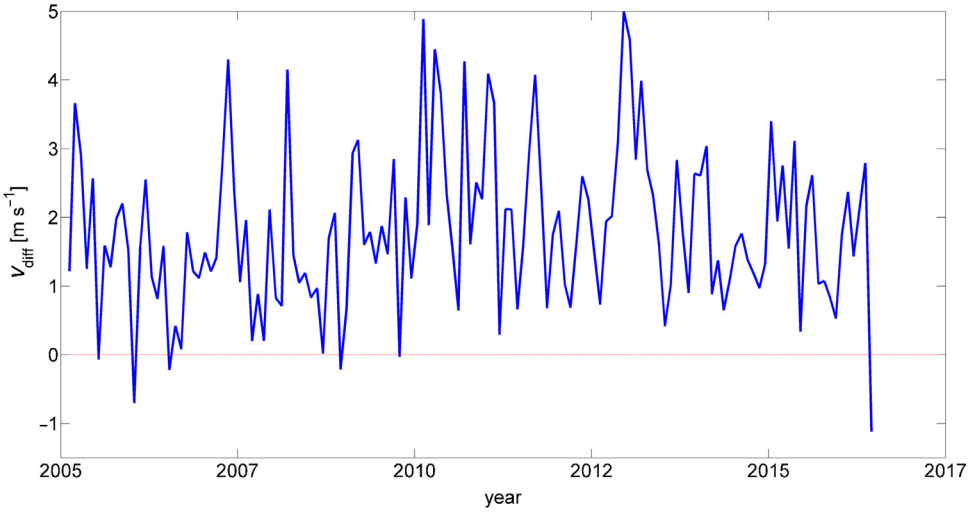

Figure 4 Differences in monthly mean values of wind speed (Hornsund–Kongsfjorden) for the period from 2005 to 2016.

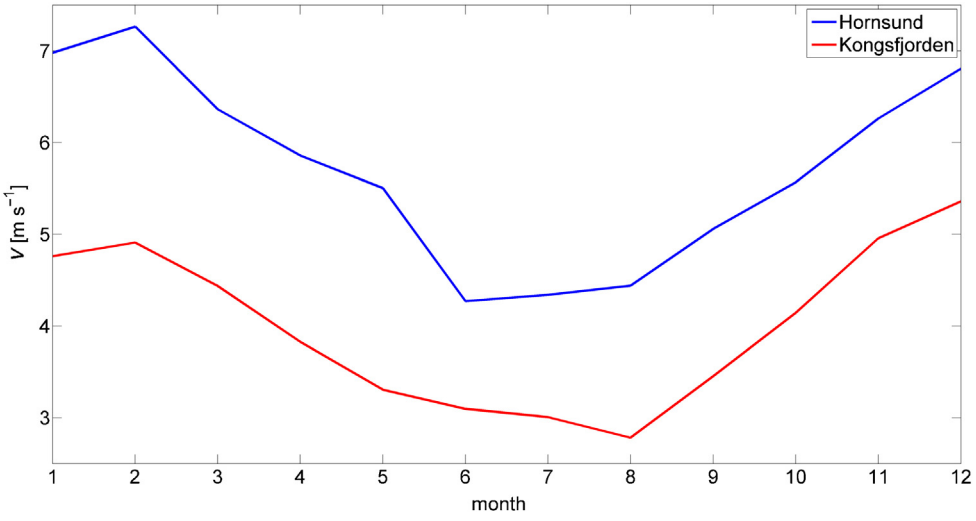

Figure 5 Multiannual monthly mean of wind speed in Hornsund (blue) and Kongsfjorden (red) for the period from 2005 to 2016. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of the article.)

3.2. Temperature

The yearly mean air temperature in Ny-Ålesund for the period from 1975 to 2000 was −5.8°C. July was the warmest month with a mean temperature of 4.9°C, February was the coldest, with a mean temperature of −14.2°C (Przybylak and Araźny, 2006). The multiannual yearly mean air temperature in Hornsund for the period from 1979 to 2006 was −4.4°C. The highest monthly mean was also recorded in July (4.4°C) and the coldest month was January with a monthly mean air temperature of −11.3°C (Marsz and Styszyńska, 2007). Over the period from 2005 to 2016 the multiannual yearly mean air temperature was −2.34°C in Hornsund, and −3.43°C in Ny-Ålesund. The coldest month in Hornsund was March with a multiannual monthly mean temperature of −8.6°C while the warmest month was July with a temperature of 4.8°C. In addition, the lowest multiannual monthly mean air temperature in Ny-Ålesund was recorded in March, −9.9°C and the highest was recorded in July at 5.9°C.

Trends for difference in air temperature between Hornsund and Kongsfjorden for the studied ten-year period were calculated and no significant trends have been found. The trendline is represented by a red line on the graph depicting changes in air temperature differences between both fjords in years 2005–2016, and shows a very slight decrease (the slope coefficient is equal to -1.14×10^{-5}). We can assume that the air temperature difference persists on constant level.

Daily mean air temperatures in both fjords and the differences between them are presented in Figs. 6 and 7. The chart of the differences in temperature has similar features to the ones of the temperature itself and the amplitude of the changes in differences is analogous to that of the temperature but is shifted by about a half a year.

In the cold season, temperatures in Ny-Ålesund are usually lower than in Hornsund, while during the warm season the situation is opposite. This dependency is well presented in Fig. 8, depicting multiannual monthly mean air temperatures in both stations.

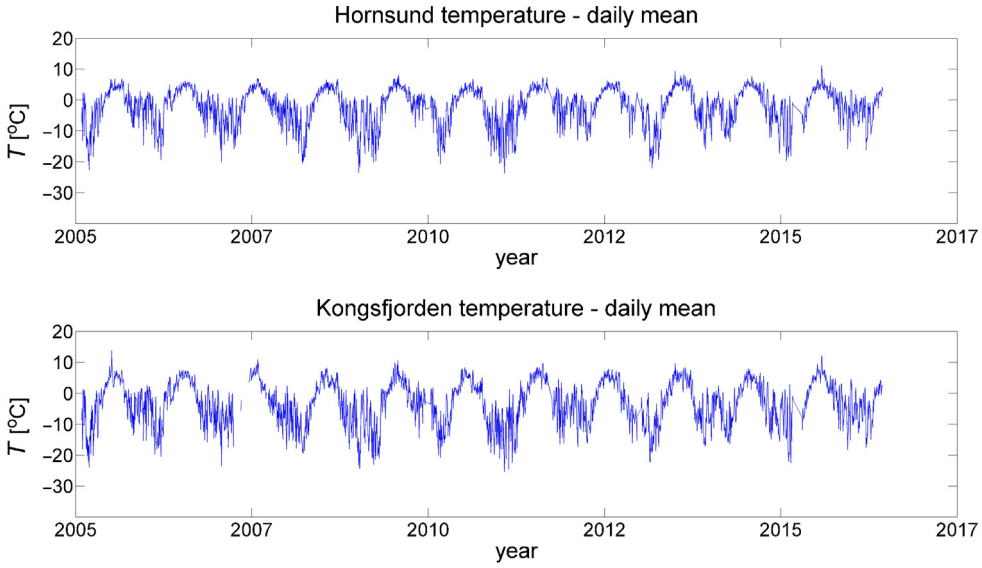

Figure 6 Daily mean air temperature from Hornsund (upper plot) and Kongsfjorden (lower plot) for the period from 2005 to 2016.

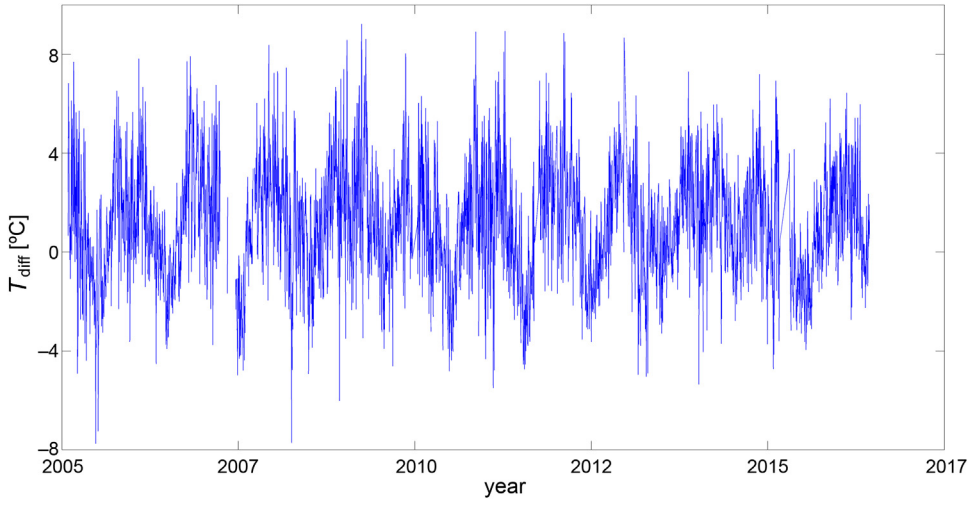

Figure 7 The difference of daily mean air temperatures (Hornsund–Kongsfjorden) for the period from 2005 to 2016.

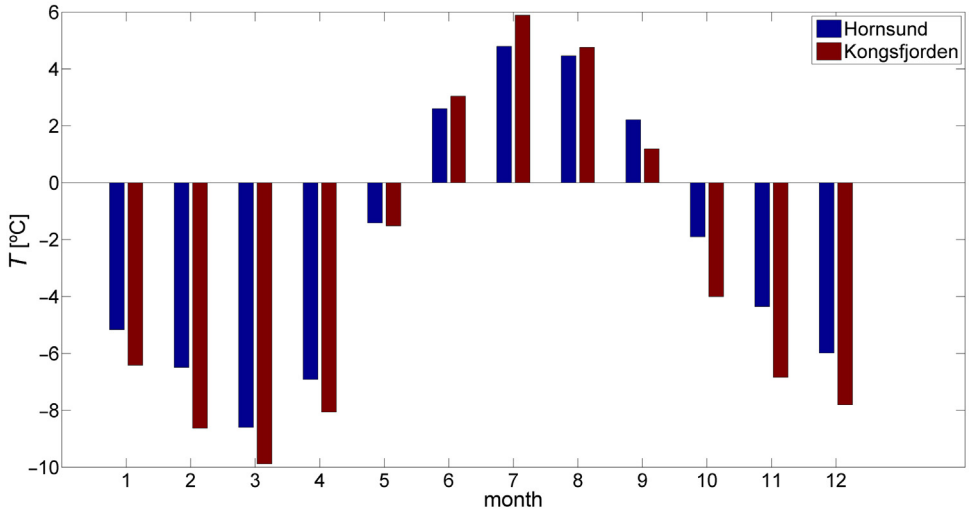

Figure 8 Multiannual monthly mean of air temperatures in Hornsund (blue bars) and Kongsfjorden (red bars) for the period from 2005 to 2016. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of the article.)

Table 1 Climatic conditions at the Hornsund station (H), the Ny-Ålesund station (N) and the difference between them (H-N). T – temperature, v – wind speed, C – cloud cover, RH – relative humidity. The table contains multiannual monthly mean values.

Parameter	Station	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	I-XII
T [°C]	H	−5.2	−6.5	−8.6	−6.9	−1.4	2.6	4.8	4.5	2.2	−1.9	−4.4	−6.0	−2.2
	N	−6.4	−8.6	−9.9	−8.1	−1.5	3.0	5.9	4.8	1.2	−4.0	−6.8	−7.8	−3.2
	H-N	1.2	2.1	1.3	1.1	0.1	−0.4	−1.1	−0.3	1.0	2.1	2.5	1.8	1.0
v [m s^{-1}]	H	6.9	7.3	6.4	5.8	5.5	4.3	4.3	4.4	5.1	5.5	6.3	6.9	5.7
	N	4.8	4.9	4.6	4.0	3.3	3.1	3.0	2.7	3.4	4.2	5.0	5.3	4.0
	H-N	2.1	2.3	1.7	1.8	2.2	1.2	1.3	1.7	1.6	1.3	1.3	1.6	1.7
C [%]	H	71.1	68.3	64.6	66.0	80.5	82.4	83.7	83.5	81.6	75.6	72.6	67.2	74.8
	N	66.9	59.3	61.9	60.1	73.9	76.8	78.1	79.8	78.6	68.7	66.1	58.4	69.1
	H-N	4.2	9.0	2.7	5.9	6.6	5.6	5.6	3.8	3.0	6.9	6.5	8.8	5.7
RH [%]	H	78.4	76.2	74.8	74.2	79.4	80.7	85.2	84.6	82.5	78.4	76.9	75.6	78.9
	N	70.9	68.6	68.5	66.4	69.4	70.7	74.1	75.8	76.1	72.5	70.5	69.1	71.0
	H-N	7.5	7.6	6.3	7.8	10.0	10.1	11.1	8.8	6.4	5.9	6.4	6.5	7.9

During the cold months, the multiannual monthly mean temperature in Ny-Ålesund is lower than in Hornsund. In May, the mean temperatures are almost equal. Beginning in June, Kongsfjorden is warmer and then in September, the temperatures are higher in Hornsund. This corresponds well with the sun path and the sun's relative position (higher above the horizon during summer months). Meteorological parameters from both stations are compiled in Table 1.

The amplitude of multiannual monthly mean air temperatures in Kongsfjorden reaches 15.8°C (between March and July), while in Hornsund it is 13.6°C.

To find out what can significantly influence the local climatic and meteorological conditions, data from ocean hydrographic measurements was analyzed. Walczowski and Piechura (2011) found a high positive correlation of the mean summer temperature of Atlantic Water in the core of the West Spitsbergen Current and the yearly mean temperatures from the Hornsund meteorological station for the period from 1996 to 2007. We also compared IO PAN time series of water temperature data from the transect 'N' along the 76°30′N parallel (close to the mouth of the Hornsund fjord) with the yearly mean air temperatures from Hornsund and Kongsfjorden. The correlation coefficient is r = 0.53 for Hornsund and r = 0.62 for Kongsfjorden for the period from 2005 to 2014.

The glance at Fig. 9 confirms that the air temperature in the investigated area increases. It shows monthly mean air temperature in Kongsfjorden from 1975 to date (41 years). This data set comes from eKlima (weather and climate data base from Norwegian Meteorological Institute). Closely 3°C increase of mean air temperature within last 40 years was presented with trend line (red line in Fig. 9) obtained from mentioned data. Additionally, in Fig. 9 it is apparent that in summer months the air temperature is almost fixed from year to year while in winter it gets unambiguously warmer in Kongsfjorden area. This change proves that this fjord climate is changing to more marine type with warmer winters.

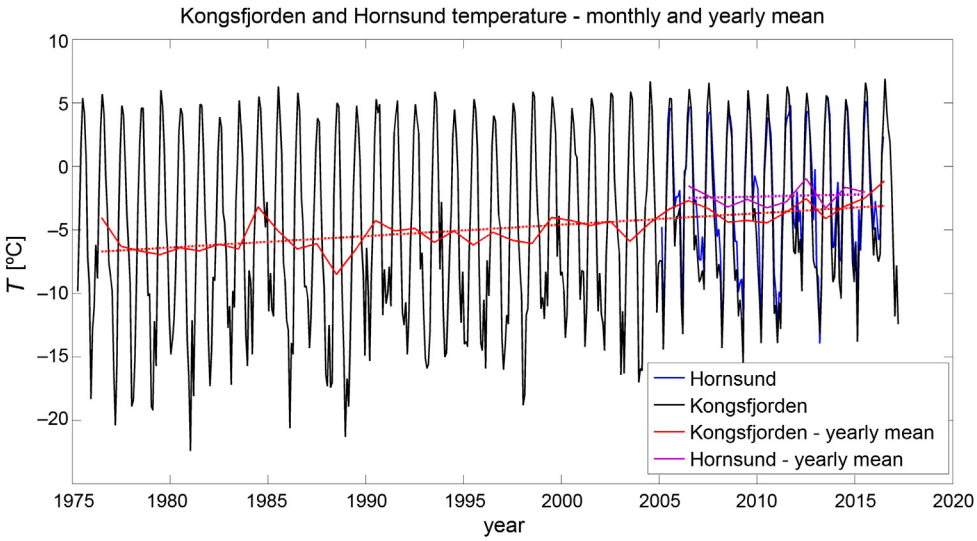

Figure 9 Monthly mean air temperature from Kongsfjorden for years 1975—2016 (black line) and from Hornsund for years 2005—2016 (blue line). Red and purple lines present yearly mean air temperature from Kongsfjorden and Honsund respectively. Dashed red line is trend line of temperature changes in last 40 years and parallel purple dashed line is trend line of temperature changes in Hornsund in last 11 years. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of the article.)

3.3. Relative humidity

The yearly mean relative humidity for the period from 1975 to 2000 was 79.3% in Hornsund, and 77.7% in Ny-Ålesund (Przybylak and Araźny, 2006). The multiannual monthly mean of humidity in Ny-Ålesund during this time oscillated between 72.1% in December and 85.6% in July. During the studied period, the multiannual yearly mean was 70.91% in Ny-Ålesund and 78.83% in Hornsund. The changes in monthly mean values of relative humidity over the last decade in both stations are presented in Fig. 10. In order to emphasize the difference between the fjords, monthly mean values have been plotted instead of daily mean values. Mean relative humidity in Hornsund is almost always higher than in Ny-Ålesund. The difference is significant and reaches up to 16%. The only month during which the mean relative humidity was lower in Hornsund than in Ny-Ålesund was December 2013. A much higher relative humidity in Hornsund may strengthen the infrared cloud radiative effect (CRE) in this region (Cox et al., 2015). This effect could also be the reason behind the mean annual air temperature differences in both fjords because Hornsund has more cloud cover than Kongsfjorden.

3.4. Cloud cover

The multiannual monthly mean of cloud cover in Hornsund and Kongsfjorden is presented in Fig. 11. The mean values are

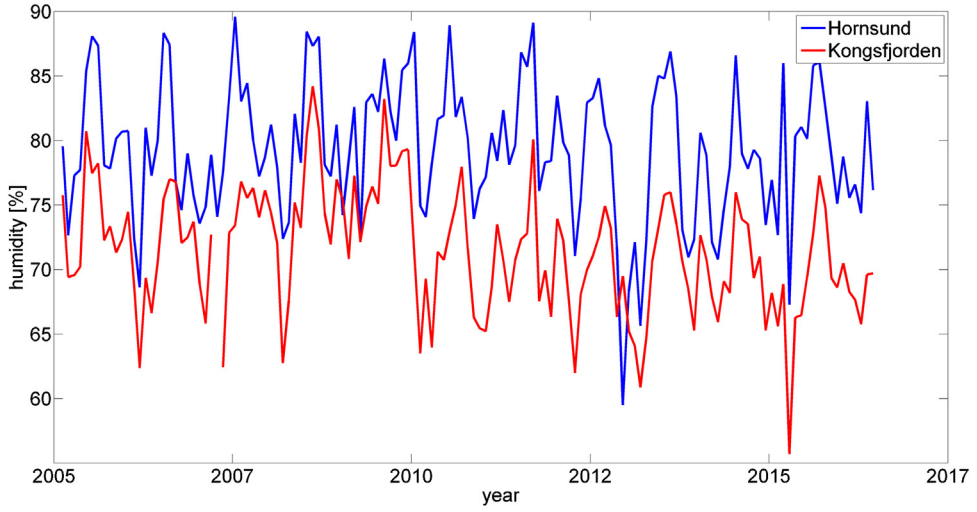

Figure 10 Monthly mean value of relative humidity from Hornsund (blue line) and Kongsfjorden (red line) for the period from 2005 to 2015. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of the article.)

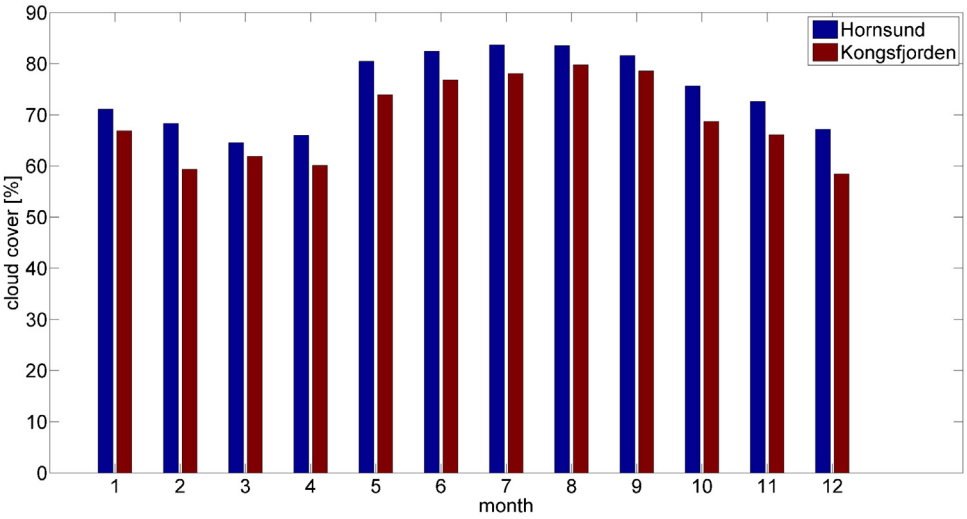

Figure 11 Multiannual monthly cloud cover in Hornsund (blue bars) and Kongsfjorden (red bars) for the period from 2005 to 2016. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of the article.)

similar for both stations, with maximum values of cloud cover during the summer, with a decline in October and November, and a minimum in the spring. In Hornsund, the mean annual cloud cover was 75% during the studied period which indicates a 2% increase, in comparison to years 1978–2009 (Marsz and Styszyńska, 2013). The same pattern was observed in these research stations over a period from 1975 to 2000 (Przybylak and Araźny, 2006). Corresponding plots are true in other Arctic stations (Shupe et al., 2011). Despite the similarity of the observed values of cloud cover in both fjords, there is a key difference between them – the cloud cover is always greater in Hornsund.

All values of the properties analyzed above were tested for statistical significance with one-sided Student's *t*-test and all differences of monthly mean values between Hornsund and Kongsfjorden became statistically significant. The *p*-values are less than 2.2×10^{-16} for wind speed and relative humidity differences, 1.22×10^{-5} for cloud cover differences, and 0.054 for temperature differences. The last *p*-value is slightly greater than 0.05 but it is very close to being statistically significant.

4. Conclusions

The differences in meteorological parameters between the Kongsfjorden and Hornsund fjords are clear and remain on the same level during the studied period, from 2005 to 2016. The comparison of conditions in both fjords for the period from 2005 to 2016 with conditions surveyed before the year 2000 shows some variations. This allows us to reach several conclusions.

Climate change and global warming is clearly present in both fjords, and is manifested by mean air temperature values. Taking long term trends into consideration, the mean annual air temperature has increased by approximately 2°C in both fjords. The difference between the annual amplitude of air temperature in Hornsund and Kongsfjorden has increased. The ocean has more influence on Hornsund than on Kongsfjorden, and it effects air temperature amplitudes, which are smaller in Hornsund.

The air temperature in Kongsfjorden is higher than in Hornsund during the summer and lower in the winter. This relation is probably caused by differences in radiation balance in both fjords. The cloud cover is greater throughout the year in Hornsund than in Kongsfjorden, which enhances the infrared radiative effect (CRE) of the clouds. This is further strengthened by the higher humidity prevailing in Hornsund. Greater cloud cover and humidity as well as a much greater mean wind speed in Hornsund can be explained by the influence of the sea on the climate of Hornsund. The southern part of Spitsbergen, where Hornsund is located, is a narrow area of the island and is surrounded by unfrozen water for most of the year. Kongsfjorden, on the other hand, borders the sea only on its west side. There is more land area east of Kongsfjorden than there is east of Hornsund. In addition, from January to June, sea ice cover occurs west of the latitude of Kongsfjorden. This location, along with the predominant eastward wind direction, makes the climate of Kongsfjorden more continental than in Hornsund. At the same time, Kongsfjorden (as well as the entire region) is under the influence of warm Atlantic Water (AW). The mean temperature of AW carried by the West Spitsbergen Current is slightly better correlated with the mean annual air temperature in Kongsfjorden than with the mean annual air temperature in Hornsund. This is because AW reaches Kongsfjorden directly, while Hornsund is separated from AW by the cold Sørkapp Current.

The relative air humidity in Kongsfjorden decreased considerably over the studied period. The mean value of humidity from the last decade is 11% lower than the multiannual mean from the period from 1975 to 2000. While the humidity in Hornsund increased slightly.

In both fjords, wind direction is conditioned mainly by local orography and the horizontal gradient of air temperature. In both cases the dominant wind direction is determined by the axis of the fjord. The wind speed is often greater in Hornsund than in Ny-Ålesund. Monthly means of wind speed are higher in Hornsund 98% of the time. The differences are significant and reach 5 m s^{-1}. This results in considerably stronger dynamics of air-sea interaction processes in the

Hornsund fjord rather than in Kongsfjorden. The difference is maintained during the studied period with no significant trend found. The authors assume that when the ice cover shrinks, the differences between the climates in these fjords should decrease.

This comparison of basic meteorological parameters in both fjords shows significant differences between them and they are unexpected and not obvious. On the basis of hydrological observations, these differences could be expected to be even greater. This effect is very interesting and needs to be further investigated with special attention given to changes in atmospheric circulation.

Acknowledgements

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